Naples Bay Water Quality and Biological Analysis Report

City of Naples

October 9, 2020

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Contact Information

Cardno
3905 Crescent Park Drive
Riverview, FL, 33578, USA

Telephone: +1 813 664 4500
www.cardno.com

Author(s)	Sheri A. Huelster Project Scientist
	Martin Griffin Water Engineer
Approved By	Ed Call Senior Project Scientist

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7.0	10/9/2020	Final revisions/Finalization	Sheri Huelster	City of Naples

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Acronyms

AEM	Autoregressive Error Model
AIC	Akaike Information Criterion
AGM	Annual Geometric Mean
ANOSIM	Analysis of Similarities
ANOVA	Analysis of Variance
CCCL	Coastal Construction Control Line
CFS	Cubic feet per second
CFU	Colony forming unit
CUSUM	Cumulative Sum
CWA	Clean Water Act
EPA	Environmental Protection Agency
ERC	Environmental Regulatory Commission
FDEP	Florida Department of Environmental Protection
GGC	Golden Gate Canal
IDW	Inverse Distance Weighting
MDL	Method Detection Limit
MDS	Multidimensional scaling
MF	Membrane filter
MGD	Million gallons per day
MHW	Mean High Water
MPN	Most Probable Number
MSE	Mean Square Error
NNC	Numeric Nutrient Criteria
NOAA	National Oceanic and Atmospheric Administration
NTU	Nephelometric Turbidity Units
PQL	Practical Quantification Limit
SCADA	Supervisory Control and Data Acquisition
SFWMD	South Florida Water Management District
SIMPER	Pairwise Comparisons of Group
STORET	STOrage and RETreival
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosporus
TSS	Total Suspended Solids
USGS	United States Geological Survey
WBID	Water Body ID
WIN	Watershed Information Network
WY	Water Year

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Executive Summary

This study provides a comprehensive update on the status of water quality and biology in Naples Bay. The analysis and information contained within this report are valuable for informed decision making regarding the management and restoration of Naples Bay. This report concentrates on Naples Bay water quality and biological communities (fish and seagrass), stormwater inputs to the Bay (stormwater lakes and pump stations), and effects of the Golden Gate Canal system, along with a comprehensive update to a previous report *Naples Bay Water Quality and Biological Analysis Project* (Hammond, Robbins, and Villanueva 2015).

In 2015, a series of focused questions were developed as guiding principles for the project. These questions centered on identifying quantifiable relationships in the data that can be relied upon to inform current and future management activities. The original questions posed in 2015 were revisited and reworked for data collected through 2019, to determine if the addition of more data, increased frequency of sampling, or conditions within Naples Bay itself had changed over time. The updated questions are listed below:

1. Are statistically significant trends in Naples Bay water quality data observed spatially and temporally?
2. Are statistically significant trends in Naples Bay biological data (fish and seagrass) observed spatially and temporally?
3. Are there statistically significant trends in the City's stormwater lakes and pump stations individually, or collectively based on the waterbody they drain to?
4. What science-based management activities can be implemented by the City to achieve the City's overall goals of protecting and improving water quality, resiliency, and enhancing habitat and fisheries?

Data for this project were compiled from publicly available sources, focusing primarily on the water quality and biological monitoring conducted by the City of Naples Natural Resource Division. Additional data were compiled from Collier County, the Florida Department of Environmental Protection (FDEP), the South Florida Water Management District (SFWMD), the United States Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA). Statistical analyses were conducted to identify significant trends in water quality, water quantity, and biology; identify links between water quality and effects on biology; determine the potential effect of stormwater inputs on Naples Bay water quality; and attempt to quantify the overall effects of ongoing management activities.

A summary of the major findings and the answers to the above four questions (in **Bold**) of this effort are:

Stormwater Lakes Water Quality

- More data were collected within the stormwater lakes and pump stations to complete a thorough statistical analysis of individual lakes and drainage basins.
- **There were statistically significant trends in individual stormwater lake and pump stations along with the collective waterbody they drain to (Question 3). The noted trends are as follows:**
    - Copper:
        - Decreases in collective inputs to Moorings Bay and Naples Bay.
        - Decreases at individual lakes draining to:
            - Moorings Bay: 1 SE-B (Devil's Lake).
            - Gordon River: 15B (Sun Lake Terrace) and 26B (NCH Lake).
            - Gulf of Mexico: 9B (South Lake).

            - Naples Bay: 11B (East Lake) and 24B (Half Moon Lake).
        - Decreases at pump stations PW-Pump (Public Works Pump) and 14-Pump (Port Royal Pump).
        - The highest copper concentrations were recorded in lakes 1SE-B (Devil's Lake), 26B (NCH Lake), and the PW-Pump Station.
        - Concentrations were somewhat variable at 9B (South Lake).
    - Salinity:
        - Decreases in collective inputs to Moorings Bay and the Gulf of Mexico.
        - Decreases at individual lakes draining to:
            - Moorings Bay: 2B (Swan Lake) and 5B (Lake Suzanne).
            - Gordon River: 15B (Sun Lake Terrace).
            - Gulf of Mexico: 9B (South Lake) and 10B (Alligator Lake).
        - Decreases at pump station 11-Pump (Cove Pump).
        - Increases at individual lakes draining to the Gordon River: 22B (Lake Manor).
        - Salinity had the greatest range at 2B (Swan Lake) from 2010 to 2014 (prior to the new weir being constructed).
        - Salinity within the brackish range at 14B (Lantern Lake) and 10B (Alligator Lake) over the entire monitoring period.
    - TSS:
        - Increases in collective inputs to the Gulf of Mexico.
        - Increases at individual lakes draining to Naples Bay: 14B (Lantern Lake).
        - Decreases at individual lakes draining to:
            - Moorings Bay: 2B (Swan Lake).
            - Gordon River: 20B (Forest Lake).
    - TN:
        - Increases in collective inputs to the Gulf of Mexico.
        - Increases at individual lakes draining to:
            - Naples Bay: 11B (East Lake) and 14B (Lantern Lake).
        - Decreases at pump station 11-Pump (Cove Pump).
    - TP:
        - Decreases in collective inputs to Moorings Bay.
        - Decreases at individual lakes draining to:
            - Moorings Bay: 3B (Colonnade Lake) and 5B (Lake Suzanne).
            - Gordon River: 20B (Forest Lake).
    - Enterococci:
        - Increases in collective inputs to the Gordon River and Gulf of Mexico.
        - Increases at individual lakes draining to the Gulf of Mexico: 9B (South Lake).
        - Increases at pump station 11-Pump (Cove Pump).

- o Fecal Coliform:
  - ▪ Increases in collective inputs to the Gordon River and Gulf of Mexico.
  - ▪ Increases at individual lakes draining to:
    - Gordon River: 19B (WTP Lake) and 20B (Forest Lake).
    - Gulf of Mexico: 8B (North Lake) and 9B (South Lake).
- TSS, TN, and TP were generally higher with a greater range of concentrations at three lakes: 14B (Lantern Lake) and 24B (Half Moon Lake) draining to the Gulf of Mexico and 8B (North Lake) draining to Naples Bay.
- The greatest salinity, TSS, and TP ranges occurred at 14-Pump Station.

<u>Naples Bay Water Quality</u>

- **There were statistically significant trends in Naples Bay and the Gordon River identified in Kendall Tau analysis both over time and spatially (at individual long-term monitoring stations) within Naples Bay (Question 1). The noted trends are as follows**:
  - o Nitrogen, phosphorus, and chlorophyll-*a* in the Gordon River (marine segment – WBID 3278R5) north of SR41 indicate exceedance of the NNC for Naples Bay. The Gordon River (marine segment – WBID 3278R5) is currently listed as impaired for TN, TP, and chlorophyll-*a*.
    - ▪ Increasing trends in chlorophyll-*a* in WBID 3278R5 from 2000 to 2019.
      - Slight slope increase of 0.11 µg/L/yr for chlorophyll-*a*.
    - ▪ Increasing trends in chlorophyll-*a* occurred at individual long-term monitoring stations in the Gordon River (GORDEXT/GORDPT and BC3).
      - BC3 slope of increase of 0.16 ug/L/yr.
      - GORDEXT/GORDPT slop of increase of 0.17 µg/L/yr.
    - ▪ No increasing or decreasing trends in TN or TP within Gordon River (marine segment – WBID 3278R5) or individual long-term stations.
  - o The dataset indicates chlorophyll-*a* and copper are exceeding their respective water quality standards in Naples Bay (WBID 3278R4). Naples Bay is currently listed as impaired for copper and chlorophyll-*a*.
    - ▪ Increasing trends in chlorophyll-*a* in WBID 3278R4 from 2000 to 2019.
      - Slight slope increase of 0.15 µg/L/yr for chlorophyll-*a*.
    - ▪ Increasing trend in chlorophyll-*a* at individual long term station NBAY29 in Naples Bay (slope 0.16 µg/L/yr).
    - ▪ Increasing trends at individual long-term monitoring stations in TN and TP (NBAYNL, NBAY29, NBAYBV, and GPASS6).
      - Increasing trend slopes may be small (0.02 mg/L/yr for TN and 0.002 mg/L/yr for TP) but they exist in both upper and lower Naples Bay.
  - o Statistically significant decreasing trend in salinity at two stations in Naples Bay.
    - ▪ NBAYNL slope of -0.34 ppt/yr.
    - ▪ GPASS6 slope of -0.17 ppt/yr.
  - o Statistically significant increasing trend in turbidity at all Gordon River (marine segment) and Naples Bay stations.

        - Slope range of 0.12 to 0.30 NTU/yr.
    - Fecal coliform colony counts had a statistically significant increasing trend in the Gordon River (marine segment) and Naples Bay.
        - Gordon River: GORDEXT/GORDPT slope 6.90 cfu/100mL/yr.
        - Naples Bay: NBAYNL, NBAY29, NBAYWS, NBAYBV, and GPASS6 slope range 0.33 to 4.60 cfu/100mL/yr.
            - Higher fecal coliform colony counts in upper Naples Bay and lower counts near mouth of bay.
    - Enterococci colony counts had a statistically significant increasing trend in the Gordon River (marine segment) and Naples Bay.
        - Gordon River: BC3 slope 41.98 cfu/100mL/yr.
        - Naples Bay: NBAYNL, NBAY29, NBAYWS, NBAYBV, and GPASS6 slope range 0.28 to 0.95 cfu/100mL/yr.
            - Higher enterococci colony counts near mouth of Naples Bay and lower counts in upper Naples Bay.

Golden Gate Canal

- Freshwater inflow from the Golden Gate Canal (GGC) plays a major role in shaping the water quality of Naples Bay. The canal flow affects salinity throughout the Bay, with the highest impacts observed in the northern region. In fact, the marine portion of the Gordon River above SR 41 shifts to a freshwater system virtually every summer.
- The Golden Gate Canal plays a significant role in nutrient loading to Naples Bay which is directly related to its flow: the more flow, the more nutrient loading.
    - From 2009 to 2014, the average daily loadings from the GGC were approximately 0.71 lbs/day copper; 710 lbs/day nitrogen; 24 lbs/day phosphorus; and 1,616 lbs/day suspended solids.
    - During the more recent 2015 to 2019 time period, the average daily loadings from the GGC were approximately 1.58 lbs/day copper, 1,280 lbs/day nitrogen, 43 lbs/day phosphorus, and 5,626 lbs/day suspended solids.
    - If 2017 loadings were excluded from the 2015 to 2019 time period, the loadings would be reduced for each of the constituents with loadings for copper of 1.22 lbs/day, nitrogen 1,042 lbs/day, phosphorus 27 lbs/day, and suspended solids 2,442 lbs/day.

Naples Bay Biological Communities

- **There were seasonal differences in the data collected for both the seagrass and fish communities. There were also differences in depth and percent cover of seagrass by year and monitoring transect. There were differences in fish diversity metrics over time, but no statistical differences in community structure observed between sampling zones (Question 2).**
- *Halodule wrightii* was increasing in density until about 2011 and then began decreasing through 2014, and was highly variable from 2015 through 2019.
- Percent occurrence for *H. wrightii* follows a similar decreasing trend from its highest occurrence in 2011 to its lowest in 2014, with percent occurrence remaining variable from 2015 through 2019.
- Diversity of fish species appears to follow a seasonal pattern with higher diversities and total taxa caught in the dry season and lower abundance in the wet season.

- Mojarras (*Eucinostomus* spp.) and anchovies (*Anchoa* spp.) were the most numerous taxa collected, accounting for over 87 percent of the total catch from 2009 to 2019. However, mojarras were the most frequently caught taxa followed by blue crabs (*Callinectes* spp.): occurring in 91 percent and 75 percent (respectively) of the trawl samples.
- The fish community in Naples Bay are dominated by euryhaline and cosmopolitan species (anchovy and mojarra) and are found in all zones of the Bay throughout the year, during times of significant canal flow as well as times of no flow.
- Four fish diversity metrics (total taxa, richness, Shannon diversity, and evenness) had two change-points over the period of record. For three of the metrics, one of the change-points occurred around the time of the change in sampling methodology in August 2011. The second change point occurred in mid-2016 for most metrics.
- There was no real relationship determined between fish communities and in-situ field water quality measurements for DO, salinity, or temperature over time.

Management Recommendations

- **Additional, science-based, resource management activities are available for review and implementation by the City to achieve the City's goals (Question 4). A summary of these are discussed below**:
- The City of Naples should continue to collect water quality, seagrass, and fish data to make informed management decisions that are focused on achieving three overall goals; protect and improve water quality, management for resiliency (sea level rise, storm surge and boat wake), and enhancing habitat and fisheries.
- Management recommendations and strategies to achieve these goals should be focused into the following areas: regulatory, water quality improvements, habitat creation/conservation, and comprehensive monitoring program needs.
    - Conduct a frequent and consistent review of the City's code and policy to ensure that regulatory elements are consistent with the City's goals and with applicable local, state, and federal regulations.
    - The City has previously invested a significant amount of resources to improving water quality and should continue implementing water quality improvement projects to address nutrient and bacterial loading.
    - Habitat creation and conservation are important strategies for the City to achieve its overall goals. The City has been actively restoring and protecting habitats which will ultimately help address water quality issues overtime.
    - The City has a robust water quality monitoring program that includes seagrass and fish data which is invaluable for identifying statistically significant trends within and between water quality and biota. These data also provide a valuable baseline by which to measure future restoration and enhancement efforts. This program is important and should remain a priority for the City.

This effort identifies focus areas for further investigation that will inform ongoing management and restoration efforts. Statistically significant trends in water quality and biology in Naples Bay were identified that will be useful to resource managers. The characterization of the current biological community provides a baseline for future management actions to measure progress and achieve restoration goals.

1 Introduction

The Naples Bay estuary is a focal point in southwestern Florida providing abundant recreational and sporting opportunities, a commercial working waterfront, and a beautiful residential setting for the residents and guests of the City of Naples. Naples Bay has a long history of transformation and development since the first European settlers arrived in the 1860s (Schmid et al. 2005). Urbanization and dredge-and-fill activities since the 1950s and 1960s have affected the function of the shallow-water Naples Bay estuary (Schmid et al. 2005). Significant canal drainage, dredged channels, and urban development have altered the Bay's water quality and timing and duration of freshwater inflows from the Golden Gate Canal (GGC) system, which was constructed in the 1960s (SFWMD 2007). The Naples Bay watershed historically drained approximately 10 square miles, up to 60 square miles if contributing tributaries (Rock Creek and Haldeman Creek) are included in the basin. Following the construction of the GGC, the area draining to Naples Bay grew to approximately 120 square miles (SFWMD 2007, Schmid et al. 2005, FDEP 2010). Stormwater previously entered Naples Bay via sheet flow, but now stormwater flow is largely channelized. Additionally, the watershed has undergone urbanization which has increased impervious area which limits aquifer recharge and the filtration of stormwater prior to reaching natural waterways.

Studies have shown that the human-induced changes to the Naples Bay watershed have had a significant effect on the biological character of the estuarine system. Schmid et al. (2005) reported that Naples Bay has lost 90 percent of its seagrass beds, 80 percent of the oyster reefs, and 70 percent of the mangrove fringe since the 1950s. Salinity stresses from unnatural freshwater inflows have affected plankton, benthic, and fish communities (FDEP 2010). Reports dating back 1970s have documented impacts as early as the 1950s in the Naples Bay aquatic system as a result of the hydrologic alterations (Baum 1973, Simpson et al. 1979, SFWMD 2007). Within Naples Bay, in addition to the effect of freshwater on the biological community, stormwater directed into Naples Bay carries pollutants, such as heavy metals, bacteria, sediment, fertilizers, herbicides and pesticides (Simpson et al. 1979, City of Naples 2010).

The Florida Department of Environmental Protection (FDEP) has classified surface waters into 29 major watersheds, or basins, and further organized them into five basin groups for assessment purposes. Within each watershed are numerous individual **W**ater **B**ody **Id**entification numbers (WBIDs), which represent waterbodies in Florida at the watershed or sub-watershed scale[1]. WBIDs can represent lakes, lake drainage areas, rivers and streams, parts of rivers and streams, springs, coastal, bay, and estuarine waters. One basin group of WBIDs is assessed annually as part of a 5-year repeating cycle. Naples Bay and surrounding waters are within Group 1 and are categorized as part of the Everglades West Coast Basin. As of 2019, the Group 1 Basins have undergone four cycles of the assessment process, with various WBIDs either being added to or removed from the verified impaired list based on the data available and seven-year assessment period. Figure 1-1 is a map showing the WBID boundaries within the study area of this report.

During the Cycle 2 assessment in 2009, Naples Bay was listed as impaired for copper and iron, and was recommended being added to the Environmental Protection Agency's (EPA) 303 (d) List. Between Cycle 2 and Cycle 3, the Naples Bay WBID (3278R) was split into two separate WBIDs (3278R4-Naples Bay [coastal segment] and 3278R5-Gordon River [marine segment]). During the Cycle 3 assessment in 2013, only the more downstream Naples Bay WBID (3278R4) was listed as impaired for copper and iron.

Historically, copper has been identified as a major pollutant in Naples Bay and continues to be through 2019. Copper sulfate has been used for decades in Naples (and throughout Florida and the country) as an algaecide in stormwater retention lakes. Over time, copper can accumulate in stormwater lakes and be released into receiving waters (in this case Naples Bay) where it can become toxic to estuarine life. Evidence of copper accumulation in Naples Bay was described in a report by the National Oceanic and Atmospheric Administration (NOAA) which stated oysters in Naples Bay had some of the highest copper concentrations observed anywhere in the nation (Kimbrough et al. 2008).

[1] https://floridadep.gov/dear/watershed-assessment-section/content/basin-411-0

During the most recent Cycle 4 assessment in 2019, additional impairments were listed by FDEP: Naples Bay – chlorophyll-*a*; Gordon River (marine segment) – dissolved oxygen (percent saturation), enterococci, chlorophyll-*a*, total nitrogen (TN), and total phosphorus (TP); and Gordon River (extension) – *Escherichia coli* (*E. coli*). FDEP is requesting that these new parameters showing impairments be added to the EPA 303 (d) list. Table 1-1 shows the list of FDEP verified impaired waters (2019) and Total Maximum Daily Loads (TMDLs) for the Naples Bay Watershed within the City.

Table 1-1. Summary of FDEP verified impaired waters (2019) and TMDLs for the Naples Bay Watershed within the City of Naples.

WBID	Waterbody Name	Waterbody Class	Parameter Assessed
3278R1	Haldeman Creek (Lower)	3M	Copper, Enterococci
3278R3	Rock Creek	3M	Copper, Iron, Enterococci
3278R4	Naples Bay (Coastal Segment)	2	Copper, Iron, Fecal Coliform, Nutrients (Chlorophyll-*a*)
3278R5	Gordon River (Marine Segment)	3M	Copper, Iron, Dissolved Oxygen (Percent Saturation), Enterococci, Nutrients (Chlorophyll-*a*), Nutrients (Total Nitrogen), Nutrients (Total Phosphorus)
3278K	Gordon River Extension	3F	*Escherichia coli*
3278K	Gordon River Extension TMDL	3F	Dissolved Oxygen (Total Nitrogen)

The story of Naples Bay is not unique and mimics that of other estuaries that experience a rapid rate of development and urbanization. Residents and guests alike are drawn to the natural appeal of the estuary and the recreational, sporting, and commercial opportunities it offers, but all too often the urbanization that follows creates adverse environmental effects that diminish that very appeal. However, the story of Naples Bay is far from complete and the City of Naples and other stakeholders are proactively engaging in identifying sources of the adverse effects and creating restoration plans to mitigate for them.

A critical component of the process of restoring Naples Bay is a water quality and biological monitoring program directed at identifying environmental issues and their sources in addition to tracking progress and improvements associated with the restoration activities. In 2006, the City's Natural Resources Division implemented a monitoring program in Naples Bay that includes a wide range of water quality constituents of interest paired with seagrass monitoring and trawling efforts to characterize the fish communities of Naples Bay.

Cardno, Inc. (Cardno) was initially retained by the City of Naples, Streets and Stormwater Department to complete the Naples Bay Water Quality Analysis Project aimed at characterizing the current status of water quality and biological communities in Naples Bay along with the effects of ongoing management and restoration activities. The original project used data that had been collected by the City since 2006 through 2014 as well as other publicly available sources (Section 2) to identify statistically and ecologically significant trends and inter-connected relationships between the water quality and biological variables. In addition, recommendations for changes to the current water quality and biology monitoring programs were made based on what was learned during the data analysis process.

For this report, updates to the original dataset were made (mainly flow data based on updated records), a new time period from 2015 through 2019 was assessed, as well as assessing the expanded time period of 2006 through 2019.

In 2015, a series of focused questions were developed as guiding principles for the project. These questions centered on identifying quantifiable relationships in the data that can be relied upon to inform current and future management activities. The original questions posed in 2015 were revisited and reworked for data collected through 2019, to determine if the addition of more data, increased frequency of sampling, or conditions within Naples Bay itself had changed over time. The updated questions are listed below:

1. Are statistically significant trends in Naples Bay water quality data observed spatially and temporally?
2. Are statistically significant trends in Naples Bay biological data (fish and seagrass) observed spatially and temporally?
3. Are there statistically significant trends in the City's stormwater lakes and pump stations individually, or collectively based on the waterbody they drain to?
4. What science-based management activities can be implemented by the City to achieve the City's overall goals of protecting and improving water quality, resiliency, and enhancing habitat and fisheries?

This report aims to answer the questions above in order to inform future resource management strategies.

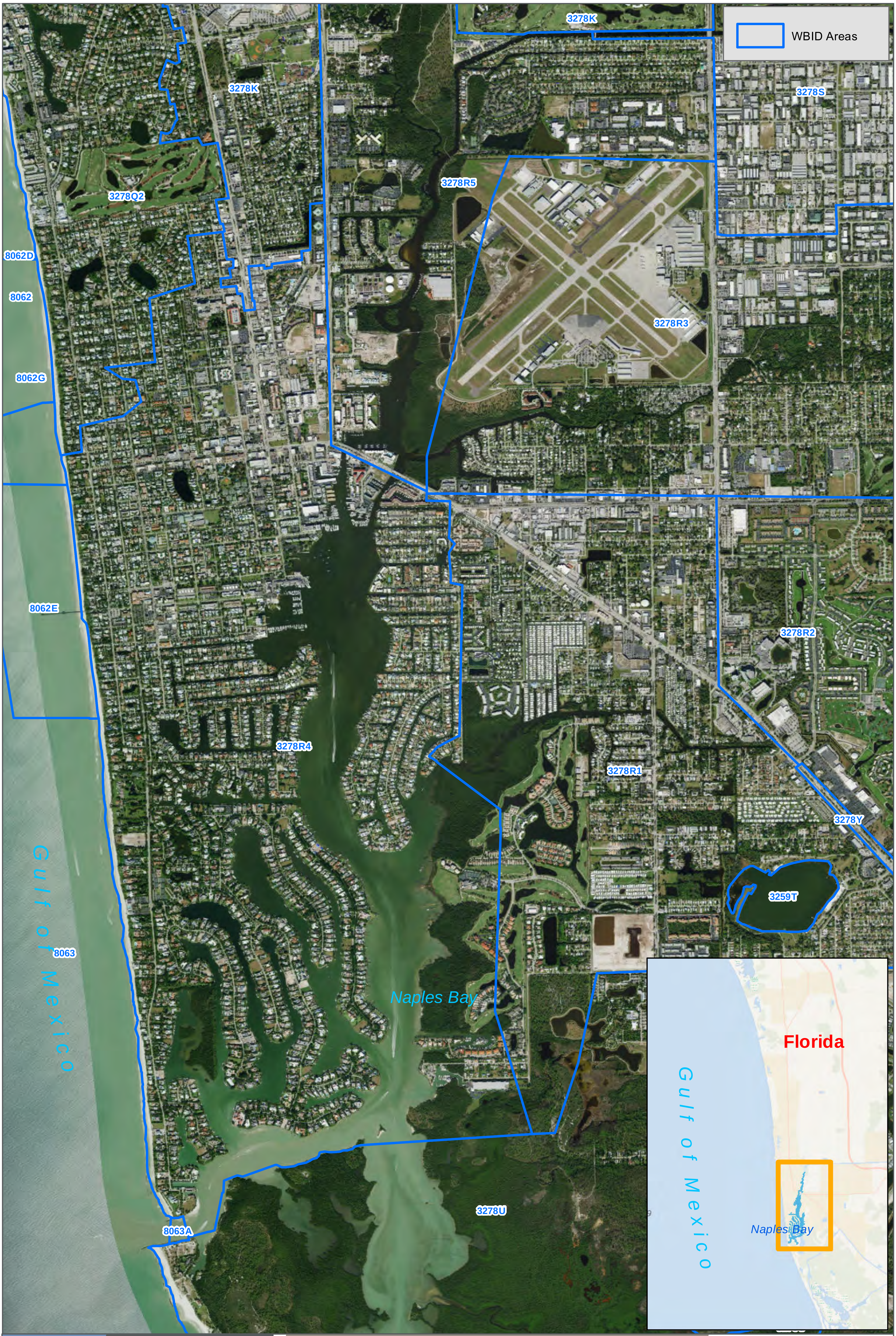

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Figure 1-1. WBID Location Map for Naples Bay

City of Naples, Natural Resources Division
Collier County, Florida

0 2,000 4,000 Feet
0 600 1,200 Meters

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Shaping the Future
3905 Crescent Park Drive, Riverview, FL 33578 USA
Phone (+1) 813-664-4500 Fax (+1) 813-664-0440
www.cardno.com

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GIS Analyst: James.Bottiger

2 Data Sources

Data from the City of Naples monitoring programs along with publicly available data were used as the basis for the analysis presented in this report. Water quality and biological data from Naples Bay were compiled[2]. Each sampling agency maintains their own monitoring program with differing sampling frequencies and constituents, and this section briefly describes the data compiled from each sampling entity. All water quality and biological data are maintained in a Microsoft Access database.

2.1 Water Quality and Quantity Data

The water quality analytical effort focused on constituents of concern to the City and those that are of regulatory concern to the FDEP with regard to the health of Naples Bay. Particular attention was paid to nutrients and nutrient response variables, heavy metals (copper), bacteria counts, and freshwater inputs (measured as salinity and/or conductivity). These parameters have been identified in previous studies and discussions with the City as those of the most interest for this effort.

Water quality data for this effort were obtained from the South Florida Water Management District (SFWMD), Collier County, and the FDEP Florida **STO**rage and **RET**rieval (STORET) and Watershed Information Network (WIN) databases, with the primary source of data being from the City of Naples Natural Resources Division. Water quantity data (rainfall and flow) were obtained from Collier County, United States Geological Survey (USGS), SFWMD, and (NOAA. Data from each source are briefly described below (Table 2-1). A depiction of all water quantity and quality data locations is provided in Figures 2-1 and 2-2, respectively. Additionally, a map of just the current City of Naples monitoring locations in Naples Bay is provided in Figure 2-3.

Data were summarized by calendar year (January to December) or water year (WY; December to November) for certain analyses throughout the report and are noted as such where applicable. Some analyses were also conducted on seasonal data, with December through May designated as the dry season and June through November designated as the wet season. The division of months into each season was based on the designations in the biological data provided by the City of Naples and supported by an analysis of flow data from the Golden Gate Canal (GGC). In order to make links between water quality and biological data, the same seasonal divisions were used for seasonal analysis of the water quality dataset.

[2] Relevant biological data from other nearby estuaries such as Rookery Bay, Estero Bay, Fakahatchee Bay, Pumpkin Bay, and Faka Union Bay were evaluated previously with analysis results presented in Appendix B.

Table 2-1. Water quality and quantity data sources, *Naples Bay Water Quality Analysis Project*.

Data Source	Location	Data type	Number of Stations	Date Range*	Number of Records
City of Naples	Naples Bay	Grab	16	2005–2010	480
	Naples Bay	Grab	9	2011–2019	22,466
	Stormwater Lakes	Grab	16	2010–2019	10,919
	Pump Stations	Grab	3	2010–2019	1,303
	Pump Stations	Flow	3	2011–2019	Annual or Monthly Totals
Collier County	Naples Bay and Tributaries	Grab	7	1995–2019	11,335
	Collier County Facilities Management	Rainfall	1	2008–2019	Daily Records
USGS	Naples Bay	Continuous Recorder	4	2011–2014	447,082
SFWMD	Naples Bay	Grab	14	2000–2015	58,288
	Golden Gate Canal	Flow	1	2008–2019	Daily Records
	Collier County Government Center	Rainfall	1	1996-2019	Daily Records
NOAA–NERRS	Henderson Ck	Continuous Recorder	1	2011–2014	118,000
NOAA	Golden Gate Canal	Rainfall	1	1977–2014	Daily Records
FDEP STORET	Naples Bay	Grab	62	1998–2017	770
FDEP WIN	Naples Bay	Grab	19	2017-2019	20,594
FDEP	Estero Bay	Continuous Recorders	3	2011–2014	143,140

*Represents longest range for the data source; individual station ranges may differ from time frame listed

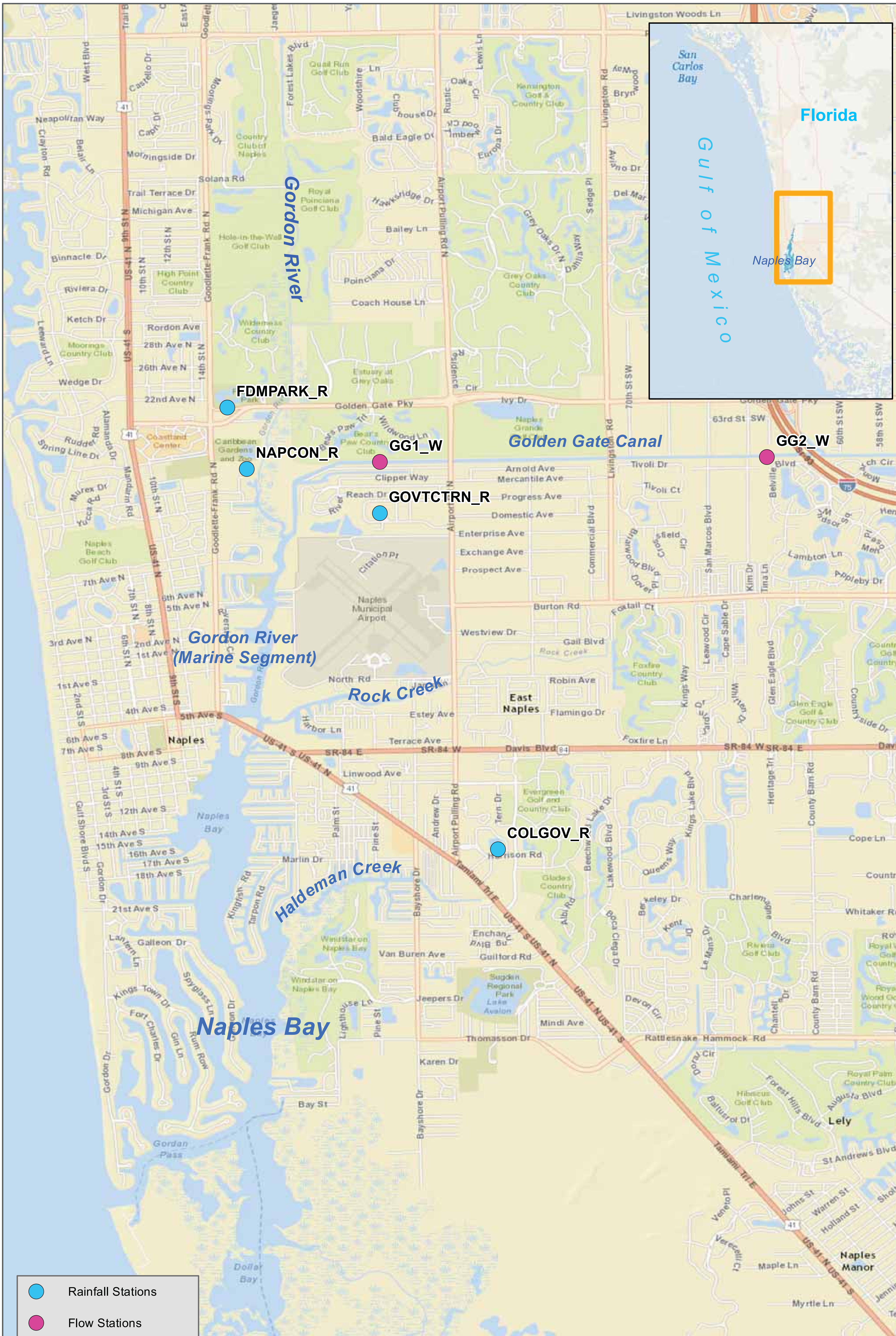

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Figure 2-1. Water Quantity Data Locations, Naples Bay

City of Naples, Natural Resources Division
Collier County, Florida

0 1 Miles
0 1 2 Kilometers

Cardno
Shaping the Future
3905 Crescent Park Drive, Riverview, FL 33578 USA
Phone (+1) 813-664-4500 Fax (+1) 813-664-0440
www.cardno.com

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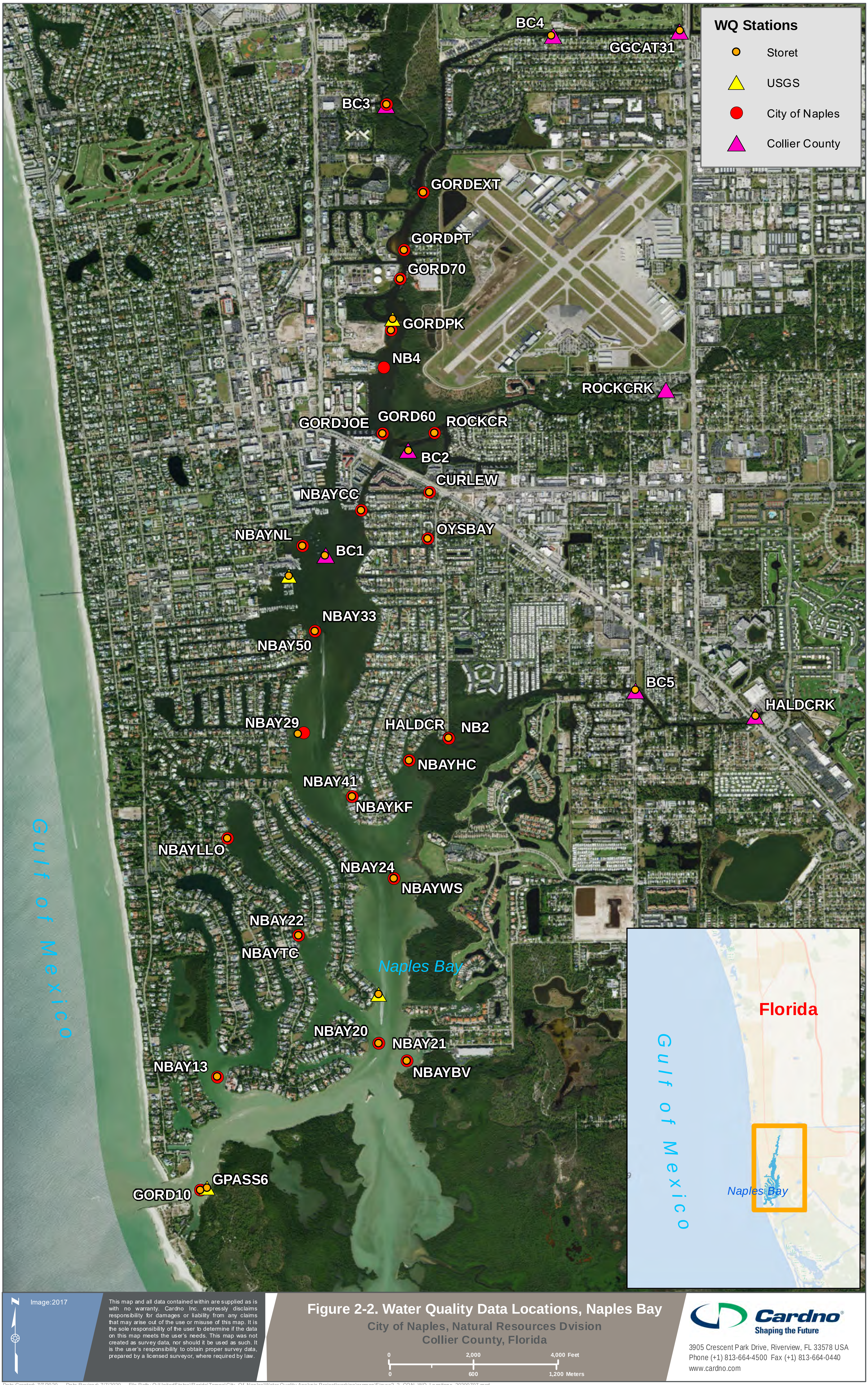

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Figure 2-2. Water Quality Data Locations, Naples Bay

City of Naples, Natural Resources Dvision
Collier County, Florida

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GIS Analyst: James.Bottiger

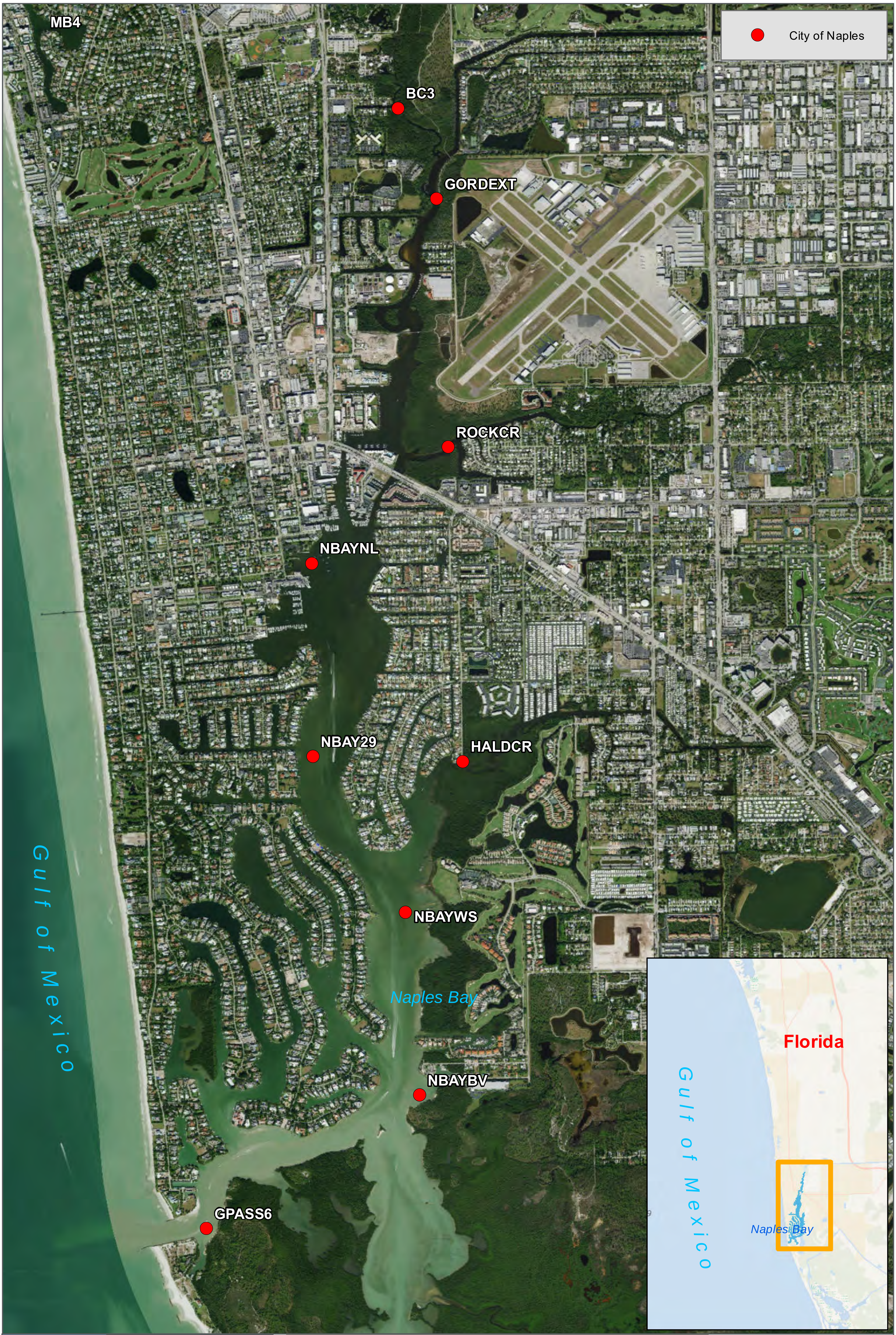

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Figure 2-3. Current City of Naples Water Quality Monitoring Locations, Naples Bay

City of Naples, Natural Resources Division
Collier County, Florida

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Date Created: 5/22/2020 Date Revised: 5/22/2020 File Path: Q:\UnitedStates\Florida\Tampa\City_Of_Naples\Water Quality Analysis Project\working\arcmap\Figure2_3_Current_City_of_Naples_Water_Quality_Monitoring_Locations_20200522.mxd
GIS Analyst: James.Bottiger

2.2 Biological Data

The primary source of biological data was the City of Naples Natural Resources Division ongoing monitoring efforts. A brief description of the biological data used in this effort is provided below.

Table 2-2. Biological data sources, *Naples Bay Water Quality Analysis Project*, 2006-2019.

Sample Type	Location	Approximate Date Range	Description
Seagrass	Southern Naples Bay	2006–2019	Five transects sampled once or twice per year between April and October (a sixth transect was added in 2015). Quadrats placed at fixed points along a transect: species composition, cover (Braun-Blanquet scale), shoot count, blade length, qualitative sediment type, water depth, and relative epiphyte coverage recorded.
Fish - Trawling	Naples and Moorings Bays	2009–2011	Otter trawls pulled for specific lengths and times at four fixed stations in each Bay. Naples Bay was trawled approximately six times per year; Moorings Bay was trawled four times per year. Species identity and abundance recorded. Length of first 20 individuals of each species recorded. Bycatch and environmental conditions recorded.
	Naples and Moorings Bays	2011–2019	Otter trawls pulled for specific length and time. Four grid zones established in each Bay. A random grid box is selected within each zone for sampling in each Bay during each event. Naples Bay is trawled six times per year; Moorings Bay is trawled four times per year. Species were identified and abundance recorded. Length of first 20 individuals of each species recorded. Bycatch and environmental conditions recorded.

3 Naples Bay Water Quality and Quantity

Changes in water quality and biology in Naples Bay as a result of rapid urbanization and hydrologic changes from the GGC are a long-standing concern. The first step in solving any issue is identifying the problem and its sources and then developing scientifically defensible and economically feasible solutions. Several public entities have been collecting water quality in Naples Bay, its tributaries, and the GGC dating back to the late 1990s. However, it wasn't until 2006 when the City of Naples instituted a more robust water quality and biological monitoring program that a more comprehensive characterization of Naples Bay was possible. Combining all of the available data from Naples Bay and its contributing sources provides the opportunity to not only characterize the current status, but also to identify statistically and ecologically significant trends over time and the sources of those trends. This effort will assist in determining if Naples Bay water quality is in compliance with applicable water quality criteria and whether water quality and biological conditions are trending toward improvement or degradation. The goal is to use these analysis results to focus on implementing science-based management activities in Naples Bay.

This section provides a characterization of the water sources to the Bay, quantification of volumes and loadings to the Bay, and a statistical analysis of the significant trends in Naples Bay water quality.

3.1 Sources of Water to Naples Bay

Naples Bay is a shallow, narrow estuary, oriented north to south along Florida's southwest coast with several freshwater inputs (FDEP 2010). The Bay has a single pass (Gordon Pass) at the southern end of the Bay providing water exchange with the Gulf of Mexico. South of Gordon Pass is the northern boundary of Rookery Bay National Estuarine Research Reserve, which connects to the Marco River further south by a shallow dredged channel (FDEP 2010). The major sources of freshwater to Naples Bay include the Golden Gate Canal, the Gordon River, Rock Creek, Haldeman Creek, and urban stormwater runoff from the surrounding areas. During the economic boom of the early 2000s, the City of Naples and Collier County were among the fastest growing areas in Florida (FDEP 2010).

A characterization of the water quality and quantity of freshwater sources to Naples Bay is provided here. This discussion focuses on the GGC and the stormwater inputs to Naples Bay from lakes and pump stations within the City limits, as a lack of information exists on the contributions of the other sources to the Bay. Collier County measures gauge height at the weirs from the Gordon River and Haldeman Creek into Naples Bay, but lacks flow measurements necessary to determine pollutant loads to Naples Bay from these sources. Some water quality data are available for Haldeman Creek, Rock Creek, and the Gordon River (marine segment and extension), which is included in the discussion in the next section (Section 3.2). Paired flow and water quality measurements from the Gordon River, Rock Creek, and Haldeman Creek would be valuable in establishing a more robust characterization of the sources of water to Naples Bay.

3.1.1 <u>Golden Gate Main Canal</u>

The Golden Gate Canal system is widely recognized as the major source of freshwater to Naples Bay (Laakkonen 2014, Schmid et al. 2005, SFWMD 2007, FDEP 2010, Simpson et al. 1979). The canal system was built in the 1960s to drain wetland systems to the northeast of Naples Bay and facilitate residential development (SFWMD 2006). Historically, Naples Bay had a drainage area of approximately 10 square miles, up to 60 square miles if contributing tributaries (Rock Creek and Haldeman Creek) are included in the basin. Following the construction of the Golden Gate Canal, the area draining to Naples Bay grew to approximately 120 square miles (SFWMD 2006, Laakkonen 2014 and City of Naples 2010) (Figure 3-1). The SFWMD operates three weirs along the Golden Gate Main Canal system which have been upgraded through the 2000s to improve flood control and better manage freshwater flows into Naples Bay (SFWMD 2006). Historically, stormwater entered Naples Bay via sheet flow, but now stormwater flow is largely channelized. Additionally, the watershed has undergone urbanization which has increased impervious area which limits aquifer recharge and the filtration of stormwater prior to reaching natural waterways.

Current flow contributions to the Gordon River (marine segment) and Naples Bay are available from flow data recorded at the downstream most weir (GGC1). Daily flow data from this gauge are available from November 27, 2008 through December 31, 2019 (Figure 3-2). Average daily flow over this time period was approximately 135 mgd, including times of no flow. When the GGC1 weir is flowing, the average daily discharge is 211 mgd. As expected, flow from the canal system is rainfall driven and, therefore, the highest magnitude flows are concentrated during the wet season (approximately June through November).

The original dataset used in the 2015 analysis was updated as the flow rating curve appeared to be corrected more recently and flows were greater than used in the previous analysis. While the daily flow data were updated, there were still a few gaps in data at GGC1 in 2011. A regression model estimating flow at station GGC1 and the next upstream gauge in the Golden Gate Main Canal system, GGC2, was used to estimate flow over the GGC1 weir into the Gordon River (marine segment) and Naples Bay where data were missing (Figure 3-3). A strong correlation (R^2 = 0.91) between flow at GGC1 and GGC2 provided the opportunity to predict flow at GGC1 during times when the flow gauge was not operating. Including the time periods of estimated flow allows for a more robust characterization of the flow regime from the GGC system into receiving waters. The estimated flows are shown in orange in Figure 3-2.

Total freshwater flow during the six months of the wet season (June to November) ranges from approximately 17 to over 101 billion gallons, typically constituting over 90 percent of the annual freshwater flow delivered from the GGC to Naples Bay (Figure 3-4). An exception was when higher dry season rainfall amounts during 2010 and 2016 led to higher than normal dry season flows from the GGC during that time period. The highest flows were observed during 2017 following Hurricane Irma.

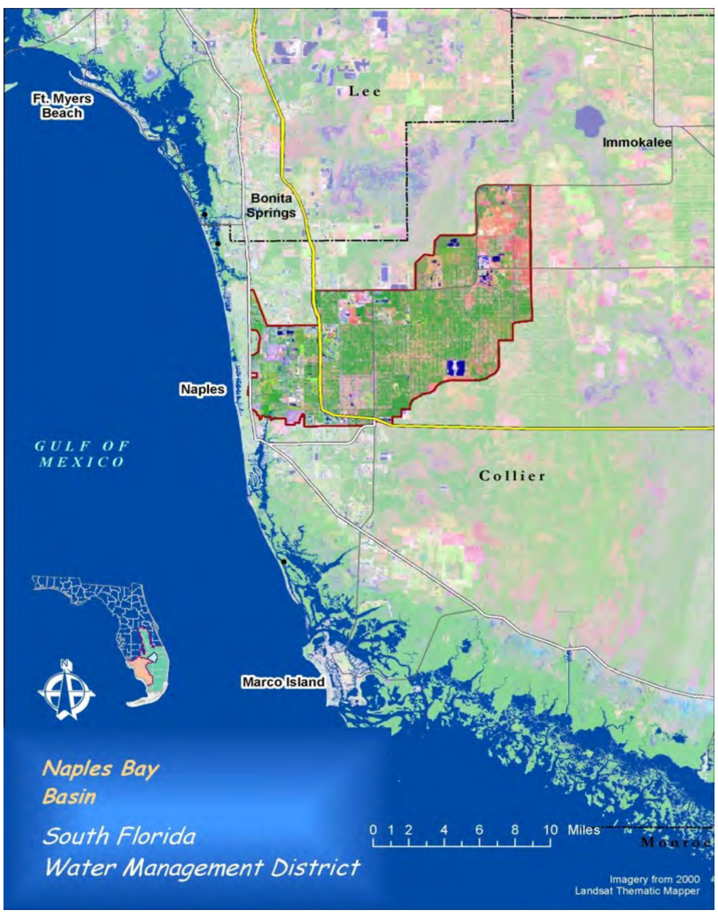

Figure 3-1. Portion of the Naples Bay watershed resulting from the construction of the Golden Gate Canal (SFWMD).

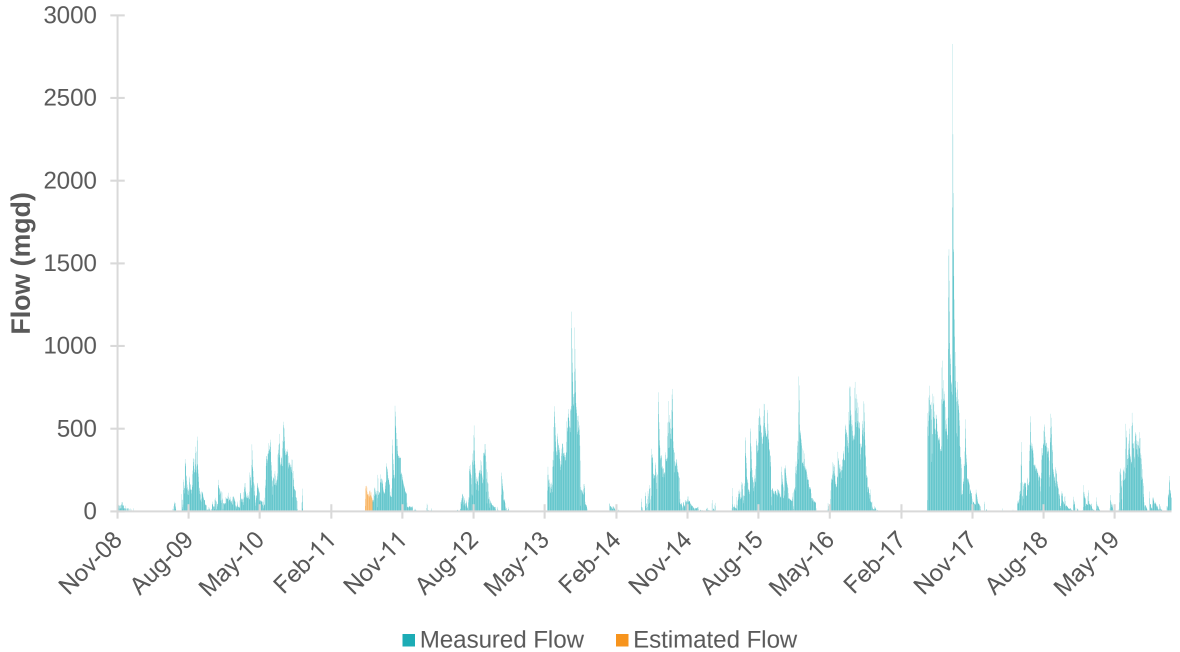

Figure 3-2. Golden Gate Main Canal daily flow (cfs) into Gordon River (marine segment), November 27, 2008 through December 31, 2019, SFWMD.

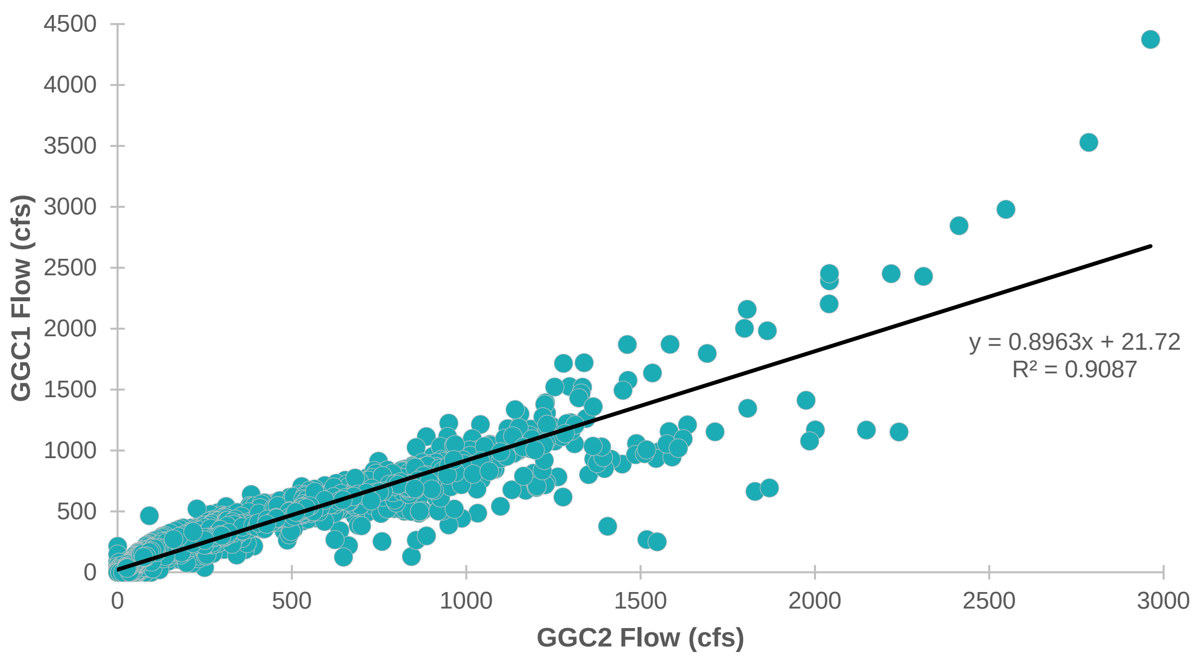

Figure 3-3. Flow relationship between Golden Gate Canal Weir 1 and Golden Gate Canal Weir 2, December 15, 2008 through December 31, 2019.

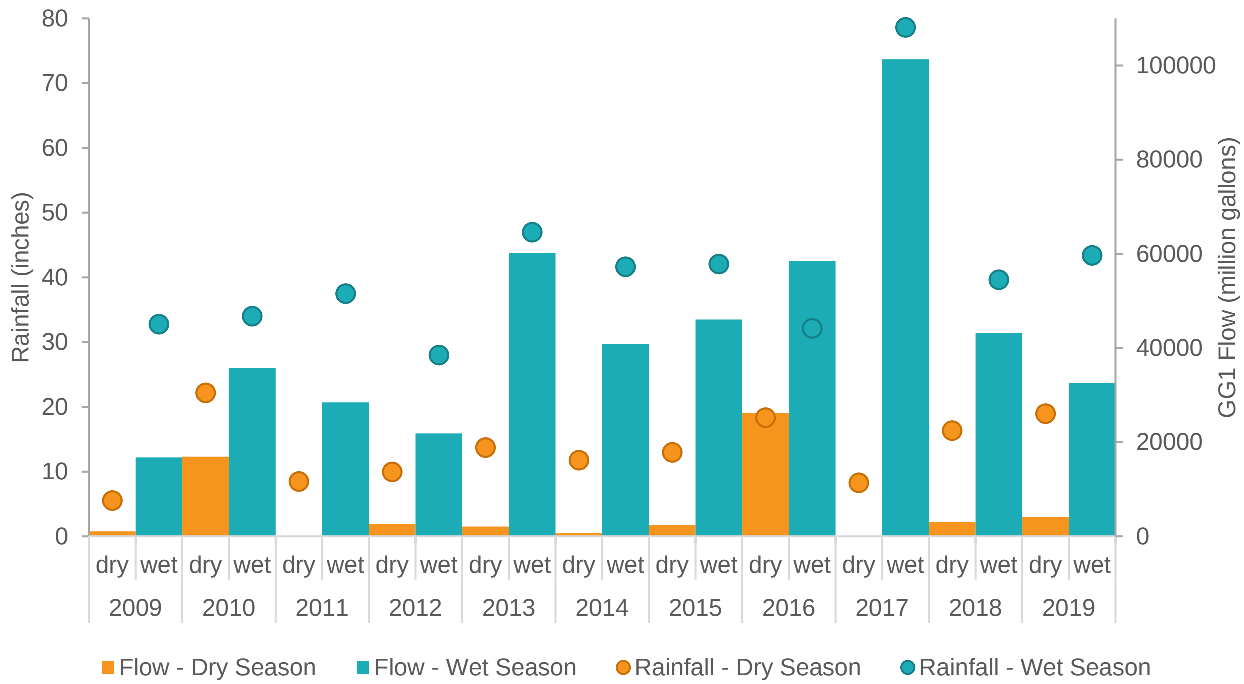

Figure 3-4. Total wet and dry season rainfall (COLGOV_R) and flows (GGC1) into Gordon River (marine segment), December 2008 through November 2019.

Along with the large volume of freshwater, the GGC also delivers significant loadings of potential pollutants to Naples Bay. The GGC loads to Naples Bay should be considered an important factor during planning and implementation of both City and County-wide management activities and restoration efforts. Collier County monitors water quality in the GGC upstream of the GGC1 weir (station GGCAT31) that allows for loading calculations of the canal contributions to the Gordon River (marine segment) and Naples Bay (see Figure 2-2). Although several water quality constituents are monitored at this location, this analysis will focus on nutrients, copper, and total suspended solids as the constituents of concern that represent potential impacts to Naples Bay. Loadings were calculated for 2009 through 2014, and 2015 through 2019 using water quality measurements from the GGCAT31 sampling location. Monthly (or quarterly, in the case of copper from 2009 through 2014) concentrations were aggregated for the month and were assumed to be representative for that calendar month (or quarter); any undetected results used one half the method detection limit (MDL) for the loading analysis.

As expected, the time periods with the highest loadings (2017 because of high continuous flow from early-June through early-November and including Hurricane Irma, followed by 2016 and 2013) were observed during years with the greatest flow from GGC (Table 3-5 and Figure 3-5). There were increases in copper loadings from 2009 through 2012 before a noticeable decrease in 2014; loadings increased again from 2015 through 2017 before decreasing in 2018 and 2019 (Figure 3-5). Loadings of total nitrogen (TN) and total phosphorus (TP) were more variable, with the highest loadings in 2017. Total suspended solids (TSS) had fairly similar annual loadings from 2009 through 2019, with the highest loadings in 2017 as well as 2013.

Over the 2009 to 2014 time period, the average daily loadings from the GGC were approximately 0.71 lbs/day copper, 710 lbs/day TN, 24 lbs/day TP, and 1,616 lbs/day TSS. During the more recent 2015 to 2019 time period, the average daily loadings from the GGC were approximately 1.58 lbs/day copper, 1,280 lbs/day TN, 43 lbs/day TP, and 5,626 lbs/day TSS. If 2017 loadings were excluded from the 2015 to 2019 summary, the loadings were reduced for each of the constituents with loadings for copper 1.22 lbs/day, TN 1,042 lbs/day, TP 27 lbs/day, and TSS 2,442 lbs/day (Table 3-1).

A five-year annual average load to Naples Bay was calculated for both the original analysis period (2009 to 2014) and the current analysis period (2015 to 2019). The most recent five-year period had loads of TN, TP, and TSS that were close to double the tons calculated from the original analysis period (Table 3-1). It appears greater annual and wet season flows from the GGC during the last five years have led to higher loadings to Naples Bay.

While the GGC is known to be the largest source of freshwater to Naples Bay, the magnitude and timing of nutrient and solids loading to the Bay is also a critical consideration for management and restoration planning. For example, ongoing seagrass and oyster restoration efforts by the City will need to consider the GGC loadings. With the vast majority of loadings delivered to the Bay during the wet season, which is also the seagrass growing season, restoration activities will likely show limited success unless simultaneous efforts to address nutrient and solids loadings from the GGC are implemented. Subsequent sections of this report provide additional evidence supporting this assertion.

Table 3-1. Comparison of annual sum of loads (lbs) from 2009 to 2019 and annual average sum of loads (lbs), annual average sum of loads (tons), and daily average loads (lbs/day) to Naples Bay from 2009-2014 and 2015-2019 (including and excluding 2017).

Loading Quantity	Year	Copper	TN	TP	TSS
Annual Sum of Load (lbs)	2009	143	150,867	5,043	298,183
	2010	224	354,003	15,768	662,187
	2011	275	209,045	6,498	348,636
	2012	398	135,932	5,795	241,282
	2013	367	436,762	11,229	1,539,079
	2014	140	268,302	8,259	450,373
	2015	397	392,032	10,295	826,071
	2016	530	549,679	14,727	1,163,936
	2017*	1,105	815,255	38,677	6,702,938
	2018	494	326,198	8,288	1,100,201
	2019	363	253,239	6,511	474,498
Annual Average Sum of Load (lbs)	2009-2014	258	259,152	8,765	589,957
	2015-2019	578	467,281	15,700	2,053,529
	2015-2019 (Excluding 2017)	446	380,287	9955	891,177
Annual Average Sum of Load (tons)	2009-2014	0.13	130	4.38	295
	2015-2019	0.29	234	7.85	1,027
	2015-2019 (Excluding 2017)	0.22	190	4.98	446
Daily Average Load (lbs/day)	2009-2014	0.71	710	24	1,616
	2015-2019	1.58	1,280	43	5,626
	2015-2019 (Excluding 2017)	1.22	1,042	27	2,442

*Higher overall daily flows and impacts of Hurricane Irma.

Figure 3-5. Total annual loads from the Golden Gate Canal System into the Gordon River (marine segment) and Naples Bay, 2009 through 2019.

3.1.2 Urban Stormwater Runoff

Rapid urbanization in the City of Naples inevitably brought with it changes in land use, an increase in impervious cover, and increased urban runoff of stormwater into receiving waters. Stormwater within the City limits is routed either directly into the receiving waters or to one of 28 stormwater lakes, and/or through one of the City's three pump stations prior to entering receiving waters. In December 2010, the City began water quality monitoring at discharge points from the stormwater lakes and pump stations. Characterization of water quality and quantity that has direct runoff to receiving waters from the City's urban areas was not possible, therefore, the characterization of stormwater lake and pump station quality is used here to represent stormwater runoff to Moorings Bay, the Gordon River, Naples Bay, and the Gulf of Mexico.

3.1.2.1 Stormwater Lakes

Currently, 16 of the 28 stormwater lakes within the City and all three pump stations are included in the water quality monitoring program (Table 3-2). Of the stormwater lakes in the monitoring program, four discharge to Moorings Bay, six discharge to the Gordon River (marine segment) above the SR 41 bridge, one discharges to northern Naples Bay, two discharge to the Port Royal canal area, and three discharge to the Gulf of Mexico (Figure 3-6). The PW-Pump station discharges to the Gordon River (marine segment) and the other two pump stations discharge into Naples Bay. The routes of discharge from the stormwater lakes are not direct: flow travels either through swales, ditches, and/or pipes to one of the three pump stations or roadside swales and culverts prior to entering the receiving waters.

Table 3-2. Monitored stormwater lakes and pump stations grouped by drainage basin.

Drainage Basin	Station Number	Station Name
Moorings Bay	1 SE-B	Devil's Lake
	2B	Swan Lake
	3B	Colonnade Lake
	5B	Lake Suzanne
Gordon River	6B	Mandarin Lake
	15B	Sun Lake Terrace
	19B	15th Ave N Lake (WTP Lake)
	20B	Forest Lake
	22B	Lake Manor
	26B	NCH Lake
	PW-Pump	Public Works Pump
Gulf of Mexico	8B	North Lake
	9B	South Lake
	10B	Alligator Lake
Naples Bay	11B	East Lake
	14B	Lantern Lake
	24B	Half Moon Lake
	11-Pump	Cove Pump
	14-Pump	Port Royal Pump

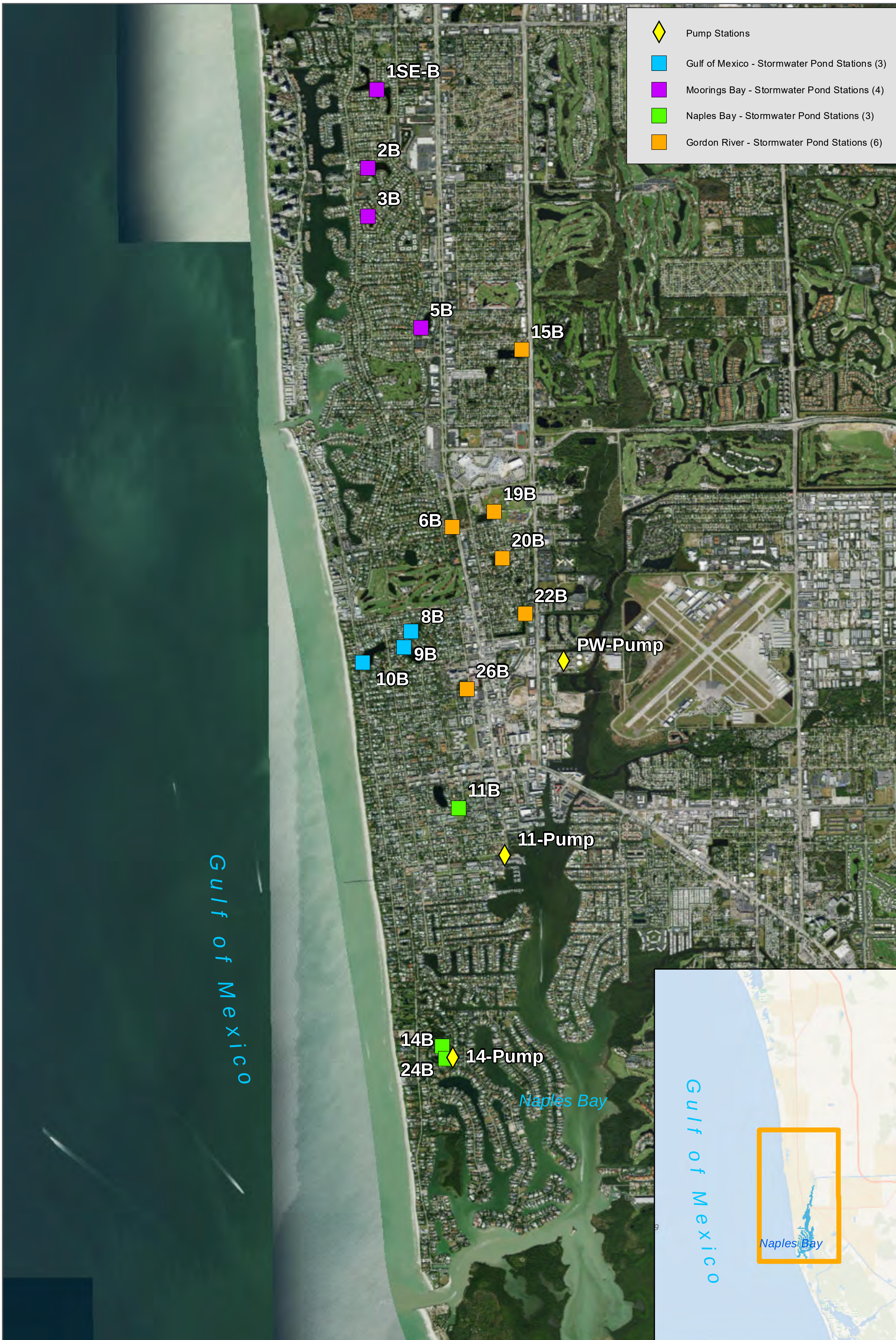

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Figure 3-6. Stormwater Lake and Pump Station Water Quality Monitoring Locations

City of Naples, Natural Resources Division

Collier County, Florida

0 3,000 6,000 Feet

0 900 1,800 Meters

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GIS Analyst: James.Bottiger

The stormwater lakes had previously been monitored twice per year (once in the wet season and once in the dry season) from December 2010 through September 2014, then quarterly from December 2014 through September 2016, and finally quarterly (six lakes) or monthly (ten lakes) starting in October 2016. The pump stations have been monitored quarterly over the period of record. This section is devoted to describing the water quality and quantity of the stormwater lake and pump station contributions to the receiving waters. There are three time periods assessed, the original analysis period of December 2010 through 2014 (excluding the January and February 2015 data used in the 2015 report), the more recent monitoring period of 2015 through 2019, and the entire period of record (POR: December 2010 through December 2019). Only one of the stormwater lakes (8B) was not sampled during the original analysis period; sampling at this lake did not begin until October 2017.

For the purposes of representing the water quality that enters receiving waterbodies, only data collected at the discharge point of each stormwater lake (characterized with a "B" after each lake number) were included here. Between four and nine individual data points were collected in each stormwater lake from December 2010 through 2014, between 21 and 45 individual data points were collected from 2015 through 2019, and between 25 and 54 individual data points were collected over the period of record (Appendix A, Table A-1). The small sample size and inconsistent sampling frequency from each individual lake precluded the use of formal time series analyses within each lake during the original analysis. However, as more data has been collected since 2015, a more thorough analysis is presented here. Additionally, a more detailed analysis of data collected from October 2015 through September 2019 is available in the *FY2015-FY2019 Water Quality Monitoring Report* (Huelster et.al. 2020).

Characterization of water quality in stormwater contributions was focused on the major parameters of concern for the City and potential pollutants in Naples Bay: copper, salinity, nutrients (TN and TP), total suspended solids, and bacteria (fecal coliform and enterococci). While both orthophosphate (reactive phosphorus) and total phosphorus (orthophosphate, condensed phosphate, and organic phosphate) concentrations were measured at all lakes, only TP is used in the analysis which is based on state standards and is generally comprised of 95 percent orthophosphate. Three nitrogen components (ammonia, nitrate-nitrite, and TKN) in addition to total nitrogen were measured at all lakes, but only TN is used in the analysis which is based on state standards, and is a calculation of nitrate-nitrite (inorganic nitrogen) and TKN (combination of ammonia, organic, and reduced nitrogen). Generally, TKN makes up the majority of TN; elevated nitrate-nitrite concentrations in the TN calculation would indicate potential fertilizer inputs.

Lake Water Quality – Median and Quartile Ranges

Boxplots were created for lakes with all three periods represented and separated by receiving waterbody (Moorings Bay, the Gordon River, Naples Bay, and the Gulf of Mexico) for the parameters of concern mentioned above (Figures 3-7 to 3-13). In the boxplot figures, the box represents the 25th to 75th percentile range (the interquartile range) and the line within the box represents the median or 50th percentile. Whisker lines represent the non-outlier range, which may extend to 1.5-times the interquartile range both above and below the top and bottom of the box. Outliers are considered values that are 1.5 to 3-times the interquartile range while extremes are 3-times the interquartile range both above and below the top and bottom of the box. Only outliers (open circles) have been graphed in the following box plots as the extremes would reduce the ability to visually compare medians and 25th to 75th percentile ranges between lakes in each receiving waterbody.

While copper concentrations were relatively low (below the marine standard of 3.7 µg/L; the fresh water standard varies depending on measured hardness concentrations) at most lakes during the two time periods and during the overall period of record, copper concentrations were elevated at two lakes (1 SE-B and 26B). At 1 SE-B, concentrations were above 3.7 µg/L over the period of record, but had a reduced 25th to 75th percentile range from 2015 to 2019 compared to the original study period of 2010 to 2014 (6.1-41.1 µg/L from 2015 to 2019 compared to 14.2-86.3 µg/L from 2010 to 2014). At 26B, the copper concentrations were higher and more variable during the more recent study period of 2015 to 2019 (Figure 3-7). Additionally, the few copper measurements taken at 9B were higher during the original study period than the last five years. The elevated copper concentrations may be an indication of regular or continuous treatment with copper sulfate to these lakes.

Salinity medians and 25th to 75th percentile ranges were generally below 0.5 ppt (freshwater designation) at all lakes during the period of record, with the exception of 2B, 14B, and 10B (Figure 3-8). The salinity measurements at 2B were elevated during the original study period of 2010 to 2014 because of tidal exchange with Moorings Bay. In September 2015, the weir was rehabbed which subsequently prevented the high tides from Moorings Bay from back flowing into the lake. The salinity measurements at 14B were consistently around 5 ppt over the period of record and the individual study periods. At 10B, salinity measurements were more variable overall and were between 2 and 10 ppt from 2015 to 2019 (Figure 3-8). As lake 10B is the closest to the Gulf of Mexico, there appears to be a consistent influence of saltwater reaching the lake either as a result of high tides or potential sea level rise.

Suspended solids concentrations tended to vary similarly among the lakes, with only 24B, 14B, and 8B having a greater range in concentrations over the time periods (Figure 3-9). Both 24B and 14B are located lower in Naples Bay near a canal section while 8B has had the shortest regular monitoring period and drains to the Gulf of Mexico.

TN was also elevated and more variable at these three lakes (24B, 14B, and 8B) compared to the others monitored in this study (Figure 3-10). The median TN concentrations at all other lakes was around 1 mg/L. The TN concentration was 2 mg/L at 8B and 14B, and 3.5 mg/L at 24B. There were higher TP concentrations at 14B (0.5 mg/L) and 24B (2.0 mg/L) compared to the other lakes which had median concentrations between 0.05 and 0.15 mg/L (Figure 3-11).

The fecal indicator bacteriological parameters of enterococci and fecal coliform had highly variable 25th to 75th percentile ranges at all lakes over the study period (Figures 3-12 and 3-13). Comparatively, lakes 1 SE-B, 9B, and 10B had lower median fecal indicator bacteria numbers (50 cfu/100mL) over both study periods for both parameters, but 75th percentile ranges were still as high as 500 cfu/100mL. It appears all are discharging elevated levels of fecal indicator bacteria (enterococci and fecal coliforms). However, fecal indicator bacteria are known to replicate in the environment (e.g. soil, sand, sediment), particularly in tropical regions, so elevated fecal indicator bacteria levels may not be indicative of recent fecal pollution events (e.g. Hardina and Fujioka 1991; Piggott et al. 2012; Yamahara et al. 2009).

