ASSESSMENT OF C-8 AND C-9 POTENTIAL WATER QUALITY IMPACTS TO NORTH BISCAYNE BAY

TECHNICAL MEMORANDUM

TASK 4B – WATER QUALITY IMPACT ANALYSIS OF MITIGATION STRATEGIES ON NORTH BISCAYNE BAY

PREPARED FOR

South Florida Water Management District
3301 Gun Club Road
West Palm Beach, FL 33146

Taylor Engineering, Inc.
14499 N. Dale Mabry Hwy, Suite 290
Tampa, FL 33618

PREPARED BY

Nova Consulting
10486 NW 31st Terrace
Doral, FL 33172

SFWMD Work Order No. 450004085-WO5

June 10, 2023

Table of Contents

1.0 Objective and Scope 8
2.0 Introduction and Background 9
2.1 Biscayne Bay 9
2.2 North Biscayne Bay 9
2.2.1 NNB-A 12
2.2.2 NNB-B 13
2.2.3 C-8 and C-9 Outfalls 13
3.0 Data Collection 14
4.0 Methods 15
4.1 General 15
4.2 Time Series Analyses 16
4.3 Cumulative Volume Analyses 16
4.3.1 Correlation Analyses 16
4.3.2 Regression Analyses 17
5.0 Contaminants of Concern 18
5.1 Standards and Criteria 18
5.2 Evaluation of COCs 18
6.0 Discharges Into North Biscayne Bay 21
6.1 C-9 Watershed 22
6.1.1 Historical Flows 22
6.1.2 Hydraulic Modeling Flows 23
6.2 Biscayne Canal and Watershed (C-8) 28
6.2.1 Historical Flows 28
6.2.2 Hydraulic Modeling Flows 29
7.0 C-9 Results and Mitigation Scenario Impacts on Water Quality 33
7.1 C-9 Time Series Results 33
7.1.1 Salinity 33
7.1.2 Chlorophyll a 35
7.1.3 Total Nitrogen 35
7.1.4 Total Phosphorus 36
7.1.5 Dissolved Oxygen 37
7.1.6 Copper 38
7.1.7 Turbidity 39
7.2 C-9 Correlation Analysis Results 40
7.2.1 Salinity 40

7.2.2 Chlorophyll a 41
7.2.3 Total Nitrogen 41
7.2.4 Total Phosphorus 42
7.2.5 Dissolved Oxygen 42
7.2.6 Turbidity 43
7.2.7 Copper 44
7.3 C-9 Regression Analyses Results 45
7.3.1 Salinity 45
7.3.2 Chlorophyll a 48
7.3.3 Dissolved Oxygen 50
7.4 NNB-A (C-9) Cumulative Volume Analysis Conclusions 53
8.0 C-8 Results and Mitigation scenario Impacts on Water Quality 57
8.1 C-8 Time Series Results 57
8.1.1 Salinity 57
8.1.2 Chlorophyll a 58
8.1.3 Total Nitrogen 59
8.1.4 Total Phosphorus 60
8.1.5 Dissolved Oxygen 60
8.1.6 Turbidity 62
8.2 C-8 Correlation Analysis Results 62
8.2.1 Salinity 63
8.2.2 Chlorophyll a 63
8.2.3 Total Nitrogen 64
8.2.4 Total Phosphorus 65
8.2.5 Dissolved Oxygen 65
8.2.6 Turbidity 65
8.3 C-8 Regression Analysis Results 66
8.3.1 Salinity 66
8.3.2 Chlorophyll a 69
8.3.3 Total Nitrogen 71
8.3.4 Dissolved Oxygen 73
8.4 NNB-B (C-8) Cumulative Volume Analyses Conclusions 76
9.0 Mitigation Scenario Impacts on Marine Life and Seagrass 80
9.1 NNB-A 81
9.1.1 Salinity Considerations 83
9.1.2 Nutrient Loading Considerations 84

9.2 NNB-B 86
9.2.1 Salinity Considerations 88
9.2.2 Nutrient Loading Considerations 88
10.0 Conclusions 91
10.1 C-9 Basin (NNB-A) 91
10.2 C-8 Basin (NNB-B) 92
Appendix A 74
Appendix B 86
Appendix C 88

List of Figures

Figure 2-1: NNB -A and NNB -B in Relation to the WQ monitoring stations, Flowmeters, Canals, and Canal Basins 11
Figure 4-1: Flowchart of Methods used for the Cumulative Volume Analysis 15
Figure 6-1: Historical Average Daily Flows at the S-29 for the Period 1/1/1996 to 1/1/2022 22
Figure 6-2: Historical Average Daily Flows at the S-29 for the Period 6/2/2017 to 6/17/2017 23
Figure 6-3: Simulated Average Daily Flows at the S-29 for All Combinations of Mitigation Strategy and Sea Level Rise Scenarios for a 5-year (top panel) and 10-Year (bottom panel) Return Period Design Storm 24
Figure 6-4: Simulated Average Daily Flows at the S-29 for All Combinations of Mitigation Strategy and Sea Level Rise Scenarios for a 25-year (top panel) and 100-Year (bottom panel) Return Period Design Storm 25
Figure 6-5: Cumulative Volume Discharges at the S-29 for Combinations of Mitigation Strategies, Sea Level Rise Scenarios, and Storm Return Periods for 6/2/2017 to 6/17/2017 (Event Simulation Period) 27
Figure 6-6: Historical Average Daily Flows at the S-28 for the Period 1/1/1996 to 1/1/2022 28
Figure 6-7: Historical Average Daily Flows at the S-28 for the Period 6/2/2017 to 6/17/2017 28
Figure 6-8: Simulated Average Daily Flows at the S-28 for All Combinations of Mitigation Strategy and Sea Level Rise Scenarios for a 5-year (top panel) and 10-Year (bottom panel) Return Period Design Storm 29
Figure 6-9: Simulated Average Daily Flows at the S-28 for All Combinations of Mitigation Strategy and Sea Level Rise Scenarios for a 25-year (top panel) and 100-Year (bottom panel) Return Period Design Storm 30
Figure 6-10: Cumulative Volume Discharges at the S-28 for Combinations of Mitigation Strategies, Sea Level Rise Scenarios, and Storm Return Periods for 6/2/2017 to 6/17/2017 (Event Simulation Period) 32
Figure 7-1: Annual Series of Average Salinity Concentrations at BB02 34
Figure 7-2: Annual Minimum Series of Salinity Concentrations at BB02 34
Figure 7-3: Annual GMs of Chlorophyll a Concentrations at BB02 35
Figure 7-4: Annual GMs of TN Concentrations at BB02 and SK02 36
Figure 7-5: Annual GMs of TP Concentrations at BB02 and SK02 Dissolved Oxygen 36
Figure 7-6: Annual Distributions of Instantaneous DO Concentrations at BB02 (1996 – 2019)..37
Figure 7-7: Annual Means of DO Concentrations at BB02 and SK02 38
Figure 7-8: Instantaneous Copper Concentrations at BB02 and SK02 38

Figure 7-9: Annual Distributions of Instantaneous Turbidity Concentrations at BB02 39
Figure 7-10: Pearson and Spearman Correlation Coefficients for Salinity versus Accumulation Period at BB02..41
Figure 7-11: Pearson and Spearman Correlation Coefficients for Chlorophyll a versus Accumulation Period at BB02..41
Figure 7-12: Pearson and Spearman Correlation Coefficients for TP versus Accumulation Period at BB02...42
Figure 7-13: Pearson and Spearman Correlation Coefficients for DO versus Accumulation Period at BB02...43
Figure 7-14: Pearson and Spearman Correlation Coefficients for Turbidity at BB02 43
Figure 7-15: Salinity Concentrations at BB02 against 5-day Cumulative Volumes from S-29....45
Figure 7-16: Projected Salinity Concentrations at BB02 for All Modeling Scenarios 47
Figure 7-17: Chlorophyll a Concentrations at BB02 against 15-day Cumulative Volumes from S-29...48
Figure 7-18: Projected Chlorophyll a Concentrations at BB02 for All Modeling Scenarios.........49
Figure 7-19: DO Concentrations at BB02 against 15-day Cumulative Volumes from S-29........50
Figure 7-20: DO Concentrations Against Chlorophyll a Concentrations at BB02.......................51
Figure 7-21: Projected DO Concentrations at BB02 for All Modeling Scenarios 52
Figure 8-1: Annual Series of Average Salinity Concentrations at BB09....................................58
Figure 8-2: Annual Minimum Series of Salinity Concentrations at BB09...................................58
Figure 8-3: Annual GMs of Chlorophyll a Concentrations at BB09 59
Figure 8-4: Annual GMs of TN Concentrations at BB09 60
Figure 8-5: Annual GMs of TP Concentrations at BB09 and BS04...60
Figure 8-6: Annual Distributions of Instantaneous DO concentrations at BB09 (1996 – 2021) ..61
Figure 8-7: Annual Means of DO Concentrations at BB09 61
Figure 8-8: Annual Distributions of Instantaneous Turbidity Concentrations at BB09 62
Figure 8-9: Pearson and Spearman Correlation Coefficients for Salinity versus Accumulation Period at BB09..63
Figure 8-10: Pearson and Spearman Correlation Coefficients for Chlorophyll a versus Accumulation Period at BB09..64
Figure 8-11: Pearson and Spearman Correlation Coefficients for TN versus Accumulation Period at BB09...64
Figure 8-12: Pearson and Spearman Correlation Coefficients for TN at BS01 65

Figure 8-13: Pearson and Spearman Correlation Coefficients for DO versus Accumulation Period at BB09 65
Figure 8-14: Salinity Concentrations at BB09 against 5-day Cumulative Volumes from the S-28 66
Figure 8-15: Projected Salinity Concentrations at BB09 for All Modeling Scenarios 68
Figure 8-16: Chlorophyll a Concentrations at BB09 against 13-day Cumulative Volumes from the S-28 69
Figure 8-17: Projected Chlorophyll a Concentrations at BB09 for All Modeling Scenarios 70
Figure 8-18: TN Concentrations at BS01 against 15-day Cumulative Volumes from the S-28 ...71
Figure 8-19: Projected TN Concentrations at BS01 for All Modeling Scenarios 72
Figure 8-20: DO Concentrations at BB09 against 15-day Cumulative Volumes from the S-28 ..73
Figure 8-21: DO Concentrations versus Chlorophyll a Concentrations at BB09 73
Figure 8-22: Projected DO Concentrations at BB09 for All Modeling Scenarios 75
Figure 9-1: Seagrass Habitat in NNB-A (as of 2022) 82
Figure 9-2: Salinity Concentrations at BB02 with 100-year Storm Mitigation Scenario Projection Range (Orange Box) 83
Figure 9-3: Empirical TN Mass Fluxes into NNB-A (1/6/1997 – 4/4/2022) 84
Figure 9-4: Best-fit Line for Percentage Seagrass Loss versus Normalized TN Loading Rates for Several Estuaries Applied to the C-9 (Steward and Green, 2007) 85
Figure 9-5: Seagrass Habitat in NNB-B (as of 2022) 87
Figure 9-6: Salinity Concentrations at BB09 (1/1/1996 – 1/1/2022) with 100-year Storm Mitigation Scenario Projection Range (Orange Box) 88
Figure 9-7: Empirical TN Mass Fluxes into NNB-B (1/6/1997 – 4/4/2022) 89
Figure 9-8: Best-fit Line for Percentage Seagrass Loss versus Normalized TN Loading Rates for Several Estuaries Applied to the C-8 (Steward and Green, 2007) 89

List of Tables

Table 2-1: List of Flowmeters and WQ Stations Associated with the C-8 and C-9 Canals and Basins 12
Table 4-1: Variable Pairs of Interest for the Correlation Analysis 16
Table 4-2: Interpretation of the Pearson's and Spearman's Correlation Coefficients 17
Table 5-1: COC Analysis in NNB-A 19
Table 5-2: COC Analysis in NNB-B 20
Table 6-1: Modeling Scenarios for the FPLOS WQ Impact Assessment 21
Table 7-1: Mann-Kendall Test Results for COCs at BB02 and SK02 33
Table 7-2: Correlation Analysis Results for Variable Pair #1 in the C-9 40
Table 7-3: Regression Results for the NNB-A Cumulative Volume Analyses 45
Table 7-4: NNB-A Correlation Analysis Results 53
Table 7-5: Results for the 5-Year Storm in NNB-A 54
Table 7-6: Results for the 10-Year Storm in NNB-A 54
Table 7-7: Results for the 25-Year Storm in NNB-A 55
Table 7-8: Results for the 100-Year Storm in NNB-A 55
Table 8-1: Mann-Kendall Test Results for COCs at BB09 and BS04 57
Table 8-2: Summary of Correlation Analysis Results for Variable Pair #2 in the C-8 62
Table 8-3: Regression Results for the NNB-B Cumulative Volume Analyses 66
Table 8-4: NNB-B Correlation Analysis Results 76
Table 8-5: Results for the 5-Year Storm in NNB-B 77
Table 8-6: Results for the 10-Year Storm in NNB-B 77
Table 8-7: Summary of Results for the 25-Year Storm in NNB-B 78
Table 8-8: Summary of Results for the 100-Year Storm in NNB-B 78
Table 9-1: Indicator Species of NNB-A and their Characteristics (BFA, 2004) 81
Table 9-2: BB02 Salinity Concentration Estimates (ppt) 84
Table 9-3: Indicator Species of NNB-B and their Characteristics (BFA, 2004) 86

1.0 OBJECTIVE AND SCOPE

The South Florida Water Management District (SFWMD or District) is conducting a system-wide review of the regional water management infrastructure to determine what mitigation projects would maintain or improve the current Flood Protection Level of Service (FPLOS). Phase II of this FPLOS assessment for the C-8 and C-9 watersheds in Miami-Dade County is currently in progress. Phase II consists of a comprehensive examination of different flood adaptation strategies and mitigation projects, together with sequencing of certain selected projects for implementation. Phase II includes the evaluation of water quality impacts resulting from these mitigation strategies and the ability to meet existing water quality standards within the Biscayne Bay Aquatic Preserve. The study area is North Biscayne Bay, which is part of the Biscayne Bay Aquatic Preserve and designated as Outstanding Florida Waters (OFW) under Chapter 62-302.700, Florida Administrative Code (FAC). The purpose of this study is to evaluate potential changes in water quality (WQ) to downstream receiving water bodies (Biscayne Bay) that could potentially result from proposed FPLOS changes in water management of the C-8 and C-9 canals and flows at the outfall structures. Potential environmental impacts pertaining to marine life and seagrass will also be evaluated.

This memorandum comprises Amendment No. 1 to Taylor Engineering Contract Number C2021-033. The scope of work for this Task is summarized below:

- Collect readily available WQ data from the study area (North Biscayne Bay) from publicly available databases, including Miami-Dade County and the SFWMD. Review existing studies relevant to North Biscayne Bay.
- Review existing WQ datasets and determine ambient background concentrations and contaminants of concern (COCs), if any, in the C-8 and C-9 canals and in North Biscayne Bay.
- Provide time-series plots of these COCs showing historical data and note changes in concentrations.
- Evaluate existing flows and, where possible, contaminant mass loading rates from the C-8 and C-9 canals into North Biscayne Bay and assess any discernable peaks. Assess the statistical significance of any correlation between canal discharges and COC concentrations in the Bay.
- Perform regression analyses for each COC exhibiting a statistically significant correlation with canal discharges.
- Based on existing WQ data and proposed changes in flowrates resulting from the implementation of selected flood adaptation strategies and mitigation project(s), make qualitative assessments of the potential effects of the implementation of FPLOS projects on water quality. This will include assessing potential environmental impacts pertaining to marine life and seagrass using established relations between contaminant concentrations/loads and marine life degradation.
- For each canal, up to fifty-two (52) flow scenarios will be utilized for these assessments. This totals one-hundred and four (104) scenarios for both the C-8 and C-9 canals. Note that this analysis will consider the C-8 and C-9 canal basins separately to assess their individual influence on bay WQ.

2.0 INTRODUCTION AND BACKGROUND

2.1 Biscayne Bay

Biscayne Bay abuts the Miami metropolitan area in southeast Florida with an area of 702 km^2 and depths ranging between 0.5 and 3.0 m. It is a shallow estuary significantly affected by nutrient loading resulting from regional population growth and accelerated coastal development (Harlem, 1979; Alleman et al. 1995). Primary drivers of circulation in the bay include tides, inlets, water depth, salinity, and wind speed/direction (BFA, 2004).

2.2 North Biscayne Bay

North Biscayne Bay is located between mainland Miami and the barrier island of Miami Beach, adjacent to the most developed areas of metropolitan Miami. North Biscayne Bay extends from Dumfoundling Bay to the Rickenbacker Causeway. Astronomical tides, canal inflows, and wind stress influence flows in North Biscayne Bay, where ocean exchange occurs every 7 to 14 days on average (Chin 2020).

Approximately 40% of North Biscayne Bay has been dredged or filled, with average depths ranging from 1.1 to 2.2 m (excluding dredged areas). The federal navigation channels in Biscayne Bay consist of three major channels: Biscayne Channel, Fisher Cut, and Jones Lagoon Channel. Biscayne Channel is the largest of the three and runs along the eastern side of the bay. Fisher Cut connects Biscayne Channel to the western side of the bay, and Jones Lagoon Channel runs along the northern side of the bay. The depths of the channels vary, but generally range from 20 to 35 feet. The Port of Miami and other industrial complexes surround North Biscayne Bay. Additionally, the Miami River (C-6 canal) is the largest source of freshwater inflow to North Biscayne Bay, which has a history of contamination from industrial runoff and untreated sewage effluent. Other major sources of freshwater flow to North Biscayne Bay include the Biscayne Canal (C8 canal), Snake Creek (C-9 canal), Arch Creek, and Little River (C-7 canal) (see **Figure 2-1**). Stormwater runoff has been identified as a source of contamination in discharges from these canals.

The Bay has been significantly impacted by modifications in land use and the transformation of creeks into canals. This is especially true in North Biscayne Bay, where the greatest amount of freshwater flow is received (Caccia and Boyer, 2005). The ramifications of these alterations include the deterioration of natural habitats, impaired water clarity, heightened levels of contaminants such as heavy metals and hydrocarbons, and an overabundance of nutrients.

Two primary contributors to nutrient loadings to North Biscayne Bay are the C-8 and C-9 canals. Average canal flows on water-sample collection dates (approximately monthly) are 173 cubic foot per second (cfs) and 376 cfs for C-8 and C-9, respectively (Chin 2020).

The main impairments to North Biscayne Bay are seagrass die-off (Avila et al. 2017) and elevated concentrations of chlorophyll *a* (Millette et al. 2019), which may be caused by nutrient loading originating in canal discharges (Chin 2020). North Biscayne Bay has the highest chlorophyll *a* levels in Biscayne Bay and historical measurements indicate that Biscayne Bay is an oligotrophic lagoon. From 1995-2014, chlorophyll *a* concentrations in North Biscayne Bay were increasing at an average rate of approximately 0.029 (µg/L)/year with a mean of 1.5-2 µg/L (Millette et al. 2019). It is likely that the increases in chlorophyll *a* are related to seagrass die-off (Zhang et al. 2003). Their die-off results in a feedback loop where the loss of seagrass causes re-suspension of nutrients and sediments, further shading surviving seagrasses and fueling phytoplankton blooms (Millette et al. 2019).

Total nitrogen (TN) and total phosphorus (TP) concentrations in the canals are generally higher than in the bay (Chin 2020; Brand 1988). Throughout North Biscayne Bay, a TN gradient was observed from the coast to the open bay. In contrast, there exists minimal difference in TP concentrations with distance from the shore (Caccia and Boyer 2005). However, TP concentrations in North Biscayne Bay are the highest out of all regions of the bay at all times of the year. Additionally, TP showed pronounced seasonal differences in areas receiving freshwater input from canals, such as North Biscayne Bay (Caccia and Boyer, 2005). The canals are the dominant sources of TN and TP loading in the bay, contributing approximately 95% of the TN load and approximately 90% of the TP load to the bay on an annual basis. (Chin 2020).

For this investigation, North Biscayne Bay was subdivided into two distinct regions: (i) Northern North Bay A (NNB-A), associated with the Snake Creek/Oleta River (C-9), and (ii) Northern North Bay B (NNB-B), associated with the Biscayne Canal (C-8) (**Figure 2-1**). Of interest to this study are eight SFWMD monitoring stations located within North Biscayne Bay, including two sites that measure flow and six sites that measure water quality (**Table 2-1**).

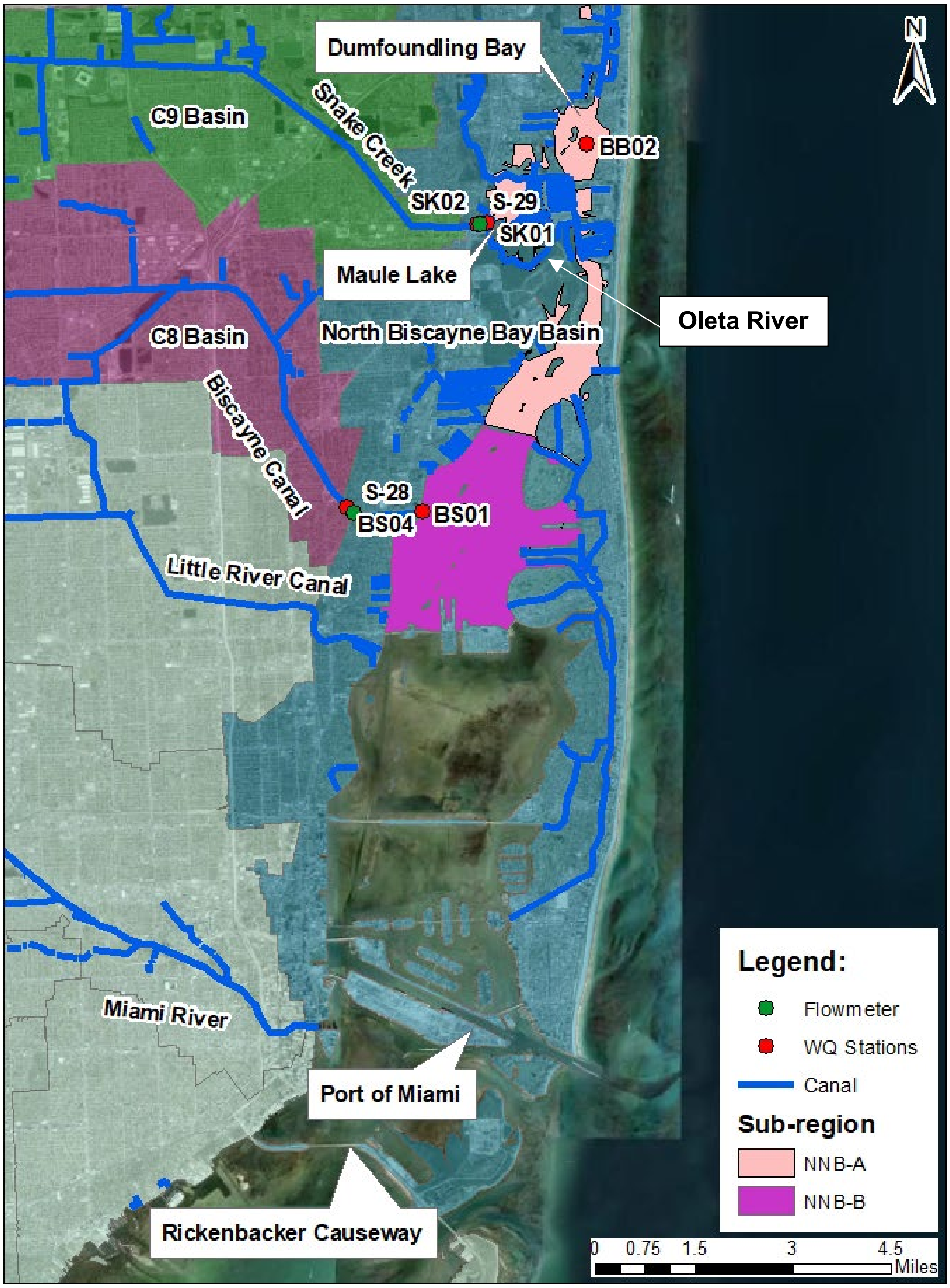

Figure 2-1: NNB -A and NNB -B in Relation to the WQ monitoring stations, Flowmeters, Canals, and Canal Basins

Table 2-1: List of Flowmeters and WQ Stations Associated with the C-8 and C-9 Canals and Basins

Station ID	Data Type	Associated Watershed
BS04	WQ Concentrations	C-8
BS01	WQ Concentrations	C-8
BB09	WQ Concentrations	C-8
S28_S	Flowrates	C-8
SK01	WQ Concentrations	C-9
SK02	WQ Concentrations	C-9
BB02	WQ Concentrations	C-9
S29_S	Flowrates	C-9

2.2.1 NNB-A

The subregion of NNB-A extends approximately seven miles from the Miami-Dade/Broward County line southwards to the Broad Causeway and Indian Creek Lake and is associated with the C-9 basin. Waterbodies and features within this sub-region include Dumfoundling Bay, Maule Lake, the Oleta River, and the Haulover inlet. The Haulover inlet serves as this region's only direct connection to the Atlantic Ocean. The width of this region of the bay varies from 0.1 to 1.5 miles. The most recent issue of the Biscayne Bay Report Card (2022), produced annually by Miami-Dade County (MDC), assessed the WQ of NNB-A as 'Fair', noting reduced seagrass coverage compared to the previous year, high levels of nutrient loading from the canals, and chlorophyll *a* concentrations that exceed the established baseline. The report card noted improvements in the bacteria enterococci and total nitrogen compared to 2021. Note that a 'Fair' rating (as opposed to a 'Poor' or 'Good' rating) describes a region experiencing degradation in its WQ, where 'essential ecological functions and species diversity are impacted and not able to perform beneficial functions at optimum levels'.

2.2.1.1 Water Quality

Chin (2020) performed a Load Duration Curve analysis for the canals discharging into North Biscayne Bay for the period 2008 – 2018 and found that the average concentration of TN at SK01 in the C-9 canal is 58 % higher under wet conditions than non-wet conditions. (Note that surface runoff is therefore the main driver of TN concentrations in the C-9.) Wet conditions are defined as high flow conditions, while dry conditions are defined as low flow conditions. The TN loading during wet conditions equaled 1,863 kg/day and for non-wet conditions equaled 381 kg/day. The average TN concentration during wet and non-wet conditions equaled 1.03 mg/L and 0.65 mg/L, respectively.

For TP loadings, Chin (2020) found no difference between wet and non-wet conditions, suggesting that stormwater runoff has little to no impact on TP loads at the C-9. The TP loading during wet conditions equaled 27 kg/day and for non-wet conditions equaled 7 kg/day. The average TP concentration equaled 13 μg/L for both wet and non-wet conditions.

2.2.2 NNB-B

NNB-B extends from the Broad Causeway south to the 79th Street Causeway over approximately three miles and is associated with the C-8 basin. The width of this region of the bay varies from 1 to 2.5 miles. The 2022 MDC Biscayne Bay Report card outlined reduced seagrass coverage from die-off events and elevated chlorophyll *a* concentrations. Although chlorophyll *a* concentrations exceeded the established baseline, there was an improvement from 2021 concentrations. NNB-B received a 'Fair' rating on the 2022 report card.

2.2.2.1 Water Quality

For the C-8 canal, the average concentration of TN at BS04 is 15% higher under wet conditions than non-wet conditions. Stormwater runoff is therefore the main driver of TN concentrations in the C-8. The TN loading during wet conditions equaled 880 kg/day and for non-wet conditions equaled 191 kg/day. The average TN concentration during wet and non-wet conditions equaled 1.06 mg/L and 0.92 mg/L, respectively (Chin, 2020).

For TP loadings, Chin (2020) found that the average concentration of TP at BS04 is 10% higher under wet conditions than non-wet conditions, suggesting that stormwater runoff influences TP loads at the C-8. The average TP concentration during wet and non-wet conditions equaled 21 µg/L and 19 µg/L, respectively.

2.2.3 C-8 and C-9 Outfalls

The S-28 and S-29 structures are reinforced concrete gated spillways located at the mouth of the C-8 and C-9 canals, respectively. The S-29 structure lies approximately 500 ft west of Lake Maule's shores, and the S-28 lies approximately one mile west of the shore of Biscayne Bay. These structures prevent saltwater intrusion when flood tides are high and maintain optimum upstream water control stages. The flood discharge rate (uncontrolled, submerged) equals 3,220 cfs and 4,780 cfs for the S-28 and S-29, respectively. The structures' cable operated vertical lift gates are automatically controlled such that the hydraulic operating system opens or closes in accordance with the District's operational criteria. Currently, they are operated to maintain an optimum headwater elevation of 1.8 ft NGVD29 at the S-28 and 2.0 ft NGVD29 at the S-29. In addition to maintaining optimum upstream freshwater control, the automatic controls have an overriding feature which closes the gates, regardless of the upstream water level in the event of a high flood tide, whenever the differential between the head and tailwater pool elevations reaches 0.3 feet. During the simultaneous occurrence of high tide and heavy rainfall, structure control is manually operated and the gates open when the headwater elevation exceeds the tailwater elevation.

3.0 DATA COLLECTION

To support this WQ data analysis, the following data/information was obtained:

- Historical reports and literature sources concerning WQ near the project site were obtained from the SFWMD, MDC, and other sources. (See the References.)
- Historical WQ data was provided by MDC. Refer to **Appendix C** for a record of the correspondence.
- Historical flow data was consolidated from the SFWMD's DBHYDRO.
- Proposed changes in flow rates based on the FPLOS modeling scenarios were provided by Taylor Engineering (*Flood Protection Level of Service Provided by Potential Mitigation Projects for Current and Future Sea Level Conditions in the C8 and C9 Watersheds, 2022*).

Where available, data were collected and analyzed for the period 1996 – 2022. Refer to **Appendix C** for the data/document control log, records of the associated correspondence, and further detail regarding the data collection effort.

4.0 METHODS

4.1 General

To investigate the relationship between discharges at the S-28 and S-29 and WQ variable concentrations measured in the bay, analyses were conducted using cumulative volume data derived from the flow stations listed in **Table 2-1**. **Figure 4-1** describes the general steps taken to assess the impact of proposed FPLOS scenarios on each WQ variable at North Biscayne Bay, which are further described in the subsequent sections. Refer to **Appendix A** for further detail regarding the methods shown in **Figure 4-1**.

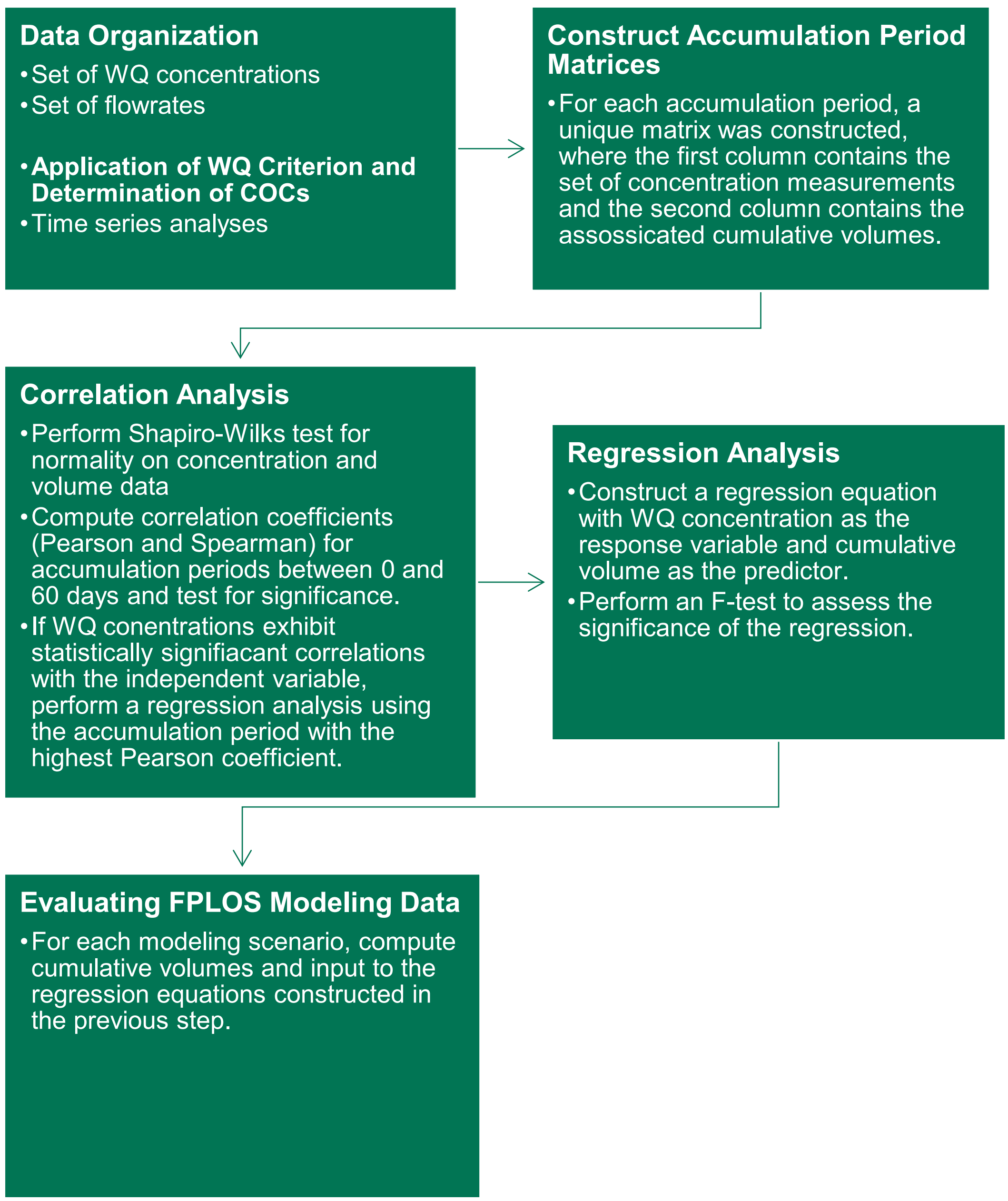

Figure 4-1: Flowchart of Methods used for the Cumulative Volume Analysis

4.2 Time Series Analyses

Time series were constructed for each WQ variable flagged as a contaminant of concern (COC). (Refer to **Section 5.0** for the determination of COCs.) For those variables whose regulatory standards utilize minimum/maximum statistics, a time series of instantaneous data was constructed for the period of interest. For those variables whose regulatory standards utilize geometric means (GMs), these means were computed and plotted for each year of the study period. The Mann-Kendall test (Kendall 1975; Mann 1945) was used on all applicable time series data to assess the direction and statistical significance of temporal trends at the 95% confidence level.

4.3 Cumulative Volume Analyses

For a given WQ variable, flow data was combined with the available WQ concentration data set by matching the time of flow measurement with the time of the contaminant concentration measurement in the bay. Then, for each contaminant concentration measurement, cumulative volumes were computed for volume accumulation periods between 0 and 60 days prior to the date of that concentration measurement. See **Appendix A** for the mathematical details associated with computing cumulative volumes for various accumulation periods.

4.3.1 Correlation Analyses

The magnitude and significance of the correlation between cumulative volume discharges from a given structure versus bay COC concentrations were assessed. **Table 4-1** summarizes the investigated variable pairs.

Table 4-1: Variable Pairs of Interest for the Correlation Analysis

Pair #	Variable 1	Variable 2	Analysis Type	Watershed
1	Cumulative Volume from S-29 (Flow Station)	WQ Variable Concentrations at BB02	Pearson/Spearman	C-9
2	Cumulative Volume from S-28 (Flow Station)	WQ Variable Concentrations at BB09	Pearson/Spearman	C-8

Correlation coefficients were computed for accumulation periods in the range of 0 to 60 days. This range was chosen because the residence time in North Biscayne Bay on average ranges between 7 and 14 days (Chin, 2020), and a 46-day buffer was added to capture the effects of unknown processes that work to distribute/retain contaminants within North Biscayne Bay, such as sediment resuspension and marine vegetation die-off acting as a source of contamination rather than a sink.

The statistical distribution of each WQ variable was evaluated using the Shapiro-Wilks test (Shapiro and Wilk, 1965) to determine whether each pair is bivariate normal. For pairs with at least one non-normally distributed variable, Spearman correlation coefficients were computed for each accumulation period and used to (i) to evaluate whether the relationship between cumulative volume and contaminant concentrations have non-linear characteristics (i.e., how closely their curve is described by a monotonic function) and (ii) whether the correlation coefficients computed based on ranks peak at an accumulation period different from that of non-ranked data. In addition, for each accumulation period, Pearson correlation coefficients were computed to provide information about the fit of linear regression relationships. For all coefficients, significance tests were performed at the 95% confidence level. Depending upon the value of the Pearson or

Spearman correlation coefficients, relationships were defined from a range of very weak to perfect (**Table 4-2**).

Table 4-2: Interpretation of the Pearson's and Spearman's Correlation Coefficients

Correlation Coefficient (+)	Correlation Coefficient (-)	Description of Strength of Correlation
0 to 0.2	-0.2 to 0	Very Weak
0.2 to 0.4	-0.4 to -0.2	Weak
0.4 to 0.6	-0.6 to -0.4	Moderate
0.6 to 0.8	-0.8 to -0.6	Strong
0.8 to 0.99	-0.99 to -0.8	Very Strong
1	-1	Perfect

4.3.2 Regression Analyses

The data set associated with the accumulation period that exhibited the highest Pearson correlation was chosen for further analysis. One regression equation was constructed per WQ variable per watershed. F-tests were performed at the 95% confidence level for all regressions. Refer to **Appendix A** for detailed reports of the regression results. In addition, refer to **Appendix B** for a regression analysis decision matrix for the C-8 and C-9 basins.

The aforementioned modeling flow data was provided by Taylor Engineering for a total of 16 days (6/2/2017 to 6/17/2017), where 6/2/2017 was set to day 0 and 6/17/2017 was set to day 15. This data was analyzed using the accumulation periods established in the correlation analyses. If an accumulation period greater than 15 days was found to coincide with the maximum/minimum correlation coefficient, then the 15-day accumulation period was used for the regression analysis.