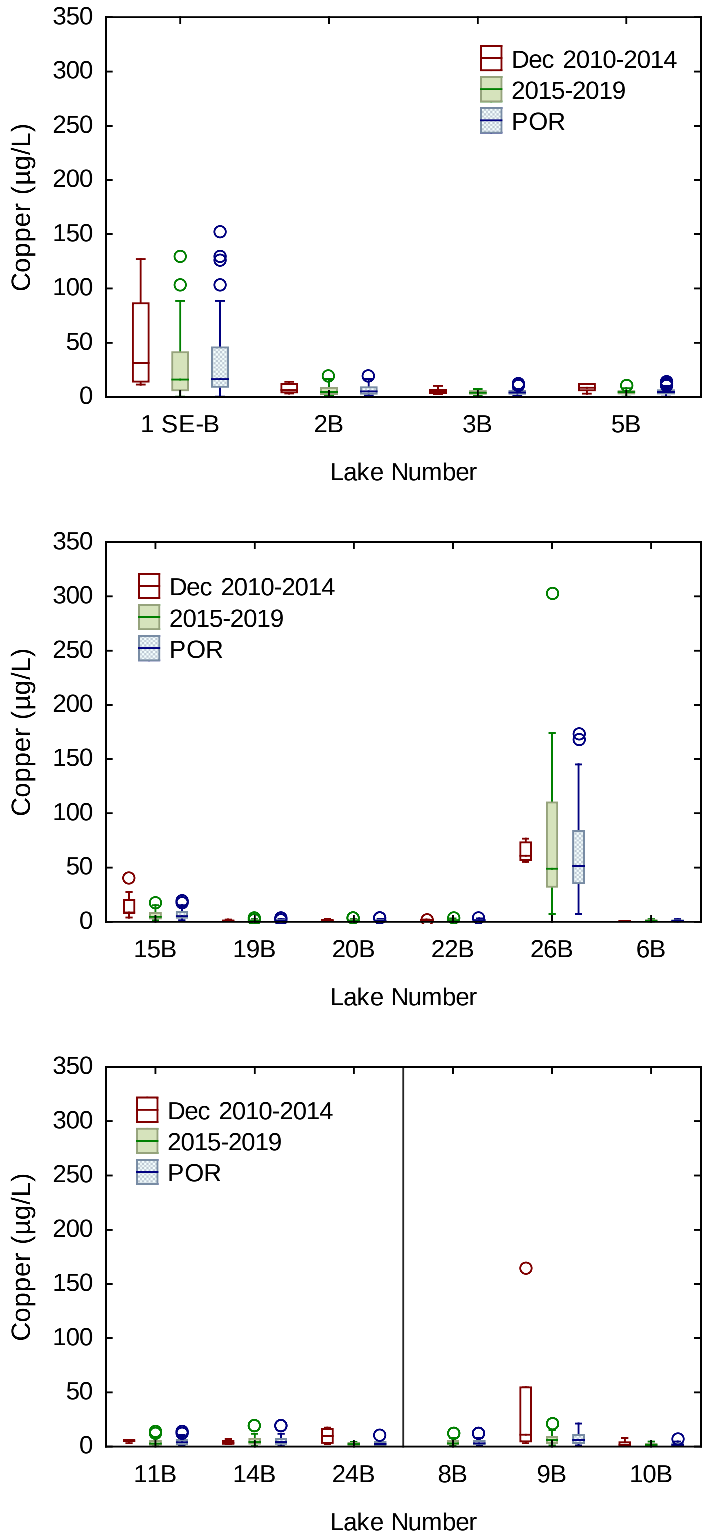
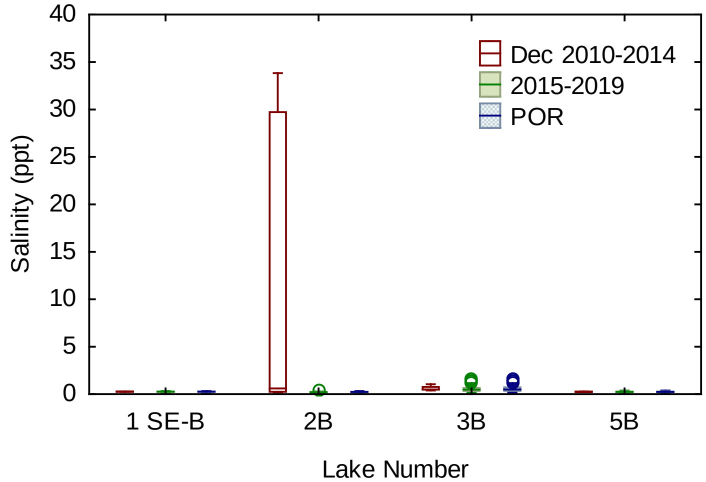
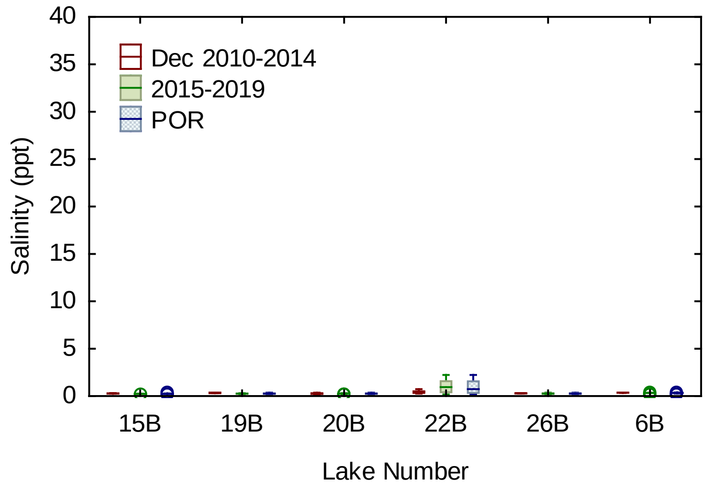


Figure 3-7. Summary of copper results for stormwater lakes discharging to Moorings Bay (top), Gordon River (middle), and Naples Bay (bottom left)/Gulf of Mexico (bottom right) for three time periods.





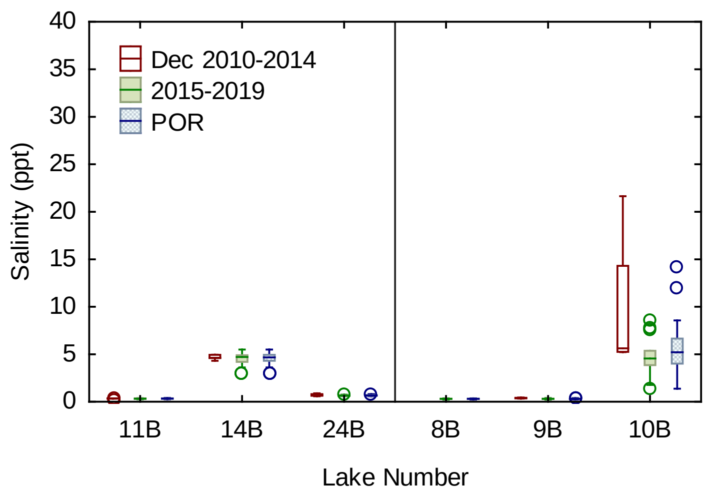


Figure 3-8. Summary of salinity results for stormwater lakes discharging to Moorings Bay (top), Gordon River (middle), and Naples Bay (bottom left)/Gulf of Mexico (bottom right) for three time periods.

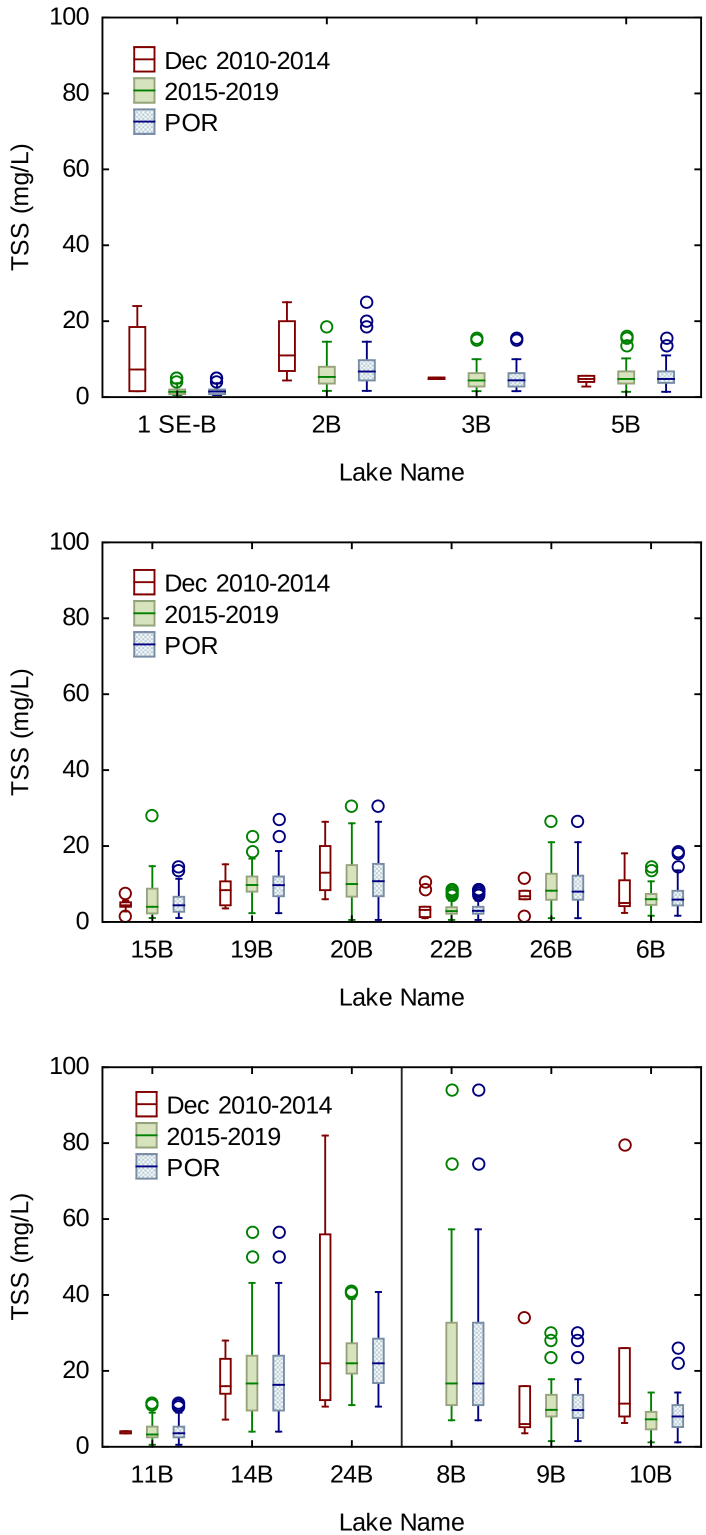


Figure 3-9. Summary of TSS results for stormwater lakes discharging to Moorings Bay (top), Gordon River (middle), and Naples Bay (bottom left)/Gulf of Mexico (bottom right) for three time periods.

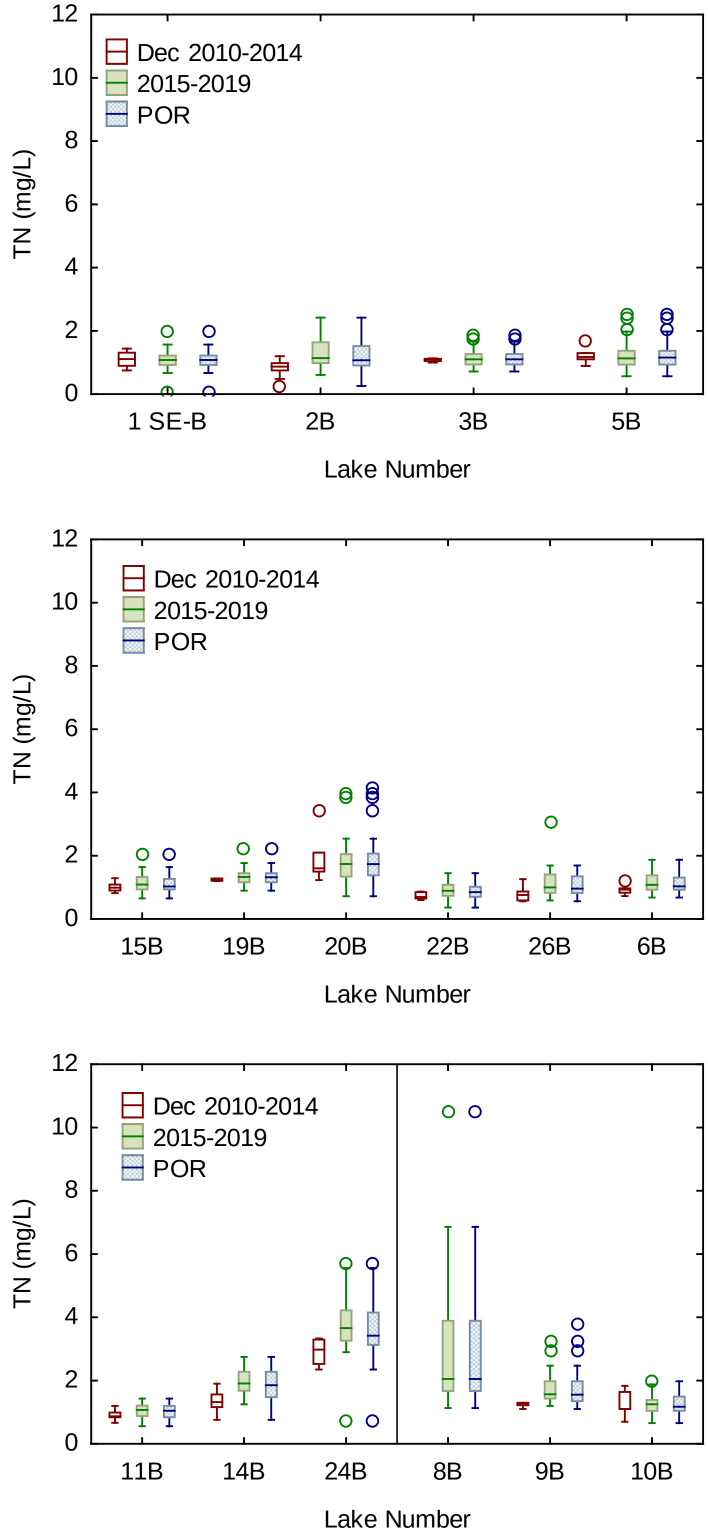


Figure 3-10. Summary of TN results for stormwater lakes discharging to Moorings Bay (top), Gordon River (middle), and Naples Bay (bottom left)/Gulf of Mexico (bottom right) for three time periods.

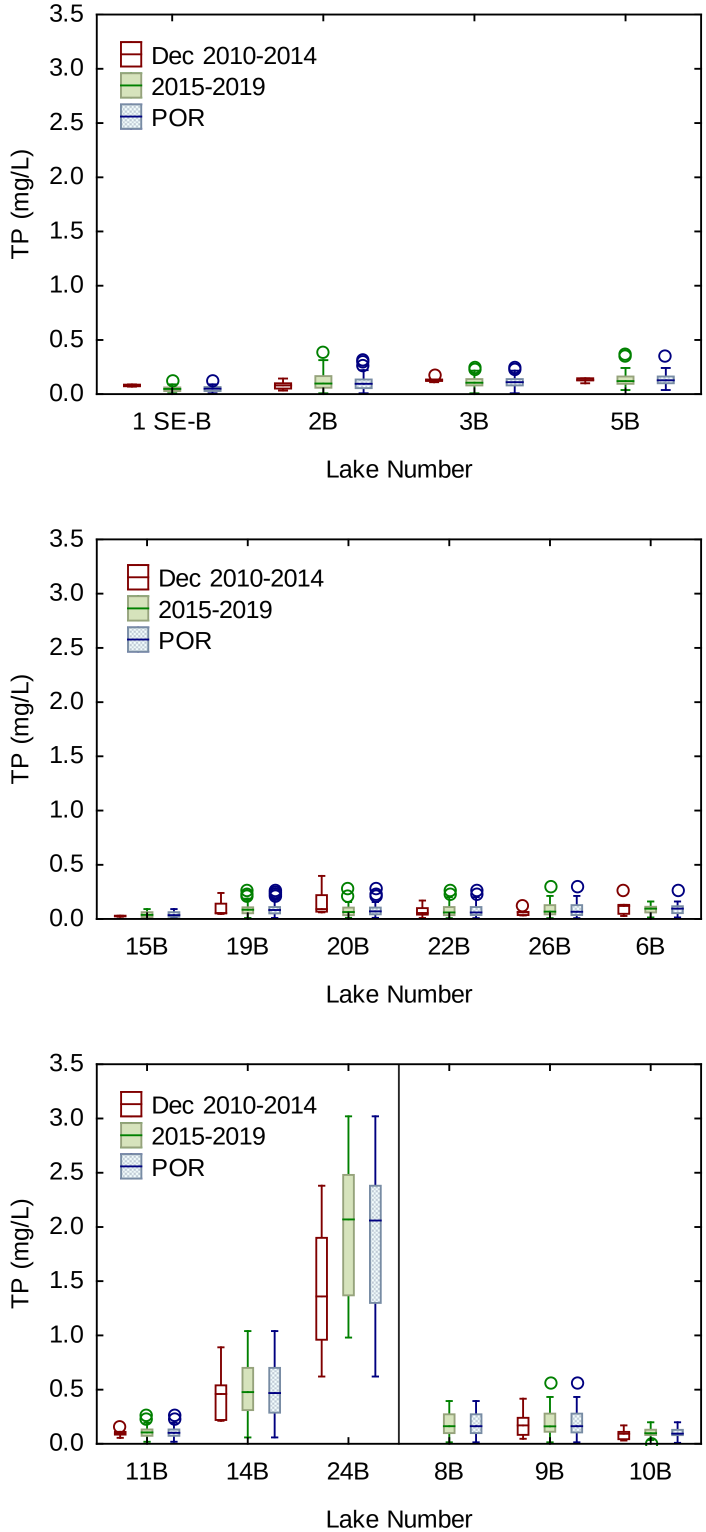


Figure 3-11. Summary of TP results for stormwater lakes discharging to Moorings Bay (top), Gordon River (middle), and Naples Bay (bottom left)/Gulf of Mexico (bottom right) for three time periods.

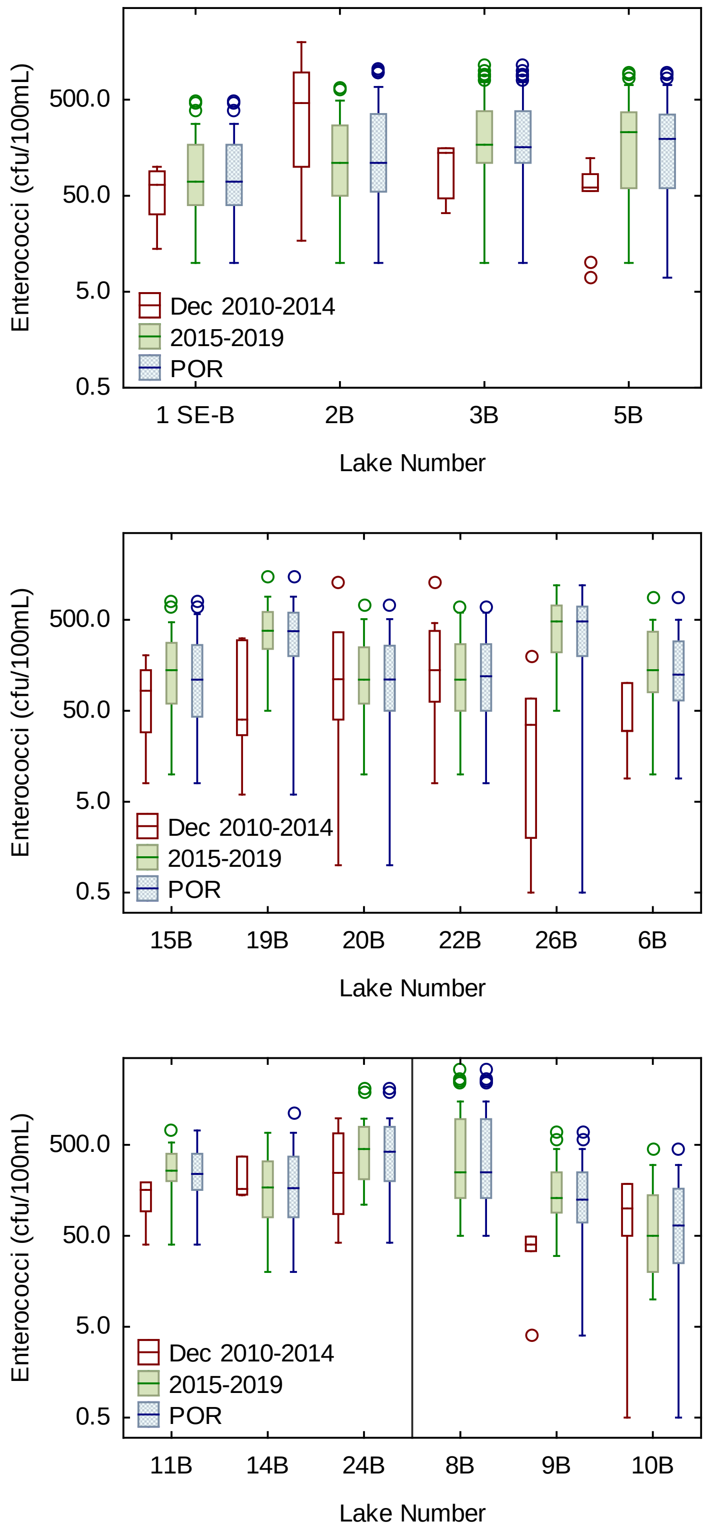


Figure 3-12. Summary of enterococci results for stormwater lakes discharging to Moorings Bay (top), Gordon River (middle), and Naples Bay (bottom left)/Gulf of Mexico (bottom right) for three time periods.

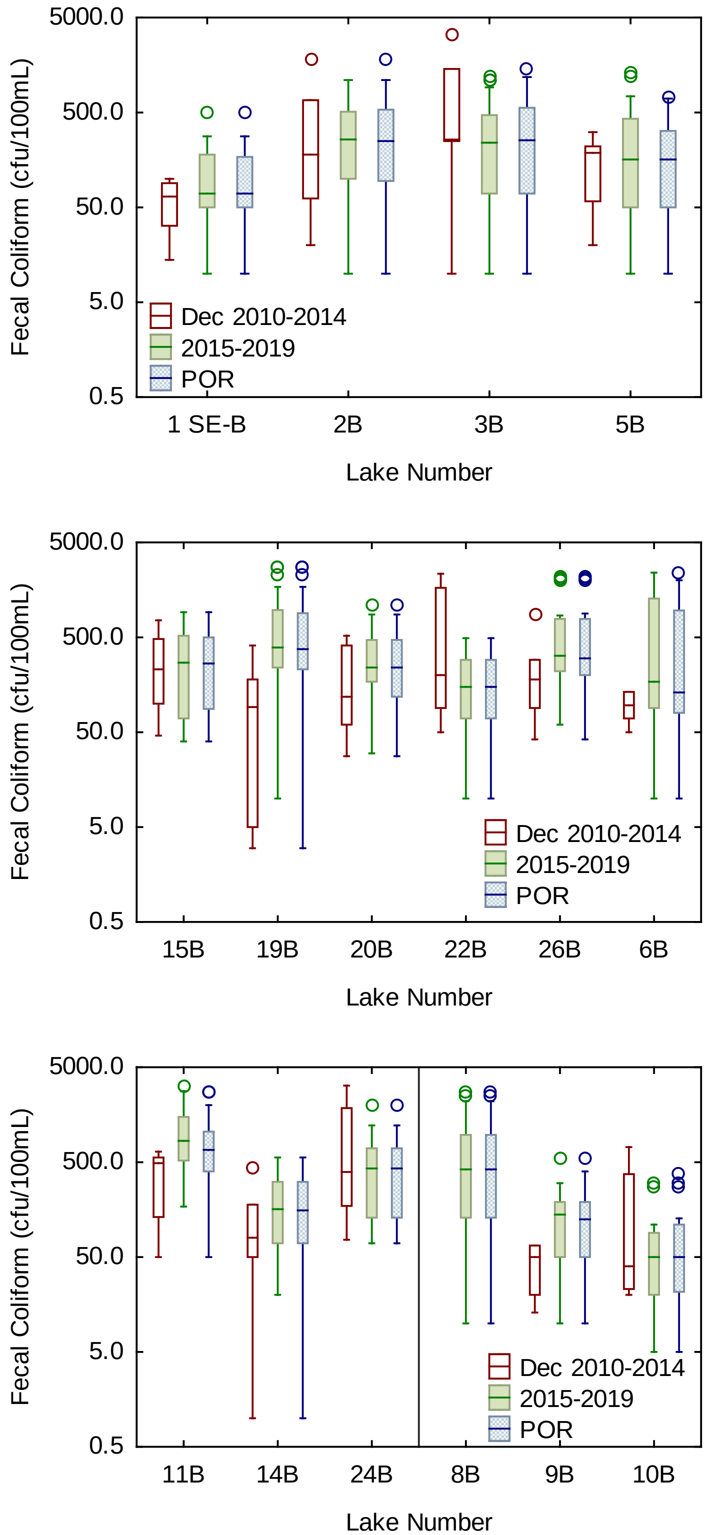


Figure 3-13. Summary of fecal coliform results for stormwater lakes discharging to Moorings Bay (top), Gordon River (middle), and Naples Bay (bottom left)/Gulf of Mexico (bottom right) for three time periods.

Lake Water Quality Comparison and Trend Analysis

As more data were collected since the original report, with some lakes being sampled monthly instead of semi-annually or quarterly, annual or Mann Kendall Tau analysis and a one-way analysis of variance (ANOVA) were run for the parameters of concern mentioned above for the period of record. For the fecal indicator bacteriological parameters, the results were Log_{10} transformed prior to running the ANOVA analysis as neither enterococci nor fecal coliform results were normally distributed (Table 3-3). No transformation was necessary for the Kendall Tau analysis as it is a non-parametric test using ranks, not magnitude of values. Analysis was performed for each individual stormwater lake along with the lake data combined and grouped by the four main receiving waterbodies. Both of these analyses utilize water quality concentrations and do not incorporate discharge volumes or loadings. It is meant as a means to compare concentrations among stormwater lakes or their combined concentration contributions to the four receiving waterbodies. However, lakes with lower concentrations but higher discharge volumes could lead to a higher pollutant loading into the receiving waterbody, than lakes with higher concentrations but lower discharge volumes. Additionally, only notes as to whether a certain lake was discharging or not were recorded, not actual discharge quantities at the time of sampling.

Lake Water Quality Comparison

The results of the ANOVA analysis indicated that there were lakes with significantly different concentrations within each receiving waterbody for all parameters:

Copper: While there were not statistically significant differences in copper concentrations among the four receiving waterbodies (ANOVA, $p > 0.05$), there were statistically significant differences among individual lakes within each receiving waterbody (Table 3-3). Copper concentrations were significantly different among lakes draining to Moorings Bay (1 SE-B, 2B, 3B, and 5B) from December 2010 through 2019 with 1 SE-B having the highest concentrations (ANOVA, $p < 0.05$, Duncan's multiple range test). There were also significant differences in copper concentrations among lakes draining to the Gordon River (6B, 15B, 19B, 20B, 22B, and 26B) from December 2010 through 2019 with 26B having the highest concentrations (ANOVA, $p < 0.05$, Duncan's multiple range test). There were no significant differences in copper concentrations among lakes draining to the Gulf of Mexico or Naples Bay (ANOVA, $p > 0.05$, Table 3-3).

Salinity: Overall, the lowest salinity concentrations of all four receiving waterbodies were found in the Gordon River (ANOVA, $p < 0.05$, Duncan's multiple range test). Additionally, there were statistically significant differences in salinity over time among lakes draining to all four receiving waterbodies (ANOVA, $p < 0.05$); 2B had the highest salinity to Moorings Bay, 22B had the highest salinity to the Gordon River, 10B had the highest salinity to the Gulf of Mexico, and 14B had the highest salinity to the Naples Bay (Duncan's multiple range test).

TSS: Concentrations were statistically different among receiving waterbodies, with the Gulf of Mexico having higher overall TSS concentrations (Duncan's multiple range test, Table 3-3). There were statistically significant differences in TSS among lakes draining to three of the receiving waterbodies (ANOVA, $p < 0.05$); 20B had the highest TSS concentration to the Gordon River, 8B had the highest concentration to the Gulf of Mexico, and 11B had the lowest TSS concentration to Naples Bay (Duncan's multiple range test).

Nutrients: There were statistically different TN and TP concentrations among receiving waterbodies with TP the highest in the Naples Bay and TN the highest in Naples Bay and the Gulf of Mexico (ANOVA, $p < 0.05$, Duncan's multiple range test, Table 3-3). TN concentrations were statistically different among lakes in three of the receiving waterbodies, with 20B highest to the Gordon River, 8B highest to the Gulf of Mexico, and 24B highest to Naples Bay (Duncan's multiple range test). There were also significant differences in TP concentrations over time among lakes in all four receiving waterbodies (ANOVA, $p < 0.05$); 5B had the highest concentrations to Moorings Bay, 15B had the lowest concentrations to the Gordon River, 10B had the lowest concentrations to the Gulf of Mexico, and 24B had the highest concentrations to Naples Bay (Duncan's multiple range test).

Fecal Indicator Bacteria: Overall, the highest enterococci colony counts were found in Naples Bay compared to the other receiving waterbodies (ANOVA, $p < 0.05$, Duncan's multiple range test, Table 3-3). There were also significant differences among stormwater lakes draining to the Gordon River, Naples

Bay, and the Gulf of Mexico over time (ANOVA, $p < 0.05$) with the Log_{10} enterococci colony counts highest at 26B and 19B (Gordon River), highest at 8B (Gulf of Mexico), and higher at 24B (Naples Bay, Duncan's multiple range test).

Among the receiving waterbodies, higher Log_{10} fecal coliform colony counts were found in Naples Bay and the Gordon River had (Duncan's multiple range test, Table 3-3). Looking at individual lakes for each receiving waterbody, there were significant differences in fecal coliforms among lakes draining to all four waterbodies (ANOVA, $p < 0.05$) with the Log_{10} fecal coliform colony counts lower at 1 SE-B (Moorings Bay), highest at 26B and 19B (Gordon River), highest at 8B (Gulf of Mexico), and lowest at 14B (Naples Bay, Duncan's multiple range test).

Lake Water Quality Trend Analysis

The results of the annual Kendall analysis for the receiving waterbodies (includes all data for lakes draining to that area) show significant increasing and decreasing trends for various parameters in various receiving waterbodies (Table 3-4). Individual lakes analysis results by parameter are included in Appendix B (Table B-1).

Copper: There were statistically significant decreases in copper to Moorings Bay (slope -0.33 µg/L/yr) and Naples Bay (slope -0.27 µg/L/yr). Looking at the individual lakes, at least one lake in each receiving waterbody had a statistically significant decreasing trend, but the other lakes had generally decreasing concentrations in copper over time (Appendix B, Table B-1).

Salinity: There were statistically significant decreases in salinity in two of the four receiving waterbodies (Table 3-4). In Moorings Bay, salinity had a decreasing slope of -0.01 ppt/yr and the Gulf of Mexico had a decreasing slope of -0.03 ppt/yr. While these were both statistically significant decreasing trends, the annual measure of decrease is very small and is within the error of the multi-parameter data sonde. Individual lakes draining to each receiving waterbody also had significant decreases over time, most with similar slopes of decrease; only 5B draining to Moorings Bay and 10B draining to the Gulf of Mexico had notable decreasing slopes (-0.30 ppt/yr and -0.35 ppt/yr, respectively, Table B-1).

TSS: There was only a statistically significant increasing trend in TSS for the Gulf of Mexico, with annual slope of increase of 0.82 mg/L/yr. The three other receiving waterbodies did not have statistically significant increasing or decreasing trends in TSS over time (Kendall Tau, $p > 0.05$). There was also a significant decreasing trend in TSS at 2B (slope -0.60 mg/L/yr). However, for individual lakes, there were statistically significant decreasing trends at 2B (slope -0.60 mg/L/yr) draining to Moorings Bay and 20B (slope -0.85 mg/L/yr) draining to the Gordon River, and an increasing trends in TSS at 14B (slope 2.99 mg/L/yr) draining to Naples Bay (Table B-1).

Nutrients: TN concentrations had a statistically significant increasing trend in the Gulf of Mexico with the annual slope of 0.07 mg/L/yr for the receiving waterbody. The three other receiving waterbodies did not have statistically significant increasing or decreasing trends in TN over time (Kendall Tau, $p > 0.05$). For individual lakes, there were only statistically significant increasing trends found for 11B and 14B (slopes 0.04 and 0.11 mg/L/yr, respectively), both draining to Naples Bay.

There was only a statistically significant decreasing trend in TP over time in Moorings Bay (slope -0.01 mg/L/yr), but it was very small. Two individual lakes that drain to Moorings Bay (3B and 5B) and one lake draining to the Gordon River (20B) had statistically significant decreasing trends in TP over time (Table B-1).

Fecal Indicator Bacteria: There were statistically significant increasing trends for both bacteriological parameters over time to the Gordon River (enterococci and fecal coliform: slopes 15.9 cfu/100mL/yr and 25.17 cfu/100mL/yr, respectively). There were similar increasing trends observed for the three lakes collectively draining to the Gulf of Mexico with significant increasing trends for both enterococci and fecal coliform (slopes 31.76 cfu/100mL/yr and 40.74 cfu/100mL/yr, respectively) When looking at the individual lakes (not the combined contribution), only 9B had a statistically significant increasing trend in enterococci (slope 20.00 cfu/100mL/yr), and two lakes draining to the Gordon River (19B and 20B) and two lakes draining to the Gulf of Mexico (8Band 9B) had increasing trends in fecal coliform (Table B-1).

Table 3-3. ANOVA results for the combined discharge from stormwater lakes to receiving waterbody by parameter.

Analysis Area	Years	F	p-value	Significantly Different Station
Copper				
All Receiving Waterbodies	2010-2019	1.44	0.23	N/A
Moorings Bay	2010-2019	4.17	0.01	1 SE-B higher
Gordon River	2010-2019	43.53	<0.0001	26B higher
Gulf of Mexico	2012-2019	2.47	0.09	N/A
Naples Bay	2011-2019	1.35	0.27	N/A
Salinity				
All Receiving Waterbodies	2010-2019	7.92	<0.001	Gordon River lowest
Moorings Bay	2010-2019	4.61	0.004	2B highest
Gordon River	2010-2019	14.02	<0.0001	22B highest
Gulf of Mexico	2012-2019	68.41	<0.0001	10B highest
Naples Bay	2011-2019	404.74	<0.0001	14B highest
TSS				
All Receiving Waterbodies	2010-2019	3.58	0.01	Gulf of Mexico higher
Moorings Bay	2010-2019	1.45	0.23	N/A
Gordon River	2010-2019	10.22	<0.0001	20B highest
Gulf of Mexico	2012-2019	6.77	0.002	8B highest
Naples Bay	2011-2019	22.24	<0.0001	11B lowest
Total Nitrogen				
All Receiving Waterbodies	2010-2019	34.41	<0.0001	Naples Bay/GOM highest
Moorings Bay	2010-2019	1.60	0.19	N/A
Gordon River	2010-2019	12.89	<0.0001	20B highest
Gulf of Mexico	2012-2019	14.37	<0.0001	8B highest
Naples Bay	2011-2019	100.72	<0.0001	24B highest
Total Phosphorus				
All Receiving Waterbodies	2010-2019	126.91	<0.0001	Naples Bay highest
Moorings Bay	2010-2019	18.05	<0.0001	5B highest
Gordon River	2010-2019	3.02	0.01	15B lowest
Gulf of Mexico	2012-2019	5.22	0.01	10B lowest
Naples Bay	2011-2019	135.31	<0.0001	24B highest
Enterococci (Log_{10})				
All Receiving Waterbodies	2010-2019	5.25	0.00	Naples Bay highest
Moorings Bay	2010-2019	2.21	0.09	N/A
Gordon River	2010-2019	6.50	<0.0001	26 and 19 highest
Gulf of Mexico	2012-2019	14.16	<0.0001	8B highest, 10B lowest
Naples Bay	2011-2019	4.64	0.01	24B higher
Fecal Coliform (Log_{10})				
All Receiving Waterbodies	2010-2019	10.22	<0.0001	Naples Bay and Gordon River higher
Moorings Bay	2010-2019	3.42	0.02	1 SE-B lower
Gordon River	2010-2019	2.97	0.12	26 and 19 highest
Gulf of Mexico	2012-2019	10.65	0.0001	8B highest
Naples Bay	2011-2019	11.90	<0.0001	14B lowest

Table 3-4. Annual Kendall Tau analysis results for the combined discharge from stormwater lakes to receiving waterbody from 2010 through 2019.

Receiving Waterbody	Years	Tau	p-value	Slope
Copper				
Moorings Bay	2010-2019	**-0.11**	**0.02**	**-0.33 µg/L/yr**
Gordon River	2010-2019	-0.01	0.90	N/A
Gulf of Mexico	2011-2019	0.02	0.74	N/A
Naples Bay	2012-2019	**-0.26**	**0.001**	**-0.27 µg/L/yr**
Salinity				
Moorings Bay	2010-2019	**-0.14**	**0.002**	**-0.01 ppt/yr**
Gordon River	2010-2019	-0.04	0.30	N/A
Gulf of Mexico	2011-2019	**-0.34**	**<0.0001**	**-0.03 ppt/yr**
Naples Bay	2012-2019	-0.01	0.94	N/A
TSS				
Moorings Bay	2010-2019	-0.09	0.07	N/A
Gordon River	2010-2019	-0.01	0.84	N/A
Gulf of Mexico	2011-2019	**0.16**	**0.02**	**0.82 mg/L/yr**
Naples Bay	2012-2019	0.12	0.11	N/A
Total Nitrogen				
Moorings Bay	2010-2019	-0.04	0.36	N/A
Gordon River	2010-2019	0.01	0.71	N/A
Gulf of Mexico	2011-2019	**0.20**	**0.002**	**0.07 mg/L/yr**
Naples Bay	2012-2019	0.11	0.15	N/A
Total Phosphorus				
Moorings Bay	2010-2019	**-0.22**	**0.000004**	**-0.01**
Gordon River	2010-2019	-0.07	0.08	N/A
Gulf of Mexico	2011-2019	0.004	0.95	N/A
Naples Bay	2012-2019	-0.01	0.89	N/A
Enterococci				
Moorings Bay	2010-2019	0.03	0.57	N/A
Gordon River	2010-2019	**0.15**	**0.0003**	**15.90 cfu/100mL/yr**
Gulf of Mexico	2011-2019	**0.34**	**<0.0001**	**31.76 cfu/100mL/yr**
Naples Bay	2012-2019	0.13	0.10	N/A
Fecal Coliform				
Moorings Bay	2010-2019	-0.03	0.53	N/A
Gordon River	2010-2019	**0.15**	**0.0003**	**25.17 cfu/100mL/yr**
Gulf of Mexico	2011-2019	**0.29**	**<0.0001**	**40.74 cfu/100mL/yr**
Naples Bay	2012-2019	0.12	0.11	N/A

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.

3.1.2.2 Pump Stations

The City's stormwater system is designed to transport stormwater either directly to receiving waters or indirectly to receiving waters via one of three pump stations through swales, ditches, and pipes. The Public Works Pump Station (PW-Pump) directs stormwater to the Gordon River (marine segment), the Cove Pump Station (11-Pump) discharges into northern Naples Bay, and the Port Royal Pump Station (14-Pump) discharges into the canals of the Port Royal area in the southern portion of Naples Bay (see Figure 3-6).

The predominant land use across the areas contributing stormwater through the pump stations and into Naples Bay is residential. A comparison of the water quality through the Naples pump stations to typical runoff concentrations indicates the stormwater quality in Naples is within the range of that observed from other residential land uses in Florida (Table 3-5). In fact, the average concentrations of copper and suspended solids observed in water traveling through the pump stations are somewhat lower than those observed by FDEP in their review of residential land uses (FDEP 2007).

In addition to the concentration of certain pollutants in stormwater, an estimate of loading to receiving waters is a valuable management tool. Calculations of loads to Naples Bay from the pump stations is possible for three distinct time periods: 2012 (October 2011 to September 2012) and calendar year 2013 through calendar year 2019 (excluding calendar year 2015 due to lack of monthly pumping data). During previous upgrades to the City's supervisory control and data acquisition (SCADA) system, a significant amount of volume data for the pump stations were lost limiting the available time frame for loadings calculations. Data needed for the loading calculations associated with the PW-Pump station were available for 2012, and 2016 through 2019. Loads were calculated using the total volume by month for the available time period and the quarterly concentration recorded during the time period.

The loadings calculated from the available time periods from the pump stations were highly variable between pump stations and over time for most parameters (Table 3-6). Copper loadings varied by year and pump station, with the highest average loadings at PW-Pump and the highest annual loadings as follows: 2017-PW-Pump, 2018-11-Pump, and 2016-14-Pump. TN loadings also varied by year and pump station with the highest loadings at 11-Pump and the lowest loadings at 14-Pump. TP and suspended solids loadings were also the highest at 11-Pump (Table 3-6).

Table 3-5. Mean Naples pump station water quality data (December 2010 to 2014, 2015 to 2019, and period of record) and typical Florida residential runoff concentrations.

Parameter	Residential Land Uses*	Naples Pump Stations		
	Range	2010-2014 Mean	2015-2019 Mean	2010-2019 Mean
Copper (µg/L)	8–16	6.16	3.50	4.44
Total Nitrogen (mg/L)	1.61–2.32	1.44	1.50	1.48
Total Phosphorus (mg/L)	0.19–0.52	0.226	0.230	0.228
Suspended Solids (mg/L)	23–78	8.56	7.09	7.59

* Source: FDEP 2007

Table 3-6. Estimated total annual loads delivered to Naples Bay through City of Naples pump stations.

Pump Station	Year	Total Annual Loads (lbs)			
		Copper	Total Nitrogen	Total Phosphorus	Suspended Solids
PW-Pump	WY2012	33.10	2,566.90	162.60	10,425.30
	2013	--	--	--	--
	2014	--	--	--	--
	2015	--	--	--	--
	2016	23.80	5,920.39	514.19	25,412.54
	2017	67.55	10,955.20	1,449.15	16,468.72
	2018	39.87	9,450.34	741.70	49,869.02
	2019	5.41	4,191.50	263.09	3,780.79
11-Pump	WY2012	8.30	5,730.30	930.50	14,371.90
	2013	11.30	8,755.50	829.50	11,514.70
	2014	5.40	1,978.60	346.50	5,376.10
	2015	--	--	--	--
	2016	6.72	10,089.95	1,052.37	11,337.01
	2017	12.13	17,005.01	2,165.67	120,683.22
	2018	33.74	25,746.74	2,647.00	277,849.54
	2019	20.00	14,870.53	1,313.78	17,319.92
14-Pump	WY2012	5.90	356.10	130.70	15,219.80
	2013	8.40	9,393.50	982.00	24,549.40
	2014	9.90	4,290.40	1,427.80	13,526.90
	2015	--	--	--	--
	2016	10.77	490.98	863.41	33,187.20
	2017	3.55	2,747.03	975.11	13,694.06
	2018	5.91	5,925.49	2,059.01	29,262.06
	2019	1.64	1,671.96	375.64	3,746.82

Stormwater Pump Station Water Quality – Median and Quartile Ranges

Similar to the stormwater lakes, box plots were created for the parameters of concern for each of the three time periods (December 2010 to 2014, 2015 to 2019, and the period of record, Figures 3-14 through 3-16). When analyzing all the data collected over the period of record to determine if there were difference in concentrations among pump stations, 14-Pump was generally dissimilar from the other two pump stations.

At 14-Pump, the 25th to 75th percentile ranges were larger and the median concentrations were higher for TN, TP, TSS, and salinity compared to the other two pump stations (Figures 3-14 and 3-15). Salinity measurements during the initial study period and the more recent time period were all within the brackish range with medians between 5 and 7 ppt at 14-Pump (Figure 3-14, middle panel). Copper concentrations at PW-Pump were more variable than the other two stations with median concentrations double that of 11-Pump and 14-Pump (Figure 3-14, top panel). The fecal indicator bacteria parameters (enterococci and fecal coliform) were slightly more variable with wider ranges of measurements; only 14-Pump fecal coliform measurements were lower and less variable over the period of record (Figure 3-16).

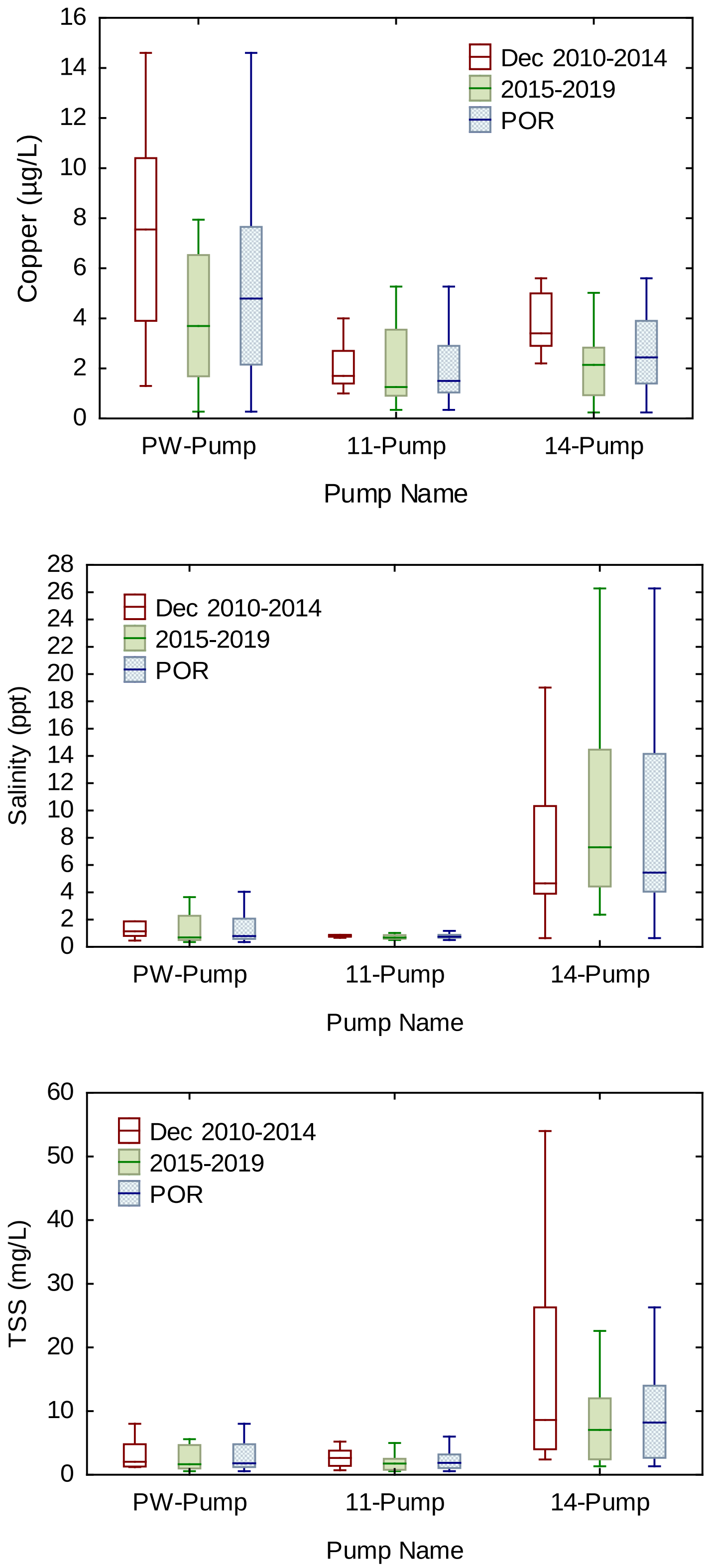


Figure 3-14. City of Naples pump station water quality summary, copper (top), salinity (middle), and suspended solids (bottom).

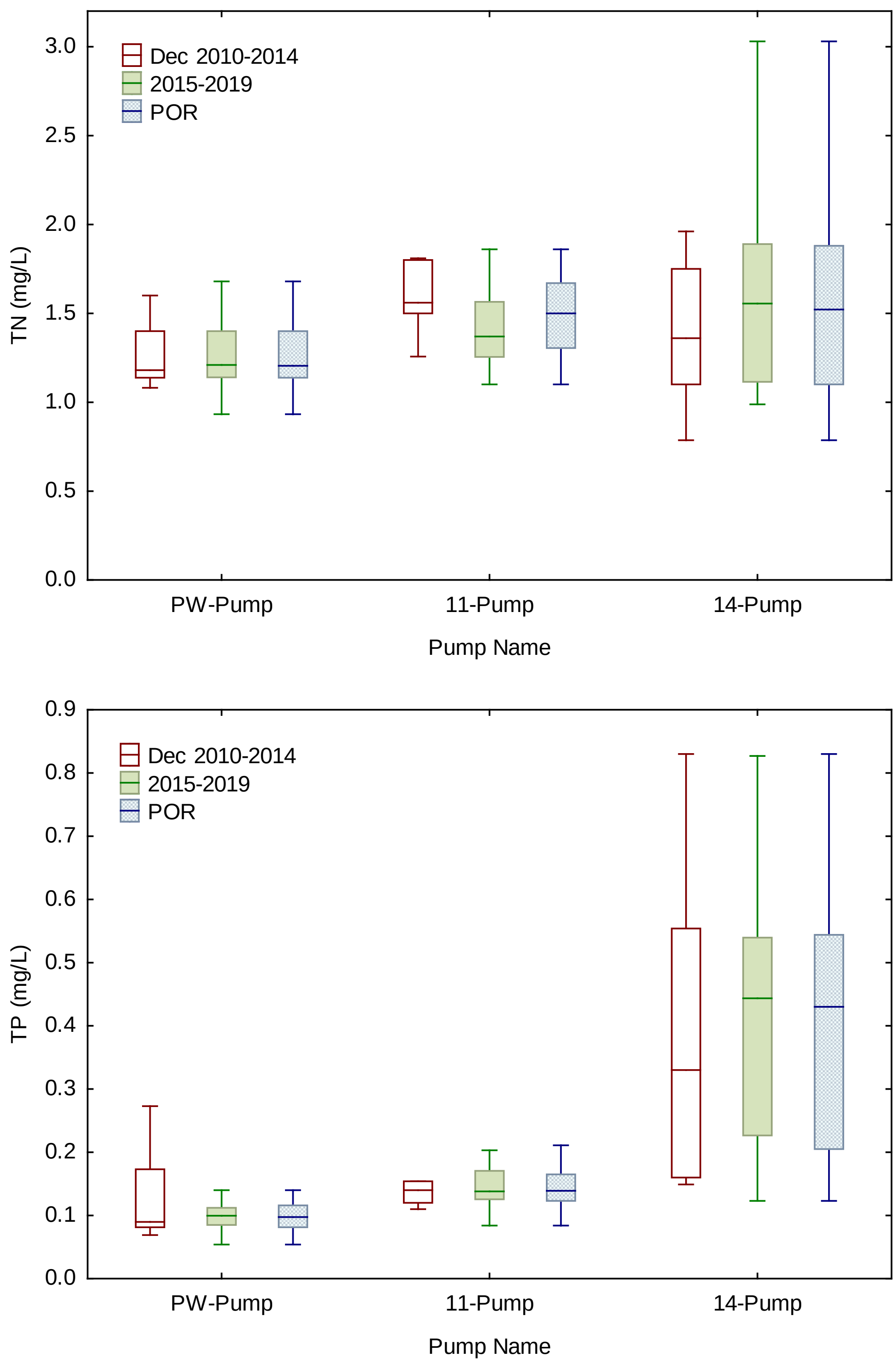


Figure 3-15. City of Naples pump station nutrients summary, total nitrogen (top) and total phosphorus (bottom).

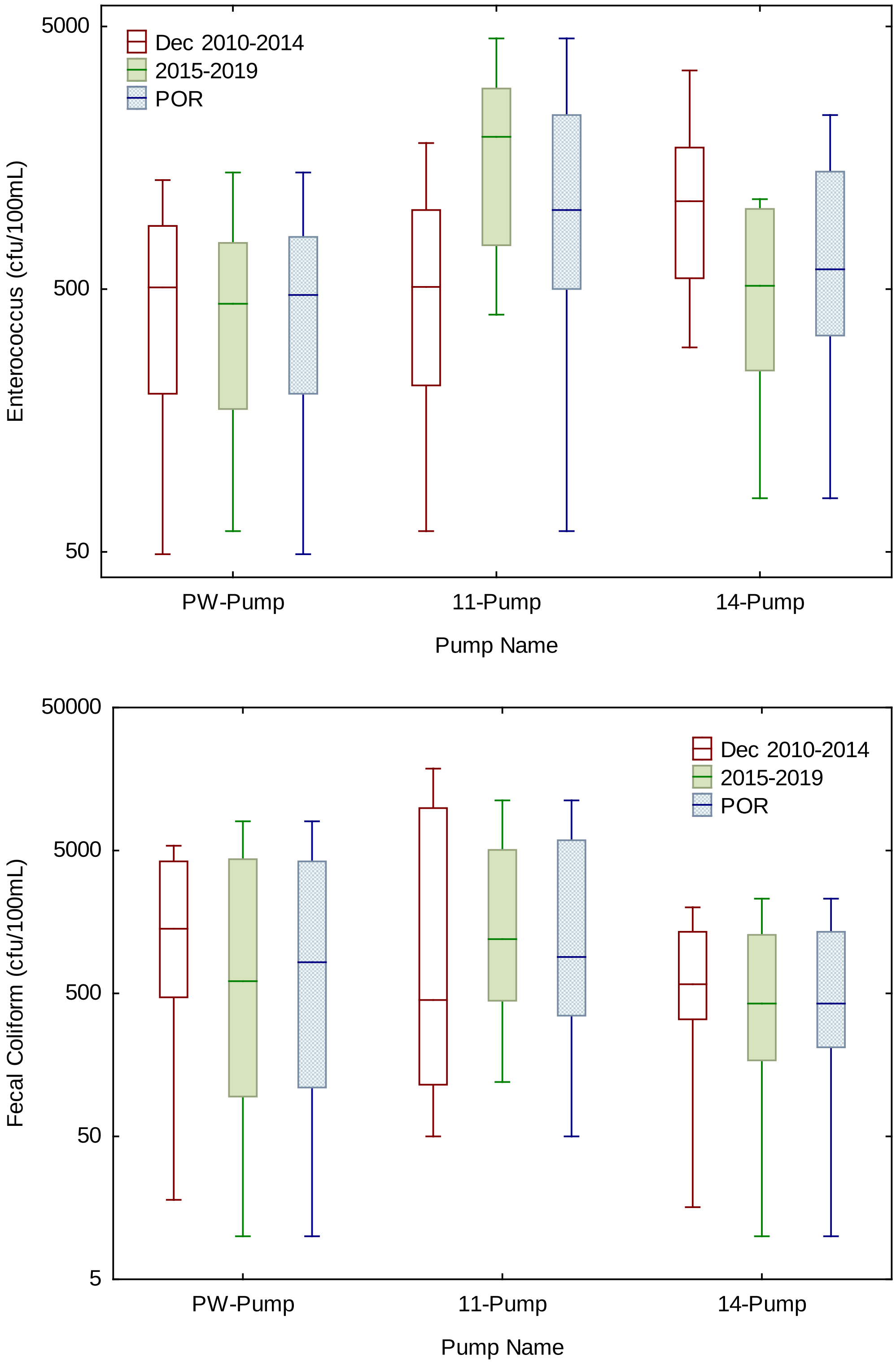


Figure 3-16. City of Naples pump station bacterial summary, enterococci (top) and fecal coliform (bottom).

Stormwater Pump Station Water Quality Comparison and Trend Analysis

Using the same dataset, a one-way ANOVA analysis was used to look for statistically significant differences among pump stations (Table 3-7). The PW-Pump station had the highest copper concentrations compared to the other two pump stations (ANOVA, $p < 0.05$, Duncan's multiple range test), which matches the loading summary above. There were no significant differences in Log_{10} fecal coliform among pump stations from December 2010 through 2019 (ANOVA, $p > 0.05$). There were significant differences in Log_{10} enterococci among pump stations over time, with 11-Pump higher than the other pump stations (ANOVA, $p < 0.05$, Duncan's multiple range test). For the remaining four parameters of concern (salinity, TN, TP, and TSS), 14-Pump had significantly higher concentrations over the study period than the other two pump stations (ANOVA, $p < 0.05$, Duncan's multiple range test).

Water quality in water discharged from the pump stations into Naples Bay (Table A-2) is very similar to the stormwater lakes, with the exception of bacteria (fecal coliform and enterococci), which was significantly higher in all the pump station discharge than in the stormwater lake discharge (one-way ANOVA, $p < 0.01$).

Additionally, annual Kendall Tau analysis were run to determine if there were statistically significant increasing or decreasing trends at the pump stations over time (Table 3-8). For copper, there were statistically significant decreases over time at PW-Pump and 14-Pump (slopes -0.89 µg/L/yr and -0.35 µg/L/yr, respectively); these trends seem to be driven by data collected early on in the study period where concentrations were higher and more variable. There were statistically significant decreasing trends in salinity and TN over time at 11-Pump, but the slopes for each parameter are relatively small (salinity slope -0.02 ppt/yr and TN slope -0.03 mg/L/yr). None of the decreasing slopes are of ecological or management concerns at this time. However, there was an increasing trend in enterococci over time at 11-Pump with a slope of 138.5 cfu/100mL/yr. This parameter should continue to be monitored to determine if the current trend continues in the future.

Table 3-7. ANOVA results for pump station water quality data.

Parameter	Years	F	p-value	Significantly Different Station
Copper (µg/L)	2010-2019	3.10	0.05	PW-Pump highest
Salinity (ppt)	2010-2019	3.10	0.05	PW-Pump highest
TSS (mg/L)	2010-2019	5.44	0.01	14-Pump highest
Total Nitrogen (mg/L)	2010-2019	4.06	0.02	14-Pump highest
Total Phosphorus (mg/L)	2010-2019	35.53	<0.0001	14-Pump highest
Enterococci (Log_{10})	2010-2019	1.88	0.16	N/A
Fecal Coliform (Log_{10})	2010-2019	2.26	0.11	N/A

Table 3-8. Annual Kendall Tau analysis results for the pump stations from 2010 through 2019.

Pump Station	Years	Tau	p-value	Slope
Copper				
PW-Pump	2010-2019	**-0.39**	**0.002**	**-0.89 µg/L/yr**
11-Pump	2010-2019	-0.10	0.43	N/A
14-Pump	2010-2019	**-0.32**	**0.01**	**-0.35 µg/L/yr**
Salinity				
PW-Pump	2010-2019	-0.04	0.74	N/A
11-Pump	2010-2019	**-0.25**	**0.04**	**-0.02 ppt/yr**
14-Pump	2010-2019	0.16	0.21	N/A
TSS				
PW-Pump	2010-2019	-0.26	0.05	N/A
11-Pump	2010-2019	-0.14	0.28	N/A
14-Pump	2010-2019	-0.07	0.58	N/A
TN				
PW-Pump	2010-2019	-0.09	0.51	N/A
11-Pump	2010-2019	**-0.29**	**0.02**	**-0.03 mg/L/yr**
14-Pump	2010-2019	0.01	0.93	N/A
TP				
PW-Pump	2010-2019	-0.02	0.85	N/A
11-Pump	2010-2019	-0.07	0.57	N/A
14-Pump	2010-2019	0.01	0.95	N/A
Enterococci				
PW-Pump	2010-2019	-0.13	0.30	N/A
11-Pump	2010-2019	**0.30**	**0.01**	**138.5 cfu/100mL/yr**
14-Pump	2010-2019	-0.19	0.15	N/A
Fecal Coliform				
PW-Pump	2010-2019	-0.06	0.64	N/A
11-Pump	2010-2019	0.05	0.66	N/A
14-Pump	2010-2019	-0.04	0.76	N/A

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.

3.2 Naples Bay Water Quality

This section summarizes the analysis of the current water quality and trends within Naples Bay using the available data from the City's monitoring program as well as other publicly available data sources. The purpose is to provide a robust characterization of the current status of water quality in the Bay as well as provide a complete understanding of the factors that can and do impact biological communities. The analysis provided here focuses on the constituents that both affect water quality in Naples Bay and have regulatory significance: salinity, nutrients (TN and TP), chlorophyll-*a*, copper, turbidity, dissolved oxygen, and fecal indicator bacteria (fecal coliform and enterococci).

The study of each water quality indicator summarized in the following sub-sections provides an in-depth look at:

- The current water quality regime of Naples Bay and trends within the past five years (December 1, 2014 to November 30, 2019: WY 2015 to 2019), including a breakdown of typical dry season (December to May) and wet season (June to November) trends. This includes a comparison of the current five-year period to the previous five-year period (WY 2010 to 2014) and to records as far back as 2005 to notice any medium-long term water quality trends.
- A trend analysis assessing the temporal changes in Naples Bay water quality while trying to isolate the influences of two covariates; GGC flows and rainfall (including any potential impacts from local stormwater runoff).
- The spatial distribution of water quality concentrations within Naples Bay.

The specific gauges and monitoring locations used in this water quality analysis for Naples Bay is summarized in Section 3.2.1, with a summary of each water quality constituent in the subsequent sub-sections. A summary of the statistical analysis methodology utilized within this section are included in Appendix B.

3.2.1 <u>Data Used</u>

3.2.1.1 Water Quality Monitoring Data

The primary source of data for this analysis is the City's water quality monitoring program. For trend analyses, data from four long-term monitoring stations were used to represent the different sections of Naples Bay:

- GORDEXT/GORDPT: North Naples Bay between GGC and Rock Creek. A single long-term data station within the area was not available for the Gordon River (marine segment) so stations GORDEXT and GORDPT were combined based on their proximity to each other to represent a single dataset for the marine section of the Gordon River above the SR 41 Bridge.
- NBAYNL: Upper Naples Bay just south of Naples Landing Park and Boat Ramp.
- NBAYWS: Mid Naples Bay just south of Haldeman Creek confluence.
- GPASS6: South Naples Bay just inside Gordon Pass.

The sample locations are shown in Figure 3-17. Water quality samples for these stations have been collected since either 2005 (GORDEXT/GORDPT and NBAYWS) or 2006 (NBAYNL and GPASS6). Initially samples were collected between 4-6 times a year (between bi-monthly and quarterly); however, by 2011 all four stations were sampled monthly (11-12 measurements a year). This analysis utilized results up to the end of November 2019 which is the end of WY 2019 for the Naples Bay watershed.

These samples were collected at the minimum depth of 0.3 to 0.5 meters which is generally regarded as a surface sample. Water quality parameters that were focused on for these analyses at these four stations include salinity, nutrients (TN and TP), chlorophyll-*a*, copper, turbidity, dissolved oxygen, and fecal indicator bacteria (fecal coliform and enterococci).

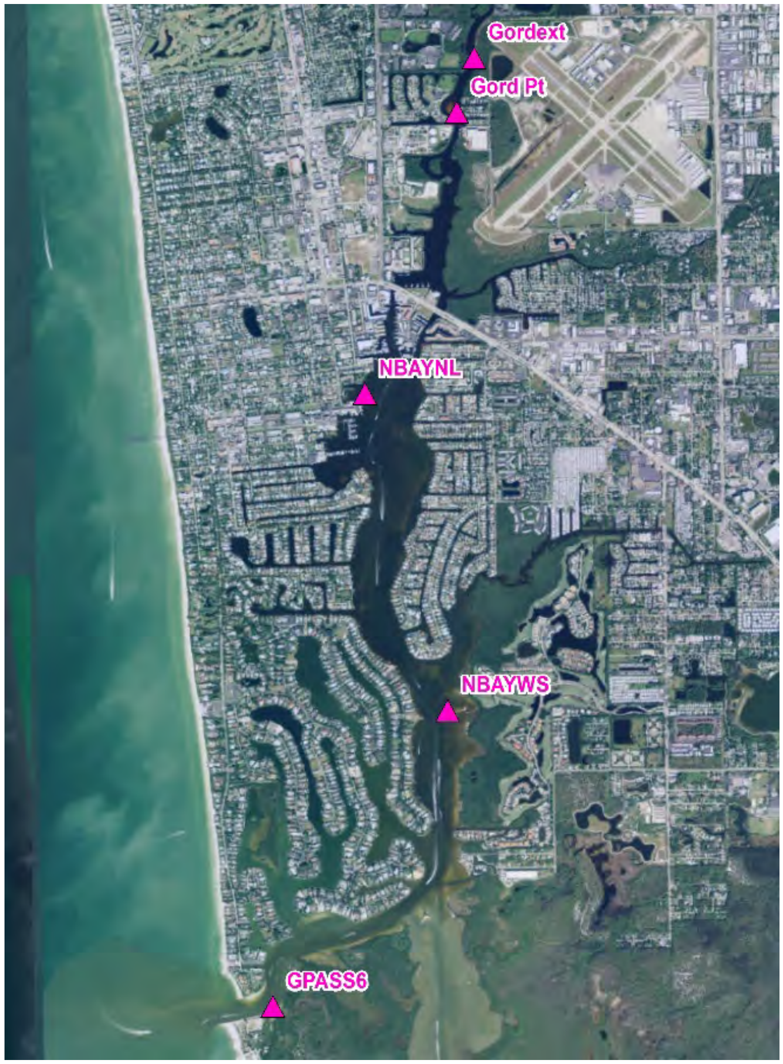


Figure 3-17. Naples Bay long term water quality monitoring locations, 2005 through 2019.

3.2.1.2 Flow and Rainfall Data

Naples Bay water quality has been assessed for relationships with two primary water sources; the freshwater GGC inflow from the north, and local rainfall for the surrounding urban area.

The daily average flow (in cubic feet / second, or cfs) from the GGC weir structure, referred to as gauge GG1, is the basis to assess the relationship between GGC flow and Naples Bay water quality. The location of the GG1 gauge is shown in Figure 2-1. These daily flow values are averages from continuous flow data throughout the day. The daily average flows measured at GG1 from November 27, 2008 through 2019, providing 11 years of flow data (complete WY 2009 to 2019).

Local daily rainfall totals in inches from the SFWMD COLGOV_R rainfall gauge (Figure 2-1) are available from mid-1996 to the present, providing 23 years of daily rainfall records. This rain gauge is located at the Collier County Government Center (Figure 2-1), near the headwaters of Haldeman Creek and approximately parallel to the mid-point of Naples Bay. The average seasonal GGC daily flow records and rainfall records from WY 2009 to 2019 are shown in Figure 3-4, with these flow and rainfall patterns discussed extensively in this section relating to water quality trends.

3.2.1.3 Continuous USGS Salinity Data

In addition to the monthly / bi-monthly salinity recordings from the City's monitoring program discussed in Section 3.2.1.1, four USGS gauges operated for approximately three years, mid-2011 or early 2012 through October 2014, collecting a salinity measurement at 15-minute intervals throughout their deployment. The four gauges recorded both surface and bottom salinity at the following stations:

- 02291310 – Gordon River at Rowing Club (Rowing Club Point)
- 02291315 – Naples Bay at City Dock (City Dock)
- 02291325 – Naples Bay Mid Estuary (Mid Estuary)
- 02291330 – Naples Bay at Gordon Pass (Gordon Pass)

The location of these four USGS gauges are shown in Figure 3-18. The four USGS gauges are generally in the proximity of the four water quality monitoring stations (compare Figure 3-18 to 3-17), which allows for a comparison of corresponding salinity data between the respective datasets (refer to Section 3.2.4.2). The sections of Naples Bay and the two corresponding salinity recording stations are listed in Table 3-9.

Though the continuous recorder data is not available for the current five-year period of analysis (WY 2015 to 2019) it provides a unique opportunity to characterize how the freshwater inflow from the GGC affects salinity in Naples Bay at four different locations at the same time. This allows for a detailed analysis of certain patterns and is supplemental to the monthly monitoring data.

Table 3-9. Summary of corresponding monitoring stations and continuous gauges for salinity.

Naples Bay Section	Water Quality Monitoring Station	USGS Continuous Gauge	Distance Between Station and Gauge
North Naples Bay between GGC and Rock Creek	GORDEXT/GORDPT	02291310 – Gordon River at Rowing Club	0.32 / 0.58 miles
Upper Naples Bay just south of Naples Landing Park and Boat Ramp	NBAYNL	02291315 – Naples Bay at City Dock	0.15 miles
Mid Naples Bay just south of Haldeman Creek confluence	NBAYWS	02291325 – Naples Bay Mid Estuary	0.52 miles
South Naples Bay just inside Gordon Pass	GPASS6	02291330 – Naples Bay at Gordon Pass	0.03 miles

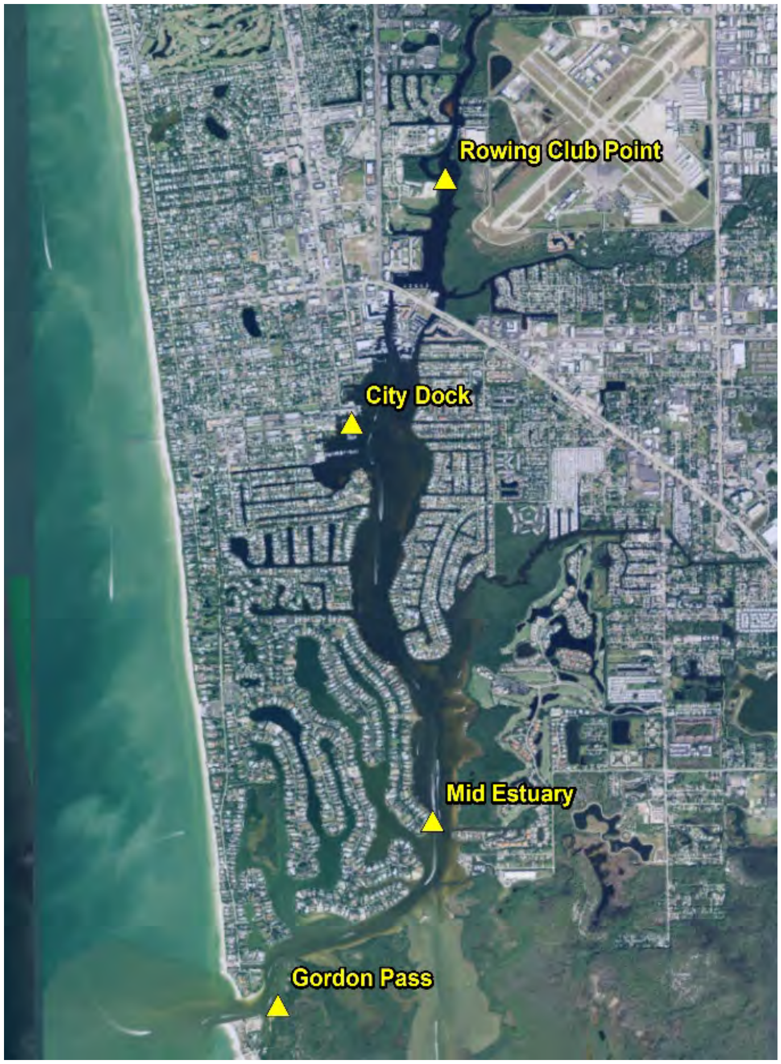


Figure 3-18. USGS continuous recorder locations for 2011 to 2014 analysis.

3.2.2 Statistical Methods Summary

In addition to a graphical and tabular interpretation of the current conditions of water quality in Naples Bay, several types of statistical analyses were performed for each constituent of concern at long-term monitoring stations throughout the Bay: autoregressive error time-series models, predictive models between salinity and flow, regression analysis, and parametric and nonparametric correlation analyses.

3.2.2.1 Autoregressive Error Models for Time Series

In order to identify trends in the water quality data from Naples Bay over time, an Autoregressive Error Model (AEM) was used on the most recent data, similar to the analysis completed in the initial 2015 analysis. For many water quality variables, observations over time are temporally correlated. For example, the value of salinity at any given time (t) is correlated with the salinity value at an earlier time (t-1). Fitting a simple regression model through this data violates many of the statistical assumptions that are required for a proper trend detection. AEM is a simple model that reduces the chance of an incorrectly specified time series model that does not take temporal correlation into account.

Mathematically, the model can be written as:

$$Y_t = \beta_0 + \beta_1 * X_t + \gamma_t$$
$$\gamma_t = \varepsilon_t - \theta_{t-1}\gamma_{t-1} - .. - .. \theta_m \gamma_{t-m}$$
$$\varepsilon_t \sim N(0, \sigma^2)$$

Where y are dependent values, t represents a time step, x are covariates (in this case, simply the time that y is observed, e.g., month = 4), m is a lag function of 1 …. n, σ is standard deviation, θ is a measure of temporal correlation at lag m, and ε is the model error which is normally distributed (N).

Effectively, the model predicts y at time t as a function of time, where the error term in the model accounts for any temporal correlation which exists in the time series. Therefore, the errors from the model are normal, thus meeting the statistical assumptions for trend detection. Using this form, a test of H0: β1 = 0, is used to detect trend.

For time series analysis, the frequency of sampling must be consistent; because sampling prior to December 2010 (start of WY 2011) was conducted only bimonthly, therefore, only the monthly sampling data available after this time for Naples Bay were utilized in this analysis. In addition, the time series analysis was limited to years where flow data from GGC and local rainfall data were available for use as a covariates, (starting 2008) which accounts for the entire model period December 2010 to December 2019. For parameters with suitable datasets, time series AEM were applied to data for four locations, one in the Gordon River (marine segment) and three in Naples Bay. Stations GPASS6 (Gordon Pass), NBAYWS (mid estuary), and NBAYNL (northern Naples Bay) were selected because of their long-term continuous data set dating back to the beginning of the City's monitoring program and, collectively, they represent upper, middle, and lower Naples Bay (Figure 3-17). A single long-term data station within the area influenced by GGC was not available for the Gordon River (marine segment) so stations GORDEXT and GORDPT were combined based on their proximity to each other to represent a single long-term dataset and the Gordon River (marine segment) above the SR 41 bridge.

Two potential covariates, natural log (LN) transformed daily flow from the GGC and natural log-transformed daily total rainfall from COLGOV_R, were considered for each model. The best fit models, using total model r^2 and corrected AIC (Akaike Information Criterion), were ones that included flow and rainfall as covariates for all water quality parameters. Water quality data, with the exception of dissolved oxygen and salinity, were also natural log-transformed as part of this trend analysis.

The model results created for each water quality parameter are the best fit models based on monthly recordings and daily flow data from December 2010 to December 2019. Models were run with numerous autoregressive error model lags to determine the best fit models for each parameter at each of the four stations. Autoregression months varied from 0 months to 2 months, with 0 to 1 month lag being the most common best fit. Often, even with best fit autoregression the overall r^2 for models was relatively weak (though some stations for some parameters had high r^2), which should be kept in mind when reviewing the stated trend results. As the results for this analysis were generally weak ($r^2 < 0.5$), both the graphs and tables which include fit (r^2), intercept, and covariate parameter estimates (with p-values) the of the model outputs are presented in Appendix B. The water quality parameters analyzed in this trend analysis are salinity, nutrients (TN and TP), chlorophyll-*a*, dissolved oxygen (DO), turbidity, fecal coliform, and enterococci.

3.2.2.2 Other Analyses

Other analyses were used to assess the water quality data, including linear regression and correlation analysis. Parametric (Pearson's product moment correlation coefficient) and non-parametric (Kendall Tau for correlations over time, Spearman's for correlations between variables) analyses were also used throughout the report to evaluate relationships between water quality variables or between water quality and time. Because there was a general poor fit in the AEM models for predicting increasing or decreasing trends in water parameters over time, annual Kendall Tau analysis was used in its place. For this analysis, all of the City's long-term monitoring stations are included (Figure 2-3) with trend results presented for each parameter and individual time frames for each station.

3.2.3 Water Quality Five-Year Average Trends

Over the current five-year period (WY 2015 to 2019), there were a total of 57 to 60 monthly measurements for all water quality parameters at all four locations in Naples Bay; the exception was fecal coliform which had between 47 and 49 recordings over the five-year period.

In order to provide an overview of the typical conditions in Naples Bay over this five-year period, the average recording for each water quality parameter is included in Table 3-10 below. The table includes a breakdown of dry and wet season's averages in addition to annual averages. For context, the average over the prior five-year period WY 2010 to 2014 has been included to provide an indication of medium-term trends on Naples Bay water quality. Additionally, average conditions for two of the main covariates for Naples Bay water quality, GGC flow and rainfall, for the two five-year periods have been included in the table. These average flow and rainfall conditions are from daily records for the days of water quality sampling, not the entire daily time series across the five-year periods. This allows for several trends to be more easily attributable with flow and rain conditions. Generally, both GGC average flow and average rainfall are higher in the current five-year period compared to the previous five years for the wet and dry season and annual averages.

This analysis of the five-year averages confirms previously known relationships with GGC flow and rainfall. The majority of the medium-term trends can be attributed to the impacts of increased runoff and rainfall from the GGC and local drainage areas surrounding Naples Bay.

Table 3-10. Annual and seasonal averages for the two five-year time periods for water quality parameters of concern in the Gordon River (marine segment) and Naples Bay including the natural logs of GGC flow and rainfall

Paramater	Station	Annual Average		Wet Season Average		Dry Season Average	
		WY 2010 - 2014	WY 2015 - 2019	WY 2010 - 2014	WY 2015 - 2019	WY 2010 - 2014	WY 2015 - 2019
Flow	GG1	161.58	287.23	280.06	485.38	152.95	225.08
LN Flow		3.14	3.91	4.71	5.60	3.17	3.96
Rain	COLGOV_R	0.15	0.19	0.18	0.33	0.09	0.10
LN Rain		-1.10	-0.90	-0.96	-0.93	-1.37	-0.79
Salinity (ppt)	GORDEXT/GORDPT	16.77	12.35	9.62	4.30	16.91	12.02
	NBAYNL	25.69	22.56	21.08	15.96	25.46	23.70
	NBAYWS	28.97	24.87	24.45	18.33	28.91	26.11
	GPASS6	32.75	30.13	30.52	26.21	32.10	30.80
Copper (µg/L)	GORDEXT/GORDPT	2.94	1.71	2.75	1.29	3.02	1.69
	NBAYNL	4.42	4.38	4.28	4.38	4.69	4.66
	NBAYWS	2.93	2.40	3.24	2.70	3.16	2.52
	GPASS6	2.05	1.81	2.20	1.92	2.06	1.99
TN (mg/L)	GORDEXT/GORDPT	0.67	0.75	0.71	0.86	0.70	0.73
	NBAYNL	0.53	0.66	0.55	0.83	0.51	0.67
	NBAYWS	0.47	0.64	0.52	0.77	0.51	0.65
	GPASS6	0.40	0.57	0.43	0.71	0.40	0.55
TP (mg/L)	GORDEXT/GORDPT	0.08	0.05	0.11	0.04	0.04	0.04
	NBAYNL	0.04	0.05	0.04	0.05	0.04	0.04
	NBAYWS	0.03	0.04	0.04	0.04	0.03	0.03
	GPASS6	0.03	0.04	0.03	0.04	0.03	0.04
Chlorophyll-*a* (µg/L)	GORDEXT/GORDPT	7.36	7.54	7.52	6.74	6.46	6.04
	NBAYNL	7.98	7.07	9.75	8.00	6.75	6.73
	NBAYWS	6.11	5.42	8.02	7.09	4.81	5.64
	GPASS6	4.54	3.86	5.57	4.90	3.97	4.01
DO (mg/L)	GORDEXT/GORDPT	4.65	5.29	4.32	4.68	4.72	5.68
	NBAYNL	6.14	6.30	5.79	5.95	6.19	6.59
	NBAYWS	5.90	6.18	5.22	5.80	6.07	6.48
	GPASS6	6.15	6.20	5.50	5.64	6.44	6.47
Turbidity (NTU)	GORDEXT/GORDPT	2.29	3.63	2.35	3.68	2.05	3.13
	NBAYNL	3.09	4.87	2.72	4.07	2.52	5.04
	NBAYWS	3.41	5.40	2.54	3.53	3.08	5.95
	GPASS6	3.81	6.63	3.50	4.20	4.03	7.68
Fecal Coliform (cfu/100mL)	GORDEXT/GORDPT	234.3	140.3	231.0	173.7	271.3	154.3
	NBAYNL	273.1	392.6	347.2	766.3	149.0	271.5
	NBAYWS	42.0	194.4	72.6	378.0	55.6	203.0
	GPASS6	19.2	52.7	34.2	101.7	14.2	18.6
Enterococci (cfu/100mL)	GORDEXT/GORDPT	121.0	65.9	96.6	72.0	168.0	68.1
	NBAYNL	217.4	134.6	188.8	200.7	178.9	123.1
	NBAYWS	22.2	63.6	23.0	71.5	32.7	74.5
	GPASS6	27.9	39.5	47.2	49.8	20.8	38.4

3.2.4 Salinity

Hydrologic alterations within the GGC system and their effect on freshwater influx and the salinity regime of Naples Bay is a primary concern for water quality and biological communities in Naples Bay (SFWMD 2007, Schmid et al. 2005, FDEP 2010, Simpson et al. 1979, City of Naples 2010, Laakkonen 2014, and Baum 1973). A thorough understanding of the current salinity regime and the effect of the GGC freshwater inflow provides the basis for determining what potential effects the freshwater may be having on the biological communities in Naples Bay. In turn, this information is essential for developing appropriate and cost-effective management programs and actions to protect, manage, and improve Naples Bay.