5.0 CONTAMINANTS OF CONCERN

5.1 Standards and Criteria

The waters of the Biscayne Bay Aquatic Preserve (BBAP) are designated as Outstanding Florida Waters (OFW) and Class III waters for recreation, fishing, and wildlife protection under Chapter 62-302, FAC. Effective August 5, 2010, the definition of Class III waters was amended to distinguish those that are "predominantly fresh" or "predominantly marine." BBAP waters in MDC are regarded as "predominantly marine" in that the chloride concentration in its surface water is greater than or equal to 1,500 mg/L. Class III-Limited waters have at least one Site Specific Alternative Criterion as established under Rule 62-302.800, F.A.C.

The FDEP's Environmental Regulatory Commission (ERC) began adopting Numeric Nutrient Criteria (NNC) for Biscayne Bay WQ thresholds in 2011. Several NNCs are expressed as annual GM concentrations which cannot be exceeded more than once in a three-year period. The allowable concentrations for the Northern North Bay (comprising NNB-A and NNB-B) are as follows: 0.30 mg/L for total nitrogen (TN); 0.012 mg/L for total phosphorus (TP); and 1.7 µg/L for chlorophyll *a*. In addition, Chapter 62-302, FAC lists WQ criteria for Class III Marine Waters for additional parameters.

5.2 Evaluation of COCs

An analysis was conducted to determine current COCs in NNB-A (C-9 Basin) and NNB-B (C-8 Basin). WQ analyses for Station BB02 (NNB-A) and Station BB09 (NNB-B) were conducted, when possible, for the period 1996 - 2022. WQ criteria analysis for the parameters analyzed were based on various statistics (minimums, maximums, and annual GMs. Note that for several WQ parameters there exists limited data. **Table 5-1** and **Table 5-2** present the COCs evaluated for NNB-A and NNB-B, respectively. Parameters identified as COCs are presented in red font, parameters not in violation of their respective WQ criteria are in green font, and parameters that did not violate any WQ criteria but because of their importance to the bay's ecological health were flagged for further analysis are identified in purple font. Salinity levels were also evaluated because changes in salinity concentrations have historically had significant impacts to marine life in the bay.

Table 5-1: COC Analysis in NNB-A

Parameter[1]	Station ID	Critical Statistic (Observed)	Statistic Type	Water Quality Criteria	Units
Salinity	BB02	NA[6]	NA	NA	ppt
Chlorophyll *a*[2]	BB02	4.15	Annual GM	≤1.7	µg/L
Total Nitrogen[2]	BB02	0.47	Annual GM	≤0.30	mg/L
Total Phosphorus[2]	BB02	0.007	Annual GM	≤0.012	mg/L
Dissolved Oxygen[3,4]	BB02	3.70	Minimum	> 4.0	mg/L
Turbidity[3,5]	BB02	1.3	Maximum	≤ 1.3 NTU	NTU
Copper[3]	BB02	4	Maximum	≤3.7	µg/L
Cadmium, Total[3]	BB02	2.0	Maximum	≤8.8	µg/L
Selenium, Total[3]	BB02	8.0	Maximum	≤71	µg/L
Silver, Total[3]	BB02	1.0	Maximum	<2.3	µg/L
Lead[3]	BB02	3.6	Maximum	≤8.5	µg/L

[1] Insufficient data was provided for arsenic and chromium.
[2] Numeric Nutrient Criteria for Biscayne Bay, FAC 62-302.532.
[3] Surface Water Quality Criteria for Class III Marine Waters, FAC 62-302.530.
[4] Dissolved Oxygen criteria represents stressful conditions for most fish species.
[5] Turbidity was used as a measure of water clarity since it is measured more frequently than TSS.
[6] Not applicable.
Red font indicates the parameter was identified as a COC for NNB-A.
Purple font indicates the parameter was not a COC but was flagged for further study.
Green font indicates the parameter was not identified as a COC for NNB-A.

Table 5-2: COC Analysis in NNB-B

Parameter[1]	Station ID	Critical Statistic (Observed)	Statistic Type	Water Quality Criteria	Units
Salinity	BB09	NA[7]	NA	NA	ppt
Chlorophyll *a*[2]	BB09	2.06	Annual GM	≤1.7	µg/L
Total Nitrogen[2]	BB09	0.34	Annual GM	≤0.30	mg/L
Total Phosphorus[2]	BB09	0.008	Annual GM	≤0.012	mg/L
Fecal Coliform[3]	BB09	410	Maximum	≤800	CFU
Dissolved Oxygen[4,5]	BB09	3.73	Minimum	> 4	mg/L
Turbidity[5,6]	BB09	2	Maximum	≤ 1.3 NTU	NTU

[1] Insufficient data was provided for copper and zinc.
[2] Numeric Nutrient Criteria for Biscayne Bay, FAC 62-302.532.
[3] Note that in 2016, the Florida Department of Environmental Protection (FDEP) revised the human health-based surface water quality criteria in Chapter 62-302 and replaced the Fecal Coliform standard with Escherichia coli (E. coli) in Class III waters. No E. Coli data exists at BB09, and therefore all analyses were performed on Fecal Coliform.
[4]Dissolved Oxygen criteria represents stressful conditions for most fish species.
[5] Surface Water Quality Criteria for Class III Marine Waters, FAC 62-302.530.
[6] Turbidity was used as a measure of water clarity since it is measured more frequently than TSS.
[7] Not applicable
Red font indicates the parameter was identified as a COC for NNB-B.
Purple font indicates the parameter was not a COC but was flagged for further study.
Green font indicates the parameter was not identified as a COC for NNB-A.

6.0 DISCHARGES INTO NORTH BISCAYNE BAY

Modeling scenarios provided by Taylor Engineering for use in assessing potential WQ impacts to North Biscayne Bay focused on evaluating several sea level rise conditions over different design storms together with flood mitigation projects (**Table 6-1**). Data associated with a combination of mitigation strategies, storm events, and sea level rise scenarios was provided for the period 6/2/2017 to 6/17/2017.

Table 6-1: Modeling Scenarios for the FPLOS WQ Impact Assessment

Scenario Type	Sea Level Rise (ft)	Storm Events (yr.)	Number of Scenarios
M0 (No mitigation)	+0	5, 10, 25, 100	4
	+1	5, 10, 25, 100	4
	+2	5, 10, 25, 100	4
	+3	5, 10, 25, 100	4
M2A	+1	5, 10, 25, 100	4
	+2	5, 10, 25, 100	4
	+3	5, 10, 25, 100	4
M2B	+1	5, 10, 25, 100	4
	+2	5, 10, 25, 100	4
	+3	5, 10, 25, 100	4
M2C	+1	5, 10, 25, 100	4
	+2	5, 10, 25, 100	4
	+3	5, 10, 25, 100	4

Note that M0 represents scenarios without mitigation. M2A, M2B, and M2C comprise sets of regional adaptation or mitigation strategies implemented as part of the primary flood control system, as listed below.

Scenario M2A includes the following mitigation projects:

- S-28 and S-29 forward pumps (1,550 cfs).
- Gate improvements: raised overtopping elevation to 9.0 ft NGVD29.
- Tieback levees/floodwalls.
- Total of 500 acre-ft of distributed storage (gravity-driven drainage areas only).
- Optimized operational controls.

Scenario M2B includes the following mitigation projects:

- S-28 and S-29 forward pumps (2,550 cfs).
- Gate improvements: raised overtopping elevation to 9.0 ft NGVD29.
- Tieback levees/floodwalls.
- Total of 500 acre-ft of distributed storage (gravity-driven drainage areas only).
- Canal improvements: improved geometries and raised banks.
- Internal drainage system along primary canal to drain water through raised banks.
- Optimized operational controls.

Scenario M2C includes the following mitigation projects:

- S-28 and S-29 forward pumps (3,550 cfs).
- Gate improvements: raised overtopping elevation to 9.0 ft NGVD29.
- Tieback levees/floodwalls.
- Total of 500 acre-ft of distributed storage (gravity-driven drainage areas only).
- Canal improvements: improved geometries, widened cross sections, and raised banks.
- Internal drainage system along primary canal to drain water through raised banks.
- Optimized operational controls.

6.1 C-9 Watershed

6.1.1 Historical Flows

Figure 6-1 shows the time series of historical average daily flows at the S-29 for the period 1/1/1996 to 1/1/2022. The average for this period equaled 286 cfs (solid green line), inclusive of days with zero flow, while the maximum flowrate equaled 3,616 cfs (4/2/2000). For the subset of data comprising non-zero flows, the average daily flow equaled 467 cfs (dashed green line).

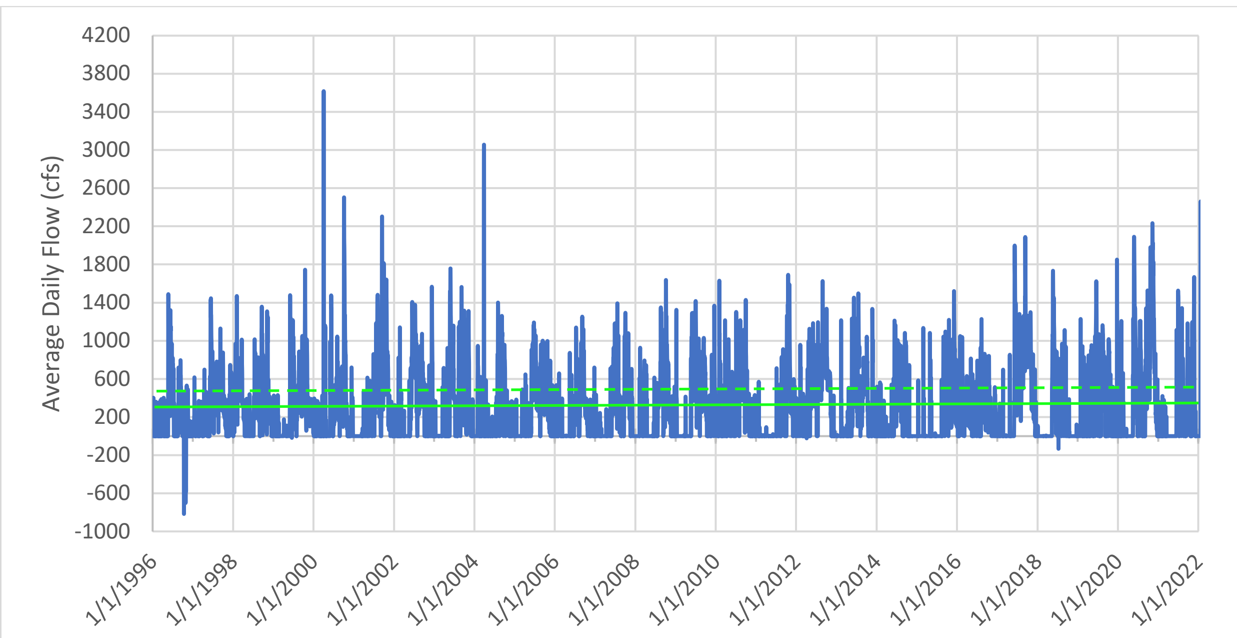

Figure 6-1: Historical Average Daily Flows at the S-29 for the Period 1/1/1996 to 1/1/2022

Figure 6-2 shows the time series of historical average daily flows for the period 6/2/2017 to 6/17/2017, which corresponds to the period utilized for the simulations presented in **Table 6-1**. Note that the peak flow of 1,913 cfs corresponds to the 99^{th} percentile for both the set of all flows and the subset of non-zero flows.

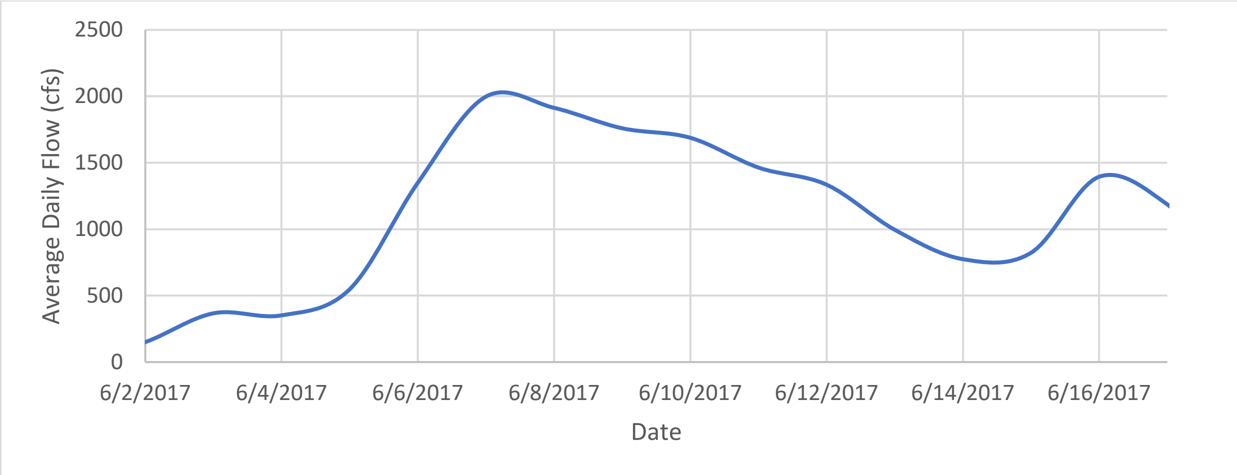

Figure 6-2: Historical Average Daily Flows at the S-29 for the Period 6/2/2017 to 6/17/2017

6.1.2 Hydraulic Modeling Flows

Figures 6-3 and **6-4** show modeled average daily flows provided by Taylor (2022) for the period 6/2/2017 to 6/17/2017 for the combination of scenarios summarized in **Table 6-1** at the S-29 on Snake Creek. Note that peak flows for M2C scenarios are generally higher than those without mitigation, for fixed SLR, across all return periods. M2A scenarios exhibit either equivalent or lower peak flows compared to M0 scenarios, for fixed SLR. Scenarios simulating 2 and 3 ft of sea level rise exhibit negative flows (backflow), which is expected to affect cumulative volume inputs. M2B peak flows generally lie between M2C and M2A peak flows. These flows were the basis for the WQ analysis performed for NNB-A.

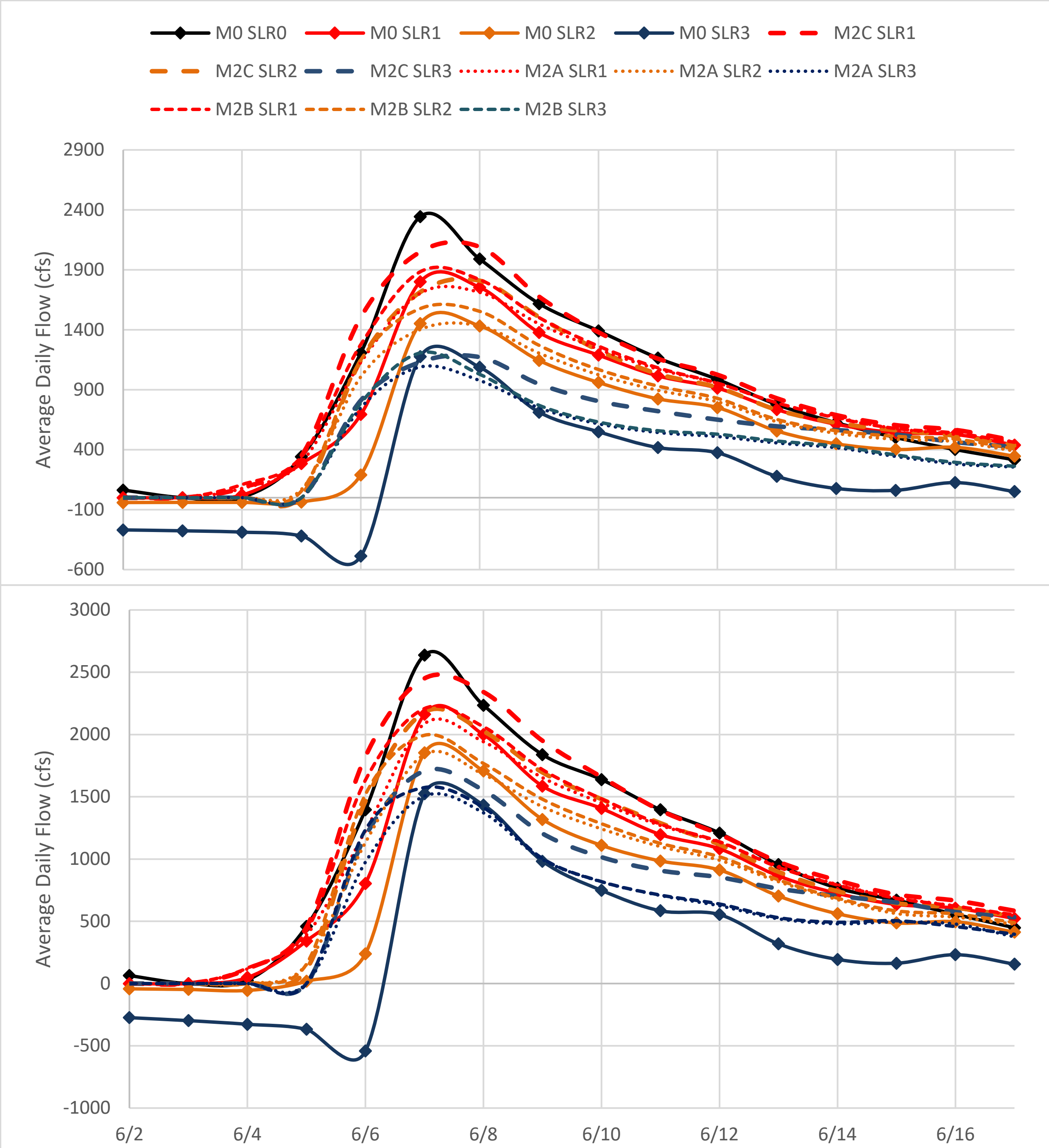

Figure 6-3: Simulated Average Daily Flows at the S-29 for All Combinations of Mitigation Strategy and Sea Level Rise Scenarios for a 5-year (top panel) and 10-Year (bottom panel) Return Period Design Storm

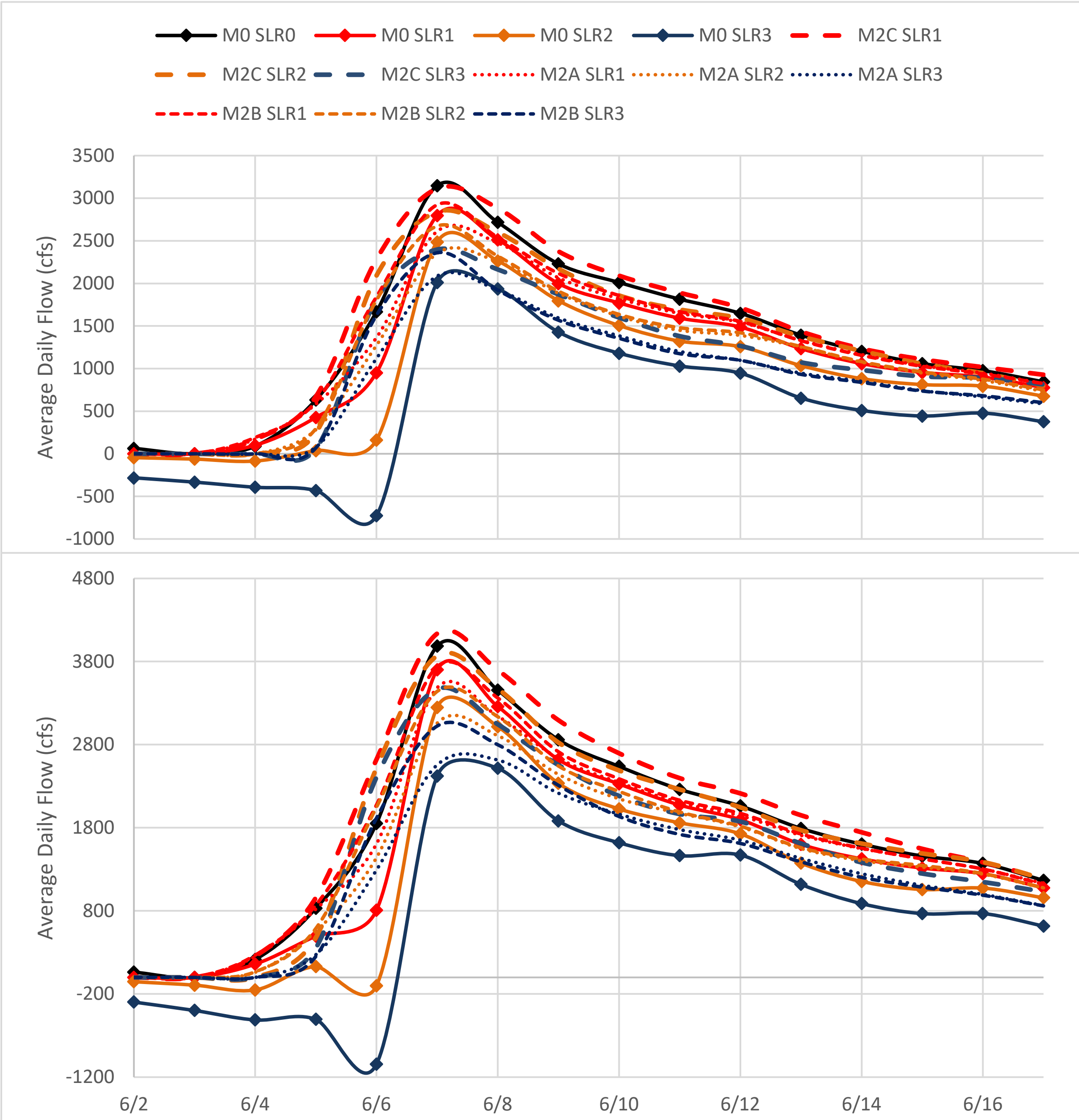

Figure 6-4: Simulated Average Daily Flows at the S-29 for All Combinations of Mitigation Strategy and Sea Level Rise Scenarios for a 25-year (top panel) and 100-Year (bottom panel) Return Period Design Storm

Figure 6-5 shows the relationship between modeled cumulative volume discharges at the S-29 and (i) mitigation strategy; (ii) sea level rise elevations; and (iii) storm return period for the period 6/2/2017 to 6/17/2017. Mitigation strategies are distinguished by shape (a square for M0, a triangle for M2A, a cross for M2B, and a circle for M2C), while sea level rise elevations are distinguished by color (red, green, and blue for 1 ft, 2 ft, and 3 ft, respectively). The following observations cane be drawn from **Figure 6-5**:

- M2A scenarios exhibit lower cumulative volumes across all return periods compared to M2C scenarios.
- M2B cumulative volumes are observed to lie between M2C and M2A for fixed SLR. Note that these volumes, however, are closer to M2A than to M2C.
- M0-SLR3 exhibits the lowest cumulative volumes compared to the other scenarios.
- M2C-SLR1 produced the highest cumulative volumes, followed by M0-SLR0. All other scenarios produce cumulative volumes lower than that of M0-SLR0 for every storm return period.

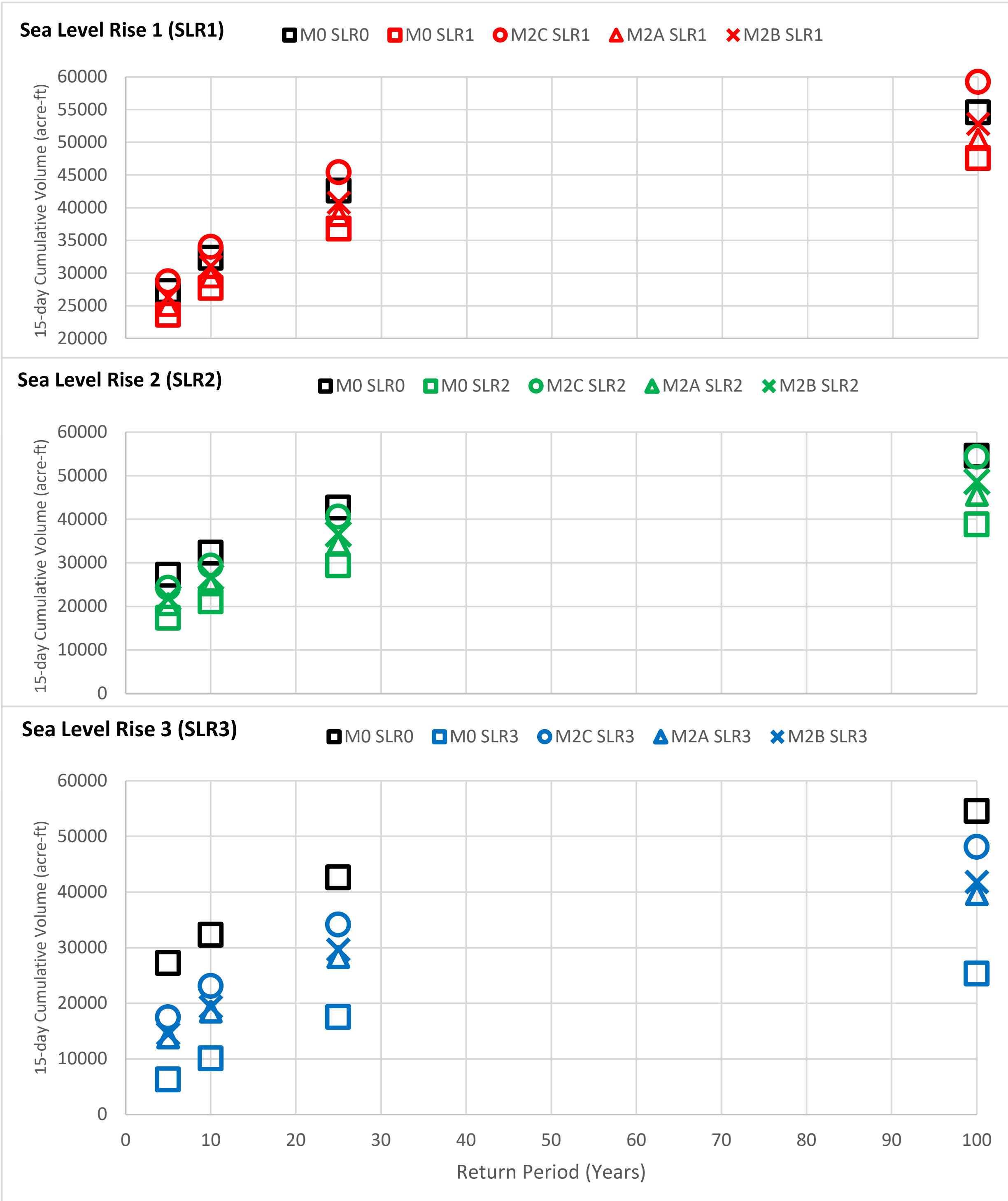

Figure 6-5: Cumulative Volume Discharges at the S-29 for Combinations of Mitigation Strategies, Sea Level Rise Scenarios, and Storm Return Periods for 6/2/2017 to 6/17/2017 (Event Simulation Period)

6.2 Biscayne Canal and Watershed (C-8)

6.2.1 Historical Flows

Figure 6-6 shows the time series of historical average daily flows at the S-28 for the period 1/1/1996 to 1/1/2022. The average for this period equaled 106 cfs, inclusive of zero flows, while the maximum flow equaled 1,757 cfs (10/4/2000). For the subset of data comprising non-zero flows, the average daily flow equaled 193 cfs.

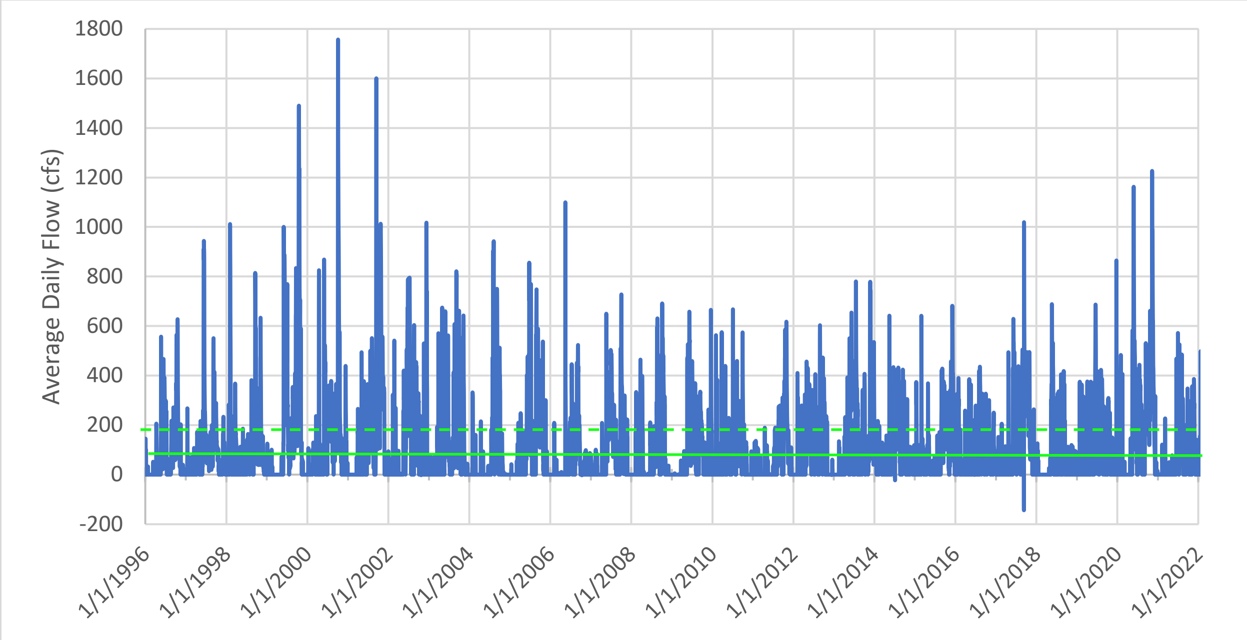

Figure 6-6: Historical Average Daily Flows at the S-28 for the Period 1/1/1996 to 1/1/2022

Figure 6-7 shows the time series of historical average daily flows for the period 6/2/2017 to 6/17/2017. Note that the peak flow of 603 cfs for this period corresponds to the 98th percentile of all flows and the 97th percentile of non-zero flows.

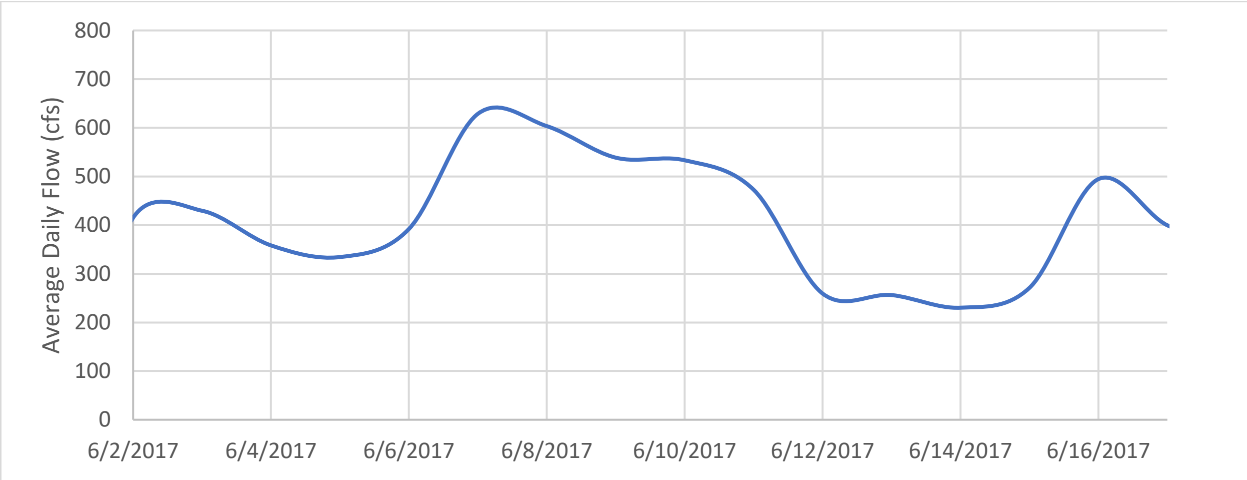

Figure 6-7: Historical Average Daily Flows at the S-28 for the Period 6/2/2017 to 6/17/2017

6.2.2 Hydraulic Modeling Flows

Figures 6-8 and **6-9** show modeled average daily flows for the period 6/2/2017 to 6/17/2017 for the combination of scenarios summarized in **Table 6-1** at the S-28 on Biscayne Canal (C-8). Note that peak flows for M2C scenarios are generally higher than those without mitigation across all return periods and M2A peak flows are lower compared to M0-SLR0. Part of the M2C mitigation strategy involves the installation of a 3,550 cfs pump at the S-28 and, therefore, M2C flows are expected to be higher than M0 flows, which consist of only gravity flow. In addition, scenarios simulating 2 and 3 ft of sea level rise exhibit negative flows (backflow), which is expected to affect cumulative volume inputs to NNB-B. Across storm return period, M2C peak flows are larger than M2B and M2A peak flows, with M2B lying between M2C and M2A.

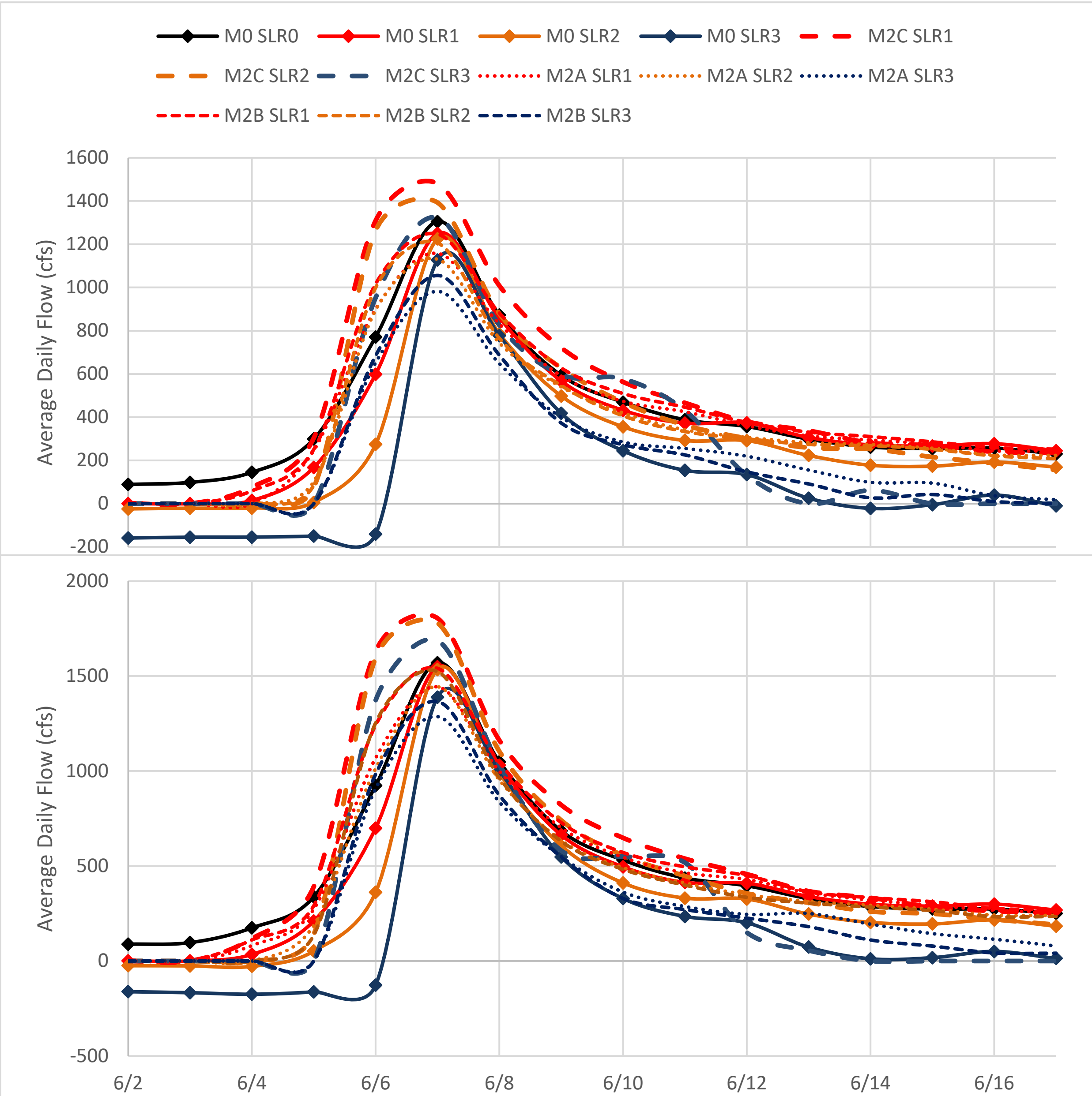

Figure 6-8: Simulated Average Daily Flows at the S-28 for All Combinations of Mitigation Strategy and Sea Level Rise Scenarios for a 5-year (top panel) and 10-Year (bottom panel) Return Period Design Storm

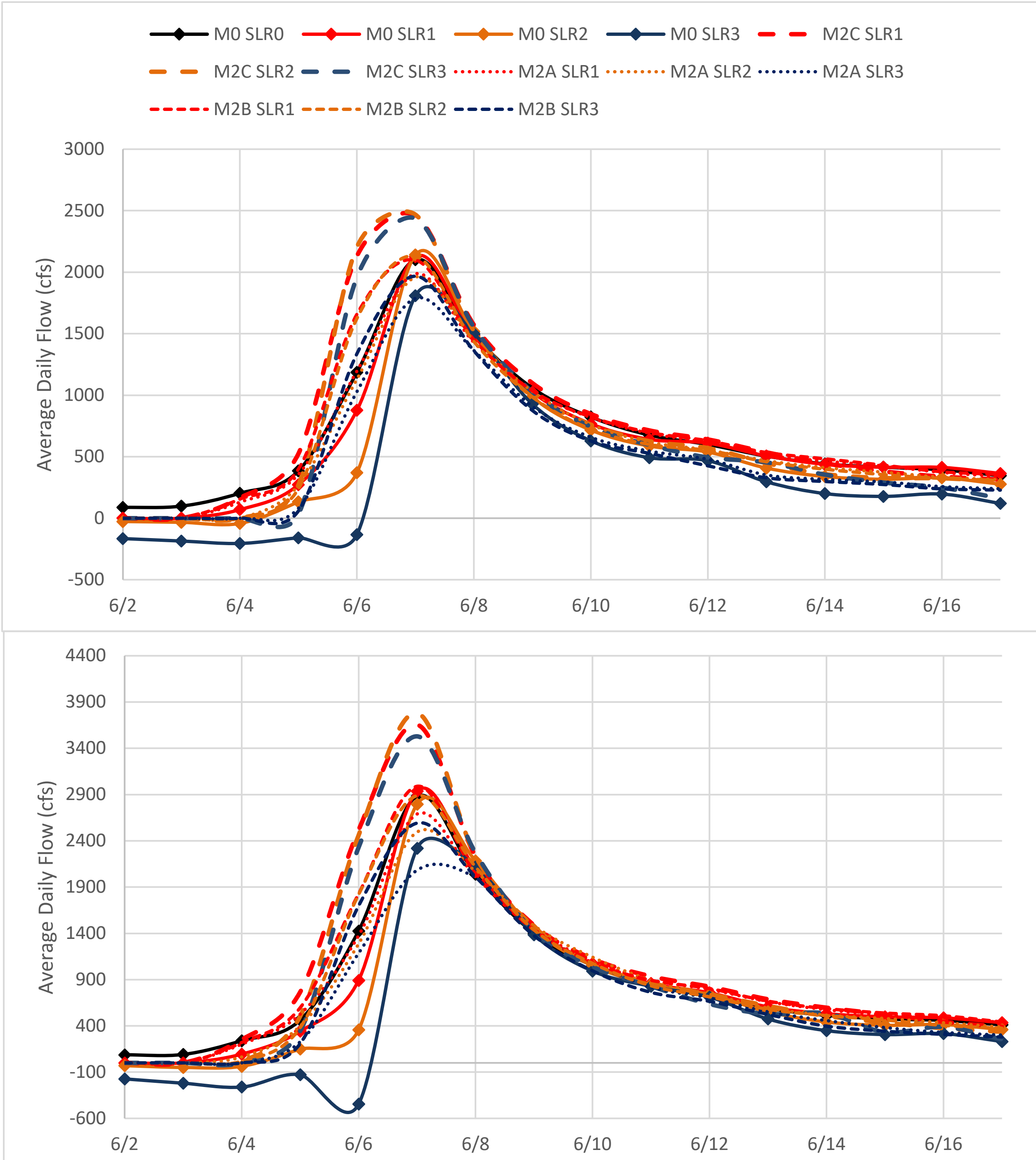

Figure 6-9: Simulated Average Daily Flows at the S-28 for All Combinations of Mitigation Strategy and Sea Level Rise Scenarios for a 25-year (top panel) and 100-Year (bottom panel) Return Period Design Storm

Figure 6-10 shows the relationship between cumulative volume discharges at the S-28 and (i) mitigation strategy; (ii) sea level rise elevations; and (iii) storm return period for the period 6/2/2017 to 6/17/2017. The following observations cane be drawn from **Figure 6-10**:

- Between M0, M2A, M2B, and M2C scenarios, results show that the difference in cumulative volume discharges becomes more pronounced with increasing return period.
- Compared to M2C, M2A scenarios exhibit lower cumulative volumes across all return periods.
- M2C-SLR1 exhibits the highest cumulative volumes of all scenarios across all return periods, and M0-SLR3 exhibits the lowest cumulative volumes.
- M2B cumulative volumes generally lie closer to M2A volumes compared to M2C volumes for fixed SLR.

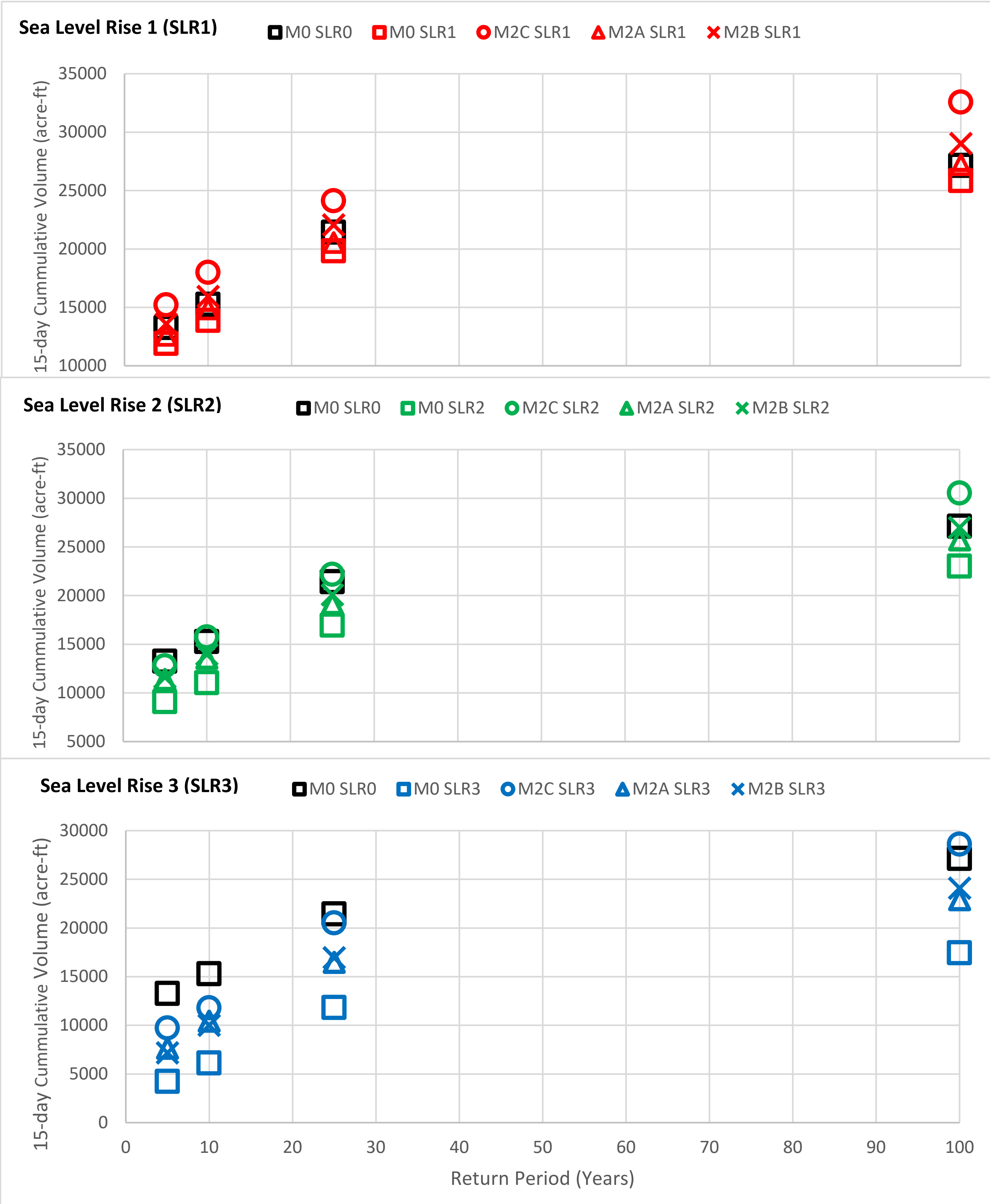

Figure 6-10: Cumulative Volume Discharges at the S-28 for Combinations of Mitigation Strategies, Sea Level Rise Scenarios, and Storm Return Periods for 6/2/2017 to 6/17/2017 (Event Simulation Period)

7.0 C-9 RESULTS AND MITIGATION SCENARIO IMPACTS ON WATER QUALITY

7.1 C-9 Time Series Results

Table 7-1 summarizes the Mann-Kendall test results for each COC at BB02 and at SK02. Note that the symbol '+' denotes a temporally increasing trend, '-' denotes a temporally decreasing trend, and 0 denotes no trend.

Table 7-1: Mann-Kendall Test Results for COCs at BB02 and SK02

WQ Parameter	Trend	Significance	Time Series Type	Station ID
Salinity	0	$p > 0.05$	Annual Mean	BB02
Salinity	0	$p > 0.05$	Annual Minimum Series	BB02
Chlorophyll a	0	$p > 0.05$	Annual GM	BB02
TN	0	$p > 0.05$	Annual GM	BB02
TN	-	$p < 0.05$	Annual GM	SK02
TP	0	$p > 0.05$	Annual GM	BB02
TP	+	$p < 0.05$	Annual GM	SK02
Dissolved Oxygen	0	$p > 0.05$	Annual Mean	BB02
Dissolved Oxygen	0	$p > 0.05$	Annual Mean	SK02
Turbidity	0	$p > 0.05$	Annual Mean	BB02
Copper	0	$p > 0.05$	Annual GM	BB02

7.1.1 Salinity

Figure 7-1 shows available annual salinity concentration means at BB02 for the period 1996 to 2019. (Note that salinity at BB02 is measured infrequently and that there exist data gaps in the time series.) The means range from 21 to 33 ppt, which is characteristic of a polyhaline regime, typical of the middle to lower part of an estuary dominated by marine influence.

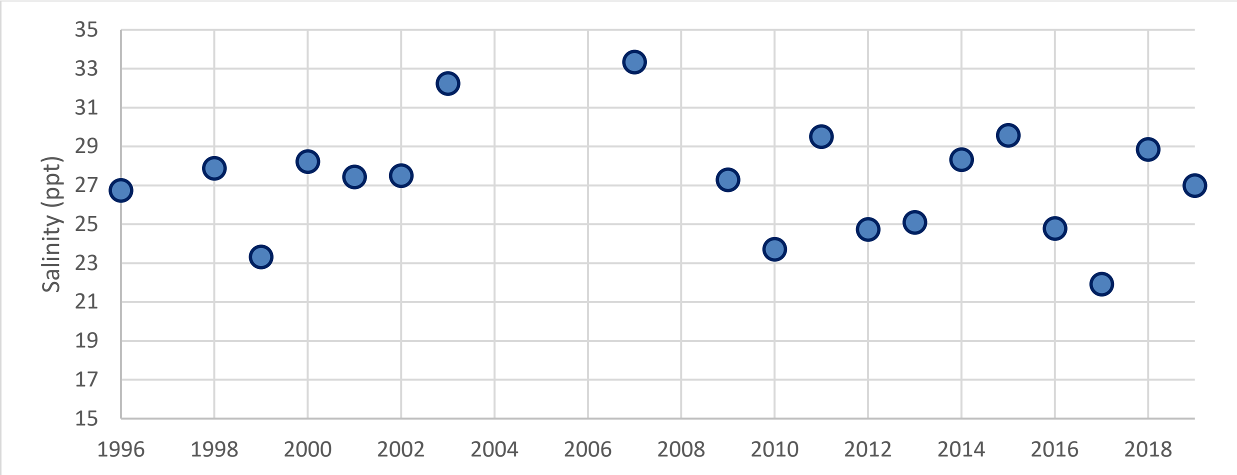

Figure 7-1: Annual Series of Average Salinity Concentrations at BB02

Figure 7-2 shows the annual minimum series (AMS) of salinity concentrations at BB02. This data represents the minimum concentration recorded for each year. In certain cases, shifts in salinity regime at BB02 are notable, since most annual minima are characteristic of a mesohaline system (5 – 18 ppt), and in 2018 there occurred an instance of 2.9 ppt, characteristic of an oligohaline system typically found near the mouths of freshwater rivers or streams. No statistically significant trends in salinity levels were detected at BB02 for both the annual average and annual minimum series.

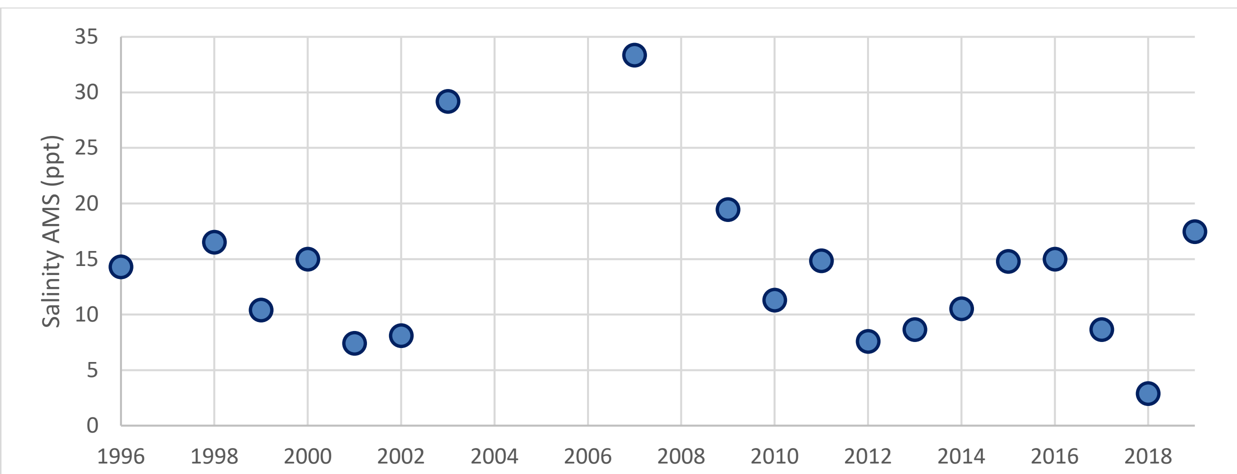

Figure 7-2: Annual Minimum Series of Salinity Concentrations at BB02

7.1.2 Chlorophyll a

Figure 7-3 shows annual GM s for chlorophyll a for the period 1996 to 2021 at BB02, plotted against the WQ criterion of 1.7 µg/L. Chlorophyll a concentrations in every year (except 2004) exceed the WQ criterion at BB02, indicating that this area of the bay shows signs of degradation. The USEPA (1974) defines a mesotrophic system as one exhibiting chlorophyll *a* concentrations between 4 and 10 µg/L. The most recent measure at BB02 equaled 4.2 µg/L, and BB02 has frequently exhibited GMs greater than 4 µg/L. No statistically significant trends in chlorophyll a levels were detected at BB02.

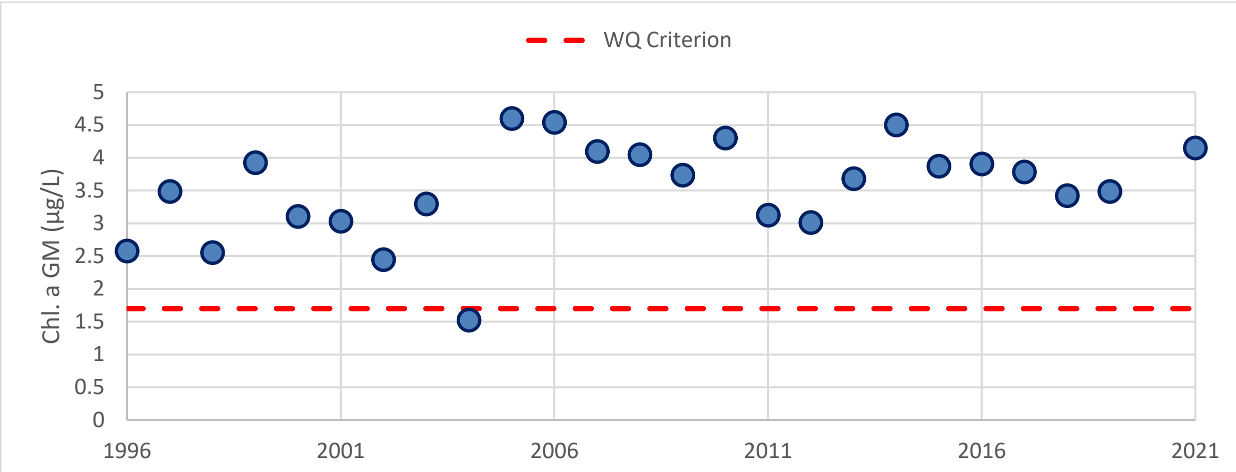

Figure 7-3: Annual GMs of Chlorophyll a Concentrations at BB02

7.1.3 Total Nitrogen

Figure 7-4 shows annual GMs for TN at BB02 and SK02 plotted against the WQ criterion of 0.30 mg/L. (Note that at BB02 data before 2008 and after 2015 is limited.) At BB02, the last two measures for which there is available data (2015 and 2019) exceeded the WQ criterion. At SK02, the WQ criterion is exceeded in every instance. The data show that TN concentrations at the discharge of the C-9 are higher on average than those measured at BB02, suggesting that flows may be acting as a concentrative force to NNB-A TN concentrations. TN annual GMs at BB02 exhibited no statistically significant trend. At SK02, however, there occurs a statistically significant decreasing trend ($p < 0.05$). For the period where data at BB02 and SK02 overlap (i.e., from 2008 to 2019), annual GMs at SK02 exhibited no statistically significant trend ($p > 0.05$).

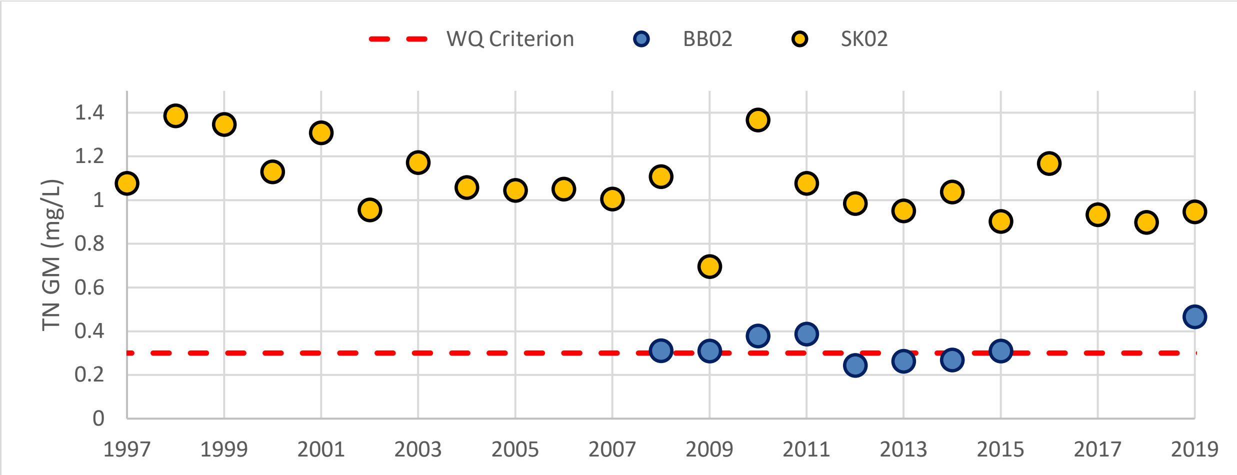

Figure 7-4: Annual GMs of TN Concentrations at BB02 and SK02

7.1.4 Total Phosphorus

Figure 7-5 shows annual GMs for TP at BB02 and SK02 plotted against the WQ criterion of 0.012 mg/L. Note that data after 2019 was not available for TP at BB02. Only in 2017 did TP concentrations at BB02 exceed the WQ criterion of 0.012 mg/L. The first instance of threshold exceedance at SK02 occurred in 2019 and then again in 2021.

TP annual GMs at both BB02 and SK02 exhibited statistically significant increasing trends ($p < 0.05$). TP concentrations at the discharge of the C-9 are approximately equal to those measured at BB02, suggesting that C-9 discharges may not have a dilutive nor a concentrative effect on BB02 concentrations. Note that increased concentrations at SK02 generally result in increased concentrations at BB02. Although no data at BB02 for the years 2020 – 2022 is available, it is likely that the WQ criterion has been exceeded for those years, given the increasing trends at both the bay and canal stations.

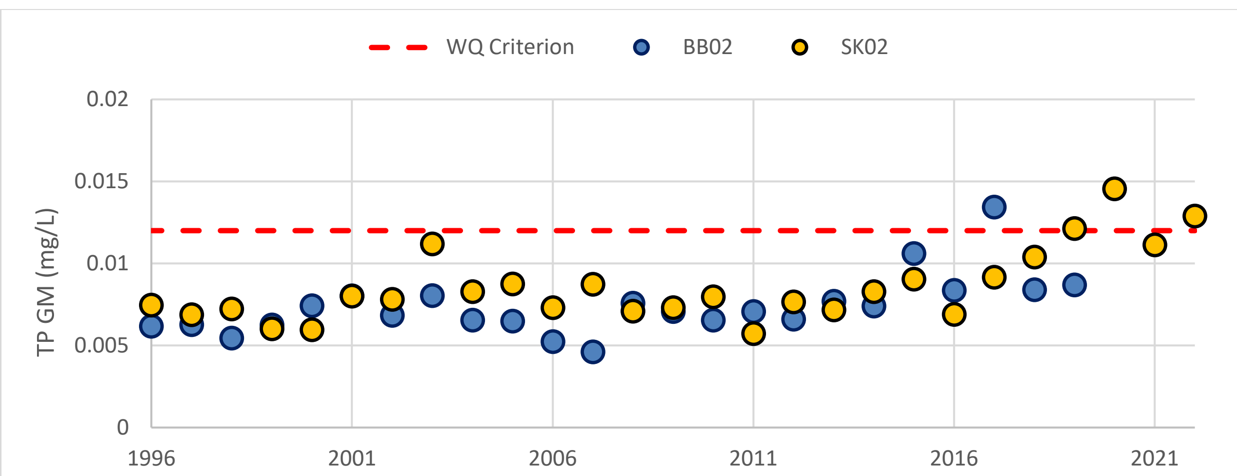

Figure 7-5: Annual GMs of TP Concentrations at BB02 and SK02 Dissolved Oxygen

7.1.5 Dissolved Oxygen

The NNC for dissolved oxygen (DO) are defined in terms of percent DO saturation, which is a function of both temperature and salinity. At BB02, DO concentrations are measured monthly, although the WQ criteria are based on daily averages, 7-day averages, and 30-day averages. DO saturation concentrations are not measured. Given the discrepancy between the current monitoring regime and NNC statistical criteria, this investigation used an alternative method of assessing DO levels using general tolerances for fish species. Note that a data gap exists at BB02 for the years 2004 to 2008.

The annual distributions of instantaneous DO concentrations taken monthly at BB02 are plotted in **Figure 7-6** against general tolerance thresholds for fish (Francis-Floyd, 2019). Stressful conditions are defined as a DO concentrations between 2.0 and 4.0 mg/L, while critically low conditions, under which most fish species cannot survive, are defined as being less than 2.0 mg/L. Optimal conditions are defined as being greater than or equal to 5.0 mg/L. Concentrations less than 5.0 mg/L comprise 15.0% of all data at BB02. Concentrations that lie between 2.0 and 4.0 comprise 6.0% of all data at BB02. Note that the critically low threshold of 2.0 mg/L has been exceeded just once (2013).

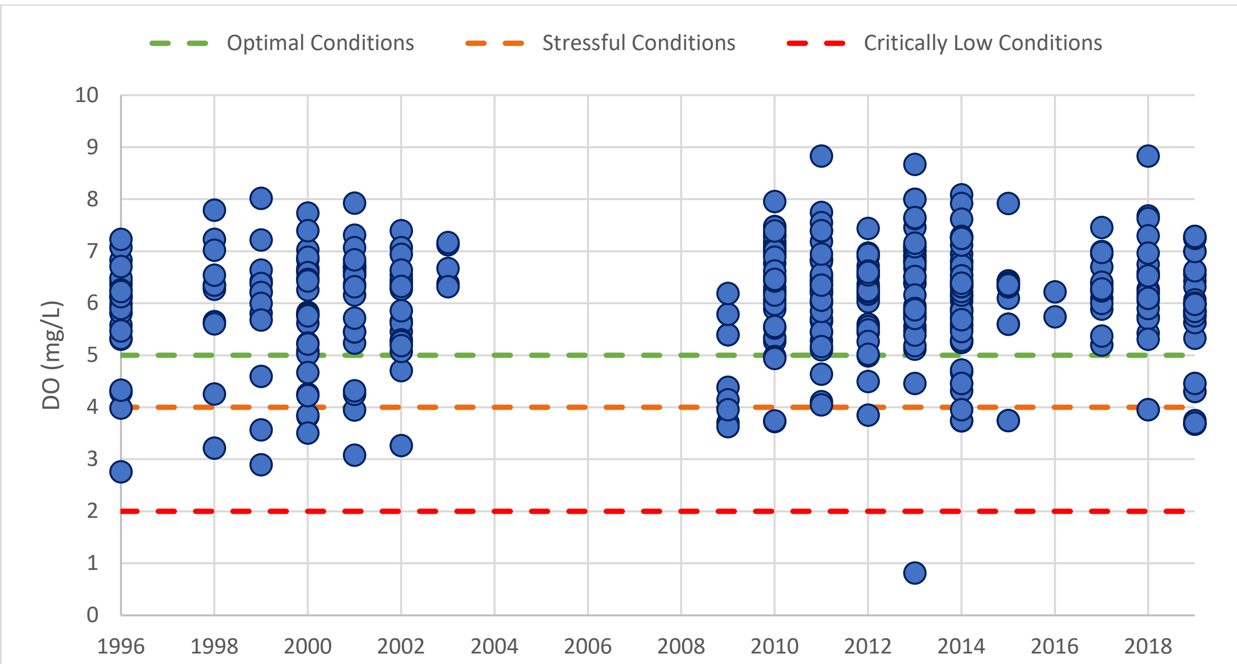

Figure 7-6: Annual Distributions of Instantaneous DO Concentrations at BB02 (1996 – 2019)

Figure 7-7 shows the annual means for DO at BB02 from 1996 to 2019. No statistically significant trend was detected for either BB02 or SK02. The average DO concentration remained above the optimal threshold of 5.0 mg/L throughout the study period at BB02, except for 2009 where it dropped below optimal but remained above the stressful threshold. Although DO concentrations are optimal on average, it has importance to the bay's ecological health and shows instantaneous occurrences of stressful conditions as well as one violation of the critical threshold in the instantaneous data. Further investigation of these occurrences are beyond the scope of this study.

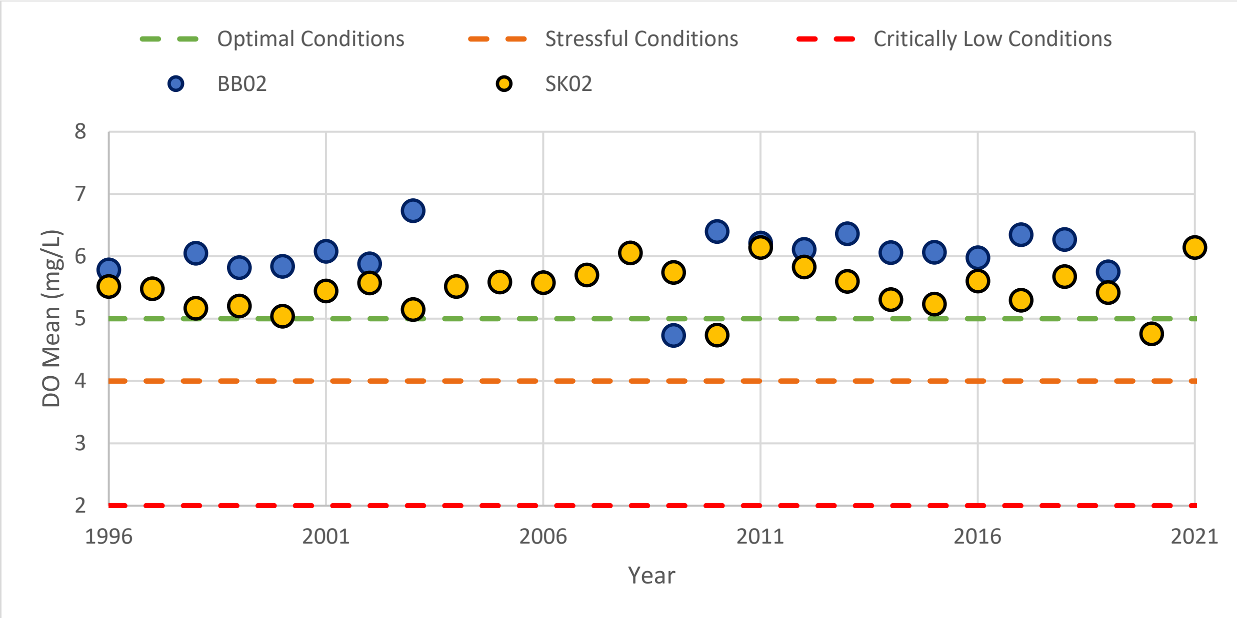

Figure 7-7: Annual Means of DO Concentrations at BB02 and SK02

7.1.6 Copper

Figure 7-8 shows available instantaneous measures of copper at BB02 and SK02 for the period 1996 to 2019. Cooper concentrations have exceeded the WQ criterion of 3.7 µg/L at BB02 five times since 1998, with a high of 26.8 µg/L in 2014 and most recently in 2019 with a recorded concentration of 4 µg/L. SK02 has not shown an exceedance of the WQ criterion during this period.

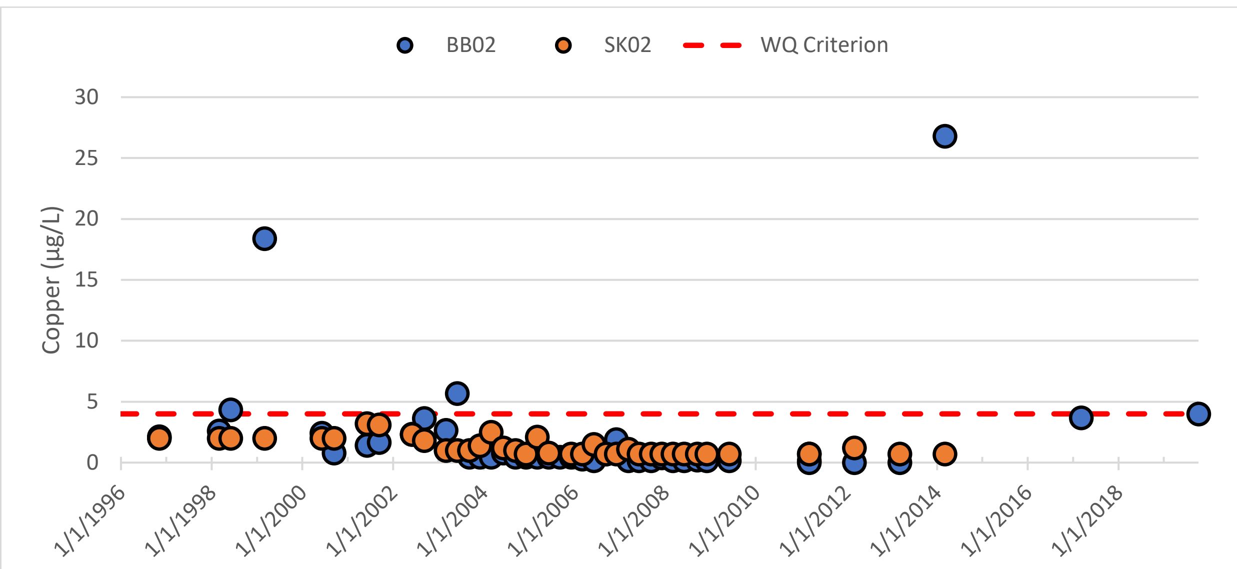

Figure 7-8: Instantaneous Copper Concentrations at BB02 and SK02

No statistically significant trend in copper concentrations was detected at BB02. Comparing instantaneous measures at BB02 with SK02 suggests that extreme concentrations at BB02 do not coincide with extreme concentrations at SK02 (3/1/1999 and 3/3/2014), and that there is likely no correlation between high canal flows and high copper concentrations in the bay.

7.1.7 Turbidity

The distribution of instantaneous turbidity measurements at BB02 is shown in **Figure 7-9**. The baseline is defined as the turbidity level associated with what has been defined in the literature as ecologically ideal conditions in Biscayne Bay (1.3 NTU, *MDC, 2022*). Within the last seven years, turbidity levels have exceeded the 1.3 NTU threshold at least once, although conditions have significantly improved compared to the 1996 to 2005 period. No statistically significant trend in turbidity levels was detected at BB02.

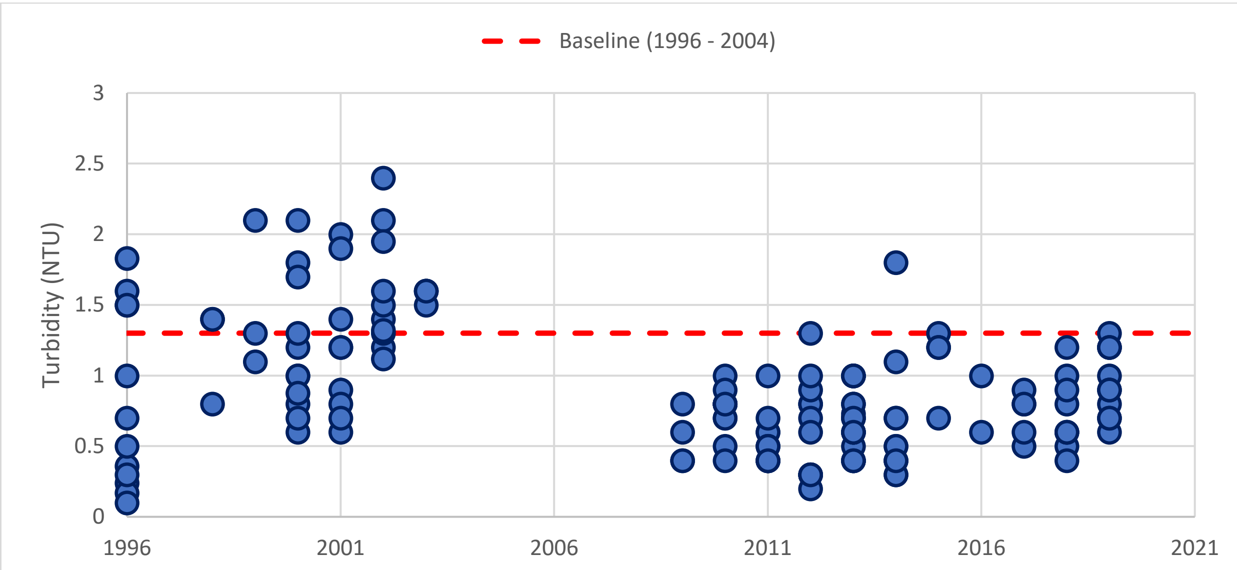

Figure 7-9: Annual Distributions of Instantaneous Turbidity Concentrations at BB02

7.2 C-9 Correlation Analysis Results

Table 7-2 reports the correlation coefficients between cumulative volumes from the S-29 (C-9 canal) and WQ variable concentrations in the bay at BB02 (refer to Variable Pair #1 in **Table 4-1**). For each WQ variable, the accumulation periods (days) associated with the highest coefficient of each type were reported. The accumulation period represents the number of days over which volumes are summed before a concentration measurement to obtain the cumulative volume. Variables in green font were determined to be adequate for regression analyses; those in red, inadequate. In the following sections, the statistical significance of correlation is shown graphically via a dotted line (insignificant, $p > 0.05$) and solid line (significant, $p < 0.05$).

Table 7-2: Correlation Analysis Results for Variable Pair #1 in the C-9

WQ Variable	Pearson r	Spearman r	Pearson Accumulation Period (days)	Spearman Accumulation Period (days)	Station ID
Salinity	-0.408	-0.518	5	4	BB02
Chlorophyll *a*	0.484	0.532	19	19	BB02
TN	0	0	NA	NA	BB02
TP	0	0.244	NA	58	BB02
Dissolved Oxygen	-0.288	-0.310	43	43	BB02
Turbidity	0.210	0.260	29	29	BB02
Copper	0	0	NA	NA	BB02

7.2.1 Salinity

Figure 7-10 shows Pearson and Spearman correlation coefficients for accumulation periods between 0 and 30 days at BB02 for salinity. Note that at BB02, coefficients of both types are statistically significant for all days. A minimum in the Pearson coefficient of -0.408 occurred on day 5. The Spearman coefficient exhibited a minimum on day 4 of -0.518. Salinity concentrations at BB02 exhibit a moderate negative association with freshwater inflow from the S-29. Freshwater inflows begin to influence salinity concentrations at BB02 on the same day of initial release, but this influence peaks after 4 to 5 days of accumulation.

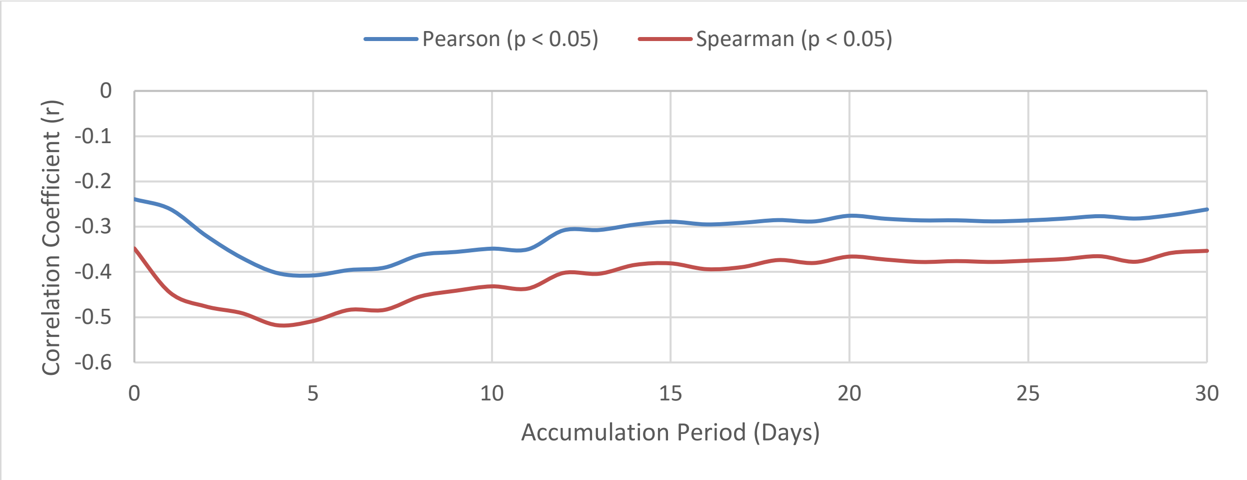

Figure 7-10: Pearson and Spearman Correlation Coefficients for Salinity versus Accumulation Period at BB02

7.2.2 Chlorophyll a

Pearson and Spearman correlation coefficients are shown in **Figure 7-11** at BB02 for chlorophyll *a*. Note that coefficients of both types are statistically significant for all accumulation periods. At BB02, there is agreement on day 19 between both types regarding the occurrence of the maximum coefficient. On day 19 the Pearson coefficient equaled 0.484 and the Spearman coefficient equaled 0.532. Chlorophyll *a* concentrations exhibit a moderate positive association with freshwater inflows from the S-29. The influence of canal flows is significant starting on the day of release and peaks at day 19, after which both correlation types become asymptotical.