As noted in the above section there are two primary salinity data sources; the monthly sampling used to assess the current conditions and trends in Section 3.2.4.1, and the USGS continuous data from 2011 to 2014 with updated analysis of this data discussed in Section 3.2.4.2.

3.2.4.1 Current Conditions (WY 2015 to 2019)

The monthly surface salinity recordings for the four stations for WY 2015 to 2019 are shown in Figure 3-19. Between 57 and 60 salinity recordings were made at the four stations throughout this five-year period. As is expected the monthly time series show a strong negative trend with the GGC flow, with lower salinity values coinciding with periods of higher GGC flow. This can be seen in the wet season every year (June to November) and particularly the WY 2017 wet season which had higher than normal flow including Hurricane Irma in September resulting in a pronounced low salinity period at all four stations. Another period of higher than expected GGC flow was during the dry season (December to May) of WY 2016 with salinity during this time lower than average dry season at all four stations. Conversely the dry season of WY 2017 had essentially no flow from GGC resulting in consistently higher salinity during this period for all four stations.

As is expected there is also a clear gradient of increasing salinity from north to south in Naples Bay, the further away from the primary GGC freshwater source to the Bay.

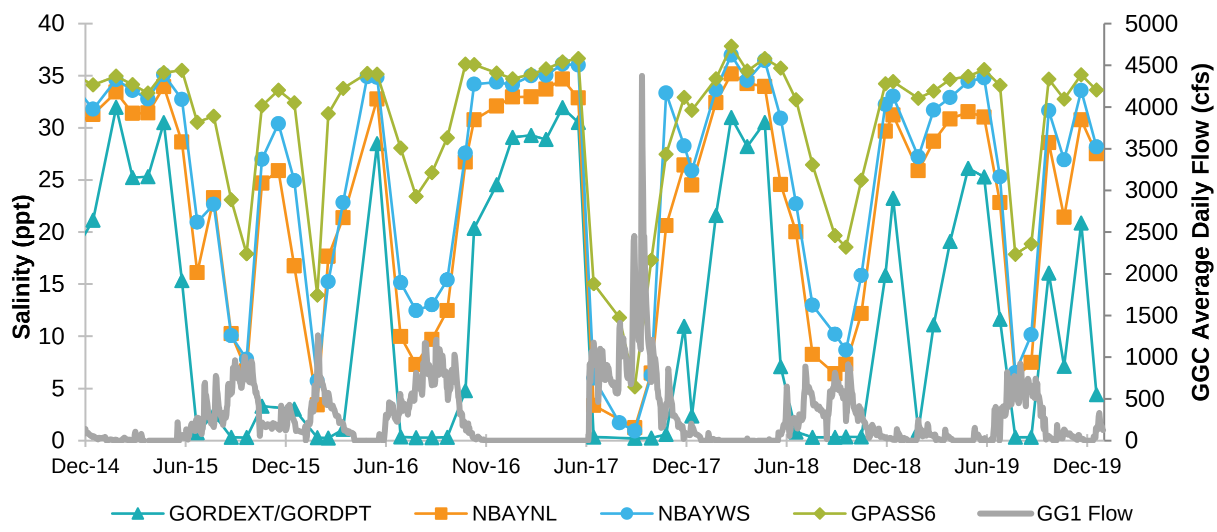
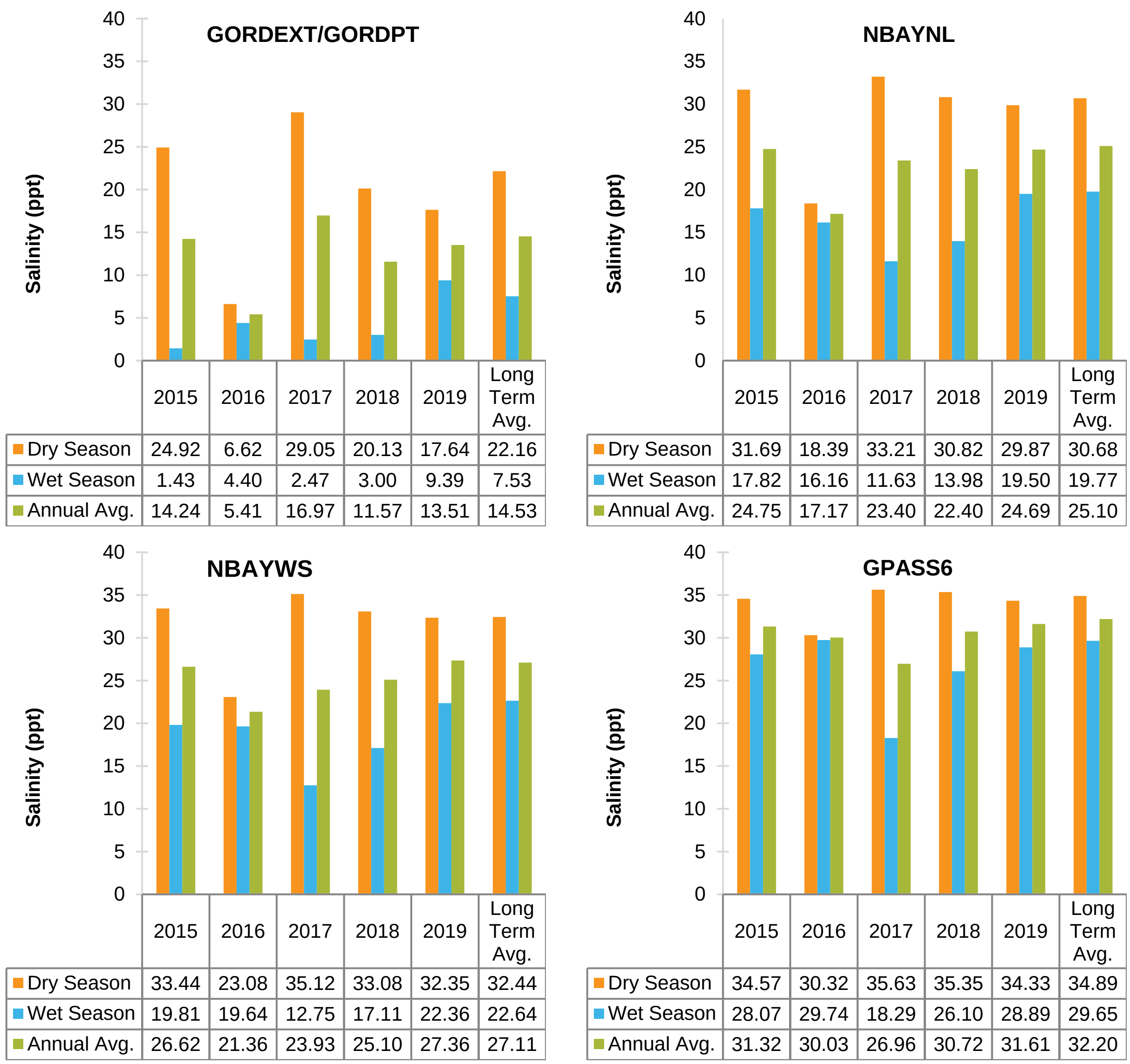


Figure 3-19. Monthly salinity records for Naples Bay for WY2015 to 2019.

The temporal patterns of particular wet and dry seasons are more clearly shown when comparing the seasonal and annual average salinity for WY 2015 to 2019 for each station as shown in Figure 3-20. The seasonal and annual averages are compared to the long-term average which includes all records from when samples were first taken in 2005 with total salinity samples of between 131 and 139 across this period.

The seasonal and annual averages for the current five-year period of record compared with that of the previous five-year period of record (WY 2010 to 2014) are shown in Figure 3-21. It can be seen that for all four stations and for both the dry and wet season and the annual average that the salinity for the current five-year period is lower than that of the prior five-year period. This is likely a direct response to this current five-year period having a higher average GGC flow than the prior five-year period from GGC in the dry season (55.8 cfs to 37.8 cfs), wet season (448.3 cfs to 310.9 cfs), and annual average (263.3 cfs to 176.9 cfs).

To ensure that some single recordings such as a large GGC flow event, for example Hurricane Irma, were not skewing the average values, an additional assessment of the exceedance probability curves for the two entire five-year datasets for the four stations are shown in Figure 3-22. This represents the distribution of the entire data range and allows for a visual comparison of median (50%), higher salinity (for example the 90%) and lower salinity (for example the 10%). Across the two datasets the exceedance curves for all four stations are lower in WY 2015 to 2019 than the prior WY 2010 to 2014 showing from both low and high salinity recordings that the current five-year period had lower salinity recordings than the prior five-year period.



GORDEXT/GORDPT

	2015	2016	2017	2018	2019	Long Term Avg.
Dry Season	24.92	6.62	29.05	20.13	17.64	22.16
Wet Season	1.43	4.40	2.47	3.00	9.39	7.53
Annual Avg.	14.24	5.41	16.97	11.57	13.51	14.53

NBAYNL

	2015	2016	2017	2018	2019	Long Term Avg.
Dry Season	31.69	18.39	33.21	30.82	29.87	30.68
Wet Season	17.82	16.16	11.63	13.98	19.50	19.77
Annual Avg.	24.75	17.17	23.40	22.40	24.69	25.10

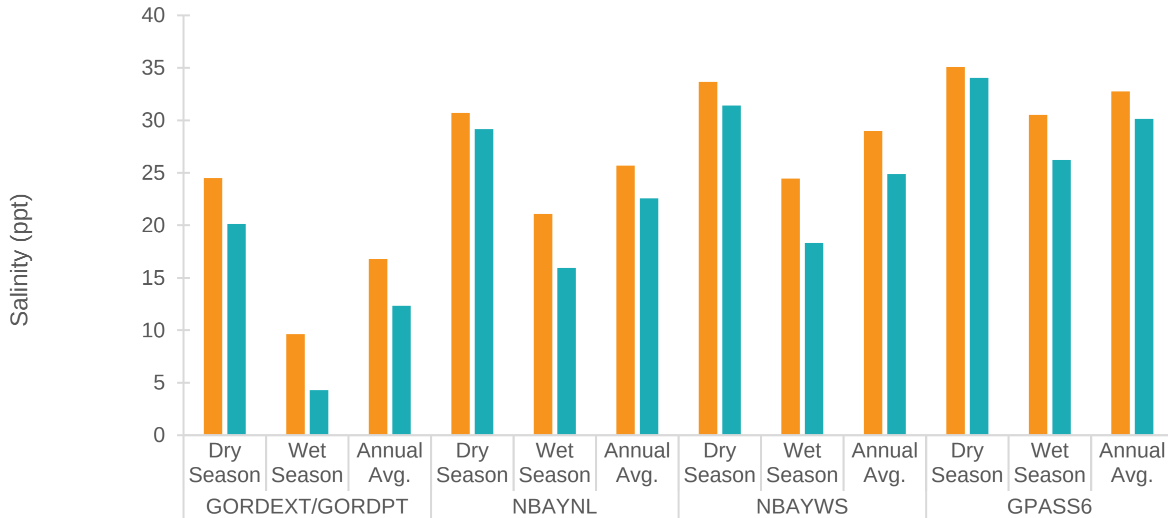
NBAYWS

	2015	2016	2017	2018	2019	Long Term Avg.
Dry Season	33.44	23.08	35.12	33.08	32.35	32.44
Wet Season	19.81	19.64	12.75	17.11	22.36	22.64
Annual Avg.	26.62	21.36	23.93	25.10	27.36	27.11

GPASS6

	2015	2016	2017	2018	2019	Long Term Avg.
Dry Season	34.57	30.32	35.63	35.35	34.33	34.89
Wet Season	28.07	29.74	18.29	26.10	28.89	29.65
Annual Avg.	31.32	30.03	26.96	30.72	31.61	32.20

Figure 3-20. Seasonal and annual salinity averages for Naples Bay for WY 2015 to 2019.



	Dry Season	Wet Season	Annual Avg.	Dry Season	Wet Season	Annual Avg.	Dry Season	Wet Season	Annual Avg.	Dry Season	Wet Season	Annual Avg.
	GORDEXT/GORDPT			NBAYNL			NBAYWS			GPASS6		
WY 2010 - 2014	24.48	9.62	16.77	30.69	21.08	25.69	33.66	24.45	28.97	35.07	30.52	32.75
WY 2015 - 2019	20.12	4.30	12.35	29.15	15.96	22.56	31.41	18.33	24.87	34.04	26.21	30.13

Figure 3-21. Seasonal and annual salinity averages for Naples Bay for most recent 5-year periods.

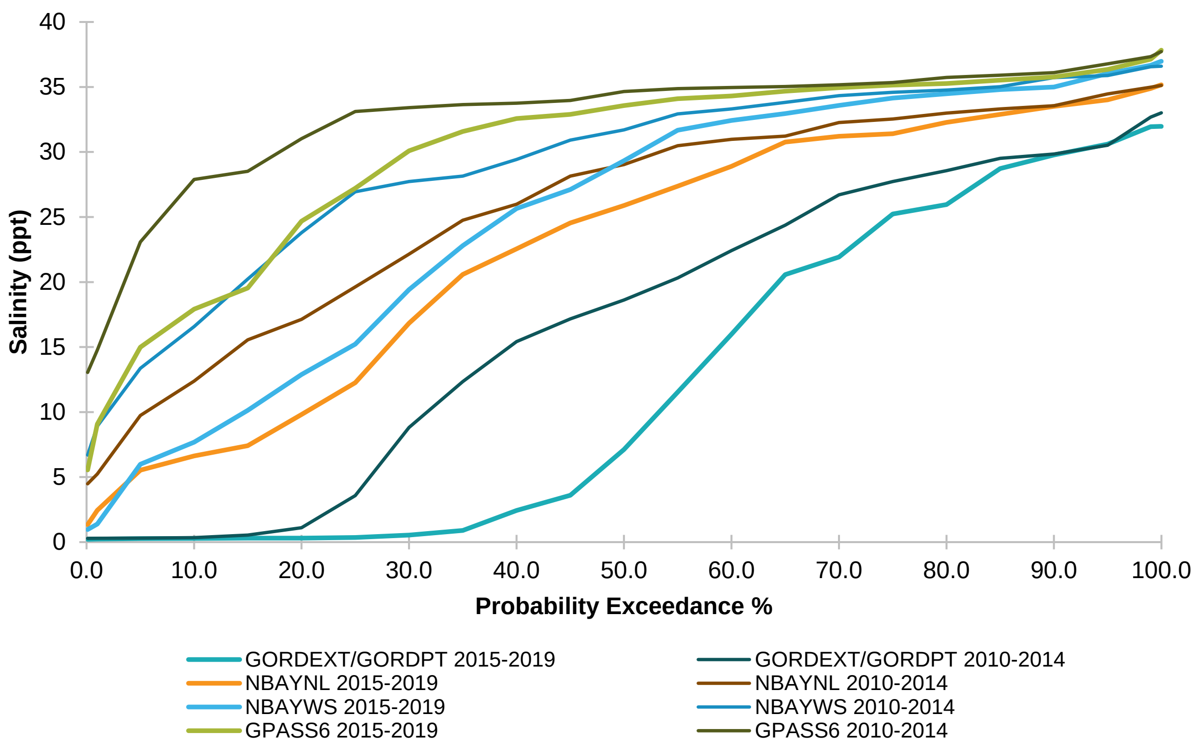


Figure 3-22. Five-year exceedance probability curves for current (WY 2015 to 2019) and prior (WY 2010 to 2014).

3.2.4.2 Updated Salinity Flow Relationship

An analysis of the USGS continuous data, including an analysis of salinity-flow relationships and daily salinity ranges, was included in the *2015 Naples Bay Water Quality and Biological Analysis* report. However, since that report was finalized, the USGS released updated flow rating curves, with some additional data gaps filled in. This has resulted in slight revisions of the salinity-flow analysis previously reported in 2015.

For the salinity-flow relationship an exponential linear regression of salinity and GGC flow was used to estimate the relationship between them. The continuous data were analyzed as daily average salinity parts per thousand (ppt) to match the daily average flow data (cfs) of the GGC weir gauge. The equation for the regression is:

$$Salinity = B_0 * e^{(B1 * flow)}$$

Where B_0 is the intercept and B_1 is the slope.

The salinity-flow regression was updated for surface and bottom salinity based on the 2011 to 2014 data as shown in Figure 3-23. As a result of the rating curve adjustments by USGS the B_0 values were marginally lower (0.063 - 0.189) than the previously reported regressions with the exception of Naples Bay at Gordon Pass (0.024 increase). The B_1 values were also slightly reduced compared to those previously reported. The R^2 values were similar to those previously reported ranging from 0.76 – 0.90 for surface salinity, with the exception of Gordon Pass where R^2 values of surface salinities are higher than bottom salinities.

Due to only minor changes that the updated USGS rating curves have on salinity-flow relationships, the general conclusions of the previous 2015 report are still relevant. Specifically, the Salinity-Flow Management Decision Tool and the predictive models that were the basis for the tools. The tools that were developed have not been updated but the original discussion of these tools has been provided for reference in Appendix B. Recognizing that the City does not have control over the GGC structures to regulate flows, the previous analysis of flow reduction scenarios still provides useful insights into potential impacts from different GGC flow conditions that can be taken into consideration by the City, County, and also the SFWMD who regulates the weirs and control structures.

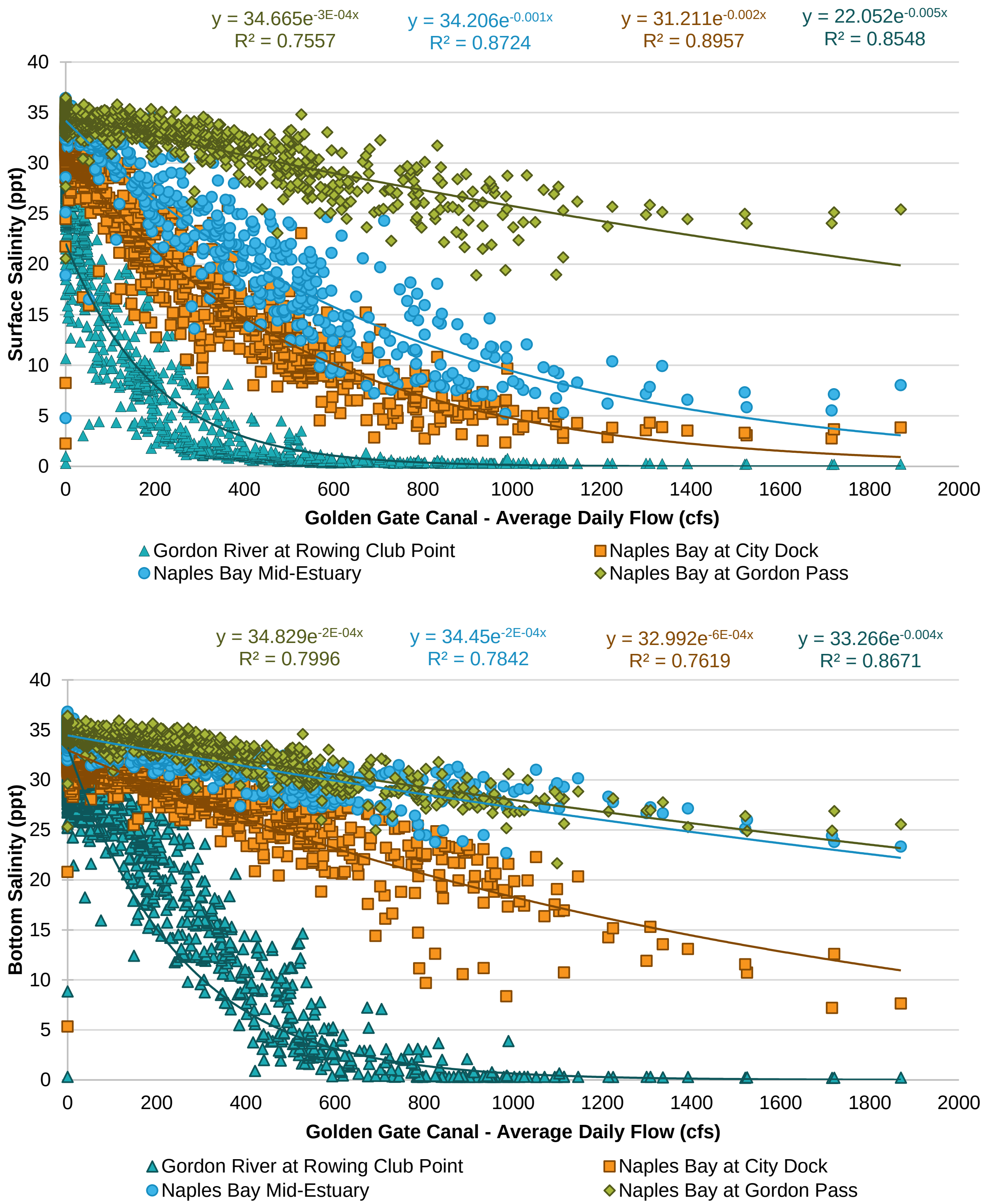


Figure 3-23. Updated surface (top) and bottom (bottom) salinity-flow regression for continuous data from 2011 to 2014.

3.2.4.3 Review of Continuous and Monthly Salinity Recordings

Though the continuous USGS recorded data is outside of the current five-year period of analysis (WY 2015 to 2019) it does provide an opportunity to review and validate the monthly salinity recordings. For this analysis, monthly recordings between WY 2011 and 2014 have been compared to the corresponding daily average, maximum and minimum salinity recordings from the corresponding continuous gauge. Three of the four stations have 37 days (NBAYWS having only 30 days) with both continuous salinity data and monthly recordings available. The average salinity across all of these coinciding days are compared in Table 3-11. It can be seen that the average of the monthly sample data for GORDEXT/GORDPT and GPASS6 are similar to the daily average from the continuous data, while NBAYNL on average is closer to the daily maximum and NBAYWS is similarly higher than the daily average of the continuous data.

To ensure that single recordings were not skewing the average values, an additional assessment of the exceedance probability curves for the datasets for the four stations are shown in Figure 3-24. There are numerous factors that could contribute to monitoring recordings not matching daily averages from the continuous gauges:

- The water quality monitoring records are typically single instantaneous samples on a given day. This type of recording does not account for fluctuations in water quality from sub-daily factors most notably tidal influences that can have a significant impact on water quality, particularly salinity. However, surface grab samples are timed (as practical) to occur on an outgoing tide.
- The locations of the continuous gauges and monthly monitoring stations are different, particularly for GORDEXT/GORDPT and NBAYWS with localized factors potentially influencing recordings.
- Different sampling techniques between the gauges and the monthly monitoring stations.

Table 3-11. Average salinity (ppt) of monthly recordings and daily average, minimum and maximum 2011 to 2014 continuous data.

Station	Monthly Recorded Salinity	USGS Continuous Salinity Gauge		
		Daily Average	Daily Minimum	Daily Maximum
GORDEXT/ GORDPT	15.6	15.3	13.0	18.1
NBAYNL	25.0	24.0	22.3	25.5
NBAYWS	28.2	27.6	25.4	30.4
GPASS6	32.0	32.2	29.3	34.5

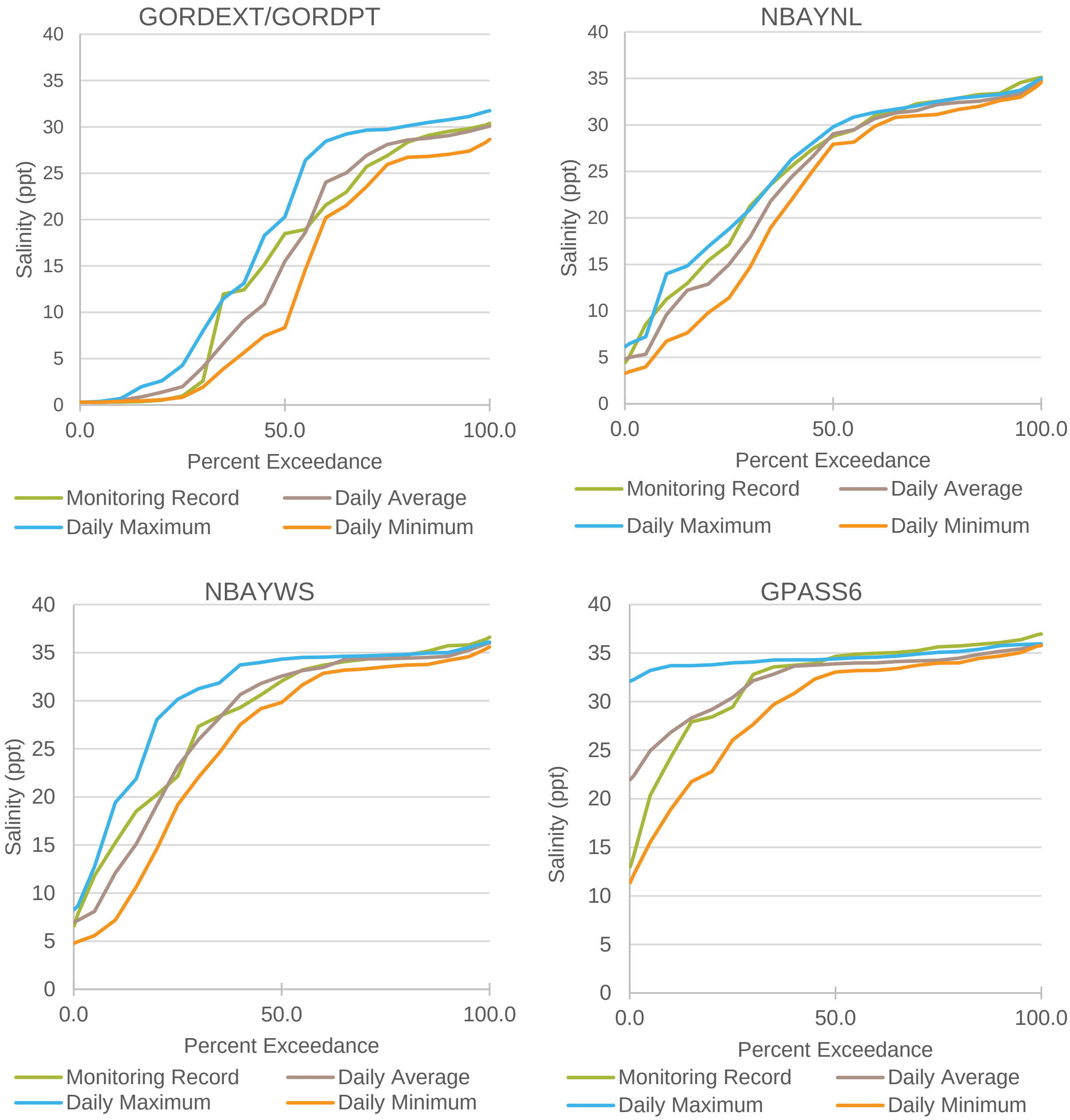


Figure 3-24. Exceedance probability curves for monthly records and daily average, maximum, and minimum from 2011 to 2014 continuous data.

3.2.4.4 Trend Analysis

Annual Kendall Tau analysis was completed for the salinity data at the nine long-term monitoring stations within the Gordon River (marine segment), Naples Bay, Rock Creek, and Haldeman Creek (Table 3-12). There were statistically significant decreasing trends in salinity in both the furthest upstream and downstream Naples Bay stations. While both stations have decreasing trends, the slope of decrease in salinity is double upstream at NBAYNL (-0.34 ppt/yr) than at the mouth of Naples Bay at GPASS6 (-0.17 ppt/yr). While the stations in between those in Naples Bay do not have statistically significant trends ($p > 0.05$), they also show a negative relationship with salinity over time. This may have to do with the timing of sampling on outgoing tides, but may also indicate greater freshwater inputs to Naples Bay.

Table 3-12. Results of annual Kendall Tau analysis for salinity at long-term monitoring stations in the Gordon River (marine segment), Naples Bay, and two tributaries.

Station	Years	Tau	p-value	Slope (ppt/yr)
BC3	2001-2019	0.05	0.27	N/A
GORDEXT/GORDPT	2005-2019	-0.04	0.52	N/A
ROCKCR	2011-2019	-0.08	0.25	N/A
NBAYNL	2006-2019	**-0.14**	**0.02**	**-0.34**
NBAY29	2006-2019	-0.13	0.09	N/A
HALDCR	2011-2019	-0.11	0.08	N/A
NBAYWS	2005-2019	-0.03	0.60	N/A
NBAYBV	2006-2019	-0.14	0.07	N/A
GPASS6	2006-2019	**-0.15**	**0.01**	**-0.17**

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.

3.2.5 Copper

The FDEP listed Naples Bay (WBID 3278R4) as impaired for copper in 2009 along with Rock Creek (WBID 3278R3), Haldeman Creek (WBID 3278R1), and the Gordon River (marine segment – WBID 3278R5) that contribute to Naples Bay. Therefore, copper is a major water quality issue for the Bay and tributaries. Copper is an essential trace element for many aquatic organisms but can be toxic at levels slightly above those necessary for growth and reproduction (Hall et al. 1988). In estuarine environments, sources of copper include atmospheric deposition, industrial and municipal discharges, urban runoff, and antifouling marine paints (Hall et al. 1988). Copper sulfate is also very commonly used as an herbicide in lake management applications to control algae.

The spatial and temporal status of copper in Naples Bay relative to the Class II water quality standard of 3.7 µg/L was evaluated. Over the period of record, higher copper concentrations are typically found in upper Naples Bay or tributaries, with the majority of stations that exceed the water quality standard found in this area (Figures 3-25 and 3-26). Additionally, the highest copper concentrations are consistently found in Haldeman Creek, at the SR 41 (Tamiami Trail Rd.) monitoring station, where annual average concentrations are four to eight times higher than the water quality standard. In 2008, the Haldeman Creek stations were both above the standard as was one station in upper Naples Bay, while in 2013 the majority of stations sampled in Haldeman Creek, Rock Creek, and upper Naples Bay were above 3.7 µg/L (Figure 3-25). In 2015 it was again Haldeman Creek with values above 3.7 µg/L; however, in 2015 and 2019, the concentrations were elevated in both Haldeman Creek and upper Naples Bay (including dead-end canals, Figure 3-26).

Statistical analysis of copper concentrations over time in Naples Bay was hindered by changes in laboratory MDLs over the period of record. In 2013 and 2014, the laboratory MDL was increased to 3.0 µg/L, masking the ability to detect copper below this concentration. In order to look at the relationship between copper and time at all of the available stations, a correlation analysis (Pearson product moment correlation) was used to determine if the percentage of samples per year over a certain concentration was increasing or decreasing over time. The concentration chosen for the threshold was 3.7 µg/L, the state marine copper standard (62-302.530 F.A.C). While this analysis does not address trends in the actual copper concentrations over time, it does allow for a determination of whether the frequency of samples with concentrations above the water quality standard is increasing or decreasing over time. Thus, this analysis can show if a station is more frequently exceeding the water quality standard in more recent years, even though it can’t be determined whether the average concentration of copper is going up over time. This is an effective alternative to trend analysis that allows for characterization of copper in Naples Bay over time.

The copper analysis was broadened to include all of the stations where data are still being collected: GGCAT31/3495, BC3, BC2, HALDCRK (2001-2017), and BC5; GORDEXT/GORDPT and NBAYWS (2005–2019); NBAYNL and GPASS6 (2006–2019); NBAY29 and NBAYBV (2006-2010 and 2015-2019); and ROCKCR and HALDCR (2011–2019) (see Figure 2-2). Data was only collected for four years at CURLEW (2011-2015) and OYSBAY (2011-2015), but the results are included in this analysis. All these stations were chosen (even those with short periods of record) because of the spatial importance of copper in Naples Bay. A potential source of copper to Naples Bay is stormwater inflow from upland applications of copper sulfate to control algae in stormwater lakes. Therefore, the ability to identify and describe patterns of where copper may be entering Naples Bay is as important, if not more important, than identifying overall changes within the Bay over time. For the purposes of this analysis, copper in the GGC and other freshwater sources was evaluated against the marine water quality standard because it represents concentrations delivered to the marine portion of the Gordon River that is currently listed as impaired for copper.

Correlation analysis will not show significant changes at stations with data that are always below and/or above the water quality standard. Copper concentrations at GGCAT31/3945 and GPASS6 were almost always below the 3.7 µg/L criteria and, therefore, were not included in the analysis. Two other stations, HALDCRK and BC5, were above the threshold almost 100 percent of the time. Therefore, the data from HALDCRK and BC5 were analyzed using the annual geometric mean concentrations instead of percentage of samples above the water quality standard.

When considering the frequency of results above the threshold of 3.7 µg/L (Figure 3-27), patterns vary from station to station. While in the previous analysis of data collected from 2001 to 2014, various stations with a longer time series had significant increases in percent copper measurements above 3.7 µg/L over time ($p < 0.05$). However, when the dataset was expanded to include 2015 through 2019, there were no statistically significant correlations between percent of copper concentrations above 3.7 µg/L and time (Pearson product, $p > 0.05$). NBAYNL previously showed a strong statistically significant decrease over time in the percent of copper measurements above 3.7 µg/L from 2006 to 2012 ($r = -0.80$, $p < 0.05$); however, when the dataset was expanded through 2019, the relationship was not significant even though there was a good negative correlation ($r = -0.52$).

Of the two stations with only five years of data (CURLEW and OYSBAY), both showed a statistically significant increase (OYSBAY: $r = 0.75$, CURLEW: $r = 0.86$, $p < 0.05$) in percent of copper above 3.7 µg/L over time. Both stations are located at dead end canals where stormwater enters the Bay and were established to provide source tracking into the Bay.

The annual average copper concentrations at BC5 and HALDCRK (the stations where copper concentrations are almost always above 3.7 µg/L) do not show a significant correlation with time for the arithmetic mean over the period of record (2001–2019). However, there was a significant correlation between the geometric mean and time at BC5, with the annual geometric means of copper decreasing over time (Figure 3-28). It is important to note that even if no significant increase in concentrations is observed, all of the annual average concentration values in the dataset exceed the marine water quality standard at these two stations.

Although this analysis shows that while copper is spatially variable among the stations in Naples Bay and the tributaries, several stations appear to exhibit copper that is more frequently above the water quality standard in more recent years compared to earlier years in the dataset.

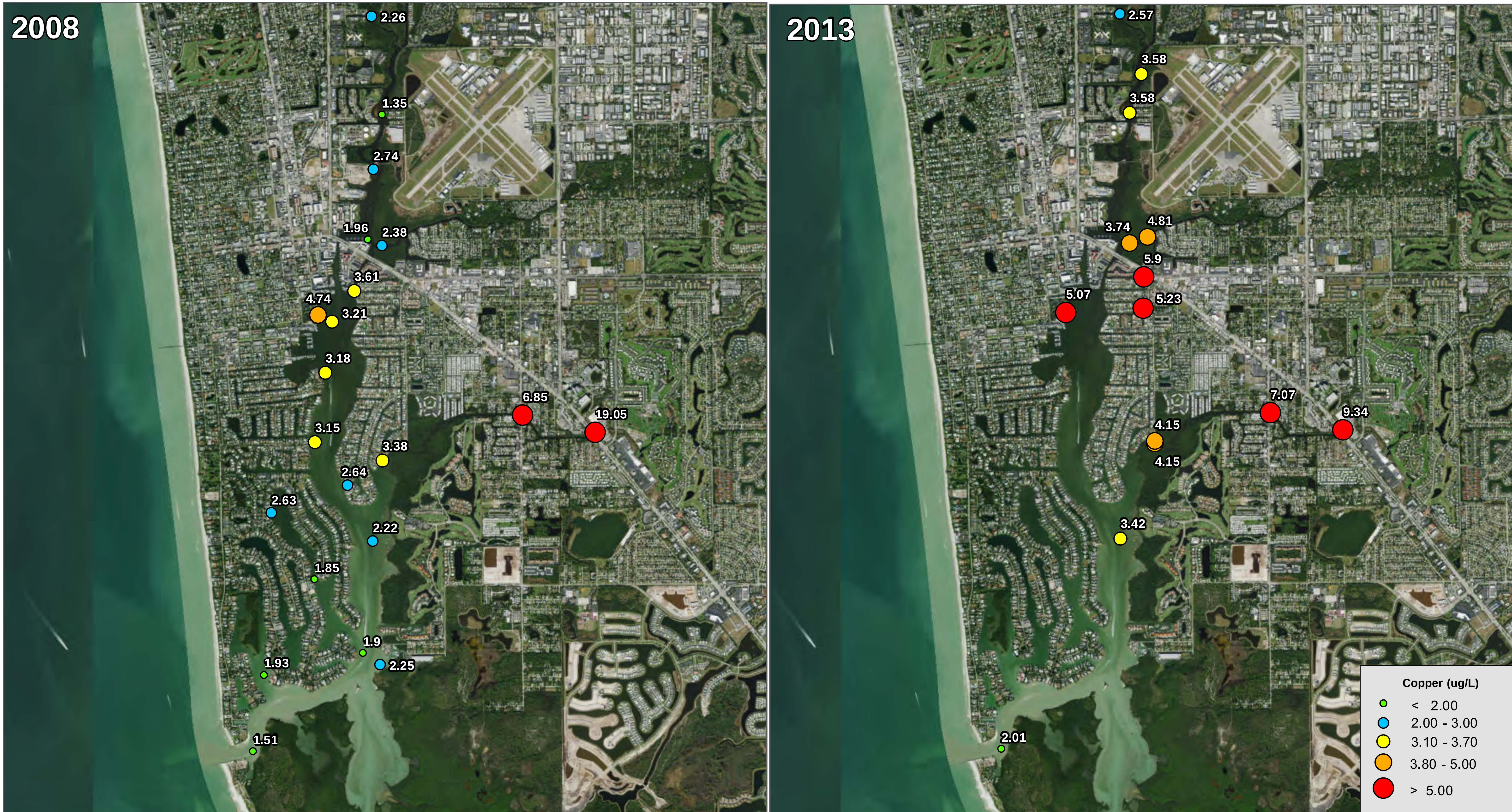


Figure 3-25. Annual Geometric Mean Copper Concentrations in Naples Bay and Gordon River (Marine Segment) 2008 and 2013.

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GIS Analyst: James Bottiger

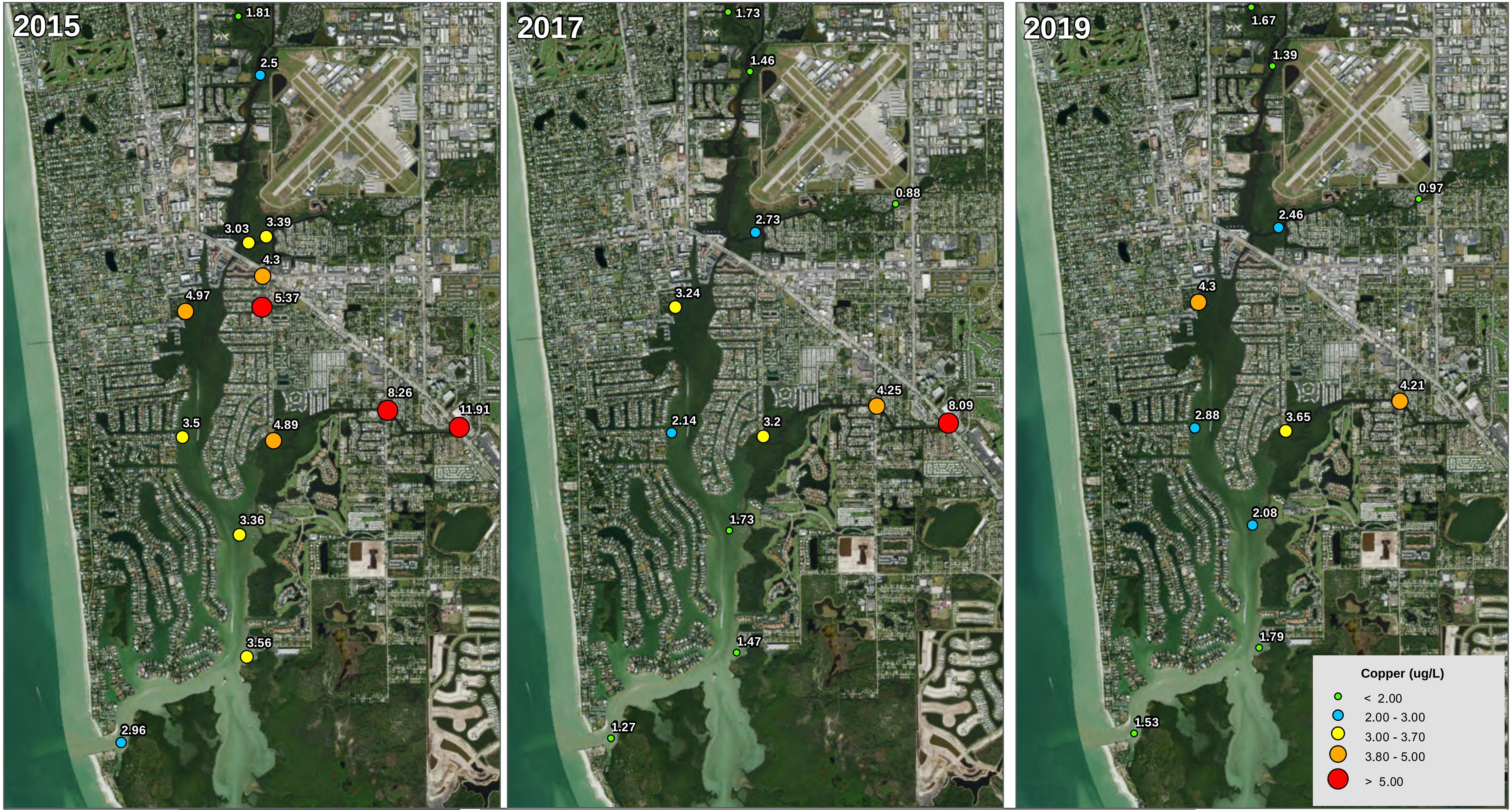

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Figure 3-26. Annual Geometric Mean Copper Concentrations in Naples Bay and Gordon River (Marine Segment) 2015, 2017, and 2019.

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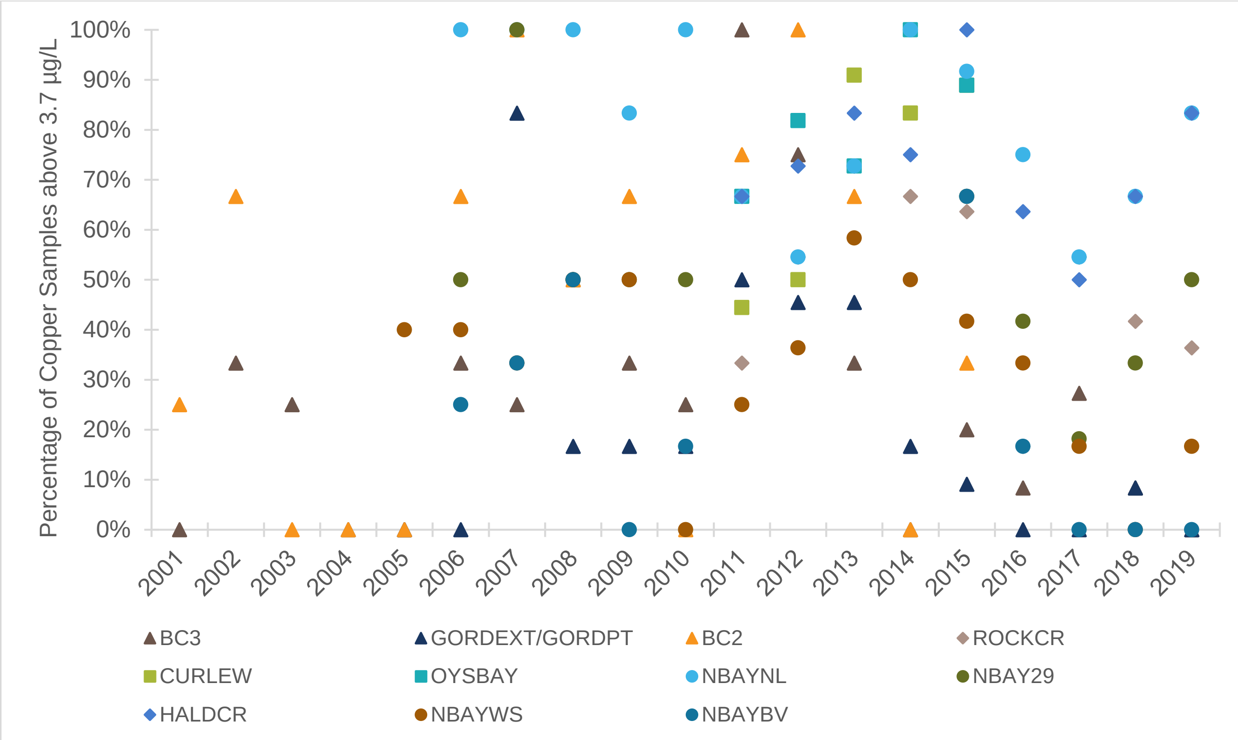


Figure 3-27. Annual percentage of copper concentrations greater than 3.7 µg/L in Naples Bay and Gordon River (marine segment).

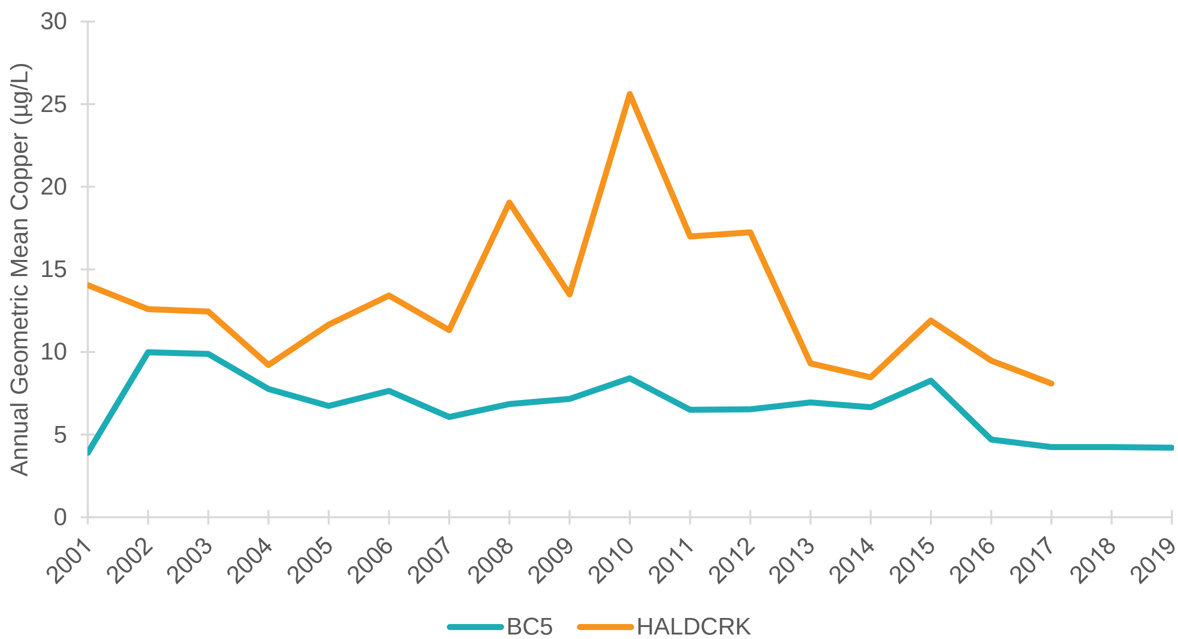


Figure 3-28. Annual geometric mean copper concentrations over time in Haldeman Creek.

3.2.6 Nutrients: TN and TP

Excess nutrients (nitrogen and phosphorus) are an issue of growing concern in waterbodies throughout the country. The EPA began providing guidance on development of numeric nutrient criteria (NNC) in 2000. In Florida the process of developing NNC was hastened in 2009 with the EPA's necessity determination that NNC were required under the Clean Water Act (CWA). Following multiple lawsuits and parallel criteria development tracts by the FDEP and EPA, NNC for many waterbodies, including most estuaries were adopted by FDEP in 2012. NNC for the remaining waterbodies became effective in October 2014. NNC for Naples Bay were adopted by the FDEP's Environmental Regulatory Commission (ERC) in 2011 and approved by EPA in 2012. The Naples Bay NNC are expressed as annual geometric mean (AGM) concentrations that are not to be exceeded more than once in a three-year period. The allowable concentrations are as follows:

Total Nitrogen (TN) = 0.57 mg/L,
Total Phosphorus (TP) = 0.045 mg/L, and
Chlorophyll-*a* = 4.3 µg/L.

The nutrient discussion and analysis provided here is conducted in light of the adopted NNC for Naples Bay to provide context for the observed nutrient conditions. With the Cycle 4 assessment for Group 1 in 2019, the Gordon River (marine segment - WBID 3278R5) was listed as impaired for both TN and TP based on the NNC adopted annual geometric mean concentrations. Additionally, both Naples Bay (WBID 3278R4) and the Gordon River (marine segment – WBID 3278R5) were listed as impaired for chlorophyll-*a*.

Prior to 2006 and the initiation of the City of Naples' water quality monitoring program, few monitoring stations existed in Naples Bay which inhibited comprehensive characterization of Naples Bay as a whole. The City's program included many portions of the Bay that were not previously monitored, especially the southern portion of Naples Bay closer to Gordon Pass. Some elements of the monitoring program changed in 2011, including the elimination of some stations and the movement of others to more accurately represent inputs to Naples Bay. The current program allows for monthly sampling of every station and provides a more robust characterization of the whole Bay than previous monitoring activities.

The water quality monitoring program in Naples Bay is particularly important in the context of nutrient regulations and compliance. Implementation of the NNC requires assessment of the waterbody on a WBID scale, incorporating all available data from all stations within the WBID in the calculation of the annual geometric mean concentration. Therefore, a more robust monitoring program leads to a more accurate representation of the nutrient condition of the WBID as a whole and is not as influenced by localized conditions at individual stations.

Over the period of record (2001 to 2019) the TN annual geometric mean concentrations were variable from year to year in the Gordon River (marine segment – WBID 3278R5) and typically fluctuated above and below the criterion. The majority of annual geometric means exceed the NNC of 0.57 mg/L (Figure 3-29), with exceedances occurring more than once in a 3-year period.

To further investigate the exceedance of the TN standard of 0.57 mg/L, annual Kendall Tau analysis was completed for WBIDs 3278R4 and 3278R5 (shaded light aqua) and individual long-term monitoring stations within each WBID along with two tributary stations (shaded grey, Table 3-13). All monitoring data were used for the overall WBID analysis, similar to Figure 3-29, but only stations with data currently being collected were used for individual analysis. For the Gordon River (marine segment – WBID 3278R5), there were no statistically significant increasing or decreasing trend in TN over time ($p > 0.05$); similarly, no individual long-term station had an increasing or decreasing trend over time ($p > 0.05$). Within Naples Bay, WBID 3278R4 did not have a statistically significant increasing or decreasing trend ($p > 0.05$), but four of the individual stations had statistically significant increasing trends (Table 3-13). The two upper (NBAYNL and NBAY29) and two lower (NBAYBV and GPASS6) Naples Bay stations had slight increasing trends with annual increasing slopes of 0.02 mg/L/yr; the only station without a statistically significant trend was NBAYWS. Just upstream of NBAYWS is the confluence with Haldeman Creek. The long-term monitoring station (HALDCR) has an increasing trend in TN over time (slope 0.04 mg/L/yr) with a reduced monitoring period from 2011 through 2019. It appears that the annual medians and annual geometric means at NBAYWS have been too variable over time to have a significant increasing or decreasing trend. There was no statistically significant increasing or decreasing trend ($p > 0.05$) in Rock Creek (ROCKCR).

TP concentrations in Naples Bay (WBID 3278R4) decreased slightly from 2011 through 2014 before increasing over the last five years. Over the period of record (2002 to 2019) the TP annual geometric mean concentrations in Naples Bay (WBID 3278R4) and the Gordon River (marine segment – WBID 3278R5) appear to have generally decreased through 2016 before increasing over the last three years (Figure 3-30). Naples Bay (WBID 3278R4) has achieved the newly adopted NNC for TP, achieving the criteria every year from 2003 to 2018, indicating the Bay is in compliance with the NNC. Prior to 2011, TP in the Gordon River (marine segment – WBID 3278R5) exceeded the annual geometric mean NNC of 0.045 mg/L at least once in three years, and was above the NNC in 2017 and 2019.

Annual Kendall Tau analysis was also run on TP both WBID wide and for individual long-term stations. There were no statistically significant increasing or decreasing trends in the Gordon River (marine segment – WBID 3278R5) or for individual stations ($p > 0.05$, Table 3-14). However, within Naples Bay, four of the long-term monitoring stations had increasing trends in TP over time, similar to TN. The annual slopes of increase are small (0.001 to 0.002 mg/L/yr) but should be monitored closely as WBID 3278R4 as a whole was above the standard of 0.045 mg/L in 2019. There were also statistically significant increasing trends found in Rock Creek and Haldeman Creek from 2011 to 2019, but the slopes of increase were small (0.003 and 0.004 mg/L/yr, respectively).

Spatial comparisons of TN annual geometric mean concentrations show slightly higher nitrogen concentrations in the upper portions of Naples Bay and the Gordon River (marine segment) compared to the lower portions of the Bay (Figures 3-31 and 3-32). This is not unexpected as the upper portion of the Bay is influenced by urban runoff and coastal tributaries and experiences reduced tidal exchange with the relatively low-nutrient Gulf waters. The decreasing overall TN concentrations are apparent when data from 2008 are compared to 2013 data. For the most recent time periods, maps were created for 2015 (beginning), 2019 (ending), and 2017 (Hurricane Irma) (Figure 3-32). In 2015, almost all of the Naples Bay monitoring stations have AGM TN concentrations below 0.57 mg/L; however in 2017 and 2019 the TN annual geometric means were both above the NNC of 0.57 mg/L.

Similarly, maps were created for TP for the 2008 and 2013 time periods along with 2015, 2017, and 2019 (Figures 3-33 and 3-34). In 2008, TP annual geometric mean concentrations were below the NNC of 0.045 mg/L in the middle and lower Naples Bay but above the NNC in the tributaries. In 2013, only Naples Bay had AGM concentration of TP below 0.45 mg/L while the Gordon River (marine segment) and the coastal tributaries had higher concentrations (Figure 3-33). The TP AGM concentrations in 2015 were similar to those observed in 2013; however, in 2017 the AGM for TP was only below 0.45 mg/L in lower Naples Bay and in 2019 all stations had AGM concentrations above 0.45 mg/L (Figure 3-34).

Table 3-13. Results of annual Kendall Tau analysis for TN for the Gordon River (marine segment – WBID 3278R5) and Naples Bay (WBID 3278R4) including individual long-term monitoring stations.

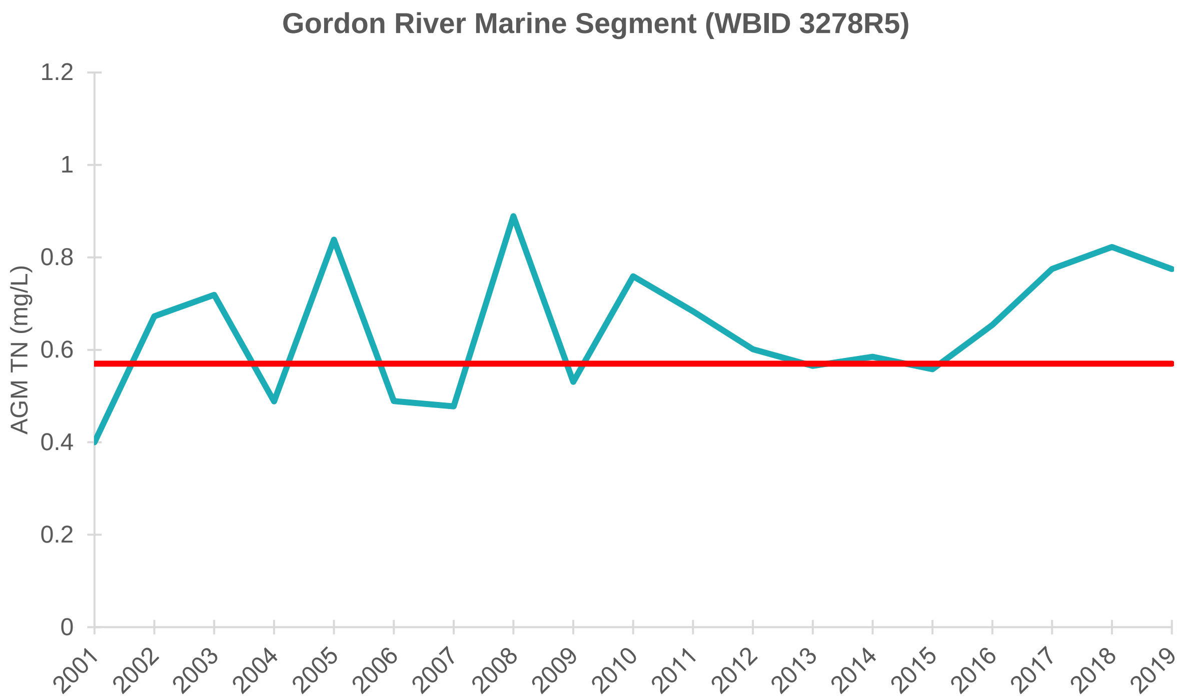
Station	Years	Tau	p-value	Slope (mg/L/yr)
WBID 3278R5	2002-2019	-0.03	0.33	N/A
BC3	2002-2019	0.01	0.80	N/A
GORDEXT/GORDPT	2005-2019	-0.03	0.57	N/A
BC2	2002-2015	-0.05	0.33	N/A
WBID 3278R4	2000-2019	-0.02	0.38	N/A
NBAYNL	2006-2019	**0.12**	**0.04**	**0.02**
NBAY29	2006-2019	**0.15**	**0.05**	**0.02**
NBAYWS	2005-2019	0.04	0.46	N/A
NBAYBV	2006-2019	**0.17**	**0.03**	**0.02**
GPASS6	2006-2019	**0.17**	**0.004**	**0.02**
ROCKCR	2011-2019	0.10	0.13	N/A
HALDCR	2011-2019	**0.24**	**0.0004**	**0.04**

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.

Table 3-14. Results of annual Kendall Tau analysis for TP for the Gordon River (marine segment – WBID 3278R5) and Naples Bay (WBID 3278R4) including individual long-term monitoring stations.

Station	Years	Tau	p-value	Slope (mg/L/yr)
WBID 3278R5	2002-2019	-0.01	0.66	N/A
BC3	2002-2019	0.03	0.51	N/A
GORDEXT/GORDPT	2005-2019	0.01	0.92	N/A
BC2	2002-2015	-0.09	0.11	N/A
WBID 3278R4	2000-2019	0.03	0.20	N/A
NBAYNL	2006-2019	**0.12**	**0.05**	**0.001**
NBAY29	2006-2019	**0.30**	**0.0001**	**0.002**
NBAYWS	2005-2019	0.10	0.09	N/A
NBAYBV	2006-2019	**0.33**	**0.00001**	**0.002**
GPASS6	2006-2019	**0.18**	**0.002**	**0.001**
ROCKCR	2011-2019	**0.21**	**0.002**	**0.003**
HALDCR	2011-2019	**0.31**	**<0.001**	**0.004**

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.



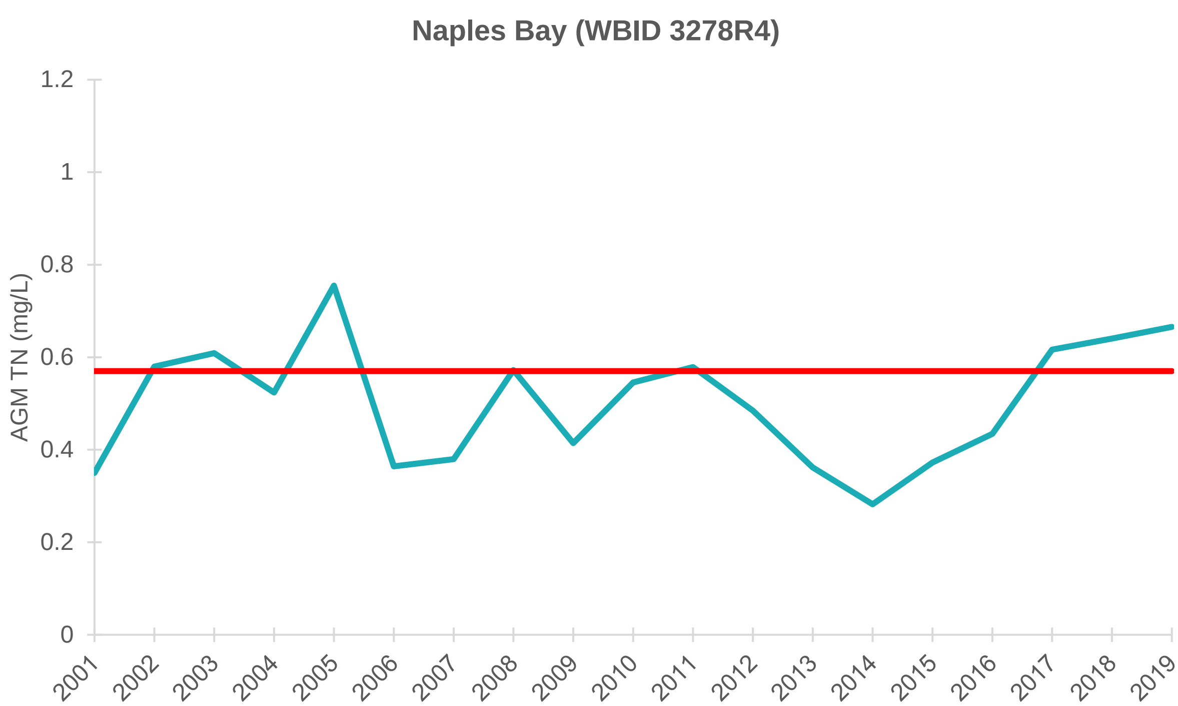


Figure 3-29. Gordon River (marine segment-WBID 3278R5) and Naples Bay (WBID 3278R4) total nitrogen annual geometric mean concentrations (turquoise) and total nitrogen numeric nutrient criterion (red), 2001-2019.

Figure 3-30. Gordon River (marine segment-WBID 3278R5) and Naples Bay (WBID 3278R4) total phosphorus annual geometric mean concentrations (turquoise) and total phosphorus numeric nutrient criterion (red), 2002-2019.

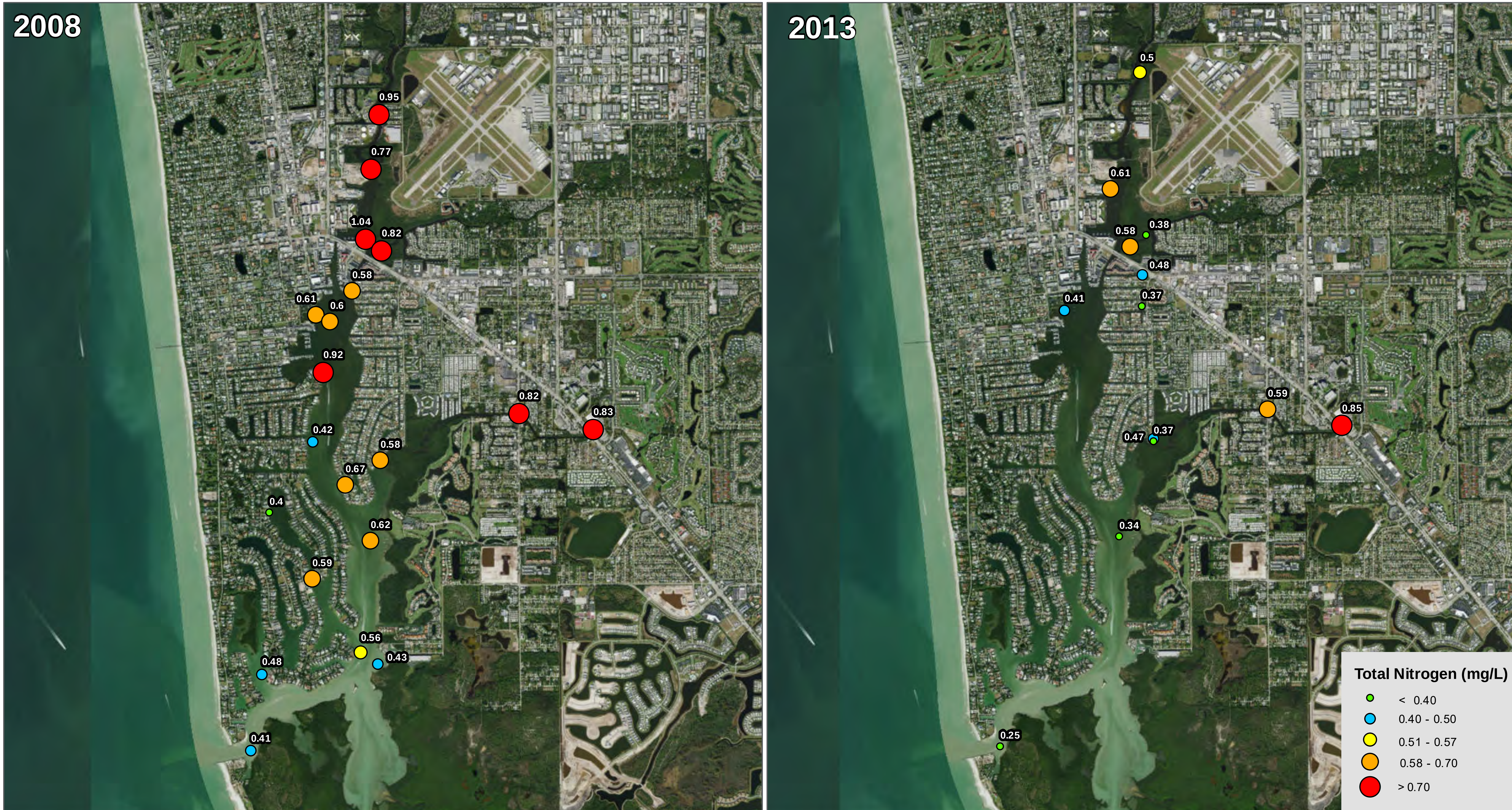


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Figure 3-31. Annual Geometric Mean Total Nitrogen Concentrations in Naples Bay and Gordon River (Marine Segment) 2008 and 2013.

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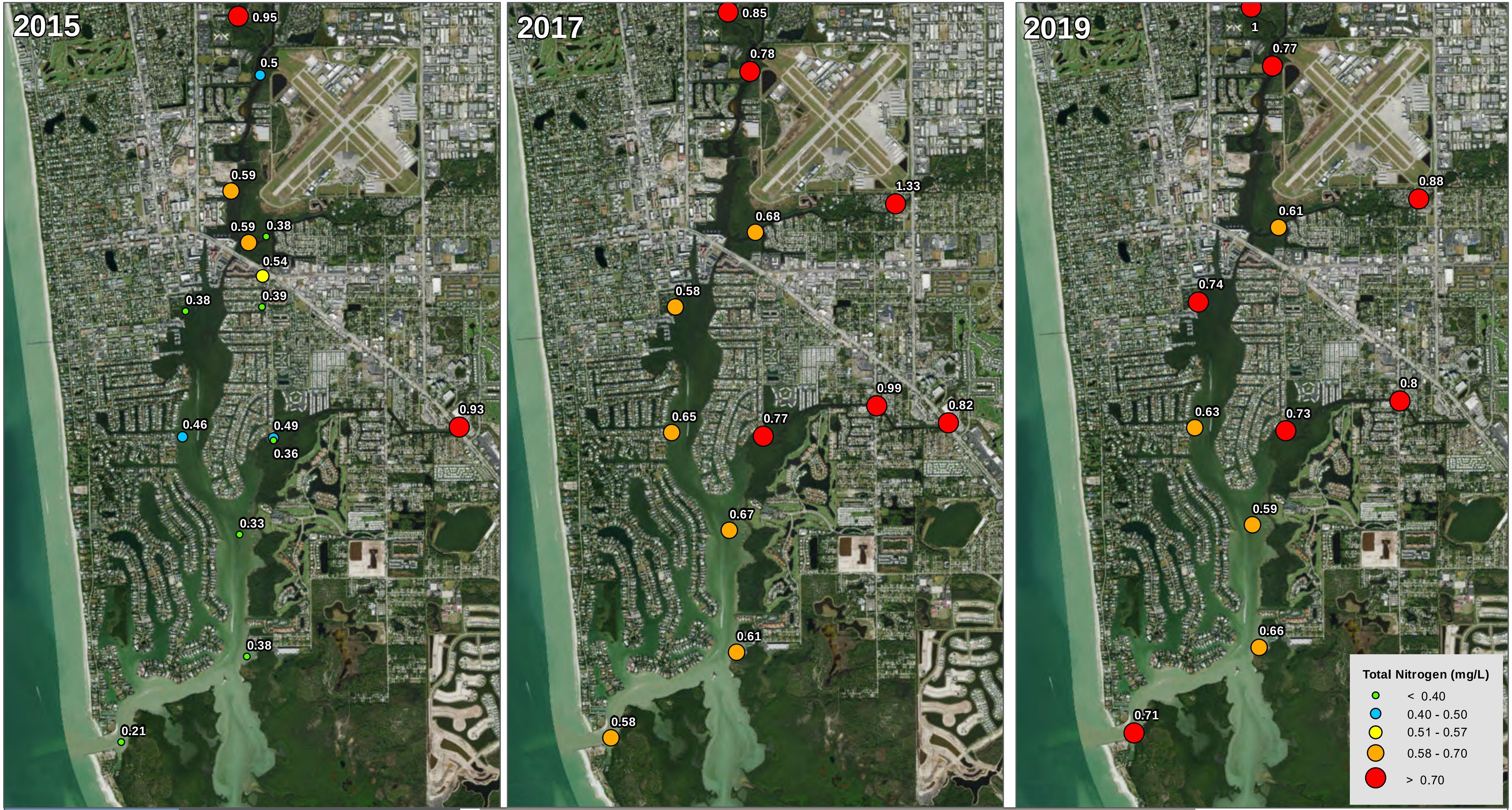

Figure 3-32. Annual Geometric Mean Total Nitrogen Concentrations in Naples Bay and Gordon River (Marine Segment) 2015, 2017, and 2019.

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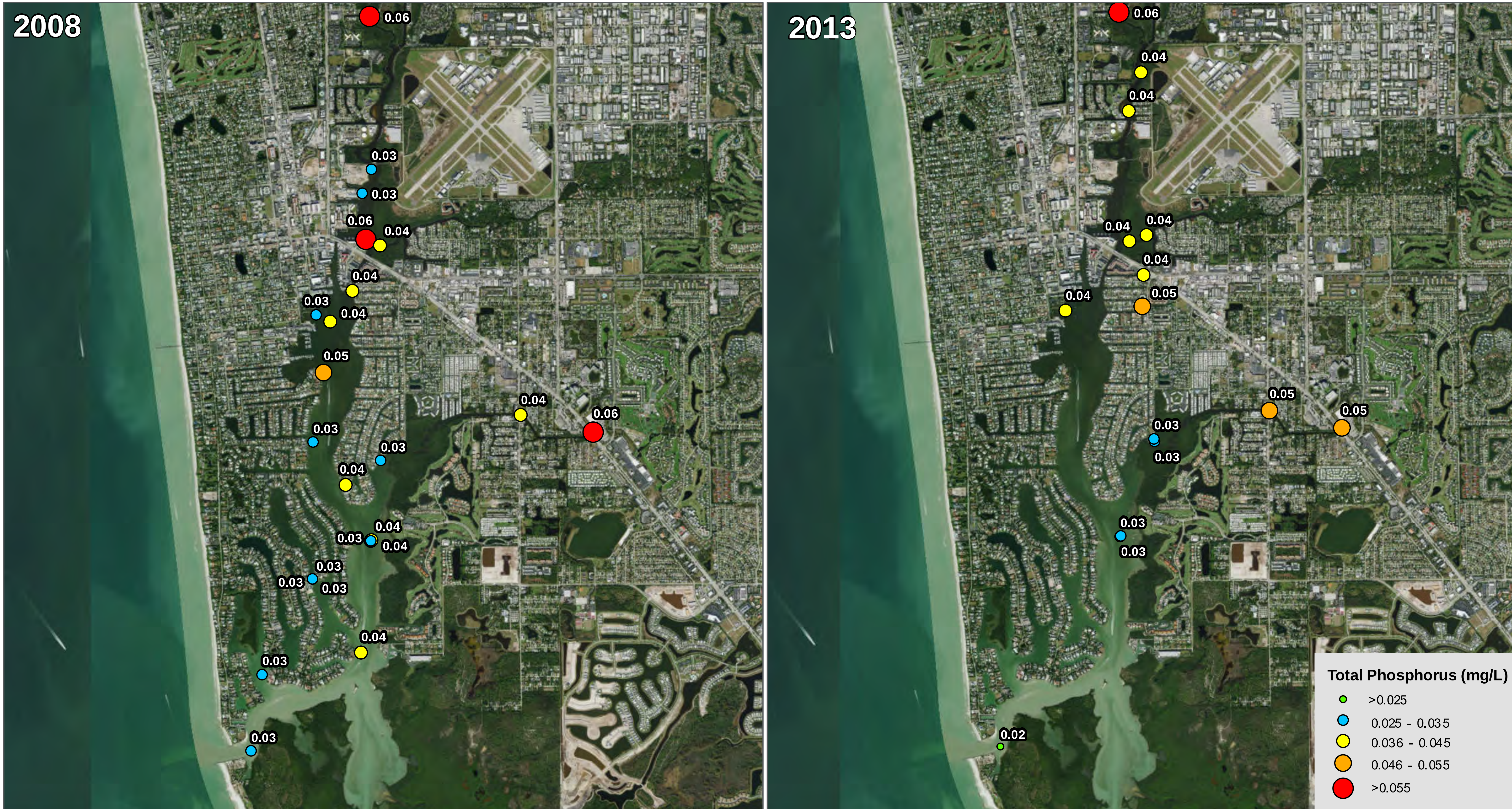

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Figure 3-33. Annual Geometric Mean Total Phosphorus Concentrations in Naples Bay and Gordon River (Marine Segment) 2008 and 2013.