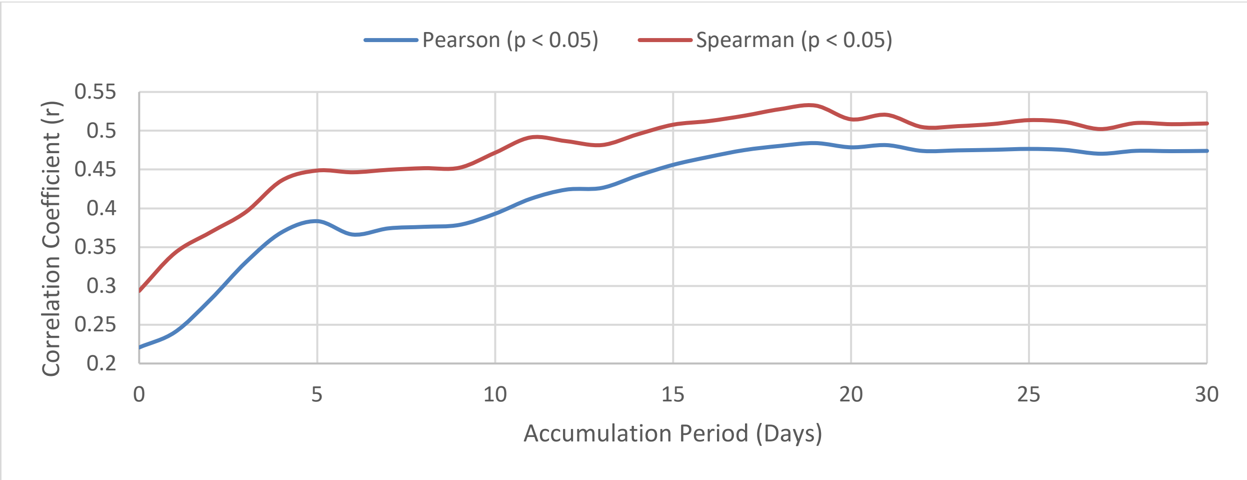

Figure 7-11: Pearson and Spearman Correlation Coefficients for Chlorophyll a versus Accumulation Period at BB02

7.2.3 Total Nitrogen

Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days. At no time did these coefficients exhibit magnitudes statistically different from zero, indicating TN concentrations at BB02 are uncorrelated with cumulative volume discharges from the S-29. Therefore, regression analyses between these variables could not be performed.

7.2.4 Total Phosphorus

For TP, Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days at BB02 (**Figure 7-12**). At no time during this period did the Pearson coefficient exhibit statistical significance. Statistical significance for the Spearman coefficient manifested on day 28, peaking on day 58 at a magnitude of 0.244 ($p < 0.05$). TP concentrations at BB02 are therefore correlated with cumulative volume discharges from the S-29 only on a rank-ordered basis (i.e., a non-linear relationship may exist). Because the Pearson coefficient exhibited no statistical significance, no regression analysis can be performed.

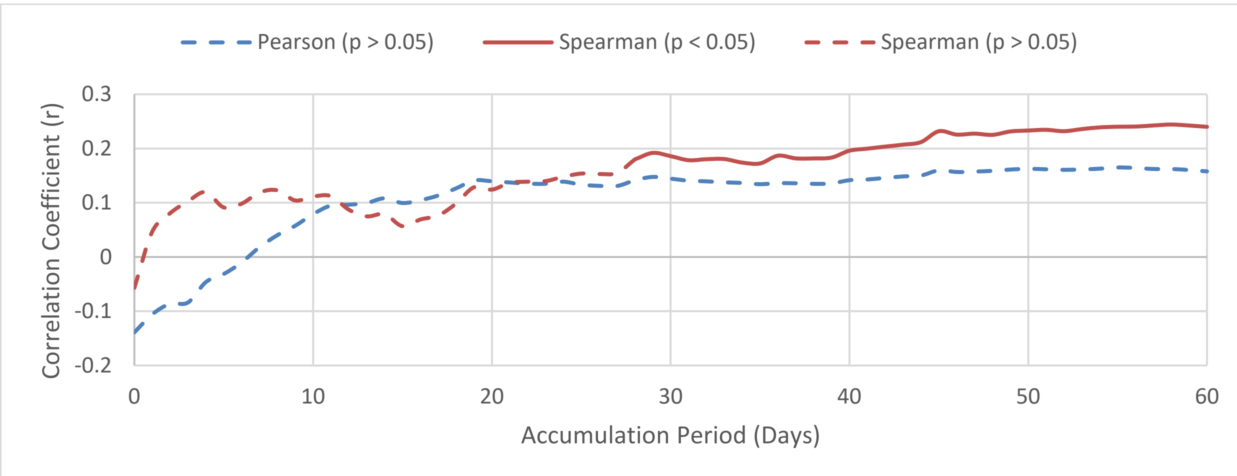

Figure 7-12: Pearson and Spearman Correlation Coefficients for TP versus Accumulation Period at BB02

7.2.5 Dissolved Oxygen

For DO, Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days at BB02 (**Figure 7-13**). For both correlation types, there occurs a statistically significant response in DO concentrations on day 0. Between days 0 and 11, the results alternate between significance and insignificance. At day 43 there is agreement for both correlation types on the occurrence of a minimum coefficient (-0.288 and -0.310 for Pearson and Spearman, respectively), after which time the strength of correlation diminishes. DO concentrations at BB02 exhibit a weak negative association with volumes from the S-29. Note that regression analyses are possible but only up to accumulation periods of 15 days due to the modeling data limitation. At this 15-day period, the Pearson coefficient equaled -0.180, which corresponds to a very weak negative association.

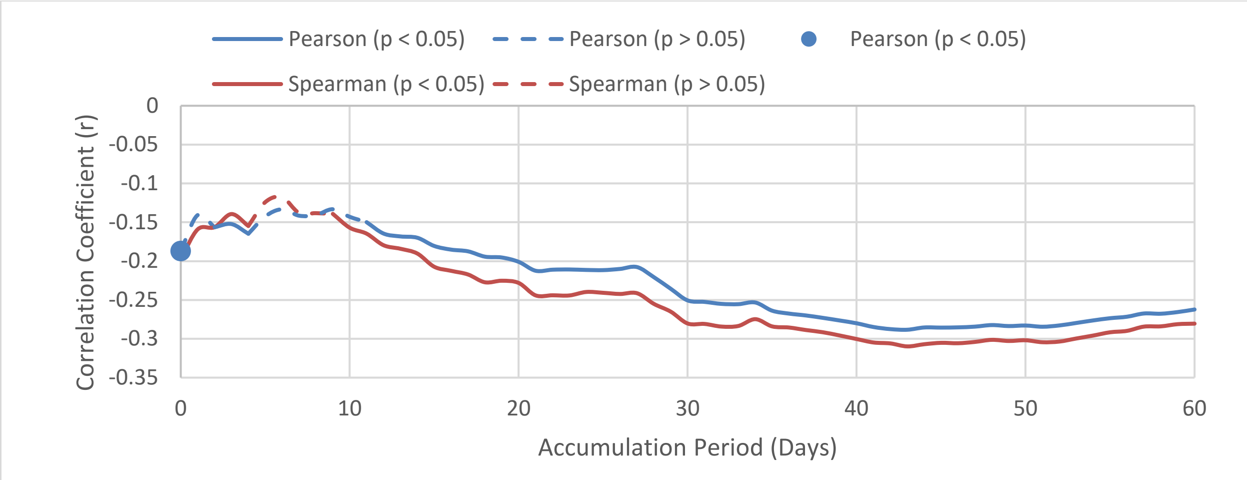

Figure 7-13: Pearson and Spearman Correlation Coefficients for DO versus Accumulation Period at BB02

7.2.6 Turbidity

For turbidity, Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days (**Figure 7-14**). A statistically significant signal in the Spearman coefficient occurs on day two, suggesting that for accumulation periods under 12 days there may exist a weak and undetectable association between turbidity at BB02 and S-29 flows. Statistical significance for the Pearson coefficient manifests beginning on day 16, and the coefficient peaks on day 29 at 0.210, indicating a weak positive association between turbidity and S-29 flows. The Spearman coefficient also peaks on day 29 at a magnitude of 0.260, bolstering evidence of a weak positive association. Because no occurrence of statistical significance in the Pearson coefficient occurs before day 16, no regression analyses can be performed.

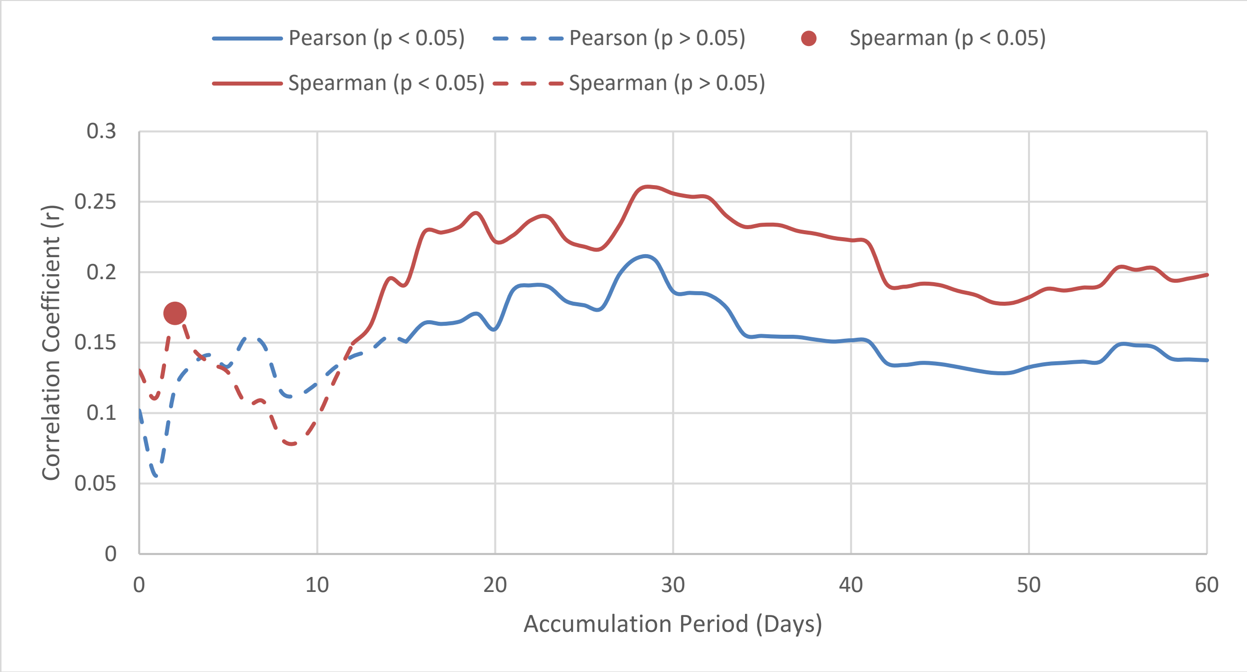

Figure 7-14: Pearson and Spearman Correlation Coefficients for Turbidity at BB02

7.2.7 Copper

For Copper, Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days. At no time did these coefficients exhibit magnitudes statistically different from zero. Copper concentrations at BB02 were determined to be uncorrelated with cumulative volume discharges from the S-29, and therefore regression analyses between these variables cannot be performed.

7.3 C-9 Regression Analyses Results

Table 7-3 provides a results summary of the regression analyses performed on WQ variable concentrations at BB02 (represented by the variable y) and cumulative volume discharges (represented by the variable V) at the S-29. Standard errors of the estimate follow the symbol '$\pm$', allowing for the construction of the 95% confidence for the response variable.

Table 7-3: Regression Results for the NNB-A Cumulative Volume Analyses

WQ Variable	Regression Equation	R^2	Statistical Significance	Calibration Accumulation Period (Days)
Salinity	$y = -0.0008 * V + 31.1496 \pm 5.92$	0.17	$p < 0.05$	5
Chlorophyll *a*	$y = 0.0001 * V + 3.0079 \pm 2.22$	0.21	$p < 0.05$	15
Dissolved Oxygen	$y = -2 * 10^{-5} * V + 5.8336 \pm 1.23$	0.03	$p < 0.05$	15

7.3.1 Salinity

The relationship between salinity concentrations at BB02 and 5-day cumulative volumes from the S-29 is shown in **Figure 7-15**. The coefficient of determination equaled 0.17, indicating that 17% of the variance in salinity concentrations is explained by 5-day cumulative volume discharges. The salinities shown in **Figure 7-15** are characteristic of three separate salinity regimes: (i) mesohaline (5 – 18 ppt); (ii) polyhaline (18 – 30 ppt); and (iii) euhaline (30 – 40 ppt). **Figure 7-1** shows that, on average, conditions at BB02 are consistent with a polyhaline regime. Measures of salinities in the mesohaline region likely coincide with instances of high freshwater input.

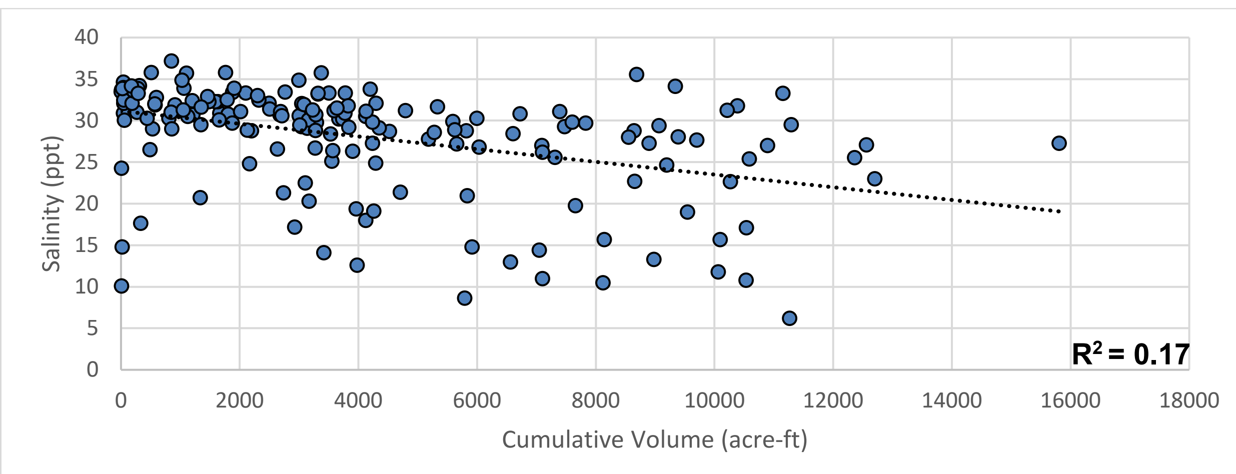

Figure 7-15: Salinity Concentrations at BB02 against 5-day Cumulative Volumes from S-29

Figure 7-16 shows projected salinity concentrations at BB02 for the modeling scenarios outlined in **Table 4-1**. At BB02, projections indicate that the scenarios are mixed between polyhaline and mesohaline salinity regimes. Increasing return period increases the number of scenarios that project a shift from a polyhaline to a mesohaline state.

At BB02, for all return periods, M2C-SLR1 is projected to result in lower salinity levels relative to M0-SLR0 (Existing Conditions), while the M0 scenarios with non-zero SLR are projected to result in higher salinity levels relative to M0-SLR0.

For the 5-year storm, the M0 scenarios exhibit slightly higher salinity concentrations than scenarios with mitigation for fixed SLR. M2B and M2C scenarios exhibit lower salinity concentrations compared to M2A and M0. Among the M2X scenarios, M2A consistently presents the highest salinity concentrations, followed by M2B and M2C.

For higher return period storms, the differences in salinity between the M2X scenarios increase with increasing return period. For the 100-year storm, the trend slightly differs as M2A scenarios exhibit slightly higher salinity concentrations than the corresponding M0 scenario for SLR1. M2B and M2C scenarios show lower concentrations compared to M0 for fixed SLR. Among the M2X scenarios for the 100-year storm return period, M2C-SLR1 results in the lowest salinity level, and M2C-SLR2 exhibits a lower salinity compared to M0-SLR0.

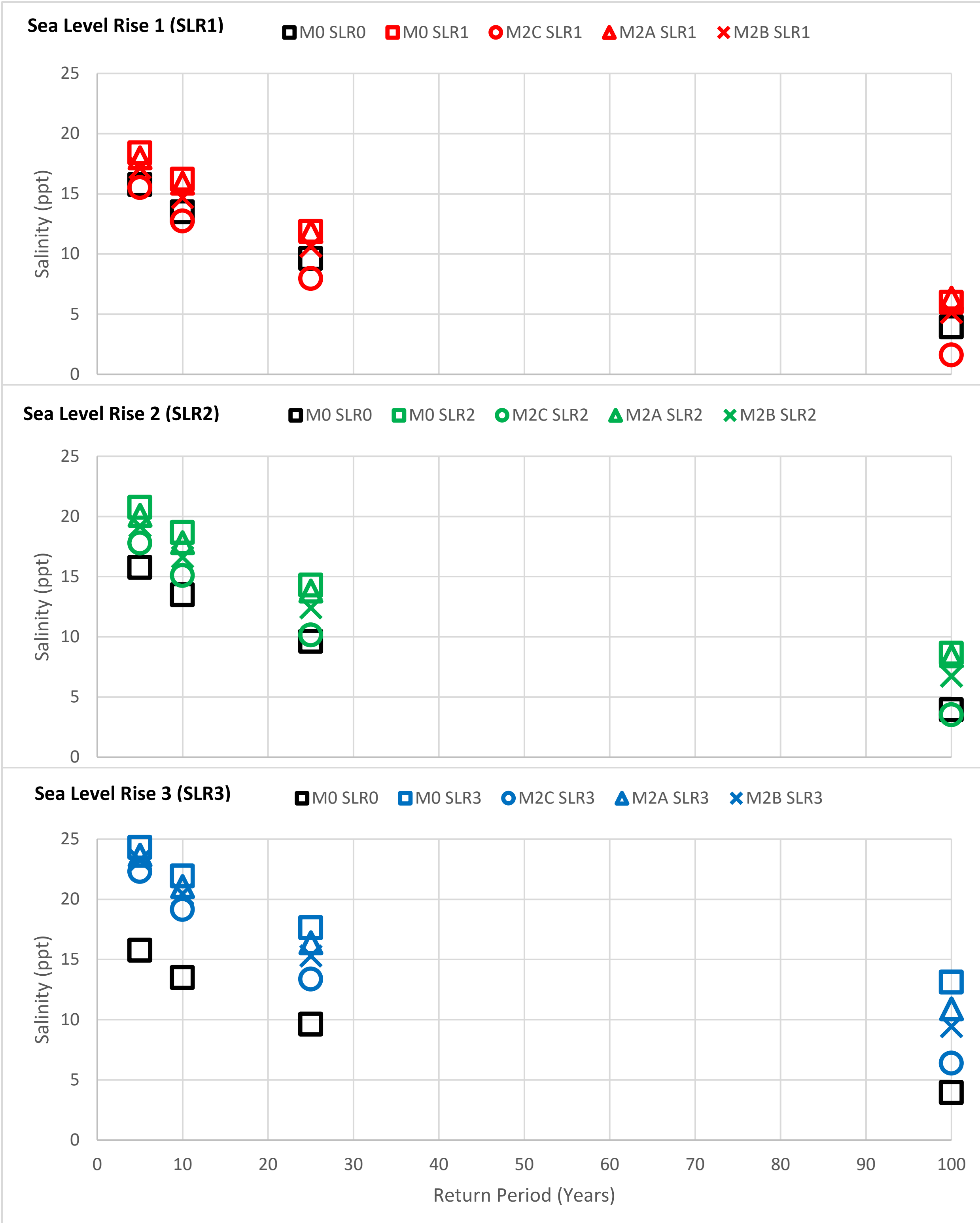

Figure 7-16: Projected Salinity Concentrations at BB02 for All Modeling Scenarios

7.3.2 Chlorophyll a

Chlorophyll *a* concentrations are plotted against 15-day cumulative volumes from the S-29 in **Figure 7-17**. At BB02, the coefficient of determination equaled 0.21, indicating that 21% of the variance in chlorophyll *a* concentrations is accounted for by the accumulation of water from the C-9 over a 15-day period. Note that 45% of concentrations equal or exceed 4 µg/L at BB02, which is characteristic of a mesotrophic system. Hence, water volume input from the C-9 is likely a significant (moderate, positive) driver of phytoplankton growth near BB02.

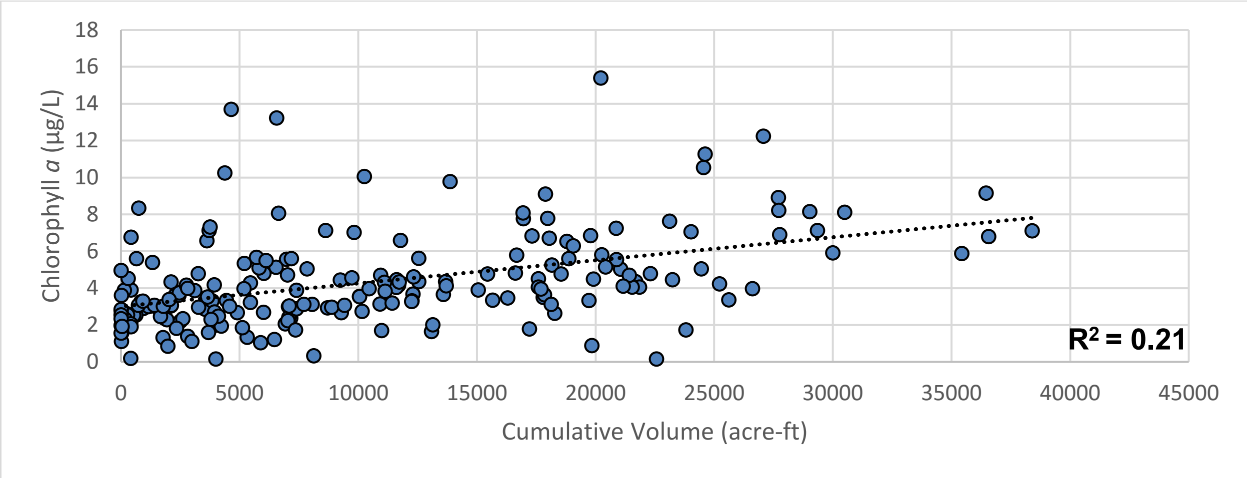

Figure 7-17: Chlorophyll a Concentrations at BB02 against 15-day Cumulative Volumes from S-29

Figure 7-18 shows projected chlorophyll *a* concentrations at BB02 for the modeling scenarios outlined in **Table 4-1**. For all return periods and of all scenarios, M2-SLR1 is projected to result in the greatest increase in chlorophyll *a* concentrations at BB02 and is the only one to exceed M0-SLR0 baseline conditions. All other scenarios, however, project a diminished effect compared to M0-SLR0 (Existing Conditions). Only M0-SLR3 (5-year storm) is projected to result in chlorophyll *a* concentrations below 4 µg/L (orange dashed line), and all scenarios would exceed the NNC of 1.7 µg/L.

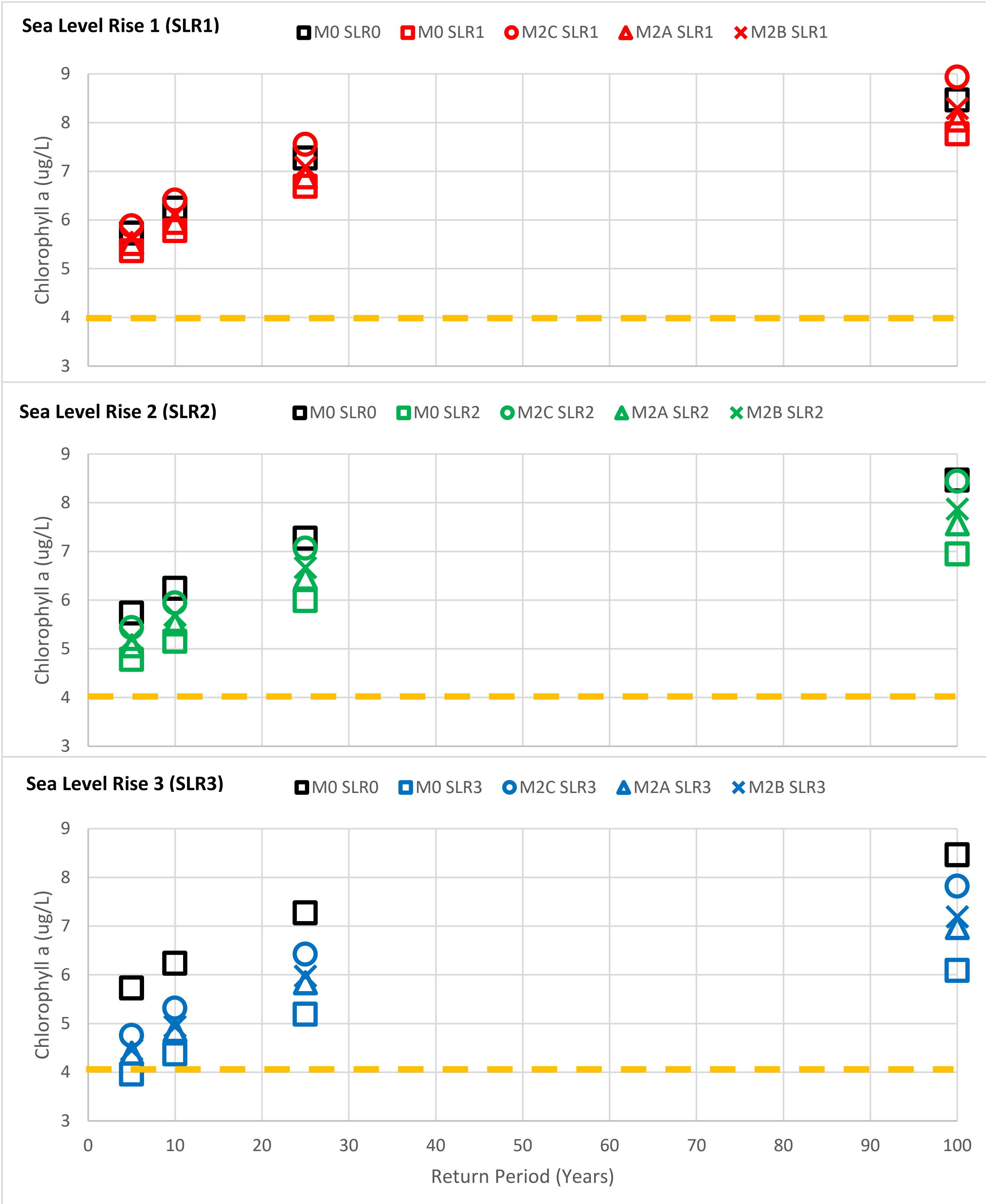

Figure 7-18: Projected Chlorophyll a Concentrations at BB02 for All Modeling Scenarios

For the 5-year storm, the M2A scenarios exhibit lower chlorophyll a concentrations than M0-SLR0. M2B and M2C scenarios project higher chlorophyll *a* concentrations compared to M0 and M2A for fixed SLR. Among the M2X scenarios, M2C consistently presents the highest chlorophyll a concentrations, followed by M2B and M2A.

For the 10- and 25-year storm return periods, both M2B and M2C scenarios have higher concentrations compared to M0 and M2A for fixed SLR. Among the M2X scenarios, M2C has the highest chlorophyll *a* concentrations, followed by M2B and M2A.

For the 100-year storm return period, M2B and M2C scenarios show higher concentrations compared to M0 and M2A for fixed SLR. Among the M2X scenarios, M2C-SLR1 results in the highest chlorophyll *a* level.

7.3.3 Dissolved Oxygen

Figure 7-19 shows the relationship between DO concentrations and 15-day cumulative volumes from the S-29. At BB02, a coefficient of determination of 0.03 indicated that only 3% of the variance in DO concentrations is explained by 15-day cumulative volumes.

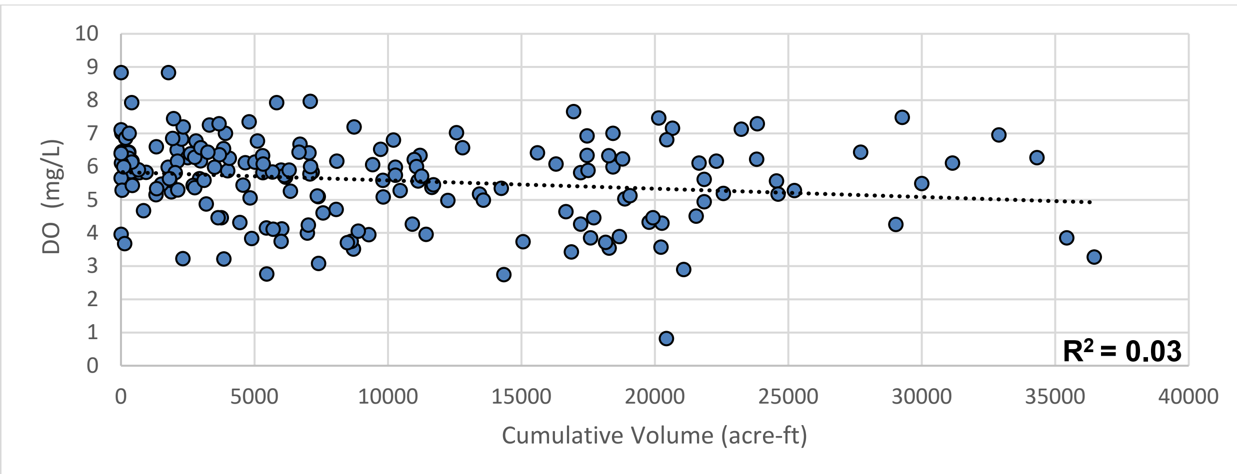

Figure 7-19: DO Concentrations at BB02 against 15-day Cumulative Volumes from S-29

The inverse relationship between DO concentrations and cumulative volume may be due to increased nutrient loadings associated with higher volume discharges at the structures. These increased nutrient loadings may cause excessive aquatic plant and algal growth in North Biscayne Bay. On cloudy days and at night these organisms consume oxygen via respiration, thereby decreasing DO levels in the bay. As these organisms die and decompose, the bacterial breakdown consumes dissolved oxygen, further depleting oxygen in the water column.

One method to evaluate whether excessive aquatic plant and algal growth may be causing decreased DO concentrations is to investigate whether depressed DO levels are associated with increased concentrations of chlorophyll *a*. **Figures 7-20** displays the relationship between DO and chlorophyll *a* concentrations measured on the same day at BB02.

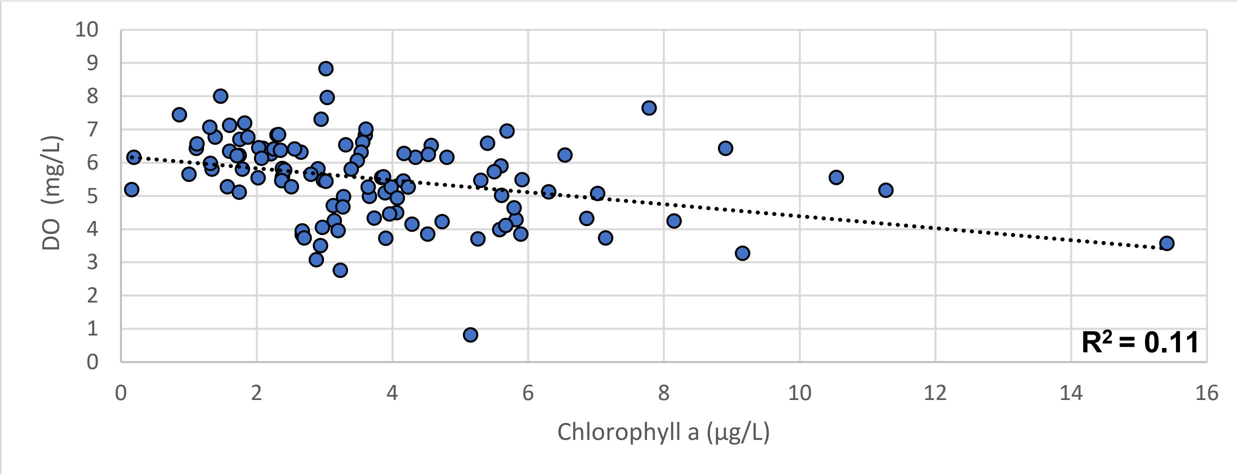

Figure 7-20: DO Concentrations Against Chlorophyll a Concentrations at BB02

A correlation coefficient of -0.33 was computed, indicating that there exists a weak negative association between DO and chlorophyll *a* concentrations at BB02. Hence, chlorophyll *a* levels account for 11% of the variance in DO concentrations. This suggests that the increased presence of phytoplankton in part drives the depletion of DO levels. Aquatic plants and other microorganisms such as attached macro-algae and drift macro-algae may also be in competition for DO. Other factors, however, are likely to be more significant than chlorophyll *a* in influencing DO concentrations, given the weakness of correlation.

Figure 7-21 shows projected DO concentrations at BB02 for the modeling scenarios outlined in **Table 4-1**. At BB02, optimal conditions for fish (above 5 mg/L— green dashed line) are achieved for every scenario for the 5- and 10-year storms. M2C-SLR1 is the only scenario projected to result in lower DO levels relative to the M0-SLR0 baseline scenario.

For the 5-year storm return period, the M2A scenarios exhibit slightly higher DO concentrations compared to M0-SLR0. M2B and M2C scenarios project lower DO concentrations compared to M0 for fixed SLR. Among the M2X scenarios, M2A consistently presents the highest DO concentrations, followed by M2B and M2C. Among the M2X scenarios for the 100-year storm return period, M2A-SLR1 results in the highest DO level, and M2C-SLR1 results in the lowest DO level.

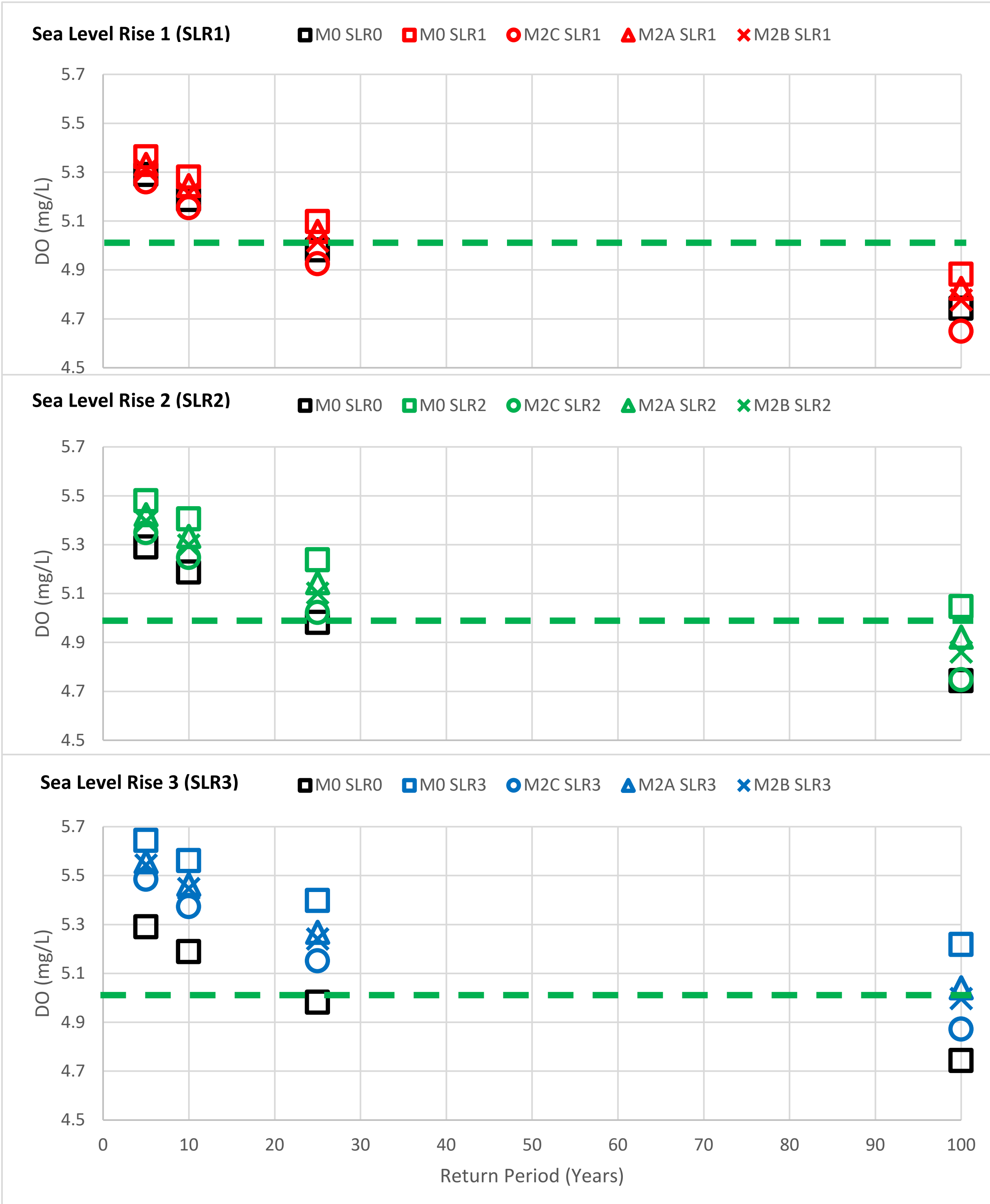

Figure 7-21: Projected DO Concentrations at BB02 for All Modeling Scenarios

7.4 NNB-A (C-9) Cumulative Volume Analysis Conclusions

Sections 7.2 and **7.3** demonstrated the feasibility of establishing useful regression relations between cumulative volume discharges from the C-9 canal and WQ parameter concentrations in the bay as the response variables. It was shown that the peak time of response (determined by the accumulation period where the maximum/minimum correlation coefficient is observed) varies among parameters, even at a fixed location. Salinity, for instance, exhibits a maximum response to cumulative volume inputs at BB02 after 4 to 5 days, while chlorophyll *a*, at that same location, exhibits a maximum response after 19 days. This difference is due to the nature of the variables in question. Salinity concentrations at BB02 reflect almost immediately the injection of freshwater to its vicinity, while the area surrounding BB02 must first assimilate the cumulative load of nutrients discharged from the canals, which are then taken up by phytoplankton and other organisms, causing a lag between times of initial canal discharge and the manifestation of chlorophyll *a.* Note that nutrient uptake in the vicinity of BB02 is further complicated by the presence of a mangrove forest (along the Oleta River) that acts as a sink to nitrogen/phosphorus prior to entering the bay. These mangroves likely distort the signal of nutrient concentration measurements at downstream WQ stations (e.g., BB02).

Table 7-4 summarizes the results of the correlation analysis between cumulative volume and several WQ variables for NNB-A. Refer to **Table 4-2** for descriptions of the strength of correlation and the color-coding key.

Table 7-4: NNB-A Correlation Analysis Results

WQ Variable	Max Pearson r	Max Spearman r	Station ID
Salinity	-0.41	-0.52	BB02
Chlorophyll *a*	0.48	0.53	BB02
Dissolved Oxygen	-0.29	-0.31	BB02

Note: Correlation Analyses were conducted only for variables that were determined to be COCs or flagged for further study.

Tables 7-5 to **7-8** summarize the results of the WQ analysis for NNB-A. For each variable and scenario, the percent change in WQ projections relative to existing conditions (M0-SLR0) was computed. Note that values highlighted in green indicate instances of short term WQ improvements; those in red, short term negative impacts to WQ; and those in orange are undetermined due to the uncertainty of impacts to the environment. The impact of changes in salinity concentrations on the local ecology, for instance, is not well understood. In addition, if the absolute value of a percentage change was computed to be less than or equal to 2%, the potential impact of the result was considered as undetermined due to statistical uncertainty of the regression.

Legend:

Undetermined
Short Term Negative Impact
Short Term WQ Improvement

Table 7-5: Results for the 5-Year Storm in NNB-A

	Percent Change Relative to Existing Conditions (M0-SLR0)											
Variable	**M0-SLR1**	**M0-SLR2**	**M0-SLR3**	**M2A-SLR1**	**M2A-SLR2**	**M2A-SLR3**	**M2B-SLR1**	**M2B-SLR2**	**M2B-SLR3**	**M2C-SLR1**	**M2C-SLR2**	**M2C-SLR3**
Salinity	16.8	31.7	54.3	14.2	27.6	50.2	8.9	21.8	47.6	-1.5	12.9	41.5
Chlorophyll a	-6.3	-16.6	-30.9	-3.7	-11.7	-23.3	-1.6	-9.3	-22.1	2.6	-5.1	-17.0
DO	1.5	3.7	7.7	0.9	2.6	5.0	0.1	1.8	4.5	-0.4	1.2	3.8

Table 7-6: Results for the 10-Year Storm in NNB-A

	Percent Change Relative to Existing Conditions (M0-SLR0)											
Variable	**M0-SLR1**	**M0-SLR2**	**M0-SLR3**	**M2A-SLR1**	**M2A-SLR2**	**M2A-SLR3**	**M2B-SLR1**	**M2B-SLR2**	**M2B-SLR3**	**M2C-SLR1**	**M2C-SLR2**	**M2C-SLR3**
Salinity	20.1	38.3	62.4	17.8	32.0	56.0	8.8	23.1	51.5	-5.6	11.8	41.9
Chlorophyll a	-7.4	-17.4	-29.9	-4.5	-11.7	-22.1	-2.0	-8.9	-20.7	2.7	-4.8	-14.8
DO	1.8	4.3	8.3	1.2	2.8	5.2	0.1	1.8	4.6	-0.6	1.2	3.6

Table 7-7: Results for the 25-Year Storm in NNB-A

	Percent Change Relative to Existing Conditions (M0-SLR0)											
Variable	**M0-SLR1**	**M0-SLR2**	**M0-SLR3**	**M2A-SLR1**	**M2A-SLR2**	**M2A-SLR3**	**M2B-SLR1**	**M2B-SLR2**	**M2B-SLR3**	**M2C-SLR1**	**M2C-SLR2**	**M2C-SLR3**
Salinity	**23.5**	**48.7**	**83.4**	**23.5**	**43.6**	**70.6**	**10.6**	**29.1**	**59.1**	**-17.3**	**5.5**	**39.0**
Chlorophyll a	**-8.0**	**-17.6**	**-28.6**	**-5.2**	**-11.2**	**-19.7**	**-2.5**	**-8.3**	**-17.8**	**3.9**	**-2.8**	**-11.7**
DO	**2.3**	**5.1**	**9.6**	**1.5**	**3.2**	**5.5**	**0.1**	**1.7**	**4.5**	**-1.1**	**0.8**	**3.4**

Table 7-8: Results for the 100-Year Storm in NNB-A

	Percent Change Relative to Existing Conditions (M0-SLR0)											
Variable	**M0-SLR1**	**M0-SLR2**	**M0-SLR3**	**M2A-SLR1**	**M2A-SLR2**	**M2A-SLR3**	**M2B-SLR1**	**M2B-SLR2**	**M2B-SLR3**	**M2C-SLR1**	**M2C-SLR2**	**M2C-SLR3**
Salinity	**51.7**	**118.8**	**233.1**	**60.7**	**113.6**	**176.5**	**30.4**	**71.2**	**139.2**	**-59.6**	**-11.0**	**62.0**
Chlorophyll a	**-8.2**	**-17.9**	**-28.1**	**-4.8**	**-10.6**	**-17.6**	**-2.0**	**-7.0**	**-15.0**	**5.5**	**-0.3**	**-7.6**
DO	**2.8**	**6.4**	**11.7**	**1.7**	**3.7**	**6.0**	**-0.2**	**1.5**	**4.3**	**-1.9**	**0.1**	**2.6**

The following summarizes observations from **Tables 7-5** to **7-8**.

- Compared to M0-SLR0, the M2A, M2B, and M2C scenarios exhibit differences in water quality variable outcomes (salinity, chlorophyll *a*, and DO).

Salinity

- Compared to M0-SLR0, the M2A, M2B, and M2C scenarios exhibit decreases in salinity, with the largest decrease observed in M2C-SLR1 during the 100-year storm return period.
- Salinity increases with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

Chlorophyll *a*

- The M2C-SLR1 scenario during the 100-year storm return period shows the largest increase in chlorophyll *a*, which is likely to cause short term negative impacts to chlorophyll *a* for all storm periods.
- Of the mitigation strategies, M2A-SLR3 scenario during the 5-year storm return period shows the largest decrease in chlorophyll *a,* which indicates the largest WQ benefit.
- Chlorophyll *a* concentrations decrease with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

Dissolved Oxygen

- The M2C-SLR1 scenario during the 100-year storm return period shows the largest decrease in DO, but the WQ impact for all storm periods is undetermined.
- Of the mitigation strategies, M2A-SLR3 scenario during the 5-year storm return period shows the largest increase in DO*,* which indicates the largest WQ benefit.
- DO concentrations increase with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

Generally, the M2C scenarios are associated with more frequent short term negative or uncertain impacts, while M2A scenarios are associated with less frequent negative impacts. However, specific trends may vary depending on the variable and sea level rise scenario being considered.

8.0 C-8 RESULTS AND MITIGATION SCENARIO IMPACTS ON WATER QUALITY

8.1 C-8 Time Series Results

Table 8-1 summarizes the Mann-Kendall test results for each COC at BB09 and at BS04. Note that the symbol '+' denotes a temporally increasing trend, '-' denotes a temporally decreasing trend, and 0 denotes no trend.

Table 8-1: Mann-Kendall Test Results for COCs at BB09 and BS04

WQ Parameter	Trend	Significance	Time Series Type	Station ID
Salinity	0	$p > 0.05$	Annual Mean	BB09
Salinity	0	$p > 0.05$	Annual Minimum Series	BB09
Chlorophyll a	0	$p > 0.05$	Annual GM	BB09
TN	+	$p < 0.05$	Annual GM	BB09
TN	0	$p > 0.05$	Annual Maximum Series	BB09
TN	-	$p < 0.05$	Annual GM	BS04
TP	+	$p < 0.05$	Annual GM	BB09
TP	0	$p > 0.05$	Annual GM	BS04
Dissolved Oxygen	+	$p < 0.05$	Annual Mean	BB09
Dissolved Oxygen	0	$p > 0.05$	Annual Mean	BS04
Turbidity	0	$p > 0.05$	Annual Mean	BB09

8.1.1 Salinity

Annual salinity concentration means for the period 1996 to 2021 at BB09 are shown in **Figure 8-1**. These means range from 29 to 33 ppt, which is consistent with a euhaline salinity regime, typical of the marine environment.

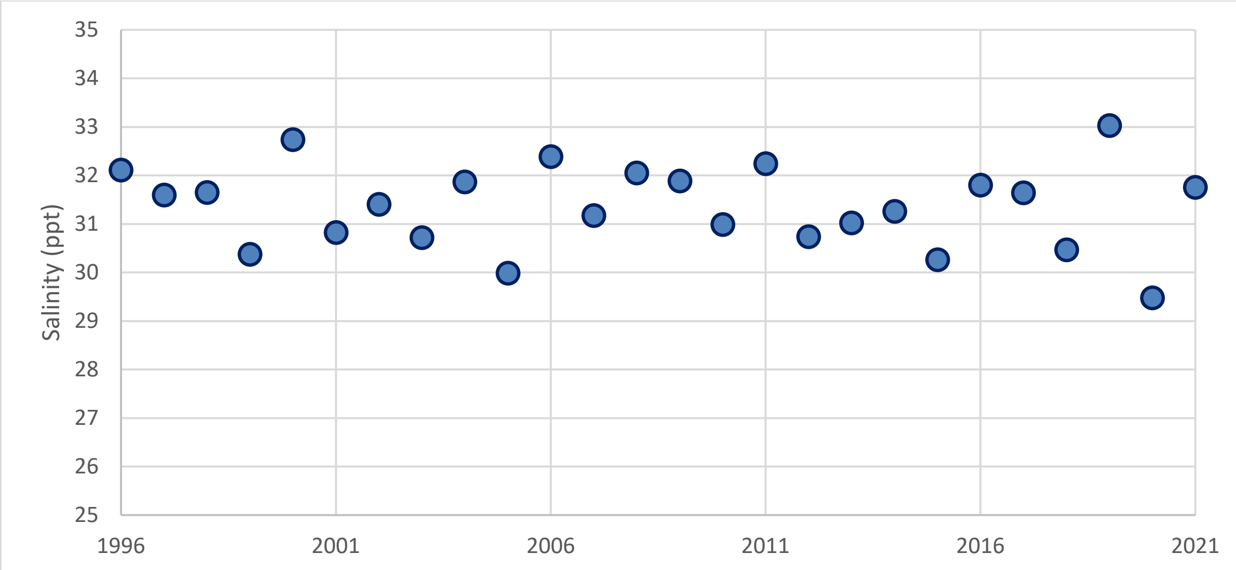

Figure 8-1: Annual Series of Average Salinity Concentrations at BB09

The AMS of salinity concentrations at BB09 is shown in **Figure 8-2**. No statistically significant trend was detected for this series. In 2005, there occurred a minimum concentration of 3.7 ppt. Note that several tropical cyclones passed over South Florida in 2005. No statistically significant trends in salinity levels were detected at BB09 for both the annual average and annual minimum series.

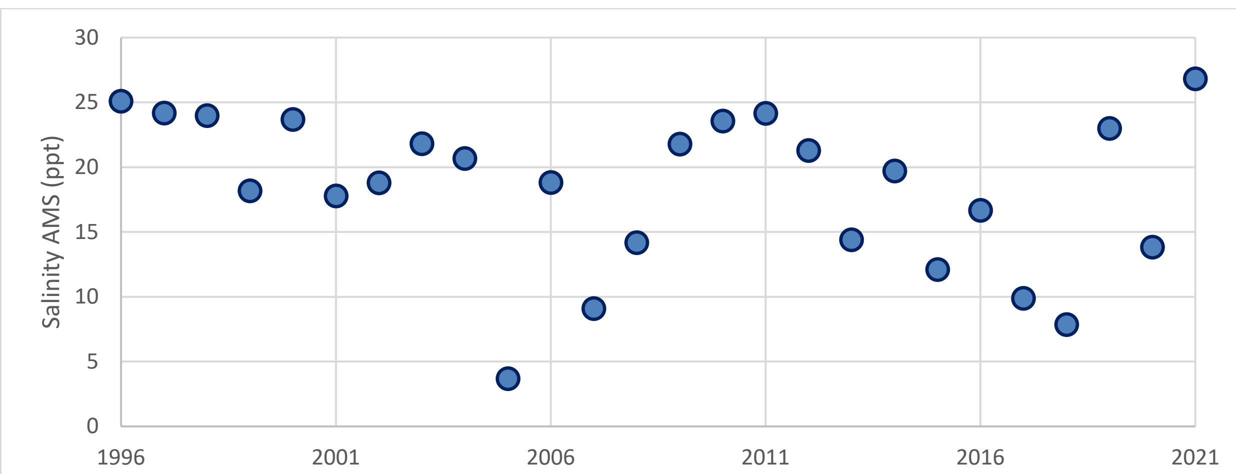

Figure 8-2: Annual Minimum Series of Salinity Concentrations at BB09

8.1.2 Chlorophyll a

Figures 8-3 shows annual GMs for chlorophyll *a* for the period 1996 to 2021 at BB09, plotted against the WQ criterion of 1.7 µg/L. Note that measures of chlorophyll *a* regularly exceed the criterion at BB09, especially from 2006 onwards. The WQ criteria was also exceeded twice in the last three years (2019 and 2020) for which data is available. These concentrations are typical of an oligotrophic system.

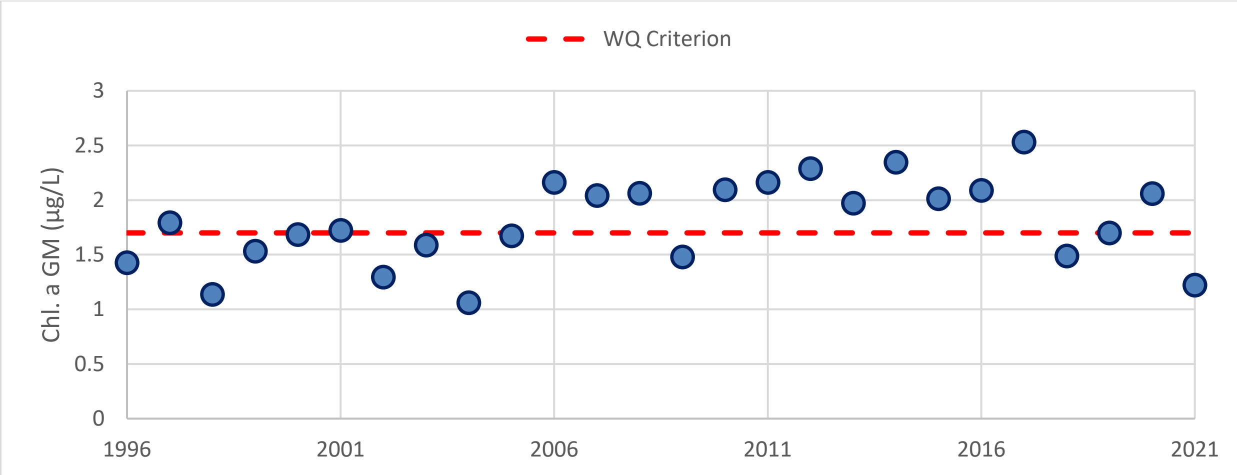

Figure 8-3: Annual GMs of Chlorophyll a Concentrations at BB09

No statistically significant trend in chlorophyll *a* levels was detected at BB09. This result is consistent with Chin (2020), who evaluated chlorophyll *a*, TN, and TP annual GMs at BB09 and found no significant trend in chlorophyll *a* concentrations between 2008 and 2018. Chin noted that, although TN and TP concentrations exhibited statistically significant increasing trends at BB09, their concentrations remain too low to significantly affect chlorophyll *a* concentrations.

Increasing trends in nutrient concentrations and none in chlorophyll *a* may be due to the nature of nutrient assimilation at the location of BB09. Phytoplankton, which produce chlorophyll *a*, may be in competition for nutrients with other organisms like attached and drift macro-algae, such that chlorophyll *a* levels remain depressed during a significant algal response (Fong et al. 1993; Harlin 1995; Nixon et al. 2001). The growth of these other algal populations can also negatively effect seagrass coverage negatively.

8.1.3 Total Nitrogen

Figure 7-4 shows annual GMs for TN for the period 1996 to 2021 at BB09 and BS04. In the last two years (2020 and 2021) the WQ criterion was exceeded at BB09, and a statistically significant increasing trend in annual TN GMs was detected. This result is consistent with Chin (2020), who analyzed this data from 2008 to 2018. A statistically significant decreasing trend was detected at BS04 ($p < 0.05$). This result suggests that factors other than C-8 canal TN loadings may be causing the increase in TN concentrations at BB09.

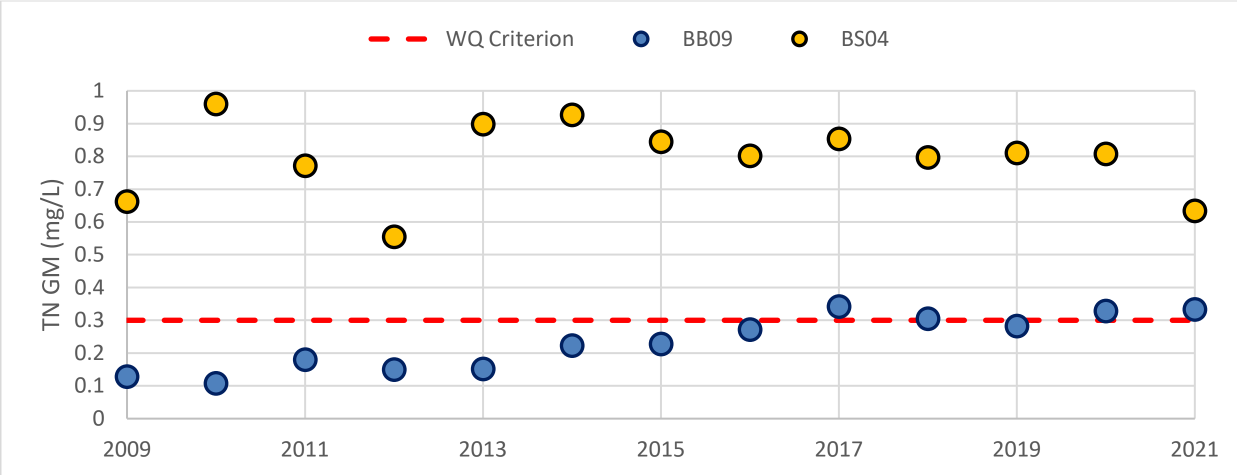

Figure 8-4: Annual GMs of TN Concentrations at BB09

8.1.4 Total Phosphorus

Figure 8-5 shows annual GMs for TP at BB09 and BS04 plotted against the WQ criterion of 0.012 mg/L. No WQ criterion exceedances have been recorded at BB09 between 2008 and 2018. Note that concentrations in the canal (BS04) are higher than concentrations in the bay (BB09) and frequently exceed WQ criterion. TP annual GMs at BB09 exhibited a statistically significant increasing trend ($p < 0.05$), while those at BB04 exhibited no statistically significant trend.

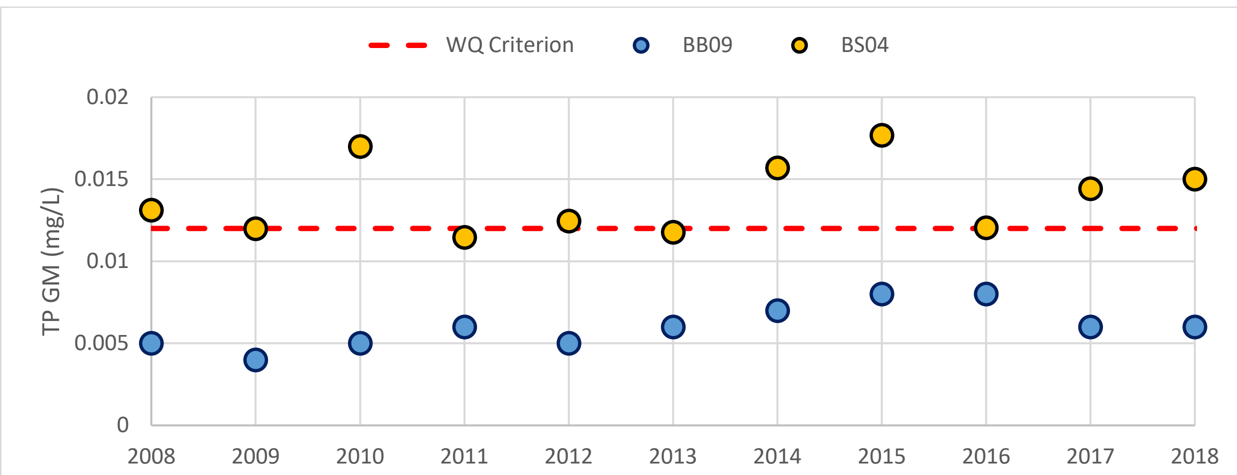

Figure 8-5: Annual GMs of TP Concentrations at BB09 and BS04

8.1.5 Dissolved Oxygen

The annual distributions of instantaneous DO concentrations are plotted at BB09 in **Figure 8-6** against general tolerance thresholds for fish (Francis-Floyd, 2019). At BB09, concentrations less than 5.0 mg/L comprise 8.0% of all data. Concentrations that lie between 2.0 and 4.0 comprise 1.2% of all data. Note that the critically low threshold of 2.0 mg/L has not been exceeded.

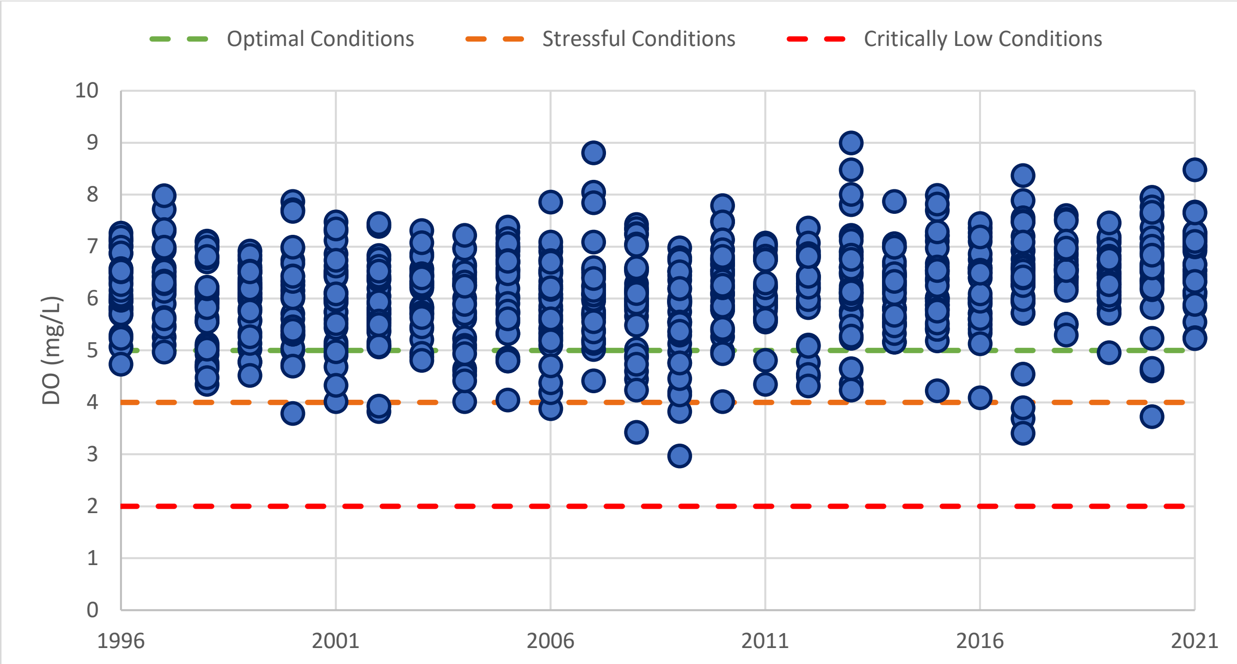

Figure 8-6: Annual Distributions of Instantaneous DO concentrations at BB09 (1996 – 2021)

Figure 8-7 shows the annual means for DO at BB09 from 1996 to 2021. A statistically significant increasing trend was detected at BB09. No statistically significant trend was detected at BS04. At BB09, the average DO concentration remained above the optimal threshold of 5.0 mg/L throughout the study period, while concentrations at BS04 were frequently below optimal.

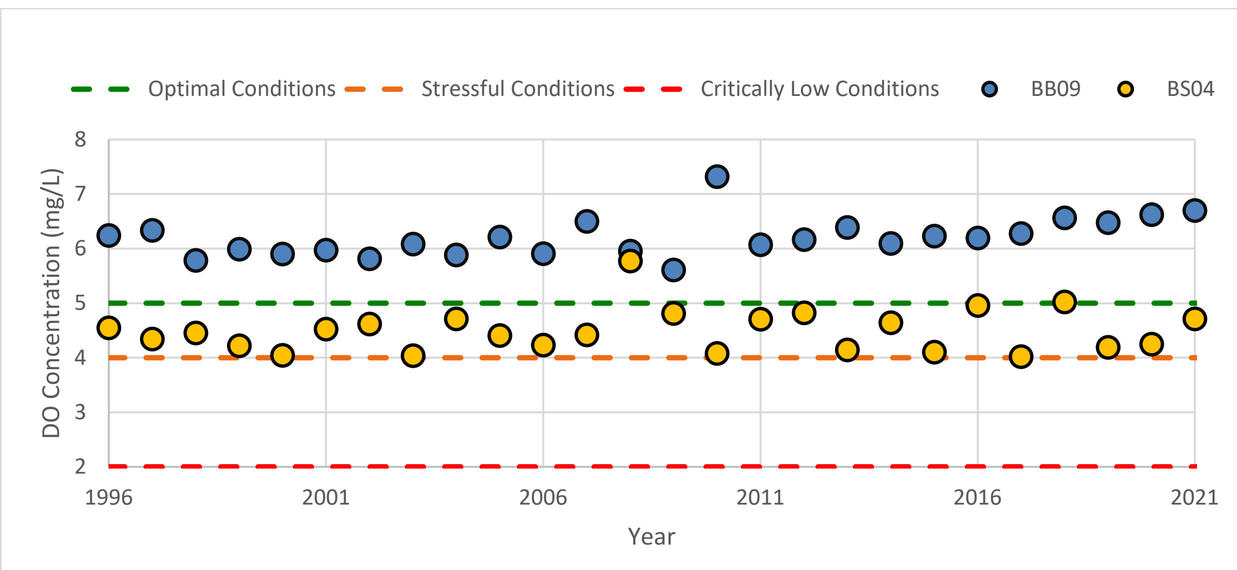

Figure 8-7: Annual Means of DO Concentrations at BB09

8.1.6 Turbidity

The distribution of instantaneous turbidity measurements at BB09 is shown in **Figures 8-8**. At BB09, in each of the last seven years, turbidity levels have exceeded the 1.3 NTU threshold at least once, although conditions have significantly improved compared to the 1996 to 2005 period.

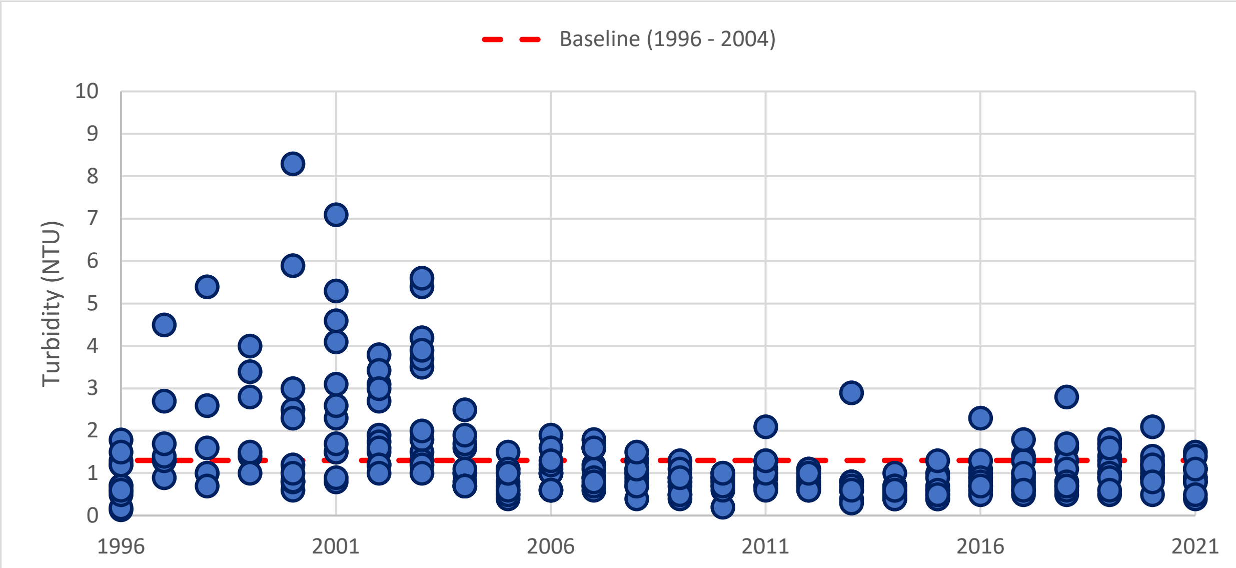

Figure 8-8: Annual Distributions of Instantaneous Turbidity Concentrations at BB09

8.2 C-8 Correlation Analysis Results

Table 8-2 reports the correlation coefficients between cumulative volumes from the S-28 and WQ variable concentrations in the bay (refer to Variable Pair #2 in **Table 4-1**). For each WQ variable, the accumulation periods (days) associated with the highest coefficient of each type were reported. The accumulation period represents the number of days over which volumes are summed before a concentration measurement to obtain the cumulative volume. Variables in green font were determined to be adequate for regression analyses; those in red, inadequate. In the following sections, the statistical significance of correlation is shown graphically via a dotted line (insignificant, $p > 0.05$) and solid line (significant, $p < 0.05$). Note that for TN, station BS01 was analyzed due to inconclusive results for station BB09.

Table 8-2: Summary of Correlation Analysis Results for Variable Pair #2 in the C-8

WQ Variable	Pearson r	Spearman r	Pearson Accumulation Period	Spearman Accumulation Period	Station ID
Salinity	-0.294	-0.464	5	26	BB09
Chlorophyll *a*	0.436	0.482	13	13	BB09
TN	0	0.283	NA	3	BB09
TN	0.660	0.707	39	39	BS01
TP	NA	NA	NA	NA	BB09
Dissolved Oxygen	-0.309	-0.389	15	11	BB09
Turbidity	0	0	NA	NA	BB09

8.2.1 Salinity

Figure 8-9 shows Pearson and Spearman correlation coefficients for accumulation periods between 0 and 30 days at BB09 for salinity. A minimum in the Pearson coefficient occurs on day 5, while Spearman coefficients decrease monotonically to day 30, where an asymptote is reached. Statistical significance in the Pearson coefficient manifests after one day of cumulative volume input from the S-28, while on a rank basis statistical significance is achieved on day 0. This suggests that the effect of continuous freshwater volume input from the S-28 on salinity concentrations peaks after 5 days of accumulation, after which time the effect of additional volume inputs remains significant but diminished. Salinity concentrations at BB09 exhibit a weak to moderate negative association with cumulative volumes from the S-28.

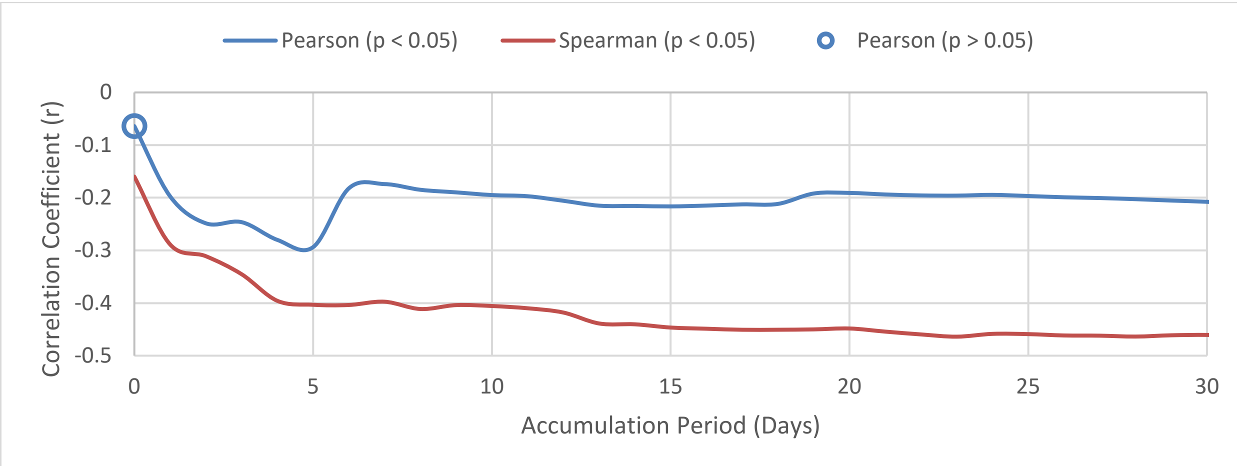

Figure 8-9: Pearson and Spearman Correlation Coefficients for Salinity versus Accumulation Period at BB09

8.2.2 Chlorophyll a

Pearson and Spearman correlation coefficients are shown in **Figure 8-10** at BB09 for chlorophyll *a*. Note that coefficients of both types are statistically significant for all accumulation periods. At BB09, for both the Pearson and Spearman coefficients, maximums of 0.436 and 0.482 occur, respectively, on day 13. At around day 4, for both correlation types, the rate of increase in correlation coefficients diminishes with increasing accumulation period for both correlation types. Hence, concentrations of chlorophyll a at BB09 exhibit a moderate positive association with cumulative volume inputs from the S-28.

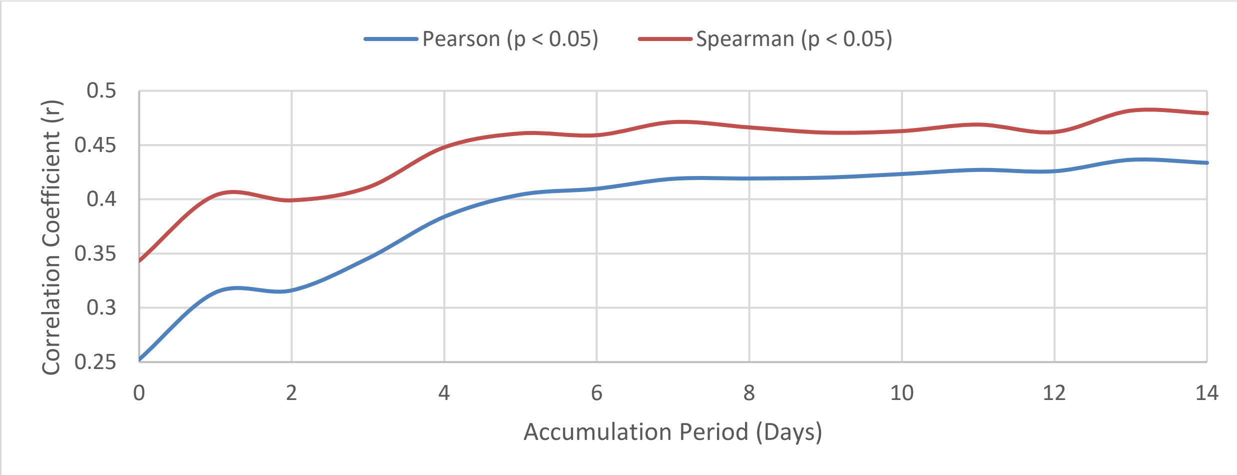

Figure 8-10: Pearson and Spearman Correlation Coefficients for Chlorophyll a versus Accumulation Period at BB09

8.2.3 Total Nitrogen

Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days. **Figure 8-11** shows Pearson and Spearman correlation coefficients for accumulation periods between 0 and 14 days at BB09. There was a lack of statistically significant correlation for both types, except on day 3 for the rank-ordered correlation. This potentially significant correlation led to the investigation of TN concentrations at WQ station BS01, which lies at the mouth of the C-8 canal, closer to the S-28 discharge point.