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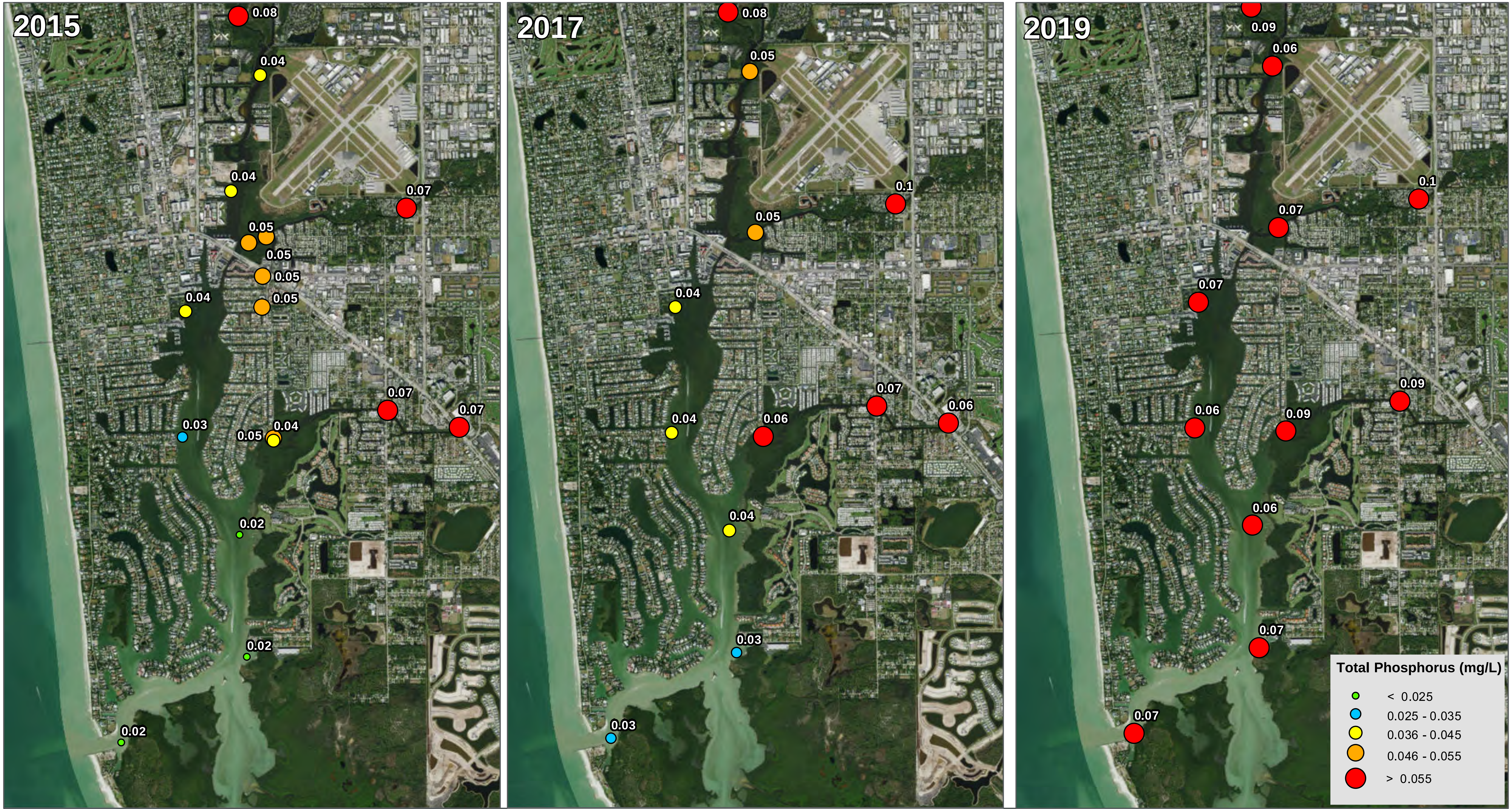

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Figure 3-34. Annual Geometric Mean Total Phosphorus Concentrations in Naples Bay and Gordon River (Marine Segment) 2015, 2017, and 2019.

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3.2.7 Chlorophyll-*a*

The estuarine NNC also includes a limit for chlorophyll-*a* in Naples Bay (WBID 3278R4) and the Gordon River (marine segment – WBID 3278R5). The criterion is expressed as an annual geometric mean concentration of 4.3 µg/L not to be exceeded more than once in a three-year period. The onset of the City's monitoring program in 2006 allowed for a more robust characterization of chlorophyll-*a* concentrations in Naples Bay.

Over the period of record (2000 to 2019), chlorophyll-*a* concentrations in the Gordon River (marine segment – WBID 3278R5) and Naples Bay (WBID 3278R4) have fluctuated around the adopted criterion through 2010, and then have been mostly above the standard from 2011 to 2019 (Figure 3-35). More than one year in each three-year period has exceeded the threshold since 2005 in both WBID 3278R5 and 3278R4, indicating chlorophyll-*a* is not in compliance with the NNC. A total of 18 individual monitoring stations are included in this assessment for Naples Bay (WBID 3278R4), but only five have sufficient chlorophyll-*a* data since 2011. Similarly, six individual stations were used in the assessment of the Gordon River (marine segment – WBID 3278R5), with only two having data from 2011-2015 and one station monitored from 2016 to 2019.

Annual Kendall Tau analysis was completed for the chlorophyll-*a* data within each WBID and then focusing on the eight long-term monitoring stations (Table 3-15). Both the Gordon River (marine segment – WBID 3278R5) and Naples Bay (WBID 3278R4) had statistically significant increasing trends in chlorophyll-*a* over time, with slopes of 0.11 µg/L/yr and 0.15 µg/L/yr, respectively. The increasing trend chlorophyll-*a* in WBID 3278R5 appears to be driven by two long-term stations GORDEXT/GORDPT and BC3, as they had statistically significant increasing trends over time (slopes 0.17 and 0.16 µg/L/yr, respectively). Only one of the Naples Bay stations had a statistically significant increasing trend in chlorophyll-*a* (NBAY29) and was located within the upper portion of the bay (see Figure 2-3).

As a result of the increasing trend observed in chlorophyll-*a*, the potential connection with nutrients as the cause was explored. A Spearman's Rank Order Correlation on individual observations of chlorophyll-*a* and either TN or TP was conducted. This correlation was used because log transformation did not meet the standards for normality, so parametric correlation was not appropriate.

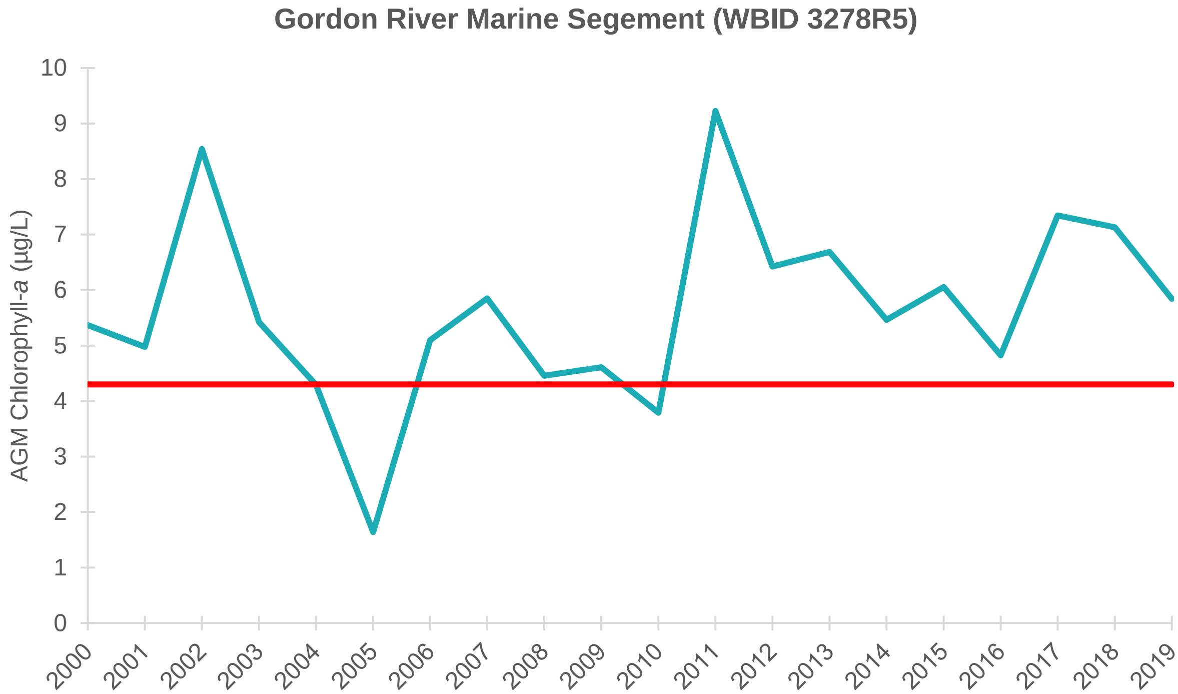
For Naples Bay (WBID 3278R4), chlorophyll-*a* is weakly positively correlated with both TN and TP ($0.15 > [r_s] > 0.16$, $p < 0.05$). For the Gordon River (marine segment – WBID 3278R5), chlorophyll-*a* is weakly negatively correlated with TN ($-0.11 > r_s$, $p < 0.05$) and weakly positively correlated with TP (Spearman's rank correlation, $0.25 > r_s$, $p < 0.05$). The weak correlations indicate that nutrient concentrations are not an accurate predictor of chlorophyll-*a* in either waterbody.

The spatial distribution of chlorophyll-*a* concentrations were also mapped for 2008 and 2013, and 2015, 2017, and 2019 (Figures 3-36 and 3-37). Higher chlorophyll-*a* concentrations are typically found in the northern bay and Gordon River (marine segment), with the highest values observed in Haldeman Creek in 2008 and 2013. A similar pattern was found in 2015, 2017, and 2019 with lower chlorophyll-*a* concentrations generally in the mid-to-lower Naples Bay and higher concentrations in the Gordon River (marine segment) and coastal tributaries.

Table 3-15. Results of annual Kendall Tau analysis for chlorophyll-*a* for the Gordon River (marine segment – WBID 3278R5) and Naples Bay (WBID 3278R4) including individual long-term monitoring stations.

Station	Years	Tau	p-value	Slope (µg/L/yr)
WBID 3278R5	2000-2019	**0.16**	**0.00001**	**0.11**
BC3	2000-2019	**0.17**	**0.0002**	**0.16**
GORDEXT/GORDPT	2005-2019	**0.14**	**0.01**	**0.17**
BC2	2000-2015	0.07	0.21	N/A
WBID 3278R4	2000-2019	**0.09**	**0.00002**	**0.15**
NBAYNL	2006-2019	0.06	0.28	N/A
NBAY29	2006-2019	**0.18**	**0.02**	**0.16**
NBAYWS	2005-2019	0.07	0.21	N/A
NBAYBV	2006-2019	0.04	0.64	N/A
GPASS6	2006-2019	0.00	0.94	N/A
ROCKCR	2011-2019	0.001	0.99	N/A
HALDCR	2011-2019	0.08	0.21	N/A

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.



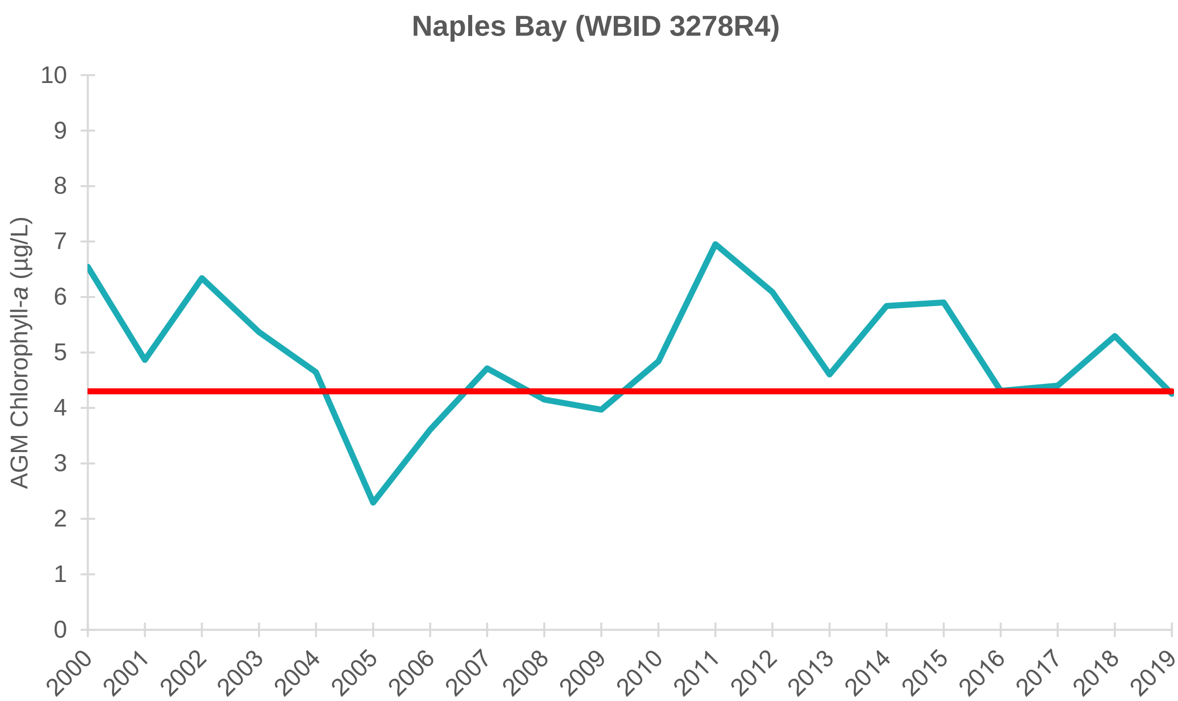


Figure 3-35. Naples Bay (WBID 3278R4) and Gordon River (marine segment-WBID 3278R5) chlorophyll-*a* annual geometric mean concentrations (turquoise) and numeric nutrient criteria (red), 2000–2019.

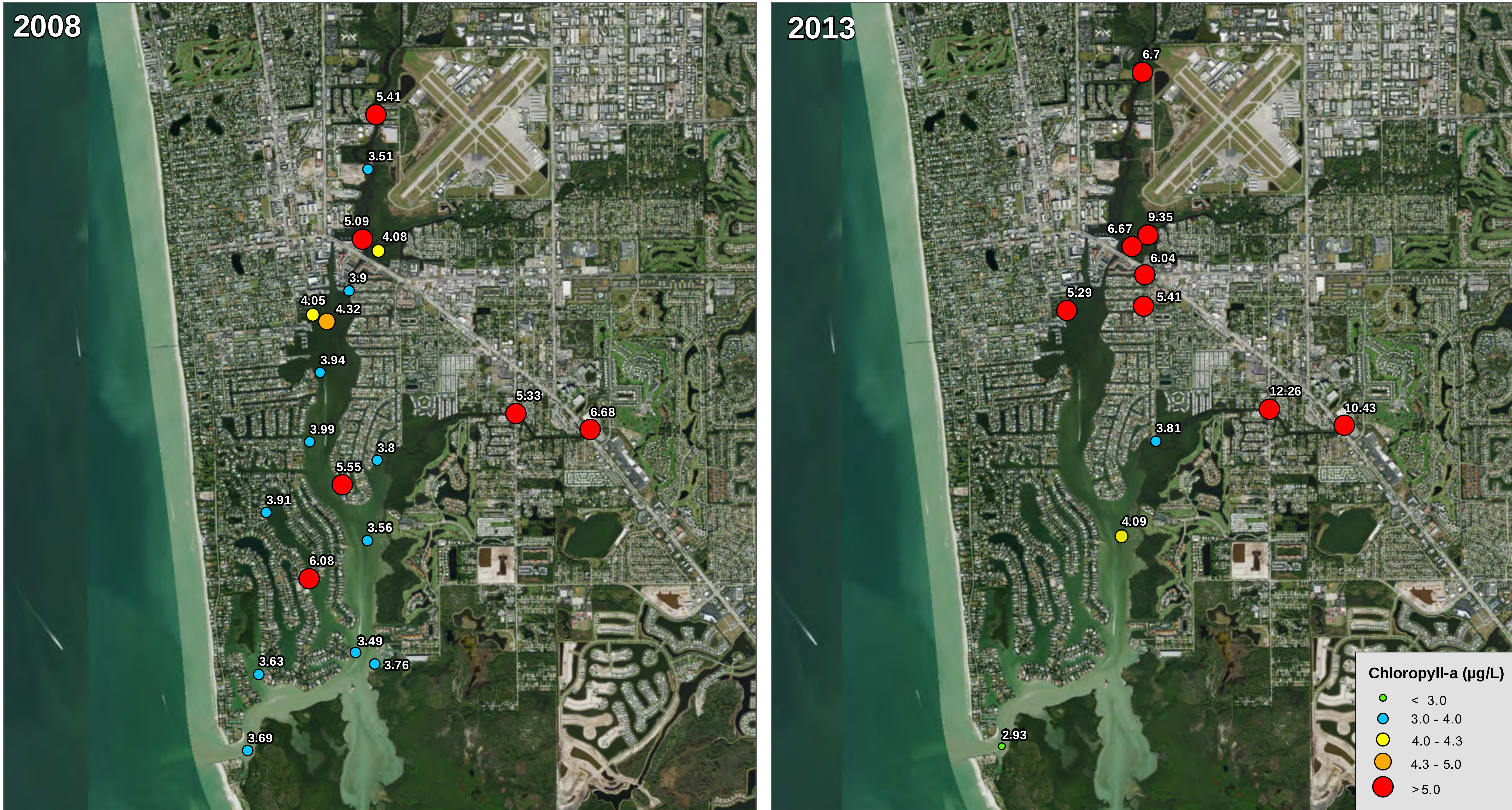


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Figure 3-36. Annual Geometric Mean Chlorophyll-*a* Concentrations in Naples Bay and Gordon River (Marine Segment) 2008 and 2013.

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0 | 3,200 | 6,400 | 9,600 | 12,800 Feet

0 | 976 | 1,952 | 2,928 | 3,904 Meters

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GIS Analyst: James Bottiger

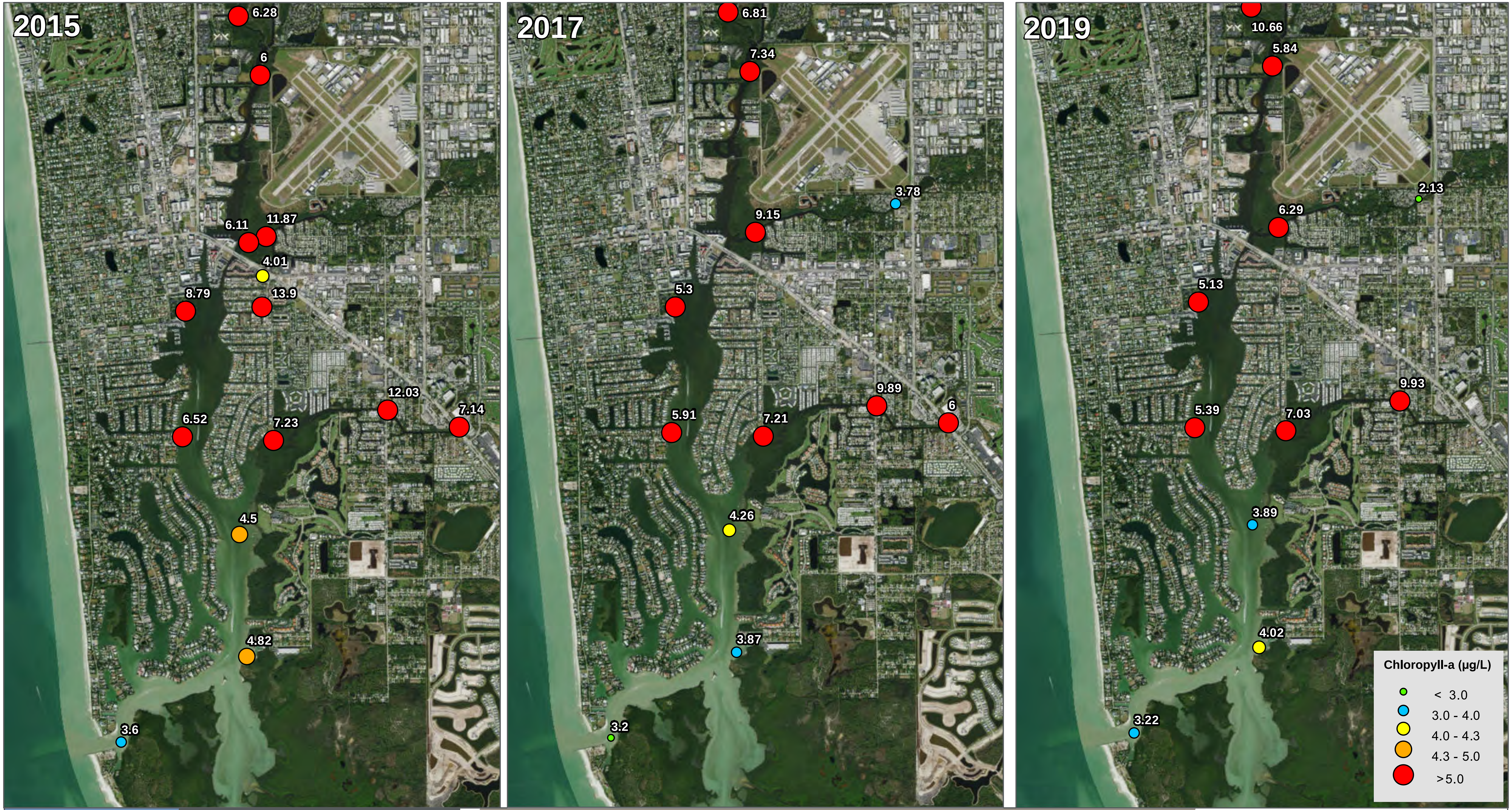

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Figure 3-37. Annual Geometric Mean Chlorophyll-*a* Concentrations in Naples Bay and Gordon River (Marine Segment) 2015, 2017, and 2019.

City of Naples, Natural Resources Division
Collier County, Florida

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0 | 976 | 1,952 | 2,928 | 3,904 Meters

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3.2.8 Dissolved Oxygen

Dissolved oxygen (DO) is viewed as a general indicator of waterbody health because it is essential to aquatic life. Since the 1970s and until recently, the marine water quality standard for DO in Florida required a minimum daily average of 5.0 mg/L, with instantaneous levels not to fall below 4.0 mg/L. However, these levels were derived with little information and were intended to be revised once more Florida-specific information and data were available (FDEP 2013). In 2013, FDEP adopted revised DO criteria for fresh and marine waters. The new marine DO criterion is based on percent saturation instead of concentration and requires DO to maintain a daily average greater than 42 percent saturation (62-302.533, F.A.C.). In addition to the daily average, a seven-day average percent saturation of 51 and a 30-day average percent saturation of 56 or greater shall also be maintained. In this report, Naples Bay DO is evaluated against the revised DO criteria for Florida which more appropriately represent necessary aquatic life conditions for Florida estuaries.

For comparisons to the marine water quality standard, DO is assessed at the WBID scale. Naples Bay had previously been listed by FDEP as impaired for DO, but more recent analysis indicated a low DO condition was natural and the Bay was removed from the impaired list. However, with the new Cycle 4 run for Group 1 in 2019, the Gordon River marine segment (3278R5) has been listed as impaired for DO (percent saturation) with nutrients as the causative pollutant.

All available DO measurements, beginning in 2000, were used in this analysis to assess the pattern of DO in Naples Bay with respect to the new marine DO criteria. DO percent saturation data were calculated from the measured DO concentration (mg/L), temperature, and salinity at the time of collection when direct DO percent saturation measurements were not available.

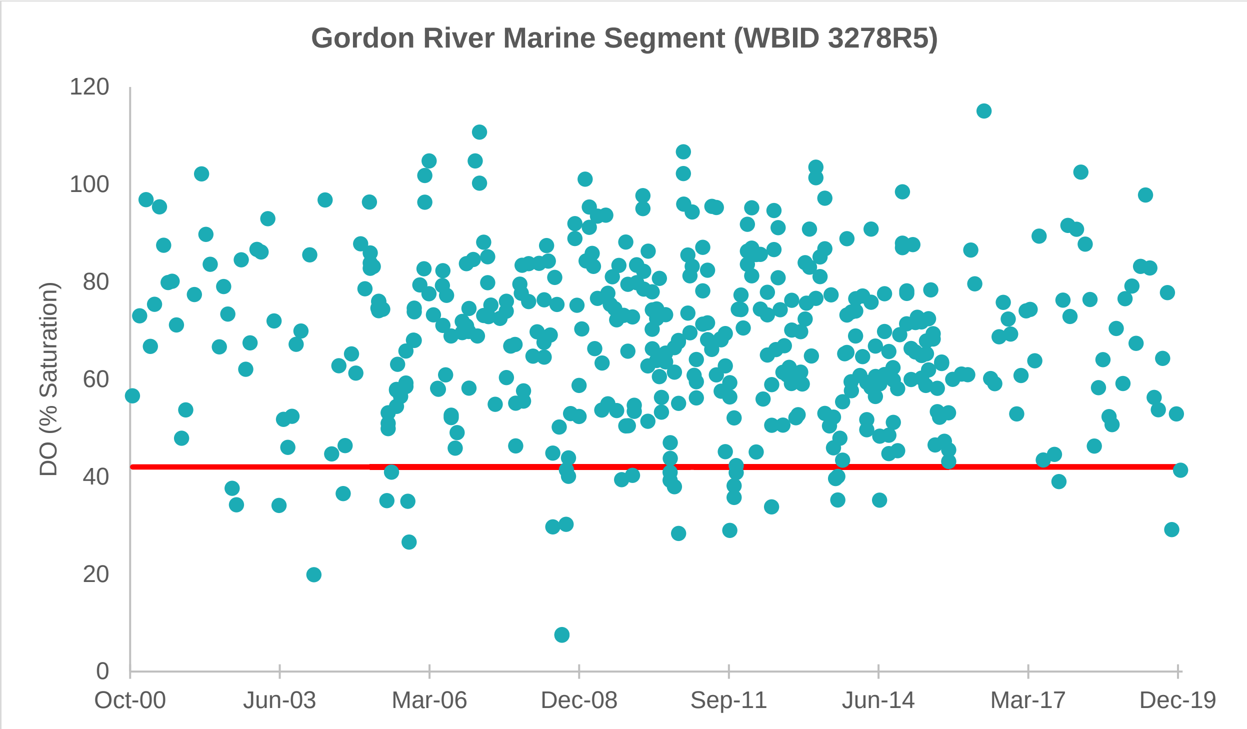
Using this dataset, WBIDs 3278R5 (Gordon River marine segment) and 3278R4 (Naples Bay) both achieve the DO criteria with far less than 10 percent of measurements below the 42 percent saturation benchmark (Figure 3-38). The frequency of the in-situ sample data available (typically collected on a monthly or bi-monthly schedule) is insufficient to assess the seven-day and 30-day average components of the criteria; however, with the vast majority of measurements above the 51 and 56 percent thresholds, there is no reason to suspect that DO would not meet the weekly and monthly thresholds in Naples Bay.

Annual Kendall Tau analysis was completed for the DO data at the nine long-term monitoring stations within the Gordon River (marine segment), Naples Bay, Rock Creek, and Haldeman Creek (Table 3-16). There were no statistically significant increasing trend in DO percent saturation at any long-term monitoring station ($p > 0.05$)

Table 3-16. Results of annual Kendall Tau analysis for dissolved oxygen percent saturation at long-term monitoring stations in the Gordon River (marine segment), Naples Bay, and two tributaries.

Station	Years	Tau	p-value	Slope (%/yr)
BC3	2001-2019	0.07	0.12	N/A
GORDEXT/GORDPT	2005-2019	0.08	0.16	N/A
ROCKCR	2011-2019	0.05	0.48	N/A
NBAYNL	2006-2019	-0.01	0.84	N/A
NBAY29	2006-2019	-0.03	0.68	N/A
HALDCR	2011-2019	0.11	0.09	N/A
NBAYWS	2005-2019	0.03	0.54	N/A
NBAYBV	2006-2019	-0.05	0.49	N/A
GPASS6	2006-2019	0.05	0.37	N/A

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.



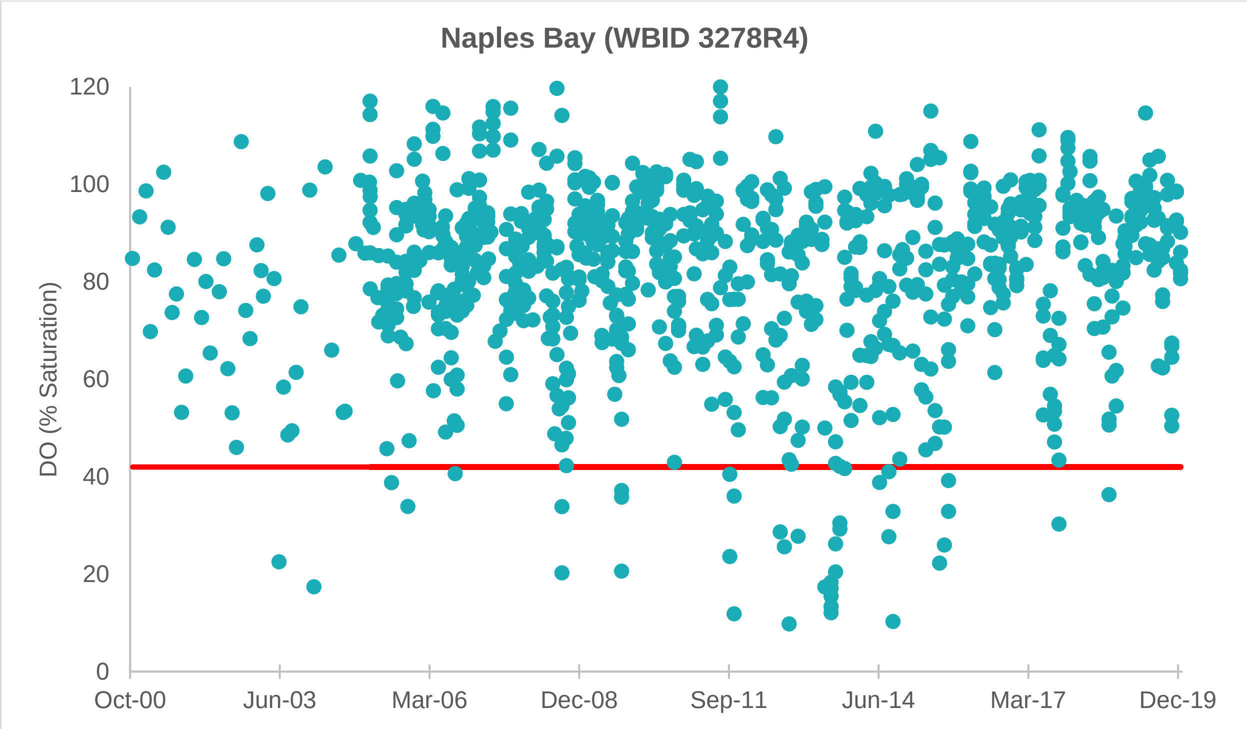


Figure 3-38. Gordon River (marine segment-WBID 3278R5) and Naples Bay (WBID 3278R4) dissolved oxygen percent saturation and the revised Class II criteria (42 percent saturation.

3.2.9 Turbidity

Turbidity is an important measure of water clarity in estuarine systems. It measures to what extent the amount of suspended material in the water column decreases the passage of light through the water. Turbidity is measured in nephelometric turbidity units (NTU), where the higher the NTU value, the more suspended materials are hindering light passage in the water. Although there is a marine water quality standard for turbidity, the standard is based on comparisons relative to natural background conditions, which are not defined for Naples Bay. In addition, turbidity values in Naples Bay are low relative to the exceedance values defined in the standard (29 NTU above background or 29 NTU if no established background average), therefore it is not necessary to do a detailed comparison against the standard. Turbidity trends were examined by station rather than by WBID.

Annual Kendall Tau analysis was completed for the turbidity data at the nine long-term monitoring stations within the Gordon River (marine segment), Naples Bay, Rock Creek, and Haldeman Creek (Table 3-17). There were statistically significant increasing trends in turbidity at all long-term monitoring stations, with varying predicted slopes of annual increase. For each station, the annual slopes of increase range from 0.12 NTU/yr at GORDEXT/GORDPT at the northern end of the bay to 0.30 NTU/yr at GPASS6 at the mouth of Naples Bay. This general increase from north to south makes sense as stations closer to the mouth of Naples Bay would receive both inputs from runoff and mixing with sediments during the incoming/outgoing tides.

The spatial distribution of turbidity was mapped using annual geometric mean values at available monitoring stations in 2008 and 2013 (Figure 3-39). Turbidity appears to be increasing from 2008 to 2013, with slightly higher values observed in the northern portion of the Bay. Spatial distribution maps were also created for data collected in 2015, 2017, and 2019 (Figure 3-40). During 2015, 2017, and 2019 increasing turbidity measurements from Gordon Pass north through the middle bay and almost to US41 can be observed over all three time periods. Turbidity measurements overall are higher in 2017 (measurements taken post Irma dominating the annual averages), and remain elevated in 2019 (Figure 3-40).

Table 3-17. Results of annual Kendall Tau analysis for turbidity at long-term monitoring stations in the Gordon River (marine segment), Naples Bay, and two tributaries.

Station	Years	Tau	p-value	Slope (NTU/yr)
BC3	2009-2019	**0.36**	**<0.001**	**0.16**
GORDEXT/GORDPT	2005-2019	**0.30**	**<0.001**	**0.12**
ROCKCR	2011-2019	**0.41**	**<0.001**	**0.28**
NBAYNL	2006-2019	**0.40**	**<0.001**	**0.19**
NBAY29	2006-2019	**0.43**	**<0.001**	**0.18**
HALDCR	2011-2019	**0.34**	**<0.001**	**0.26**
NBAYWS	2005-2019	**0.34**	**<0.001**	**0.18**
NBAYBV	2005-2019	**0.43**	**<0.001**	**0.27**
GPASS6	2005-2019	**0.39**	**<0.001**	**0.30**

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.

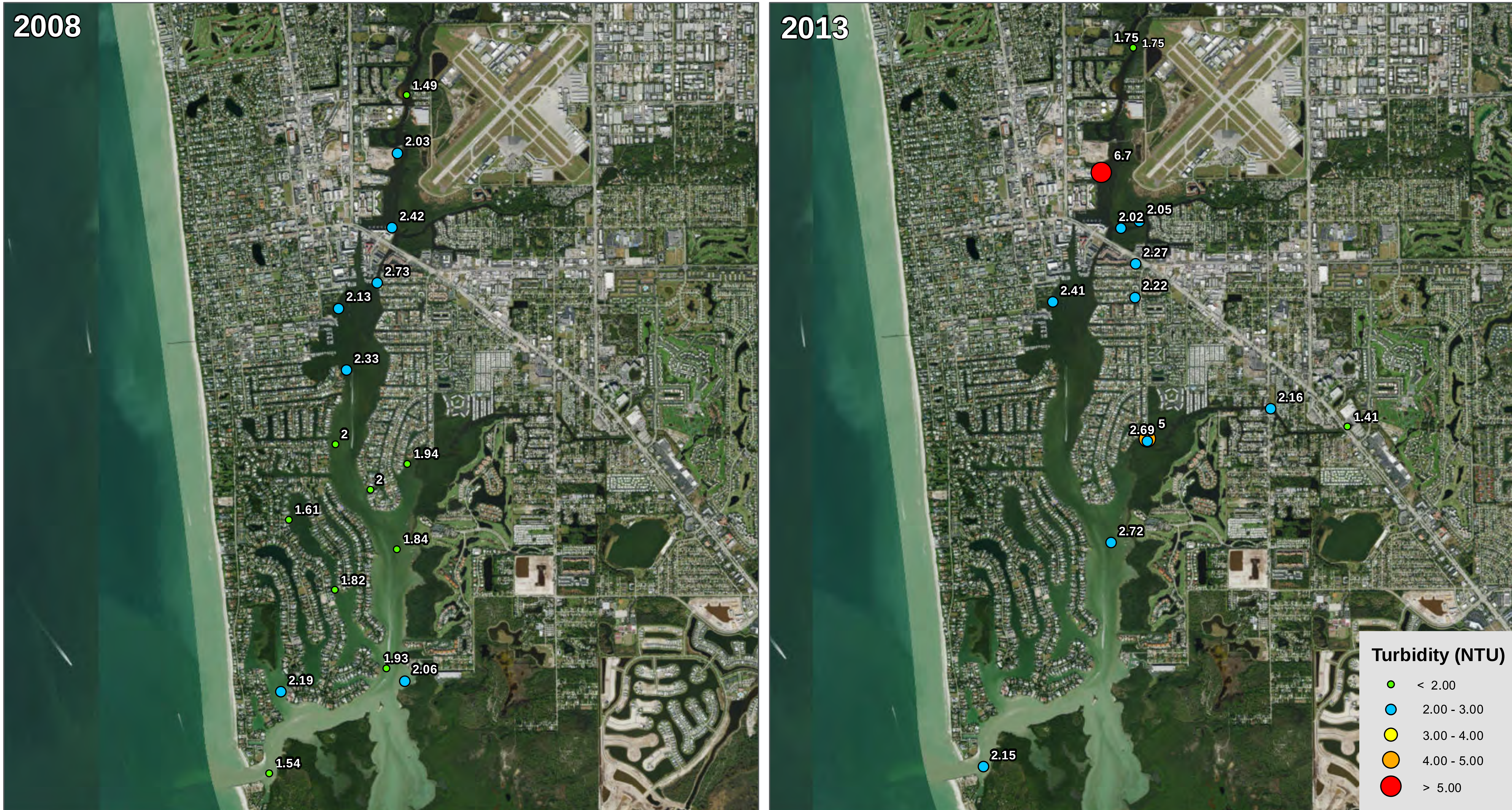


Figure 3-39. Annual Geometric Mean Turbidity Concentrations in Naples Bay and Gordon River (Marine Segment) 2008 and 2013.

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Collier County, Florida

0 3,000 6,000 9,000 Feet
0 900 1,800 2,700 Meters

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GIS Analyst: James.Bottiger

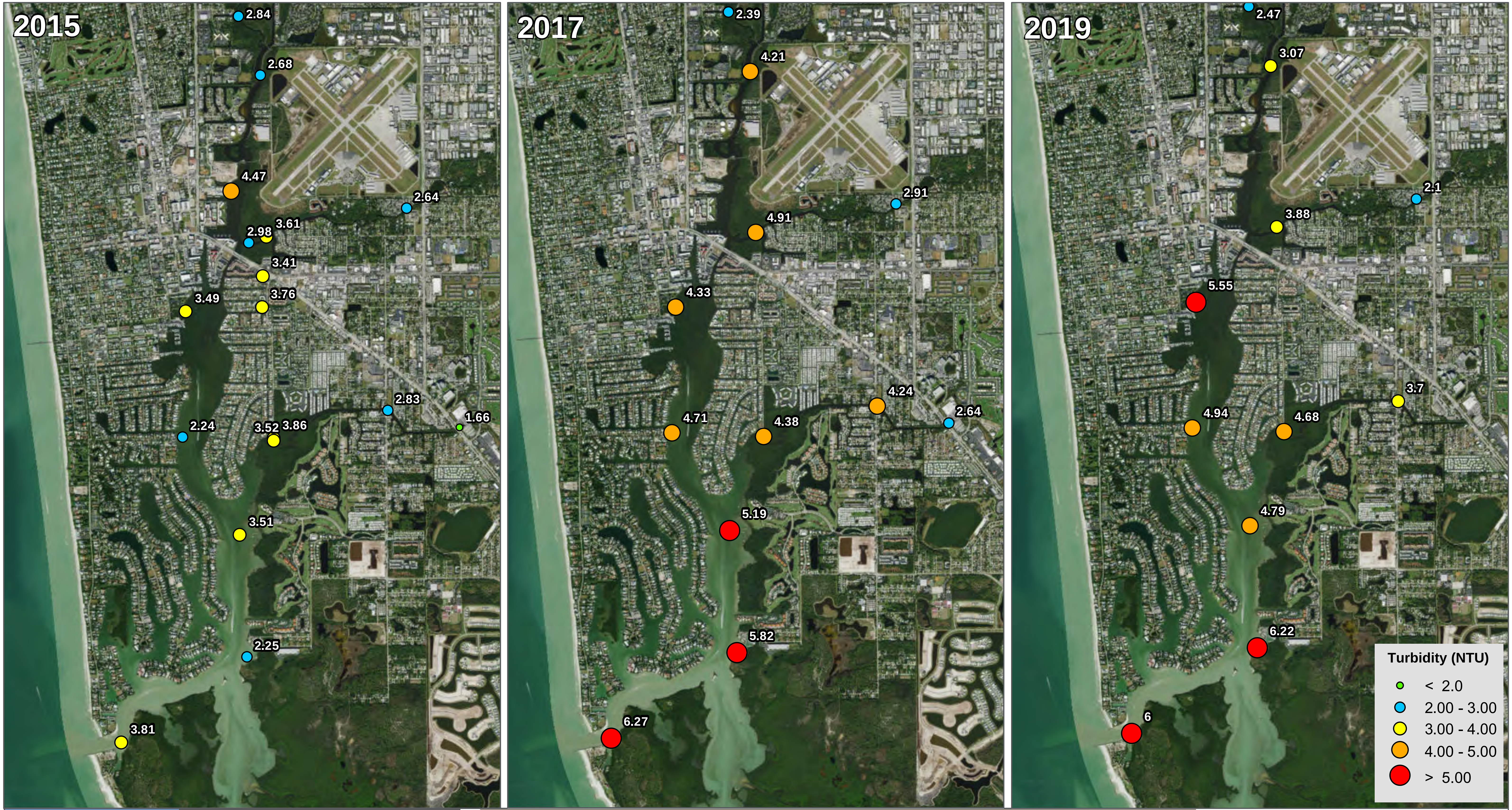

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Figure 3-40. Annual Geometric Mean Turbidity Concentrations in Naples Bay and Gordon River (Marine Segment) 2015, 2017, and 2019.

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0 976 1,952 2,928 3,904 Meters

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GIS Analyst: James Bottiger

3.2.10 Fecal Indicator Bacteria (Fecal Coliform and Enterococci)

Florida surface waters are classified according to designated uses (62-302.400, F.A.C.). The marine section of the Naples Bay watershed consists of two surface water classifications: Class II (Shellfish Propagation or Harvesting) and Class III (Fish Consumption, Recreation, Propagation and Maintenance of a Healthy, Well-Balanced Population of Fish and Wildlife). Class II marine water quality standards apply throughout Naples Bay (including monitoring stations NBAYNL, NBAYWS and GPASS6). Class III marine water quality standards apply in the Gordon River (including monitoring stations GORDEXT/GORDPT).

Florida state surface water quality criteria for bacteriological quality (Enterococci) in Class II and III marine waters states that most probable number (MPN) or membrane filter (MF) counts shall not exceed a monthly geometric mean of 35, with no more than 10 percent of values to exceed 130 during any 30-day period (62-302.530 (6)(c), F.A.C.; 2016). A minimum of 10 daily samples taken over a 30-day period are required to calculate the monthly geometric means.

Florida state surface water quality criteria for bacteriological quality (Fecal Coliform Bacteria) in Class II marine waters states that MPN or MF counts shall not exceed a median of 14, with no more than 10 percent of values to exceed 43 (for MPN) or 31 (for MF), nor exceed 800 on any one day (62-302.530 (6)(c), F.A.C.; 2016). The City terminated fecal coliform bacteria testing in 2019 because Naples Bay is not a designated Shellfish Harvest Area and FDEP recommended enterococci as the more robust recreational water quality bacteriological indicator.

Annual Kendall Tau analysis was completed for both fecal coliform and enterococci data at the nine long-term monitoring stations within the Gordon River (marine segment), Naples Bay, Rock Creek, and Haldeman Creek (Tables 3-18 and 3-19). In the Gordon River (marine segment) GORDEXT/GORDPT has a statistically significant increasing trend for fecal coliform (slope 6.90 cfu/100mL/yr) as did all stations in Naples Bay. The slopes of increase ranged from the highest in the north at NBAYNL (slope 4.60 cfu/100mL/yr) to the lowest near the mouth of Naples Bay at GPASS6 (slope 0.33 cfu/100mL/yr). There were no statistically significant increasing or decreasing trends in fecal coliform in either tributary station ($p > 0.05$, Table 3-18).

Enterococci had similar statistically significant increasing trends over time but the other long-term monitoring station (BC3) in the Gordon River (marine segment) had the significant trend (slope 41.98 cfu/100mL/yr, Table 3-19). All five Naples Bay stations had statistically significant increasing trends in enterococci colony counts, but the range in slopes of increase were reversed from the fecal coliform analysis. The smallest slope of increase of 0.28 cfu/100mL/yr was at the farthest north station (NBAYNL) and the largest slope of increase of 0.95 cfu/100mL/yr was at GPASS6. There were also no statistically significant increasing or decreasing trends in enterococci colony counts in either tributary station ($p > 0.05$, Table 3-18).

The spatial distribution of enterococci counts was mapped in 2008 and 2013, and again in 2015, 2017, and 2019 (Figures 3-41 and 3-42). Enterococci colony counts appear to be higher in upper Naples Bay and tributaries in 2013 than 2008. Annual geometric mean enterococci counts were lower again in Naples Bay during 2015, 2017, and 2019 (generally between 10 and 30 cfu/100mL) but much higher in the Gordon River (marine segment) and tributaries (Figure 3-42). The annual geometric means observed in graphics coincide with the latest FDEP determination that the Gordon River (marine segment – WBID 3278R5) is impaired for enterococci.

Table 3-18. Results of annual Kendall Tau analysis for fecal coliform at long-term monitoring stations in the Gordon River (marine segment), Naples Bay, and two tributaries.

Station	Years	Tau	p-value	Slope (cfu/100mL/yr)
BC3	2001-2018	-0.05	0.30	N/A
GORDEXT/GORDPT	2005-2018	**0.23**	**<0.001**	**6.90**
ROCKCR	2011-2018	-0.01	0.84	N/A
NBAYNL	2006-2018	**0.24**	**<0.001**	**4.60**
NBAY29	2006-2018	**0.25**	**0.004**	**1.58**
HALDCR	2011-2018	0.12	0.10	N/A
NBAYWS	2005-2018	**0.16**	**0.01**	**0.86**
NBAYBV	2006-2018	**0.26**	**0.002**	**1.01**
GPASS6	2006-2018	**0.18**	**0.002**	**0.33**

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.

Table 3-19. Results of annual Kendall Tau analysis for enterococci at long-term monitoring stations in the Gordon River (marine segment), Naples Bay, and two tributaries.

Station	Years	Tau	p-value	Slope (cfu/100mL/yr)
BC3	2015-2019	**0.36**	**<0.001**	**41.98**
GORDEXT/GORDPT	2006-2019	0.08	0.17	N/A
ROCKCR	2011-2019	-0.04	0.52	N/A
NBAYNL	2007-2019	**0.13**	**0.02**	**0.28**
NBAY29	2007-2019	**0.46**	**<0.001**	**0.79**
HALDCR	2011-2019	0.10	0.14	N/A
NBAYWS	2007-2019	**0.28**	**<0.001**	**0.83**
NBAYBV	2007-2019	**0.42**	**<0.001**	**0.71**
GPASS6	2007-2019	**0.41**	**<0.001**	**0.95**

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.

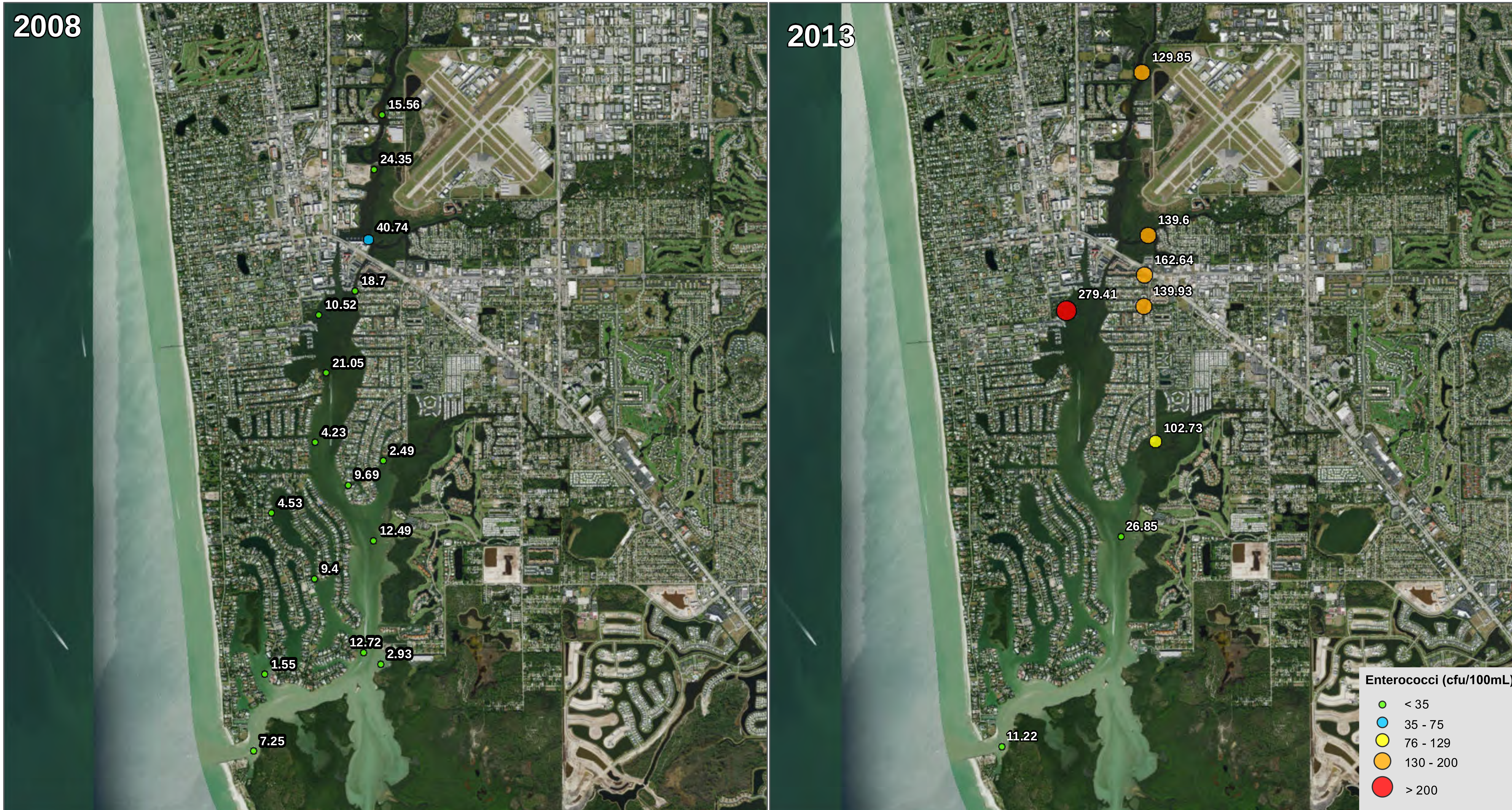

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Figure 3-41. Annual Geometric Mean Enterococci Counts in Naples Bay and Gordon River (Marine Segment) 2008 and 2013.

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GIS Analyst: James.Bottiger

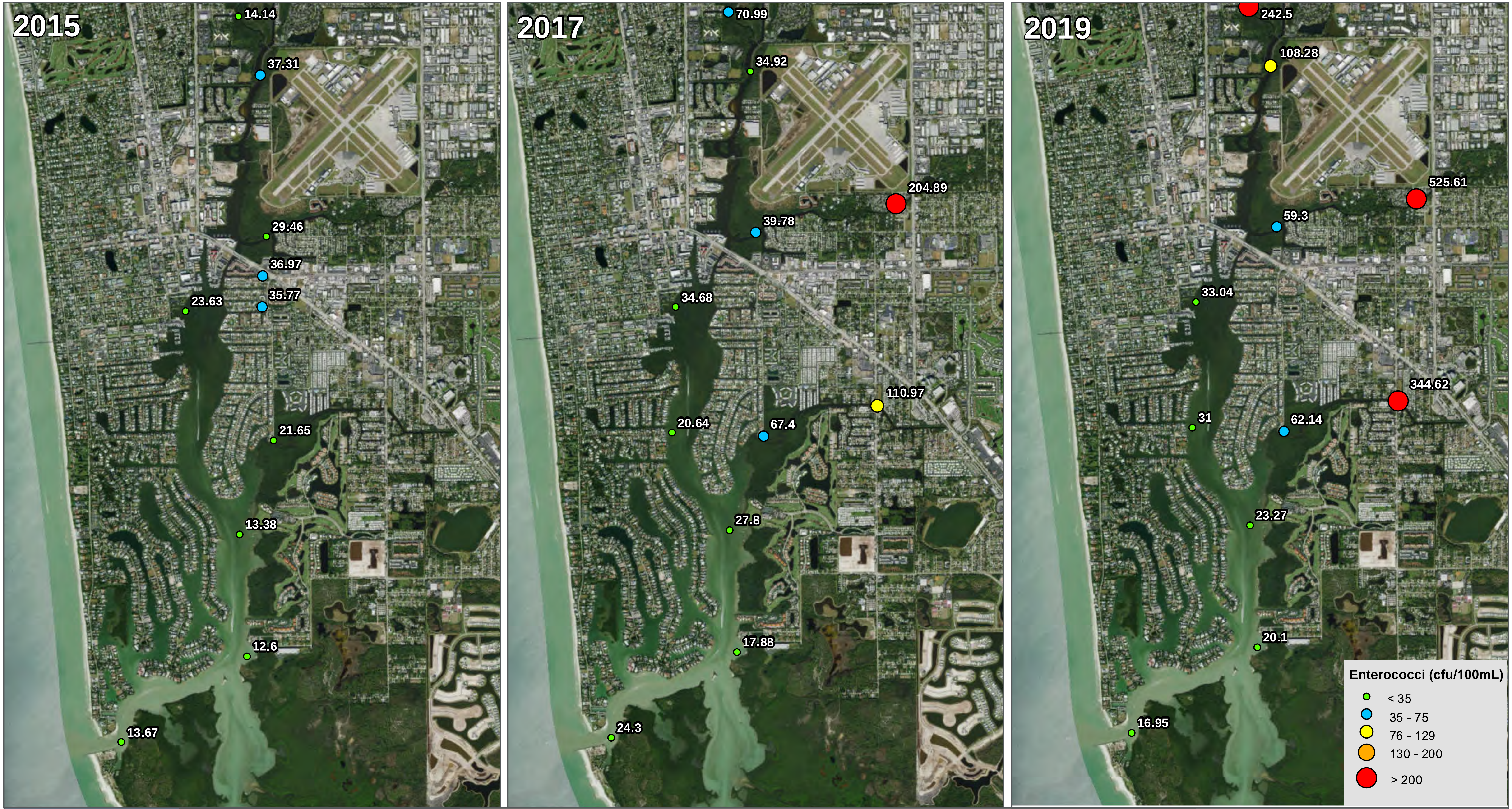

Figure 3-42. Annual Geometric Mean Enterococci Counts in Naples Bay and Gordon River (Marine Segment) 2015, 2017, and 2019.

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GIS Analyst: James.Bottiger

4 Naples Bay Biological Community

This section is devoted to the identification of statistically significant trends in biological community data in Naples Bay. The potential for changes in the biological community over time or between different zones within Naples Bay are explored. The analysis presented here focuses on the seagrass and fish community monitoring programs conducted by the City of Naples. The City has been monitoring seagrass since 2006 and fish since 2009 (in cooperation with Rookery Bay National Estuarine Research Reserve). Analysis of the current status of these communities along with quantifying any significant changes over time is an important tool in terms of resource management.

4.1 Seagrass Community

The City of Naples monitors six fixed transects located in three separate seagrass areas (designated BV, NChannel, and SPortRoyal) located in the southernmost portion of the Bay (Figure 4-1). The Habitat Island (HabIsland) transect was added in 2015 and is the northernmost transect and is adjacent to a dense stand of mangroves. These beds are the known areas which consistently have had seagrass found over multiple years in Naples Bay. Other seagrass areas exist in Naples Bay, but may be ephemeral in nature and are not able to be monitored via the fixed transect method. The following indicators were used to evaluate and identify general patterns in these seagrass areas in Naples Bay over time:

- Seagrass composition: Number of species present
- Seagrass cover: Categories of percent cover
- Seagrass density: Number of seagrass short shoots per square meter
- Seagrass depth distribution: Maximum water depth and depth range

On any sampling day, the variance among the location-specific measurements was relatively small, indicting little spatial variance at the time of the sample. Therefore, for the purpose of analysis (unless otherwise noted), data for each metric were pooled, resulting in a single value per sampling day.

Seagrass transects were monitored once or twice per year during the growing season from 2006 to 2019. In early years, surveys were generally once in the early part of the season and once later in the season. From 2011 to 2014, surveys were only conducted once, and from 2012 to 2014, only in the later part of the season (Table 4-1). During the last five years, twice per year monitoring occurred at most transects in 2016, 2018, and 2019. In 2015 monitoring occurred early in the growing season with the exception of SPortRoyal, and in 2017 monitoring only occurred early in the growing season because of the passage of Hurricane Irma in September 2017.

Table 4-1. Timing of seagrass surveys for each transect in Naples Bay, 2006 to 2019.

Year	Transect ID					
	BV1West	BV2Mid	BV3East	NChannel	SPortRoyal	HabIsland
2006	July	July	August	September	October	
2007	April, September	April, September	September	September	June, November	
2008	May, October	May, October	May, October	May, October	May, October	
2009	May, October	May, October	May, October	May, October	June, October	
2010	June, September	June, September	June, September	June, September	June, September	
2011	June	June	June	June	June	
2012	August	August	August	August	August	
2013	September	September	September	September	September	
2014	August	August	August	August	September	
2015	June	June	June	June	September	June
2016	May, September	September	May, September	May, September	May, September	May, September
2017	May	May	May	May	May	May
2018	May, September	May, September	May, September	June, September	May, September	May, September
2019	May, August	May, August	May, August	May	May, August	May

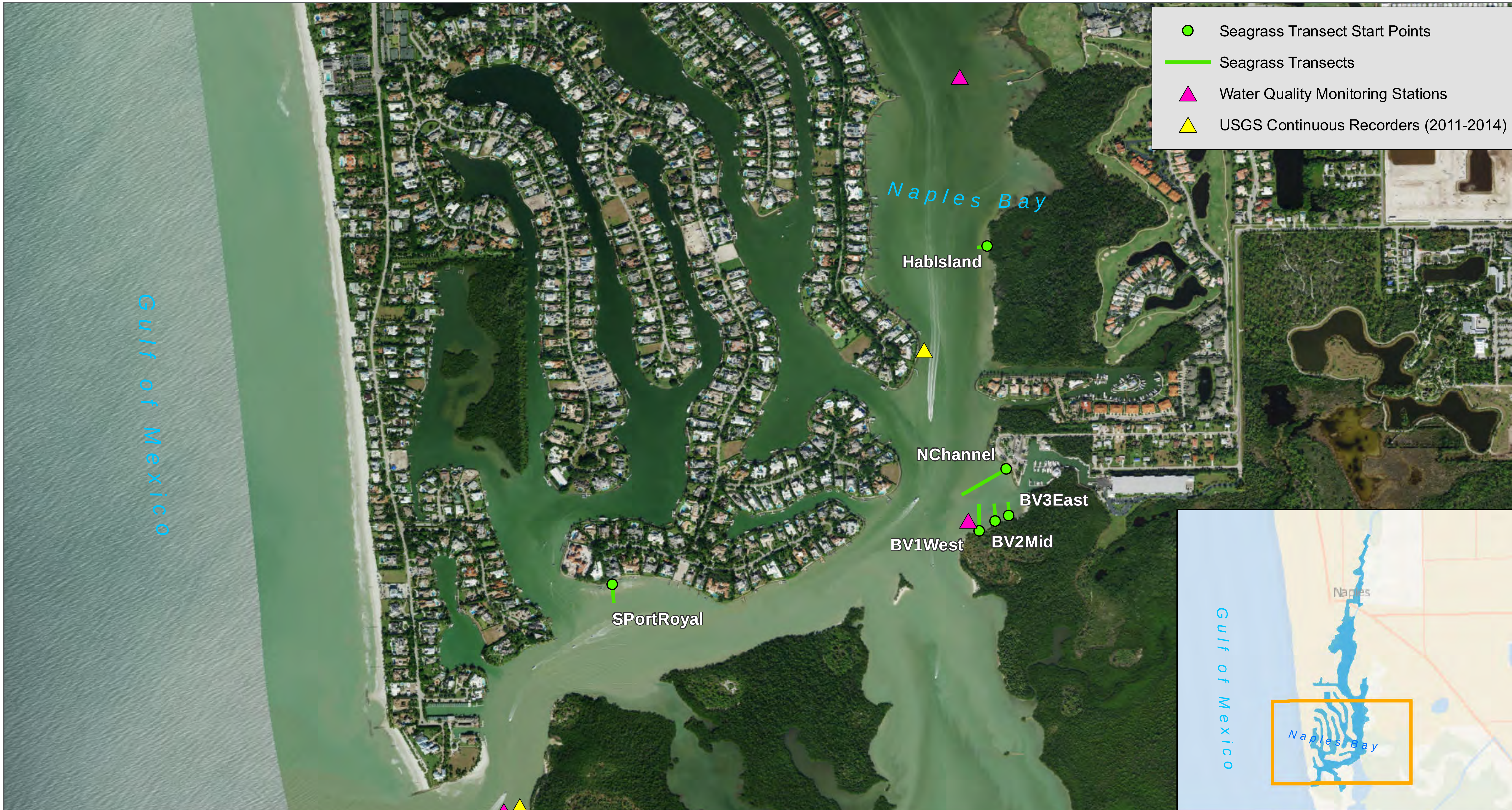

Figure 4-1. Naples Bay Seagrass Monitoring Transects and Nearby Water Quality Monitoring Stations

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GIS Analyst: James.Bottiger

4.1.1 <u>Seagrass Species Composition</u>

Three species of seagrass were observed in the survey area: *Halodue wrightii*, *Halophila decipiens*, and *Halophila englemannii*. Two species of rhizophytic, bed-forming macroalgae were also occasionally present: *Caulerpa prolifera*, *Caulerpa mexicana*, and a "feathery *Caulerpa*" possibly *Caulerpa sertularioides*. *H. wrightii*, generally growing in monospecific beds, was by far the most common seagrass, occurring in 81 percent of the quadrats surveyed along the transects (Table 4-2). *Halophila decipiens* occurred in around 10 percent of the quadrats and *Halophila engelmannii* was much less common, occurring in less than 2 percent of quadrats surveyed for the whole survey period from 2006 to 2019.

H. wrightii is one of the most commonly occurring species of seagrass in Florida (Dawes 2004). It can tolerate a wide range of salinity, nutrient, and physical environments (Zieman 1982, van Tussenbroek *et al.* 2010) and can be found in intertidal and subtidal areas (Zieman and Zieman 1989). Subtidally, *H. wrightii* can grow in both monospecific beds and mixed with other seagrasses (Yarbro & Carlson 2013). *Halophila engelmanni* and *Halophila decipiens* are generally considered to be low-light species and can grow in much deeper depths than many other Florida species; however, both species can be found at shallower depths where water is more turbid (van Tussenbroek, *et al.*, 2010). Within Florida, *Halophila englemanni* is most commonly found along the southwest coast (Yabro and Carlson 2013) and generally only grows as an understory to other species (van Tussenbroek, *et al.* 2010). *Halophila decipiens* is limited to areas with near-marine salinities (Zieman 1982, van Tussenbroek *et al.* 2010).

Table 4-2. Percentage occurrence of seagrasses and rhizophytic algae by species at fixed monitoring stations in Naples Bay by year from 2006 to 2019 and study period total percent occurrence.

Species	Year														Overall Total
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
Halodule wrightii	88.2	85.2	91.2	97	91.4	93.8	88.2	93.3	62.1	89.7	79.3	79.3	66.2	69.4	81.2
Halophila decipiens	5.9	3.7	8.8	15.2	--	--	5.9	--	--	24.1	--	27.6	15.4	26.5	10.4
Halophila engelmannii	--	--	--	--	--	--	--	6.7	--	3.4	3.4	3.4	--	--	1.3
Caulerpa prolifera	--	--	--	--	2.9	--	5.9	--	--	10.3	5.2	6.9	1.5	6.1	3.0
Caulerpa mexicana	--	3.7	--	--	--	--	--	--	--	--	--	--			0.2
Caulerpa sertularioides	--	--	--	--	--	--	--	--	--	--	--	--	6.2	--	0.9
none	5.9	11.1	8.8	3	5.7	6.3	11.8	6.7	34.5	6.9	20.7	10.3	24.6	15.3	14.5

4.1.2 Seagrass Cover

Seagrass cover was assessed using a modified Braun-Blanquet scale where a categorical score is assigned to a range of percent bottom cover. Total seagrass cover was generally low across all transects over the entire survey period (Figure 4-1); the highest Braun-Blanquet cover score recorded from 2006 to 2014 was a 2 which corresponds to 5–25 percent cover. During the 2015 to 2019 assessment period, there was a single cover score of 3 recorded in 2015 at NChannel, and in 2017 at SPortRoyal. The most frequently recorded score was 1, which indicates less than 5 percent seagrass cover. The qualitative Braun-Blanquet cover score method does not allow detection of small changes in seagrass cover because the range of percentages covered by one score is quite large (Bell et al. 2008). For low density systems like Naples Bay, where small gains would be worth documenting, more quantitative methods, like actual percent cover or biomass measurements, would allow for a more in-depth statistical analysis of seagrass patterns.

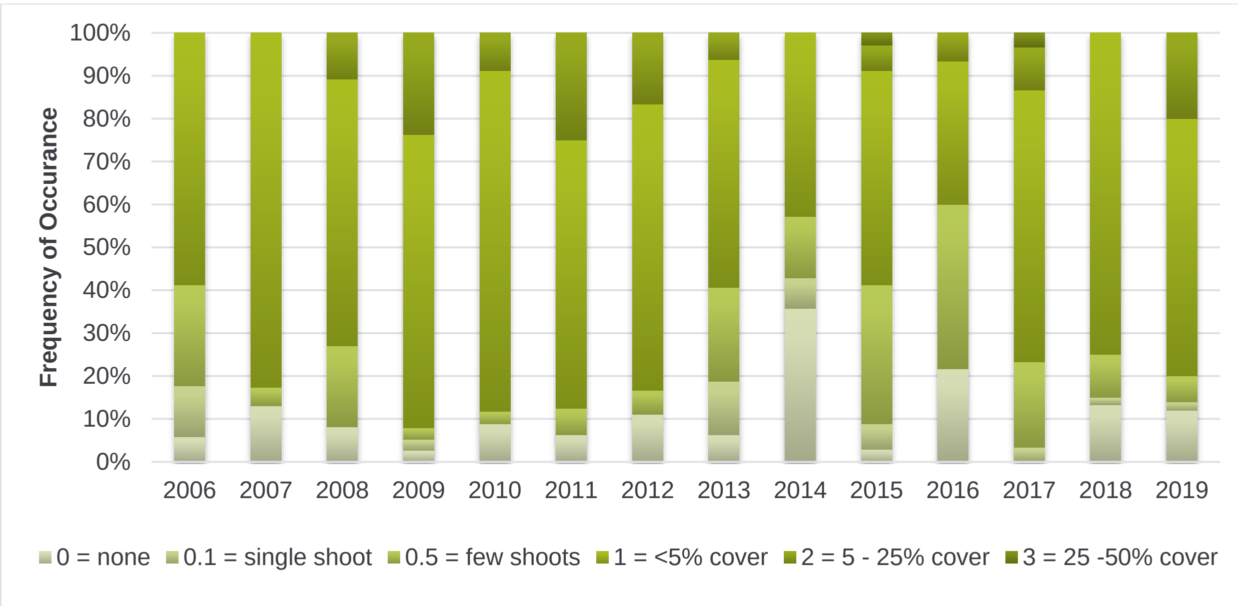

Figure 4-2. Occurrence of each cover score category (Braun-Blanquet) for *H. wrightii* at fixed monitoring stations in Naples Bay, 2006–2019.

4.1.3 Seagrass Density

Seagrass density (number of short shoots per square meter) was measured in each fixed quadrat sampling location during each survey event. When data from all transects and all survey events are considered together by year, it appears that *H. wrightii* was increasing in density until about 2011, decreased through 2014, and more variable from 2015 through 2019 (Figure 4-3). However, when the data are combined from 2006 to 2019 by month, a trend of decreasing density as the growing season progresses becomes apparent (Figure 4-4). Naturally decreasing seagrass density as the season progresses from summer to winter is common in Southwest Florida bays (Yarbro and Carlson 2013). Because seagrass surveys were conducted only during the later months of the survey season between 2012 and 2014, generally early in 2015 and 2017, and then twice per year in 2016, 2018, and 2019 (Table 4-1), it is difficult to separate a potential seasonal sampling bias from actual overall declines in seagrass in Naples Bay. It is also likely that water quality (i.e. nutrient and solids loading from the GGC) plays a role in the observed decreasing trend, and further investigation into the potential causes is warranted.

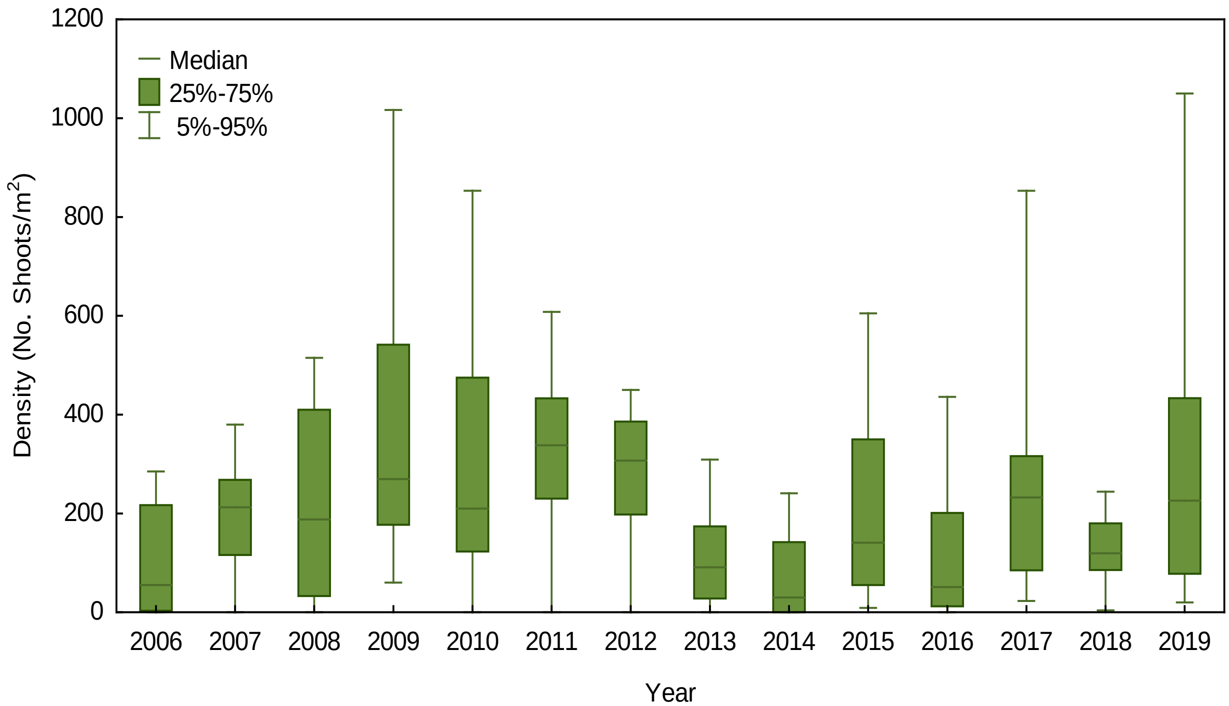

Figure 4-3. Seagrass (*H. wrightii*) density (number of shoots/m²) in Naples Bay, 2006 to 2019.

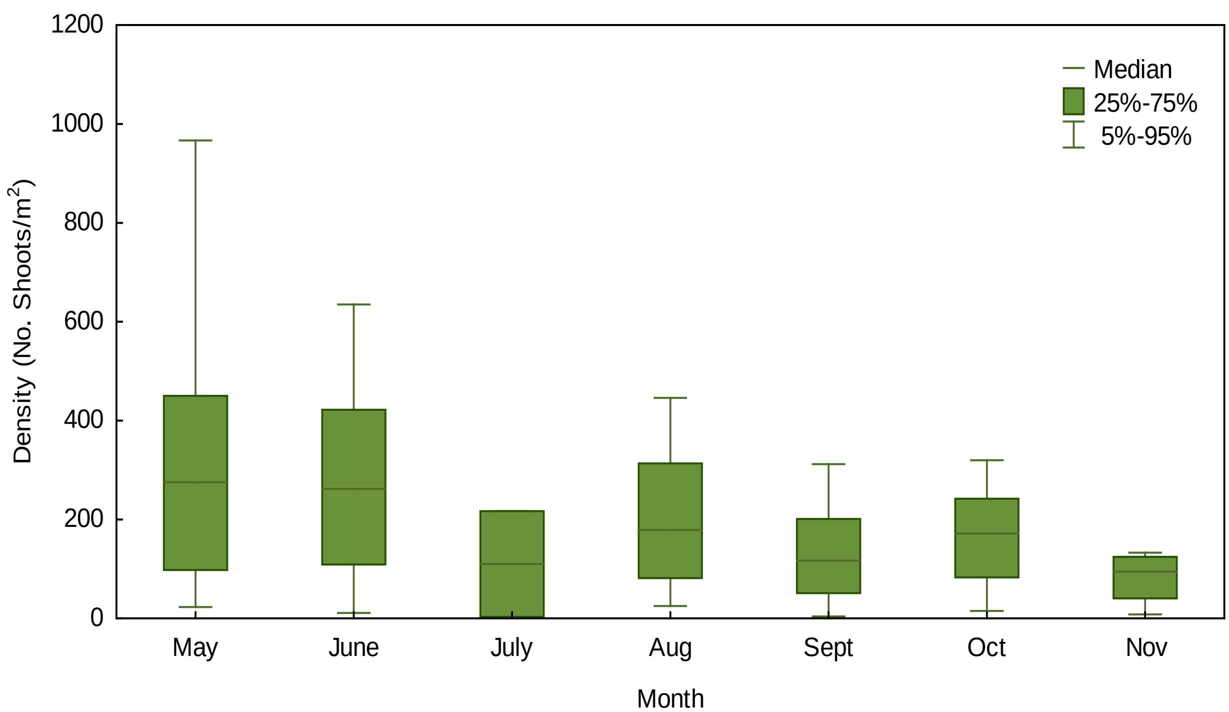

Figure 4-4. Seagrass (*H. wrightii*) density (number of shoots/m²) by month in Naples Bay, 2006 to 2019.

4.1.4 Seagrass Depth Distribution

Water depths along the survey transects were standardized relative to mean high water (MHW) to eliminate tidal influence on water depth measurements. Of the three species of seagrass encountered during surveys from 2006 to 2019, *H. wrightii* grows at the widest range of water depths (Figure 4-5). *Halophila decipiens* and *Halophila engelmannii* were present only in slightly deeper water depths, in areas that are not likely to be exposed during low tides. The depth distributions are within the expected range for each species (see Section 4.4.1).

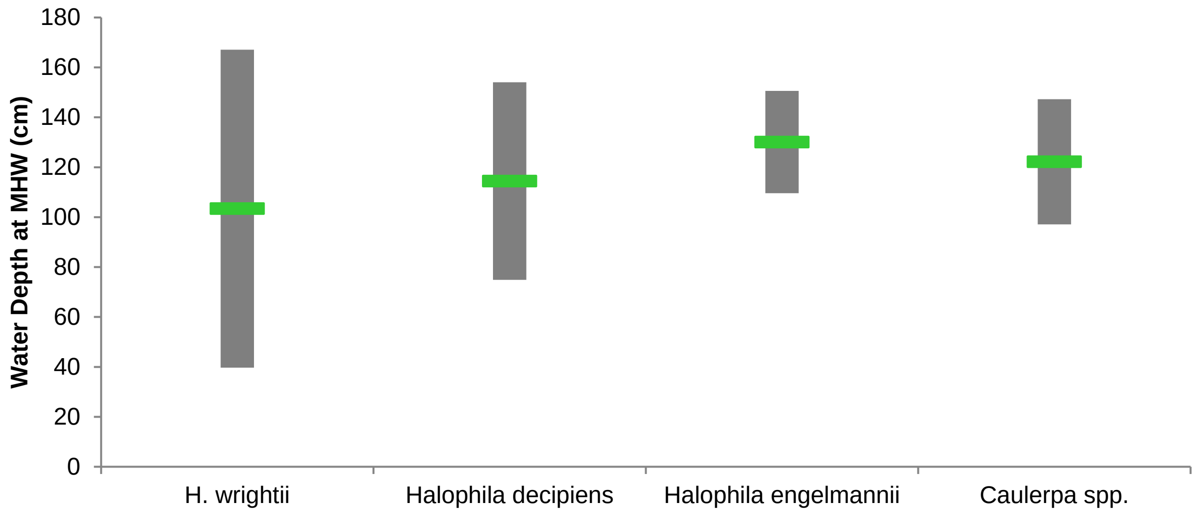

Figure 4-5. Depth range of Naples Bay seagrasses (*H. wrightii*, *Halophila decipiens*, and *Halophila engelmannii*) and macroalgae (*Caulerpa* spp.). Green lines represent the mean depth for each species.

In general, for transect seagrass surveys, changes in overall transect length from year to year can be an indicator of whether overall seagrass areal extent is increasing or decreasing. In addition, extension of the seagrass along the deep edge of the transect can be an indicator of improved water quality conditions. Likewise changes in the maximum depth of seagrass occurrence can signal changes in water quality, especially in terms of light availability.

Five of the six transects are located on relatively narrow shoals that run into the edge of a deep channel; thus, overall seagrass expansion on the deep edge of the bed is mostly likely limited by physical factors, not water quality. However, it is still useful to look at changes in transect length (measured as the distance from the landward seagrass edge to the furthest seaward seagrass location), in particular whether the transects are decreasing in length, as an indication of changes over seagrass area (Table 4-3). Notably, four out of five transects show relatively large drops in overall transect length in 2014 after several years of relatively little change. The fifth transect, NChannel, which is located on a much wider shoal, increased greatly in length starting in 2012, when seagrass colonized a gap between two previously discontinuous beds and the transect was extended to include the whole area. The overall transect length for NChannel was highest in 2014, but it should be noted that there were several areas along the transect with very little or no seagrass cover in 2014. Thus, seagrass appears to have expanded to a larger portion of the shoal but it may not be a continuous bed at this time.