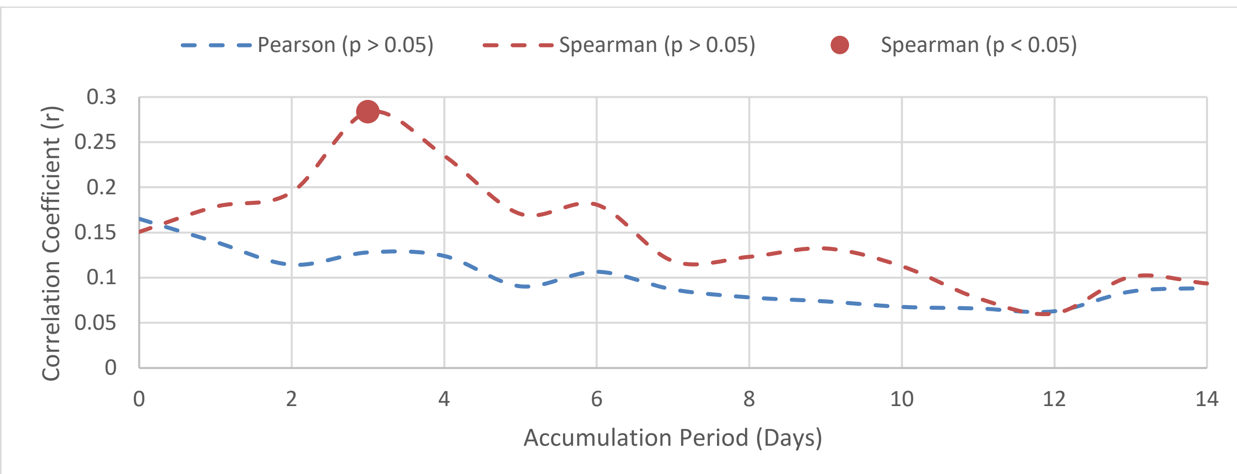

Figure 8-11: Pearson and Spearman Correlation Coefficients for TN versus Accumulation Period at BB09

Figure 7-23 shows Pearson and Spearman correlation coefficients for accumulation periods between 0 and 60 days at BS01. Within the first fifteen accumulation periods, a maximum in the Pearson coefficient of 0.567 occurred on day 3, while a global maximum of 0.660 occurred on day 39. A maximum in the Spearman coefficient of 0.707 occurs on day 39. Therefore, there exists a moderate to strong positive association between TN concentrations at BS01 and cumulative volume discharges from the S-28.

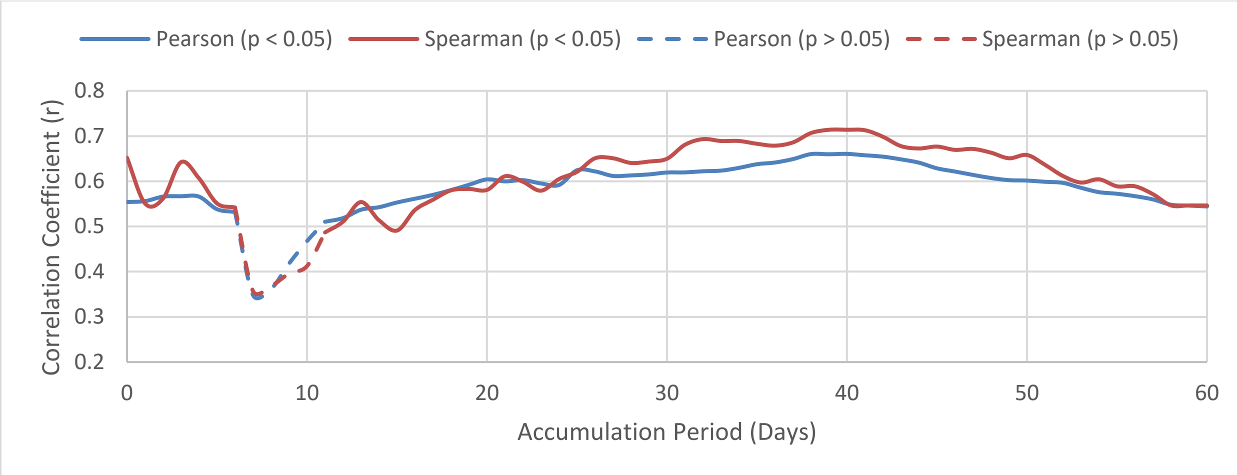

Figure 8-12: Pearson and Spearman Correlation Coefficients for TN at BS01

8.2.4 Total Phosphorus

Instantaneous TP data at BB09 was deemed insufficient for any correlation/regression analyses due to data gaps and imprecision in the available data. In addition, TP concentrations at BB09 have not exceeded the WQ criterion described by the time series in **Section 8.1.4**.

8.2.5 Dissolved Oxygen

For DO, Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days at BB09 (**Figure 8-13**). A minimum in the Pearson coefficient of -0.311 occurs on day 17, while a minimum in the Spearman coefficient of -0.389 occurs on day 11. Hence, DO concentrations at BB09 and cumulative volume inputs from the S-28 exhibit a weak negative association, and the maximum effect of cumulative volume inputs manifests between 11 to 17 days after the start of accumulation.

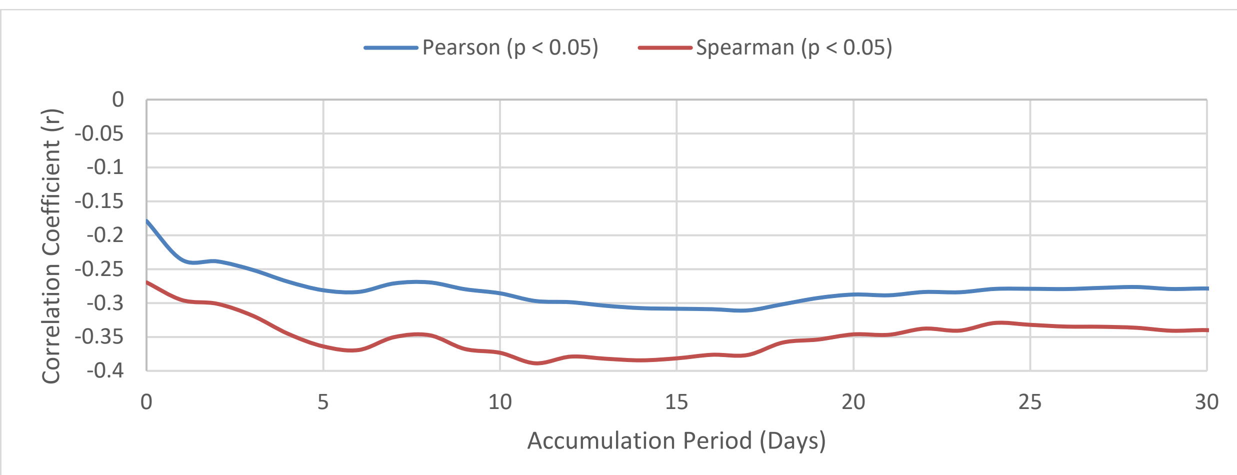

Figure 8-13: Pearson and Spearman Correlation Coefficients for DO versus Accumulation Period at BB09

8.2.6 Turbidity

For turbidity, Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days. At BB09, these coefficients never exhibited magnitudes statistically different from zero. Turbidity concentrations at BB09 are uncorrelated with cumulative volume discharges from the S-28, and therefore regression analyses between these variables cannot be performed.

8.3 C-8 Regression Analysis Results

Table 8-3 provides a results summary of the regression analyses performed on WQ variable concentrations at BB09 and BS01 (represented by the variable y) and cumulative volume discharges (represented by the variable V) at the S-28. Standard errors of the estimate follow the symbol '$\pm$', allowing for the construction of the 95% confidence for the response variable.

Table 8-3: Regression Results for the NNB-B Cumulative Volume Analyses

WQ Variable	Regression Equation	R^2	Statistical Significance	Calibration Accumulation Period (Days)
Salinity	$y = -0.0004 * V + 33.6384 \pm 2.10$	0.09	$p < 0.05$	5
Chlorophyll *a*	$y = 0.0002 * V + 1.612 \pm 1.39$	0.19	$p < 0.05$	13
TN	$y = 3.33 * 10^{-5} * V + 0.3597 \pm 0.16$	0.31	$p < 0.05$	15
Dissolved Oxygen	$y = -9.54 * 10^{-5} * V + 6.3797 \pm 1.20$	0.10	$p < 0.05$	15

8.3.1 Salinity

The relationship between salinity concentrations at BB09 and 5-day cumulative volume discharges at the S-28 is shown in **Figure 8-14**. The coefficient of determination equaled 0.09, indicating that 9% of the variance in salinity concentrations are explained by 5-day cumulative volume discharges. Average salinity conditions at BB09 are characteristic of a Euhaline salinity regime (**Figure 8-1**). Polyhaline conditions are at times observed at BB09, which may be caused by the interplay between freshwater inflow from the C-8 canal and tidal phases.

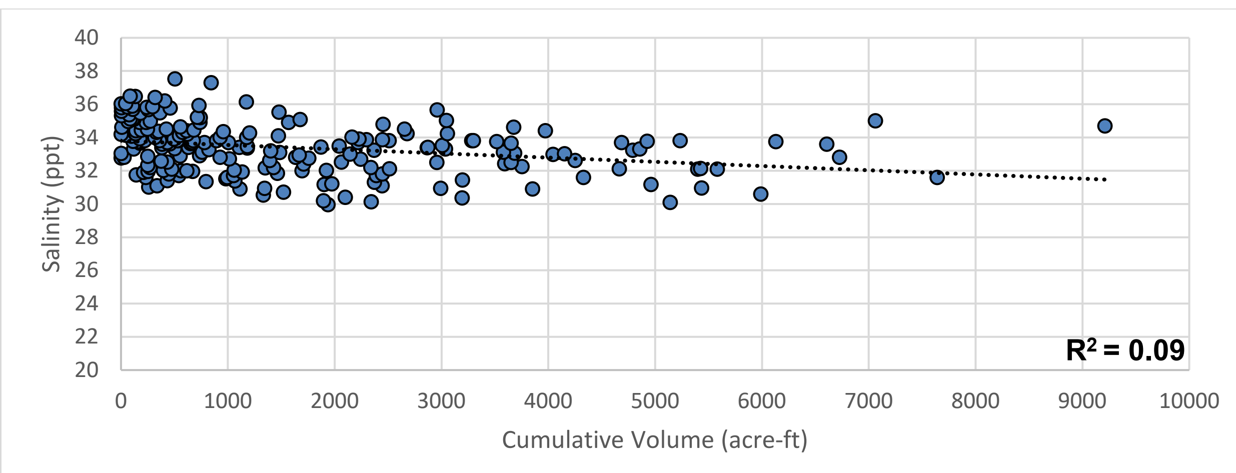

Figure 8-14: Salinity Concentrations at BB09 against 5-day Cumulative Volumes from the S-28

Figure 8-15 shows projected salinity concentrations at BB02 for the modeling scenarios outlined in **Table 4-1**. At BB09, for all return periods, the M2C scenarios are projected to result in lower salinity levels relative to M0-SLR0, while the M0 scenarios with non-zero SLR are projected to result in higher salinity levels relative to M0-SLR0.

For the 5-year storm, M2A scenarios exhibit slightly higher salinity concentrations than the corresponding M2B and M2C scenarios for fixed SLR. M2B scenarios display lower salinity concentrations compared to M0 and M2A, while M2C scenarios show the lowest salinity concentrations among all scenarios.

For the 10- and 25-year storm, a similar trend is observed. For the 100-year storm return period, the M2A scenarios exhibit higher salinity concentrations than M0-SLR0. M2B scenarios display lower salinity concentrations compared to M0 and M2A, while M2C scenarios show the lowest salinity concentrations among all scenarios.

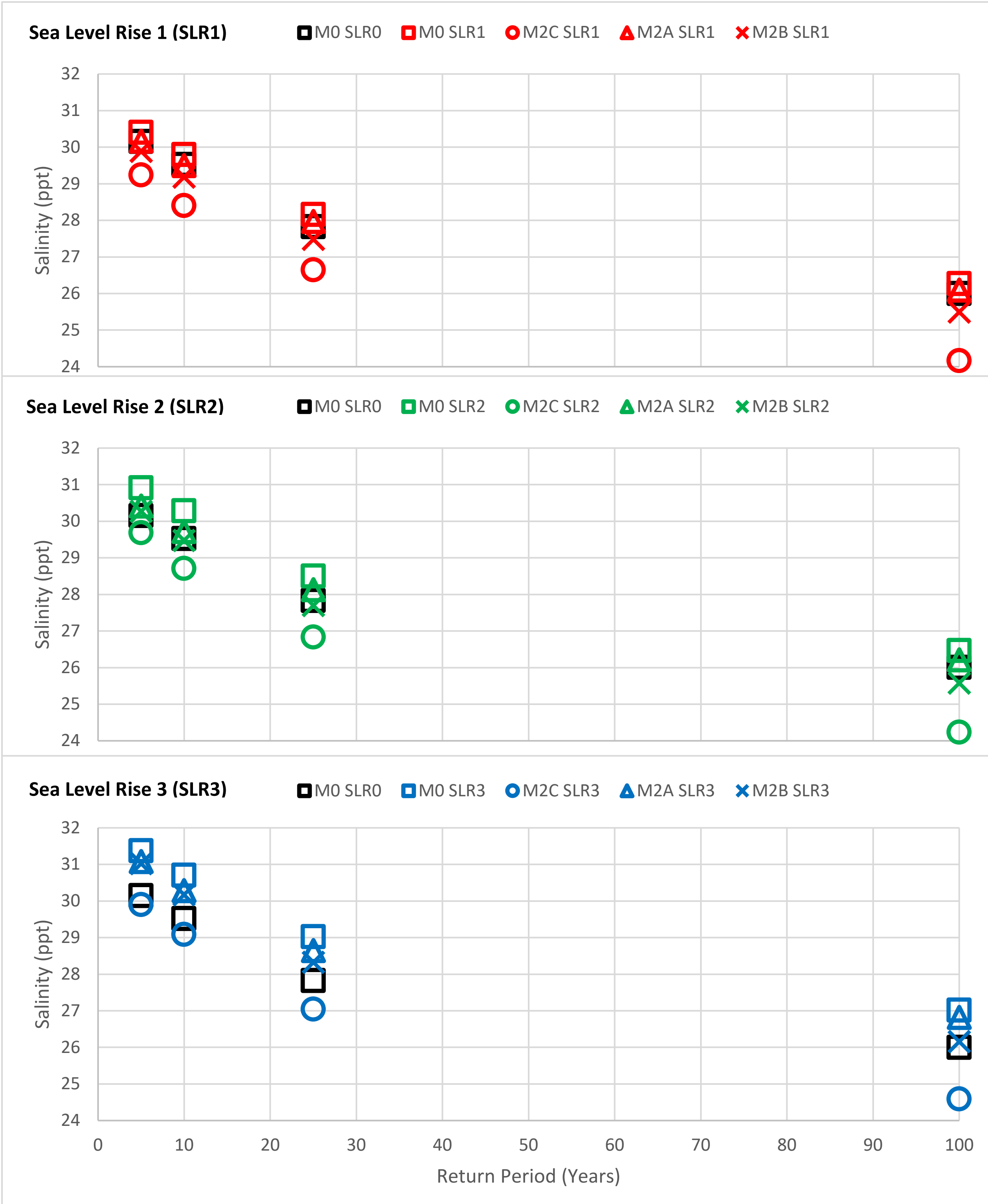

Figure 8-15: Projected Salinity Concentrations at BB09 for All Modeling Scenarios

8.3.2 Chlorophyll a

Chlorophyll *a* concentrations are plotted against 13-day cumulative volumes from the S-29 in **Figure 8-16**. At BB09, the coefficient of determination equaled 0.19, indicating that 19% of the variance in chlorophyll *a* concentrations are explained by 13-day cumulative volume discharges. Hence, water volume input from the C-8 is likely a significant (moderate positive) driver of phytoplankton growth near BB09.

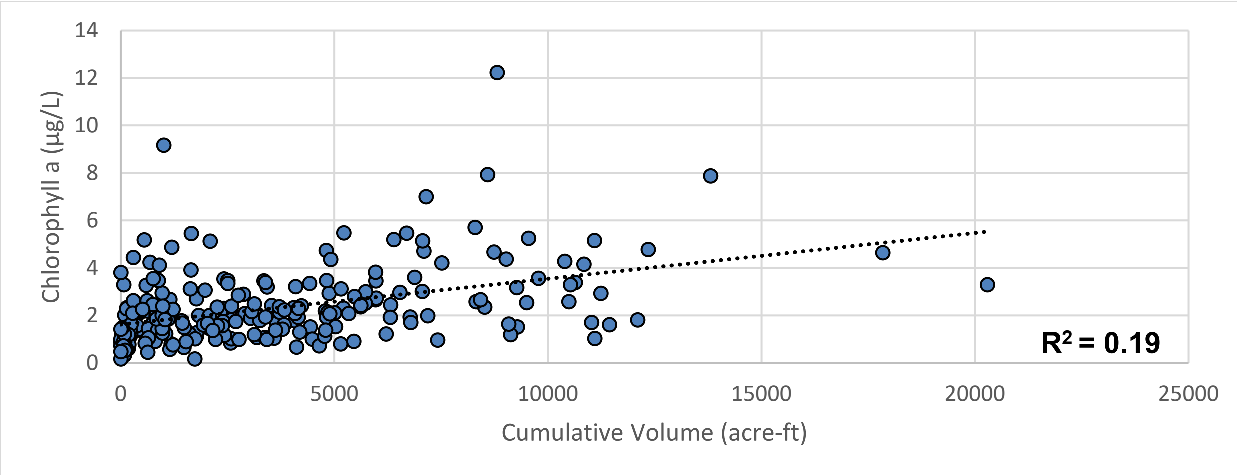

Figure 8-16: Chlorophyll a Concentrations at BB09 against 13-day Cumulative Volumes from the S-28

Figure 8-17 shows projected chlorophyll *a* concentrations at BB09 for the modeling scenarios outlined in **Table 4-1**. Note that M2C scenarios are generally projected to cause higher chlorophyll *a* levels than those without mitigation (M0), especially at higher return periods. For all return periods, M2A scenario projections are equivalent (M2A-SLR1) or less than M0-SLR0. For the 100-year storm, all M2C scenario projections are higher than M0-SLR0. Several scenarios at each SLR are projected to result in chlorophyll *a* concentrations above 4 µg/L (orange dashed line).

For the 5-year storm, M2A scenarios exhibit lower chlorophyll *a* concentrations than the corresponding M2B and M2C scenarios for fixed SLR. M2B scenarios display higher chlorophyll *a* concentrations compared to M0 and M2A, while M2C scenarios show the highest chlorophyll *a* concentrations among all scenarios.

For the 10- and 25-year storm, a similar trend is observed. For the 100-year storm return period, M2A-SLR1 exhibits slightly higher chlorophyll *a* concentrations than M0-SLR0. M2B scenarios display higher chlorophyll *a* concentrations compared to M0 and M2A for fixed SLR, while M2C scenarios show the highest chlorophyll *a* concentrations among all scenarios.

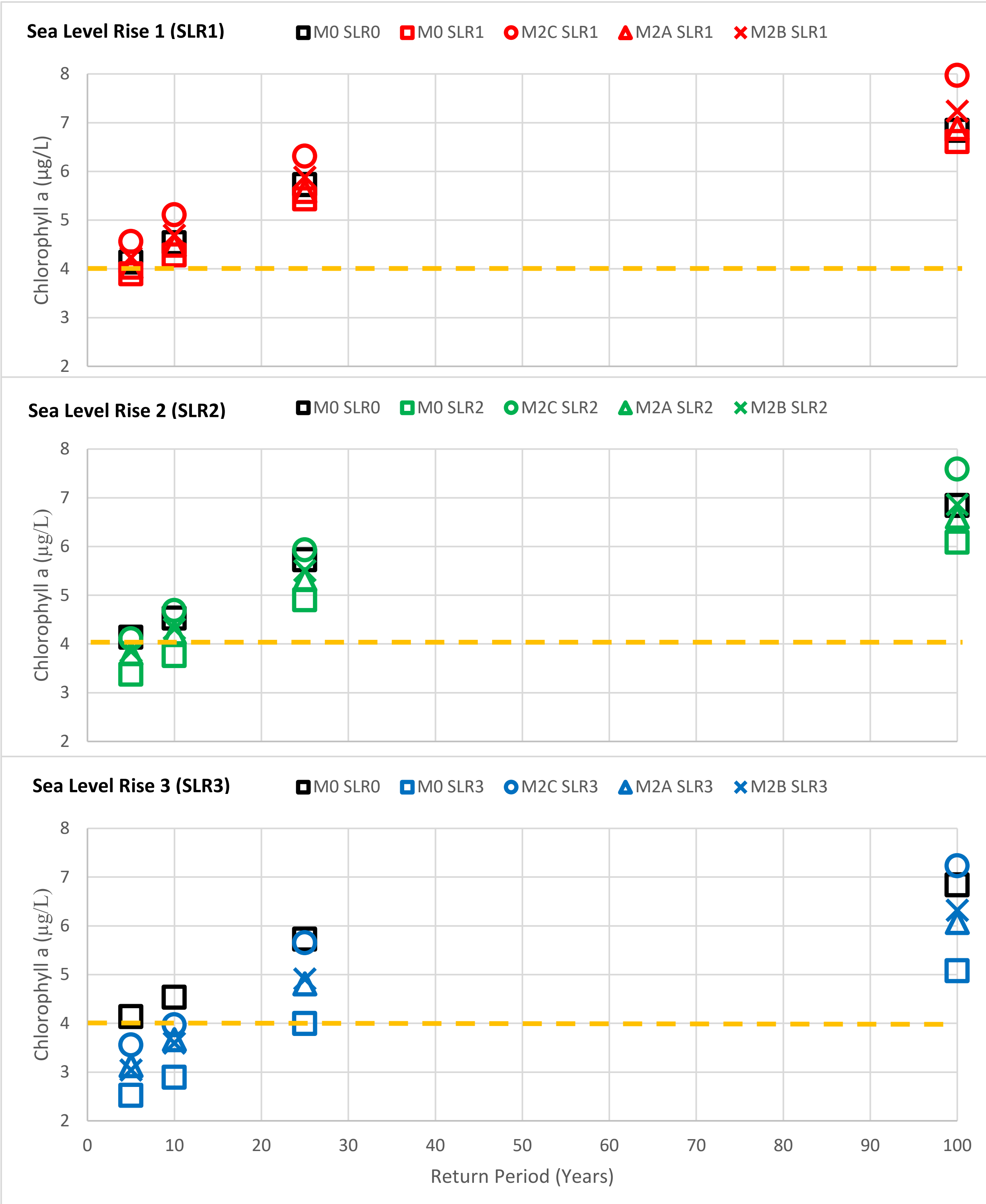

Figure 8-17: Projected Chlorophyll a Concentrations at BB09 for All Modeling Scenarios

8.3.3 Total Nitrogen

Pearson correlation coefficients were not statistically significant for the range of accumulation periods investigated at BB09; therefore, regression analyses were performed between TN concentrations at BS01 and cumulative volume discharge from the S-28. **Figure 8-18** shows the relationship between TN concentrations at BS01 and 15-day cumulative volumes. A coefficient of determination equal to 0.31 was computed, indicating that 31% of the variation in TN concentrations is explained by cumulative volume inputs.

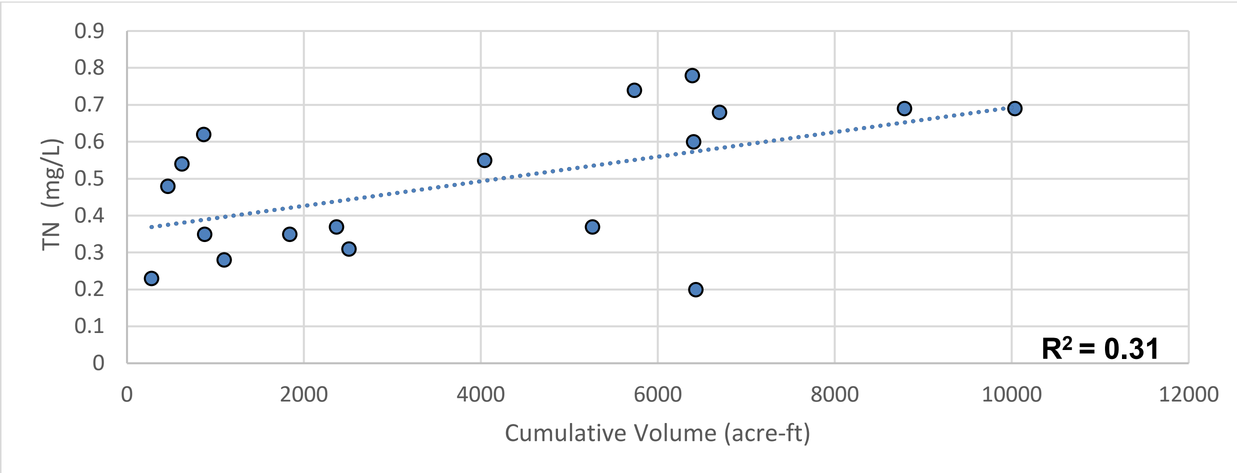

Figure 8-18: TN Concentrations at BS01 against 15-day Cumulative Volumes from the S-28

Figure 8-19 shows projected TN concentrations at BS01 for the modeling scenarios outlined in **Table 4-1**. Note that M2C scenarios are generally projected to result in higher TN concentrations than those without mitigation (M0), especially at higher return periods. In all cases the NNC of 0.3 mg/L is exceeded. Across all return periods, M2A scenario projections are equivalent (M2A-SLR1) or less than M0-SLR0. For the 100-year storm, all M2C scenario projections are higher than M0-SLR0.

For the 5-year storm, M2A scenarios exhibit lower TN concentrations than the corresponding M2B and M2C scenarios for fixed SLR. M2B scenarios display higher TN concentrations compared to M0 and M2A, while M2C scenarios show the highest TN concentrations among all scenarios.

For the 10- and 25-year storm, a similar trend is observed. For the 100-year storm return period, the M2A-SLR1 exhibits slightly higher TN concentrations than M0-SLR0. M2B scenarios display higher TN concentrations compared to M0 and M2A for fixed SLR, while M2C scenarios show the highest TN concentrations among all scenarios.

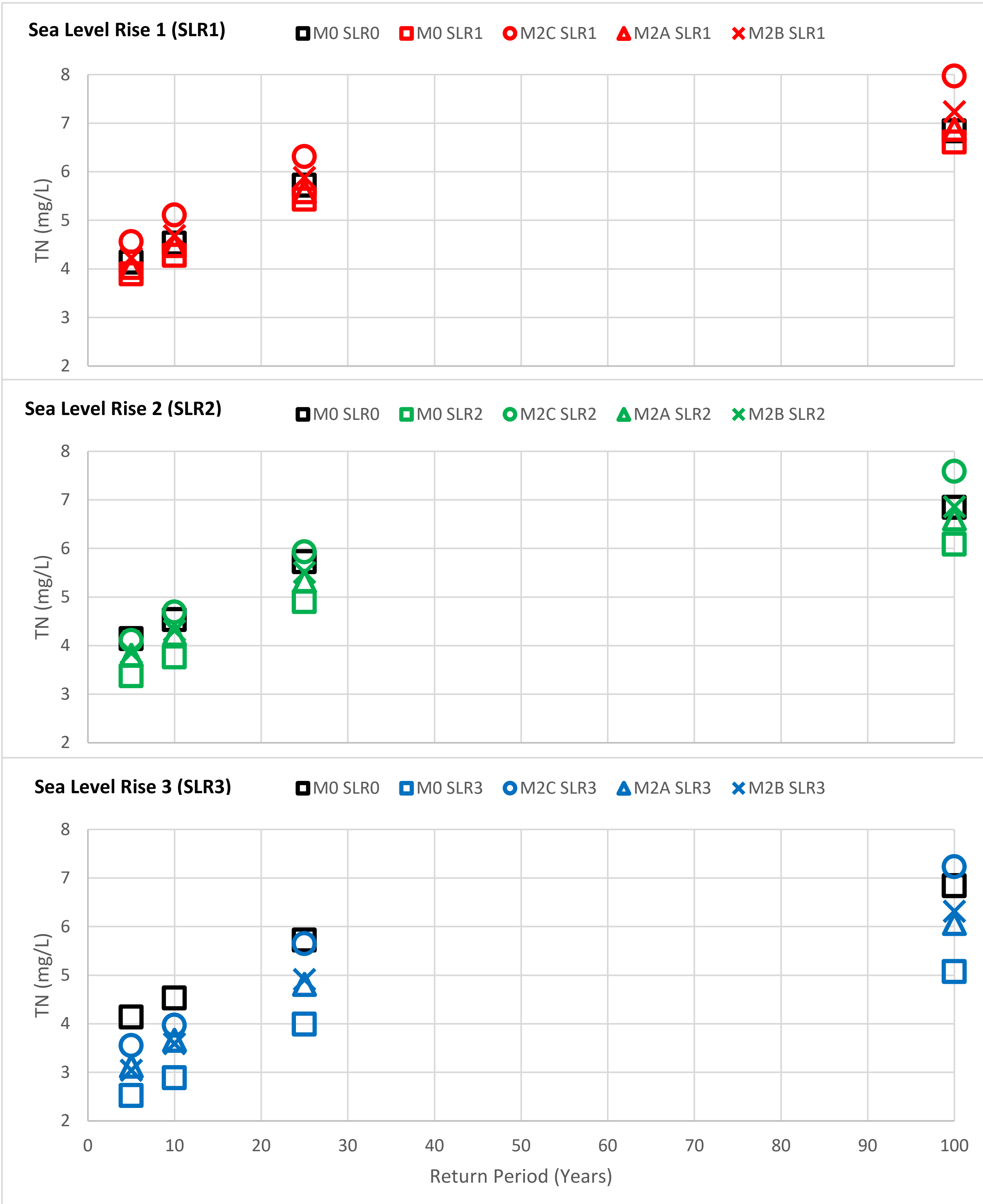

Figure 8-19: Projected TN Concentrations at BS01 for All Modeling Scenarios

8.3.4 Dissolved Oxygen

Figure 8-20 shows the relationship between DO concentrations and 15-day cumulative volumes from the S-28. At BB09, a linear function best fits the data. A coefficient of determination of 0.10 was computed, suggesting that 15-day cumulative volumes account for 10% of the variance in DO concentrations.

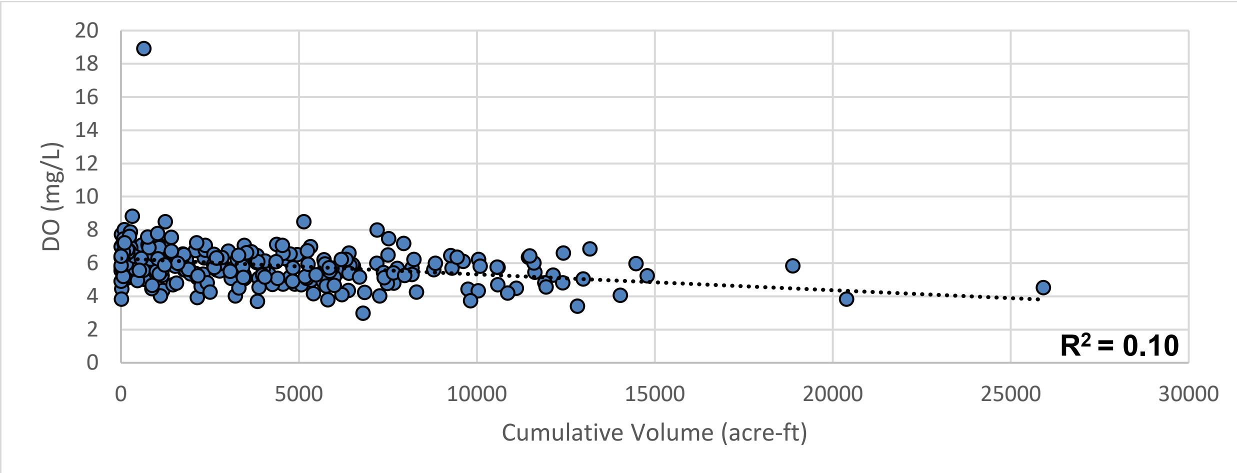

Figure 8-20: DO Concentrations at BB09 against 15-day Cumulative Volumes from the S-28

As presented for BB02, the inverse relationship between DO concentrations and cumulative volume may be due to increased nutrient loadings associated with higher volume discharges at the structures resulting in excessive aquatic plant and algal growth and eventual die-off in North Biscayne Bay. **Figures 8-21** displays the relationship between DO and chlorophyll *a* concentrations measured on the same day at BB09.

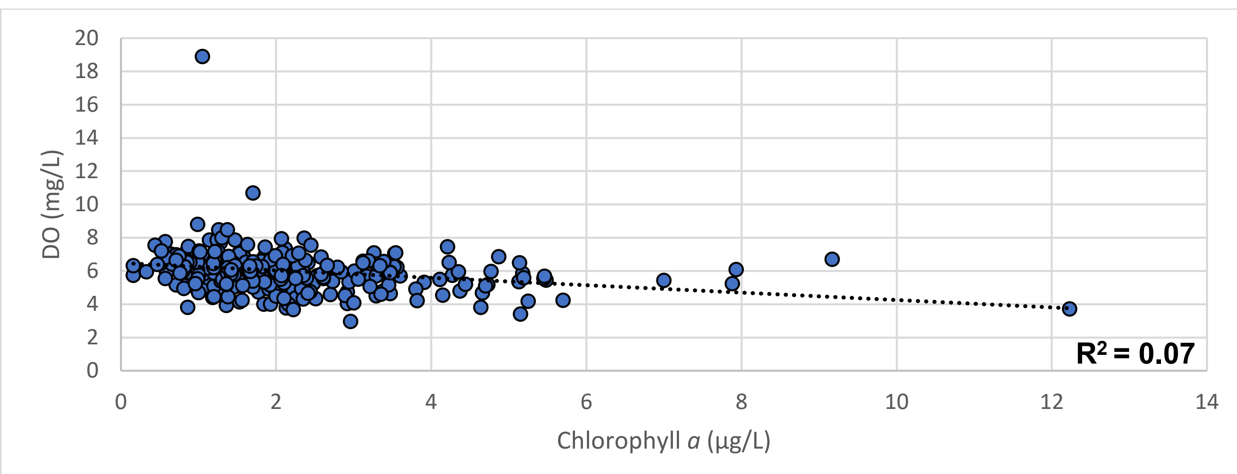

Figure 8-21: DO Concentrations versus Chlorophyll a Concentrations at BB09

A coefficient of determination equal to 0.07 was computed, suggesting that 7% of the variance in DO concentrations is explained by chlorophyll *a*. This corresponds to a Pearson coefficient equal to -0.26, indicating a statistically significant weak negative association between these variables. This indicates that oxygen depletion at BB09 is at least in part influenced by the increased presence of aquatic plants and organisms, given that chlorophyll *a* is an indicator of algal biomass. Other factors, however, are likely to be more significant than chlorophyll *a* in influencing DO concentrations.

Figure 8-22 shows projected DO concentrations at BB09 for the modeling scenarios outlined in **Table 4-1**. At BB09, optimal conditions (green dashed line) are achieved for all scenarios for the 5-year storm, except for M2C-SLR1. Several scenarios are projected to cause stressful conditions (orange dashed line) for the 25- and 100-year storm.

For the 5-year storm, M2A scenarios exhibit slightly DO salinity concentrations than the corresponding M2B and M2C scenarios for fixed SLR. M2B scenarios display lower DO concentrations compared to M0 and M2A, while M2C scenarios show the lowest DO concentrations among all scenarios for fixed SLR.

For the 10- and 25-year storm, a similar trend is observed. For the 100-year storm return period, the M2A scenarios exhibit equivalent or higher DO concentrations than M0-SLR0. M2B scenarios display lower DO concentrations compared to M0 and M2A, while M2C scenarios show the lowest DO concentrations among all scenarios.

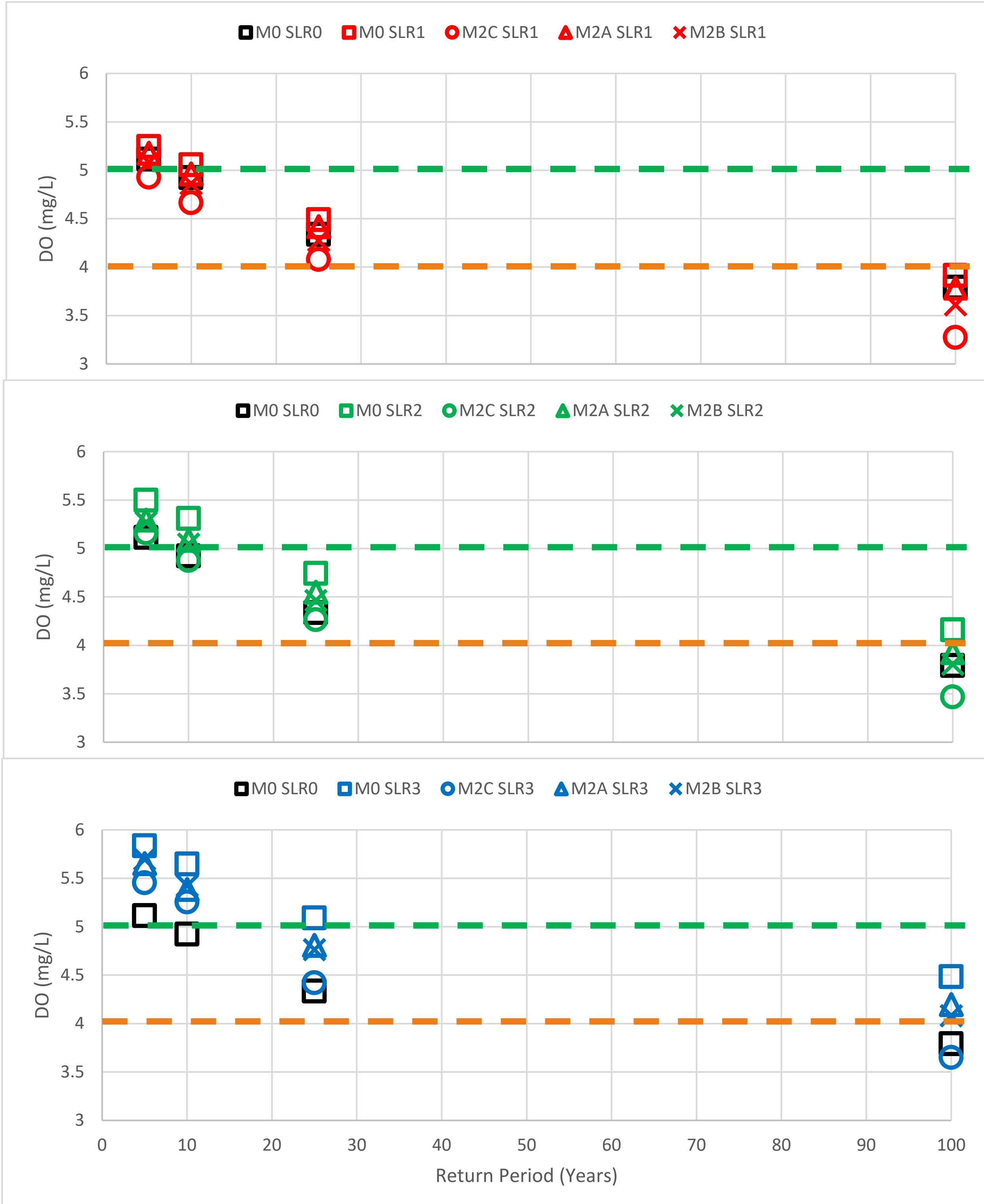

Figure 8-22: Projected DO Concentrations at BB09 for All Modeling Scenarios

8.4 NNB-B (C-8) Cumulative Volume Analyses Conclusions

Sections 8.2 and **8.3** demonstrated the feasibility of establishing useful regression relations between cumulative volume discharges from the C-8 canal and WQ parameter concentrations in the bay as the response variables. **Table 8-4** summarizes the results of the correlation analysis for NNB-A. Refer to **Table 4-2** for descriptions of the strength of correlation and the color-coding key.

Table 8-4: NNB-B Correlation Analysis Results

WQ Variable	Max Pearson r	Max Spearman r	Station ID
Salinity	-0.29	-0.46	BB09
Chlorophyll *a*	0.44	0.48	BB09
TN	0.66	0.71	BS01
Dissolved Oxygen	-0.31	-0.39	BB09

Note: Correlation Analyses were conducted only for variables that were determined to be COCs or flagged for further study.

Tables 8-5 to **8-8** summarize the results of the WQ analysis for NNB-B. For each variable and scenario, the percent change in WQ projections relative to existing conditions (M0-SLR0) was computed. Note that values highlighted in green indicate instances of WQ improvements; those in red, WQ degradation; and those in orange are undetermined due to the uncertainty of impacts to the environment. The impact of changes in salinity concentrations on the local ecology, for instance, is not well understood. In addition, if the absolute value of a percentage change was computed to be less than or equal to 2%, the potential impact of the result was considered as undetermined due to statistical uncertainty of the regression.

Legend:

Undetermined
Short Term Negative Impact
Short Term WQ Improvement

Table 8-5: Results for the 5-Year Storm in NNB-B

	Percent Change Relative to Existing Conditions (M0-SLR0)											
Variable	**M0-SLR1**	**M0-SLR2**	**M0-SLR3**	**M2A-SLR1**	**M2A-SLR2**	**M2A-SLR3**	**M2B-SLR1**	**M2B-SLR2**	**M2B-SLR3**	**M2C-SLR1**	**M2C-SLR2**	**M2C-SLR3**
Salinity	0.8	2.5	4.1	0.1	0.9	3.1	-0.9	0.4	2.9	-3.0	-1.6	-0.8
Chlorophyll a	-5.9	-18.4	-39.1	-2.5	-8.2	-24.4	2.2	-6.9	-26.4	10.2	-0.8	-14.1
TN	-5.7	-16.7	-31.4	-2.7	-7.8	-23.4	1.4	-6.8	-25.3	8.1	-2.1	-14.7
DO	2.5	7.5	14.1	1.2	3.5	10.5	-0.6	3.1	11.4	-3.6	0.9	6.6

Table 8-6: Results for the 10-Year Storm in NNB-B

	Percent Change Relative to Existing Conditions (M0-SLR0)											
Variable	**M0-SLR1**	**M0-SLR2**	**M0-SLR3**	**M2A-SLR1**	**M2A-SLR2**	**M2A-SLR3**	**M2B-SLR1**	**M2B-SLR2**	**M2B-SLR3**	**M2C-SLR1**	**M2C-SLR2**	**M2C-SLR3**
Salinity	0.9	2.6	4.0	-0.1	0.7	2.6	-1.2	-0.2	2.2	-3.8	-2.8	-1.5
Chlorophyll a	-5.5	-17.0	-36.2	-1.0	-6.6	-19.1	3.5	-4.8	-20.6	12.8	3.4	-12.4
TN	-5.3	-15.5	-29.1	-1.5	-6.5	-18.6	2.5	-5.0	-20.2	10.4	1.9	-13.4
DO	2.7	7.9	14.7	0.8	3.3	9.4	-1.3	2.5	10.2	-5.3	-0.9	6.7

Table 8-7: Summary of Results for the 25-Year Storm in NNB-B

Variable	Percent Change Relative to Existing Conditions (M0-SLR0)											
	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
Salinity	1.2	2.4	4.3	0.5	1.1	3.0	-1.2	-0.5	1.8	-4.2	-3.6	-2.8
Chlorophyll a	-5.1	-14.3	-30.2	-2.4	-7.0	-16.0	2.8	-3.8	-14.2	10.2	3.6	-1.3
TN	-4.9	-13.2	-24.6	-2.7	-7.0	-15.4	2.0	-4.2	-13.9	8.4	2.4	-2.8
DO	3.5	9.4	17.4	1.9	4.9	10.9	-1.4	2.9	9.8	-5.9	-1.7	2.0

Table 8-8: Summary of Results for the 100-Year Storm in NNB-B

Variable	Percent Change Relative to Existing Conditions (M0-SLR0)											
	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
Salinity	1.0	1.8	3.9	0.4	0.8	3.2	-1.9	-1.6	0.6	-7.1	-6.8	-5.4
Chlorophyll a	-3.4	-11.0	-25.8	0.6	-3.4	-11.3	5.8	0.3	-7.6	16.5	10.9	5.7
TN	-3.4	-10.2	-19.2	0.2	-3.7	-11.2	5.0	-0.4	-8.0	14.3	9.0	3.9
DO	3.2	9.7	18.3	-0.2	3.5	10.7	-4.7	0.4	7.7	-13.7	-8.6	-3.7

The following summarizes observations from **Tables 8-5** to **8-8**.

- Compared to M0-SLR0, the M2A, M2B, and M2C scenarios exhibit differences in water quality variable outcomes (salinity, chlorophyll *a*, TN, and DO).

Salinity

- Compared to M0-SLR0, the M2A, M2B, and M2C scenarios exhibit decreases in salinity, with the largest decrease observed in M2C-SLR1 during the 100-year storm return period.
- Salinity increases with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

Chlorophyll *a*

- The M2C-SLR1 scenario during the 100-year storm return period shows the largest increase in chlorophyll *a*, which is likely to cause short term negative impacts to chlorophyll *a* for all storm periods.
- Of the mitigation strategies, M2B-SLR3 scenario during the 5-year storm return period shows the largest decrease in chlorophyll *a,* which indicates the largest WQ benefit.
- Chlorophyll *a* concentrations decrease with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

Total Nitrogen

- The M2C-SLR1 scenario during the 100-year storm return period shows the largest increase in TN, which is likely to cause short term negative impacts to chlorophyll *a* for all storm periods.
- Of the mitigation strategies, M2B-SLR3 scenario during the 5-year storm return period shows the largest decrease in TN*,* which indicates the largest WQ benefit.
- TN concentrations decrease with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

Dissolved Oxygen

- The M2C-SLR1 scenario during the 100-year storm return period shows the largest decrease in DO, which is likely to cause short term negative impacts to DO for all storm periods.
- Of the mitigation strategies, M2B-SLR3 scenario during the 5-year storm return period shows the largest increase in DO*,* which indicates the largest WQ benefit.
- DO concentrations increase with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

Generally, the M2C scenarios are associated with more frequent short term negative or uncertain impacts, while M2A scenarios are associated with less frequent negative impacts. However, specific trends may vary depending on the variable and sea level rise scenario being considered.

9.0 MITIGATION SCENARIO IMPACTS ON MARINE LIFE AND SEAGRASS

Major ecosystems present in Biscayne Bay include mangrove forests, tidal marshes, seagrass meadows and macroalgae, oyster bars, hardbottom habitats, and softbottom habitats. The species of seagrass that populate the bay include: turtlegrass (*Thalassia testudinum*), shoal grass (*Halodule wrightii*), manatee grass (*Syringodium filiforme*), paddlegrass (*Halophila decipiens*), stargrass (*Halophila englemanii*), Johnson's Seagrass (*Halophila johnsonii*), and wigeon grass (*Ruppia maritima*). NNB-A is characterized by sparse seagrass (of which turtle grass is dominant). Shoal and manatee seagrass characterize the distribution of seagrasses within NNB-B. Other marine species in the bay include caridian shrimp, penaeid shrimp, crabs, clams, snails, and fish (BFA, 2004).

North Biscayne Bay is a critical component of the local ecosystem, is designated as Critical Habitat for the manatee by the United States Fish and Wildlife Service (USFWS), and has been identified as USFWS Consultation Areas for the American crocodile, piping plover, and Atlantic Coastal Plant. It is also designated as Essential Fish Habitat (EFH) by the National Oceanic and Atmospheric Administration (NOAA) for several important species including Snapper, Grouper, Spiny Lobster, Corals, Skipjack Tuna, Sailfish, and 10 species of sharks. The area's corals, coral reefs, and hard bottom habitats are identified as NOAA Habitat Areas of Particular Concern (HAPC) for Snapper, Grouper, and Penaeid Shrimp.

Oyster bars comprised of the American oyster (*Crassostrea virginica*), Black drum oysters (*Pogamias cromis*), and red drum oysters (*Sciaenops occelatus*) inhabited NNB-A until the construction of Haulover Cut, which is a man-made channel connecting Biscayne Bay and the Atlantic Ocean. It was constructed in 1925 to improve navigation and increase water flow between the two bodies of water. The construction of the Haulover Cut had significant impacts on the oyster habitats in the surrounding area. Before its construction, oyster reefs were abundant in Biscayne Bay and provided important habitat and food for a variety of marine organisms. Its construction altered the natural flow of water in the Bay, leading to changes in salinity levels and increased sedimentation. These changes, along with other factors such as pollution and over-harvesting, contributed to the decline of oyster reefs in the area.

Oyster reefs currently exist primarily at the mouth of the Oleta River. The health of oysters in the bay depends on salinity fluctuations, and changes in freshwater flow to the bay have inhibited oyster reef formation (BFA, 2004). Salinities below 15 ppt must be attained at some level of frequency for the formation of oyster beds. These low salinities protect oysters from gastropods, starfish, and other predators acclimated to more saline waters. Note that oyster beds at the mouths of canals/rivers can act as filters and nutrient sinks, and the disappearance of oysters in NNB-A may be a contributor to increased nutrient loads to the bay.

The installation of the canals that deliver freshwater to the bay altered the natural salinity gradient, thereby disturbing the habitat of species local to the estuary. Freshwater inputs as a result assumed a pulsed nature, which caused high variations in salinity concentrations at short time scales near the mouths of the canals. Alterations to timing, volume, and the concentration of freshwater discharges have undermined the viability of ecosystems in the bay (Caccia and Boyer, 2007).

A 2004 report by BFA Environmental Consultants (BFA) identified various indicator species for each of the sub-regions of Biscayne Bay to monitor ecological health as part of the Minimum Flows and Levels rule development process. In the following sections, each sub-region of the bay and their associated indicator species will be investigated.

9.1 NNB-A

In NNB-A, the American Oyster, the West Indian Manatee, and Johnson's Seagrass were identified as indicator species. BFA (2004) notes that no general mapping exists of the oyster beds in this area and that the state of their health is unknown. Oyster habitat is found at the mouth of the Snake Creek Canal, and these oysters prefer salinities ranging between 5 to 20 ppt. Uncertainty surrounds the potential impacts of freshwater flows on the health of these species. Seagrass coverage in this sub-region is mostly patchy/discontinuous. No seagrass has been reported in Maude Lake, while Dumbfounding Bay contains primarily patchy seagrass. See **Figure 9-1** for a schematic of the seagrass habitat in NNB-A. The following table lists the indicator species for NNB-A and their salinity/habitat requirements.

Table 9-1: Indicator Species of NNB-A and their Characteristics (BFA, 2004)

Species	Salinity Range (ppt)		Substrate/Habitat	Characteristics
	Juvenile	Adult		
American Oyster	15 – 26	14 – 30	Solid substrate	Tolerant of varying salinity, temperature, and WQ conditions
West Indian Manatee	0 – 35+		Open water, seagrasses	Inhabit fresh water, estuaries & marine environments. In Biscayne Bay, combination of warm water and fresh water in a predominately marine system causes aggregations
Johnson's Seagrass	15 - 43		Soft sand/mud	Submerged, herbaceous. Distribution only north of Virginia Key

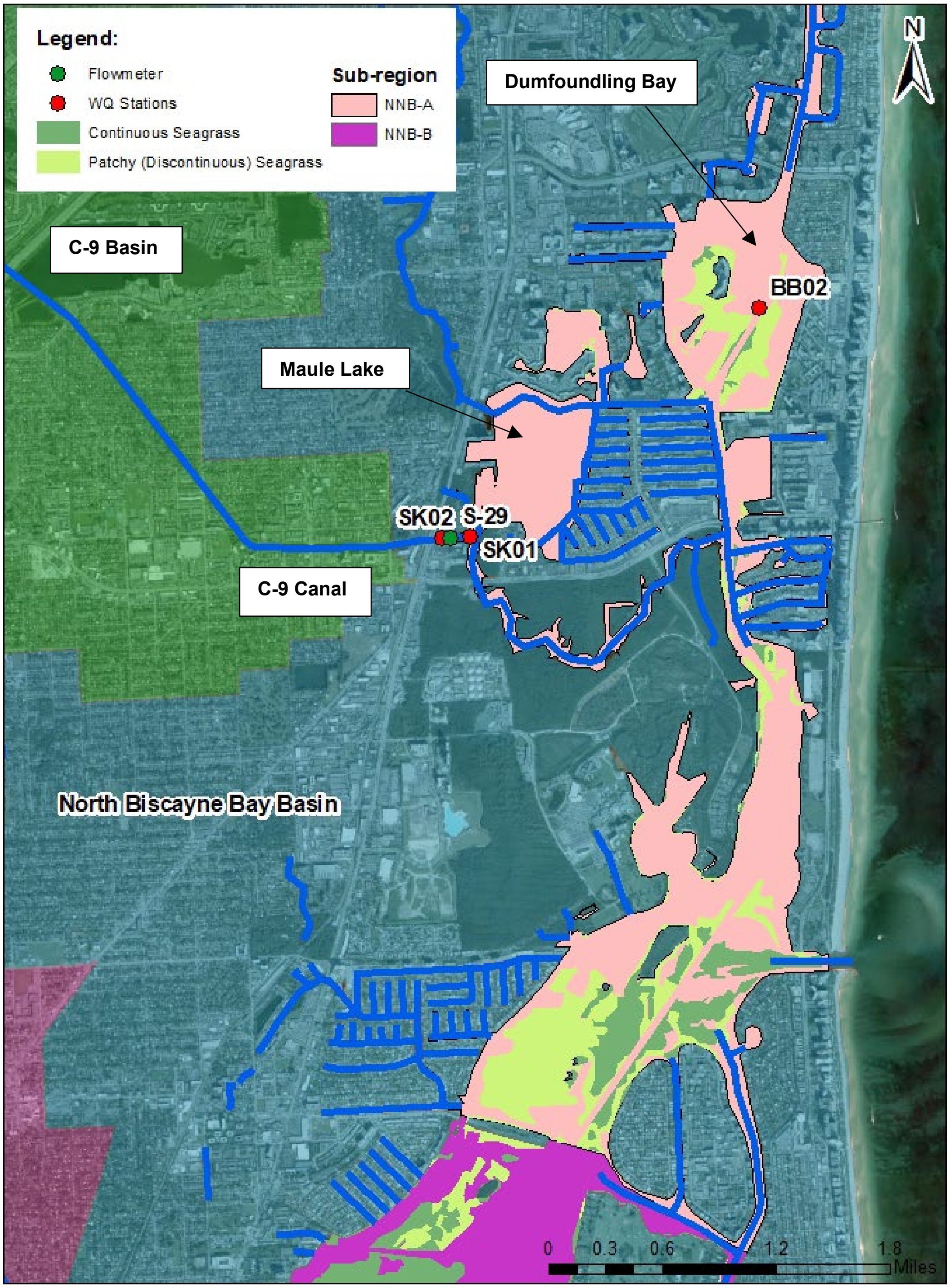

Figure 9-1: Seagrass Habitat in NNB-A (as of 2022)

9.1.1 Salinity Considerations

Salinity concentrations measured at BB02 are shown in **Figure 9-2** and plotted against the upper and lower limit salinity preferences of the American Oyster (AO) for both juveniles (red lines) and adults (green lines). Average salinities at BB02 range between 21 and 33 ppt. Note that the upper bounds for both AO juveniles and adults have been frequently exceeded. For the 25- and 100-year return period storms, salinity projections begin to violate the lower bound for the AO. Mitigation scenario projections do not violate the upper thresholds (**Figure 7-16**).

The West Indian Manatee tolerates a wide range of salinities from fresh to marine waters and proposed mitigation scenarios would not negatively impact this species. The lower threshold for Johnson's seagrass has been crossed at times in the empirical data, and salinity projections show that for the 25-year and 100-year design storms, this threshold may continue to be crossed, depending on the scenario (**Figure 7-16**).

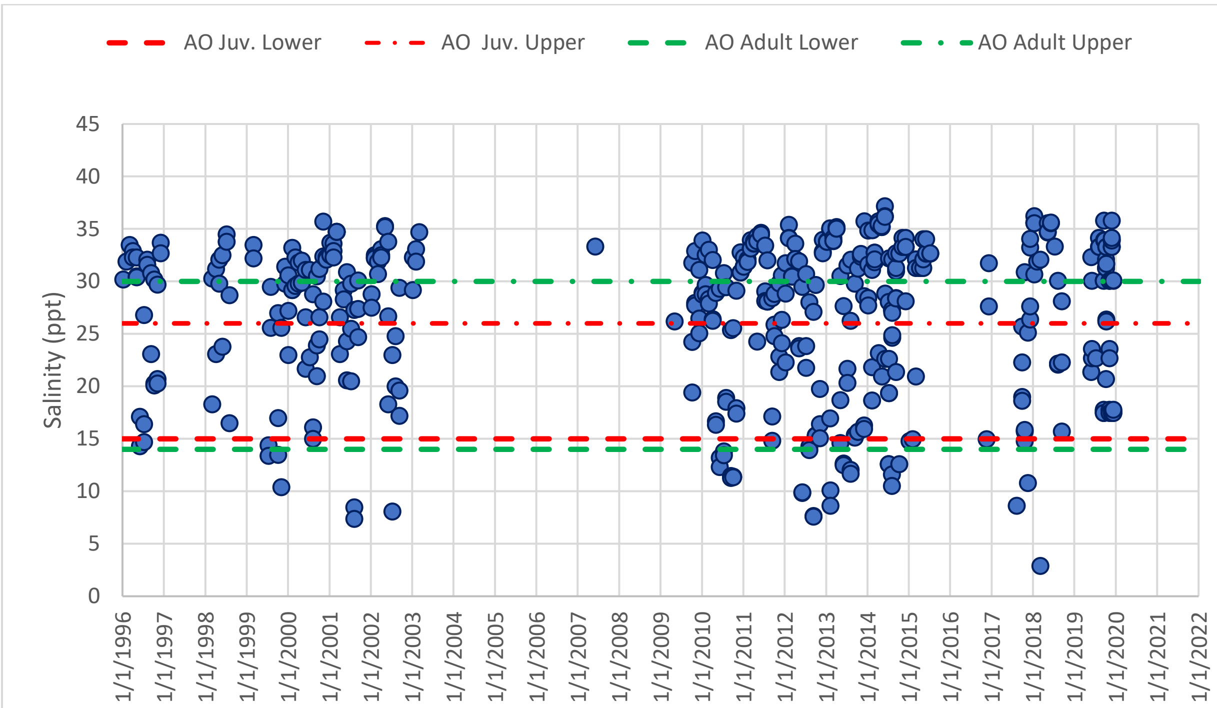

Figure 9-2: Salinity Concentrations at BB02 with 100-year Storm Mitigation Scenario Projection Range (Orange Box)

Table 9-2 reports the salinity concentration estimates at BB02. Cells highlighted in orange represent values that violate the salinity tolerances of at least one indicator species presented in **Table 9-1**. Note that the 5- and 10-year storms for M2A-SLR1 and M2B-SLR1 show an improvement compared to existing conditions. The M2C scenarios for the 25- and 100-year storms are projected to lead to more frequent violations of the salinity threshold.

Table 9-2: BB02 Salinity Concentration Estimates (ppt)

BB02 Salinity Concentration Estimates (ppt)										
Storm Return Period	M0-SLR0	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**15.7**	**18.0**	**20.1**	**23.7**	**17.2**	**19.2**	**23.2**	**15.5**	**17.8**	**22.3**
10 Year	**13.5**	**15.9**	**17.8**	**21.0**	**14.7**	**16.6**	**20.4**	**12.7**	**15.1**	**19.1**
25 Year	**9.6**	**11.9**	**13.8**	**16.4**	**10.6**	**12.4**	**15.3**	**7.9**	**10.1**	**13.3**
100 Year	**3.9**	**6.3**	**8.4**	**10.9**	**5.1**	**6.7**	**9.4**	**1.6**	**3.5**	**6.4**

9.1.2 Nutrient Loading Considerations

Empirical TN mass fluxes were evaluated using flow data from structure S-29 and concentration data from WQ station SK02 and normalized using the NNB-A sub-region area (approximately 1,092 ha). The average normalized TN loading for the C-9 canal equaled 432.4 kg N/yr/ha for the period of record (1/6/1997 to 4/4/2022). **Figure 9-3** shows historical normalized TN mass loadings for this period.

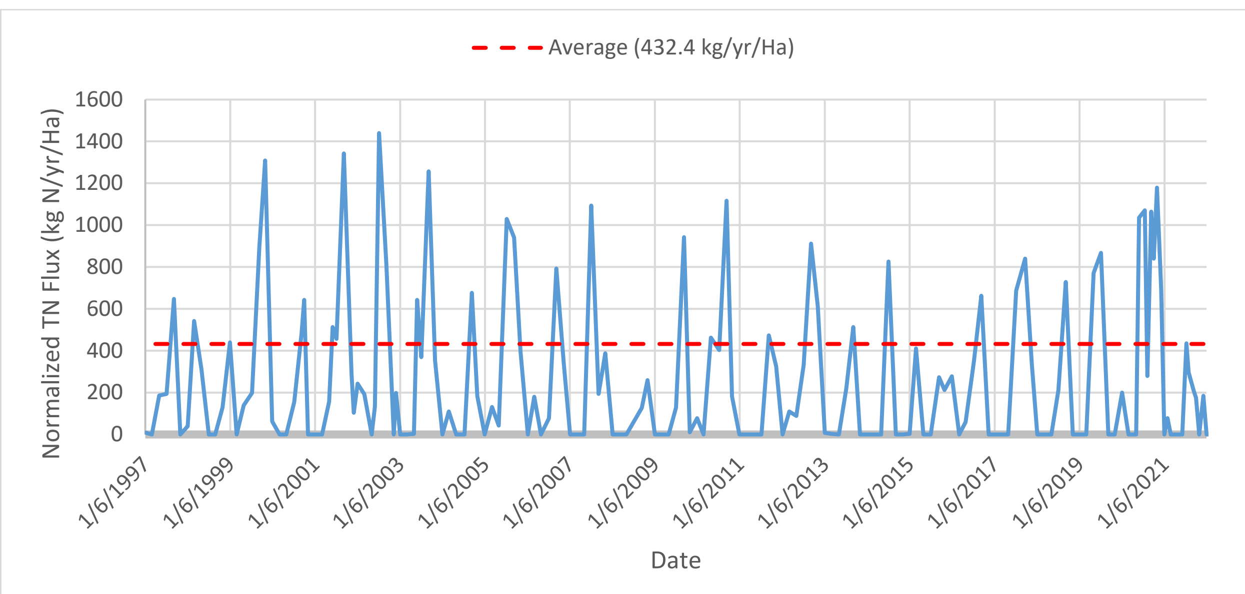

Figure 9-3: Empirical TN Mass Fluxes into NNB-A (1/6/1997 – 4/4/2022)

Steward and Green (2007) related the percent loss of seagrass to nitrogen loading rates normalized to estuary areas for several estuaries globally, which is shown in **Figure 9-4**.

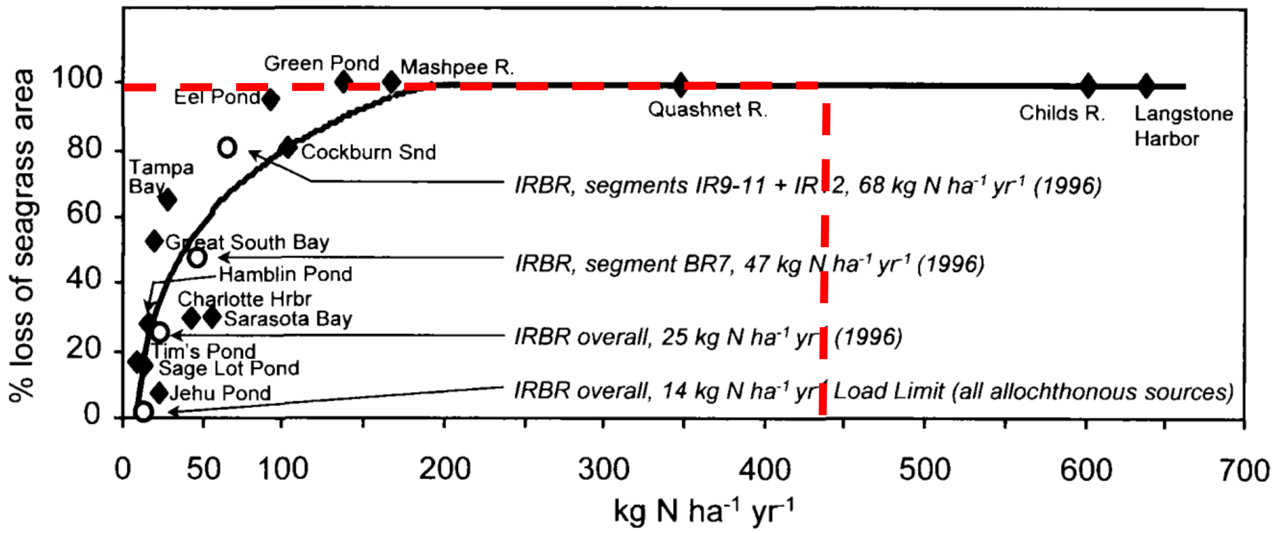

Figure 9-4: Best-fit Line for Percentage Seagrass Loss versus Normalized TN Loading Rates for Several Estuaries Applied to the C-9 (Steward and Green, 2007)

The dotted red lines on **Figure 9-4** indicate that a TN loading rate of 432.4 kg N/yr/ha corresponds to a 100% decrease in seagrass. TN mass loadings may therefore account for the complete disappearance of seagrass from Maude Lake (see **Figure 9-1**) and the patchiness of seagrass in Dumfoundling Bay. The presence of seagrass in the remainder of NNB-A may be due to the presence of a mangrove forest surrounding the Oleta River, which likely functions as a sink for TN as flow travels from the C-9 canal to the bay.

Work by Driscolla et al. (2003) indicates that a TN load limit of less than 20 kg/yr/ha is required to recover and maintain lost seagrass beds. In the C-9 canal, this would require a 95% decrease in the average TN mass loading rate to the bay. Valeria and Cole (2002) found that significant losses in seagrass coverage occur when TN loads exceed 30 kg/yr/ha in several estuaries worldwide. This corresponds to a 93% reduction in TN loading from the average in NNB-A.

9.2 NNB-B

For NBB-B, spotted seatrout (*Cynoscion nebulosus*) and manatee grass were identified by BFA (2004) as indicator species where the spawning of seatrout depends on the stability of low salinity areas and manatee grass appears to grow in areas with stable salinities and tolerates lower levels of light (i.e., high turbidity). (See **Table 9-3**.) This region of the bay is characterized by more dense continuous stretches of seagrass in the western portion. Note that station BB09 lies adjacent to the channel, surrounded by the largest seagrass beds growing in NNB-B (see **Figure 9-6**).

Table 9-3: Indicator Species of NNB-B and their Characteristics (BFA, 2004)

Species	Salinity Range (ppt)		Substrate/Habitat	Characteristics
	Juvenile	Adult		
Spotted Seatrout	1 – 25	5 – 37	Estuarine waters and seagrass	Prefers seagrass habitats
Manatee Grass	5 – 45		Soft sand/mud	Submerged, herbaceous.

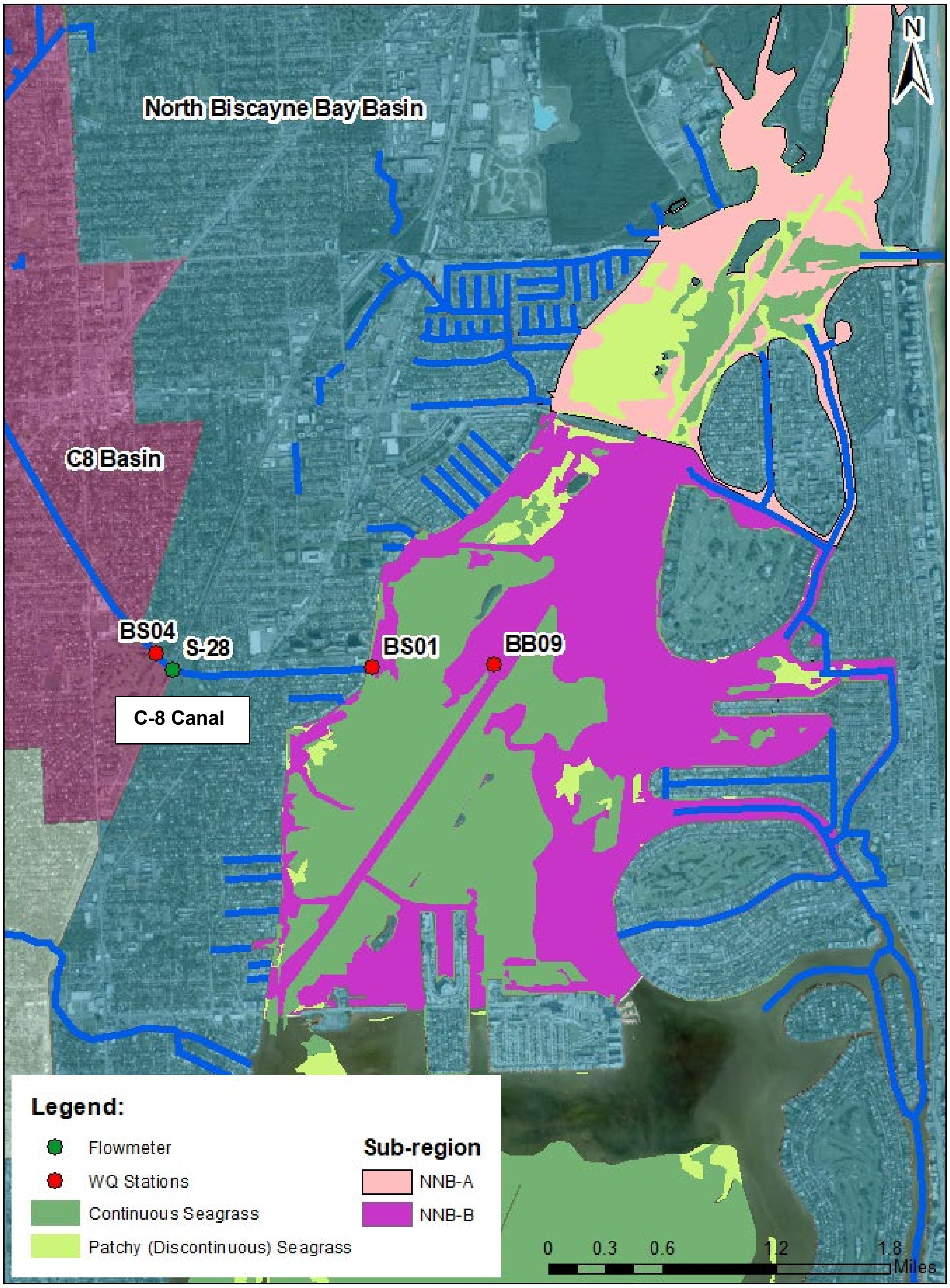

Figure 9-5: Seagrass Habitat in NNB-B (as of 2022)

9.2.1 Salinity Considerations

Salinity concentrations measured at BB09 are shown in **Figure 9-6** and plotted against the upper and lower limit salinity preferences of spotted seatrout (SS) for both juveniles (red line) and adults (green line). It is apparent that salinity concentrations lie within the tolerance range of adult SS with few exceptions, but that concentrations often exceed the tolerance range of juvenile SS. It may be that juvenile SS exist closer to the mouth of C-8 canal, where salinities are generally lower and are influenced more by freshwater flow. The orange box in **Figure 9-6** represents the range of salinity concentrations projected for the 100-year storm across all M0, M2A, M2B, and M2C scenarios (all SLR).

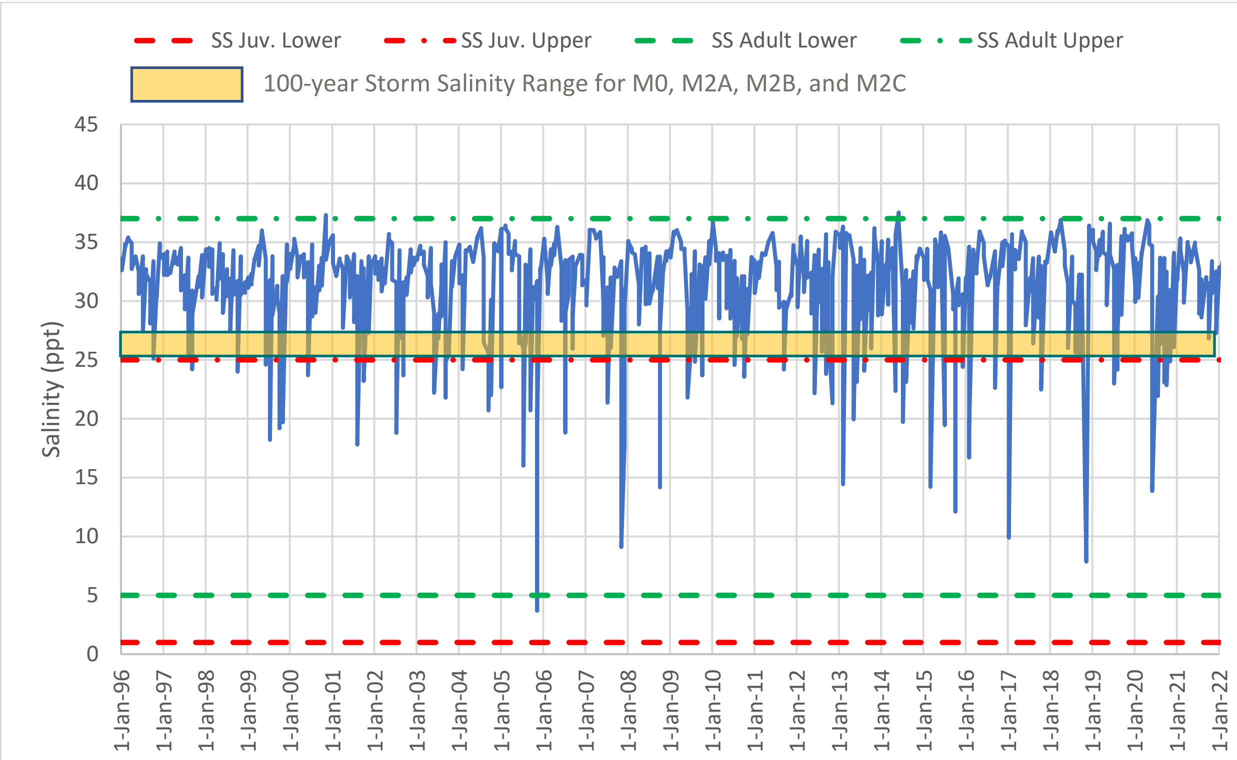

Figure 9-6: Salinity Concentrations at BB09 (1/1/1996 – 1/1/2022) with 100-year Storm Mitigation Scenario Projection Range (Orange Box)

From **Figure 8-15**, the impact to salinity from even the worst-case mitigation scenario (100-year M2-SLR1) is on the order of 25 ppt, which is within the range of tolerances for adult SS and just touches the upper bound for juveniles.

Given that manatee grass is tolerant to a wide range of salinities (5 – 45 ppt), changes in absolute salinity levels likely do not affect manatee grass coverage as much as other factors such as nutrient loadings, chlorophyll *a* concentrations, and temperature. BFA (2004) however notes uncertainties regarding the impact of freshwater flows on manatee grass health. For instance, the effects on manatee grass from salinity pulses and large variations in salinity concentrations at short time scales have not been investigated.

9.2.2 Nutrient Loading Considerations

TN mass loadings were evaluated using flow data from structure S-28 and concentration data from WQ station BS04 and normalized using the NNB-B sub-region area (approximately 1,463 ha). The average normalized TN loading for the C-8 canal equaled 115.3 kg N/yr/ha for the period of record (1/6/1997 to 4/4/2022). **Figure 9-7** shows historical normalized TN mass loadings for this period.