From 2015 to 2019, the lengths of the transects were more variable, with increases during some events followed by decreases during the next event. The transect with the highest event to event percent change was SPortRoyal (Table 4-3). There was very little seagrass noted in late 2016 (start and end of bed at the same point) followed by a large increase in early 2017. Then early 2019 SPortRoyal had a total transect length similar to those recorded pre-2013. The newest transect, HabIsland, had the most stable overall transect length from 2015 through 2019, with the overall transect length increasing each year (Table 4-3).

The average depth of seagrass occurrence (Figure 4-6) was highest (maximum = 153 cm MHW) and most variable over time along the NChannel transect. The other five transects varied much less over time and generally averaged from 90 cm MHW to 115 cm MHW until 2011. After that, average seagrass depth declined along all four transects from 2012 through early 2016. The average transect depths increased again in early 2017 and 2019 overall. Surprisingly, there was minimal impact from increase flows and storm surge from Hurricane Irma in 2017, as the early-2018 depths were not that different from early-2017. As mentioned above, this could be related to physical factors rather than water quality changes and might be biased by differences in survey timing in more recent years.

The maximum depth of seagrass was also plotted to highlight possible improvement in water clarity if the seagrass was spreading to deeper waters at each transect (Figure 4-7). Similar to the average depth of seagrass occurrence, the maximum depth of occurrence was along the NChannel transect (167.1 cm MHW in September 2010). The other five transects had fairly similar maximum seagrass depth occurrences over time, with seagrass found at the deepest depths during various sampling events (Figure 4-7). The maximum depth seagrass was recorded at BV1West was at 131.9 cm MHW during July 2006, the second highest event was in August 2019 (127.2 cm MHW). The maximum depth for seagrass at BV2Mid occurred in August 2019 (133.5 cm MHW), and for BV3East the maximum depth of occurrence was 129.9 cm MHW in May 2009. At SPortRoyal and HabIsland, the maximum recorded depths occurred in August 2019 (154.0 and 148.0 cm MHW, respectively). There have been no increasing or decreasing trends in maximum seagrass depth over time at any monitoring transect (Kendall Tau, $p > 0.05$).

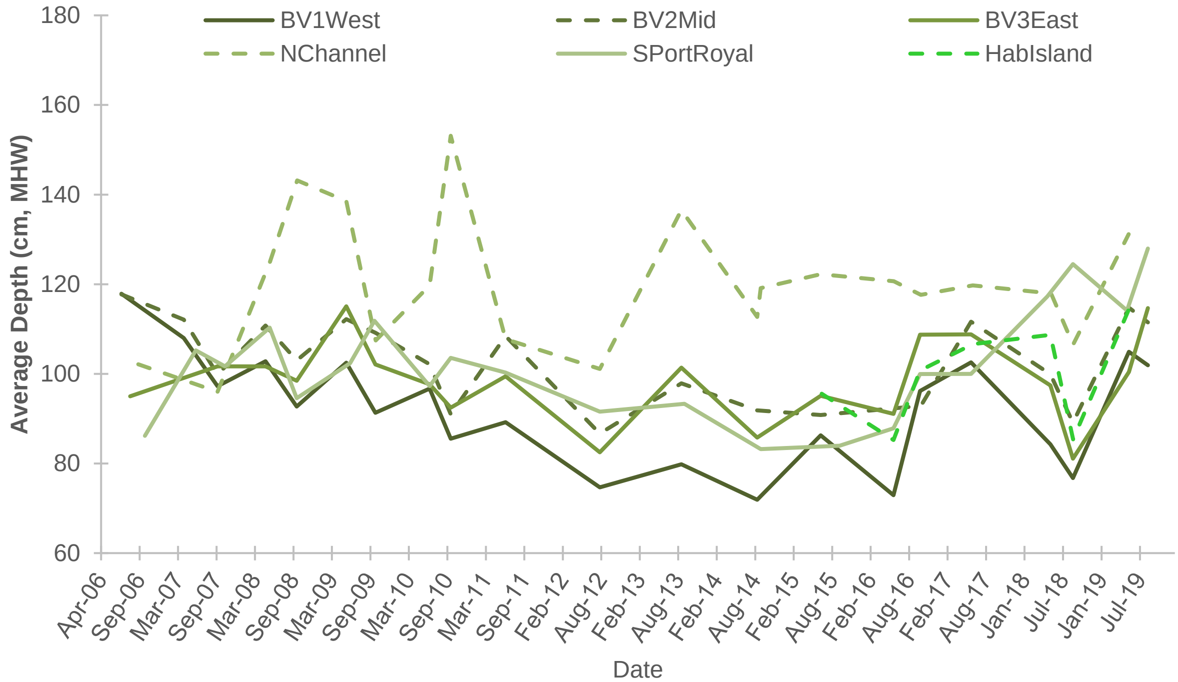

Figure 4-6. **Average depth (relative to MHW) of seagrass occurrence along transects in Naples Bay, 2006 to 2019.**

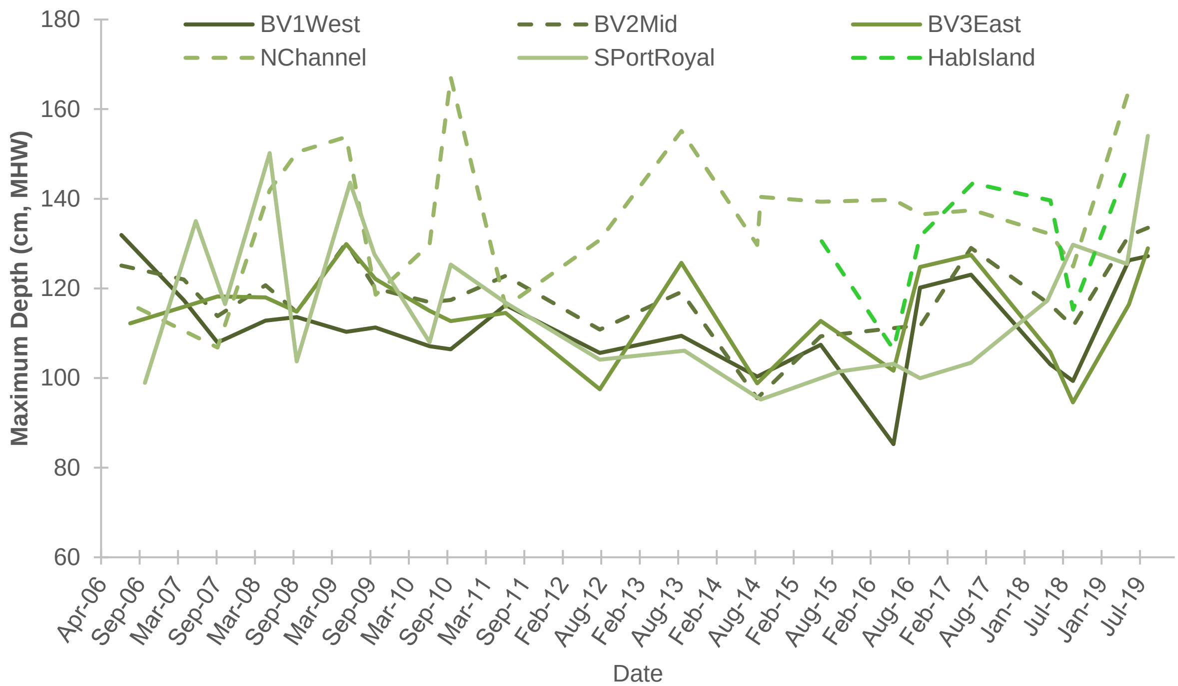

Figure 4-7. **Maximum depth (relative to MHW) of seagrass occurrence along transects in Naples Bay, 2006 to 2019.**

Table 4-3. Overall seagrass transect length at each survey in Naples Bay, 2006 to 2019. Bold values represent the minimum value for each transect.

Survey Event	BV1West		BV2Mid		BV3East		NChannel*		SPortRoyal		HabIsland	
	Total Length (m)	% Change	Total Length (m)	% Change	Total Length (m)	% Change	Total Length (m)	% Change	Total Length (m)	% Change	Total Length (m)	% Change
2006	20.7	--	26.4	--	26.8	--	20	--	30	--		
Early 2007	**11.3**	**-45**	24.7	-6					38.7	29		
Late 2007	13.8	22	24.4	-1	29.7	11	22.6	13	31	-20		
Early 2008	16	16	30.3	24	30.4	2	26.2	16	37.15	20		
Late 2008	16.2	1	20.1	-34	29.3	-4	**21.7**	**-17**	30	-19		
Early 2009	16.2	0	31.4	56	30.9	5	28	29	37.3	24		
Late 2009	20.3	25	30	-4	31.6	2	23	-18	35.8	-4		
Early 2010	14.3	-30	27.9	-7	31	-2	22.5	-2	35.3	-1		
Late 2010	19.3	35	27.8	0	31	0	22.1	-2	37.3	6		
Early 2011	19.8	3	27.8	0	30.8	-1	26.6	20	37.3	0		
Late 2012	20	1	25.8	-7	30.7	0	29.3*	10	38.8	4		
Late 2013	20	0	25.2	-2	32.1	5	175.3*	498	35.3	-9		
Late 2014	13.7	-32	**11.1**	**-56**	**23.6**	**-26**	181.2*	3	**17.7**	**-50**		
Early 2015	14.3	4	20.5	85	26.2	11	150.7	-16.8	--	--	17.4	--
Late 2015	--	--	--	--	--	--	--	--	21.2	20	--	--
Early 2016	8.6	-40	--	--	12.9	-51	151.2	0.3	17.7	-17	15.1	-13
Late 2016	6.9	-20	14.9	-27	13.4	4	175.9	16.3	0.1	-99	18.9	25
Early 2017	16.5	139	16.5	11	13	-3	175.9	0.0	15.2	15100	20.7	10
Early 2018	13.4	-19	19.8	20	15.2	17	176.5	0.3	13.8	-9	35.7	72
Late 2018	14.9	11	25.8	30	19.1	26	183.5	4.0	7	-49	35	-2
Early 2019	20.8	40	25.8	0	21.2	11	180.4	-1.7	35.3	404	38.2	9
Late 2019	13.7	-34	26.2	2	21.5	1	--	--	9.7	-73	--	--

*The number of sites along surveyed along this transect increased to cover a larger area. The large jump in transect length is due to the change in methodology.

4.2 Fish Community

Fish sampling in Naples Bay was conducted using bottom trawls. Samples were collected approximately six times per year (generally every other month) with trawls in each of four zones in the bay (Figure 4-8) during each sampling event. From 2009 to August 2011, sampling was conducted at fixed transect stations. Starting in October 2011, sampling was conducted in one randomly selected grid within each zone at each sampling event. Fish species were identified, counted, and measured. Results of statistical analysis of fish community structure, diversity, richness, and abundance are presented in this section. Fish length data were not statistically analyzed, but are graphically summarized for the most common species in Appendix C.

4.2.1 Abundance and Species Composition

From April 2009 to November 2019, 256 bottom trawl samples were collected in Naples Bay: 64 samples from each of the four zones. A total of 56,301 individuals from 83 fish taxa and five invertebrate taxa were collected during the study (see Appendix C, Table C-1 and Table C-2 for a full list of taxa). Catch per trawl ranged from zero to 2,571 individuals. The number of different taxa per trawl ranged from zero to 22.

Mojarras (*Eucinostomus* spp.) and anchovies (*Anchoa* spp.) were the most numerous taxa collected, accounting for over 87 percent of the total catch from 2009 to 2019. However, mojarras were the most frequently caught taxa followed by blue crabs (*Callinectes* spp.), occurring in 91 percent and 75 percent (respectively) of the trawl samples. In general, the other most frequently encountered species were also the most abundant overall (Table 4-4). Thirteen taxa were only caught once, and in each case it was a single individual (Table 4-5).

Table 4-4. Ten most commonly caught and most abundant taxa (grouped to genus level) in Naples Bay bottom trawls from 2009 to 2019.

<table>
<tr><th rowspan="2">Taxa</th><th rowspan="2">Common Name</th><th colspan="3">Occurrence</th><th colspan="3">Abundance</th></tr>
<tr><th>Rank</th><th>Number</th><th>% of Total</th><th>Rank</th><th>Number</th><th>% of Total</th></tr>
<tr><td>Eucinostomus sp.</td><td rowspan="4">Mojarra</td><td rowspan="4">1</td><td rowspan="4">233</td><td rowspan="4">91.0</td><td rowspan="4">1</td><td rowspan="4">31498</td><td rowspan="4">55.9</td></tr>
<tr><td>E. harengulus</td></tr>
<tr><td>E. gula</td></tr>
<tr><td>Eugerres plumieri</td></tr>
<tr><td>Callinectes sapidus</td><td rowspan="2">Blue Crabs</td><td rowspan="2">2</td><td rowspan="2">192</td><td rowspan="2">75.0</td><td rowspan="2">6</td><td rowspan="2">590</td><td rowspan="2">1.0</td></tr>
<tr><td>C. similis</td></tr>
<tr><td>Farfantepenaeus duorarum</td><td>Pink Shrimp</td><td>3</td><td>148</td><td>57.8</td><td>4</td><td>1026</td><td>1.8</td></tr>
<tr><td>Synodus foetens</td><td>Inshore Lizardfish</td><td>4</td><td>127</td><td>49.6</td><td>9</td><td>373</td><td>0.7</td></tr>
<tr><td>Lutjanus sp.</td><td rowspan="3">Snappers</td><td rowspan="3">5</td><td rowspan="3">119</td><td rowspan="3">46.5</td><td rowspan="3">8</td><td rowspan="3">401</td><td rowspan="3">0.7</td></tr>
<tr><td>L. synagris</td></tr>
<tr><td>L. griseus</td></tr>
<tr><td>Ariopsis felis</td><td>Hardhead Catfish</td><td>6</td><td>111</td><td>43.4</td><td>10</td><td>269</td><td>0.5</td></tr>
<tr><td>Anchoa sp.</td><td rowspan="3">Anchovies</td><td rowspan="3">7</td><td rowspan="3">105</td><td rowspan="3">41.0</td><td rowspan="3">2</td><td rowspan="3">17909</td><td rowspan="3">31.8</td></tr>
<tr><td>A. hepsetus</td></tr>
<tr><td>A. mitchilli</td></tr>
<tr><td>Prionotus scitulus</td><td rowspan="2">Searobins</td><td rowspan="2">8</td><td rowspan="2">79</td><td rowspan="2">30.9</td><td rowspan="2">--</td><td rowspan="2">167</td><td rowspan="2">0.3</td></tr>
<tr><td>P. tribulus</td></tr>
<tr><td>Lagodon rhomboides</td><td>Pinfish</td><td>9</td><td>60</td><td>23.4</td><td>3</td><td>1047</td><td>1.9</td></tr>
<tr><td>Cynoscion sp.</td><td rowspan="3">Seatrout</td><td rowspan="3">10</td><td rowspan="3">60</td><td rowspan="3">23.4</td><td rowspan="3">7</td><td rowspan="3">470</td><td rowspan="3">0.8</td></tr>
<tr><td>C. arenarius</td></tr>
<tr><td>C. nebulosus</td></tr>
<tr><td>Leiostomus xanthurus</td><td>Spot</td><td>--</td><td>16</td><td>6.3</td><td>5</td><td>691</td><td>1.2</td></tr>
</table>

Table 4-5. Least commonly caught and least abundant taxa (grouped to genus level) in Naples Bay bottom trawls from 2009 to 2019.

Least Common and Least Abundant			
Taxa	**Common Name**	**Number of Occurrences**	**Number of Individuals**
Citharichthys macrops	Spotted whiff	1	1
Dasyatis americanus	Southern stingray	1	1
Echeneis neucratoides	Whitefin Sharksucker	1	1
Elops saurus	Ladyfish	1	1
Gymnura micrura	Smooth butterfly ray	1	1
Microgobius microlepis	Banner Goby	1	1
Micropogonias undulatus	Atlantic croaker	1	1
Ophichthus gomesii	Shrimp Eel	1	1
Rhinoptera bonasus	Cownose ray	1	1
Unidentified Family Clupeidae	Herrings	1	1
Unidentified Family Gobiidae	Gobies	1	1
Unidentified Family Sciaenidae	Croakers/Drums	1	1
Unidentified Suborder Pleuronectoidei	Flatfishes	1	1

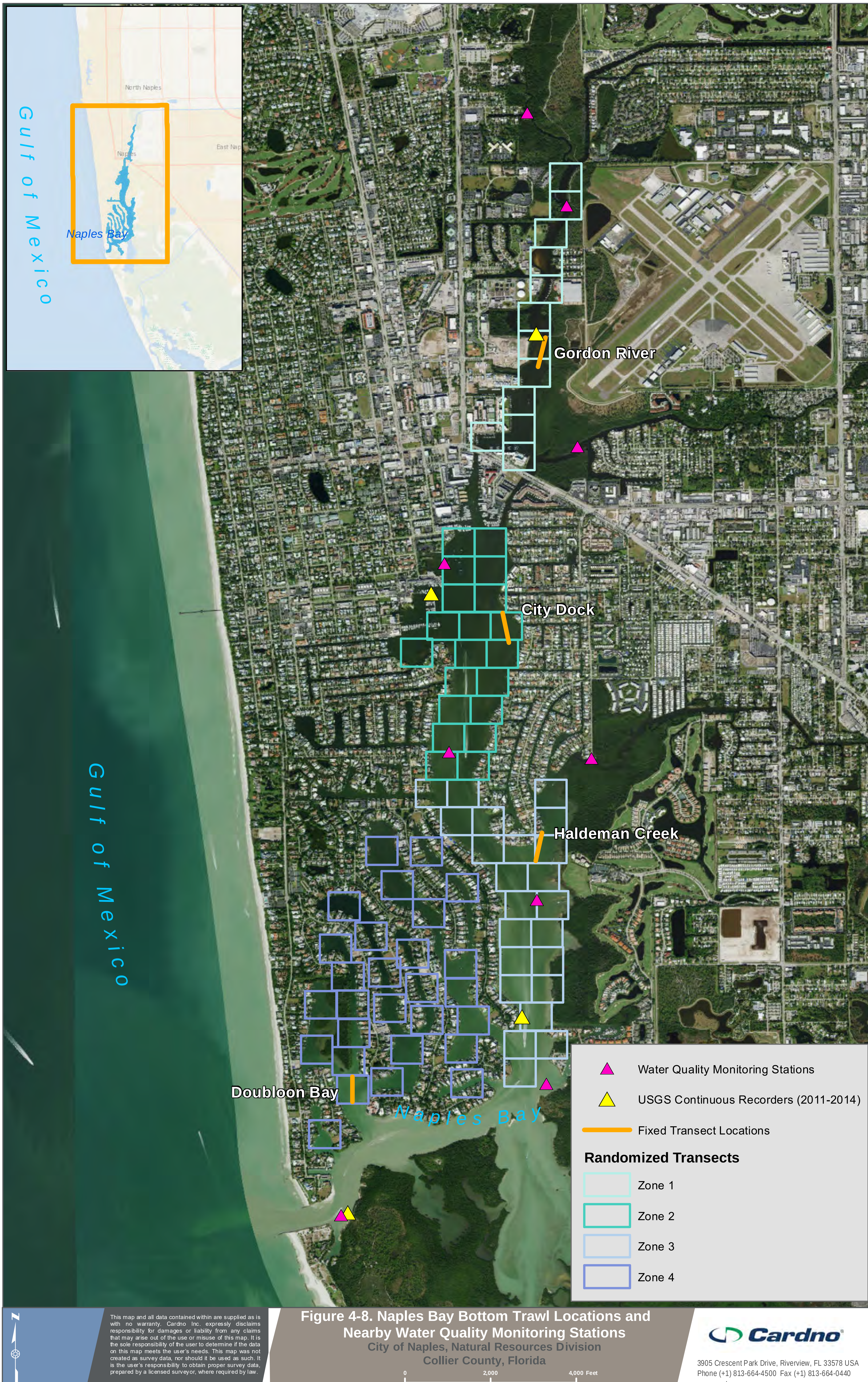

Figure 4-8. Naples Bay Bottom Trawl Locations and Nearby Water Quality Monitoring Stations

City of Naples, Natural Resources Division
Collier County, Florida

Cardno
3905 Crescent Park Drive, Riverview, FL 33578 USA
Phone (+1) 813-664-4500 Fax (+1) 813-664-0440
www.cardno.com

Date Created: 5/22/2020 Date Revised: 5/22/2020 File Path: Q:\UnitedStates\Florida\Tampa\City_Of_Naples\Water Quality Analysis Project\working\arcmap\Figure4_7_CON_BottomTrawl_20200522.mxd
GIS Analyst: James.Bottiger

4.2.2 Diversity Indices

There are no significant differences in Shannon diversity among the sampling zones (factorial ANOVA with season and zone; $p > 0.05$); however, there were significant differences among the sampling zones for abundance and number of taxa from 2009 to 2019 (factorial ANOVA with season and zone; $p < 0.01$) with the wet season in Zones 2 and 3 having higher abundance and the dry season in Zones 2 and 3 having a greater number of taxa. Some of these general patterns between seasons and over the sampling period can also be observed in Figure 4-9 when data is pooled for the zones. Dry season samples have lower abundance and higher diversity and number of taxa than the wet season (one-way ANOVA of season pooled across all zones and years; $F = 420.8$, $p < 0.01$). In addition, the number of taxa caught all appear to have a downward shift sometime in 2011 while the abundance and diversity metrics have been more variable over the 2009 to 2019 sampling period (Figure 4-9).

Change-point analysis was used (Change-Point Analyzer v2.3 from Taylor Enterprises, Inc., Taylor 2000) to pinpoint the timing of this change in abundance, richness, and diversity graphically (Figure 4-10) and statistically, which allows for a comparison of the timing of the downward shift with respect to the timing of the change in methodology. Change-point analysis works by plotting the cumulative sum (CUSUM) over time of the differences between each observation and the average of all observations; changes in slope of the CUSUM plot indicate that a change in the mean of the observations has occurred (Figure 4-10). Bootstrapping the data is used to determine if the change in the CUSUM plot is statistically significant. The exact estimate of when the change occurred is given by moving the change point back and forth and minimizing the mean square error (MSE) of the two datasets on either side of the proposed change point. Once the change-points are defined (the first sampling event following the detected change), they are given a confidence level and confidence intervals (Taylor 2000).

For Naples Bay, the primary change points and confidence intervals from 2009 to 2019 were identified for five biological metrics (Figure 4-11). The primary change-point is predicted at the sampling methodology change for total taxa and richness measures, just after the methodology change for diversity, and two years after the methodology change for evenness (Figure 4-11). There was no change-point observed for abundance metrics. In all cases, the metrics noticeably level off or begin to trend downward before the designated change-point and before the change in sampling methodology. This indicates the change in methodology may be coincidental and does not appear to be the cause of the downward trend. Additionally, the total taxa, richness, diversity, and evenness metrics had a second change point (all but total taxa occurring in 2016). The evenness metric had a third change point in May 2016 where the other metrics did not (Figure 4-11).

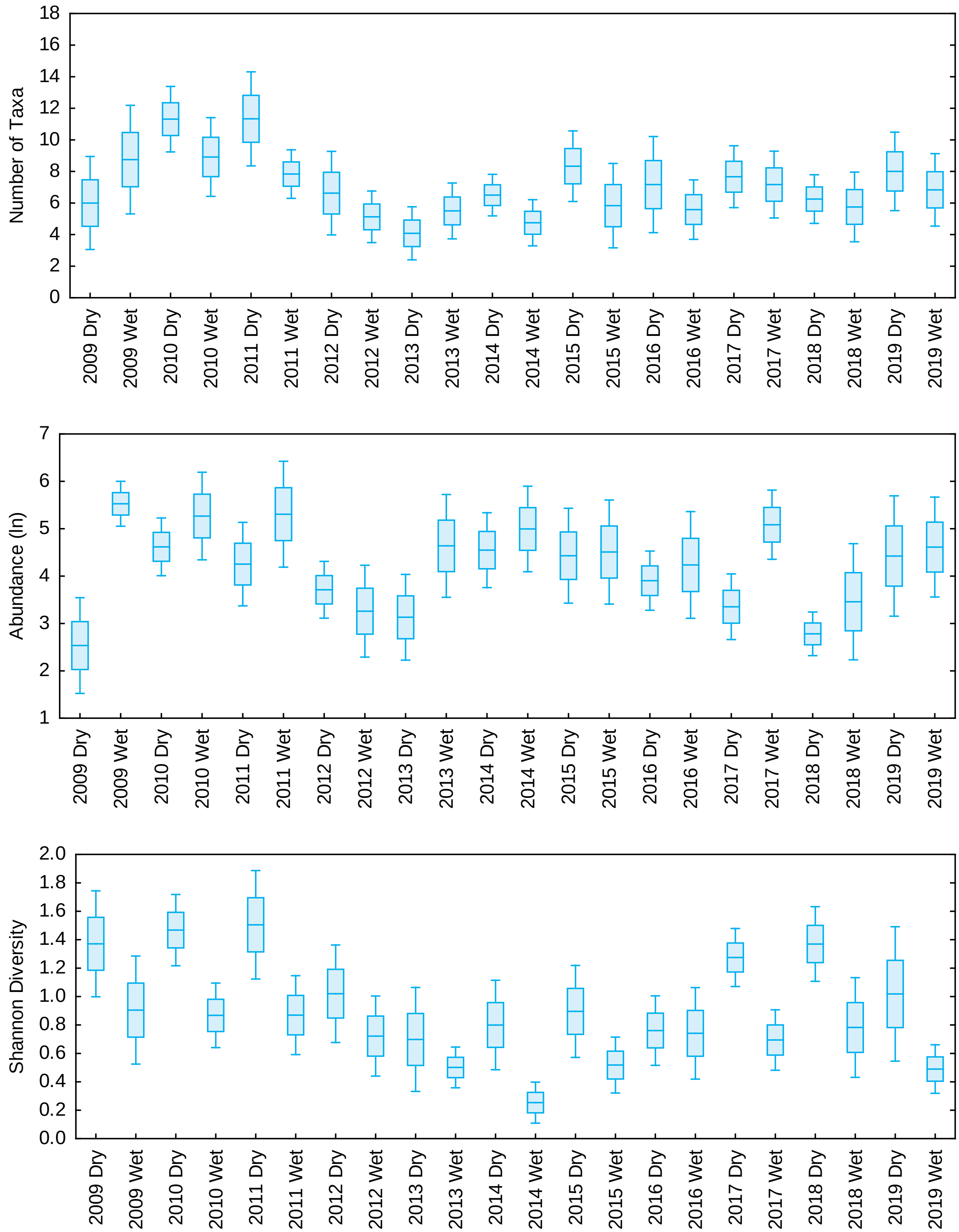

Figure 4-9. Number of taxa, abundance, and diversity by season in Naples Bay bottom trawls, 2009–2019 (mean, line; ±1SE, box; ±2SE, whiskers).

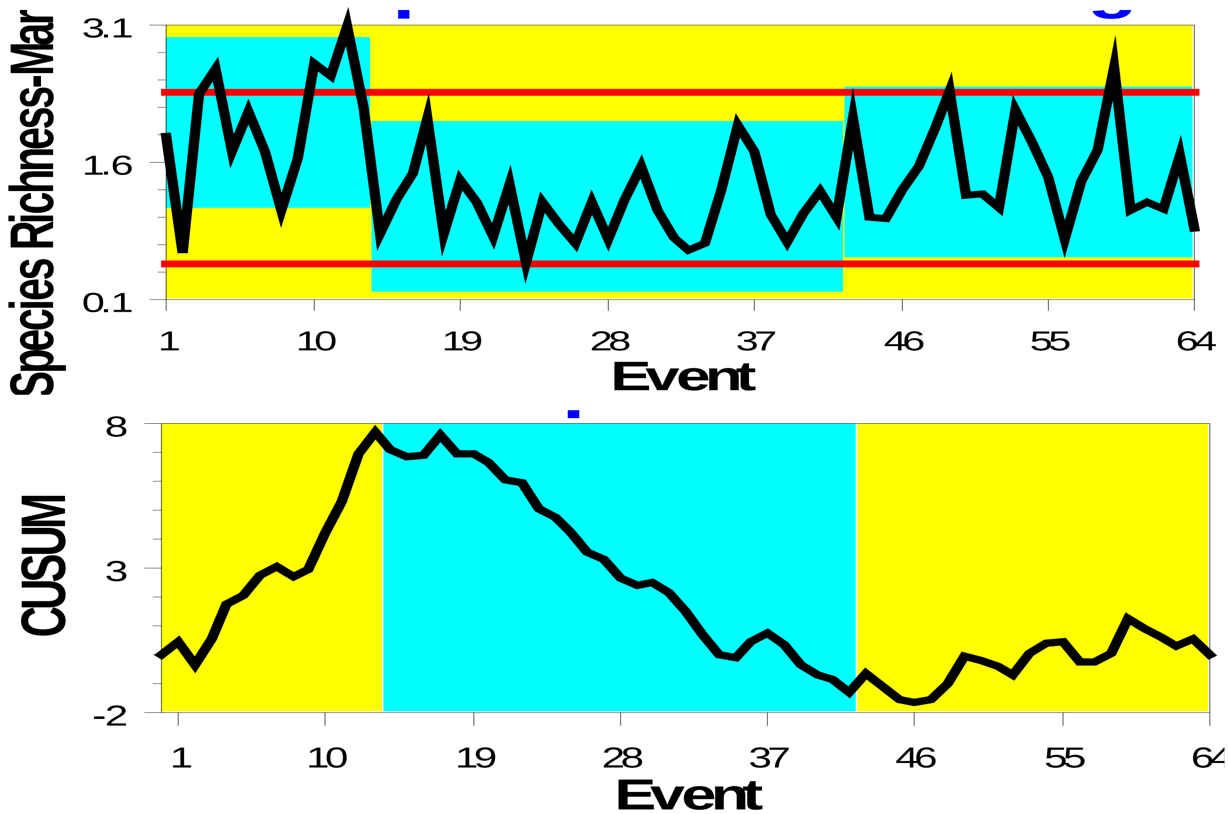

Figure 4-10. Example of a change-point graph from Naples Bay with the time-series plot (top) and CUSUM plot (bottom) indicating a change-point in August 2011 and May 2016.

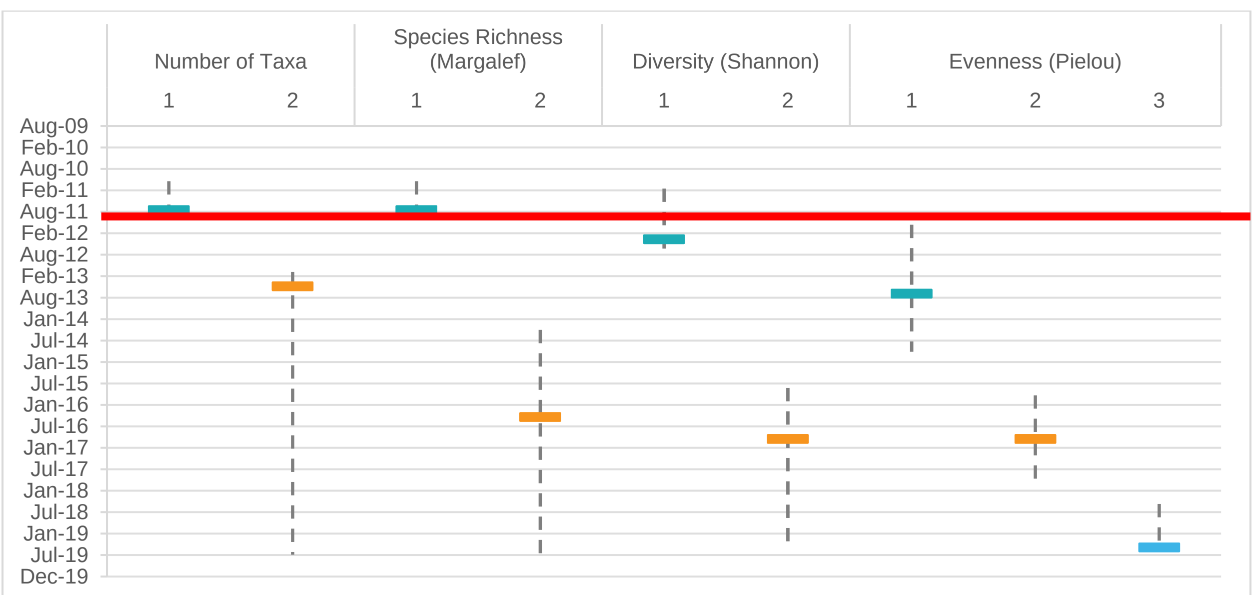

Figure 4-11. Change-points (turquoise, orange, or blue lines) and 95 percent confidence intervals (grey dashed lines) for several fish diversity metrics in Naples Bay. The red line represents the date when the sampling methodology changed.

4.2.3 Community Structure

Nonparametric multivariate analyses were used to assess similarity in species composition and abundance (‘community structure’). Analyses were conducted using PRIMER v7 statistical software (Clarke and Gorley 2015). Similarity was calculated using taxa abundance data for each sample (unless otherwise noted as pooled). Non-metric multidimensional scaling (MDS) was used for a visual depiction of the community structure relationship among samples. Statistical differences in community structure among or between groups of samples were identified using Analysis of Similarity (ANOSIM), and Similarity Percentage analysis (SIMPER) was used to identify which taxa were representative of dissimilarities among groups. The focus within Naples Bay was on differences among sampling zones between seasons and over time (among years).

Differences Among Zones

Species presence/absence data from the entire survey period (2009 to 2019) were pooled together by zone to give broad level picture of similarity in the species assemblages across zones. Overall, the similarity (Bray-Curtis) between zones ranged from 71.7 percent to 79.3 percent, with Zone 1 having the lowest similarity to the other zones and the lowest within-group similarity (Table 4-6). More simply put, of all the zones, Zone 1 had the most variable species assemblage from sample to sample and the least in common with other zones. In general, all four zones contain the same taxa (grouped to Genus level or higher); however, there are some taxa that are missing from or unique to a specific zone or are notably more abundant (contributing to ≥ 80 percent of total) in one zone than the others (Table 4-7).

Table 4-6. Similarity of species assemblage between zones within Naples Bay, 2009 to 2019. (Bray-Curtis similarity, presence/absence data, pooled by zone).

Zone	1	2	3	4
1				
2	75			
3	71.70	73.33		
4	74.34	77.17	79.34	

The one-way ANOSIM test for differences among samples (unpooled data, aggregated to genus level, log (x+1) transformed, Bray-Curtis Similarity) from different zones shows that there are significant but very weak differences (ANOSIM Global $R = 0.05$, $p = 0.001$)) among zones: Zones 1, 2 and 3 are all different from one another, but Zone 4 is not different from Zone 2. A nMDS plot of these data does not show good separation among the zones (Figure 4-12), but does show that samples from Zone 1 are more widely scattered than those from Zone 2 or 3.

Table 4-7. Taxa (grouped to Genus level or above) that are unique to, absent from, or most commonly associated with a specific zone in Naples Bay from 2009 to 2019.

Unique to Zone			
Zone	**Genus**	**Species Common Name**	**Total Number**
1	*Lophogobius*	Crested Goby	5
	Sciaenops	Red drum	58
	Clupeidae (Family)	Herrings	1
2	*Albula*	Bonefish	2
	Caranx	Jack-Caranx juvenile	2
	Echeneis	Whitefin Sharksucker	1
	Elops	Ladyfish	1
	Ophichthus	Shrimp eel	1
	Rhinoptera	Cownose ray	1
	Umbrina	Sand drum	4
	Gobiidae (Family)	Gobies	1
3	Citharichthys	Spotted whiff	1
	Diplectrum	Sand perch	2
	Gymnura	Smooth butterfly ray	1
	Micropogonias	Atlantic croaker	1
	Serraniculus	Pygmy sea bass	2
	Sciaenidae (Family)	Croakers/Drums	1
4	*Mugil*	Mullet	6
	Pleuronectoidei (Suborder)	Flatfishes	1
Absent from Zone			
Zone	**Genus**	**Species Common Name**	**Total Number in Other Zones**
1	*Harengula*	Scaled sardine	35
	Ogcocephalus	Polka dot batfish	71
	Opisthonema	Atlantic thread herring	11
2	none	--	--
3	*Achirus*	Lined sole	91
	Gobiosoma	Naked Goby/Code Goby	20
4	none	--	--
More Common in One Zone			
Zone	**Genus**	**Species Common Name**	**Number in Zone (Total Number)**
1	*Achirus*	Lined sole	83 (91)
	Trinectes	Hogchoker	9 (10)
2	none	--	--
3	Chilomycterus	Burrfishes	15 (21)
	Leiostomus	Spot	572 (691)
	Ogcocephalus	Polka dot batfish	59 (71)
4	*Ancylopsetta*	Ocellated flounder	4 (5)
	Portunidae (Family)	Swimming crabs	159 (169)

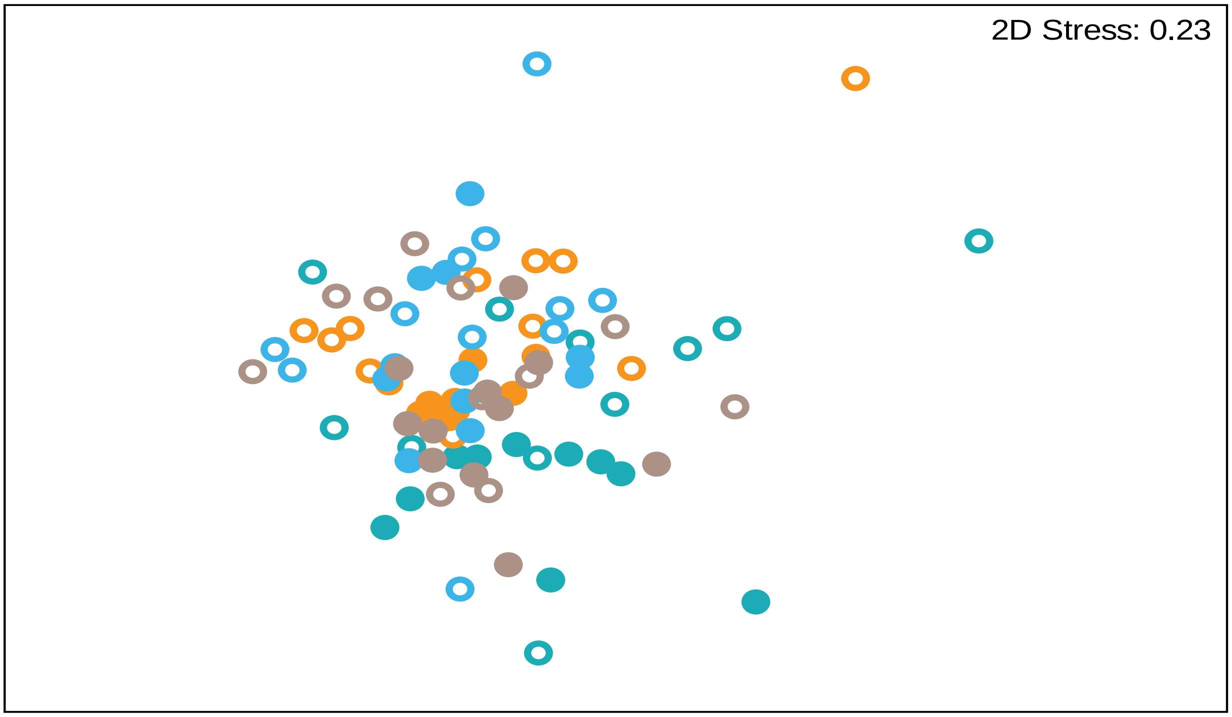

Figure 4-12. nMDS ordination plot (Bray-Curtis similarity, log(x+1) transformed data) of the fish community structure within Naples Bay, 2009 to 2019. Turquoise = Zone 1; Orange = Zone 2; Light blue = Zone 3; Light brown = Zone 4. Open circles = dry season; Closed circles = wet season.

Seasonal Effects

When the points on the MDS plot are coded by season, a separation between wet and dry season samples is evident in the pattern (Figure 4-12). Considering season and zone together in a two-way ANOSIM test shows that there is a weak but significant difference between seasons (Global R = 0.105, p = 0.001) and the differences among the zones are a little weaker when season is taken into account (Global R = 0.068, p = 0.001). In addition to the pairwise differences noted in the one-way test, Zones 1 and 4 are significantly different from one another when season is a factor. A deeper look into differences among zones within each season reveals season-specific relationships between zones that are not evident in the one-way test: Zones 1 and 2 are only significantly different in the wet season, Zones 1 and 4 are only different in the dry season, and Zones 2 and 3 are only different in the dry season.

SIMPER analysis was used to quantify the average similarity among samples within season or zone, the average dissimilarity between seasons or zones, and which taxa contribute most to the similarity/dissimilarity. As noted above, most of the taxa found in Naples Bay are ubiquitous rather than limited to a specific zone. The same is true across seasons: there are few seasonal differences in which species are present. Thus, most of the similarities within and differences between seasons and zones is the result of differences in how species are assembled (which species co-occur) and differences in their overall abundance. The SIMPER results show that, for the most part, the same species are responsible for similarity within groups and dissimilarity between groups. Mojarras (*Eucinostomus* spp.) and anchovies (*Anchoa* spp.) are the largest contributors to dissimilarity in all pairwise comparisons, followed by pink shrimp (*Farfantepenaeus duorarum*), blue crabs (Callinectes spp.), inshore lizardfish (*Synodus foetens*), pinfish (*Lagodon rhomboides*), and snappers (*Lutjanus* spp.), (Appendix C, Tables C-3 & C-4). Within-group similarity was lower in the dry season than the wet season and lower in Zone 1 than the other zones (Table 4-8); this indicates more variation in community structure among samples in those groups.

Table 4-8. Average within group similarity (bold, italics) and between group dissimilarity for season and zones within Naples Bay, 2009 to 2019. (Bray-Curtis similarity, Genus-level, log(x+1) transformed data).

Average Similarity & Dissimilarity				
Between Seasons				
Season	**Wet**		**Dry**	
Wet	***42.20***			
Dry	65.68		***33.03***	
Between Zones				
Zone	**1**	**2**	**3**	**4**
1	***31.30***			
2	64.93	***44.40***		
3	69.79	59.82	***38.97***	
4	68.33	60.09	63.65	***36.12***

Inter-annual Patterns

There were significant differences (ANOSIM, Global R = 0.086, p = 0.001) in community structure among years. Pairwise tests show too many unique year to year pairings for further analysis using nMDS for the year groupings. Instead, the change point years as determined for species richness (Margalef) in Section 4.2.2 were used for further analysis below. The first division between year groups (or change-point) occurs at the same time frame as the change in sampling methodology. There were small significant differences (ANOSIM, Global R = 0.071, $p < 0.05$) in community structure among change-point groups (Figure 4-13).

Average similarity within years was generally low (< 40 percent) and dissimilarity between years was generally as high as dissimilarity within a year (Table 4-9). Similarly, average similarity within change-point groups was around a third and dissimilarity between change-point groups was similar between each group (Table 4-10). The same species that are responsible for seasonal and zone differences account for the differences between the change-point groups (April 2009 to August 2011, October 2011 to May 2016, and July 2016 to November 2019): mojarras (*Eucinostomus* spp.) and anchovies (*Anchoa* spp.) make the highest contributions to dissimilarity, followed by pink shrimp (*Farfantepenaeus duorarum*), blue crabs (Callinectes spp.), pinfish (*Lagodon rhomboides*), inshore lizardfish (*Synodus foetens*), and snappers (*Lutjanus* spp.) (Appendix C, Table C-5).

Table 4-9. Average within group similarity (bold, italics) and between group dissimilarity for years within Naples Bay, 2010 to 2019. (Bray-Curtis similarity, Genus-level, log(x+1) transformed data).

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2010	***36.5***									
2011	64.71	***33.92***								
2012	67.37	66.67	***39.46***							
2013	71.13	69.48	64.72	***31.71***						
2014	67.13	67.00	61.53	66.98	***40.58***					
2015	64.00	64.62	61.13	67.51	58.38	***43.48***				
2016	67.34	67.35	62.46	68.79	60.96	58.87	***37.91***			
2017	66.90	67.45	63.65	70.00	63.16	61.73	63.97	***34.38***		
2018	70.57	71.6	68.87	73.63	69.21	67.33	68.60	69.55	***29.22***	
2019	64.56	65.6	64.02	69.58	61.07	58.40	61.22	63.55	67.74	***40.06***

Table 4-10. Average within change-point group similarity (bold, italics) and between group dissimilarity for years within Naples Bay, 2009-2019. (Bray-Curtis similarity, Genus-level, log(x+1) transformed data).

Change-Point Group	1	2	3
1	**36.36**		
2	66.67	**36.65**	
3	66.96	65.50	**34.12**

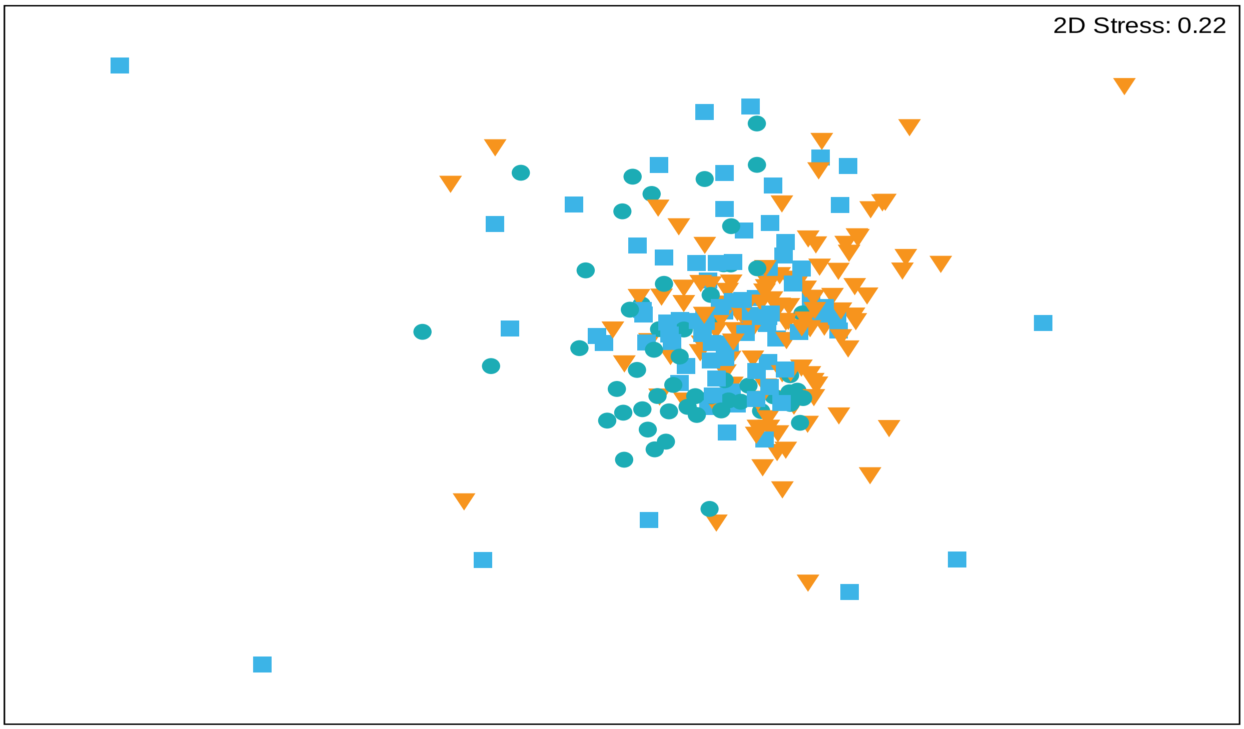

Figure 4-13. nMDS ordination plot (Bray-Curtis similarity, log(x+1) transformed data) of the fish community structure within Naples Bay, 2009–2019. Groupings based on species richness change points (April 2009 to August 2011: green circle, October 2011 to May 2016: orange triangle, July 2016 to November 2019: blue square).

4.2.4 Fish and Water Quality

Flow from the GGC was considered to be the most likely potential driver of water quality and biological changes in Naples Bay. Seasonal water quality changes related to GGC flow differ among the fish sampling zones within the Bay. Even though the current sampling program is designed to sample typical wet and dry seasons equally, it does not capture low/no flow and high flow conditions with the same frequency (Figure 4-14).

Several different methods were used to look for links between the fish community and water quality parameters. Initial, exploratory analyses were conducted using water quality measurements collected during trawling sampling events: bottom salinity, bottom temperature, and bottom DO. Several univariate diversity metrics such as number of taxa, species richness, abundance, and Shannon diversity were plotted against each of the three water quality parameters to see if correlations between the variables existed (see Appendix C, Figure C-1 for examples). No relationships were found over time or within or among zones.

The next step was to construct a water quality dataset, perform a Principle Components Analysis (PCA) on the data, and plot the univariate diversity metrics against the PC axis scores. Two different water quality datasets were constructed: one using the three variables measured during trawling events and one constructed from water quality variables from monitoring stations in the bay. The second dataset included measures of flow from the Golden Gate Canal, rainfall, salinity, water temperature, turbidity, TN, TP, chlorophyll-*a*, and DO; data were from the 30-day period preceding each sampling event. Water quality variables were appropriately transformed and normalized before analysis. No relationships were found when the diversity metrics were plotted against the PC scores (see Appendix C, Figure C-2 for examples).

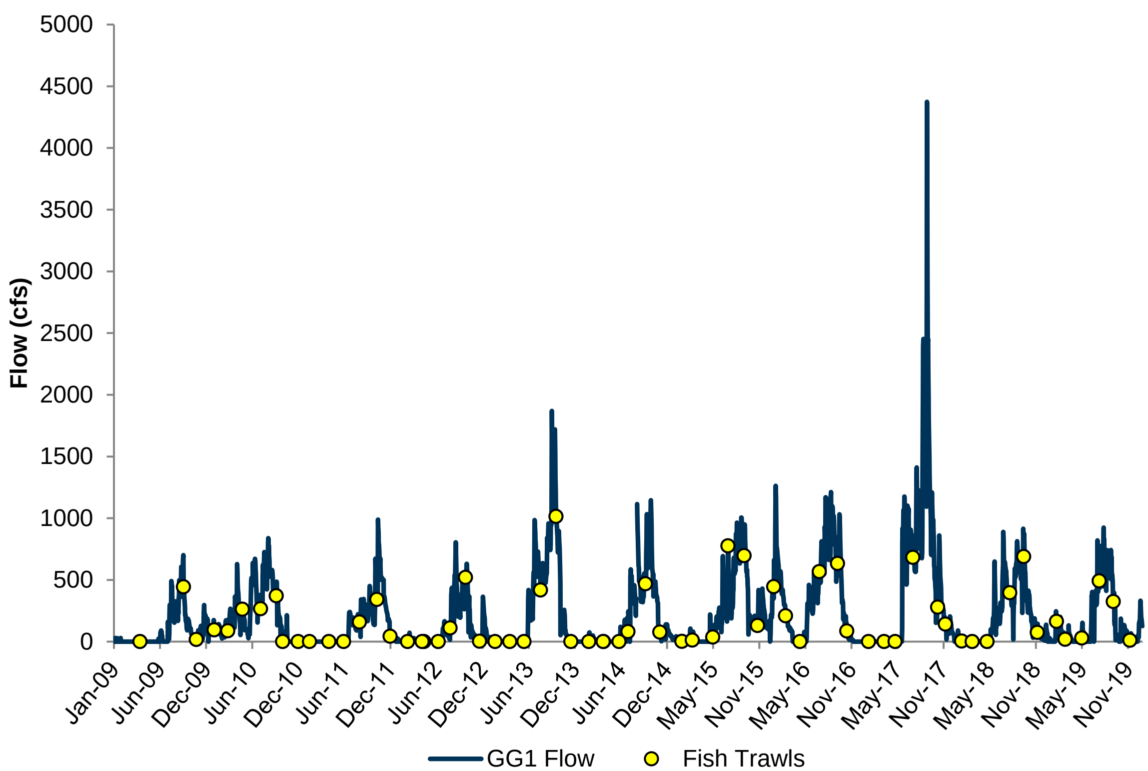

Figure 4-14. Fish sampling events and Golden Gate Canal flow by season.

5 Naples Bay Resource Management

The City of Naples (City) has a long standing and robust water resource management program to monitor, protect, and restore Naples Bay. The City has been actively monitoring water quality in Naples Bay and Moorings Bay since 2005 and 2008, respectively, along with fish (Naples and Moorings Bays) and seagrass monitoring (Naples Bay) efforts. In late 2010, the City began water quality monitoring of the stormwater lakes and pump stations that contribute to Naples and Moorings Bays in an effort to characterize their potential influence on Bay water quality and biology. In addition, the City has devoted significant resources to water resource management activities designed specifically to improve water quality in the City's stormwater lakes and the downstream receiving waters of Naples and Moorings Bays. As discussed throughout this report, robust data is crucial to identify trends and potential relationships between water quality, biology, and the effects of water quality on the biological communities in Naples and Moorings Bay.

Management strategies within the City of Naples can be defined as actions that are focused on achieving three overall goals; to protect and improve water quality, management for resiliency (sea level rise, storm surge and boat wake), and enhancing habitat and fisheries. The following management recommendations and strategies have been selected to achieve the City's goals and are separated into four general categories; regulatory, water quality improvements, habitat creation/conservation, and comprehensive monitoring program needs:

1. Regulatory strategies are designed to provide criteria and guidelines to address both water quality and habitat goals as part of the city, county, state or federal permitting process. A large variety of project types require permits for construction and commonly contain seawall replacement, dock repair/replacement permits, coastal construction of both residential and commercial properties and other projects that have significant potential impacts to coastal resources (i.e. dredging or filling of coastal resources). It is highly recommended that the City consider regular updates and modification of the City code and ordinances to include specific design criteria that promotes avoidance, minimization, and mitigation strategies for potential impacts to uplands, wetlands, seagrass and benthic communities. These permitting criteria may also include direct water quality benefits by requiring littoral plantings in lakes, native plant buffer zones along seawalls, use of riprap or reef balls for repair and replacement of seawalls during the permitting process. Consideration and inclusion of the following regulatory elements for both coastal and inland projects will assist the City to achieve its goals and include:
    a. Protect native species from destruction by limiting removal of native species and encourage transplanting where removal is unavoidable.
    b. Require the use of native species in landscaping.
    c. Use of native buffer zones along existing seawalls to slow sheet flow and reduce nutrient loading to the canal and bays from lawn and garden areas.
    d. Require a minimum greenspace permit condition for new construction or redevelopment to reduce impervious surface area.
    e. Encourage and require removal of undesirable exotics where applicable.
    f. Require a vegetation permit for removal/transplanting/trimming of any vegetation seaward of the 1974 Coastal Construction Control Line (CCCL), chemical control of aquatic plants, for trimming of more than 25% of leaf area of any native tree or shrub over 6‘height, and for removal of native trees over 6 feet in height or native shrubs more than 2 feet height.
    g. All construction or repair of structures should be required to actively avoid and minimize impacts to mangroves, oyster reefs, seagrass and benthic communities or provide mitigation measures within the City where this is not feasible.
    h. Review and streamline permitting process (e.g. consider administrative for coastal projects, utilizing lobbyists and state legislature).

   i. Although the City does not have the regulatory authority to ban the use of copper sulfate and other copper-based treatments for algae within the City Limits, continued lobbying at the state level coupled with education and outreach programs at the local level may help to reduce copper loading and toxic effects to the bay and Gulf.
   j. Enforcement of fertilizer, landscaping, and illicit discharge regulations.

2. Water quality improvement and reduction strategies should be targeted for the restoration of lakes and canals which contain legacy nutrients. Nutrient loading from stormwater lakes and canals ultimately are deposited into the Bay which may have a negative effect on natural communities and habitats. Potential management strategies for reducing nutrient loading and accumulation are briefly described below:
   a. Mechanical removal of organic muck within existing lakes and canals, where feasible.
   b. Retrofitting stormwater conveyance systems with nutrient reduction/pre-treatment systems to increase nutrient removal.
   c. Routine maintenance of catchment basins and use of binding agents or additional aeration where appropriate and necessary as part of a restoration project.
   d. Installing and maintaining pet waste stations coupled with targeted stormwater education/outreach may provide an effective management strategy for reducing bacterial loading from stormwater.
   e. Changes in the duration and timing of street sweeping program for the management of fecal coliform, enterococci, and nutrients (total phosphorus).
   f. Creation of additional native littoral shelf planting areas within stormwater lakes and planted buffer zones on the upland banks to reduce nutrient loading and promote nutrient uptake prior to entering the lake.
   g. Education on the use of fertilizers, irrigation, landscaping, and illicit discharge regulations.

3. Habitat creation and conservation strategies should focus on creating additional habitat along existing hardened areas (seawalls and concrete abutments) and the conservation of natural habitats where feasible. Strategies may include:
   a. Use of native buffer zones along existing seawalls to slow sheet flow and reduce nutrient loading to the canal and bays from lawn and garden areas.
   b. Living shoreline creation along existing hardened shoreline using riprap planted with mangroves, and installing reef balls to create critical habitats for economically valuable fisheries (commercial and recreation species) as well as increasing the life of seawalls by reducing wave force and undercutting.
   c. Identify and remove invasive species.
   d. Develop management plans for current and future conservation areas. Management plans should identify restoration and conservation opportunities that foster key partnerships within the community, nonprofits, local, state, and federal government entities to help achieve the management plan goals.
   e. Creation of coastal education programs that incorporate management plan goals and partnerships about the importance and benefits of restoration and conservation of coastal resources.
   f. Identify priority projects that create new habitats (oyster reef, seagrass and mangrove), retrofit existing habitats (riprap installation along existing seawalls), protect vulnerable shorelines from erosion (reef construction), and create ecologically important resources.

4. The City of Naples created a comprehensive monitoring program in 2005 with inclusion of additional ecological data in 2010 to temporally and spatially quantify the magnitude of the restoration efforts and trends in water quality, fish and seagrass communities over time.

Recommendations within this category are specific to data gaps that exist within the current data set that will be advantageous for future adaptive management practices to achieve the City's long-term goals and may include:

a. Coordinate the installation of instantaneous flow monitoring equipment at the Gordon River and Haldeman Creek weirs, as well as in Rock Creek to generate daily flow volume data comparable to flow volume generated at the GGC weirs.

b. Paired flow and water quality measurements from the Gordon River, Rock Creek, and Haldeman Creek would be valuable in establishing a more robust characterization of the sources of water and pollutant loading into Naples Bay.

c. Maintain water quality monitoring at the same 16 stormwater lakes and all three pump stations to facilitate continuation of a long-term dataset and possibly expand the program as funds allow.

d. Increase sampling efforts at stormwater lakes and pump stations to include monthly sampling at all sites.

e. Generate estimates of flow from each stormwater lake being monitored either through direct flow monitoring or estimations based on lake design and rainfall amounts to calculate loadings to receiving waters from the lakes.

f. Copper is a specific water quality constituent of concern in Naples Bay. A copper-specific monitoring program to determine the effects of elevated copper concentrations on the biological community of the Bay should be considered. The program may include water quality, sediment, and biology (e.g. fish tissue samples, epiphyte copper accumulation) data to compare with known toxicological (mortality, growth, and reproduction) thresholds which can be valuable for identifying any links between copper and the observed biological community in Naples Bay.

g. Consider installation of continuous recorders at the same four locations of the USGS recorders that were discontinued in 2014. These provide extremely useful data on daily and seasonal patterns that provide a robust characterization of Bay conditions and identify patterns and changes over time.

h. Collect water quality grab samples during each biological (fish and seagrass) monitoring event at the location of monitoring for the same parameters as the monthly water quality monitoring.

i. Install in-situ instantaneous flow recorders for pump stations to get more accurate and precise volumetric data which will refine loading calculations to Naples Bay.

j. Fisheries sampling is currently based on a random sample design to characterize communities within the Bay as a whole. A modified sampling design that has one fixed sampling station along with the random sample within each zone is recommended to better able to analyze fish community changes over time.

5. Lakes that have either consistently high values or have significant statistical increasing trends are included in Table 5-1 along with specific recommendations for restoration options to address both the elevated values and increasing trends. It is important to note that restoration strategies are often effective in reducing more than one water quality parameter at a time and combining these strategies provide the most effective approach especially for reductions in TSS, TN, and TP.

Table 5-1. Summary of stormwater lakes with elevated parameter concentrations or increasing trends over time.

Lake	Water Quality Parameter of Concern	Restoration Strategy
14B, 11B, 24B and 8B	TSS, TN, TP	• Perform targeted nutrient source studies to determine the exact nutrient and its source. The results from this study should guide the development of restoration strategies that may include any or all of the below mentioned strategies. • Increased littoral planting within City owned property around identified stormwater lakes. • Develop a community outreach program to encourage citizen plantings of native littoral buffers along seawalls and private property surrounding and upland of the effected lakes. • Community outreach and education on fertilizer use along with City enforcement of fertilizer ordinance rules. • Biannual stormwater basin catchment clean outs. • Retrofit existing stormwater pipes and inlets to use inlet traps, advanced filtration media systems and include bio filtration where applicable. • Evaluate the use of binding agents within the targeted lake area. • Mechanical removal of organic muck and legacy nutrients in each of the listed lakes. • Consider the use of biological agents if no other restoration option listed above achieves the reduction in nutrients.
19B, 20B, 8B, and 9B	Fecal Coliform and Enterococci	• Conduct a Bacterial sourcing study for each of the lakes of concern to identify the source of bacterial loading and develop appropriate restoration strategies based on the results that may include any of the following actions. • For the identified lakes pet waste stations should be installed and maintained to help reduce animal waste from washing into stormwater lakes. • City wide education program on bacterial loading into lakes and how citizens can help prevent animal waste from entering stormwater lakes. • Routine maintenance of stormwater catchment basins to remove potential bacterial loading. • Biological controls may be used to reduce bacterial increases in stormwater lakes but only after all other options fail to reach to attain the desired reductions.
26B, 1SE-B and 26B	Copper	• Copper loading in the identified lakes is most likely a result of algal treatment of the lakes and a targeted education and prevention program for both citizens and lake management companies on the detrimental effects of copper on Naples and Moorings bay biology should be implemented. • Install and maintain either surface aeration or bottom diffuser in these lakes to help prevent anoxic and stagnant conditions for algal growth. • Consider installing a lake circulation device similar to those used by solar bee to ensure adequate lake mixing throughout the year.

The recommendations provided in this section are in no way a complete list of available actions but may provide a road map for the City when developing projects and administrative procedure in order to achieve the overall goals of the City.

6 Conclusions

This report provides a comprehensive look at the status of water quality and biology in Naples Bay. The goal of this study was to provide the information and analysis necessary to make informed decisions regarding resource management and to determine what effect ongoing management activities are having on Naples Bay.

The questions investigated in this study were as follows:

1. Are statistically significant trends in Naples Bay water quality data observed spatially and temporally?
2. Are statistically significant trends in Naples Bay biological data (fish and seagrass) observed spatially and temporally?
3. Are there statistically significant trends in the City's stormwater lakes and pump stations individually, or collectively based on the waterbody they drain to?
4. What science-based management activities can be implemented by the City to achieve the City's overall goals of protecting and improving water quality, resiliency, and enhancing habitat and fisheries?

Statistically significant trends in water quality and biological communities (fish and seagrass) were identified, and links between them that can inform management decisions were investigated. Inputs to Naples Bay (Golden Gate Canal, stormwater lakes, and pump stations) were quantified, where possible, and were included in the investigation for their potential effect on Naples Bay. A summary of the major conclusions is provided below.

Stormwater Lakes Water Quality

- More data were collected within the stormwater lakes and pump stations to complete a thorough statistical analysis of individual lakes and drainage basins.
- **There were statistically significant trends in individual stormwater lake and pump stations along with the collective waterbody they drain to (Question 3). The noted trends are as follows:**
    - Copper:
        - Decreases in collective inputs to Moorings Bay and Naples Bay.
        - Decreases at individual lakes draining to:
            - Moorings Bay: 1 SE-B (Devil's Lake).
            - Gordon River: 15B (Sun Lake Terrace) and 26B (NCH Lake).
            - Gulf of Mexico: 9B (South Lake).
            - Naples Bay: 11B (East Lake) and 24B (Half Moon Lake).
        - Decreases at pump stations PW-Pump (Public Works Pump) and 14-Pump (Port Royal Pump).
        - The highest copper concentrations were recorded in lakes 1SE-B (Devil's Lake), 26B (NCH Lake), and the PW-Pump Station.
        - Concentrations were somewhat variable at 9B (South Lake).
    - Salinity:
        - Decreases in collective inputs to Moorings Bay and the Gulf of Mexico.
        - Decreases at individual lakes draining to:

        - Moorings Bay: 2B (Swan Lake) and 5B (Lake Suzanne).
        - Gordon River: 15B (Sun Lake Terrace).
        - Gulf of Mexico: 9B (South Lake) and 10B (Alligator Lake).
      - Decreases at pump station 11-Pump (Cove Pump).
      - Increases at individual lakes draining to the Gordon River: 22B (Lake Manor).
      - Salinity had the greatest range at 2B (Swan Lake) from 2010 to 2014 (prior to the new weir being constructed).
      - Salinity within the brackish range at 14B (Lantern Lake) and 10B (Alligator Lake) over the entire monitoring period.
  - TSS:
      - Increases in collective inputs to the Gulf of Mexico.
      - Increases at individual lakes draining to Naples Bay: 14B (Lantern Lake).
      - Decreases at individual lakes draining to:
        - Moorings Bay: 2B (Swan Lake).
        - Gordon River: 20B (Forest Lake).
  - TN:
      - Increases in collective inputs to the Gulf of Mexico.
      - Increases at individual lakes draining to:
        - Naples Bay: 11B (East Lake) and 14B (Lantern Lake).
      - Decreases at pump station 11-Pump (Cove Pump).
  - TP:
      - Decreases in collective inputs to Moorings Bay.
      - Decreases at individual lakes draining to:
        - Moorings Bay: 3B (Colonnade Lake) and 5B (Lake Suzanne).
        - Gordon River: 20B (Forest Lake).
  - Enterococci:
      - Increases in collective inputs to the Gordon River and Gulf of Mexico.
      - Increases at individual lakes draining to the Gulf of Mexico: 9B (South Lake).
      - Increases at pump station 11-Pump (Cove Pump).
  - Fecal Coliform:
      - Increases in collective inputs to the Gordon River and Gulf of Mexico.
      - Increases at individual lakes draining to:
        - Gordon River: 19B (WTP Lake) and 20B (Forest Lake).
        - Gulf of Mexico: 8B (North Lake) and 9B (South Lake).
- TSS, TN, and TP were generally higher with a greater range of concentrations at three lakes: 14B (Lantern Lake) and 24B (Half Moon Lake) draining to the Gulf of Mexico and 8B (North Lake) draining to Naples Bay.
- The greatest salinity, TSS, and TP ranges occurred at 14-Pump Station.

Naples Bay Water Quality

- **There were statistically significant trends in Naples Bay and the Gordon River identified in Kendall Tau analysis both over time and spatially (at individual long-term monitoring stations) within Naples Bay (Question 1). The noted trends are as follows**:
    - Nitrogen, phosphorus, and chlorophyll-*a* in the Gordon River (marine segment – WBID 3278R5) north of SR41 indicate exceedance of the NNC for Naples Bay. The Gordon River (marine segment – WBID 3278R5) is currently listed as impaired for TN, TP, and chlorophyll-*a*.
        - Increasing trends in chlorophyll-*a* in WBID 3278R5 from 2000 to 2019.
            - Slight slope increase of 0.11 µg/L/yr for chlorophyll-*a*.
        - Increasing trends in chlorophyll-*a* occurred at individual long-term monitoring stations in the Gordon River (GORDEXT/GORDPT and BC3).
            - BC3 slope of increase of 0.16 ug/L/yr.
            - GORDEXT/GORDPT slop of increase of 0.17 µg/L/yr.
        - No increasing or decreasing trends in TN or TP within Gordon River (marine segment – WBID 3278R5) or individual long-term stations.
    - The dataset indicates chlorophyll-*a* and copper are exceeding their respective water quality standards in Naples Bay (WBID 3278R4). Naples Bay is currently listed as impaired for copper and chlorophyll-*a*.
        - Increasing trends in chlorophyll-*a* in WBID 3278R4 from 2000 to 2019.
            - Slight slope increase of 0.15 µg/L/yr for chlorophyll-*a*.
        - Increasing trend in chlorophyll-*a* at individual long term station NBAY29 in Naples Bay (slope 0.16 µg/L/yr).
        - Increasing trends at individual long-term monitoring stations in TN and TP (NBAYNL, NBAY29, NBAYBV, and GPASS6).
            - Increasing trend slopes may be small (0.02 mg/L/yr for TN and 0.002 mg/L/yr for TP) but they exist in both upper and lower Naples Bay.
    - Statistically significant decreasing trend in salinity at two stations in Naples Bay.
        - NBAYNL slope of -0.34 ppt/yr
        - GPASS6 slope of -0.17 ppt/yr
    - Statistically significant increasing trend in turbidity at all Gordon River (marine segment) and Naples Bay stations.
        - Slope range of 0.12 to 0.30 NTU/yr.
    - Fecal coliform colony counts had a statistically significant increasing trend in the Gordon River (marine segment) and Naples Bay.
        - Gordon River: GORDEXT/GORDPT slope 6.90 cfu/100mL/yr.
        - Naples Bay: NBAYNL, NBAY29, NBAYWS, NBAYBV, and GPASS6 slope range 0.33 to 4.60 cfu/100mL/yr.
            - Higher fecal coliform colony counts in upper Naples Bay and lower counts near mouth of bay.
    - Enterococci colony counts had a statistically significant increasing trend in the Gordon River (marine segment) and Naples Bay.

    - Gordon River: BC3 slope 41.98 cfu/100mL/yr.
    - Naples Bay: NBAYNL, NBAY29, NBAYWS, NBAYBV, and GPASS6 slope range 0.28 to 0.95 cfu/100mL/yr.
        - Higher enterococci colony counts near mouth of Naples Bay and lower counts in upper Naples Bay.

<u>Golden Gate Canal</u>

- Freshwater inflow from the GGC plays a major role in shaping the water quality of Naples Bay. The canal flow affects salinity throughout the Bay, with the highest impacts observed in the northern region. In fact, the marine portion of the Gordon River above SR 41 shifts to a freshwater system virtually every summer.
- The Golden Gate Canal plays a significant role in nutrient loading to Naples Bay which is directly related to its flow, the more flow the more nutrient loading.
    - From 2009 to 2014, the average daily loadings from the GGC were approximately 0.71 lbs/day copper; 710 lbs/day nitrogen; 24 lbs/day phosphorus; and 1,616 lbs/day suspended solids.
    - During the more recent 2015 to 2019 time period, the average daily loadings from the GGC were approximately 1.58 lbs/day copper, 1,280 lbs/day nitrogen, 43 lbs/day phosphorus, and 5,626 lbs/day suspended solids.
    - If 2017 loadings were excluded from the 2015 to 2019 time period, the loadings would be reduced for each of the constituents with loadings for copper of 1.22 lbs/day, nitrogen 1,042 lbs/day, phosphorus 27 lbs/day, and suspended solids 2,442 lbs/day.

<u>Naples Bay Biological Communities</u>

- **There were seasonal differences in the data collected for both the seagrass and fish communities. There were also differences in depth and percent cover of seagrass by year and monitoring transect. There were differences in fish diversity metrics over time, but no statistical differences in community structure observed between sampling zones (Question 2).**
- *Halodule wrightii* was increasing in density until about 2011 and then began decreasing through 2014, and was highly variable from 2015 through 2019.
- Percent occurrence for *H. wrightii* follows a similar decreasing trend from its highest occurrence in 2011 to its lowest in 2014, with percent occurrence remaining variable from 2015 through 2019.
- Diversity of fish species appears to follow a seasonal pattern with higher diversities and total taxa caught in the dry season and lower abundance in the wet season.
- Mojarras (*Eucinostomus* spp.) and anchovies (*Anchoa* spp.) were the most numerous taxa collected, accounting for over 87 percent of the total catch from 2009 to 2019. However, mojarras were the most frequently caught taxa followed by blue crabs (*Callinectes* spp.): occurring in 91 percent and 75 percent (respectively) of the trawl samples.
- The fish community in Naples Bay are dominated by euryhaline and cosmopolitan species (anchovy and mojarra) and are found in all zones of the Bay throughout the year, during times of significant canal flow as well as times of no flow.
- Four fish diversity metrics (total taxa, richness, Shannon diversity, and evenness) had two change-points over the period of record. For three of the metrics, one of the change-points occurred around the time of the change in sampling methodology in August 2011. The second change point occurred in mid-2016 for most metrics.
- There was no real relationship determined between fish communities and in-situ field water quality measurements for DO, salinity, or temperature over time.

Naples Bay Management Activities

- **Additional, science-based, resource management activities are available for review and implementation by the City to achieve the City's goals (Question 4). A summary of these are discussed below**:
- Management strategies for Naples Bay are focused on achieving three overall goals; to protect and improve water quality, management for resiliency (sea level rise, storm surge and boat wake), and enhancing habitat and fisheries. Management recommendations and strategies were provided to achieve the City's goals in four general categories: regulatory, water quality improvements, habitat creation/conservation, and comprehensive monitoring program needs.
- Conduct a frequent and consistent review of the City's code and policy to ensure that regulatory elements are consistent with the City's goals and with applicable local, state, and federal regulations.
  - Review and update fertilizer ordinance and illicit discharge regulations.
  - Require a minimum greenspace permit condition for new construction or redevelopment to reduce impervious surface area.
  - Use of native buffer zones along existing seawalls to slow sheet flow and reduce nutrient loading to the canal and bays from lawn and garden areas.
- The City has previously invested a significant amount of resources to improving water quality and should continue implementing water quality improvement projects to address nutrient and bacterial loading.
  - The City should continue implementing lake improvement projects that may consist of the following actions:
    - Mechanical removal of organic muck within existing lakes and canals, where feasible.
    - Routine maintenance of catchment basins and use of binding agents or additional aeration where appropriate and necessary as part of a restoration project.
    - Installing and maintaining pet waste stations coupled with targeted stormwater education/outreach may provide an effective management strategy for reducing bacterial loading from stormwater.
    - Changes in the duration and timing of street sweeping program for the management of fecal coliform, enterococci, and nutrients (total phosphorus).
    - Creation of additional native littoral shelf planting areas within stormwater lakes and planted buffer zones on the upland banks to reduce nutrient loading and promote nutrient uptake prior to entering the lake.
    - Retrofitting stormwater conveyance systems with nutrient reduction/pre-treatment systems to increase nutrient removal.
- Habitat creation and conservation are important strategies for the City to achieve its overall goals. The City has been actively restoring and protecting habitats which will ultimately help address water quality issues over time and should consider the following actions.
  - Living shoreline creation along existing hardened shoreline using riprap planted with mangroves, and installing reef balls to create critical habitats for economically valuable fisheries (commercial and recreation species) as well as increasing the life of seawalls by reducing wave force and undercutting.
  - Identify and remove invasive species.

    - Develop management plans for current and future conservation areas. Management plans should identify restoration and conservation opportunities that foster key partnerships within the community, nonprofits, local, state, and federal government entities to help achieve the management plan goals.
    - Identify priority projects that create new habitats (oyster reef, seagrass and mangrove), retrofit existing habitats (riprap installation along existing seawalls), protect vulnerable shorelines from erosion (reef construction), and create ecologically important resources.

- The City has a robust water quality monitoring program that includes seagrass and fish data which is invaluable for identifying statistically significant trends within and between water quality and biota. This program is important and should remain a priority for the City. The following management actions are recommended for consistent and robust data collection:
    - At a minimum the City should maintain water quality monitoring at the same 16 stormwater lakes and all three pump stations to facilitate continuation of a long-term dataset. Ideally, increased sampling to include monthly sampling efforts at all stormwater lakes and pump stations should be implemented within the next fiscal year.
    - Coordinate the installation of instantaneous flow monitoring equipment at the Gordon River and Haldeman Creek weirs, as well as in Rock Creek to generate daily flow volume data comparable to flow volume generated at the GGC weirs.
    - Consider installation of continuous recorders at the same four locations of the USGS recorders that were discontinued in 2014. These provide extremely useful data on daily and seasonal patterns that provide a robust characterization of Bay conditions and identify patterns and changes over time.
    - Install in-situ instantaneous flow recorders for pump stations to get more accurate and precise volumetric data which will refine loading calculations to Naples Bay.
    - Fisheries sampling is currently based on a random sample design to characterize communities within the Bay as a whole. A modified sampling design that has one fixed sampling station along with the random sample within each zone is recommended to better able to analyze fish community changes over time.

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City of Naples

APPENDIX

A

RAW DATA SUMMARY

Appendix A
Raw Data Summary

A.1 Stormwater Lake and Pump Station Results

Table A-1. Summary of raw stormwater lake water quality data, City of Naples, December 2010 through December 2019.

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
Moorings Bay	**1 SE-B**							
	12-Sep	17.0	0.25	0.75	0.080	24	231	100
	13-May	45.6	0.30	1.04	0.070	13	1000	80
	13-Nov	11.4	0.25	1.18	0.090	1.6	40	14
	14-Dec	127.0	0.28	1.44	0.090	1.6	290	50
	15-Feb	40.6	0.26	1.06	0.030	1	50	80
	15-Jul	1.0	0.21	0.94	0.049	1.47	40	80
	15-Nov	31.2	0.23	1.33	0.054	1	150	60
	16-Feb	16.0	0.34	1.51	0.035	1.2	40	40
	16-May	16.3	0.26	0.67	0.015	0.57	50	3200
	16-Aug	53.2	0.20	1.13	0.023	0.947	170	170
	16-Oct	32.7	0.22	1.24	0.070	1.19	60	40
	16-Nov	103.0	0.24	1.19	0.068	1.79	280	12500
	16-Dec	129.0	0.28	1.99	0.053	0.757	170	40
	17-Jan	56.5	0.27	1.31	0.033	4	260	280
	17-Feb	27.8	0.27	1.31	0.065	0.737	130	40
	17-Mar	30.9	0.28	1.32	0.053	1.23	30	20
	17-Apr	18.2	0.29	0.96	0.008	1.64	1800	1600
	17-May	50.2	0.29	1.02	0.048	1.8	60	1400
	17-Jun	5.5	0.20	1.12	0.122	12.3	240	60
	17-Jul	2.5	0.20	0.74	0.068	0.57	70	20
	17-Aug	15.1	0.18	0.71	0.080	0.57	50	20
	17-Sep	2.0	0.18	1.22	0.208	2.25	1090	250
	17-Oct	5.6	0.22	0.91	0.086	0.57	240	80
	17-Nov	41.1	0.23	1.11	0.014	0.57	80	30
	17-Dec	65.8	0.22	0.86	0.056	1	40	50
	18-Jan	49.0	0.25	0.86	0.008	0.57	50	80
	18-Feb	152.0	0.26	1.01	0.037	0.8	10	60
	18-Mar	14.8	0.27	1.18	0.029	0.667	60	60
	18-Apr	18.5	0.27	1.08	0.026	3.67	80	60
	18-May	6.1	0.24	1.10	0.052	2	70	50
	18-Jun	4.0	0.25	0.92	0.015	1	220	170
	18-Jul	88.6	0.24	1.04	0.035	1.4	60	10
	18-Aug	4.7	0.18	0.89	0.066	2	2400	480
	18-Sep	62.4	0.21	1.49	0.041	3.2	10	150
	18-Oct	5.9	0.24	0.78	0.025	0.57	60	220
	18-Nov	14.2	0.30	1.13	0.041	2	500	70
	18-Dec	11.1	0.27	0.95	0.026	1.67	70	50

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	19-Jan	18.2	0.24	1.57	0.090	3.33	60	390
	19-Feb	1160.0	5.84	1.38	0.057	5	10	250
	19-Mar	25.3	3.46	1.17	0.017	5	50	470
	19-Apr	10.6	2.30	1.22	0.062	1.8	180	60
	19-May	4.2	1.52	0.99	0.029	1.8	10	30
	19-Jun	0.3	0.72	0.05	0.040	0.8	10	70
	19-Jul	4.1	0.28	0.81	0.030	1.4	120	140
	19-Aug	10.7	0.27	1.06	0.052	2	90	160
	19-Sep	12.5	0.27	0.93	0.017	1.4	30	10
	19-Oct	10.0	0.25	1.34	0.062	0.57	1500	90
	19-Nov	9.9	0.28	0.91	0.059	2.25	190	10
	19-Dec	9.4	0.27	1.16	0.050	2	170	30
	2B							
	10-Dec	5.20	32.90	0.48	0.03	11	62	961
	11-Mar	63.00	33.83	0.26	0.05	20	40	1010
	11-Jun	14.00	27.85	0.93	0.05	25	190	1990
	11-Sep	3.20	0.22	1.70	0.09	11	673	100
	12-Apr	12.00	0.26	1.20	0.1	808	180	461
	12-Sep	6.20	0.96	0.85	0.05	6.4	1840	961
	13-May	7.00	0.25	0.98	0.08	7.5	3900	400
	13-Nov	4.20	0.26	0.87	0.14	4.4	132	17
	14-Dec	3.50	29.73	0.75	0.1	6.9	20	40
	15-Feb	11.00	21.89	0.98	0.12	5.3	80	10
	15-Jul	2.85	10.56	1.17	0.076	7.4	3200	630
	15-Nov	6.35	0.21	1.25	0.171	4.7	240	30
	16-Feb	2.46	0.34	1.34	0.175	6.7	20000	3600
	16-May	9.05	0.20	1.01	0.098	7	320	40
	16-Aug	3.02	0.17	1.11	0.107	7.05	5200	220
	16-Oct	1.31	0.23	1.93	0.314	14.6	320	80
	16-Nov	2.09	0.25	1.98	0.262	4.84	170	170
	16-Dec	1.93	0.28	1.99	0.298	2	490	80
	17-Feb	19.40	0.25	2.10	0.386	10.4	120	150
	17-May	16.40	0.21	0.99	0.208	4.4	250	40
	17-Aug	4.59	0.70	0.70	0.166	3.67	270	90
	17-Oct	2.64	0.23	0.95	0.127	3.4	510	290
	17-Nov	6.18	0.23	1.14	0.221	3.6	100	60
	17-Dec	11.90	0.21	1.31	0.122	10.3	300	110
	18-Jan	7.51	0.25	1.01	0.114	6.8	320	190
	18-Feb	59.40	0.24	1.89	0.169	9.8	110	310
	18-Mar	14.20	0.23	1.56	0.094	8.2	260	300
	18-Apr	9.69	0.23	1.69	0.079	6.67	90	50
	18-May	4.71	0.18	0.92	0.008	6.8	40	40
	18-Jun	5.56	0.17	1.09	0.046	7.8	110	20
	18-Jul	3.66	0.20	0.89	0.035	3.33	100	180
	18-Aug	3.37	0.12	0.74	0.084	7.33	2900	1070
	18-Sep	8.41	0.21	0.84	0.097	4.8	50	200
	18-Oct	5.18	0.18	1.26	0.103	5.33	80	70
	18-Nov	5.56	0.26	1.03	0.073	3	250	200

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	18-Dec	33.00	0.23	0.85	0.047	1.67	150	50
	19-Jan	4.74	0.18	1.32	0.083	8	70	680
	19-Feb	4.96	0.23	1.84	0.143	1.67	460	420
	19-Mar	4.63	0.20	2.42	0.037	9.67	70	110
	19-Apr	8.42	0.17	1.48	0.059	12	280	70
	19-May	7.20	0.18	2.06	0.099	18.5	10	10
	19-Jun	3.09	0.17	0.61	0.046	2	80	110
	19-Jul	1.46	0.15	0.73	0.117	3.4	560	490
	19-Aug	2.54	0.20	1.03	0.01	5	2000	100
	19-Sep	3.71	0.21	1.64	0.057	11	370	80
	19-Oct	2.16	0.18	1.42	0.087	2.75	1100	60
	19-Nov	2.88	0.21	1.05	0.069	4.5	2000	30
	19-Dec	2.68	0.19	1.01	0.042	4.4	840	270
	3B							
	12-Apr	5.60	0.39	1.10	0.11	4.8	1440	140
	12-Sep	2.80	0.49	1.00	0.13	5.2	259	47
	13-May	10.30	0.47	1.05	0.14	4.8	3300	156
	13-Nov	3.50	1.05	1.12	0.12	1.7	250	33
	14-Dec	6.50	0.76	1.13	0.17	7.9	10	2200
	15-Feb	14.30	0.43	0.95	0.08	6.2	120	110
	15-Jul	1.00	0.25	0.94	0.107	2.33	270	40
	15-Nov	5.71	1.31	1.34	0.133	5	100	150
	16-Feb	3.96	0.73	1.26	0.089	8.4	470	1150
	16-May	3.00	0.60	0.89	0.092	6.32	1180	900
	16-Aug	5.58	0.25	1.34	0.157	3.26	330	240
	16-Oct	5.55	1.48	1.31	0.155	7.4	10	50
	16-Nov	4.56	1.59	1.27	0.173	5.13	10	110
	16-Dec	4.62	1.16	1.24	0.104	6	30	150
	17-Jan	4.60	0.67	1.85	0.08	10	10	160
	17-Feb	5.67	0.58	1.10	0.008	6.35	330	130
	17-Mar	5.76	0.41	1.20	0.009	4.11	290	320
	17-Apr	23.60	0.60	1.23	0.036	7.3	60	100
	17-May	6.23	0.72	1.13	0.128	6.2	190	130
	17-Jun	3.82	0.26	1.77	0.235	5	1100	4600
	17-Jul	1.87	0.25	0.88	0.151	2.4	900	870
	17-Aug	1.69	0.26	0.72	0.132	3.2	330	130
	17-Sep	1.91	0.30	0.94	0.249	2.5	4900	360
	17-Oct	3.15	1.02	1.30	0.216	2	320	180
	17-Nov	4.06	0.59	1.08	0.163	4.2	20	10
	17-Dec	4.21	0.62	1.06	0.156	3.2	140	160
	18-Jan	4.33	0.39	1.17	0.139	8.6	70	230
	18-Feb	4.69	0.34	0.92	0.089	1.6	50	50
	18-Mar	3.08	0.55	1.19	0.106	4.2	100	380
	18-Apr	7.15	0.54	1.62	0.013	15.3	300	170
	18-May	13.20	0.30	1.02	0.102	2.6	280	160
	18-Jun	2.74	0.26	0.92	0.091	2.8	1100	500
	18-Jul	2.32	0.46	0.91	0.075	1.8	10	10
	18-Aug	2.24	0.18	1.04	0.173	7.33	2300	760

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	18-Sep	3.92	0.39	0.84	0.085	1.6	10	290
	18-Oct	2.65	0.50	1.34	0.123	3	240	420
	18-Nov	5.60	0.99	1.38	0.137	2.67	40	110
	18-Dec	3.99	0.64	1.27	0.131	3.33	40	220
	19-Jan	3.66	0.38	0.99	0.114	4.33	160	1270
	19-Feb	3.60	0.38	0.95	0.097	5	100	210
	19-Mar	4.73	0.32	0.96	0.083	6.33	80	160
	19-Apr	5.15	0.44	0.82	0.073	4.4	170	40
	19-May	3.13	0.46	0.92	0.076	4.4	450	340
	19-Jun	3.18	0.58	0.85	0.055	1.6	220	70
	19-Jul	2.28	0.24	0.90	0.053	7	820	1000
	19-Aug	5.14	0.35	1.66	0.06	14.8	560	630
	19-Sep	3.28	0.48	1.48	0.115	6.33	720	40
	19-Oct	0.99	3.59	1.06	0.028	4.5	2200	230
	19-Nov	2.20	1.93	1.19	0.147	1.75	300	10
	19-Dec	4.66	0.95	1.13	0.112	3.5	920	790
	5B							
	10-Dec	12.00	0.29	1.20	0.13	5.2	88	61
	11-Mar	8.60	0.26	0.92	0.13	4	58	56
	11-Jun	6.10	0.23	1.30	0.14	2.8	220	56
	11-Sep	5.00	0.23	1.10	0.1	4	200	123
	12-Apr	10.00	0.25	5.30	0.42	17	270	84
	12-Sep	3.00	0.23	0.89	0.12	4.8	310	7
	13-May	35.00	0.29	1.14	0.15	4.8	188	600
	13-Nov	6.10	0.27	1.18	0.13	5.6	44	71
	14-Dec	30.10	0.27	1.69	0.22	11	20	10
	15-Feb	13.70	0.18	1.26	0.13	10.2	70	90
	15-Jul	1.00	0.17	1.02	0.352	1.4	7500	630
	15-Nov	10.90	0.30	1.33	0.199	3.4	160	20
	16-Feb	4.23	0.20	1.38	0.1	8.89	740	940
	16-May	4.81	0.28	0.96	0.109	6.21	240	260
	16-Aug	1.78	0.37	1.50	0.241	2.53	10700	330
	16-Oct	2.59	0.36	1.13	0.361	4.56	200	20
	16-Nov	0.35	0.38	1.22	0.454	3.11	3800	3100
	16-Dec	7.92	0.30	2.04	0.153	13.7	160	210
	17-Jan	4.82	0.28	2.42	0.085	16	20	290
	17-Feb	5.80	0.29	1.98	0.137	3.25	20	30
	17-Mar	4.27	0.26	1.53	0.135	6.12	10	40
	17-Apr	4.88	0.28	1.57	0.183	5.41	190	90
	17-May	4.76	0.24	1.25	0.163	4.8	260	60
	17-Jun	3.31	0.12	0.67	0.133	2.25	3900	2200
	17-Jul	4.57	0.19	0.63	0.111	6.24	90	680
	17-Aug	2.83	0.17	0.69	0.134	5	530	280
	17-Sep	1.91	0.19	0.76	0.205	3.4	4800	850
	17-Oct	2.54	0.22	0.93	0.164	4.8	300	920
	17-Nov	5.22	0.25	1.37	0.183	9.8	10	110
	17-Dec	4.83	0.24	1.91	0.208	15.6	100	230
	18-Jan	4.04	0.29	1.01	0.104	7.8	10	330

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	18-Feb	4.42	0.28	1.09	0.091	4.4	90	20
	18-Mar	5.13	0.27	1.24	0.121	6.8	160	340
	18-Apr	3.93	0.26	1.35	0.132	4.8	40	220
	18-May	3.65	0.21	1.12	0.086	4.2	50	40
	18-Jun	3.63	0.19	0.62	0.066	6.4	430	30
	18-Jul	3.86	0.21	1.01	0.077	10	80	10
	18-Aug	3.07	0.13	0.84	0.076	4.67	700	710
	18-Sep	5.99	0.21	0.76	0.084	2.8	20	160
	18-Oct	4.33	0.90	1.01	0.121	4.33	90	240
	18-Nov	3.06	0.28	1.41	0.096	4.33	20	60
	18-Dec	7.54	0.26	1.37	0.116	2.33	20	250
	19-Jan	15.80	0.20	1.31	0.104	5.67	10	320
	19-Feb	6.11	0.25	1.26	0.185	7.67	1300	350
	19-Mar	5.07	0.23	1.28	0.158	3.33	120	190
	19-Apr	6.96	0.20	2.50	0.081	28	80	200
	19-May	2.77	0.22	1.04	0.103	3.6	30	60
	19-Jun	3.15	0.20	0.70	0.038	4.2	60	150
	19-Jul	1.50	0.15	0.57	0.111	5.4	430	500
	19-Aug	3.13	0.23	0.78	0.051	6.75	1200	160
	19-Sep	3.63	0.23	0.97	0.059	6.33	320	370
	19-Oct	7.87	0.21	1.26	0.163	3.25	3900	650
	19-Nov	3.99	0.24	0.88	0.104	3.75	230	10
	19-Dec	20.00	0.23	0.94	0.099	7.75	290	390
Gordon River	**6B**							
	12-Apr	0.60	0.34	0.83	0.05	2.4	50	9
	12-Sep	0.50	0.36	1.20	0.13	11	5200	101
	13-May	0.50	0.44	0.97	0.26	18.1	96	331
	13-Nov	0.70	0.34	0.73	0.03	4.2	133	30
	14-Dec	2.00	0.36	0.93	0.12	5	70	30
	15-Feb	9.40	0.35	1.38	0.11	5.2	90	80
	15-Jul	1.00	0.30	0.94	0.091	7.2	280	10
	15-Nov	0.35	0.35	0.95	0.097	4.17	10	20
	16-Feb	1.78	0.34	1.87	0.063	9.8	70	440
	16-May	0.93	0.33	0.75	0.06	13.6	1300	500
	16-Aug	0.35	0.30	1.12	0.098	6.43	1280	90
	16-Oct	0.74	0.33	1.52	0.024	18.3	10	500
	16-Nov	0.35	0.34	1.29	0.105	6.29	100	170
	16-Dec	0.36	0.37	1.33	0.09	5.8	370	240
	17-Jan	7.66	0.34	1.83	0.075	6.87	440	120
	17-Feb	0.45	0.34	1.47	0.113	5.6	60	130
	17-Mar	2.26	0.35	1.46	0.106	7.4	170	250
	17-Apr	1.23	0.35	1.08	0.12	14.4	260	220
	17-May	0.68	0.32	1.10	0.014	6	120	10
	17-Jun	1.07	0.24	1.04	0.16	4.25	1500	2300
	17-Jul	0.59	0.30	0.86	0.136	5.46	640	60
	17-Aug	0.86	0.27	0.93	0.162	4.5	1700	100
	17-Sep	0.83	0.34	1.03	0.113	6.25	19400	870
	17-Nov	0.49	0.36	1.55	0.016	2	50	80

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	18-Feb	1.26	0.37	1.09	0.095	2.8	90	150
	18-May	0.35	0.32	0.92	0.04	4.6	130	170
	18-Aug	1.11	0.24	0.93	0.117	6.33	2400	370
	18-Nov	0.66	0.40	0.68	0.018	1.67	60	100
	19-Feb	1.54	0.36	1.18	0.145	10.7	130	60
	19-May	0.50	0.34	0.92	0.071	3.6	130	140
	19-Aug	1.80	0.32	0.83	0.047	5.5	2000	390
	19-Nov	0.44	0.33	0.96	0.08	9	370	70
	15B							
	10-Dec	3.90	0.29	0.90	0.03	5.6	380	204
	11-Mar	4.30	0.32	0.94	0.03	5.2	86	83
	11-Jun	20.00	0.29	0.82	0.03	4.4	755	579
	11-Sep	11.00	0.27	0.99	0.02	2.8	200	29
	12-Apr	41.00	0.28	1.20	0.02	4.4	100	46
	12-Sep	8.20	0.27	0.89	0.03	4.8	230	17
	13-May	8.60	0.31	0.99	0.03	7.3	2000	85
	13-Nov	27.70	0.25	1.29	0.07	1.3	46	8
	14-Dec	8.50	0.27	1.09	0.08	4	480	140
	15-Feb	15.10	0.25	0.87	0.02	2.6	190	260
	15-Jul	26.60	0.22	1.03	0.356	4.53	180	90
	15-Nov	18.40	0.24	0.93	0.033	5.4	70	40
	16-Feb	4.14	0.24	1.35	0.038	13.6	640	70
	16-May	9.60	0.23	0.65	0.012	1.05	460	680
	16-Aug	4.97	0.22	1.33	0.008	4	250	60
	16-Oct	2.31	0.23	1.42	0.092	1.58	60	10
	16-Nov	3.04	0.23	1.14	0.086	1.67	50	10
	16-Dec	5.07	0.26	1.25	0.068	1.9	390	270
	17-Jan	6.25	0.24	0.99	0.041	3.57	14400	2400
	17-Feb	5.07	0.24	1.64	0.017	5.6	90	10
	17-Mar	8.54	0.25	2.03	0.009	9.6	920	800
	17-Apr	4.40	0.26	1.09	0.008	14.7	270	70
	17-May	4.34	0.26	1.03	0.008	6	370	240
	17-Jun	1.98	0.23	0.84	0.01	4.5	380	220
	17-Jul	1.28	0.23	0.94	0.063	2.75	50	20
	17-Aug	1.30	0.22	0.71	0.063	2.25	50	10
	17-Sep	2.51	0.18	1.14	0.057	3	280	140
	17-Nov	4.69	0.22	1.33	0.069	11.4	70	280
	18-Feb	4.65	0.23	1.35	0.054	8.8	40	80
	18-May	3.34	0.24	1.24	0.039	8.8	240	230
	18-Aug	3.87	0.22	1.12	0.038	3.67	420	470
	18-Nov	65.70	0.25	1.49	0.078	1.33	830	200
	19-Feb	8.17	0.24	1.03	0.034	3.67	590	340
	19-May	3.77	0.24	0.98	0.054	8.2	520	130
	19-Aug	6.50	0.22	1.02	0.018	28	720	390
	19-Nov	2.43	0.24	0.88	0.037	2	260	60
	19B							
	12-Apr	1.20	0.58	2.40	0.06	4.4	180	313
	12-Sep	0.40	0.31	1.20	0.05	8.4	410	27

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	13-May	0.50	0.36	1.21	0.05	10.7	92	298
	13-Nov	0.50	0.31	1.28	0.14	15.2	3	6
	14-Dec	2.00	0.36	1.24	0.24	3.6	5	40
	15-Feb	7.40	0.24	1.37	0.13	9.8	60	200
	15-Jul	1.00	0.24	0.90	0.048	9.33	130	50
	15-Nov	0.73	0.26	1.09	0.092	11.4	670	280
	16-Feb	0.50	0.30	1.35	0.07	8.8	10	480
	16-May	1.41	0.28	1.34	0.055	10.8	230	500
	16-Aug	0.46	0.21	1.33	0.098	8.55	530	130
	16-Oct	0.41	0.28	1.34	0.229	11.4	420	2000
	16-Nov	1.04	0.29	1.20	0.217	9.75	460	600
	16-Dec	5.29	0.31	1.32	0.097	4.24	970	650
	17-Jan	1.28	0.28	1.17	0.072	4	310	340
	17-Feb	0.91	0.28	1.68	0.106	9.13	2700	5900
	17-Mar	1.11	0.25	1.69	0.034	6.6	370	390
	17-Apr	1.64	0.24	1.35	0.022	28.7	1700	880
	17-May	0.35	0.22	1.03	0.058	10.8	180	130
	17-Jun	1.04	0.20	1.08	0.026	8.75	3500	1900
	17-Jul	0.50	0.25	1.03	0.111	6	250	380
	17-Aug	0.70	0.24	0.91	0.148	4.75	980	610
	17-Sep	0.65	0.23	0.95	0.095	9.67	2700	570
	17-Oct	0.35	0.26	1.31	0.064	6	220	210
	17-Nov	0.35	0.29	1.52	0.188	2.33	230	370
	17-Dec	1.54	0.28	2.23	0.27	16.7	630	10500
	18-Jan	0.75	0.30	1.08	0.118	10.4	310	900
	18-Feb	2.83	0.28	1.32	0.081	11.6	380	570
	18-Mar	1.02	0.24	4.33	0.009	40	1000	1500
	18-Apr	0.60	0.25	3.53	0.057	27	240	630
	18-May	0.35	0.24	2.59	0.066	18.7	870	460
	18-Jun	0.44	0.21	1.45	0.04	14.7	320	350
	18-Jul	0.48	0.23	1.77	0.085	22.3	800	350
	18-Aug	1.49	0.24	1.24	0.11	8.67	1600	620
	18-Sep	2.28	0.25	1.14	0.104	6.8	110	180
	18-Oct	1.12	0.25	1.38	0.09	8	290	300
	18-Nov	0.97	0.30	1.34	0.097	12.7	220	130
	18-Dec	2.68	0.27	1.57	0.107	14.5	160	270
	19-Jan	1.23	0.27	1.38	0.116	12	240	350
	19-Feb	0.96	0.29	1.16	0.066	10.3	390	120
	19-Mar	0.71	0.29	0.99	0.031	8.33	250	50
	19-Apr	0.54	0.24	1.33	0.071	15.7	370	140
	19-May	0.52	0.28	1.38	0.052	14.4	490	240
	19-Jun	0.56	0.27	1.16	0.027	9.06	1450	420
	19-Jul	0.63	0.23	1.11	0.036	10.3	2300	610
	19-Aug	1.33	0.27	1.17	0.053	8.5	900	400
	19-Sep	2.23	0.29	1.52	0.046	6	360	130
	19-Oct	0.64	0.28	1.22	0.089	5.75	3400	380
	19-Nov	0.58	0.30	1.45	0.108	11.5	1500	480
	19-Dec	0.35	0.29	1.16	0.111	2.6	540	380

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	20B							
	10-Dec	2.50	0.23	1.50	0.09	6	370	111
	11-Mar	1.00	0.25	1.40	0.22	20	118	164
	11-Jun	1.00	0.20	2.10	0.09	11	520	1300
	11-Sep	0.40	0.23	1.60	0.1	14	410	365
	12-Apr	0.60	0.30	1.60	0.06	8.4	50	29
	12-Sep	0.90	0.24	1.80	0.07	13	4000	2420
	13-May	1.50	0.32	1.23	0.06	69.7	72	57
	13-Nov	0.50	0.36	4.12	0.4	8	28	1
	14-Dec	2.00	0.29	3.41	0.32	26.4	60	40
	15-Feb	8.00	0.27	6.69	0.42	56	470	170
	15-Jul	1.00	0.26	1.45	0.099	26	50	10
	15-Nov	0.35	0.26	1.18	0.074	15.3	80	70
	16-Feb	0.69	0.17	1.81	0.059	8.2	60	80
	16-May	1.09	0.27	1.40	0.063	30.5	170	50
	16-Aug	0.59	0.21	1.90	0.082	10.7	240	320
	16-Oct	0.61	0.26	2.29	0.032	21	200	40
	16-Nov	0.35	0.26	2.54	0.219	13.8	170	50
	16-Dec	0.72	0.29	1.81	0.094	12	580	80
	17-Jan	0.77	0.28	3.85	0.085	10	530	80
	17-Feb	0.84	0.29	3.97	0.031	78.5	260	100
	17-Mar	1.29	0.30	1.91	0.01	10.8	240	50
	17-Apr	0.80	0.31	1.10	0.025	14	330	140
	17-May	0.45	0.31	1.57	0.025	14	80	40
	17-Jun	1.84	0.25	1.53	0.022	9	780	330
	17-Jul	0.83	0.25	1.96	0.018	11.5	80	40
	17-Aug	1.04	0.22	1.27	0.024	12.8	470	50
	17-Sep	1.45	0.21	0.87	0.131	2.5	590	260
	17-Oct	0.35	0.26	2.45	0.328	1.6	180	280
	17-Nov	0.35	0.26	1.57	0.069	10	100	120
	17-Dec	0.80	0.25	1.33	0.275	7.6	200	100
	18-Jan	0.52	0.28	0.95	0.157	1.4	100	30
	18-Feb	1.49	0.27	1.42	0.092	6.6	420	200
	18-Mar	0.64	0.29	2.00	0.071	0.57	210	210
	18-Apr	0.66	0.28	1.34	0.053	7.33	420	110
	18-May	0.38	0.29	1.21	0.047	5.8	1600	260
	18-Jun	0.73	0.28	0.72	0.026	3.67	330	80
	18-Jul	1.34	0.24	2.25	0.12	23.4	820	20000
	18-Aug	1.36	0.23	1.59	0.128	9.33	2700	710
	18-Sep	2.36	0.19	1.74	0.064	12.4	210	230
	18-Oct	3.16	0.23	1.33	0.094	6.67	110	100
	18-Nov	1.13	0.29	1.78	0.111	15	180	40
	18-Dec	2.09	0.27	1.81	0.105	6	210	170
	19-Jan	1.05	0.28	1.73	0.015	4	170	510
	19-Feb	1.11	0.25	1.38	0.047	6.67	130	140
	19-Mar	3.32	0.28	2.05	0.043	3.33	470	60
	19-Apr	0.59	0.25	2.12	0.039	6.8	350	20
	19-May	0.59	0.29	1.38	0.062	9.67	30	70

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	19-Jun	0.72	0.22	1.16	0.036	8.4	340	110
	19-Jul	0.70	0.19	1.33	0.11	12	450	460
	19-Aug	1.39	0.19	2.17	0.09	22.5	180	300
	19-Sep	1.00	0.30	2.23	0.044	23	840	130
	19-Oct	1.93	0.29	2.00	0.05	15.8	1100	200
	19-Nov	0.44	0.32	2.07	0.106	17.6	870	250
	19-Dec	0.35	0.31	1.89	0.033	10	580	290
	22B							
	10-Dec	1.00	0.73	0.63	0.06	1	208	63
	11-Mar	2.60	0.48	0.70	0.06	3.2	200	201
	11-Jun	1.40	0.34	0.60	0.04	2.4	1660	461
	11-Sep	0.80	0.26	0.66	0.04	4	1750	1300
	12-Apr	1.10	0.26	0.85	0.01	1.2	50	8
	12-Sep	0.60	0.33	0.85	0.1	8.8	2340	378
	13-May	0.70	0.44	0.65	0.06	3.9	128	132
	13-Nov	0.80	0.50	0.82	0.12	1.3	54	35
	14-Dec	2.00	1.86	0.87	0.17	10.7	90	140
	15-Feb	13.50	1.66	1.24	0.11	2.3	150	130
	15-Jul	1.00	0.29	1.00	0.06	5	190	90
	15-Nov	1.36	2.23	0.89	0.099	8.57	200	170
	16-Feb	1.09	0.48	1.24	0.121	3.9	40	110
	16-May	2.67	0.58	0.98	0.037	5.63	130	140
	16-Aug	0.73	0.22	1.45	0.016	8.71	290	50
	16-Oct	0.69	0.54	1.08	0.138	2.75	70	30
	16-Nov	0.35	0.56	1.18	0.122	3.05	110	50
	16-Dec	0.70	2.09	1.08	0.058	1.78	360	100
	17-Jan	1.49	1.89	1.03	0.036	1.26	40	40
	17-Feb	1.31	1.86	0.93	0.008	2.21	80	30
	17-Mar	1.86	1.58	1.15	0.008	2.81	20	10
	17-Apr	1.76	1.56	0.69	0.008	3.37	50	110
	17-May	0.91	1.26	0.85	0.027	0.923	10	20
	17-Jun	1.78	0.48	0.80	0.125	3	4300	4400
	17-Jul	1.27	0.28	0.74	0.111	2.88	160	460
	17-Aug	1.04	0.24	0.58	0.13	2.75	370	140
	17-Sep	0.58	0.18	0.93	0.201	4.5	3700	110
	17-Oct	0.35	0.41	1.10	0.265	1.4	70	140
	17-Nov	0.35	0.55	1.08	0.153	2.67	100	80
	17-Dec	1.52	1.53	1.08	0.236	7	290	5200
	18-Jan	2.09	1.23	0.87	0.102	3.2	150	270
	18-Feb	2.75	1.04	0.80	0.048	2.8	40	50
	18-Mar	1.95	0.91	1.17	0.008	3	10	50
	18-Apr	1.84	0.93	1.02	0.009	3	30	10
	18-May	1.02	0.74	0.84	0.041	3.8	160	100
	18-Jun	0.99	1.17	0.52	0.008	2.33	30	40
	18-Jul	0.50	0.32	0.90	0.008	2.6	80	60
	18-Aug	1.77	0.21	0.73	0.09	4	1900	680
	18-Sep	2.43	0.24	0.77	0.041	2.8	40	600
	18-Oct	3.03	0.48	0.89	0.076	2.67	50	4100

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	18-Nov	25.60	0.96	0.93	0.096	2	150	150
	18-Dec	1.39	1.10	0.86	0.07	3	100	270
	19-Jan	4.03	2.03	0.66	0.064	1.67	90	3100
	19-Feb	1.66	1.69	2.84	0.035	1.33	150	80
	19-Mar	1.25	1.64	0.63	0.06	3.67	130	50
	19-Apr	2.19	1.22	0.36	0.051	2	280	160
	19-May	0.83	0.97	0.77	0.037	2.2	220	130
	19-Jun	0.73	1.09	0.49	0.044	1.4	140	30
	19-Jul	0.95	0.25	0.49	0.078	4	290	280
	19-Aug	2.04	0.34	0.97	0.037	7.5	300	540
	19-Sep	1.74	0.29	0.72	0.017	5	490	80
	19-Oct	1.15	8.90	0.73	0.121	3.5	13100	2800
	19-Nov	0.27	8.33	0.64	0.082	8.25	280	110
	19-Dec	0.27	6.84	0.79	0.118	0.57	390	180
	26B							
	12-Apr	57.00	0.28	0.59	0.04	1.6	180	68
	12-Sep	61.00	0.30	0.76	0.07	6	890	2
	13-May	55.40	0.29	0.87	0.06	8.2	290	1
	13-Nov	76.70	0.34	0.56	0.03	6.8	42	35
	14-Dec	73.20	0.30	1.26	0.13	11.6	90	200
	15-Feb	50.00	0.25	1.21	0.06	5.2	90	140
	15-Jul	12.00	0.22	0.76	0.078	10.4	640	490
	15-Nov	129.00	0.27	1.01	0.116	9.22	790	4400
	16-Feb	110.00	0.33	1.35	0.109	7.8	160	680
	16-May	39.70	0.22	0.74	0.046	5.87	180	150
	16-Aug	28.80	0.24	1.19	0.128	6	3800	200
	16-Oct	168.00	0.31	1.50	0.186	19.3	2100	3200
	16-Nov	43.70	0.31	1.19	0.131	14.8	280	590
	16-Dec	436.00	0.30	7.75	0.155	48	3400	20000
	17-Jan	144.00	0.27	1.44	0.063	14.8	370	1100
	17-Feb	112.00	0.26	1.49	0.016	26.3	210	620
	17-Mar	126.00	0.26	1.44	0.015	16	220	730
	17-Apr	116.00	0.26	0.83	0.011	13.4	140	570
	17-May	118.00	0.20	0.83	0.009	9.8	440	570
	17-Jun	21.70	0.22	0.70	0.128	1.25	190	480
	17-Jul	31.70	0.24	0.82	0.149	7.8	630	1160
	17-Aug	42.00	0.28	0.74	0.164	7	280	180
	17-Sep	50.80	0.34	0.85	0.194	3.75	260	210
	17-Oct	79.30	0.30	0.59	0.083	74	2200	3200
	17-Nov	76.50	0.31	1.54	0.014	4.33	290	700
	17-Dec	61.80	0.28	1.27	0.028	12.2	310	710
	18-Jan	145.00	0.31	1.23	0.016	13.6	220	480
	18-Feb	174.00	0.28	0.96	0.075	8.8	200	400
	18-Mar	302.00	0.25	1.17	0.008	8.4	400	1200
	18-Apr	30.40	0.22	1.03	0.037	12	220	470
	18-May	40.80	0.17	0.87	0.012	21	220	220
	18-Jun	37.90	0.20	0.79	0.047	7.6	790	810
	18-Jul	52.40	0.26	0.85	0.067	11.8	760	190

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	18-Aug	32.40	0.30	0.94	0.104	4	11400	940
	18-Sep	64.00	0.30	0.71	0.068	7.6	440	160
	18-Oct	49.00	0.25	0.93	0.084	8.67	140	340
	18-Nov	30.60	0.26	1.47	0.177	6	240	330
	18-Dec	81.50	0.26	1.69	0.132	12.7	170	480
	19-Jan	22.50	0.23	0.68	0.047	1	60	450
	19-Feb	38.60	0.27	0.79	0.052	6	320	220
	19-Mar	40.30	0.27	0.86	0.043	3.67	250	110
	19-Apr	52.40	0.20	1.00	0.029	20.3	340	630
	19-May	27.90	0.21	0.96	0.045	4.8	830	240
	19-Jun	36.80	0.24	0.93	0.063	6.2	780	510
	19-Jul	7.24	0.26	0.83	0.122	2.33	3000	
	19-Aug	27.60	0.34	3.08	0.084	7.5	170	330
	19-Sep	42.10	0.34	3.17	0.213	4	750	60
	19-Oct	35.50	0.31	1.41	0.293	4.5	850	480
	19-Nov	29.80	0.36	1.10	0.067	8.25	370	50
	19-Dec	83.60	0.34	1.45	0.13	9	2000	930
Gulf of Mexico	**8B**							
	17-Oct	2.11	0.30	1.97	0.149	19.6	220	130
	17-Nov	4.14	0.31	1.87	0.287	10.7	20	350
	17-Dec	3.75	0.30	1.68	0.237	9.67	130	80
	18-Jan	2.60	0.34	1.55	0.273	10.8	90	250
	18-Feb	2.65	0.35	1.62	0.225	13	10	70
	18-Mar	5.35	0.35	2.31	0.014	16	30	230
	18-Apr	2.74	0.36	2.36	0.041	10.3	100	130
	18-May	1.64	0.33	1.67	0.099	13	150	150
	18-Jun	1.73	0.33	1.45	0.084	12.7	500	340
	18-Jul	1.40	0.30	1.93	0.082	9.6	10	160
	18-Aug	1.95	0.23	1.34	0.163	7	2200	960
	18-Sep	4.74	0.27	2.24	0.263	94	570	330
	18-Oct	12.00	0.26	6.86	0.176	282	950	9000
	18-Nov	41.00	0.32	10.50	1.07	354	2700	290
	18-Dec	29.50	0.31	6.82	0.395	103	400	440
	19-Jan	7.84	0.29	4.73	0.334	28	230	830
	19-Feb	2.97	0.33	1.74	0.175	18	970	110
	19-Mar	12.20	0.31	4.25	0.2	74.3	420	250
	19-Apr	17.80	0.27	5.32	0.099	16.7	530	50
	19-May	3.50	0.31	1.71	0.104	17.3	350	2500
	19-Jun	2.44	0.23	1.51	0.022	13	580	3400
	19-Jul	2.90	0.23	1.13	0.114	11.4	850	2400
	19-Aug	3.33	0.30	3.38	0.337	57.3	1000	2700
	19-Sep	4.36	0.32	2.05	0.104	22.7	1800	1500
	19-Oct	2.17	0.30	2.38	0.112	19.7	8900	250
	19-Nov	2.25	0.31	3.89	0.394	32.7	2500	70
	19-Dec	2.33	0.30	2.22	0.073	11	360	180
	9B							
	12-Apr	11.0	0.4	1.3	0.17	6	50	34
	12-Sep	3.1	0.4	1.1	0.05	16	66	49

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	13-May	54.6	0.4	3.8	0.42	34	400	208
	13-Nov	164.0	0.3	1.2	0.08	3.6	13	4
	14-Dec	4.8	0.4	1.3	0.24	5.2	20	40
	15-Feb	47.2	0.0	3.2	0.56	57	160	130
	15-Jul	1.0	0.3	2.1	0.122	12.2	150	330
	15-Nov	6.9	0.4	1.2	0.112	9.17	140	90
	16-Feb	5.4	0.2	2.1	0.163	8	50	110
	16-May	21.3	0.3	1.9	0.13	14.8	30	180
	16-Aug	21.1	0.3	1.6	0.021	7.14	110	60
	16-Oct	6.8	0.3	1.6	0.067	9.11	80	90
	16-Nov	8.4	0.3	1.6	0.134	6.71	40	50
	16-Dec	9.0	0.4	4.9	0.325	29.8	2000	380
	17-Jan	7.6	0.4	2.0	0.198	8	10	240
	17-Feb	5.4	0.3	2.4	0.398	23.3	20	70
	17-Mar	10.9	0.4	2.0	0.292	17.8	120	280
	17-Apr	7.7	0.4	1.3	0.323	13.6	90	200
	17-May	4.7	0.3	1.5	0.279	7.6	200	90
	17-Jun	4.0	0.3	1.3	0.204	4.75	190	100
	17-Jul	3.1	0.3	1.3	0.17	7.2	80	250
	17-Aug	3.4	0.3	1.8	0.155	9.75	540	270
	17-Sep	2.3	0.3	1.2	0.304	4.8	130	50
	17-Oct	6.8	0.3	1.6	0.169	8.33	120	120
	17-Nov	3.7	0.3	1.5	0.342	13.7	160	140
	17-Dec	6.0	0.3	1.5	0.317	8.33	170	40
	18-Jan	6.6	0.3	1.9	0.432	8.67	30	80
	18-Feb	6.4	0.3	1.4	0.364	9	140	250
	18-Mar	15.2	0.3	2.4	0.409	14.8	150	150
	18-Apr	10.9	0.4	1.4	0.254	5.6	70	50
	18-May	3.2	0.3	1.4	0.141	10	150	90
	18-Jun	2.9	0.3	1.3	0.09	13	30	100
	18-Jul	2.4	0.3	1.5	0.053	6.2	50	30
	18-Aug	5.6	0.3	1.2	0.071	13.7	800	850
	18-Sep	10.0	0.3	1.5	0.151	11.2	20	40
	18-Oct	46.0	0.3	1.6	0.162	12.7	80	130
	18-Nov	10.8	0.3	1.6	0.179	17	190	150
	18-Dec	13.2	0.3	2.5	0.231	12.5	140	90
	19-Jan	6.1	0.3	2.2	0.228	28	40	150
	19-Feb	4.6	0.3	2.9	0.189	1.5	30	170
	19-Mar	11.7	0.3	1.9	0.124	8	30	70
	19-Apr	4.5	0.3	1.6	0.014	7.6	60	680
	19-May	6.4	0.3	1.7	0.025	9.6	180	90
	19-Jun	7.5	0.3	1.2	0.035	10.6	300	200
	19-Jul	1.2	0.2	1.4	0.051	12.3	300	380
	19-Aug	3.1	0.3	1.5	0.122	12	300	570
	19-Sep	2.5	0.3	1.9	0.081	8.67	240	60
	19-Oct	2.2	0.3	1.8	0.156	4.75	3400	450
	19-Nov	2.0	0.4	1.4	0.128	15.5	940	400
	19-Dec	1.5	0.3	2.3	0.106	50	6100	2100

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	10B							
	10-Dec							
	11-Mar	7.80	14.31	0.70	0.06	26	40	2420
	11-Jun	0.80	21.64	1.10	0.04	22	40	100
	11-Sep							
	12-Apr	1.90	5.57	1.60	0.1	9.6	721	182
	12-Sep	1.80	5.26	1.10	0.03	8	374	186
	13-May	3.90	5.23	1.83	0.11	79.4	23	1
	13-Nov	1.20	5.64	1.64	0.09	11.4	128	81
	14-Dec	0.60	5.63	1.10	0.17	6.3	20	50
	15-Feb	1.00	5.34	1.05	0.13	3.9	5	10
	15-Jul	1.00	2.32	1.51	0.11	9.2	30	20
	15-Nov	1.08	11.98	1.06	0.093	7.49	50	30
	16-Feb	0.77	5.20	1.34	0.079	4.3	20	20
	16-May	1.07	4.03	0.92	0.061	5.8	80	20
	16-Aug	4.74	2.65	1.77	0.009	8	50	20
	16-Oct	1.69	5.37	1.25	0.122	6.67	110	70
	16-Nov	4.58	4.96	1.48	0.146	3.67	110	40
	16-Dec	1.87	8.56	1.88	0.085	8.6	90	110
	17-Feb	2.55	7.87	1.35	0.129	11	50	60
	17-May	0.51	7.67	1.37	0.036	14.3	20	70
	17-Aug	1.94	1.78	0.90	0.117	7.25	270	170
	17-Nov	1.90	4.56	1.04	0.199	4.67	10	30
	18-Feb	3.13	4.93	0.94	0.162	1.2	10	10
	18-May	0.27	4.13	1.08	0.085	4.6	30	50
	18-Aug	1.70	1.38	1.31	0.098	13	1080	440
	18-Nov	1.53	3.99	1.39	0.148	10	20	30
	19-Feb	22.30	3.86	1.98	0.166	11	70	300
	19-May	0.27	4.11	1.09	0.092	7.2	70	140
	19-Aug	20.10	3.64	1.03	0.082	9	300	230
	19-Nov	0.27	16.17	0.66	0.081	3.75	70	160
Naples Bay	**11B**							
	12-Apr	4.90	0.35	1.20	0.06	3.6	50	93
	12-Sep	3.00	0.30	0.99	0.11	3.6	489	194
	13-May	5.00	0.41	0.84	0.1	10.4	645	649
	13-Nov	10.60	0.33	0.67	0.09	1.6	132	40
	14-Dec	6.30	0.35	0.87	0.16	4.1	560	160
	15-Feb	13.00	0.36	0.84	0.08	5.1	350	290
	15-Jul	1.00	0.28	1.11	0.398	4.53	520	40
	15-Nov	8.61	0.30	0.80	0.135	1.44	2800	300
	16-Feb	2.85	0.30	1.19	0.088	11.5	850	720
	16-May	7.87	0.33	0.72	0.042	2.74	2700	2800
	16-Aug	13.70	0.28	1.20	0.105	2.56	830	160
	16-Oct	4.01	0.30	0.88	0.111	2.7	6400	3600
	16-Nov	4.50	0.31	1.13	0.118	2.67	350	330
	16-Dec	4.03	0.37	1.30	0.099	2	840	240
	17-Feb	3.86	0.36	1.41	0.019	5.47	1050	400
	17-May	1.68	0.32	0.89	0.056	3.26	260	90

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	17-Aug	2.15	0.26	0.56	0.133	0.57	1500	380
	17-Nov	8.45	0.34	1.03	0.222	5	550	140
	18-Feb	1.66	0.38	1.21	0.195	4.2	630	200
	18-May	2.29	0.37	1.02	0.257	2	400	510
	18-Aug	1.52	0.26	1.35	0.112	7.3	2000	530
	18-Nov	2.03	0.34	0.76	0.074	11	170	120
	19-Feb	5.11	0.37	1.39	0.131	9	910	220
	19-May	2.20	0.34	1.07	0.065	2.2	1010	260
	19-Aug	1.76	0.32	1.43	0.057	5.33	3100	220
	19-Nov	0.80	0.32	1.06	0.078	2.5	700	240
	14B							
	12-Apr	3.40	4.63	0.76	0.89	7.2	50	372
	12-Sep	2.30	4.31	1.90	0.22	14	1	142
	13-May	5.00	4.96	1.56	0.54	28	178	1120
	13-Nov	2.70	4.60	1.16	0.21	23.2	430	164
	14-Dec	7.10	4.94	1.32	0.46	16	80	140
	15-Feb	11.90	5.17	1.25	0.7	9.3	210	330
	15-Jul	1.00	3.91	1.73	0.322	20	1060	2800
	15-Nov	99.30	5.22	2.28	0.457	10.2	150	80
	16-Feb	3.50	4.20	1.82	0.725	9.4	50	60
	16-May	3.74	7.53	1.86	0.743	17.5	180	280
	16-Aug	5.21	3.61	2.58	0.375	13.7	100	20
	16-Oct	2.75	4.81	1.51	0.345	4	160	20
	16-Nov	4.15	4.72	2.28	0.537	9.57	70	30
	16-Dec	7.36	5.50	2.40	0.477	9.8	190	150
	17-Feb	6.51	4.49	1.48	1.04	7.05	70	80
	17-May	4.03	4.43	1.68	0.986	24	120	170
	17-Aug	3.08	2.95	1.27	0.231	10.6	20	210
	17-Nov	4.11	4.46	2.47	0.585	5	60	80
	18-Feb	20.00	4.56	2.75	0.88	36	460	250
	18-May	1.46	4.90	2.03	0.516	23.8	110	90
	18-Aug	0.27	3.07	1.85	0.311	16.7	440	680
	18-Nov	1.84	4.78	1.34	0.288	21	310	200
	19-Feb	4.97	4.84	1.91	0.665	32	160	550
	19-May	19.30	4.83	2.39	0.059	43.2	30	150
	19-Aug	9.85	3.86	1.95	0.087	56.7	560	380
	19-Nov	0.27	7.88	1.98	0.185	50	2500	430
	24B							
	12-Sep	2.40	0.72	2.70	1.3	14	3200	42
	13-May	14.90	0.89	3.33	0.62	82	520	980
	13-Nov	17.50	0.58	2.35	1.42	30	76	132
	14-Dec	4.60	0.70	3.26	2.38	10.6	270	360
	15-Feb	4.40	0.72	3.26	1.56	28.5	130	200
	15-Jul	1.00	0.67	3.79	1.22	34	330	790
	15-Nov	13.00	0.62	3.38	2.61	16.8	650	400
	16-Feb	2.59	0.60	2.97	2.48	24	80	190
	16-May	2.13	0.67	2.97	1.11	20.4	570	750
	16-Aug	0.90	0.64	4.22	2.16	15.3	2000	540

Drainage Basin	Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
	16-Oct	4.09	0.61	4.15	2.17	22	2800	690
	16-Nov	2.51	0.63	2.90	2.07	21.3	80	200
	16-Dec	3.43	0.69	4.29	2.25	19.3	220	420
	17-Feb	3.13	0.68	4.59	1.87	20.8	90	180
	17-May	1.47	0.72	3.62	1.22	40.8	430	370
	17-Aug	1.07	0.60	4.62	3.02	27.3	860	450
	17-Nov	0.83	0.69	3.88	2.17	12.3	120	270
	18-Feb	3.41	0.75	3.42	1.9	21.3	70	210
	18-May	1.18	0.80	5.72	2.06	39	700	970
	18-Aug	2.09	0.62	5.56	2.69	26	2600	1900
	18-Nov	11.30	0.61	3.33	1.37	40.7	1220	2100
	19-Feb	1.69	0.62	0.72	1.16	15	140	450
	19-May	1.85	0.65	3.13	0.98	25	470	3300
	19-Aug	3.43	0.59	3.84	2.64	11	670	2600
	19-Nov	0.76	0.70	3.66	2.6	22	200	110

Table A-2. Summary of raw pump station water quality data, City of Naples, December 2010 through December 2019.

Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
PW-Pump							
10-Dec	8.60	0.47	1.60	0.220	8.0	855	1300
11-Mar							
11-Jun							
11-Sep							
12-Apr	2.00	0.80	1.30	0.070	2.8	3400	870
12-Jul	8.20	4.04	1.19	0.080	7.6	1980	500
12-Sep	38.00	0.83	1.10	0.090	4.8	4200	516
12-Dec	1.30	1.87	1.40	0.100	1.2	5200	437
13-May	6.30	1.47	1.17	0.080	1.3	18	594
13-Jun							
13-Aug	14.60	0.46	1.08	0.170	1.8	470	140
13-Nov	3.90	0.83	1.17	0.090		5400	49
14-Feb	6.90	1.46		0.090	1.2	800	5400
14-Dec	10.40	4.60	1.90	0.270	2.1	20	200
15-Feb	21.40	0.94	1.49	0.100	4.0	110	790
15-May	7.65	0.39	0.97	0.073	3.6	3000	710
15-Jul	5.00	2.07	1.17	0.100	2.4	1800	210
15-Nov	7.15	0.65	1.20	0.105	1.7	190	140
16-Feb	3.64	0.42	1.30	0.102	1.8	30	270
16-May	3.75	3.55	0.95	0.108	12.6	20000	13400
16-Aug	4.58	0.37	1.68	0.095	23.3	12300	3800
16-Nov	2.15	0.60	1.58	0.131	1.7	10	510
17-Feb	0.46	2.57	1.41	0.099	0.8	4600	200
17-May	0.71	0.58	1.39	0.091	0.9	730	590
17-Aug	7.24	0.36	0.93	0.140	1.6	4700	510
17-Nov	7.94	0.69	1.39	0.116	5.3	50	80
18-Feb	5.76	0.69	1.45	0.079	28.6	140	150
18-May	3.21	2.50	1.17	0.065	1.7	490	450
18-Aug	5.91	0.35	1.37	0.139	5.6	8000	1390
18-Nov	1.22	0.79	1.21	0.054	0.6	80	80
19-Feb	2.95	0.77	1.21	0.071	1.0	80	220
19-May	0.35	8.18	1.11	0.096	1.6	490	60
19-Aug	3.23	0.64	1.06	0.117	0.6	2600	2900
19-Nov	0.27	3.65	1.19	0.095	1.0	4100	430
11-Pump							
10-Dec	1.40	0.81	1.50	0.130	1.6	390	215
11-Mar	1.60	0.75	1.70	0.110	1.6	82	1000
11-Jun	2.70	1.14	1.80	0.210	13.0	18700	510
11-Sep	1.20	0.67	1.30	0.150	2.8	11200	1800
12-Apr	1.70	1.36	1.60	0.120	3.6	9910	1730
12-Jul	2.90	0.83	1.52	0.140	4.0	112000	200
12-Sep	3.20	0.75	1.80	0.600	5.2	4700	127

Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
12-Dec	1.10	1.17	1.81	0.130	2.8	450	501
13-May							
13-Jun	1.40	0.73	1.31	0.120	2.5	61	472
13-Aug	1.70	0.66	1.26	0.150	1.1	210	60
13-Nov	2.20	0.82	1.54	0.120		115	961
14-Feb	1.00	0.77		0.140	1.2	918	96100
14-Dec	2.00	0.88	1.56	0.210	0.7	50	540
15-Feb	15.50	1.50	1.57	0.120	0.6	350	2900
15-May	5.27	0.71	1.56	0.164	0.6	4200	1800
15-Jul	1.00	0.58	1.33	0.136	2.4	1700	470
15-Nov	0.35	0.97	1.41	0.139	0.6	900	740
16-Feb	0.72	0.68	1.35	0.137	1.0	220	400
16-May	4.26	0.58	1.10	0.132	1.9	11200	10200
16-Aug	4.26	0.55	1.67	0.203	1.3	17900	1390
16-Nov	1.20	0.97	1.86	0.176	1.9	790	730
17-Feb	0.84	0.72	1.67	0.165	2.2	540	14900
17-May	0.49	0.78	1.73	0.197	30.3	480	2900
17-Aug	1.31	0.65	1.14	0.176	1.2	1900	410
17-Nov	1.18	0.54	1.56	0.188	46.7	240	1060
18-Feb	1.04	0.94	1.13	0.084	2.7	900	14800
18-May	3.09	0.67	1.35	0.150	5.0	1500	4500
18-Aug	1.69	0.50	1.38	0.129	6.0	3000	2000
18-Nov	1.50	0.69	1.38	0.123	1.7	120	2300
19-Feb	2.83	0.60	1.21	0.123	2.3	410	2800
19-May	0.98	0.77	1.28	0.097	0.6	5900	630
19-Aug	4.01	0.67	1.23	0.128	1.0	9900	860
19-Nov	0.76	1.02	1.36	0.141	0.6	7800	2200
14-Pump							
10-Dec	5.00	3.89	1.60	0.480	2.4	360	1730
11-Mar							
11-Jun							
11-Sep							
12-Apr	2.90	4.05	1.10	0.830	4.8	4000	300
12-Jul	45.00	5.03	0.91	0.150	54.0	1350	1200
12-Sep	3.60	19.01	1.10	0.160	74.0	220	333
12-Dec	2.20	0.64	1.92	0.400	4.0	360	550
13-May							
13-Jun	3.20	24.84	0.79	0.150	26.3	2000	1400
13-Aug	2.50	10.33	1.22	0.210	8.6	800	3400
13-Nov	3.90	6.48	1.50	0.260	8.6	16	961
14-Feb	3.00	3.85		0.680	3.1	918	96100
14-Dec	5.60	4.28	1.75	0.550	8.6	330	880
15-Feb	2.10	4.25	1.81	0.550	1.3	2300	2200
15-May	5.02	11.20	1.54	0.300	8.4	520	840
15-Jul	1.13	14.15	1.09	0.210	9.1	1500	180

Sampling Year-Month	Copper (µg/L)	Salinity (ppt)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)
15-Nov	0.72	4.83	1.91	0.460	2.4	310	3500
16-Feb	2.38	3.37	1.90	0.540	6.1	170	490
16-May	19.30	8.98	3.93	0.490	48.4	9500	5200
16-Aug	2.35	3.26	4.91	0.440	14.0	590	100
16-Nov	2.18	26.28	1.03	0.180	2.4	10	80
17-Feb	1.40	4.87	1.25	0.760	2.1	30	2300
17-May	2.33	5.27	1.71	0.830	15.4	420	190
17-Aug	0.99	13.12	1.01	0.250	3.4	410	340
17-Nov	0.87	3.45	1.50	0.420	1.3	10	120
18-Feb	4.38	5.63	1.88	0.540	10.0	130	640
18-May	0.24	14.77	1.68	0.490	22.6	900	1100
18-Aug	3.12	2.36	3.03	1.210	10.0	5300	920
18-Nov	2.54	18.24	0.99	0.200	2.7	170	540
19-Feb	0.27	4.61	1.57	0.440	3.0	210	550
19-May	0.27	17.47	1.08	0.150	2.4	1070	390
19-Aug	9.48	10.02	1.27	0.240	42.0	4600	300
19-Nov	2.08	23.15	1.14	0.120	8.0	430	390

City of Naples

APPENDIX

B

SUMMARY OF STATISTICAL ANALYSES

Appendix B
Summary of Statistical Analysis

B.1 Water Quality Statistical Analyses

B.1.1 Stormwater Lakes and Pump Stations

Annual Kendall Tau Analysis

The main body of the report summarized significant increasing and decreasing trends in annual Kendall Tau analysis for the combined receiving waterbody. Below in Table B-1 are the annual Kendall Tau results for the individual stormwater lakes and parameters over time. Statistically significant increasing or decreasing trends including their annual slope of change are indicated in bold red.

Table B-1. Annual Kendall Tau analysis results for the individual lakes separated by receiving waterbody from 2010 through 2019.

Copper				
Lake	**Years**	**Tau**	**p-value**	**Slope (µg/L/yr)**
Moorings Bay				
1 SE-B	2012-2019	**-0.22**	**0.02**	**-3.92**
2B	2010-2019	-0.14	0.16	N/A
3B	2012-2019	-0.19	0.06	N/A
5B	2010-2019	-0.13	0.15	N/A
Gordon River				
6B	2012-2019	0.09	0.46	N/A
15B	2010-2019	**-0.30**	**0.01**	**-0.96**
19B	2012-2019	-0.02	0.83	N/A
20B	2010-2019	0.04	0.70	N/A
22B	2010-2019	0.10	0.29	N/A
26B	2012-2019	**-0.26**	**0.01**	**-5.81**
Gulf of Mexico				
8B	2017-2019	0.07	0.60	N/A
9B	2012-2019	**-0.26**	**0.01**	**-1.17**
10B	2011-2019	-0.01	0.93	N/A
Naples Bay				
11B	2012-2019	**-0.40**	**0.005**	**-0.70**
14B	2012-2019	0	1.00	N/A
24B	2012-2019	**-0.34**	**0.02**	**-0.57**

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.

Salinity				
Lake	**Years**	**Tau**	**p-value**	**Slope (ppt/yr)**
Moorings Bay				
1 SE-B	2012-2019	0.18	0.07	N/A
2B	2010-2019	**-0.56**	**<0.0001**	**-0.03**
3B	2012-2019	-0.14	0.15	N/A
5B	2010-2019	**-0.22**	**0.02**	**-0.30**
Gordon River				
6B	2012-2019	-0.16	0.19	N/A
15B	2010-2019	**-0.43**	**0.0002**	**-0.01**
19B	2012-2019	-0.12	0.23	N/A
20B	2010-2019	0.07	0.45	N/A
22B	2010-2019	**0.19**	**0.04**	**0.05**
26B	2012-2019	-0.06	0.53	N/A
Gulf of Mexico				
8B	2017-2019	-0.19	0.17	N/A
9B	2012-2019	**-0.25**	**0.01**	**-0.01**
10B	2011-2019	**-0.37**	**0.01**	**-0.35**
Naples Bay				
11B	2012-2019	0.07	0.61	N/A
14B	2012-2019	-0.02	0.87	N/A
24B	2012-2019	-0.11	0.43	N/A
TSS				
Lake	**Years**	**Tau**	**p-value**	**Slope (mg/L/yr)**
Moorings Bay				
1 SE-B	2012-2019	0.10	0.31	N/A
2B	2010-2019	**-0.22**	**0.03**	**-0.60**
3B	2012-2019	-0.06	0.51	N/A
5B	2010-2019	0.02	0.86	N/A
Gordon River				
6B	2012-2019	-0.09	0.45	N/A
15B	2010-2019	0.09	0.46	N/A
19B	2012-2019	0.10	0.31	N/A
20B	2010-2019	**-0.22**	**0.02**	**-0.85**
22B	2010-2019	-0.07	0.43	N/A
26B	2012-2019	-0.14	0.16	N/A
Gulf of Mexico				
8B	2017-2019	0.23	0.10	N/A
9B	2012-2019	0.03	0.77	N/A
10B	2011-2019	-0.22	0.10	N/A
Naples Bay				
11B	2012-2019	0.08	0.57	N/A
14B	2012-2019	**0.34**	**0.01**	**2.99**
24B	2012-2019	-0.01	0.94	N/A

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.

Total Nitrogen				
Lake	**Years**	**Tau**	**p-value**	**Slope (mg/L/yr)**
Moorings Bay				
1 SE-B	2012-2019	-0.07	0.50	N/A
2B	2010-2019	0.17	0.10	N/A
3B	2012-2019	-0.11	0.26	N/A
5B	2010-2019	-0.15	0.10	N/A
Gordon River				
6B	2012-2019	-0.07	0.58	N/A
15B	2010-2019	0.16	0.18	N/A
19B	2012-2019	0.05	0.64	N/A
20B	2010-2019	-0.05	0.61	N/A
22B	2010-2019	-0.17	0.07	N/A
26B	2012-2019	0.11	0.28	N/A
Gulf of Mexico				
8B	2017-2019	0.12	0.40	N/A
9B	2012-2019	0.06	0.55	N/A
10B	2011-2019	-0.13	0.34	N/A
Naples Bay				
11B	2012-2019	**0.29**	**0.04**	**0.04**
14B	2012-2019	**0.31**	**0.03**	**0.11**
24B	2012-2019	0.25	0.08	N/A
Total Phosphorus				
Lake	**Years**	**Tau**	**p-value**	**Slope (mg/L/yr)**
Moorings Bay				
1 SE-B	2012-2019	-0.19	0.06	N/A
2B	2010-2019	-0.17	0.09	N/A
3B	2012-2019	**-0.26**	**0.01**	**-0.01**
5B	2010-2019	**-0.37**	**0.0001**	**-0.01**
Gordon River				
6B	2012-2019	-0.07	0.60	N/A
15B	2010-2019	0.03	0.80	N/A
19B	2012-2019	-0.14	0.14	N/A
20B	2010-2019	**-0.21**	**0.03**	**-0.01**
22B	2010-2019	-0.09	0.31	N/A
26B	2012-2019	-0.001	0.99	N/A
Gulf of Mexico				
8B	2017-2019	-0.10	0.47	N/A
9B	2012-2019	-0.17	0.08	N/A
10B	2011-2019	0.16	0.23	N/A
Naples Bay				
11B	2012-2019	-0.03	0.85	N/A
14B	2012-2019	-0.11	0.41	N/A
24B	2012-2019	0.10	0.47	N/A

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.

Enterococci				
Lake	**Years**	**Tau**	**p-value**	**Slope (cfu/100mL/yr)**
Moorings Bay				
1 SE-B	2012-2019	0.003	0.98	N/A
2B	2010-2019	-0.11	0.27	N/A
3B	2012-2019	0.13	0.19	N/A
5B	2010-2019	0.12	0.19	N/A
Gordon River				
6B	2012-2019	0.16	0.21	N/A
15B	2010-2019	0.19	0.11	N/A
19B	2012-2019	0.04	0.66	N/A
20B	2010-2019	0.17	0.07	N/A
22B	2010-2019	0.06	0.55	N/A
26B	2012-2019	-0.01	0.94	N/A
Gulf of Mexico				
8B	2017-2019	0.17	0.22	N/A
9B	2012-2019	**0.26**	**0.01**	**20.00**
10B	2011-2019	0.10	0.47	N/A
Naples Bay				
11B	2012-2019	0.10	0.48	N/A
14B	2012-2019	0.11	0.42	N/A
24B	2012-2019	0.27	0.06	N/A
Fecal Coliform				
Lake	**Years**	**Tau**	**p-value**	**Slope (cfu/100mL/yr)**
Moorings Bay				
1 SE-B	2012-2019	-0.12	0.23	N/A
2B	2010-2019	-0.02	0.83	N/A
3B	2012-2019	0.05	0.61	N/A
5B	2010-2019	-0.04	0.66	N/A
Gordon River				
6B	2012-2019	0.17	0.18	N/A
15B	2010-2019	0.11	0.33	N/A
19B	2012-2019	**0.27**	**0.01**	**72.00**
20B	2010-2019	**0.22**	**0.02**	**28.13**
22B	2010-2019	0.01	0.90	N/A
26B	2012-2019	0.12	0.20	N/A
Gulf of Mexico				
8B	2017-2019	**0.40**	**0.003**	**468.80**
9B	2012-2019	**0.24**	**0.01**	**23.17**
10B	2011-2019	0.01	0.97	N/A
Naples Bay				
11B	2012-2019	0.25	0.07	N/A
14B	2012-2019	0.16	0.24	N/A
24B	2012-2019	0.004	0.98	N/A

All significant correlations ($p < 0.05$) and trend slopes are in **bold red**.

B.1.2 Naples Bay Water Quality Data – 2015 Analysis

Autoregressive Error Models for Time Series

In order to identify trends in the water quality data from Naples Bay over time, the previous analysis report used an Autoregressive Error Model (AEM). For many water quality variables, observations over time are temporally correlated. For example, the value of salinity at any given time (t) is correlated with the salinity value at an earlier time (t-1). Fitting a simple regression model through this data violates many of the statistical assumptions that are required for a proper trend detection. AEM is a simple model that reduces the chance of an incorrectly specified time series model that does not take temporal correlation into account.

Mathematically, the model can be written as:

$$Y_t = \beta_0 + \beta_1 * X_t + \gamma_t$$
$$\gamma_t = \varepsilon_t - \theta_{t-1}\gamma_{t-1} - .. - ..\theta_m\gamma_{t-m}$$
$$\varepsilon_t \sim N(0, \sigma^2)$$

Where y are dependent values, t represents a time step, x are covariates (in this case, simply the time that y is observed, e.g., month = 4), m is a lag function of 1 …. n, σ is standard deviation, θ is a measure of temporal correlation at lag m, and ε is the model error which is normally distributed (N).

Effectively, the model predicts y at time t as a function of time, where the error term in the model accounts for any temporal correlation which exists in the time series. Therefore, the errors from the model are normal, thus meeting the statistical assumptions for trend detection. Using this form, a test of H0: β1 = 0, is used to detect trend.

For time series analysis, the frequency of sampling must be consistent; because sampling prior to 2011 was conducted only bimonthly, the monthly sampling data available after 2011 for Naples Bay were subset to only include samples from every other month. Using only a bimonthly subset of the data allows data from a longer time period to be included in the models. In addition, the time series analysis was limited to years where flow data from GGC were available for use as a covariate, 2008–2014. For parameters with suitable datasets, time series AEM were applied to data for four locations in the Gordon River (Marine Segment) and Naples Bay. Stations GPASS6 (Gordon Pass), NBAYWS (mid estuary), and NBAYNL (northern Naples Bay) were selected because of their long-term continuous data set dating back to the beginning of the City's monitoring program and, collectively, they represent upper, middle, and lower Naples Bay. A single long-term data station within the area influenced by GGC was not available for the Gordon River (marine segment) so stations GORDEXT and GORDPT were combined based on their proximity to each other to represent a single long-term dataset and the marine section of the Gordon River above the SR 41 bridge. Two potential covariates, natural log-transformed daily flow from the GGC and monthly total rainfall, were considered for each model. The best fit models, using total model r^2 and corrected AIC (Akaike Information Criterion), were ones that included flow and rainfall for almost all parameters, with the exception of TN (flow was not included in the best fit model) and TP (flow was not included in a time series model that extended back to 2005, when flow data were not available). Water quality data, with the exception of dissolved oxygen and salinity, were also natural log-transformed.

The model results shown in the following sections for each water quality parameter are the best fit models from 2008–2014. Models were also run with just rainfall as a covariate or with no covariates from 2008–2014 and 2005–2014, but results were only reported if trends appeared that were not in in the full model scenario. In many cases, extending the model back to 2005 and without covariates eliminated significant trends seen in the best fit models.

Salinity-Flow Modeling

Cardno developed a model designed to evaluate the effect of freshwater flow emanating from the Golden Gate Canal on salinity concentrations at downstream areas during the 2008 to 2014 time period. Sensitivity testing of several time series model forms was implemented, including the use of autoregressive integrated moving average (ARIMA) models, autoregressive error models, and general linear models with trigonometric functions. The use of daily, weekly, and monthly data was also evaluated. The final model was fit to three years of monthly data (8/2011–7/2014, n = 36) for each of four downstream stations (Gordon River, City Dock, Mid-estuary, and Gordon Pass). The use of monthly data effectively smoothed the model development data set and provided a reasonable model fit for all areas.

The time series data for flow and salinity (average of surface and bottom where available) showed strong lag one autocorrelation (i.e., the value at time t is correlated with the value at time t-1) with the daily data, but there were a great deal of missing information (i.e., measurements on consecutive days) using either monthly or weekly data points. Using monthly means negated the need for a lagged relationship between salinity and flow, and resulted in a reasonable model. The best model for the three years of monthly data was simply:

$$Salinity_t = B_0 + B_1 * \ln(flow_t) + E_t$$

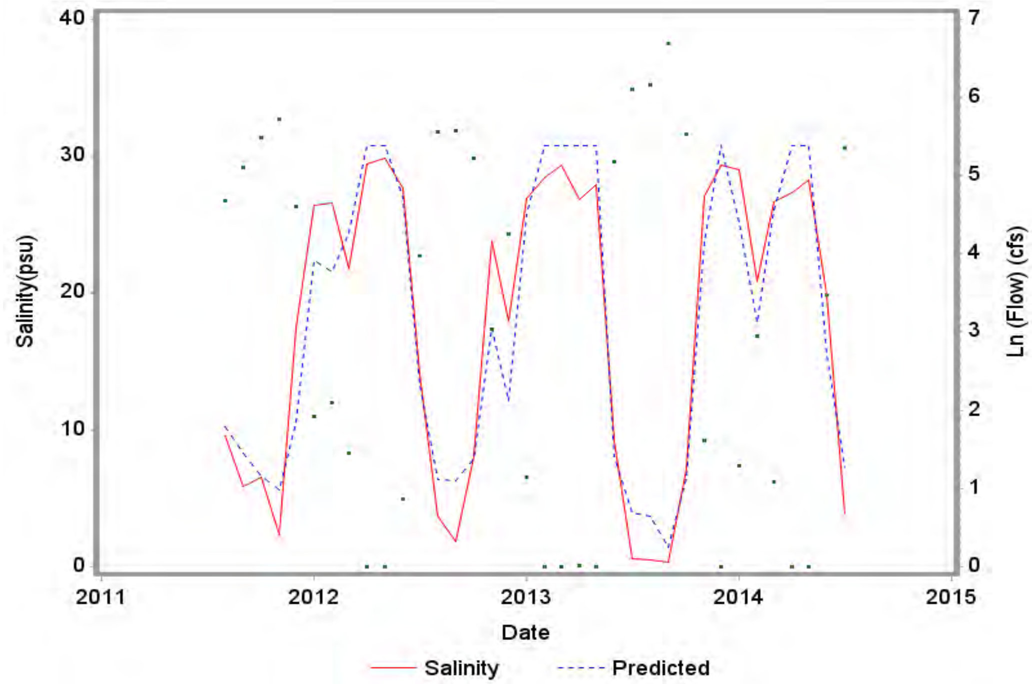
Effectively, the model predicts salinity at any month (t) as a function of the natural log of flow in the month. The degree of response that salinity has to flow decreases as the distance from GGC increases. Graphics illustrating the predictive ability of the models for each area are below.

The model was developed to estimate the change in salinity in Naples Bay as a result of potential GGC flow reduction scenarios. Three scenarios were chosen to represent a 30, 50, and 70 percent reduction in GGC flow. Graphics of the model results are also provided below.

Daily and seasonal salinity fluctuations in Naples Bay can be large, with flow from the GGC playing a significant role in determining the salinity regime in the Bay. In order to determine if the salinity regime in the Bay is changing over time, an AEM time-series model was fit to the available salinity data with daily average flow and monthly average rainfall as covariates. The results indicate salinity in Naples Bay is not changing over time ($p > 0.05$), although the model confirmed that GGC flow and rainfall have a statistically significant negative relationship with salinity in Naples Bay for most stations ($p < 0.05$, Table B-2).

Table B-2. Results of AEM time series models of bimonthly salinity in Gordon River (marine segment) and Naples Bay, 2008-2014, including total model fit (r^2); intercept, time, and covariate parameter estimates and p-values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		LN Flow		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	X_2	p	
GORDEXT/ GORDPT	0.8	21.9	0.3	-0.00008	0.9	-3.5	**0.003**	-1.4	**0.0001**	None
NBAYNL	0.7	52.5	0.05	-0.001	0.3	-2.2	**0.007**	-0.9	**0.0001**	None
NBAYWS	0.5	26.7	0.2	0.0002	0.8	-1.9	**0.02**	-0.6	**0.0005**	None
GPASS6	0.2	34.5	0.04	-0.00002	0.9	-0.7	0.2	-0.2	**0.04**	None



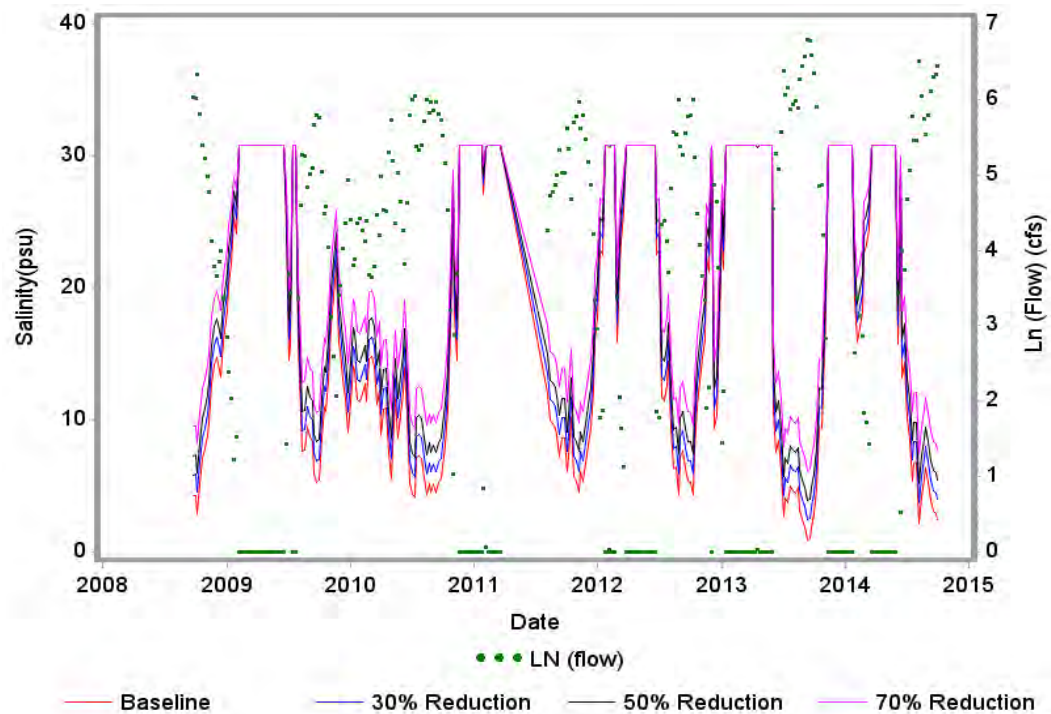
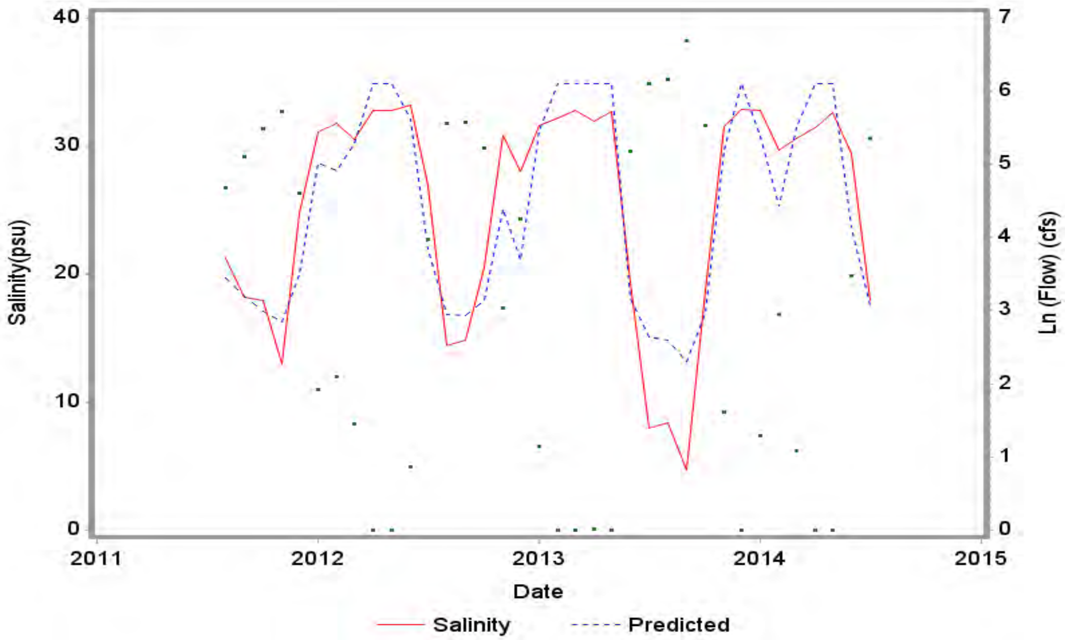


Figure B-1. Relationship of observed and predicted salinity, including flow magnitude (green dots) for Gordon River (top). Model results showing estimated salinity from flow reduction scenarios (bottom).



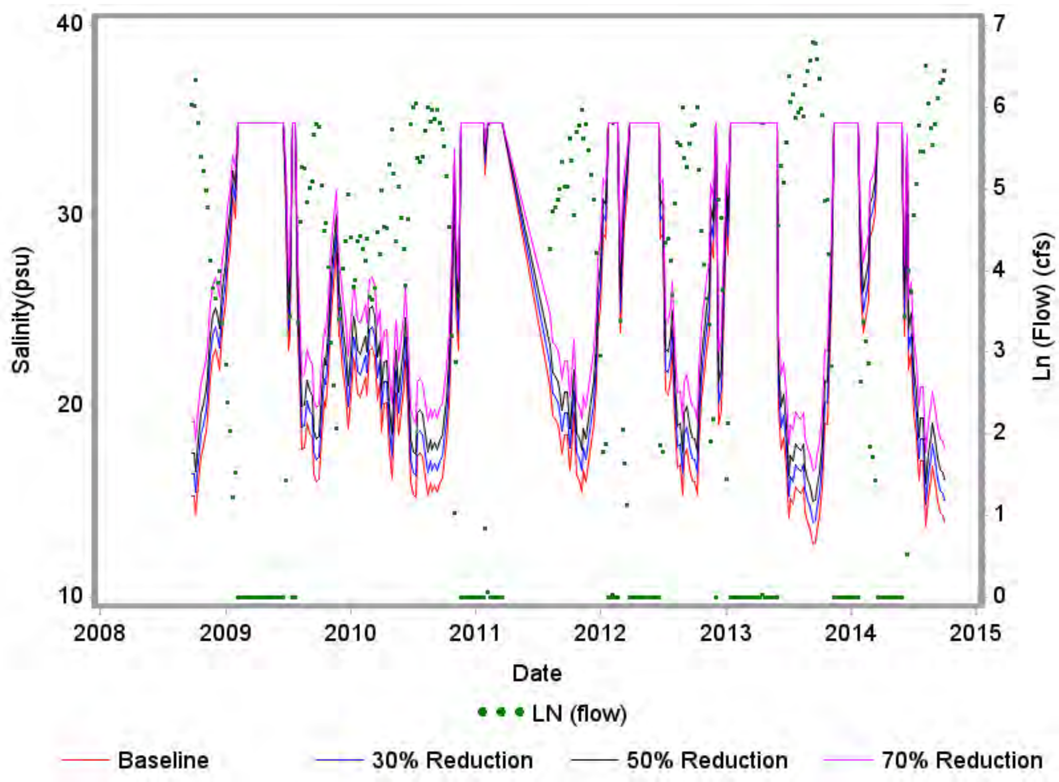
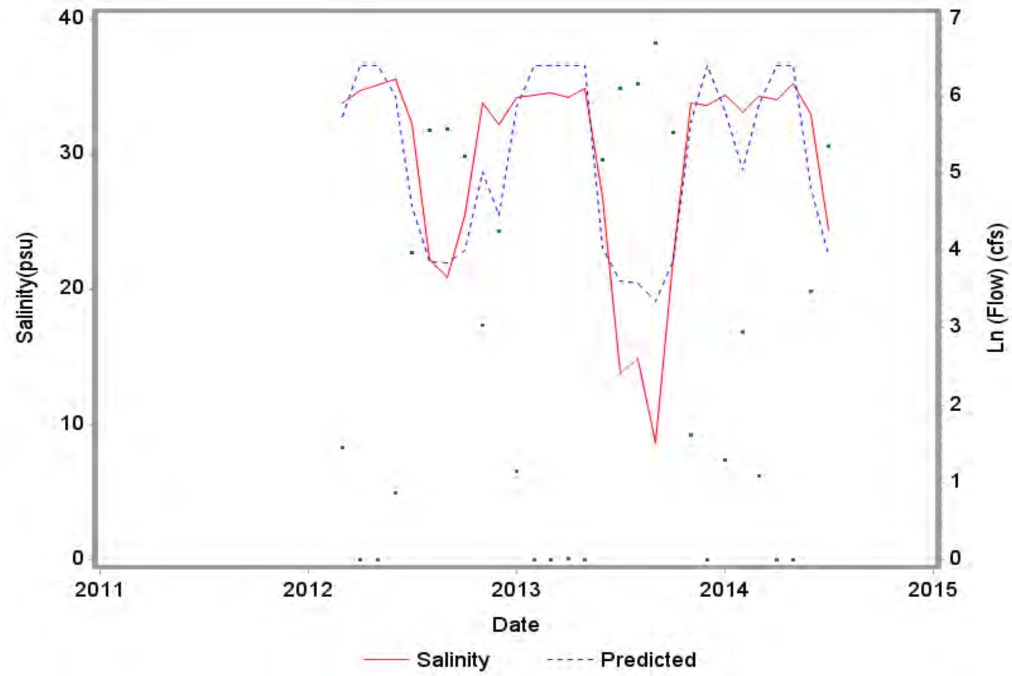


Figure B-2. Relationship of observed and predicted salinity, including flow magnitude (green dots) for Naples Bay at City Dock (top). Model results showing estimated salinity from flow reduction scenarios (bottom).



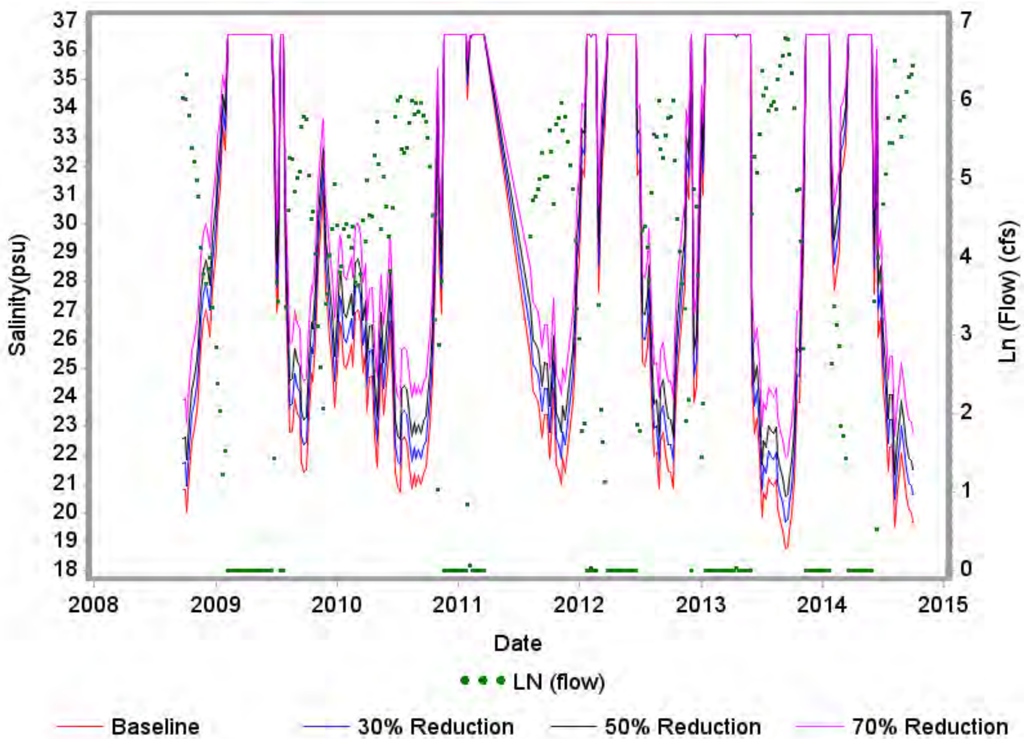


Figure B-3. Relationship of observed and predicted salinity, including flow magnitude (green dots) for Naples Bay Mid Estuary (top). Model results showing estimated salinity from flow reduction scenarios (bottom).

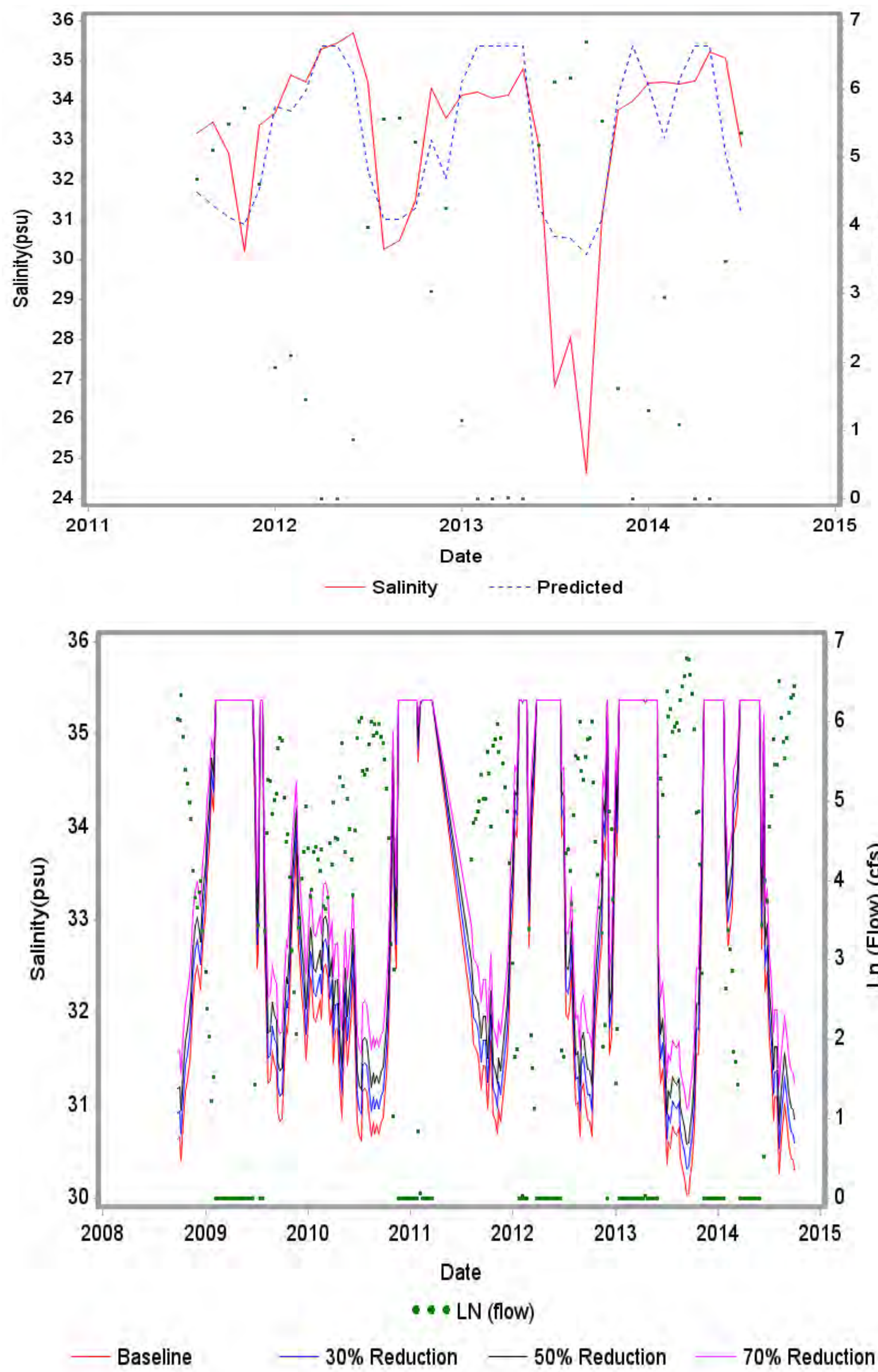


Figure B-4. Relationship of observed and predicted salinity, including flow magnitude (green dots) for Naples Bay at Gordon Pass (top). Model results showing estimated salinity from flow reduction scenarios (bottom).

Salinity Flow Management Tools

As a key component of any overall management and restoration plan for Naples Bay, focus should be given to controlling and reducing flow from the GGC. The Surface Water Improvement and Management Plan (SWIM) for the Naples Bay watershed includes strategies and actions to evaluate the magnitude and timing of freshwater inflow from the GGC to determine how to best manage the freshwater effect and minimize impact to Naples Bay (SFWMD 2007). This effort is supported by elements of the Big Cypress Basin Strategic Plan 2013-2018 (SFWMD 2013) which has suggested plans to improve the quantity, quality, timing, and distribution of water delivered to Naples Bay and Rookery Bay including the Northern Golden Gate Estates Flowway, North Belle Meade Rehydration, and the Henderson Creek Diversion projects. Although these potential projects are part of the Big Cypress Basin Strategic Plan and the Collier County Watershed Management Plan, investigations into the feasibility and potential consequences of each project are ongoing and no definitive water diversion projects are in progress at this time. This section briefly discusses the potential effects of flow reductions to Naples Bay in terms of salinity and offers insights into how flow reduction and alternative uses of GGC water may benefit Naples Bay.

As a management tool designed to provide the City with information necessary to understand the effect of reduced inflow from the GGC on the salinity regime of Naples Bay, a flow and salinity predictive model was developed. This model was developed using the salinity data from the four USGS continuous recorders that were operating in the Bay from 2011 through 2014.

The current condition and three GGC flow reduction scenarios were modeled: 30 percent, 50 percent, and 70 percent. The 30 percent flow reduction scenario (scenario 1) was chosen to represent the suggested potential diversion of GGC flow into the Henderson Creek watershed; the 50 percent reduction scenario (scenario 2) represents the Henderson Creek diversion along with the Aquifer Storage and Recovery (ASR) systems included in future planning for the City of Naples as well as the City of Marco Island (City of Naples 2010). Finally, the 70 percent reduction scenario (scenario 3) is meant to represent a potential maximum feasible GGC flow reduction from a combination of potential water diversion projects to provide an estimate of how much change in salinity regime can be expected from the current condition. Note that the 70 percent maximum flow reduction is an arbitrary threshold used for modeling purposes only, and does not represent any analysis that suggests this is the maximum level of flow reduction possible.

Assuming that the observed data from the USGS continuous recorders from 2011 to 2014 are representative of any future salinity and flow concentrations that could occur (given environmental conditions) without any explicit management of the GGC flow, the expected (or mean) percent increase in salinity was simulated as a function of the expected (or mean) percent decrease in flow. The regression model was used to predict the base case salinity using the observed GGC flow in the stated time frame. A reduction in flow was simulated simply by reducing the observed GGC flow by the selected percentage in each reduction scenario.

The model was used to predict percent change in salinity and the average wet season salinity at each station in each of the three reduction scenarios (Table B-3). The majority (over 90 percent) of the GGC flow occurs during the wet season, therefore the change in salinity regime would be expected to be concentrated in only the wet season. Under the 30 percent diversion plan (scenario 1), the model predicts the average salinity would increase by between 0.5 to 14 percent from south to north, respectively, in Naples Bay. In this scenario, the predicted wet season average surface salinity at Gordon Pass is predicted to increase from 31.8 to 31.96 ppt. Under the same scenario, the model predicts the Gordon River location to exhibit a wet season salinity increase of 14.2 percent resulting in an increase from 8.4 ppt in the current condition to 9.6 ppt on average. Scenario 3 (70 percent reduction in GGC flow) results in the largest predicted percentage change in salinity in Naples Bay, with the Gordon River location predicted to show an increase in wet season average salinity from 8.4 ppt in the current condition to 12.4 ppt on average. Yet, a 70 percent reduction in GGC flow is only predicted to increase average wet season salinity at Gordon Pass from 31.8 ppt to 32.4 ppt on average.

The model-predicted changes in the salinity regime in Naples Bay shown here are similar to the predicted changes in salinity developed by Weisberg and Zheng (2007) with a modeled 350 cfs reduction in GGC flow from 2005 conditions. Weisberg and Zheng (2007) used a Finite-Volume Coastal Ocean Model (FVCOM) that could be used to describe the circulation of the Rookery Bay estuarine complex (including

Naples Bay) and study the relationship between freshwater inflows and salinity patterns. The results of the modeling effort estimate salinity would increase between 2.2 and 5.1 ppt with a 350 cfs reduction in GGC flow (Weisberg and Zheng 2007). The range of salinity increase is similar to that observed in our predictive modeling effort.

The predicted changes in mean salinity under the three flow reduction scenarios are relatively modest given the large daily and seasonal swings in salinity that Naples Bay currently exhibits. As described in sections 4 and 5 of this document, the fish and seagrass communities of Naples Bay may not show a significant response to these predicted changes in salinity. However, in terms of management of Naples Bay, this result does not suggest that flow diversion projects would not be beneficial. Reduction in freshwater flow from the GGC into Naples Bay can significantly reduce loadings of solids and nutrients to the Bay. Concentrations of solids and nutrients delivered to Naples Bay are relatively low; however, the extremely high volume of water flowing from the GGC results in a large load delivery (see Section 3.1.1). Significant load reductions from a combination of water diversion projects may have a significant positive impact on Naples Bay biology (i.e. seagrass) (see Sections 4.1 and 5.1). In addition to the potential water diversion projects already discussed, alternative uses for the GGC water such as water supply and salt water intrusion barriers should also be considered as viable options to significantly reduce the inflow to Naples Bay as part of a holistic water management strategy that benefits not only the ecology of Naples Bay, but the water demands of one of the fastest growing regions in the United States.

Table B-3. Predicted percent change in average salinity and predicted average wet season salinity in Naples Bay under different Golden Gate Canal flow reduction scenarios.

Location	Predicted % Increase in Mean Salinity			Current and Predicted Average Wet Season Salinity (ppt)			
	Scenario 1	Scenario 2	Scenario 3	Current Condition	Scenario 1	Scenario 2	Scenario 3
Gordon River at Rowing Club Point	14.18	27.49	47.52	8.4	9.59	10.71	12.39
Naples Bay at City Dock	3.85	7.46	12.84	19.3	20.04	20.74	21.78
Naples Bay Mid Estuary	2.45	4.75	8.18	23.5	24.08	24.62	25.42
Naples Bay at Gordon Pass	0.56	1.07	1.85	31.8	31.96	32.14	32.38

Inverse Distance Weighting

In order to assess the spatial distribution of water quality concentrations within Naples Bay, a method of interpolation called Inverse Distance Weighting (IDW) was used in ArcGIS to develop a relative raster surface of concentrations where samples points did not exist. IDW is an interpolation method that assumes that points close together are more similar than those points father apart. To make a prediction at any one location, IDW assigns weights to neighboring observed values inversely related to the distance between the prediction and observation. The weights are assigned to each observation based on an inverse power function: $w(d) = 1/d^p$, where w is the assigned weight, d is the distance between points, and p is the exponent of the power function. With lower values of p, more weight is given to neighbors that are farther away, resulting in a smoother predicted surface. With higher values of p, almost all weight is given to very close neighbors, which increases local attenuation.

To implement IDW in Naples Bay, it was assumed that the low number of samples points was sufficiently distributed across the study area to provide a valid interpretation of values at unknown locations. To do this and accommodate the non-linear nature of the study area, barriers to interpolation were set where a line-of-sight rule from one sample point to another was maintained and a fixed distance rule of 9000 feet was required for inclusion into the interpolation. This means that in order for a neighboring sample point to be included in the interpolation surrounding another sample location it had to be within a line-of-sight of that point and within 9000 feet to be considered a neighbor. With the small number of samples, this required that a minimum of three to five nearest neighbors be used in the interpolation. The significance of surrounding points on the interpolated value, Power or *p*, was also set at a central value of 2. The output is a 20-ft cell size raster surface of interpolated concentrations, which can be color graded to indicate a simplified visualization of what that parameters distribution across the study area.

For most of the water quality parameters discussed below, the spatial distribution of concentrations using IDW are presented using data from 2008 and 2013.

B.1.3 Autoregressive Error Models for Time Series – 2010 to 2019

The model results shown for each water quality parameter are the best fit models based on monthly recordings and daily flow data from December 2010 to December 2019. Models were run with numerous autoregressive error model lags to determine the best fit models for each parameter at each of the four stations. Autoregression months varied from 0 months to 2 months, with 0 to 1 month lag being the most common best fit. Often even with best fit autoregression the overall r^2 for models was relatively weak (though some stations for some parameters had high r^2), which should be kept in mind when reviewing the stated trend results. As the results for this analysis were generally weak ($r^2 < 0.5$), so the graphs and tables of model outputs including fit (r^2), intercept, and covariate parameter estimates (with p-values) are included here. The water quality parameters analyzed in this trend analysis are salinity, nutrients (TN and TP), chlorophyll-*a*, dissolved oxygen (DO), turbidity, fecal coliform, and enterococci. The AEM analysis discussed looks to quantify the direct influences of these two main covariates and to assess if general trends of water quality increases or decreases over time are occurring.

Salinity

Daily and seasonal salinity fluctuations in Naples Bay can be large, with flow from the GGC playing a significant role in determining the salinity regime in the Bay. In order to determine if the salinity regime in the Bay is changing over time, an AEM time-series model was fit to the available monthly salinity data with daily average flow and monthly average rainfall as covariates (see Section 3.2.2.1). The key results of the AEM time series model are shown in Table B-4. The predicted time series from the AEM compared to the recorded time series for all four stations is shown in Figure B-5.

The results indicate salinity in Naples Bay is not changing over time ($p > 0.05$), with the exception of GORDEXT/GORDPT which has a statistically significant very slight decrease in salinity over time. The model confirmed that GGC flow in particular and rainfall (except for GORDEXT/GORDPT) have a statistically significant negative relationship with salinity in Naples Bay for most stations ($p < 0.05$).

Table B-4. Results of AEM time series models of monthly salinity in Naples Bay, WY 2011–2019, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		LN Flow		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	X_2	p	
GORDEXT/ GORDPT	0.45	10.89	0	-0.00025	<0.0001	0	0.97	-0.02	0.0004	1
NBAYNL	0.64	23.6	0.41	-0.00018	0.78	-0.22	0.04	-0.55	<0.0001	2
NBAYWS	0.62	47.66	0.10	-0.00069	0.31	-0.21	0.06	-0.46	<0.0001	2
GPASS6	0.44	28.3	0.22	-0.00027	0.62	-0.23	0.01	-0.23	0.0005	1

Note: statistically significant relationships or trends are colored in red.

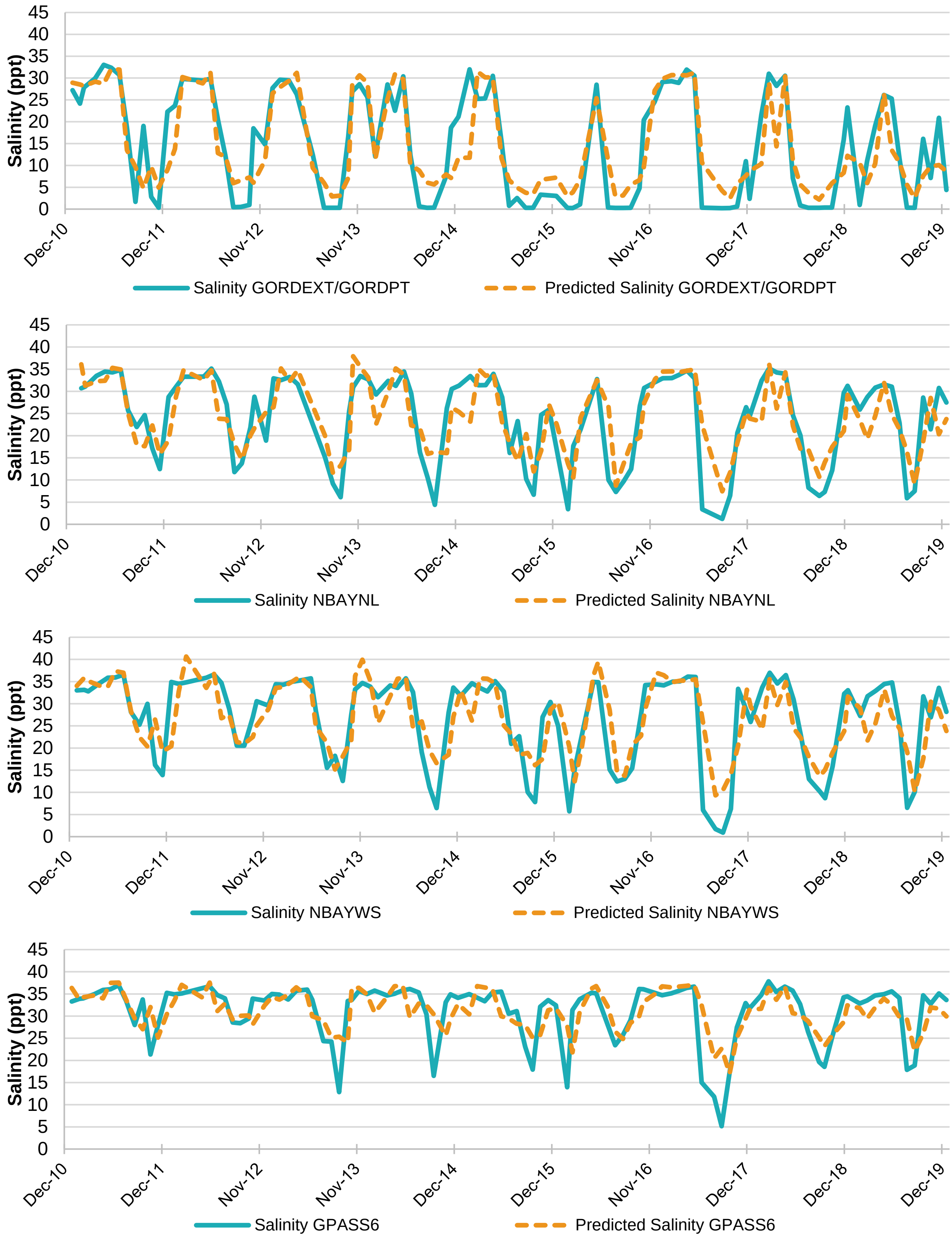


Figure B-5. Salinity measurements and AEM regression projected for WY 2011 to 2019 for the Gordon River (marine segment) and Naples Bay.

Nutrients (TN and TP)

Four stations in Naples Bay (WBID 3278R4) and the Gordon River (marine segment – WBID 3278R5) had enough long-term monitoring data to examine trends in nutrient concentrations over time at individual stations, accounting for the effects of flow from the Golden Gate Canal and regional rainfall. Graphs of the natural log transformed TN and TP data and modeled results are presented in Figures B-6 and B-7.

The AEM time series models do not indicate a statistically significant increasing or decreasing trend in TN over time for the December 2010 to 2019 period at two of the long-term stations (GORDEXT/GORDPT or GPASS, $p > 0.05$). However, there was a very slight increasing trend at NBAYNL and NBAYWS (coefficient 0.0001, $p < 0.05$). Flow was a statistically significant covariate at three of the stations (excluding GPASS6); however, rainfall showed no statistically significant relationship with TN at any of the long-term stations (Table B-5).

Three stations, NBAYNL, NBAYWS, and GPASS6 showed statistically significant trends over time in TP with slight increases over time (coefficients 0.0001 to 0.0003) using the AEM time series models. Two of these stations (NBAYNL and GPASS6) also had a significant positive relationship with rainfall (coefficients 0.03 and 0.02 respectively), and GORDEXT/GORDPT had a significant negative trend with flow. The models, similar to those of TN generally had relatively poor fit (Table B-6).

Table B-5. Results of AEM time series models of monthly TN in Naples Bay, WY 2011–2019, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		LN Flow		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	X_2	p	
GORDEXT/ GORDPT	0.20	-1.51	0.39	0.00003	0.48	0.01	0.42	0.01	0.003	1
NBAYNL	0.19	-5.24	0.03	0.0001	0.04	0.02	0.08	0.02	0.002	0
NBAYWS	0.25	-5.91	0.04	0.0001	0.05	0.01	0.15	0.004	0.05	2
GPASS6	0.33	-5.91	0.06	0.0001	0.08	0.02	0.11	0.01	0.43	2

Note: statistically significant relationships or trends are colored in red.

Table B-6. Results of AEM time series models of monthly TP in Naples Bay, WY 2011–2019, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		LN Flow		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	X_2	p	
GORDEXT/ GORDPT	0.05	-6.37	0.03	0.00008	0.27	0.01	0.33	-0.02	0.04	0
NBAYNL	0.15	-10.41	<0.0001	0.0002	0.002	0.03	0.004	-0.003	0.07	0
NBAYWS	0.26	-6.92	0.01	0.0001	0.05	-0.002	0.81	-0.0004	0.09	2
GPASS6	0.24	-16.03	<0.0001	0.0003	<0.0001	0.02	0.01	0.003	0.71	0

Note: statistically significant relationships or trends are colored in red.

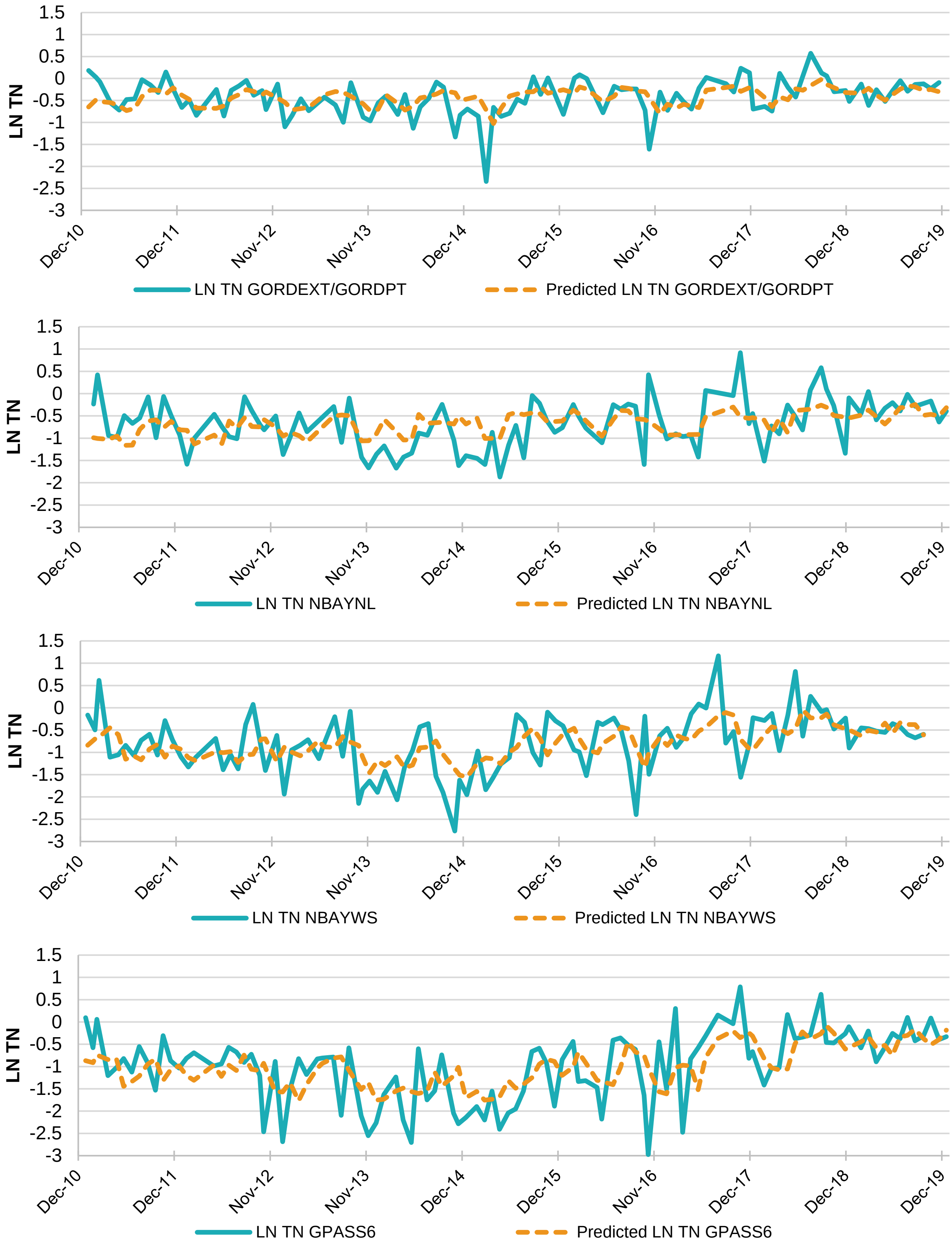


Figure B-6. LN TN concentrations and AEM regression projected for WY 2011 to 2019 for the Gordon River (marine segment) and Naples Bay.

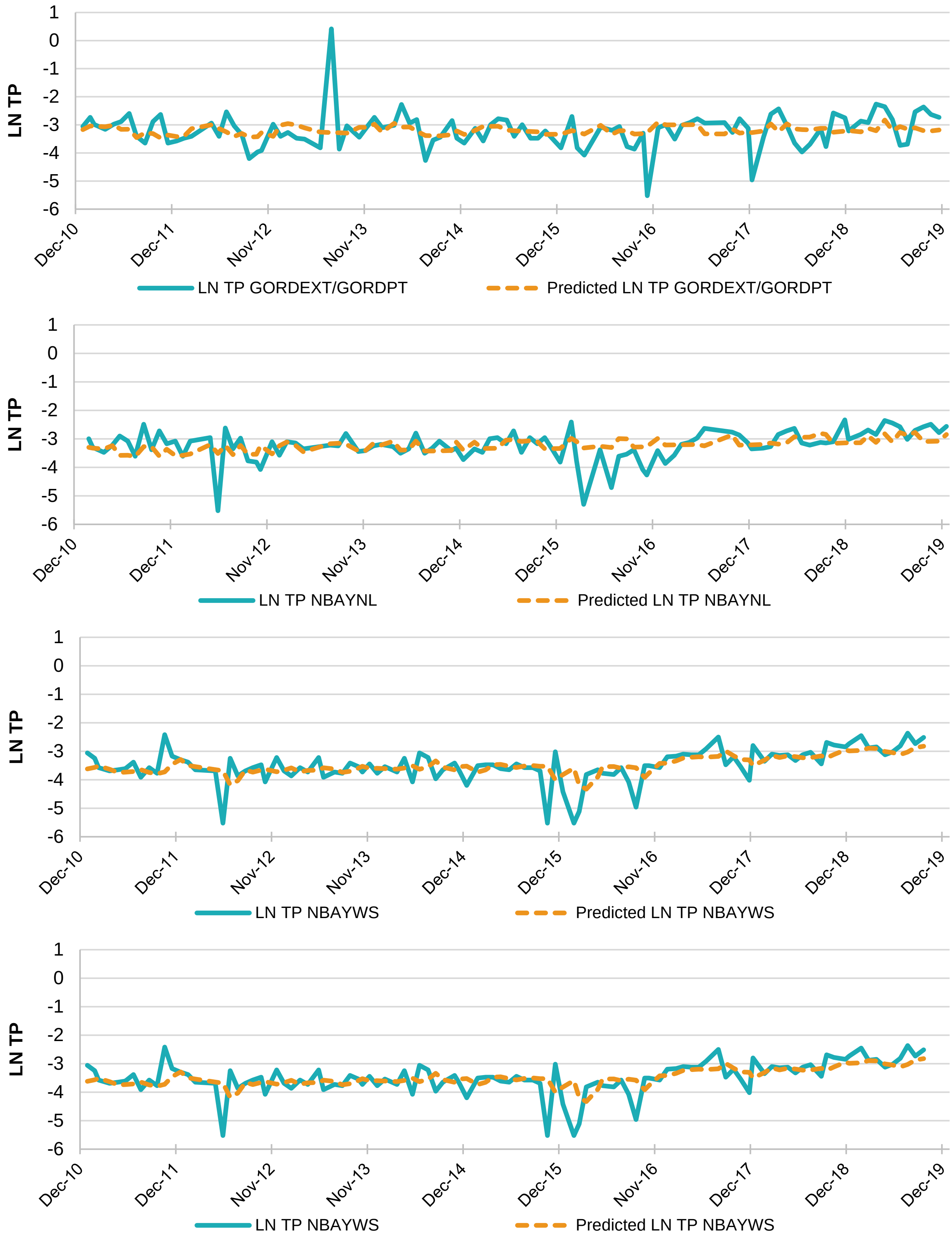


Figure B-7. LN TP concentrations and AEM regression projected for WY 2011 to 2019 for the Gordon River (marine segment) and Naples Bay.

Chlorophyll-a

Using AEM time series models, one station, NBAYNL showed a slight statistically significant decreasing trend over time in chlorophyll-*a* (coefficient -0.0001). While there was no increasing or decreasing trend in chlorophyll-*a* identified using the annual Kendall Tau analysis for NBAYNL, the very small decreasing trend identified AEM model could be a result of using natural log transformed data or utilizing all points instead of an annual value. All four stations also had a significant relationship with flow (positive for all but GORDEXT/GORDPT), and only NBAYWS had a significant correlation with rain. The models generally had relatively poor fit (Table B-7). Additionally, graphs of the natural log transformed chlorophyll-*a* data and AEM modeled results are presented in Figure B-8.

Table B-7. Results of AEM time series models of monthly chlorophyll-*a* in Naples Bay, WY 2011–2019, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		LN Flow		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	X_2	p	
GORDEXT/ GORDPT	0.11	0.61	0.84	0.00003	0.72	-0.01	0.48	-0.03	0.002	0
NBAYNL	0.09	6.91	0.01	-0.0001	0.04	-0.002	0.83	0.02	0.005	0
NBAYWS	0.08	1.90	0.49	0	0.96	0.03	0.01	0.01	0.04	0
GPASS6	0.13	6.33	0.02	-0.0001	0.06	0.01	0.61	0.02	0.0005	0

Note: statistically significant relationships or trends are colored in red.

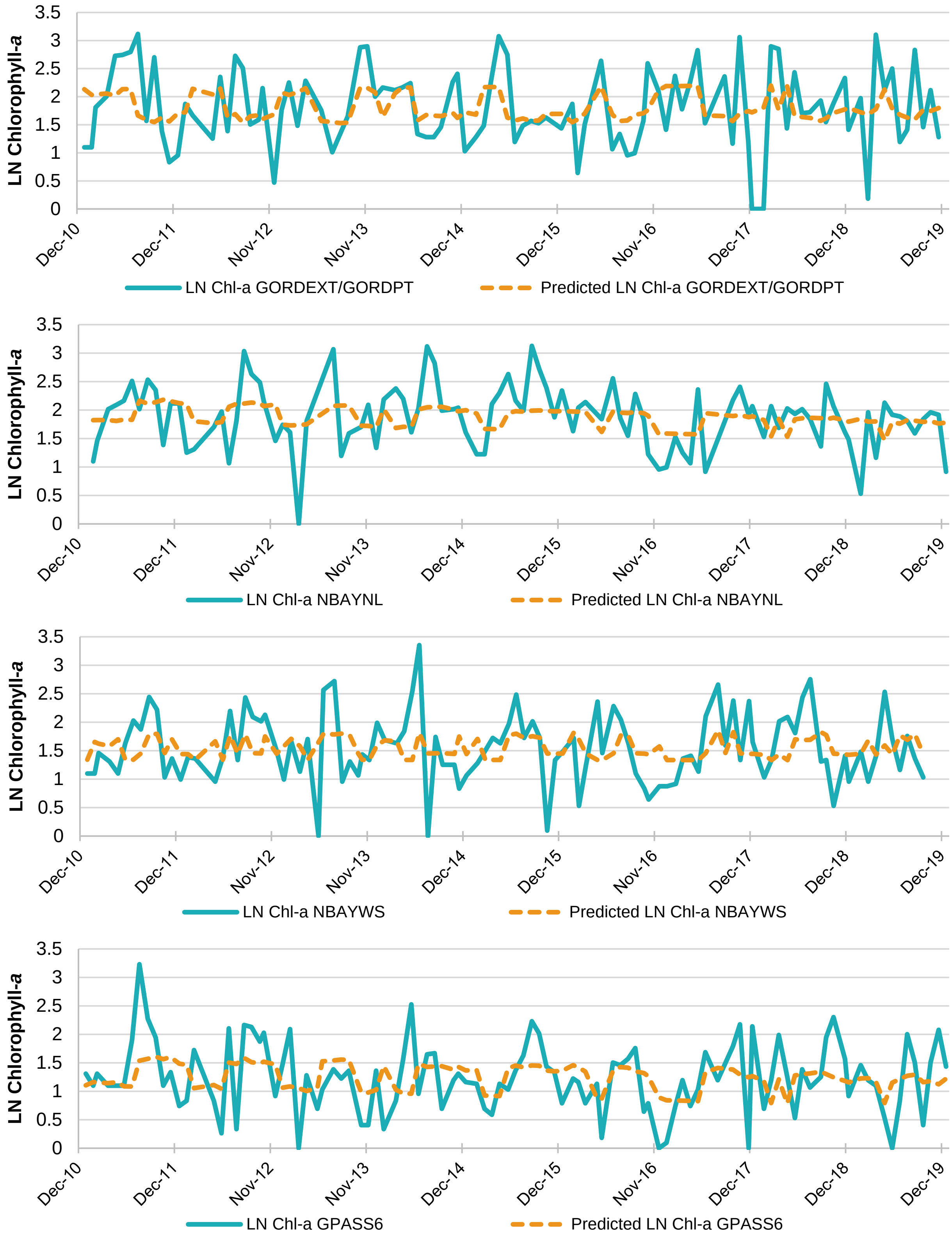


Figure B-8. LN chlorophyll-*a* concentrations and AEM regression projected for WY 2011 to 2019 for the Gordon River (marine segment) and Naples Bay.

Dissolved Oxygen

Regarding AEM trend analysis, none of the monitoring stations showed statistically significant trends over time in DO ($p > 0.05$). However, all four monitoring stations had a significant inverse relationship with rainfall (all coefficients negative from -0.04 to -0.05), and two stations (NBAYNL and NBAYWS) had a significant inverse correlation with flow (all negative coefficients). The models generally had relatively poor fit (Table B-8). Graphs of the DO concentrations and AEM modeled results are presented in Figure B-9.

Table B-8. Results of AEM time series models of monthly DO concentration (mg/L) in Naples Bay, WY 2011–2019, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		LN Flow		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	X_2	p	
GORDEXT/ GORDPT	0.20	-1.94	0.70	0.00012	0.33	-0.05	0.016	-0.003	0.08	1
NBAYNL	0.25	2.90	0.49	0.00004	0.73	-0.04	0.009	-0.01	0.05	2
NBAYWS	0.20	0.74	0.87	0.00008	0.49	-0.04	0.03	-0.02	0.01	1
GPASS6	0.27	4.39	0.29	-0.00001	0.90	-0.04	0.01	-0.02	0.07	1

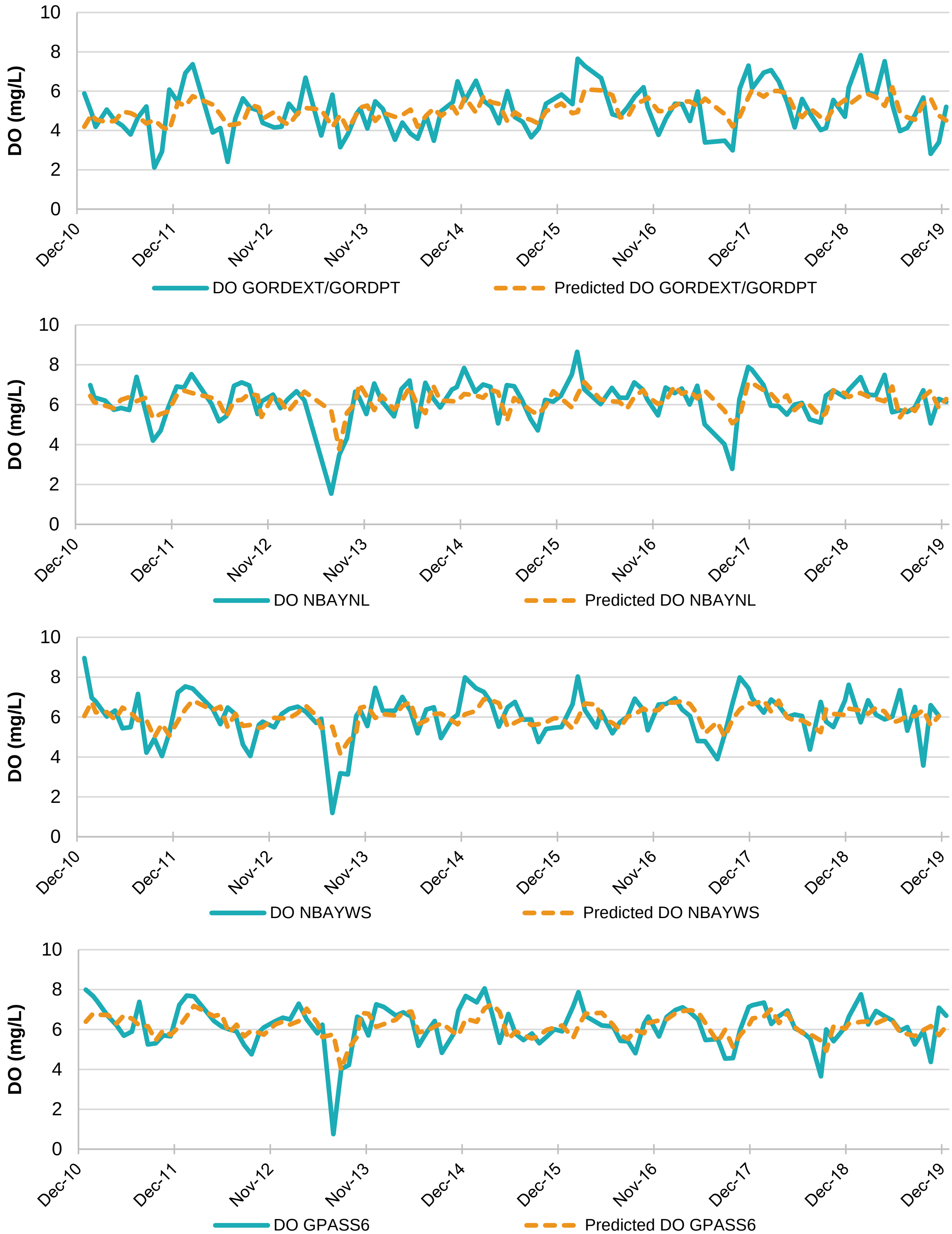


Figure B-9. DO concentrations and AEM regression projected for WY2011 to 2019 for the Gordon River (marine segment) and Naples Bay.

Turbidity

Regarding AEM trend analysis, all four stations showed statistically significant trends over time in turbidity (all coefficients slightly positive). No monitoring stations had a significant relationship with rainfall; however, all but GPASS6 had a significant inverse correlation with flow (all negative coefficients). The models generally had relatively poor fit (Table B-9). Graphs of the natural log transformed turbidity data and AEM modeled results are presented in Figure B-10.

Table B-9. Results of AEM time series models of monthly turbidity in Naples Bay, WY 2011–2019, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		LN Flow		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	X_2	p	
GORDEXT/ GORDPT	0.12	-8.42	0.002	0.0002	<0.001	0.01	0.20	-0.01	0.01	0
NBAYNL	0.33	-8.33	0.0002	0.0002	<0.0001	0.00	0.75	-0.02	<0.001	1
NBAYWS	0.43	-8.81	0.0002	0.0002	<0.0001	-0.01	0.22	-0.03	<0.0001	1
GPASS6	0.15	-14.00	0.0005	0.0004	<0.001	-0.02	0.30	-0.01	0.46	0

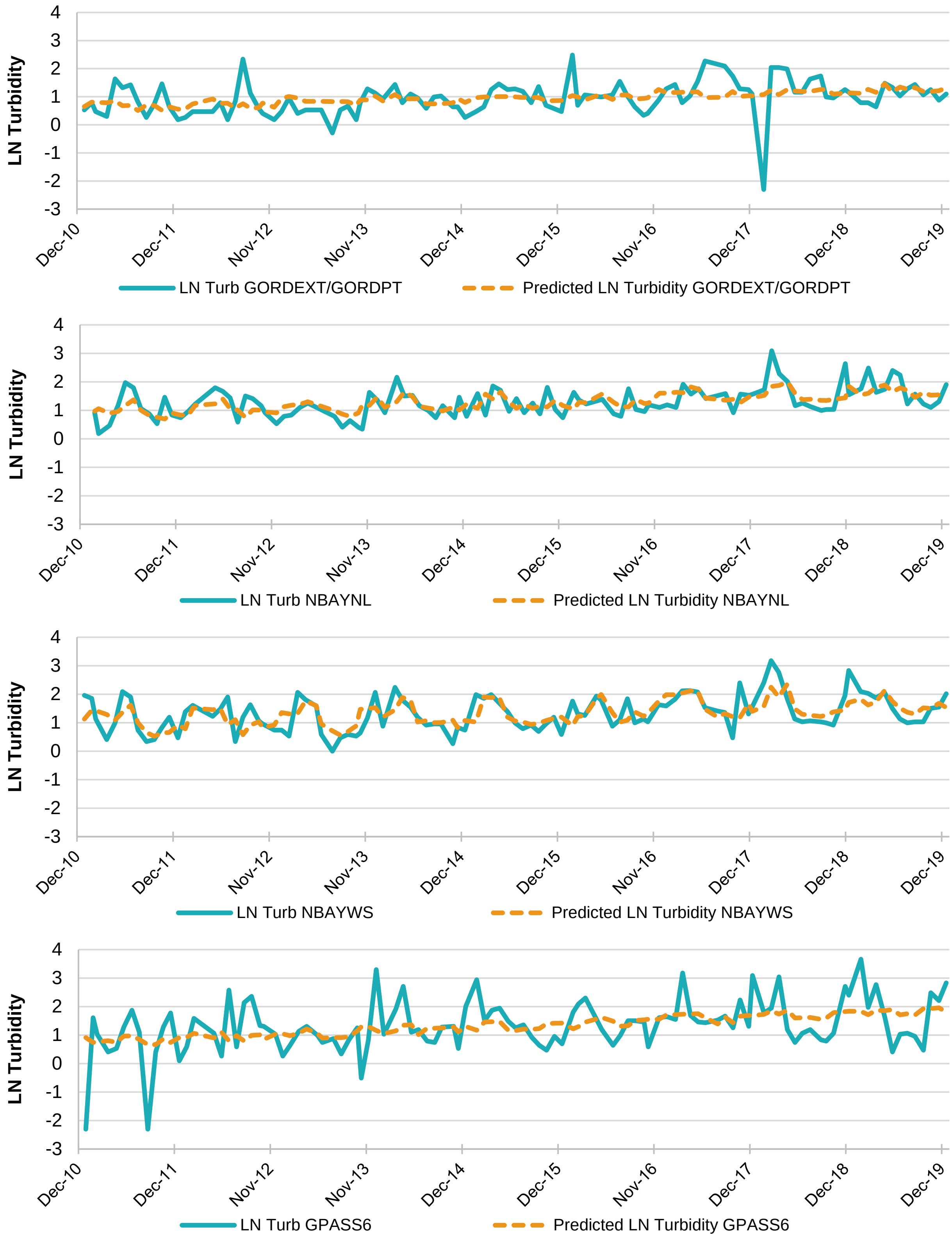


Figure B-10. LN turbidity measurements and AEM regression projected for WY 2011 to 2019 for the Gordon River (marine segment) and Naples Bay.

Fecal Coliform and Enterococci

Regarding AEM trend analysis, none of the four monitoring stations showed statistically significant trends over time for fecal coliform. Two stations had a significant relationship with rainfall, NBAYWS and GPASS6 (positive coefficients) and all but GORDEXT/GORD/PT had a significant correlation with flow (all positive coefficients). The models generally had relatively poor fit (Table B-10).

Enterococci bacteria show a statistically significant increasing trend over time at NBAYWS and GPASS6 (slightly positive coefficients). Three stations (except GORDEXT/GORDPT) had a significant relationship with rainfall (positive coefficients), and only GPASS6 had a significant correlation with flow (positive coefficients). The models generally had relatively poor fit (Table B-11).

Graphs of the natural log transformed fecal coliform and enterococci data and AEM modeled results are presented in Figures B-11 and B-12.

Table B-10. Results of AEM time series models of monthly fecal coliform in Naples Bay, WY 2011–2019, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		LN Flow		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	X_2	p	
GORDEXT/ GORDPT	0.01	9.68	0.18	-0.0001	0.50	0.02	0.512	0.00	0.08	0
NBAYNL	0.13	-1.41	0.88	0.0001	0.55	-0.01	0.82	0.07	0.001	0
NBAYWS	0.50	-7.55	0.31	0.0003	0.16	0.07	0.004	0.10	<0.0001	1
GPASS6	0.40	-9.26	0.19	0.0003	0.09	0.08	0.002	0.09	<0.0001	0

Note: statistically significant relationships or trends are colored in red.

Table B-11. Results of AEM time series models of monthly enterococci in Naples Bay, WY 2011–2019, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		LN Flow		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	X_2	p	
GORDEXT/ GORDPT	0.01	4.91	0.34	-0.00002	0.87	0.02	0.32	-0.005	0.71	0
NBAYNL	0.15	2.12	0.77	0.00003	0.84	0.07	0.01	0.02	0.27	1
NBAYWS	0.28	-18.54	0.001	0.0005	0.0001	0.08	0.003	0.03	0.06	0
GPASS6	0.30	-19.80	0.0005	0.0005	<0.0001	0.05	0.009	0.04	0.003	0

Note: statistically significant relationships or trends are colored in red.

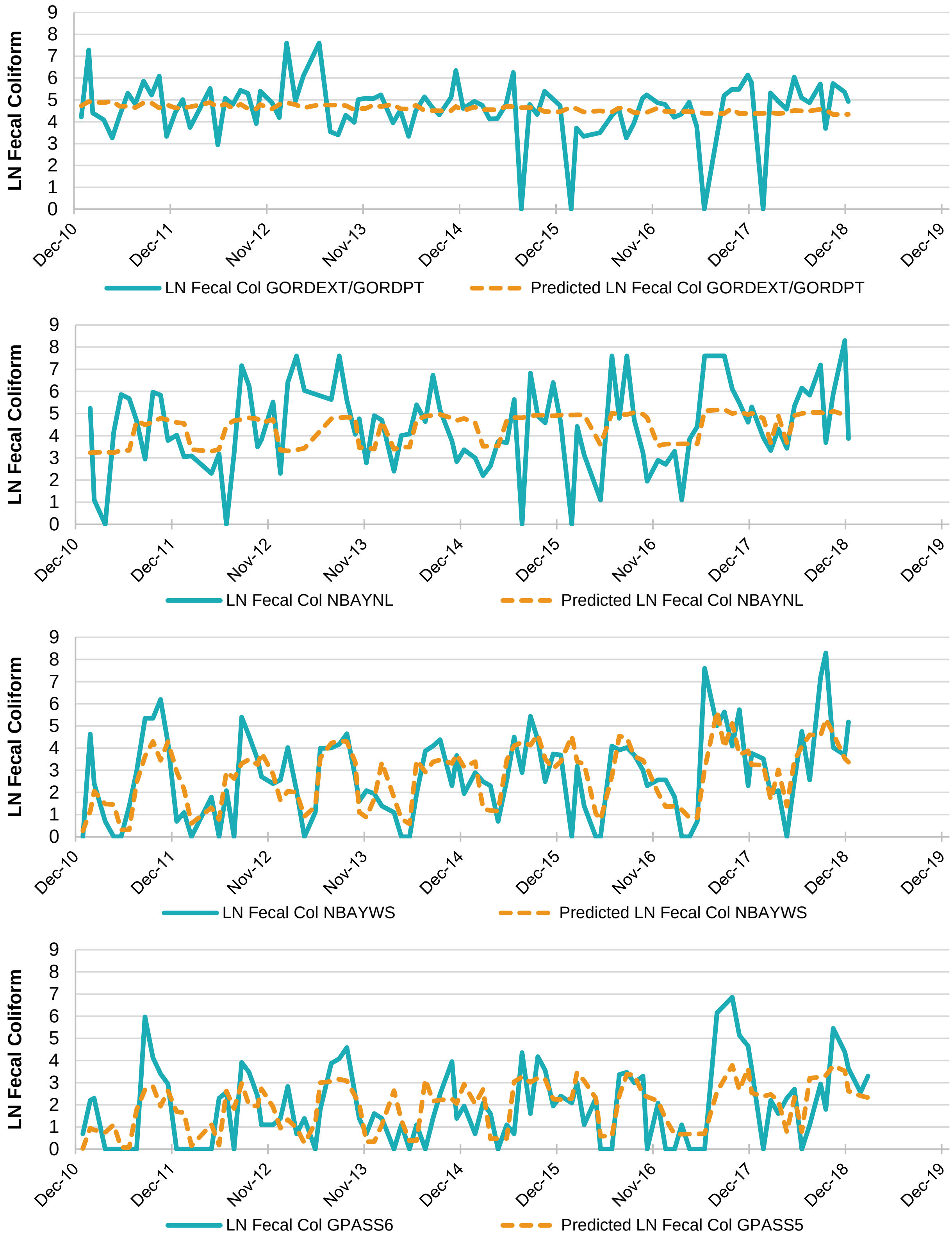


Figure B-11. LN fecal coliform measurements and AEM regression projected for WY 2011 to 2019 for the Gordon River (marine segment) and Naples Bay.

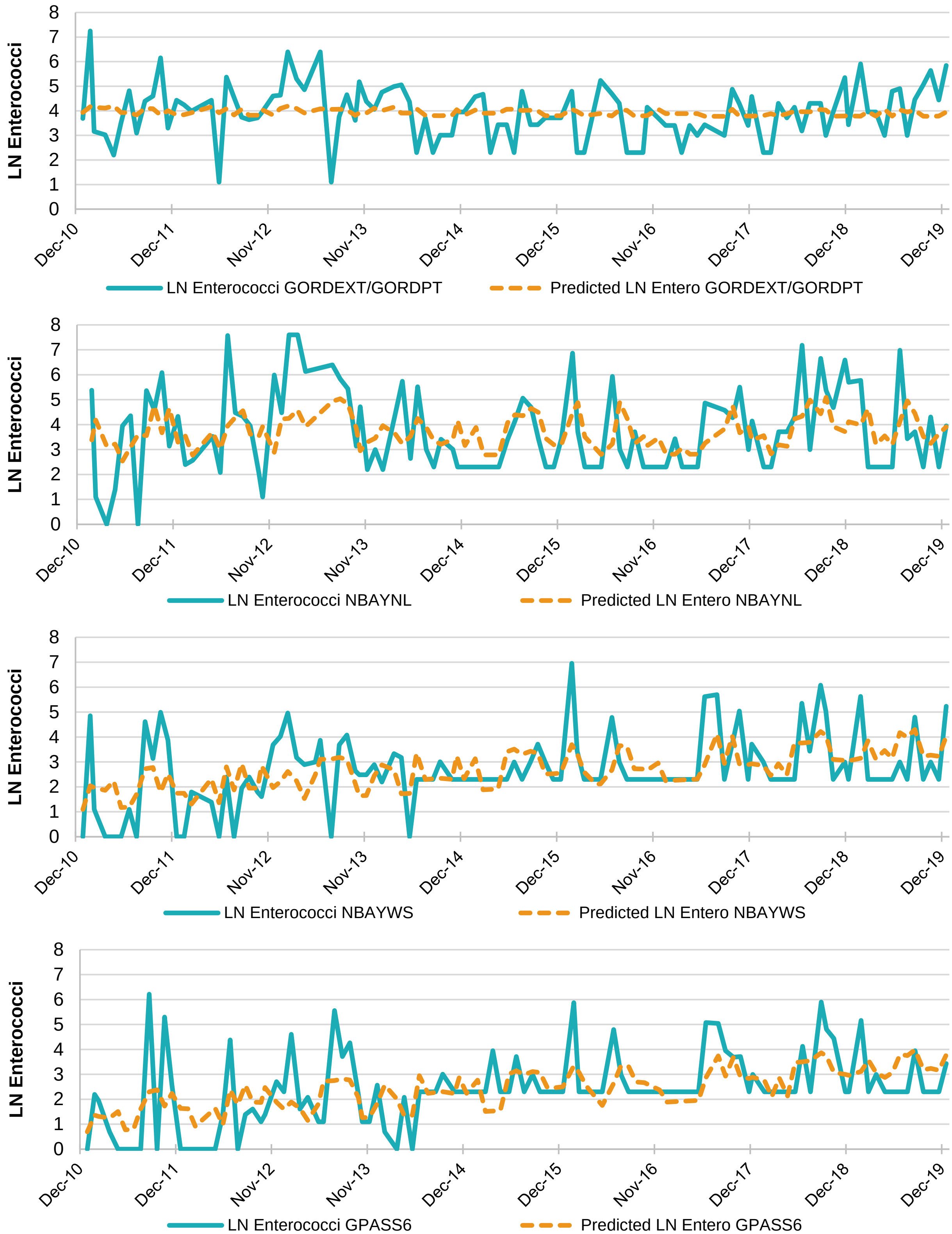


Figure B-12. LN enterococci measurements and AEM regression projected for WY 2011 to 2019 for the Gordon River (marine segment) and Naples Bay.

B.2 Previous Biological Statistical Analyses

This section builds upon the 2015 Naples Bay water quality and biological community analysis (Sections 3.2 and 4) to attempt to identify potential causal links between the observed trends in water quality with the observed trends in biological communities in Naples Bay. While all water quality trends are considered here, the focus is on attempting to identify the potential effects of salinity and GGC freshwater flow on biology because freshwater flow and salinity stress have been identified as the primary pollutants in Naples Bay (City of Naples 2010, Laakkonen 2014, Schmid et al. 2005, SFWMD 2007, FDEP 2010).

The following section describes the results of statistical and data analyses conducted to identify links between water quality and biological parameters of concern. Additionally, comparisons to other southwest Florida estuaries are included to determine if observed changes and potential effects of water quality are unique to Naples Bay or may have a regional connection.

B.2.4 Seagrass and Water Quality

Identifying the effects of water quality on a seagrass community is a complex undertaking since many factors work in series or parallel to shape how and where a seagrass community will grow or thrive. Biological, chemical, and physical factors all play a role in shaping a seagrass community (Figure B-13). This is especially true in Naples Bay. Schmid et al. (2005) reported an approximate 80 percent decrease in seagrass from the 1950s to 2003. The decline is presumed to be linked to a combination of channel dredging, urban buildup of the shoreline areas, and freshwater inputs, mostly from the GGC (Schmid et al. 2005).

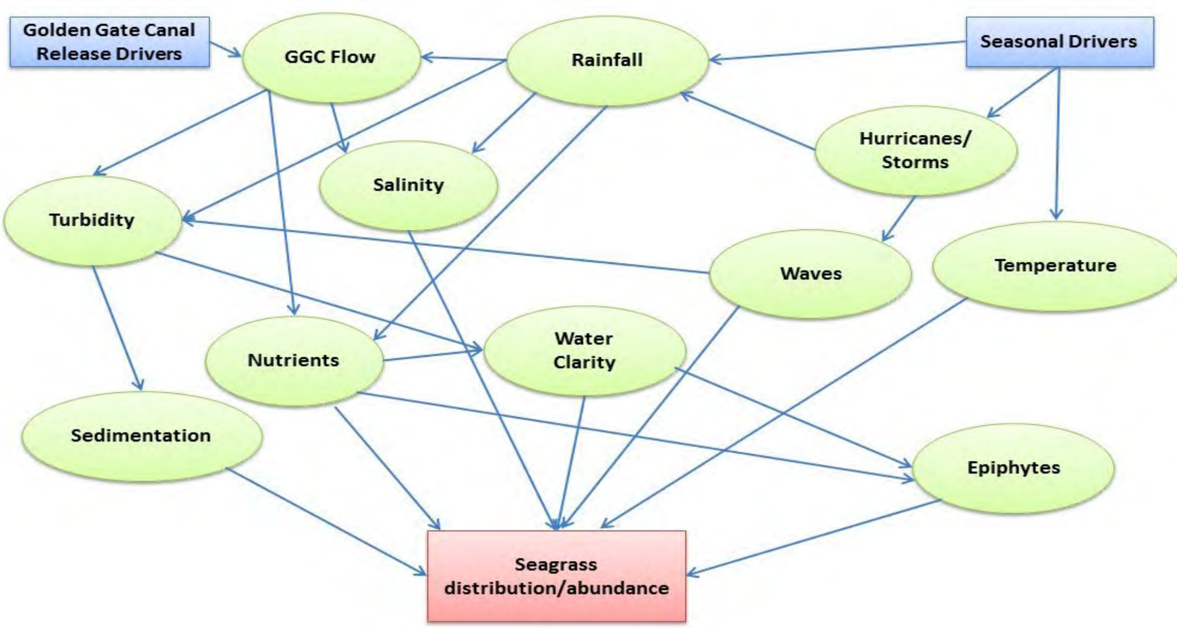


Figure B-13. Conceptual model of potential seagrass drivers in Naples Bay.

In an ideal world, scientists would have perfect information for describing the casual relationships that underlay the issues of concern, such as the response of seagrasses to water quality in Naples Bay. But, in the real world examination of casual relationships is confounded by complex interactions among not only the causative effect of interest (in this case water quality), but the natural influences on seagrass biomass on a wide range of temporal and spatial scales (such as water clarity and physical stressors). The City's monitoring programs have generated a great deal of information that can be used in a decision analytic framework to evaluate the effect of water quality on seagrass. Examination of the strength of these sources of evidence can provide resource managers with a rigorous approach to teasing out the actual impact of water quality on seagrass biomass, and observed changes associated with other factors such as tidal flux, temperature, and salinity changes over space and time.

A Bayesian network (BN) is a tool for linking multiple lines of information and examining the strength of complex environmental and effects-based relationships. A BN can be thought of as a graphical model with a series of nodes linked by arrows, where the arrows in a BN represent probabilities. The arrows indicate causal linkages among the nodes, and the nodes denote important system attributes. Each node is characterized by probabilities or probabilistic mathematical expressions that represent knowledge about these system attributes. The mathematical expressions may be 1) mechanistic descriptions such as chemical reaction kinetics, 2) empirical relationships such as linear regression models, or 3) relationships derived from expert judgment, depending on how much information exists about the relationships characterizing a particular node. The possible outcomes at each node are expressed probabilistically; thus a Bayes net is a set of conditional probabilities describing a set of likely system responses. The ability to incorporate mechanistic, empirical, and judgmental information makes the BN approach extremely flexible and facilitates an extension to non-traditional model endpoints (e.g., seagrass biomass) of concern. A full description of a BN network and the model set up and implementation for Naples Bay seagrass can be found in Appendix B, only the results are presented here.

Data are not available to represent all of the nodes in the conceptual model shown in Figure 5-1. However, available data were combined and the information is believed suitable for a draft assessment of the Naples Bay ecosystem, at least as a generalized approach. The chosen model output combined available data for the rainfall, flow, turbidity, salinity, total nitrogen, chlorophyll-*a*, and seagrass biomass nodes (Appendix B.2.4). The results of the Naples Bay seagrass BN indicate, not surprisingly, that seagrass biomass is most influenced by a combination of salinity, turbidity, and chlorophyll-*a*. In the BN model, the greatest possibility of a “good” seagrass state coincides with salinities at the higher end of normal estuarine conditions, low turbidity, and low chlorophyll-*a*. The BN model predicts that because the effect of flow (GGC flow) on salinity is low in the southern portion of the Bay, changes in GGC flow are not expected to have a great deal of influence on seagrass biomass in the southern portion of the Bay. However, the predictive ability of this model is limited to the data that it includes. If historical data on seagrass, water quantity, and water quality was available for Naples Bay all the way back to 1950, then the relationships between each of the variables within the BN could change based on a wider range of physical conditions and biological responses prior to increased urbanization and freshwater stress.

While this model can be generally useful, we are careful not to over interpret the results because limited information is available to characterize all possible effects on seagrass in Naples Bay, which leads to uncertainty in the results. For example, the current seagrass beds in the southern portion of the Bay may be highly influenced by boat traffic, wave action, and sedimentation, about which little to no information are currently available. In the vicinity of the seagrass transects, a channel and marina were built during the monitoring period which can contribute to increased disturbance. Additionally, data concerning light attenuation and water clarity are lacking for the location of the current seagrass beds that would be valuable in determining causal links for important measures of water quality. Furthermore, this model cannot provide any information regarding the suitability of seagrass restoration for any other portions of the Bay, as it is restricted to the available information regarding the current seagrass in southern Naples Bay. This exercise provides an example of the type of analyses that can be used to link several potential factors that influence seagrass in Naples Bay and tease out which ones may play a more dominant role. The current application of the model for Naples Bay should be viewed as generally informative, but should not be used to draw any specific conclusions regarding causal factors of seagrass biomass or management decisions for seagrass restoration.

On average, the GGC delivers approximately 90 tons of nitrogen and 355 tons of solids to Naples Bay each year, with over 90 percent of it delivered during the wet season (June–November). Relative to bay volume, the loadings from the GGC to Naples Bay are many times greater than total loadings to Tampa Bay, which has exhibited significant seagrass recovery. While further investigation into the loading events is warranted to identify concrete causal links, the available information is sufficient to conclude that loadings likely play a significant role in observed seagrass trends and should be an essential consideration for management and restoration activities.

Additional study on factors connected with water clarity and light attenuation are needed to identify the connections between turbidity, suspended solids loadings, localized perturbations from wave action and/or boat traffic, and seagrass growth and density in Naples Bay.

B.2.5 Seagrass BayesNet Analytical Framework

A BN is a tool for linking multiple lines of information and examining the strength of complex environmental and effects-based relationships. A BN can be thought of as a graphical model with a series of nodes linked by arrows, where the arrows in a BN represent probabilities. The arrows indicate causal linkages among the nodes, and the nodes denote important system attributes. Each node is characterized by probabilities or probabilistic mathematical expressions that represent knowledge about these system attributes. The mathematical expressions may be 1) mechanistic descriptions such as chemical reaction kinetics, 2) empirical relationships such as linear regression models, or 3) relationships derived from expert judgment, depending on how much information is available for the relationships characterizing a particular node. The possible outcomes at each node are expressed probabilistically; thus a Bayes net is a set of conditional probabilities describing a set of likely system responses. The ability to incorporate mechanistic, empirical, and judgmental information makes the BN approach extremely flexible and facilitates an extension to non-traditional model endpoints (e.g., seagrass biomass) of public concern.

Bayesian model building often begins with a graphical model that consists of boxes and arrows characterizing key relationships (see Figure B-13). The lines of evidence are complex, with several intertwining interactions finally leading to a possible effect on seagrass. By displaying the conceptual model in this fashion, changes in seagrass caused by sources other than water quality can be evaluated. The advantage of this approach, relative to standard regression models, is that each link within a complex ecological system can be modeled.

Model Implementation

An appropriate data set for implementing the Bayes Net consists of columns containing information for each node of the net, and rows representing repeated measures of each variable. Combining the various variables of interest can be challenging, in that each row should represent consistent information in both space and time. Information available to Cardno does not represent all of the conceptual model nodes shown above. However, available data were combined and the information believed to be suitable for a draft assessment of the Naples Bay ecosystem, at least as a generalized approach.

See the *Naples Bay Water Quality and Biological Analysis Project* report from 2015 for detailed information on the BN tool.

B.2.6 Regional Fish Comparison

Even though no correlations were found between specific water quality variables and fish diversity metrics and community structure, there were general seasonal and annual patterns within the Naples Bay biological dataset. Comparing the communities and patterns in Naples Bay to other bays in the region can help determine whether those patterns are unique to Naples Bay or part of larger, regional environmental patterns. In addition, a bay to bay comparison will show how the Naples Bay community compares to other bays with different levels of human impact. Naples Bay is unique in southwest Florida in that it is the only estuary that experiences the extreme freshwater inflow from the GGC and resulting effect on salinity. The GGC effectively increases the natural Naples Bay drainage area by 10-fold, a condition not experienced in the other bays.

Five other bays in Southwest Florida have fish monitoring programs that use the same methodology employed in Naples Bay (NB) and were monitored during the same time period: Moorings Bay (MB), Rookery Bay (RB), Pumpkin Bay (PB), Faka Union Bay (FU), and Fakahatchee Bay (FH) (Table B-12 and Figure B-14). In general, Rookery, Pumpkin, Faka Union, and Fakahatchee Bays have considerably less local coastal development than Naples Bay. However, in terms of potential impacts to bay hydrology, Faka Union Bay receives large amounts of fresh water canal flow from developed land, Rookery Bay experiences an altered hydrological flow pattern based on flood control, while Fakahatchee and Pumpkin Bays have less direct anthropogenic impacts to hydrology relative to the other bays in the comparison.

The monitoring program in Rookery Bay ended in 2011. Data collection in Moorings Bay does not occur as frequently as it does in Naples Bay. Some comparisons below will be limited to only the bays with comparable sampling dates or frequency.

Table B-12. Biological data sources from other bays in the Naples Bay region.

<table>
<tr><th>Organization</th><th>Sample Type</th><th>Location</th><th>Approximate Date Range</th><th>Description</th></tr>
<tr><td rowspan="4">Rookery Bay National Estuarine Research Reserve</td><td rowspan="4">Fish - Trawling</td><td>Rookery Bay</td><td>2009–2011</td><td>Otter trawls pulled for specific length and time. A random grid box was selected for sampling at each event. Sampling approximately every other month from April 2009 to April 2011. Species identity and abundance recorded. Length of first 20 individuals of each species recorded. Bycatch and environmental conditions recorded.</td></tr>
<tr><td>Fakahatchee Bay</td><td rowspan="3">2009–2014</td><td rowspan="3">Otter trawls pulled for specific length and time. A random grid box was selected for sampling within each bay during each event. All bays trawled six times per year. Species identity and abundance recorded. Length of first 20 individuals of each species recorded. Bycatch and environmental conditions recorded.</td></tr>
<tr><td>Faka Union Bay</td></tr>
<tr><td>Pumpkin Bay</td></tr>
</table>

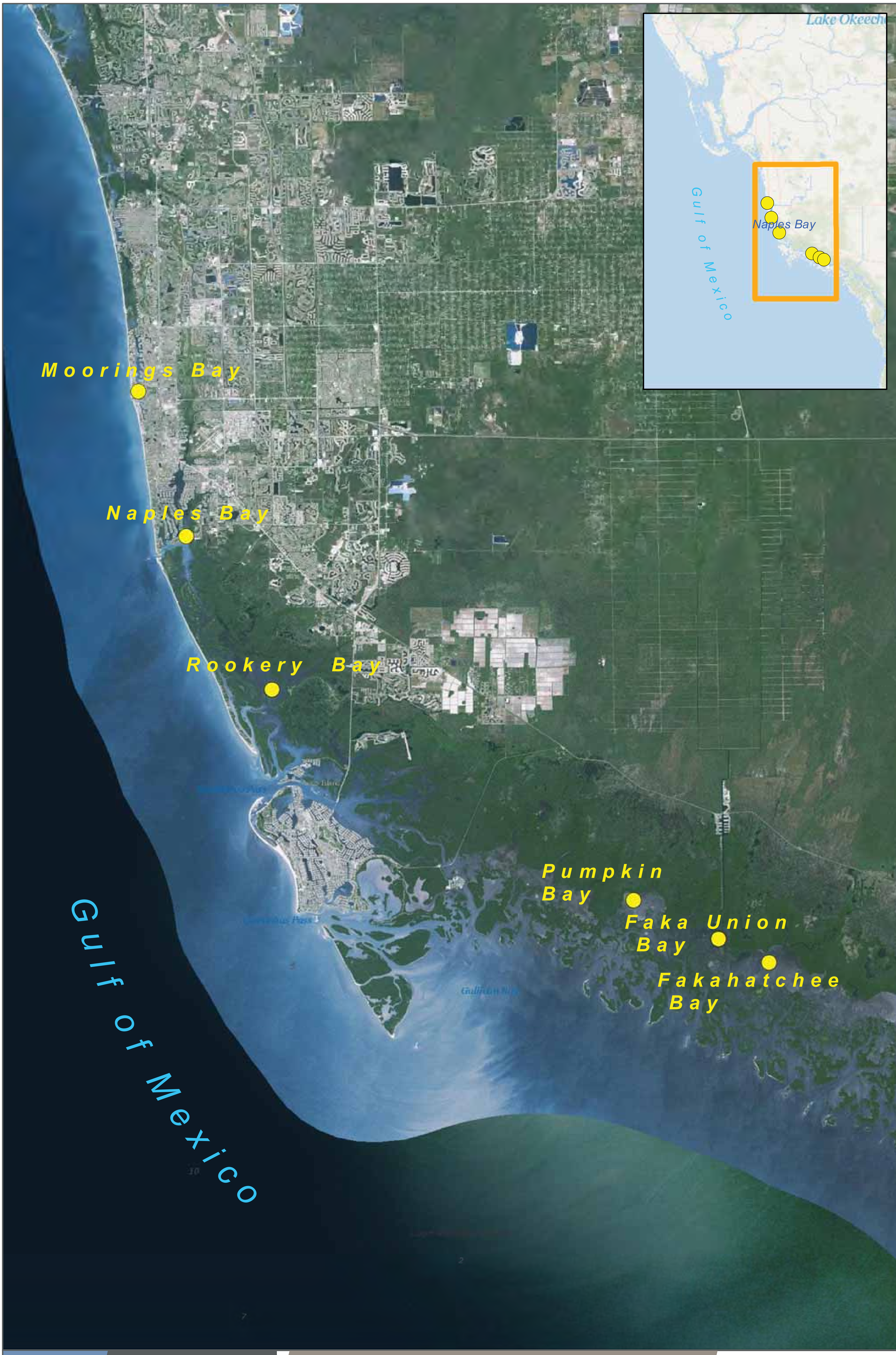


Figure B-14. Southwest Florida Bays with Fish Monitoring Programs Comparable to Naples Bay

City of Naples, Natural Resources Division
Collier County, Florida

0 1 2 3 4 5 6 Miles
0 1 2 3 4 5 6 7 8 9 10 Kilometers

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Date Created: 5/8/2015 Date Revised: 5/8/2015 File Path: Q:\UnitedStates\Florida\Tampa\City_Of_Naples\Water Quality Analysis Project\working\arcmap\Figure5_3_CON_Bays_20150507.mxd
GIS Analyst: adam.bausch

Abundance and Species Composition

Overall, more taxa (grouped to Genus level or above) were caught in Naples Bay than in the other bays in this comparison (Table B-13). However, higher species richness is most likely the result of comparing unequal numbers of trawls from each bay: increased trawling effort increases the likelihood of encountering rare species. Naples Bay also had higher catch per trawl than all other bays, with the exception of Moorings Bay. Higher overall catch numbers are likely linked to the predominance of small, schooling fish in Naples Bay, where just two taxa groups, mojarras (*Eucinostomus* spp.) and anchovies (*Anchoa* spp.) account for over 85 percent of the total catch. Both taxa are also abundant in other regional bays, but, except for Moorings Bay, do not contribute as highly to overall abundance (Table B-14). In all other bays, the top 85 percent of total catch is also made up of pink shrimp (*Farfantepenaeus duorarum*) and pinfish (*Lagodon rhomboides*).While it appears that numerical dominance of mojarras and anchovies is a characteristic of the more developed bays like Moorings Bay and Naples Bay, it is not clear what is driving that pattern; habitat variables, water quality, hydrology, and bay morphology could all be contributing factors.

Table B-13. Summary of total abundance and total number of taxa by Bay.

Summary Metric	NB	MB	RB	FH	FU	PB
Total Number of Individuals	32036	23048	3472	20928	15278	21780
Total Number of Taxa	56	53	40	45	44	46
Total Number of Trawls	132	64	48	100	100	100
Average Catch per Trawl	242.7	360.1	72.3	209.3	152.8	217.8

Table B-14. Taxa contributing to the top 85 percent of abundance in each Bay.

Taxon	Percentage of Total Abundance*					
	NB	MB	RB	FH	FU	PB
Anchoa spp.	40.4	14.9	12.3	40.5	10.4	20.2
Eucinostomus spp.	46.9	77.3	47.4	23.3	41.9	45.5
Total	**87.3**	**92.2**	**59.7**	**63.8**	**52.3**	**65.7**
Lagodon rhomboides	(2.1)	(0.4)	13.4	5.1	14.6	11.4
Farfantepenaeus duorarum	(1.5)	(0.6)	8.6	17.8	15.4	9.7
Orthopristis chrysoptera	(0.2)	(0.07)	3.7	(0.6)	(0.2)	(0.5)
Symphurus plaguisa	(0.2)	(0.06)	(1.0)	(2.2)	5.4	(2.4)

*Numbers in parentheses are shown for comparison but do not contribute to the top 85% of individuals for that particular bay.

Diversity Indices

When the data for each bay are grouped by year and season, the same general patterns in diversity, richness, and abundance across seasons and years seen in Naples Bay are evident in other bays. In general, dry season samples have lower abundance and higher diversity than the preceding wet season. In addition, the downward shift in 2011 seen in Naples Bay is also apparent in other bays (Figure B-15). Factorial ANOVA tests (with season and bay as factors) with post-hoc pairwise comparisons (Bonferroni tests, alpha = 0.05) were performed to look for differences in diversity, richness and abundance between Naples Bay and the other bays. Abundance in Naples Bay does not differ from any other bay ($p > 0.05$). Number of taxa is lower in Naples Bay than in Fakahatchee and Pumpkin Bays ($F = 9.32$, $p < 0.01$) and Shannon diversity is lower in Naples Bay than in Faka Union, Fakahatchee, and Pumpkin Bays ($F = 9.28$, $p < 0.01$).

Using change-point analysis, a major step change was detected in 2011 in Naples Bay (Section 4.2.2). The difference in diversity between Naples Bay and other bays only occurs after the 2011 change-point in Naples Bay (Factorial ANOVA on season and bay, 2009–2011, $F = 7.78$, $p < 0.01$); before the change-point, diversity in Naples Bay was not different from the other bays (Factorial ANOVA on season and bay, 2012–2014, $p > 0.05$). Change-point analysis univariate community metrics from the other bays shows that the timing of the overall downward shift in diversity, abundance, and richness in Faka Union and Fakahatchee Bays is very close to the timing of the change in Naples Bay (Figure B-16). Pumpkin Bay and Moorings Bay did not have change-points at the same time; for Moorings Bay, this might be due to lower sampling frequency. The aligned timing of change across bays indicates that the driver for the change may be regional rather than localized to Naples Bay. Environmental factors such as temperature or rainfall might have impacted Naples Bay, Faka Union, and Fakahatchee Bays all at the same time. However, diversity is lower in Naples Bay than the other bays after the change point, suggesting that local factors within Naples Bay are also at work.

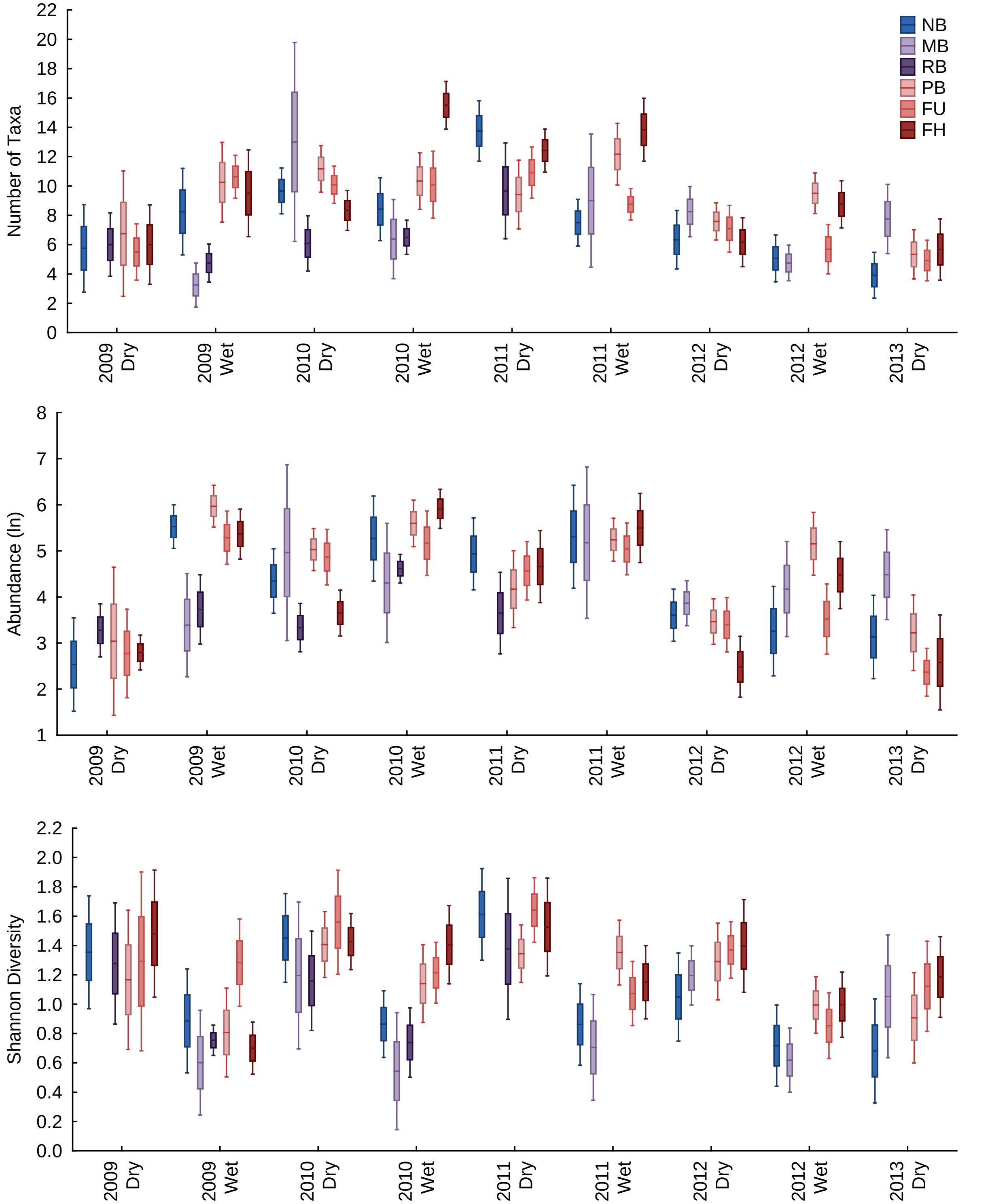

Figure B-15. Number of taxa, abundance, and diversity by season in bottom trawls in Southwest Florida Bays from 2009-2013 (mean, line; ±1 SE, box; ±2 SE, whiskers).

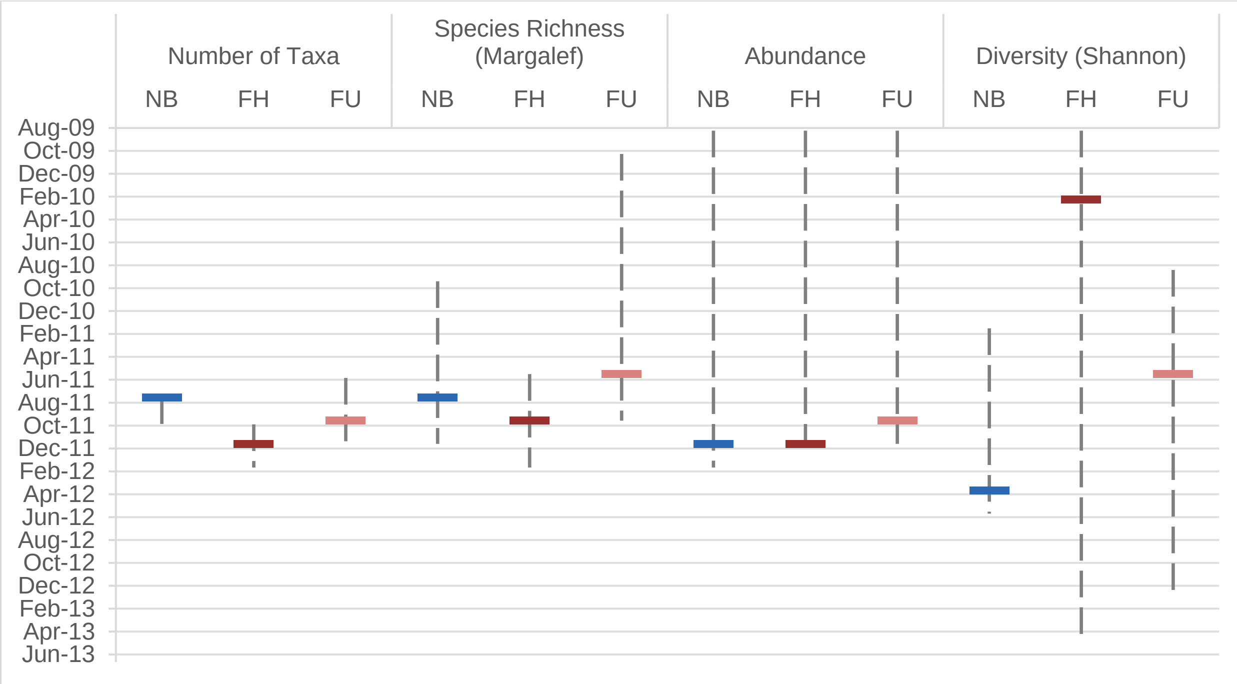

Figure B-16 Change-points (colored lines) and 95 percent confidence intervals (grey dashed lines) for several fish diversity metrics in Naples, Fakahatchee, and Faka Union Bays. Pumpkin Bay did not show any change points for these indices.

Community Structure

Species presence/absence data from the survey period (2009–2014) were pooled together by bay to give broad level picture of similarity in the species assemblages across bays. Overall, the similarity (Bray-Curtis) between bays was high, ranging from 77 percent to 92 percent, (Table B-15). Several taxa were not captured in Naples Bay but were present in other, less developed bays (Table B-16). All taxa absent from Naples Bay were only found in relatively low abundances in the other bays.

Table B-15. Species assemblage similarity (Bray-Curtis, presence/absence, pooled by bay) between Bays.

Bay	MB	NB	RB	PB	FU	FH
MB						
NB	86.5					
RB	82.1	**77.6**				
PB	80	**77.7**	80.5			
FU	76.8	**80.4**	81.4	83.5		
FH	80.8	**78.4**	81.4	92.3	84.4	

Table B-16. Taxa (grouped to genus level or above) that are absent from or unique to Naples Bay when compared to Rookery Bay, Fahakatchee Bay, Faka Union Bay, or Pumpkin Bay.

Taxa	Common Name
Absent from NB	
Aluterus schoepfii	Orange filefish
Chasmodes saburrae	Florida blenny
Diplectrum formosum	Sand perch
Elops saurus	Ladyfish
Eugerres plumieri	Striped mojarra
Floridichthys carpio	Gold spotted killifish
Lucania parva	Rainwater killifish
Monacanthus ciliatus	Fringed filefish
Mugil sp., *Mugil gyrans*	Mullet, Fantail mullet
Pogonias cromis	Black drum
Rachycentron canadum	Cobia
Unique to NB	
Gobionellus oceanicus	Highfin goby
Gobiesox strumosus	Skilletfish
Hypsoblennius hentz	Feather blenny
Ophichthus gomesii	Shrimp eel
Sciaenops ocellata	Red drum
Selene vomer	Lookdown
Order Teuthida	Squid

Because ANOSIM tests on Naples Bay data showed a significant difference between seasons, season was used as a factor when looking for differences among bays. A two-way ANOSIM test among samples using bay and season as factors (unpooled data, aggregated to Genus level, log (x+1) transformed, Bray-Curtis similarity) shows that there are weak but significant differences among bays (ANOSIM Global R = 0.126, p = 0.001) and between seasons (Global R = 0.198, p = 0.001). Pairwise bay to bay comparisons show that Naples Bay, Moorings Bay, and Rookery Bay are not significantly different from one another but are different from the other three bays (Figure B-17). Fakahatchee, Faka Union, and Pumpkin Bays are all significantly different from one another. The differences in community structure across years in Naples Bay was only evident in one of the two bays (Faka Union) that had similar change points in diversity metrics.

SIMPER analysis was used to quantify the average dissimilarity between Naples Bay and other bays and which taxa contribute most to the dissimilarity. As with the patterns within Naples Bay, most of the differences between bays is the result of differences in how species are assembled (which species co-occur) and differences in their overall abundance. The SIMPER results show that, for the most part, the same species are responsible for dissimilarity between bays: mojarras (*Eucinostomus* spp.) and anchovies (*Anchoa* spp.) are the largest contributors to dissimilarity in all pairwise comparisons, followed by pink shrimp (*Farfantepenaeus duorarum*), blue crabs (*Callinectes* spp.), pinfish (*Lagodon rhomboides*), lizardfish (*Synodus foetens*), snappers (*Lutjanus* spp.), hardhead catfish (*Ariopsis felis*), and blackcheek tonguefish (*Symphurus plagiusa*). (Appendix C, Table C6). When comparing Naples Bay to those bays with different community structure (Pumpkin, Faka Union, and Fakahatchee Bays), mojarras, anchovies and hardhead catfish are generally more abundant in Naples Bay; pink shrimp, and inshore lizardfish, blackcheek tounguefish and pinfish are generally less abundant in Naples Bay; and blue crabs and snappers show mixed results.

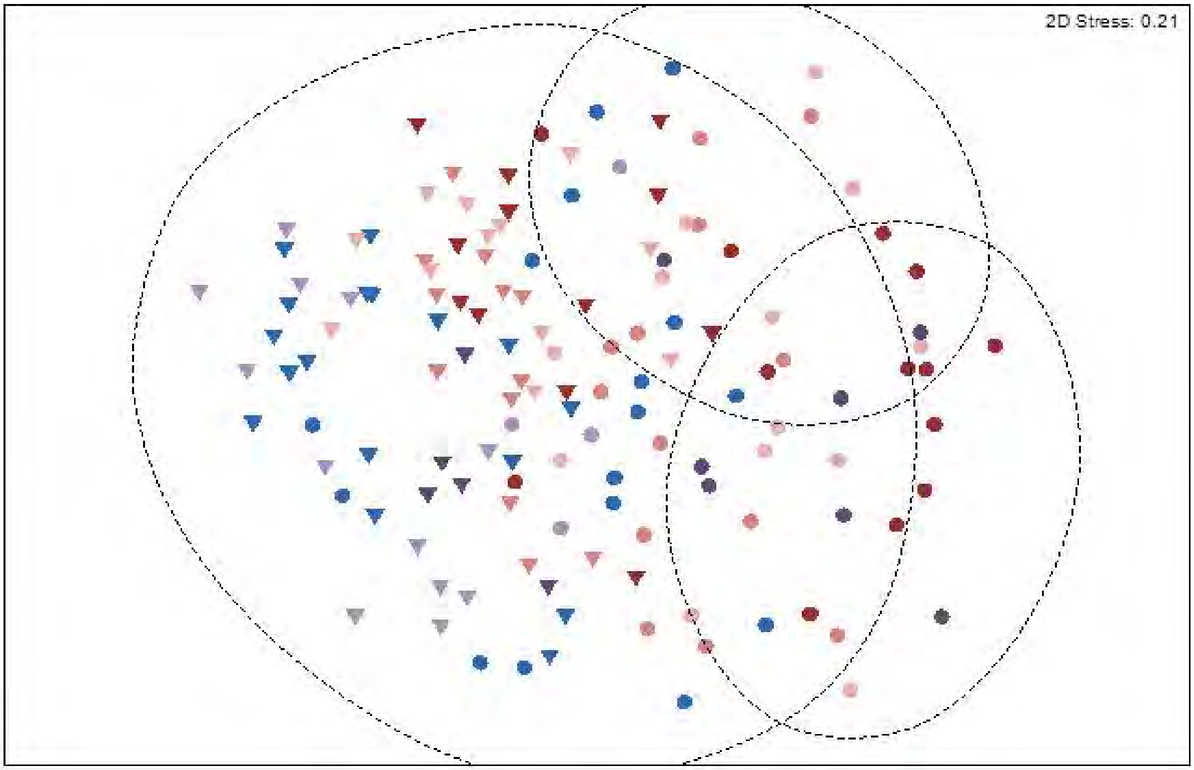

Figure B-17. MDS of fish community for all bays (Bray-Curtis similarity, log (x+1) transformed data). Data were pooled by month within year for illustration purposes only. FH, FU, and PB are represented in reds and pinks, MB and RB are violet, and NB is blue. Wet season samples are represented by triangles and dry season by circles. Dashed black circles enclose samples with at least 40 percent similarity.

Summary of Interbay Relationships

As described previously, no direct links or patterns between water quality and the biology data could be identified. Although some differences exist, as expected, the Naples Bay fish community is similar to that of the other southwest Florida bays. The high level of similarity indicates that large scale community shifts or adverse impacts that might be attributed to human induced impacts that Naples Bay has experienced are not apparent in the fish community data when compared to other southwest Florida estuaries that don't have the same level of human impact. This may indicate either the fish community is actually not affected by these variables in Naples Bay or perhaps the fish community is not sensitive enough to the impacts to be detected in the trawling dataset.

The downward shift in fish community univariate metrics (2011) observed in Naples Bay appears to also have occurred in other southwest Florida bays. However, after the shift, Naples Bay appears to have lower diversity and fewer taxa than the other bays in the comparison. Here, a potential role of the pattern of freshwater flow delivery to Naples Bay and its effect on salinity was explored, and further hypothesized on how it may affect fish community.

During the dry season of 2010, approximately two to four times more rainfall occurred than other dry seasons during the time period of this study (see Section 3.1.1). This led to approximately 17 times more dry season flow from the GGC during the 2010 dry season than the average dry season flow during the time period for which GGC flow data are available (2009–2014). The substantially different rain and flow pattern during this time period altered the typical salinity and GGC flow pattern from the typical dry season "off" and wet season "on" pattern that was typical during the 2012–2014 time period.

The USGS continuous recorders in Naples Bay were not installed until summer of 2011 or early 2012 and, therefore, daily salinity data is not available to represent the 2010 time period. However, the salinity pattern can be estimated by creating a spreadsheet model of the GGC flow and USGS salinity correlation in each section of the Bay. The estimated daily average salinity during the 2010 time period was calculated from the correlation equation observed at each USGS continuous recorder location in Naples Bay. As the figure indicates, this simplistic model predicts daily average salinity fairly well at most locations, with the exception of the Gordon River station at Rowing Club Point. The model under-predicts salinity at this station when flow from the GGC is zero. However, the model is useful in estimating the different pattern of salinity that would have occurred as a result of the significantly different flow pattern during the 2009–2011 time period.

During 2010, the GGC contributed flow almost every day throughout the entire year. In contrast, the typical pattern of flow from the GGC is only during the wet season or after high dry season rain events. Although the dry season flows during 2010 were less in magnitude then typical wet season flows, the pattern significantly altered the salinity in the Bay at all locations from the normal dry season salinities. Dry season salinity was lower and more variable during 2010, but the pattern of salinity was more stable over the course of the entire year with less abrupt fluctuation between the dry and wet seasons when compared to the 2011–2014 time period.

The 2009–2011 time period saw a different pattern of flow and salinity in Naples Bay that happens to coincide with the highest fish diversity and richness. At this time, the specific causal links between these two patterns cannot be identified, but further investigation is warranted to potentially identify causation. It is possible that some dry season flows from the GGC, with a less abrupt change between dry and wet season flows, provides a more favorable environment for the fish community in Naples Bay. If a connection between flow pattern, salinity, and fish community can be identified for Naples Bay, this may inform potential management strategies for long-term restoration goals.

City of Naples

APPENDIX

C

SUPPLEMENTAL BIOLOGICAL TABLES AND FIGURES

Appendix C
Supplemental Biological Tables and Figures

Table C-1. Fish taxa* caught in Naples Bay bottom trawls, 2009 to 2019.

Scientific Name	Common Name	Species Code
Acanthostracion quadricornis	Scrawled cowfish	LACT QUAD
Achirus lineatus	Lined sole	ACHI LINE
Achirus spp.	Sole	ACHI
Albula vulpes	Bonefish	ALBU VULP
Anchoa hepsetus	Striped anchovy	ANCH HEPS
Anchoa mitchilli	Bay anchovy	ANCH MITC
Anchoa spp.	Anchovies	ANCH SPP
Ancylopsetta ommata	Ocellated flounder	ANCL QUAD
Archosargus probatocephalus	Sheepshead	ARCH PROB
Ariopsis felis	Hardhead catfish	ARIU FELI
Bagre marinus	Gafftopsail catfish	BAGR MARI
Bairdiella chrysoura	Silver perch	BAIR CHRY
Brevoortia smithi	Yellowfin menhaden	BREV SMIT
Caranx spp.	Jack-Caranx juvenile	CARA SPP
Chaetodipterus faber	Atlantic spadefish	CHAE FABE
Chilomycterus schoepfii	Striped burrfish	CHIL SCHO
Chilomycterus spp.	Burrfishes	CHIL
Chloroscombrus chrysurus	Atlantic bumper	CHLO CHRY
Citharichthys macrops	Spotted whiff	CITH MACR
Ctenogobius smaragdus	Emerald goby	GOBI SMAR
Cynoscion arenarius	Sand seatrout	CYNO AREN
Cynoscion nebulosus	Spotted seatrout	CYNO NEBU
Cynoscion sp.	Seatrout	AYNO F
Dasyatis americanus	Southern stingray	DASY AMER
Dasyatis sabina	Atlantic stingray	DASY SABI
Eugerres plumieri	Striped mojarra	DIAP PLUM
Diplectrum formosum	Sand perch	DIPL FORM
Echeneis neucratoides	Whitefin Sharksucker	ECHI NAUC
Elops saurus	Ladyfish	ELOP SAUR
Etropus crossotus	Fringed flounder	ETRO CROS
Etropus spp.	Large-tooth flounder	ETRO
Eucinostomus gula	Silver jenny	EUCI GULA
Eucinostomus harengulus	Spotfin mojarra	EUCI HARE
Eucinostomus spp.	mojarra species	EUCI SPP

Scientific Name	Common Name	Species Code
Family Clupeidae	Herrings	CLUPEIDAE
Family Gobiidae	Gobies	GOBI R
Family Sciaenidae	Croakers/Drums	SCIAENIDAE
Gobiesox strumosus	Skilletfish	GOBI STRU
Gobionellus oceanicus	Highfin goby	GOBI OCEA
Gobiosoma robustum	Code goby	GOBI ROBU
Gymnura micrura	Smooth butterfly ray	GYMN MICR
Harengula jaguana	Scaled sardine	HARE JAGU
Hippocampus erectus	Lined seahorse	HIPP EREC
Hypsoblennius hentz	Feather Blenny	HYPS HENT
Lagodon rhomboides	Pinfish	LAGA RHOM
Leiostomus xanthurus	Spot	LEIO XANT
Lophogobius cyprinoides	Crested goby	LOPH CYPR
Lutjanus griseus	Mangrove Snapper	LUTJ GRIS
Lutjanus spp.	Snappers	LUTJ GRIS/APO
Lutjanus synagris	Lane Snapper	LUTJ SYNA
Menticirrhus americanus	Southern Kingfish	MENT AMER
Menticirrhus spp.	Kingfishes	MENT SPP
Microgobius gulosus	Clown Goby	MICR GULO
Microgobius microlepis	Banner Goby	MICR MICR???
Microgobius thalassinus	Green Goby	MICR THAL, GOBI THAL
Micropogon undulatus	Atlantic croaker	MICROPOGONIUS UNDULATUS
Mugil spp.	Mullet	MUGIL SPP
Nicholsina usta	Emerald Parrotfish	NICH USTA
Ogcocephalus cubifrons	Polka-Dot Batfish	OGCO CUBI
Ophichthus gomesii	Shrimp Eel	OPHI GOME
Opisthonema oglinum	Atlantic Thread Herring	OPIS OGLI
Opsanus beta	Gulf Toadfish	OPSA BETA
Orthopristis chrysoptera	Pigfish	ORTH CHRY
Orthopristis spp.	Grunts	ORTH
Paralichthys albigutta	Gulf Flounder	PARA ALBI
Prionotus scitulus	Leopard Searobin	PRIO SCIT
Prionotus tribulus	Bighead Searobin	PRIO TRIB
Rhinoptera bonasus	Cownose ray	RHIN BONA
Sciaenops ocellata	Red Drum	SCIA OCEL
Scorpaena brasiliensis	Barbfish	SCOR BRAS
Selene vomer	Lookdown	SELE VOME
Serraniculus pumilio	Pygmy sea bass	SERR PUMI
Sphoeroides nephelus	Southern Puffer	SPHR NEPH
Sphoeroides spengleri	Bandtail Puffer	SPHR SPEN

Scientific Name	Common Name	Species Code
Stephanolepis hispidus	Planehead Filefish	MONA HISP
Suborder Pleuronectoidei	Flatfishes	FLOUNDER?
Symphurus plagiusa	Blackcheek Tonguefish	SYMP PLAG
Syngnathus louisianae	Chain Pipefish	SYNG LOUI
Syngnathus scovelli	Gulf Pipefish	SYNG SCOV
Synodus foetens	Inshore Lizardfish	SYNO FOET
Trinectes maculatus	Hogchoker	TRIN MACU
Umbrina coroides	Sand drum	UMBR CORR
Urophycis floridana	Southern Hake	UROP FLOR

*Leptocephalus larvae were not included in analysis presented in this report.

Table C-2. Invertebrate taxa caught in Naples Bay bottom trawls, 2009 to 2019.

Scientific Name	Common Name	Species Code
Included in Analysis		
Callinectes sapidus	Blue Crab	CALI SAP, CALI S
Callinectes similis	Lesser Blue Crab	CALI SIM, CALI SIMILUS, SALI SIM
Farfantepenaeus duorarum	Pink Shrimp	PENA SPP
Family Portunidae	Swimming Crabs	SWIM CRABS
Order Teuthida	Squids	SQUID
Excluded from Analysis		
Family Inachidae	Arrow Crabs	ARROW CRAB
Perna viridis	Asian Green Mussel	ASIAN GREEN MJUSCLE
Limulus polyphemus	Atlantic Horseshoe Crab	HORSESHOE CRAB
Class Ophiuroidea	Brittle Stars	BRITTLE STAR
Hepatus epheliticus	Calico Box Crab	CALICO CRAB
Family Cardiidae	Cockle	COCKLE
Melongena corona	Crown Conch	CROWN CONCH
Superfamily Majoidea	Decorator Crab	DECORATOR CRAB
Class Asteroidea	Five-Armed Sea Star	5 ARM SEA STAR
Dondice occidentalis	Fringe-back Nudibranch	FRINGED NUDIBRANCH
Superfamily Paguroidea	Hermit Crabs	HERMIT CRAB
Order Stomatopoda	Mantis Shrimp	MANTIS SHRIMP
Aplysia fasciata	Mottled Seahare	MOTTLED SEA HARE
Family Xanthidae	Mud Crabs	MUD CRAB, MUD CRABS
Luidia sp.	Nine-Armed Sea Star	9 ARM SEA STAR, 9ARM
Order Decapoda	Purple Crab	PURPLE CRAB
Bursatella leachii	Ragged Seahare	RAGGED SEA HARE, RAGGED SEA HARES
Aplysia sp.	Seahares	APLYSIA SEAHARE
Order Anaspidea	Seahares	SEA HARES
Family Alpheidae	Snapping Shrimp	PISTOL SHRIMP
Libinia sp. (?)	Spider Crab	SPIDER CRAB
Menippe mercenaria	Stone Crab	MENI MERC
Order Neogastropoda	Whelk Egg Case	WHELK EGG CASE

Table C-3. SIMPER two-way (season and zone) results for Naples Bay sampling zones. All taxa that contributed to dissimilarity (up to 90 percent) between groups are listed here in order of greatest contribution to overall difference among groups.

Taxon	Average Group Abundance				% Contribution to Dissimilarity					
	Zone 1	Zone 2	Zone 3	Zone 4	Zones 1 & 2	Zones 1 & 3	Zones 1 & 4	Zones 2 & 3	Zones 2 & 4	Zones 3 & 4
Eucinostomus	3.01	3.76	3.48	3.46	17.57	17.48	20.27	12.81	14.12	15.49
Anchoa	1.03	1.99	1.23	1.51	14.24	10.80	12.98	14.06	15.33	12.54
Farfantepenaeus	0.70	1.13	1.01	1.13	7.94	6.98	8.57	7.40	8.17	8.02
Lutjanus	0.11	0.69	0.94	0.49	4.81	6.75	3.69	5.99	5.33	6.50
Callinectes	0.74	0.82	0.49	0.44	6.81	5.37	5.70	5.31	5.60	3.83
Synodus	0.22	0.76	0.86	0.56	5.44	5.95	4.32	5.40	5.49	5.76
Lagadon	0.37	0.72	0.30	0.26	5.52	3.69	3.57	4.96	4.90	2.88
Ariopsis	0.55	0.54	0.28	0.46	5.02	4.42	5.23	3.84	4.42	3.74
Cynoscion	0.38	0.36	0.23	0.34	3.76	3.19	4.31	2.92	3.59	3.16
Order Teuthida	0.17	0.30	0.35	0.28	2.77	3.06	2.86	3.41	3.01	3.39
Prionotus	0.17	0.20	0.40	0.32	1.99	3.05	2.71	3.00	2.74	3.64
Etropus	0.01	0.09	0.52	0.33		3.36	1.94	3.49	2.24	4.02
Ogcocephalus		0.03	0.43	0.10		3.69		3.33	0.81	3.67
Orthopristis	0.07	0.34	0.16	0.19	2.34	1.35	1.41	2.52	2.64	1.72
Microgobius	0.24	0.10	0.07	0.08	2.00	1.80	2.10	0.87	1.01	0.67
Bairdiella	0.01	0.30	0.29	0.20	1.98	1.60	1.15	3.04	2.62	2.38
Family Portunidae	0.03	0.12	0.22	0.25	1.04	1.53	1.57	1.90	1.97	2.38
Achirus	0.22	0.05		0.03	1.57	1.29	1.67			
Symphurus	0.06	0.17	0.18	0.21	1.15	1.05	1.38	1.59	1.83	1.77
Menticirrhus	0.04	0.11	0.07	0.14	0.94		1.19	1.02	1.47	1.17
Leiostomus	0.06	0.21	0.21	0.04	1.23	1.10		1.70	1.15	1.04
Chilomycterus	0.02	0.01	0.14	0.03		1.19		1.05		1.15
Opsanus	0.04	0.11	0.08	0.07	0.83			1.00	0.97	0.83
Gobiosoma	0.10	0.06		0.02	0.93		0.77			
Archosargus	0.08	0.05	0.03	0.07			1.18		0.82	
Sphoeroides	0.09	0.05	0.07	0.07	0.88	0.97	1.01			0.81
Harengula		0.03	0.09	0.07						0.82
Syngnathus	0.06	0.08	0.06	0.07			0.69			

Table C-4. SIMPER two-way (season and zone) results for Naples Bay season groups. All taxa that contributed to dissimilarity (up to 90 percent) between groups are listed here in order of greatest contribution to overall difference.

Taxon	Average Group Abundance		% Contribution to Dissimilarity
	Dry	Wet	
Eucinostomus	2.74	4.1	18.27
Anchoa	1.13	1.74	13.06
Farfantepenaeus	0.91	1.06	7.45
Callinectes	0.88	0.38	6.34
Synodus	0.65	0.56	4.65
Lagodon	0.69	0.15	4.62
Lutjanus	0.38	0.73	4.58
Ariopsis	0.5	0.42	4.51
Cynoscion	0.13	0.52	3.79
Order Teuthida	0.27	0.28	3.04
Prionotus	0.38	0.17	2.77
Etropus	0.33	0.15	2.23
Bairdiella	0.26	0.15	1.94
Orthopristis	0.27	0.12	1.93
Family Portunidae	0.26	0.05	1.69
Ogcocephalus	0.17	0.11	1.51
Microgobius	0.11	0.14	1.47
Symphurus	0.16	0.14	1.36
Leiostomus	0.22	0.04	1.14
Achirus	0.05	0.1	1.03
Menticirrhus	0.09	0.09	0.99
Sphoeroides	0.11	0.03	0.93
Archosargus	0.08	0.03	0.87

Table C-5. SIMPER results for Naples Bay change-point groups. All taxa that contributed to dissimilarity (up to 90 percent) between groups are listed here in order of greatest contribution to overall difference.

Species	Average Group Abundance			% Contribution to Dissimilarity		
	Apr 2009-Aug 2011	Oct 2011-May 2016	July 2016-Nov 2019	Group 1 & 2	Group 1 & 3	Group 2 & 3
Eucinostomus	3.31	3.54	3.36	14.45	14.67	19.06
Anchoa	2.49	1.31	0.90	14.64	13.66	11.95
Farfantepenaeus	1.43	0.69	1.10	7.48	7.49	8.13
Callinectes	1.11	0.50	0.47	6.42	5.76	5.47
Lagodon	0.92	0.20	0.36	5.97	6.04	3.32
Synodus	0.59	0.45	0.82	3.93	4.86	6.06
Lutjanus	0.52	0.57	0.57	4.52	4.24	5.77
Ariopsis	0.58	0.38	0.49	3.82	3.96	4.86
Cynoscion	0.48	0.23	0.36	3.48	4.06	3.70
Order Teuthida	0.28	0.31	0.22	2.75	2.22	3.21
Prionotus	0.47	0.16	0.29	2.70	3.17	2.90
Etropus	0.39	0.23	0.14	2.88	2.48	2.18
Bairdiella	0.41	0.14	0.15	2.71	2.61	1.53
Leiostomus	0.55	0.02		2.47	2.36	
Orthopristis	0.15	0.19	0.22	1.58	1.49	2.23
Family Portunidae	0.29	0.07	0.18	1.79	2.30	1.62
Symphurus	0.35	0.11	0.08	1.98	1.82	0.97
Ogcocephalus	0.12	0.19	0.08	1.76	1.16	2.10
Microgobius	0.11	0.13	0.13	1.07	1.22	1.66
Menticirrhus	0.07	0.07	0.13		1.07	1.18
Opsanus	0.13	0.05	0.07	0.87	0.95	
Paralichthys	0.13	0.02	0.02	0.87		
Sphoeroides	0.09	0.06	0.09		0.87	1.00
Archosargus	0.09	0.05	0.05	0.87	0.86	
Achirus	0.04	0.10	0.06	0.82		1.10
Syngnathus	0.12	0.04	0.06		0.84	

Table C-6. SIMPER two-way (season and zone) results for Southwest Florida bays from 2009-2013 . All taxa that contributed to dissimilarity (up to 90 percent) with Naples Bay are listed here in order of greatest contribution to overall difference.

Taxon	Average Group Abundance						% Contribution to Dissimilarty with NB				
	NB	MB	RB	PB	FU	FH	MB	RB	PB	FU	FH
Anchoa	2.15	1.52	1.05	1.38	1.09	1.29	16.97	13.6	12.07	12.1	11.47
Eucinostomus	3.02	3.71	2.51	3.09	2.89	2.67	16.1	12.98	10.96	12.24	10.7
Farfantepenaeus	0.99	0.6	1.11	2.04	2.13	1.79	6.73	8.21	8.95	9.97	8.1
Lagodon	0.63	0.38	0.99	1.61	0.86	1.42	4.13	8.05	8.96	6	8.21
Callinectes	0.81	0.23	0.52	0.95	0.67	0.57	4.43	6.04	6	5.26	5.01
Synodus	0.45	0.43	0.69	0.57	0.82	0.69	4.08	5.24	3.45	4.8	3.85
Lutjanus	0.54	0.44	0.34	0.7	0.26	0.61	5.49	3.79	3.73	3.71	3.58
Ariopsis	0.53	0.51	0.23	0.23	0.28	0.21	4.58	4.08	3.4	3.73	3.55
Symphurus	0.22	0.15	0.28	0.86	1.24	0.79	1.72	2.31	4.02	6.14	3.63
Bairdiella	0.28	0.17	0.28	0.47	0.38	0.59	2.32	3.01	3.05	3.03	3.68
Cynoscion	0.38	0.29	0.19	0.3	0.43	0.33	3.8	2.84	2.46	2.97	2.36
Etropus	0.27	0.33	0.29	0.18	0.2	0.41	2.77	2.83	2.08	2.35	3.11
Prionotus	0.3	0.24	0.2	0.35	0.33	0.49	2.17	2.3	2.67	2.82	3.1
Ogcocephalus	0.18	0.18	0.16	0.23	0.05	0.12	2.34	2.26	2.28	1.49	1.83
Leiostomus	0.31	0.37	0.14	0.07	0.12	0.12	2.46	2.19	1.58	1.73	1.72
Order Teuthida	0.28	0.22	0	0	0	0	3.02	1.59	1.33	1.44	1.32
Sphoeroides	0.08	0.07	0.14	0.21	0.26	0.32	0.85	1.45	1.33	1.84	2.14
Orthopristis	0.13		0.36	0.25		0.46		3.09	1.8		2.71
Syngnathus	0.07			0.64	0.2	0.49			3.33	1.29	2.48
Paralichthys	0.08	0.09	0.16	0.19	0.25	0.25	0.93	1.47	1.21	1.66	1.72
Achirus	0.05			0.38	0.59	0.37			1.72	2.98	1.64
Gobiosoma	0.05			0.36		0.62			1.9		3.1
Microgobius	0.09	0.14	0.07		0.41		1.2	0.89		2.11	
Opsanus	0.09			0.19	0.13	0.33			1.32	1.03	1.65
Archosargus	0.07	0.08		0.2			0.98		1.35		
Chloroscombrus	0.06	0.21					1.9				
Menticirrhus	0.07		0.14					1.13			
Family Portunidae	0.17		0					1.03			
Bagre	0.06	0.06					0.92				
Sciaenops	0.07	0.05					0.9				

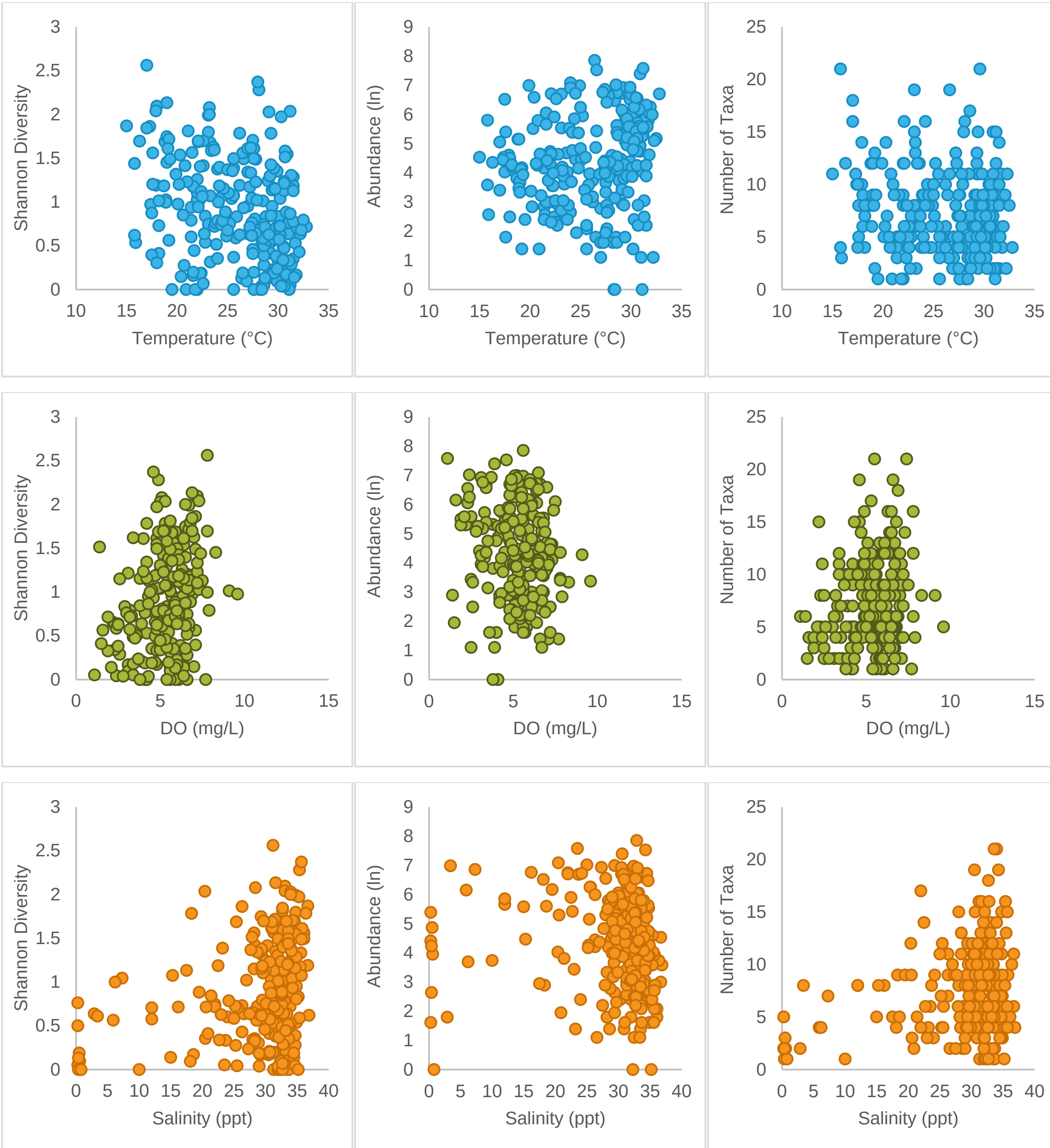

Figure C-1. Example plots of diversity metrics against bottom depth field water quality measurements.

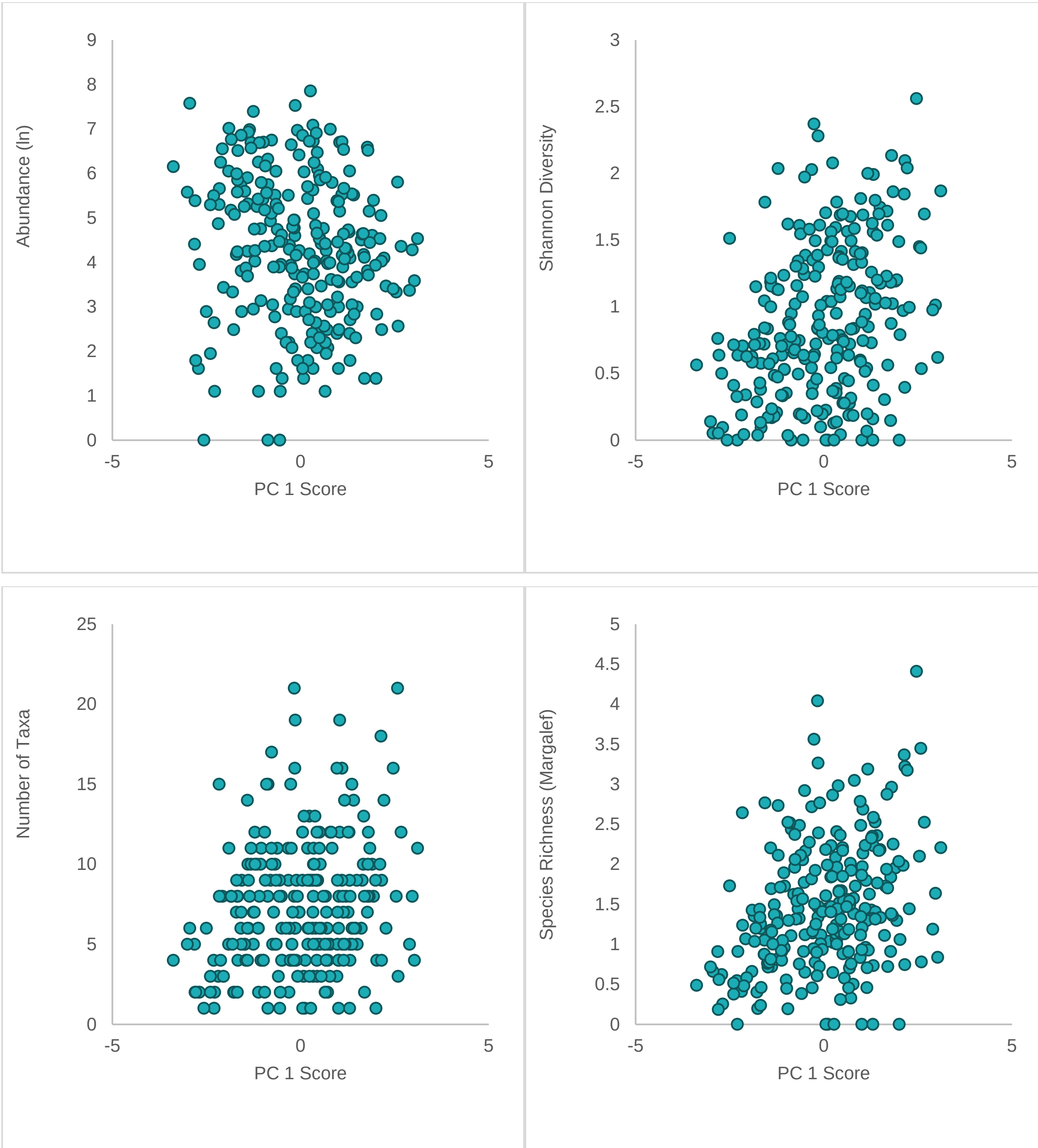

Figure C-2. Example plots of diversity metrics against PC scores from the bottom water quality dataset.

City of Naples

APPENDIX

D

NAPLES BAY HISTORICAL COMPARISON FROM 2015 REPORT

Appendix D
Naples Bay Historical Comparison from 2015 Report

Until 2006, when the City began its water quality and biological monitoring program, the only large scale, comprehensive monitoring, data analysis, and reporting effort in Naples Bay was completed in 1979 (Simpson et al. 1979). Data collection for this previous effort was completed over the course of a year from late 1976 through late 1977. This report concluded that the number one source of pollution in Naples Bay was the GGC freshwater flow and cessation of flow was the only course of action to restore the Bay (Simpson et al. 1979). The GGC flow brought enormous volumes of freshwater, silt, nutrients, and other pollutants that dramatically altered the water quality and biological community in Naples Bay (Simpson et al. 1979). These conclusions persist today in the discussion of the status of Naples Bay.

Now the opportunity exists to compare the current water quality and biological status of Naples Bay to the results of the 1979 study to determine what, if any, improvements have been realized in Naples Bay, and quantify any changes. Since the 1979 report several significant advancements in water resources have occurred that could play a role in any changes observed in Naples Bay from 1979 to current day. Most notably, the amendments to the Clean Water Act and adoption of water quality criteria, advanced wastewater treatment, stormwater management and treatment technologies, and specific to Naples Bay, the replacement and upgrades made to the GGC weir system. Although the sampling methodologies are not identical between the two time periods, there is significant overlap that allows for a meaningful comparison. Here pertinent water quality and biological parameters were compared from the 1979 Naples Bay Study to the current status observed in Naples Bay to identify and quantify changes and/or improvements since the last large-scale monitoring effort was completed.

Comparisons are available between the Naples Bay Study and current data collection for some water quality and quantity parameters (nitrogen, phosphorus, chlorophyll-*a*, salinity, rainfall, and GGC flow) as well as fish community abundance and diversity. These parameters were chosen because of their similar sampling methodologies and methods of reporting in the 1979 study. Specific information regarding how the comparisons were done and any necessary assumptions about the data are described in the following sections.

D.1 Golden Gate Canal Flow

Construction of the Golden Gate Main Canal system was completed in the late 1960s to drain upland areas, historically outside of the Naples Bay watershed, for residential development (City of Naples 2010, SFWMD 2007, FDEP 2010, and Simpson et al. 1979). When first constructed, the weir separating the GGC from the Gordon River was a concrete dam that allowed free flow over the weir whenever water exceeded the weir elevation (Simpson et al. 1979). This was the case at the time of the Naples Bay Study in the late 1970s. Since the mid-1980s, the SFWMD has been working to upgrade the GGC weir system and install structures to better manage flow, increase groundwater recharge, and improve water quality in Naples Bay by reducing freshwater inflow from the GGC, with the most recent improvements being implemented in 2012 (SFWMD 2012). The differences in GGC flow magnitude and timing that occurred during the Naples Bay Study in the late 1970s (Simpson et al. 1979) was examined, along with the current flow conditions that are observed today. This examination will serve as the basis for the subsequent discussions regarding water quality and biological comparisons between the historical and current time periods.

Simpson et al. (1979) reported daily flow from the GGC into the Gordon River during their study for water year 1977 (October 1976–September 1977). For the current time period, the GGC daily flow for water years 2009–2014 was calculated. Recorded GGC flow for water year 1977 averaged 193 mgd over the course of 335 days for which flow was recorded (Table D-1). In comparison, the current years all showed fewer days of flow and less flow per day, with the exception of 2010 (358 days of flow) and 2013 (212 mgd on average). Flow during the Naples Bay Study was 33 to 85 percent greater than the flow recorded during the current time period. In 2010, the number of days of flow was greater, but the magnitude of flow was significantly reduced from the 1977 time period, and in 2013, the average daily flow was increased, but the number of days of flow was less than the historical time period.

Table D-1. Golden Gate Canal flow comparison between water year 1977 (historical) and water years 2009-2014 (current). Historical data from Simpson et al. (1979); current data from SFWMD.

Time Period	Water Year	Total Flow (Million Gallons)	Days of Flow	MGD
Historical	1977	65,656	335	193
Current	2009			
	2010	36,533	358	102
	2011	10,116	119	85
	2012	22,745	219	103
	2013	43,918	207	212
	2014	28,221	199	142

Since the GGC flow is heavily rainfall driven, the rainfall conditions between the historical and current time periods were examined to determine if rain patterns could explain the difference in flow pattern between the two time periods. Monthly and annual rainfall totals for both time periods were obtained from the National Oceanic and Atmospheric Administration (NOAA) rain gauge (GHCND:USC00086078) located in the Golden Gate area near Naples (see Figure 2-1). Rainfall in 1977 totaled 50.5 inches compared to total rainfall of between 52.7 and 64.5 inches for the current time period. This indicates rainfall during the historical period was similar to or even less than rainfall during the current time period.

This comparison indicates that GGC flow has been significantly reduced since the Naples Bay Study (1979). In fact, during 2013 when the highest rainfall (64.5 inches) and highest flow of the current time period (43.9 billion gallons) were recorded, flow was still 33 percent less than flow during the historical period. The GGC may have still been actively dewatering the upland areas during the late 1970s. In addition, control structure upgrades made to the canal system over the last 20 years are likely responsible for reduced flow observed since the Simpson et al. (1979) study. The potential effects of the reduced flow on Naples Bay water quality and biology are discussed below.

D.2 Water Quality

During the 1979 Naples Bay Study, water quality data were collected at nine locations throughout Naples Bay and the Gordon River (Marine Segment) monthly for one year (December 1976–November 1977) (Simpson et al. 1979). Four of those locations were in proximity to the City's current long-term sampling stations to allow for adequate comparisons of data (Figure D-1). For grab sample data of TN, TP, and chlorophyll-*a*, historical monitoring locations (Stations 10, 40, 50, and 70) were compared to current monitoring locations GPASS6, NBAYWS, NBAYNL, and GORDEXT/GORDPT, respectively. Simpson et al. (1979) conducted monthly diel monitoring for salinity, which allowed for comparison to USGS continuous recorder data from 2011 to 2014. Therefore, historical monitoring locations 10, 20, 50, and 70 were used to coincide with the USGS monitoring locations (Figure D-1).

For the current water quality data, monthly measurements at each station for the 2006–2014 time period were averaged to obtain a current representation for a given month and compared to the monthly measurement collected in 1976–1977. The individual diel sampling events at each station in the historical data were merged to generate a daily range in salinity for the surface and bottom and compared to surface and bottom salinity ranges observed in the current data. The results of this analysis are described below.

The current average surface salinity in Naples Bay and the Gordon River follows the same general pattern as the historical data with significant differences observed between the wet and dry seasons (Figure D-2). The largest differences in average surface salinity are observed in the Gordon River and northern Naples Bay locations, with the current data showing increased salinity concentrations during most months, and especially during the wet season months. In addition, the daily range in salinity concentrations (shown in Figure D-2 as the gray bars) is increased in the current data, with the two northern most stations (Gordon River and City Dock) showing the most significant change from the historical condition.

The shift in salinity regime in the current data can be attributed to the change in flow regime from the GGC canal between the two time periods. The significant reduction in GGC flow from the historical time period leads to greater overall salinity in the Bay, as well as allowing greater tidal influence further north in the Bay creating larger daily swings in salinity. This explains the increased daily salinity range, which is even more pronounced during the wet season when canal flow trends to be greater in magnitude and longer in duration. Although wet season flow from the canal is greater than during the dry season, the observed overall reduction in flow from the historical condition allows more tidal influence and therefore larger daily salinity swings. The observed daily range in salinity is less at the southern Bay locations (Mid Estuary and Gordon Pass) because the influence of the GGC canal flow on salinity is diminished.

Throughout the Bay and Gordon River, significant changes in nutrients and chlorophyll-*a* concentrations are also observed in the current data versus the historical data reported by Simpson et al. (1979). Average TN concentrations are 25 to 45 percent lower than reported in the 1976–1977 data, while average TP concentrations are 55 to 75 percent lower, and average chlorophyll-*a* concentrations are 66 to 75 percent lower in the current data than reported in the historical data (Figure D-3).

The observed decrease in nutrients and chlorophyll-*a* concentrations in the Bay is not surprising given the multitude of advancements in water quality and water resources since the late 1970s including improved stormwater management, adoption and implementation of water quality criteria, and advanced wastewater treatment. All of these in combination would result in improved water quality in Naples Bay. Additionally, the reduction in GGC flow and loadings from the 1976–1977 would also contribute to the improved water quality. For the 2008–2014 time-frame, the annual loadings to Naples Bay ranged from approximately 100,000–300,000 lbs of nitrogen and from approximately 3,500–11,000 lbs of phosphorus (see section 3.1.1). Nutrient loadings to Naples Bay during the December 1976–November 1977 time period were approximately 430,000 lbs and 17,500 lbs of nitrogen and phosphorus, respectively. As a result of the lower nutrient concentrations and reduced GGC flow, the maximum observed nutrient loadings in the current condition (2013, see section 3.1.1) represent a 30 percent reduction in nitrogen loading and approximate 40 percent reduction in phosphorus loading to Naples Bay from the historical condition.

This comparison indicates that water quality conditions (salinity, nutrients and chlorophyll-*a*) in Naples Bay have improved significantly from the conditions observed by Simpson et al. in the late 1970s. Nutrient and chlorophyll-*a* concentrations have been reduced and the salinity concentrations have somewhat increased with daily ranges that indicate more tidal influx in the upper Bay is occurring now. Several factors likely contribute to this improvement as mentioned above and we have no credible method of discerning which factors play the most influential role in this improvement with the data that currently exists. However, is it reasonable to conclude that the observed reduction in flow from and loading from the GGC canal from the 1970s levels likely played a significant role in the Bay's observed water quality improvement.

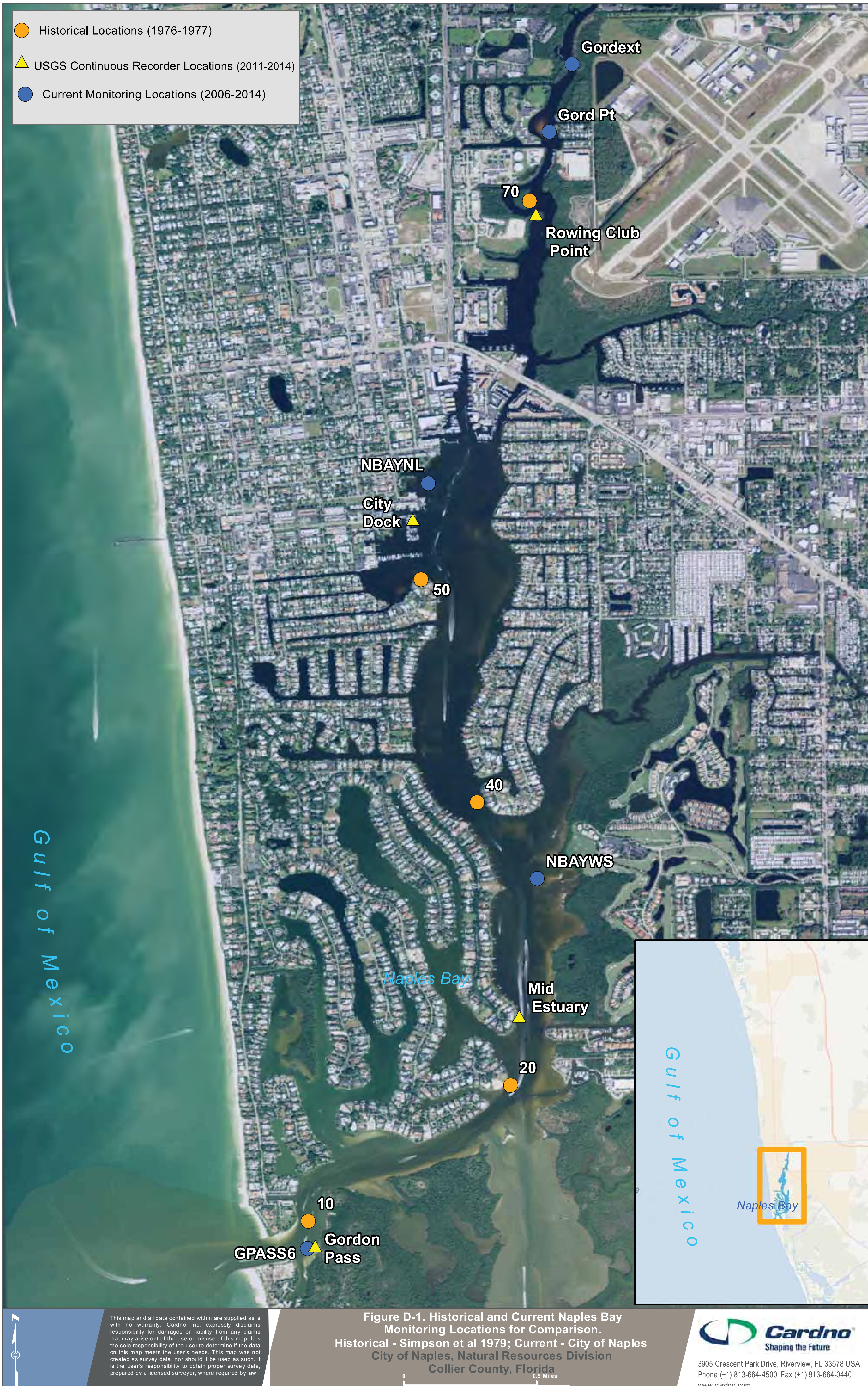

Figure D-1. Historical and Current Naples Bay Monitoring Locations for Comparison.
Historical - Simpson et al 1979; Current - City of Naples
City of Naples, Natural Resources Division
Collier County, Florida

Cardno
Shaping the Future
3905 Crescent Park Drive, Riverview, FL 33578 USA
Phone (+1) 813-664-4500 Fax (+1) 813-664-0440
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Date Created: 5/8/2015 Date Revised: 5/8/2015 File Path: Q:\UnitedStates\Florida\Tampa\City_Of_Naples\Water Quality Analysis Project\working\arcmap\Fig7_1_CON_WQ_Hist_Curr_20150505.mxd
GIS Analyst: adam.bausch

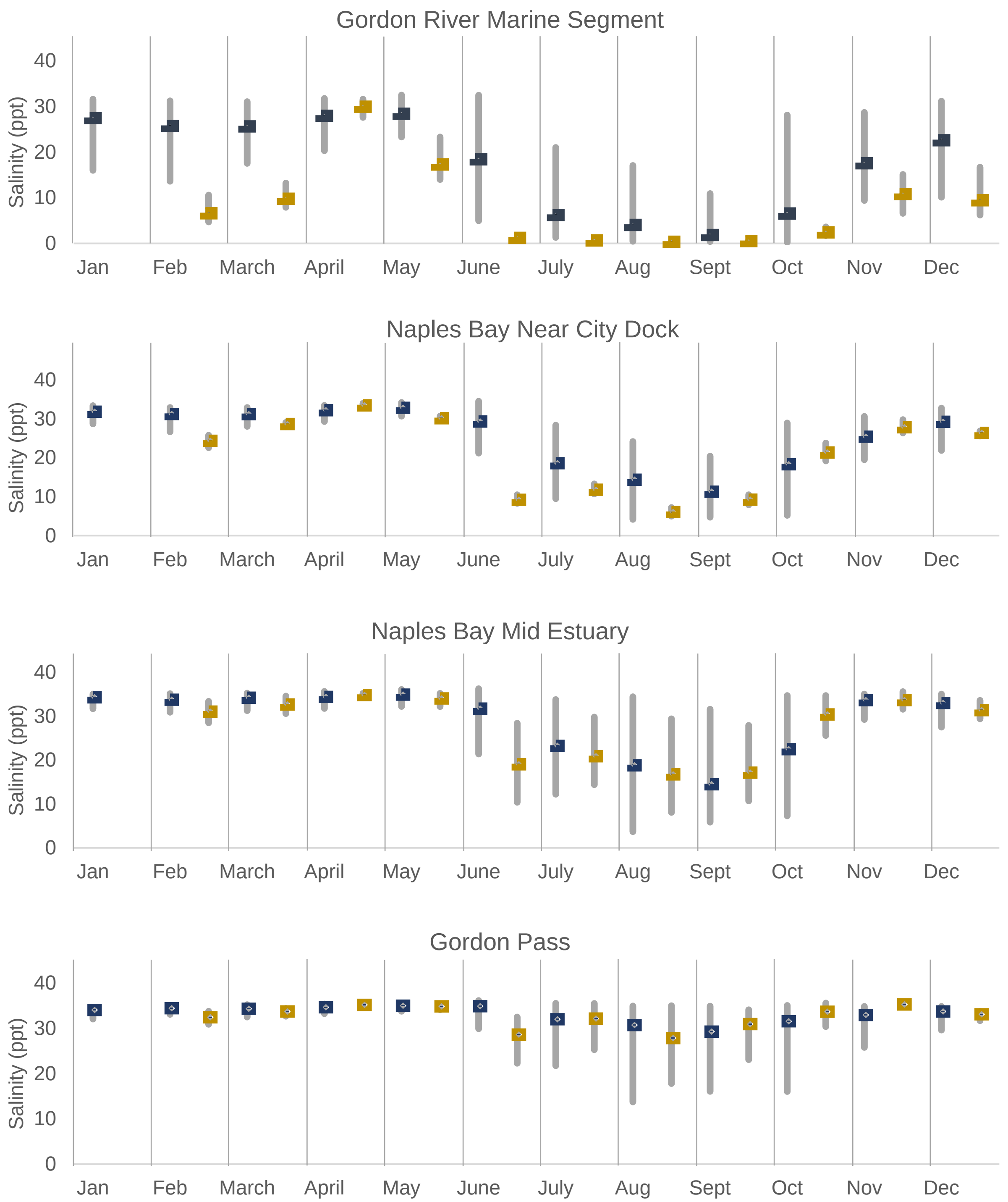

Figure D-2. Mean and range monthly salinity comparison between historical (1976-1977) and current (2011-2014) data in Naples Bay and Gordon River (marine segment). Simpson et al. 1979; USGS 2011-2014. Blue = current data, yellow = historical data, gray bars = daily salinity range.

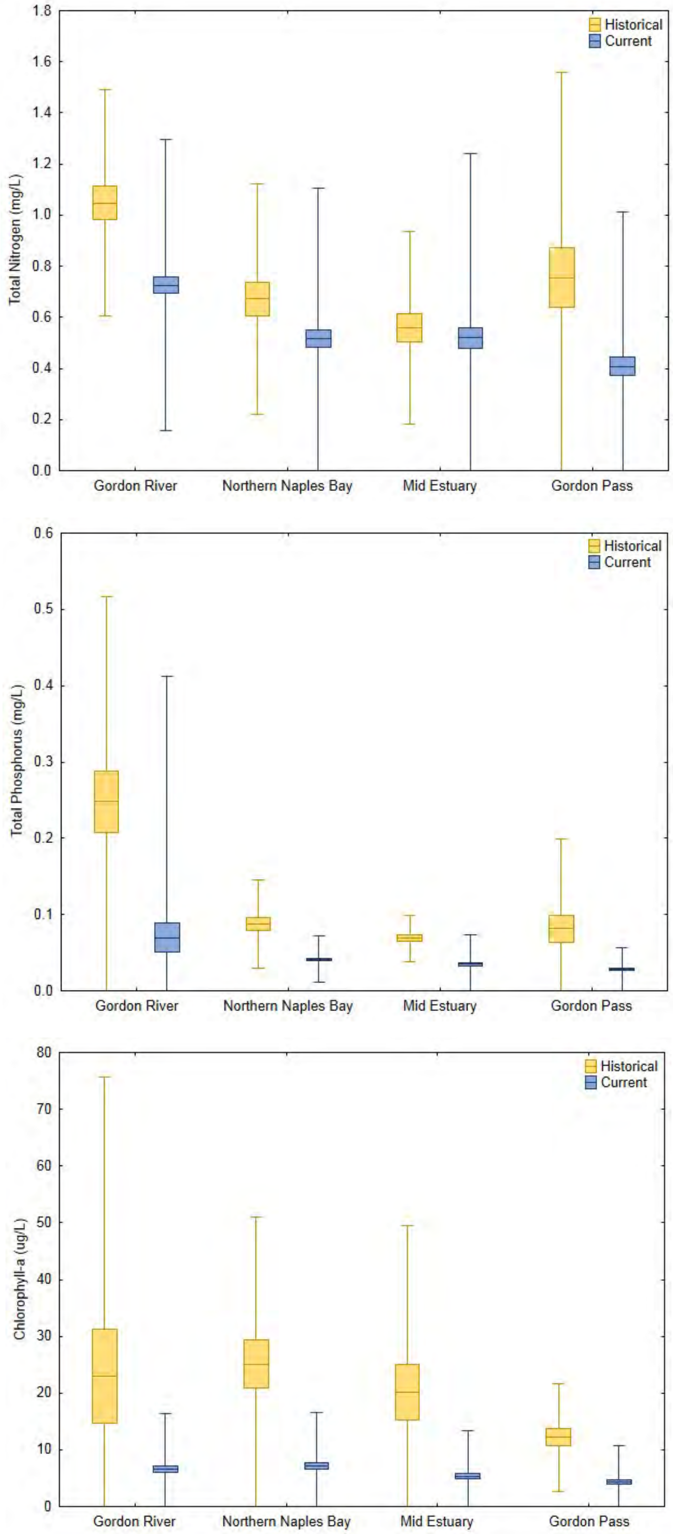

Figure D-3. Comparison of nutrient (nitrogen and phosphorus) and chlorophyll-*a* concentrations between historical (1976-1977) and current (2008-2014) conditions. Historical data from Simpson et al. (1979); current data from City of Naples.

D.3 Biology

Comparison of the biology community (fish) observed by Simpson et al. (1979) and the current data set are also possible. Although Simpson et al. (1979) also collected phytoplankton and benthic samples, this comparison will focus on fish as the current data set do not include benthic and phytoplankton data. Fish collection in the Naples Bay Study (1979) were conducted monthly using two 100m mid-water trawls pulled at each of 17 fixed locations throughout the Bay, Gordon River, tributary canals, and a control station in Dollar Bay. By comparison, trawling conducted by the City in the current dataset consists of bottom trawls at random locations within four different zones within the Bay, Gordon River, and Port Royal canal area.

Comparisons of fish results between the two time periods will focus on observed patterns across months and among zones of the Bay and not comparisons of the numbers themselves. We understand the difference in sampling methodologies and gear type play a significant role in understanding why the data may differ. Therefore, the comparison will focus on whether or not the current data exhibits the same pattern (seasonal and spatial) as observed in the Simpson et al. (1979) study. This type of comparison will allow us to understand whether changes have occurred over time in the fish communities, even though sampling methodologies were different.

Abundance and diversity data published in the Naples Bay Study (1979) were plotted by zone next to average data from the current Naples Bay monitoring program. Only stations that overlapped the current sampling zones were included in the comparison. Thus, historical station 90 was not part of this comparison. Station 90 was located in the Golden Gate Canal directly below the dam, and not within current sampling Zone 1. Notably, without station 90, the conclusions in the 1979 report about the diminished state of the Gordon River as a whole are not as apparent. The patterns showing large drops in diversity and abundance were completely driven by data from a station that is not representative of the rest of the Gordon River area. When patterns of abundance and diversity in 1977 are compared to patterns in the recent years (Figure D-4 and Figure D-5) a few differences are visible. First, the difference in abundance in Zones 2 and 3 is smaller in the recent dataset than it was in 1977. Second, the difference in abundance between Zone 1 and the other zones was greatest in the wet season during 1977, while it is greatest in the dry season in the recent data. This could be related to changes in flow between the two time frames: in 1977 the flow from the Golden Gate Canal was much higher than has been recently and did not completely shut off for several months at a time in the dry season as it has recently. In terms of diversity, there seems to be a stronger wet-dry seasonal trend in recent years that is not as evident in 1977. The current pattern shows gradually decreasing diversity as the summer and wet season progresses with an increase again in the drier winter months. In addition, there is less separation between Zone 1 and Zones 2 and 3 in the more recent dataset.

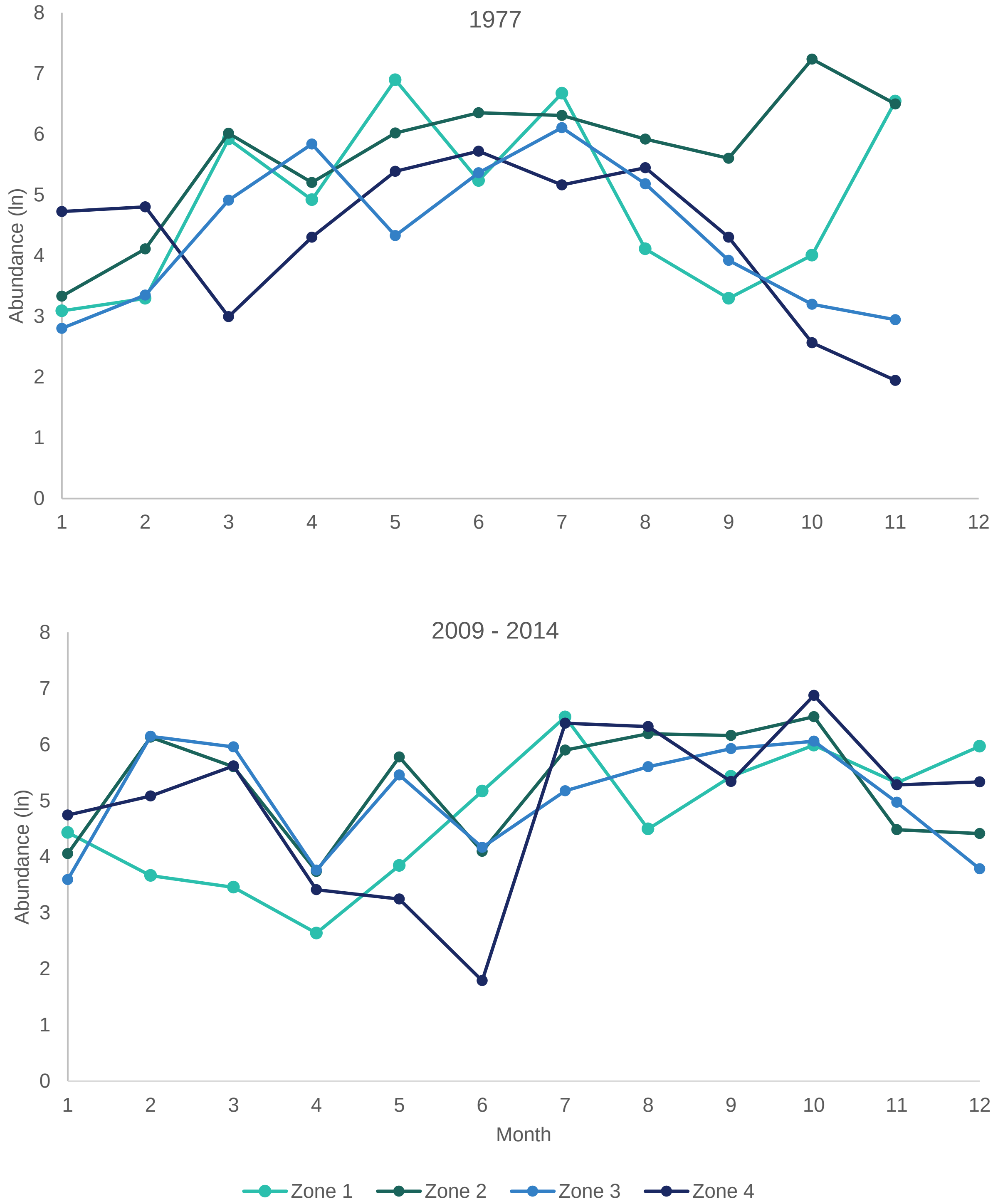

Figure D-4. Average fish abundance by zone for 1977 and 2009-2014 in Naples Bay.

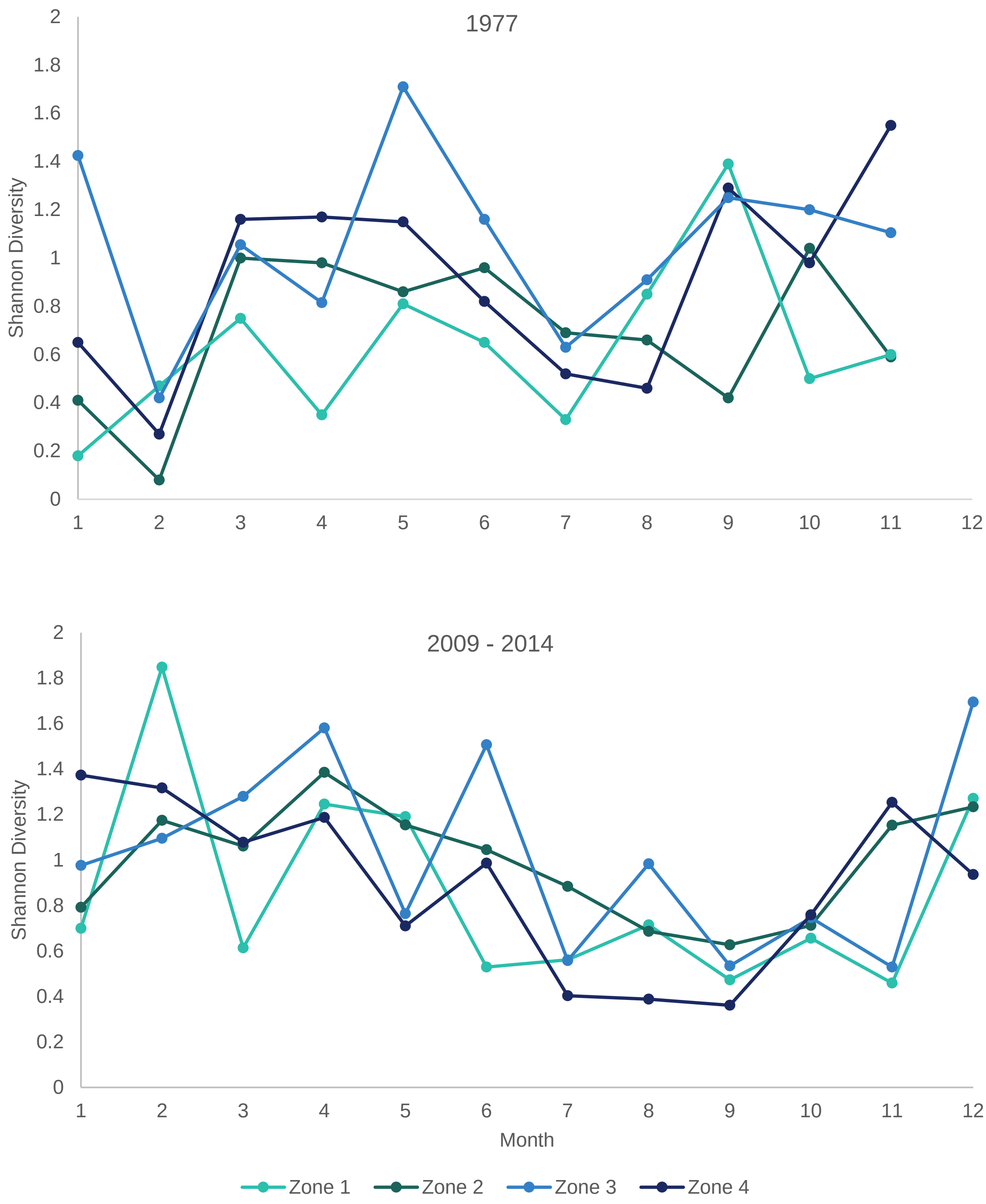

Figure D-5. Average fish diversity by zone for 1977 and 2009-2014 in Naples Bay.

About Cardno

Cardno is an ASX-200 professional infrastructure and environmental services company, with expertise in the development and improvement of physical and social infrastructure for communities around the world. Cardno's team includes leading professionals who plan, design, manage, and deliver sustainable projects and community programs. Cardno is an international company listed on the Australian Securities Exchange [ASX:CDD].

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