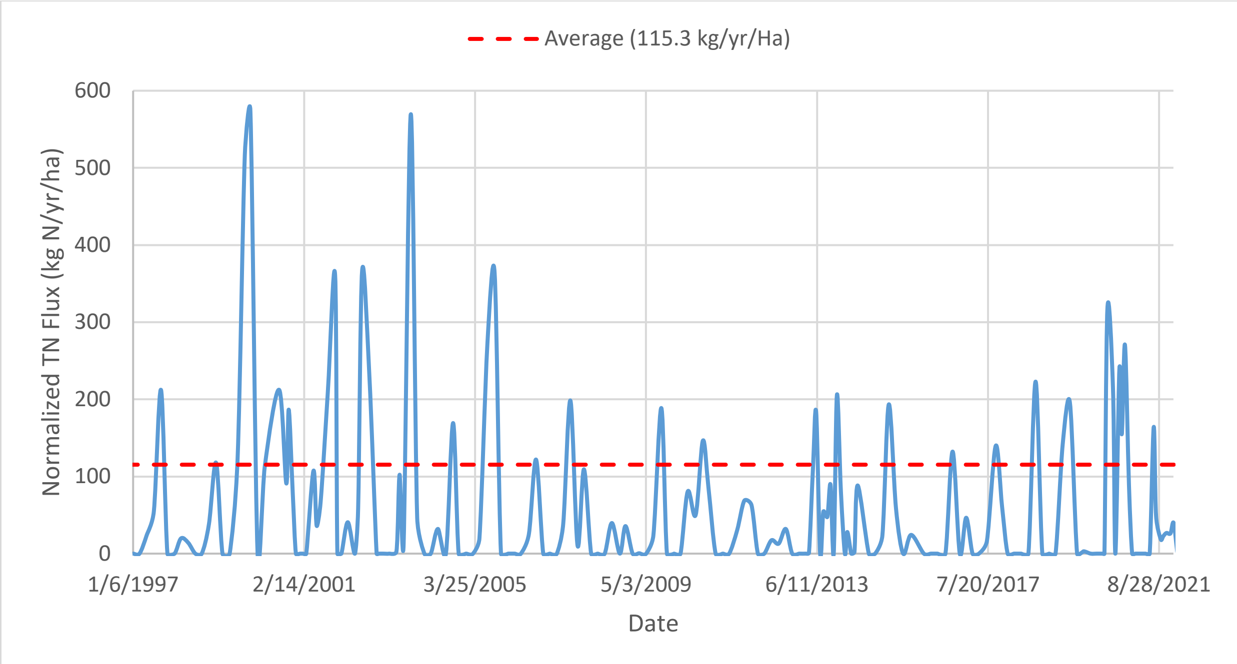

Figure 9-7: Empirical TN Mass Fluxes into NNB-B (1/6/1997 – 4/4/2022)

A 2019 report produced by MDC titled 'Report on the Findings of the County's Study on the Decline of Seagrass and Hardbottom Habitat in Biscayne Bay' (hereon referred to as the 2019 MDC Seagrass Report) reported that there has occurred an approximately 89.61% decrease in seagrass coverage in the 79th Street Basin (i.e., the NNB-B sub-region). TN mass fluxes into NNB-B were applied to the following figure taken from Steward and Green (2007) (see **Section 9.1.2**).

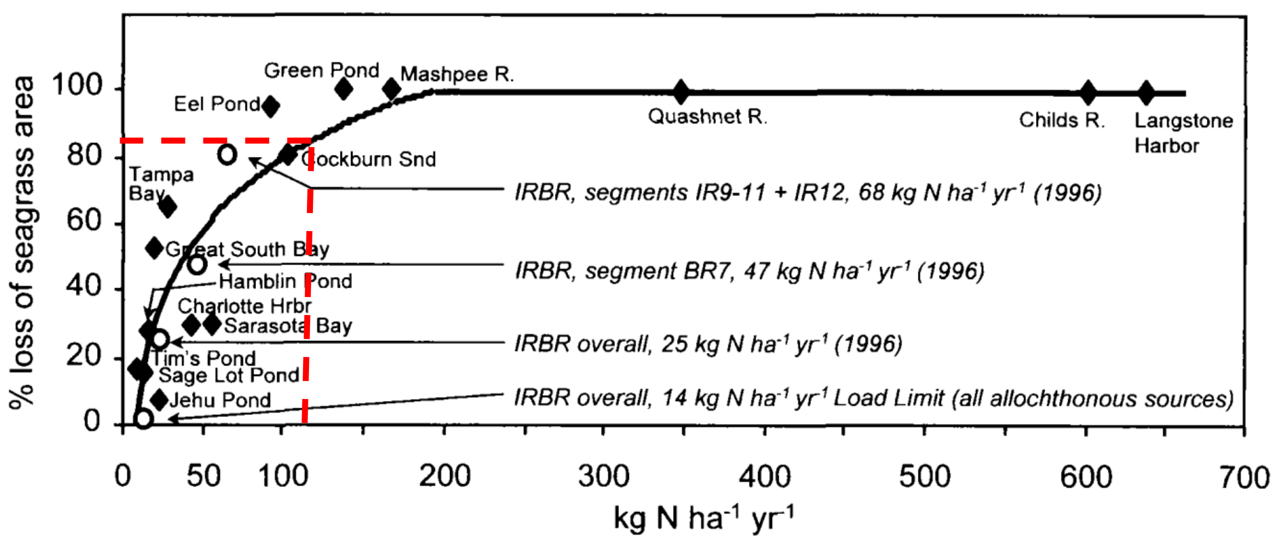

Figure 9-8: Best-fit Line for Percentage Seagrass Loss versus Normalized TN Loading Rates for Several Estuaries Applied to the C-8 (Steward and Green, 2007)

The dotted red lines on **Figure 9-8** indicate that a TN loading rate of 115.3 kg N/yr/Ha (x-axis) corresponds to approximately an 85% decrease in seagrass coverage (y-axis). This value is close to the historically observed value of 89.61%, suggesting that TN loadings from the C-8 significantly influence seagrass coverage in NNB-B. **Figure 9-8** further demonstrates that TN loadings from the C-8 are highly variable and frequently exceed the average. Applying the work by Driscolla et al. (2003) and Valeria and Cole (2002) to the C-8 led to the estimation that a 73 to 82% reduction in average TN mass fluxes is required to recover lost seagrass beds in NNB-B.

10.0 CONCLUSIONS

This memorandum comprised an analysis of potential WQ impacts to the regions NNB-A (associated with the C-9 basin) and NNB-B (associated with the C-8 basin) of North Biscayne Bay using the proposed implementation of mitigation scenarios described in **Table 4-1**. To this end, WQ data was gathered from databases affiliated with MDC, the SFWMD, and other sources. This data was utilized to identify COCs, for which time series plots were constructed and correlation/regression analyses were performed. A total of eighty (80) scenarios were assessed for both the C-8 and C-9 canals based on the results of the regression analyses. This assessment suggested statistically significant changes in COCs concentrations resulting from future conditions (i.e., combinations of sea level rise and mitigation projects). Potential environmental impacts pertaining to marine life and seagrass were estimated using established relations between contaminant concentrations/loads and marine life degradation.

The following are the conclusions of these analyses. Note that the terms 'positive' and 'negative' in the context of the correlation/regression analysis results refer to the direction of correlation (proportional or inversely proportional, respectively) and do not refer to WQ benefits or negative impacts. Positive/negative impacts are addressed in bullets 3 and 4 of **Sections 10.1** and **10.2**.

10.1 C-9 Basin (NNB-A)

- COCs identified:
    - Chlorophyll *a*, TN, DO, and copper. In addition, salinity, TP, and turbidity were identified for further analysis.
- Correlation/regression analyses results:
    - Salinity
        - A **moderate negative** association exists between cumulative volume inputs from the S-29 and salinity concentrations at BB02.
    - Chlorophyll *a*
        - A **moderate positive** association exists between cumulative volume inputs from the S-29 and chlorophyll *a* concentrations at BB02.
    - TN
        - **No statistically significant** association exists between cumulative volume inputs from the S-29 and TN concentrations at BB02.
    - TP
        - **No statistically significant** association exists between cumulative volume inputs from the S-29 and TP concentrations at BB02 in the Pearson coefficient. Hence, regression analyses could not be performed.
    - DO
        - A **weak negative** association exists between cumulative volume inputs from the S-29 and DO concentrations at BB02.
    - Turbidity
        - A **weak positive** association exists between cumulative volume inputs from the S-29 and turbidity concentrations at BB02. A regression analysis could not be performed due to the statistically significant accumulation period not matching the modeling data time window.
    - Copper
        - **No statistically significant** association exists between cumulative volume inputs from the S-29 and copper concentrations at BB02.

- WQ Impacts:
  - Cumulative volume discharges from the C-9 were shown to be lower for all scenarios across all return periods compared to existing conditions (M0-SLR0) except for scenario M2C-SLR1 and M2C-SLR2. Hence, WQ conditions may be maintained or improved under most scenarios (**Section 7.4**).
    - M2C scenarios are associated with more frequent short term negative or uncertain impacts, while M2A scenarios are associated with less frequent negative impacts.
- Mitigation scenario impacts to marine life and seagrass were evaluated in **Section 9.0**.
  - The 100-year return period storm for the M2A, M2B, and M2C scenarios is anticipated to violate the salinity tolerances of American Oyster and Johnson's Seagrass, two indicator species for NNB-A. Only scenario M2C-SLR1 is anticipated to lead to lower salinities compared to existing conditions (M0-SLR0). Regarding TN loads, only scenario M2C-SLR1 would result in increased TN loads compared to M0-SLR0 for all return periods.

10.2 C-8 Basin (NNB-B)

- COCs identified:
  - Chlorophyll *a*, TN, TP, DO, and turbidity. In addition, salinity was identified for further analysis.
- Correlation/regression analyses results:
  - Salinity
    - A **<u>weak to moderate negative</u>** association exists between cumulative volume inputs from the S-28 and salinity concentrations at BB09.
  - Chlorophyll *a*
    - A **<u>moderate positive</u>** association exists between cumulative volume inputs from the S-28 and Chlorophyll *a* concentrations at BB09.
  - TN
    - A **<u>moderate to strong positive</u>** association exists between cumulative volume inputs from the S-28 and TN concentrations at BS01.
  - TP
    - Correlation/regression analyses could not be performed due to data deficiencies. See **Appendix B** for further details.
  - DO
    - A **<u>weak negative</u>** association exists between cumulative volume inputs from the S-28 and DO concentrations at BB09.
  - Turbidity
    - **<u>No statistically significant</u>** association exists between cumulative volume inputs from the S-28 and turbidity concentrations at BB09.
- WQ Impacts:
  - Cumulative volume discharges from the C-8 were shown to be higher for M2C scenarios for the 100-year storm compared to existing conditions (M0-SLR0). Hence, short term negative WQ conditions may result from M2C mitigation compared to existing conditions for higher return period storms (**Section 8.4**). For the 100-year storm, scenario M2B-SLR1 all M2C scenarios are projected to result in short term negative WQ conditions.
    - M2C scenarios are associated with more frequent short term negative or uncertain impacts.

- Mitigation scenario impacts to marine life and seagrass were estimated in **Section 9.0**.
  - Projected salinities are not anticipated to violate the tolerances of any NNB-B indicator species. All M2C scenarios may cause higher TN loads for this same return period. For the 10- and 25-year return period storms, only M2C-SLR1 and M2C-SLR2 are anticipated to cause higher TN loads.

References

Alleman, R.W., Bellmund, S.A., Black, D.W., Formati, S.E., Gove, C.A., and Gulick, L.K., 1995. An update of the surface water improvement and management plan for Biscayne Bay. Technical Supporting Document and Appendices, South Florida Water Management District, West Palm Beach, FL.

Avila, C., Varona, G., Pierre, M., Abdelrahman, O., and Monty, J., 2017. "A review of seagrass losses and algal blooms in Biscayne Bay." In Proc., Greater Everglades Ecosystem Restoration. Coral Springs, FL: Greater Everglades Ecosystem restoration.

Brand, L., 1988. Assessment of plankton resources and their environmental interactions in Biscayne Bay, Florida. Metro Dade DERM Technical Rep. No. 88-1. Miami, FL: Rosenstiel School of Marine and Atmospheric Science, Univ. of Miami.

Brand, L., Gottfried, M., Baylon. C., and Romer, N., 1991. "Spatial and temporal distribution of phytoplankton in Biscayne Bay, Florida." Bull. Mar. Sci. 49(1-2): 599-613.

Caccia, V.G., and Boyer, J.N., 2005. "Spatial patterning of water quality in Biscayne Bay, Florida as a function of land use and water management." Mar. Pollut. Bull. 50(11): 1416-1429. https://doi.org/10.1016/j.marpolbul.2005.08.002.

Caccia, V.G., and Boyer, J.N., 2007. A nutrient loading budget for Biscayne Bay, Florida. Mar. Poll. Bull. 54(2007): 994-1008.

Carey, R.O., K.W. Migliaccio, Y. Li, B. Schaffer, G.A. Kiker, and M.T.Brown. 2011. Land use disturbance indicators and water quality variability in the Biscayne Bay Watershed, Florida. EcologicalIndicators11: 1093–1104. https://doi.org/10.1016/j.ecolind.2010.12.009

Chin, D., 2020. "Source Identification of Nutrient Impairment in North Biscayne Bay, Florida, USA." J. Environ. Eng. 146(9): 04020101. https://doi.org/10.1061/(ASCE)EE.1943-7870.0001786.

Florida Department of Environmental Protection. 2018. Comprehensive Verified List 08012018. https://floridadep.gov/dear/watershed-assessment-section/documents/comprehensive-verified-list. Accessed 31 December 2018.

Fong, P., R. M. Donohoe, and J. B. Zedler. 1993. Competition with macroalgae and benthic cyanobacterial mats limits phytoplankton abundance in experimental microcosms. Marine Ecology Progress Series 100:97–102.

Francis-Floyd, R., 1992. Dissolved oxygen for fish production [Fact sheet]. University of Florida Institute of Food and Agricultural Sciences.

Graves, G.A., Wan, Y., Fike, D.L., 2004. Water quality characteristics of stormwater from major land uses in South Florida. Journal of the American Water Resources Association (December), 1405-1419. https://doi.org/10.1111/j.1752-1688.2004.tb01595.x

Hang, J., S.E. Jørgensen, M. Beklioglu, and O. Ince. 2003. Hysteresis in vegetation shift—Lake Morgan prognoses. Ecological Modelling164: 227–238.

Harlem, P.W., 1979. Aerial photographic interpretation of the historical changes in northern Biscayne Bay, Florida: 1925–1976. SeaGrant Technical Bulletin No. 40, University of Miami, Miami, FL

Harlin, M. 1995. Changes in major plant groups following nutrient enrichment (Chapter 11), p. 173–187.In A. J. McComb (ed.), Eutrophic Shallow Estuaries and Lagoons. CRC Press, Boca Raton, Florida.

Hirsch, R.M., D.L. Moyer, S.A. Archfield. 2010. Weighted regressions on time, discharge, and season (WRTDS), with an application to Chesapeake Bay River Inputs. Journal of the American Water Resources Association. 46(5): 857-880. https://doi.org/10.1111/j.1752-1688.2010.00482.x

Jarossy, S.M. 2016. An evaluation of the Seagrass Habitat in North Biscayne Bay, Florida, in relation to a changing environment and urbanization in the Port of Miami Harbor Basin 2005-2011. Master's Thesis. Nova Southeastern University. Retrieved from NSUWorks, (434). https://nsuworks.nova.edu/occ_stuetd/434

Kendall, M. 1975. Rank correlation methods. London: Griffin.

Kleppel, G., and The Estuarine Theme Panel. 1996. State of Florida's estuaries and future needs in estuarine research. Part I: A synopsis of Florida estuarine resources with recommendations for their conservation and management. Rep. No. TP-85. Gainesville, FL: The Florida Sea Grant College Program.

Lirman, D. and W.P. Cropper. 2003. The influence of salinity on seagrass growth, survivorship, and distribution within Biscayne Bay, Florida: Field experimental and modeling studies. Estuaries 26: 131-141.

Mann, H. 1945. "Nonparametric tests against trend." Econometrica 13 (3): 245–259. https://doi.org/10.2307/1907187.

Miami-Dade County. 2022. "Biscayne Bay Report Card 2022." Miami-Dade County. https://mdc.maps.arcgis.com/apps/MapSeries/index.html?appid=b517ceec4bd34cfd805a3854444fb21a

Millette, N., Kelble, C., Linhoss, A., Ashby, S., and Visser, L. 2019. "Using spatial variability in the rate of change of chlorophyll a to improve water quality management in a subtropical oligotrophic estuary." Estuaries Coasts 42(7): 1792-1803. https://doi.org/10.1007/s12237-019-00610-5.

Nixon, S., B. Buckley, S. Granger, and J. Bintz. 2001. Responses of very shallow marine ecosystems to nutrient enrichment. Human and Ecological Risk Assessment 7:1457–1481.

Rojas, M. 2012. Fecal Coliform TMDLs for C-8 (Biscayne) Canal (WBID 3285), C-7 (Little River) Canal (WBID 3287), C-6 (Miami River) Canal (WBID 3288), C-6 (Miami River) Lower Segment (WBID 3288B), and C-6 (Miami) Canal (WBID 3290). Florida Department of Environmental Protection.

SFWMD. 1993. Operations Control Center (OCC) Structure Books. South Florida Water Management District.

Shapiro, S. S., and Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). Biometrika, 52(3–4), 591–611. https://doi.org/10.1093/biomet/52.3-4.591

Steward, J.S. and W.C. Green. 2007. Setting load limits for nutrients and Suspended Solids upon Seagrass Depth-limit. Estuaries and Coasts 30 (4): 657-670/

USGS. 2004.Changing salinity patterns in Biscayne Bay, Florida [Fact sheet]. United States Geological Survey.

USGS. 2015. User Guide to Exploration and Graphics for RivEr Trends (EGRET) and dataRetrieval: R Packages for Hydrologic Data. *Book 4, Hydrologic Analysis and Interpretation: Chapter 10 of Section A, Statistical Analysis*. United States Geological Survey.

APPENDIX A

The following sections serve as a guide to the methods described in **Section 4.0**.

Time Series Analyses

WQ criteria for the parameters analyzed were based on various statistics (maximums, annual geometric means). COCs for NNB-A and NNB-B were determined in accordance with the NNC thresholds and water quality criteria for Class III waters. To determine the geometric mean, μ_{geo}, the following equation was applied to annual data for the appropriate WQ parameters (e.g., chlorophyll a, TN, and TP):

$$\mu_{geo} = \left(\prod_{i}^{n} x_i\right)^{\frac{1}{n}}$$

where x_i equals the magnitude of the ith element in the data set and n equals the data set's total number of elements.

The Mann-Kendall test for monotonic trends was applied to the time series presented in **Section 7.1** and **8.1**. It is a non-parametric test that compares relative magnitudes of a sample's data rather than their absolute magnitudes (Gilbert, 1987). The test evaluates sample values as an ordered time series, where a given data value is compared to all subsequent data values. The test statistic, S, is initially assumed to be nil. S is incremented by 1 if the subsequent data value is higher than the initial value; decremented by 1 if lower. A final value for S is the result of all increments/decrements over the sample period. The Python package pyMannKendall was utilized to obtain test statistics as well as to test for statistical significance. Refer to the following link for more information regarding this statistical package: https://pypi.org/project/pymannkendall/.

Cumulative Volume Analyses

Let C represent the set of concentration values for a given WQ variable, such that $C = \{C_1, C_2, \dots, C_N\}$, where C_1 equals the concentration at time t_{C_1} and where N equals the number of elements in set C. Similarly, let F represent the set of average daily flowrates, such that $F = \{F_1, F_2, \dots, F_P\}$, where P equals the number of elements in set F. An algorithm was constructed to perform the following operations between C and F for a given accumulation period (A_k). For each variable, accumulation periods between 0 and 60 days were evaluated.

The first iteration of the algorithm evaluated an accumulation period of zero ($A_k = 0$), meaning that each element of C was matched to the flowrate recorded on the same day as the concentration measurement. An $n\,x\,2$ matrix was thereby constructed, with each row of the first column containing all concentration data and each row of the second column containing the corresponding flowrates.

$$\begin{bmatrix} C_1 & F\left(t_{C_1}\right) \\ C_2 & F\left(t_{C_2}\right) \\ \dots & \dots \\ C_N & F\left(t_{C_N}\right) \end{bmatrix}_{A_k=0}$$

where $F\left(t_{C_i}\right)$ equals the flowrate associated with C_i.

The average daily flowrates were then converted to volumes, and correlation analyses were performed between columns 1 and 2.

The second iteration evaluated an accumulation period of one ($A_p = 1$), meaning that each element of C was matched to the average daily flowrate recorded on the same day in addition to that of the previous day of the concentration measurement. What resulted remained an $n\,x\,2$ matrix, but now each element of the second column contained the sum of the volumes associated with a given concentration measurement.

$$\begin{bmatrix} C_1 & F\left(t_{C_1}\right) + F(t_{C_1} - 1) \\ C_2 & F\left(t_{C_1}\right) + F(t_{C_1} - 1) \\ \dots & \dots \\ C_N & F\left(t_{C_N}\right) + F(t_{C_N} - 1) \end{bmatrix}_{A_k=1}$$

A general relation for any accumulation period was then derived.

$$\begin{bmatrix} C_1 & \sum_{i=0}^{A_k} F(t_{C_1} - A_k) \\ C_2 & \sum_{i=0}^{A_k} F(t_{C_2} - A_k) \\ \dots & \dots \\ C_N & \sum_{i=0}^{A_k} F(t_{C_N} - A_k) \end{bmatrix}$$

For each iteration, the Shapiro-Wilk test for normality was applied separately to columns 1 and 2. The test evaluates whether a random sample comes from a normal distribution. More information regarding this test can be found using the following link:

https://www.itl.nist.gov/div898/handbook/prc/section2/prc213.htm.

The scipy.stats.shapiro tool in Python was utilized to perform this test.

https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.shapiro.html

Pearson correlation coefficients between columns 1 and 2 were computed for each accumulation period. This coefficient is a measure of the linear correlation between two sets of data and equals the ratio between the covariance of two variables and the product of their standard deviations. The scipy.stats.pearsonr tool was utilized in Python to compute these coefficients and to perform tests of statistical significance.

Spearman rank-correlation coefficients were computed for each accumulation period between columns 1 and 2. This coefficient is a nonparametric measure of the monotonicity of the relationship between two variables. The Python tool scipy.stats.spearmanr was used to compute these coefficients

(https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.spearmanr.html.)

Ordinary Least Squares regression analyses were then performed for the accumulation period that exhibited the highest Pearson correlation coefficient. The numpy, pandas, and statsmodels.api packages in Python were used to perform these analyses. F-tests were performed to evaluate the statistical significance of the regression.

(https://www.statsmodels.org/dev/examples/notebooks/generated/ols.html.)

Variables for which statistically significant regression equations were constructed were then further evaluated for FPLOS impacts. Cumulative volumes were computed for each of the modeling scenarios listed in **Table 4-1**, and the accumulation period for which these modeling cumulative volumes were computed matched that of the occurrence of the maximum Pearson correlation coefficient. The following sections report the output of the OLS analyses and F-tests.

C-9 Salinity: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.166
Model:                            OLS   Adj. R-squared:                  0.161
Method:                 Least Squares   F-statistic:                     34.29
Date:                Tue, 08 Nov 2022   Prob (F-statistic):           2.36e-08
Time:                        15:04:46   Log-Likelihood:                -555.30
No. Observations:                 174   AIC:                             1115.
Df Residuals:                     172   BIC:                             1121.
Df Model:                           1
Covariance Type:            nonrobust
=====================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------
const                31.1496      0.703     44.284      0.000      29.761      32.538
Cummulative Volume   -0.0008      0.000     -5.855      0.000      -0.001      -0.001
==============================================================================
Omnibus:                       43.779   Durbin-Watson:                   1.340
Prob(Omnibus):                  0.000   Jarque-Bera (JB):               69.467
Skew:                          -1.345   Prob(JB):                     8.23e-16
Kurtosis:                       4.533   Cond. No.                     8.45e+03
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
```

C-9 Chlorophyll a: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.208
Model:                            OLS   Adj. R-squared:                  0.204
Method:                 Least Squares   F-statistic:                     55.15
Date:                Tue, 08 Nov 2022   Prob (F-statistic):           2.76e-12
Time:                        15:21:49   Log-Likelihood:                -469.17
No. Observations:                 212   AIC:                             942.3
Df Residuals:                     210   BIC:                             949.1
Df Model:                           1
Covariance Type:            nonrobust
======================================================================================
                         coef    std err          t      P>|t|      [0.025      0.975]
--------------------------------------------------------------------------------------
const                  3.0079      0.230     13.066      0.000       2.554       3.462
Cummulative Volume     0.0001   1.68e-05      7.426      0.000    9.18e-05       0.000
==============================================================================
Omnibus:                       83.599   Durbin-Watson:                   1.802
Prob(Omnibus):                  0.000   Jarque-Bera (JB):              294.304
Skew:                           1.612   Prob(JB):                     1.24e-64
Kurtosis:                       7.788   Cond. No.                     2.06e+04
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
```

C-9 Dissolved Oxygen: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.033
Model:                            OLS   Adj. R-squared:                  0.027
Method:                 Least Squares   F-statistic:                     6.332
Date:                Tue, 08 Nov 2022   Prob (F-statistic):             0.0127
Time:                        15:27:11   Log-Likelihood:                -308.32
No. Observations:                 190   AIC:                             620.6
Df Residuals:                     188   BIC:                             627.1
Df Model:                           1
Covariance Type:            nonrobust
=====================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------
const                 5.8336      0.129     45.258      0.000       5.579       6.088
Cummulative Volume -2.498e-05   9.93e-06     -2.516      0.013   -4.46e-05    -5.4e-06
==============================================================================
Omnibus:                        5.667   Durbin-Watson:                   1.475
Prob(Omnibus):                  0.059   Jarque-Bera (JB):                5.272
Skew:                          -0.374   Prob(JB):                       0.0716
Kurtosis:                       3.328   Cond. No.                     1.87e+04
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
```

C-8 Salinity: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.086
Model:                            OLS   Adj. R-squared:                  0.082
Method:                 Least Squares   F-statistic:                     20.97
Date:                Tue, 08 Nov 2022   Prob (F-statistic):           7.76e-06
Time:                        15:31:59   Log-Likelihood:                -482.79
No. Observations:                 224   AIC:                             969.6
Df Residuals:                     222   BIC:                             976.4
Df Model:                           1
Covariance Type:            nonrobust
======================================================================================
                         coef    std err          t      P>|t|      [0.025      0.975]
--------------------------------------------------------------------------------------
const                 33.6384      0.194    173.139      0.000      33.255      34.021
Cummulative Volume    -0.0004   7.79e-05     -4.580      0.000      -0.001      -0.000
==============================================================================
Omnibus:                      110.371   Durbin-Watson:                   2.111
Prob(Omnibus):                  0.000   Jarque-Bera (JB):              668.994
Skew:                          -1.849   Prob(JB):                    5.37e-146
Kurtosis:                      10.616   Cond. No.                     3.46e+03
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
```

C-8 Chlorophyll a: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.191
Model:                            OLS   Adj. R-squared:                  0.187
Method:                 Least Squares   F-statistic:                     59.13
Date:                Tue, 08 Nov 2022   Prob (F-statistic):           3.34e-13
Time:                        15:40:14   Log-Likelihood:                -441.60
No. Observations:                 253   AIC:                             887.2
Df Residuals:                     251   BIC:                             894.3
Df Model:                           1
Covariance Type:            nonrobust
=====================================================================================
                      coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------
const               1.6117      0.121     13.353      0.000       1.374       1.849
Cummulative Volume  0.0002   2.51e-05      7.690      0.000       0.000       0.000
==============================================================================
Omnibus:                      146.018   Durbin-Watson:                   1.776
Prob(Omnibus):                  0.000   Jarque-Bera (JB):             1115.802
Skew:                           2.217   Prob(JB):                    5.09e-243
Kurtosis:                      12.284   Cond. No.                     6.63e+03
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
```

C-8 TN: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.306
Model:                            OLS   Adj. R-squared:                  0.262
Method:                 Least Squares   F-statistic:                     7.051
Date:                Tue, 08 Nov 2022   Prob (F-statistic):             0.0173
Time:                        15:44:25   Log-Likelihood:                 8.4449
No. Observations:                  18   AIC:                            -12.89
Df Residuals:                      16   BIC:                            -11.11
Df Model:                           1
Covariance Type:            nonrobust
=====================================================================================
                      coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------
const               0.3597      0.062      5.791      0.000       0.228       0.491
Cummulative Volume 3.331e-05   1.25e-05      2.655      0.017    6.72e-06    5.99e-05
==============================================================================
Omnibus:                        1.377   Durbin-Watson:                   1.905
Prob(Omnibus):                  0.502   Jarque-Bera (JB):                0.677
Skew:                          -0.475   Prob(JB):                        0.713
Kurtosis:                       2.971   Cond. No.                     8.13e+03
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
```

C-8 Dissolved Oxygen: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.095
Model:                            OLS   Adj. R-squared:                  0.092
Method:                 Least Squares   F-statistic:                     28.58
Date:                Mon, 28 Nov 2022   Prob (F-statistic):           1.90e-07
Time:                        14:55:04   Log-Likelihood:                -437.03
No. Observations:                 274   AIC:                             878.1
Df Residuals:                     272   BIC:                             885.3
Df Model:                           1
Covariance Type:            nonrobust
======================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
--------------------------------------------------------------------------------------
const                 6.2776      0.100     63.043      0.000       6.082       6.474
Cummulative Volume -9.543e-05   1.78e-05     -5.346      0.000      -0.000   -6.03e-05
==============================================================================
Omnibus:                      299.992   Durbin-Watson:                   1.757
Prob(Omnibus):                  0.000   Jarque-Bera (JB):            23772.654
Skew:                           4.307   Prob(JB):                         0.00
Kurtosis:                      47.811   Cond. No.                     7.68e+03
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

C-9 WQ Concentration FPLOS Estimates

Salinity Concentration Estimates with 95% Confidence Intervals (ppt)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**15.7** (9.8-21.7)	**18.4** (12.5-24.3)	**20.7** (14.8-26.7)	**24.3** (18.4-30.2)	**18.0** (12.1-23.9)	**20.1** (14.2-26.0)	**23.7** (17.7-29.6)	**17.2** (11.2-23.1)	**19.2** (13.3-25.1)	**23.2** (17.3-29.2)	**15.5** (9.6-21.4)	**17.8** (11.9-23.7)	**22.3** (16.4-28.2)
10 Year	**13.5** (7.6-19.4)	**16.2** (10.3-22.1)	**18.7** (12.7-24.6)	**21.9** (16.0-27.8)	**15.9** (10.0-21.8)	**17.8** (11.9-23.7)	**21.0** (15.1-27.0)	**14.7** (8.8-20.6)	**16.6** (10.7-22.5)	**20.4** (14.5-26.4)	**12.7** (6.8-18.7)	**15.1** (9.2-21.0)	**19.1** (13.2-25.1)
25 Year	**9.6** (3.7-15.5)	**11.9** (5.9-17.8)	**14.3** (8.4-20.2)	**17.6** (11.7-23.5)	**11.9** (5.9-17.8)	**13.8** (7.9-19.7)	**16.4** (10.5-22.3)	**10.6** (4.7-16.5)	**12.4** (6.5-18.3)	**15.3** (9.4-21.2)	**7.9** (2.0-13.9)	**10.1** (4.2-16.1)	**13.3** (7.4-19.3)
100 Year	**3.9** (0 - 9.9)	**6.0** (0.1-11.9)	**8.6** (2.7-14.5)	**13.1** (7.2-19.0)	**6.3** (0.4-12.2)	**8.4** (2.5-14.3)	**10.9** (5.0-16.8)	**5.1** (0-11.1)	**6.7** (0.8-12.7)	**9.4** (3.5-15.3)	**1.6** (0.0-7.5)	**3.5** (0 -9.4)	**6.4** (0.5-12.3)

Chlorophyll a Concentration Estimates with 95% Confidence Intervals (µg/L)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**5.7** (3.5-7.9)	**5.4** (3.1-7.6)	**4.8** (2.6-7.0)	**4.0** (1.7-6.2)	**5.5** (3.3-7.7)	**5.1** (2.8-7.3)	**4.4** (2.2-6.6)	**5.6** (3.4-7.9)	**5.2** (3.0-7.4)	**4.5** (2.2-6.7)	**5.9** (3.7-8.1)	**5.4** (3.2-7.7)	**4.8** (2.5-7.0)
10 Year	**6.2** (4.0-8.5)	**5.8** (3.6-8.0)	**5.1** (2.9-7.4)	**4.4** (2.2-6.6)	**6.0** (3.7-8.2)	**5.5** (3.3-7.7)	**4.9** (2.6-7.1)	**6.1** (3.9-8.3)	**5.7** (3.5-7.9)	**4.9** (2.7-7.2)	**6.4** (4.2-8.6)	**5.9** (3.7-8.2)	**5.3** (3.1-7.5)
25 Year	**7.3** (5.0-9.5)	**6.7** (4.5-8.9)	**6.0** (3.8-8.2)	**5.2** (3.0-7.4)	**6.9** (4.7-9.1)	**6.5** (4.2-8.7)	**5.8** (3.6-8.1)	**7.1** (4.9-9.3)	**6.7** (4.4-8.9)	**6.0** (3.8-8.2)	**7.5** (5.3-9.8)	**7.1** (4.8-9.3)	**6.4** (4.2-8.6)
100 Year	**8.5** (6.2-10.7)	**7.8** (5.5-10.0)	**6.9** (4.7-9.2)	**6.1** (3.9-8.3)	**8.1** (5.8-10.3)	**7.6** (5.3-9.8)	**7.0** (4.8-9.2)	**8.3** (6.1-10.5)	**7.9** (5.6-10.1)	**7.2** (5.0-9.4)	**8.9** (6.7-11.2)	**8.4** (6.2-10.7)	**7.8** (5.6-10.0)

Dissolved Oxygen Concentration Estimates with 95% Confidence Intervals (mg/L)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**5.3** (4.1-6.5)	**5.4** (4.1-6.6)	**5.5** (4.3-6.7)	**5.7** (4.5-6.9)	**5.4** (4.1-6.6)	**5.4** (4.2-6.7)	**5.6** (4.3-6.8)	**5.3** (4.1-6.5)	**5.4** (4.2-6.6)	**5.5** (4.3-6.8)	**5.3** (4.0-6.5)	**5.4** (4.1-6.6)	**5.5** (4.3-6.7)
10 Year	**5.2** (4.0-6.4)	**5.3** (4.1-6.5)	**5.4** (4.2-6.7)	**5.6** (4.4-6.9)	**5.3** (4.0-6.5)	**5.4** (4.1-6.6)	**5.5** (4.2-6.7)	**5.2** (4.0-6.4)	**5.3** (4.1-6.5)	**5.4** (4.2-6.7)	**5.2** (3.9-6.4)	**5.3** (4.0-6.5)	**5.4** (4.2-6.6)
25 Year	**5.0** (3.8-6.2)	**5.1** (3.9-6.4)	**5.3** (4.0-6.5)	**5.5** (4.3-6.7)	**5.1** (3.9-6.3)	**5.2** (3.9-6.4)	**5.3** (4.1-6.5)	**5.0** (3.8-6.2)	**5.1** (3.9-6.3)	**5.2** (4.0-6.5)	**5.0** (3.7-6.2)	**5.1** (3.8-6.3)	**5.2** (4.0-6.4)
100 Year	**4.8** (3.6-6.0)	**4.9** (3.7-6.2)	**5.1** (3.9-6.3)	**5.4** (4.1-6.6)	**4.9** (3.6-6.1)	**5.0** (3.7-6.2)	**5.1** (3.8-6.3)	**4.8** (3.5-6.0)	**4.9** (3.6-6.1)	**5.0** (3.8-6.2)	**4.7** (3.5-5.9)	**4.8** (3.6-6.0)	**4.9** (3.7-6.1)

C-8 WQ Concentration FPLOS Estimates

Salinity Concentration Estimates with 95% Confidence Intervals (ppt)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**30.2** (24.2-36.1)	**30.4** (24.5-36.3)	**30.9** (25.0-36.8)	**31.4** (25.5-37.3)	**30.2** (24.2-36.1)	**30.4** (24.5-36.3)	**31.1** (25.2-37.0)	**29.9** (23.3-35.2)	**30.3** (23.8-35.6)	**31.0** (24.0-35.8)	**29.2** (23.3-35.2)	**29.7** (23.8-35.6)	**29.9** (24.0-35.8)
10 Year	**29.5** (23.6-35.4)	**29.8** (23.9-35.7)	**30.3** (24.4-36.2)	**30.7** (24.8-36.6)	**29.5** (23.6-35.4)	**29.7** (23.8-35.6)	**30.3** (24.4-36.2)	**29.2** (22.5-34.3)	**29.5** (22.8-34.6)	**30.2** (23.2-35.0)	**28.4** (22.5-34.3)	**28.7** (22.8-34.6)	**29.1** (23.2-35.0)
25 Year	**27.8** (21.9-33.7)	**28.2** (22.2-34.1)	**28.5** (22.6-34.4)	**29.0** (23.1-34.9)	**28.0** (22.0-33.9)	**28.1** (22.2-34.0)	**28.7** (22.7-34.6)	**27.5** (20.7-32.6)	**27.7** (20.9-32.7)	**28.3** (21.1-33.0)	**26.6** (20.7-32.6)	**26.8** (20.9-32.7)	**27.0** (21.1-33.0)
100 Year	**26.0** (20.1-31.9)	**26.3** (20.3-32.2)	**26.5** (20.5-32.4)	**27.0** (21.1-32.9)	**26.1** (20.2-32.0)	**26.2** (20.3-32.1)	**26.8** (20.9-32.7)	**25.5** (0.0-30.1)	**25.6** (18.3-30.1)	**26.2** (18.7-30.5)	**24.2** (0.0-30.1)	**24.2** (18.3-30.1)	**24.6** (18.7-30.5)

Chlorophyll a Concentration Estimates with 95% Confidence Intervals (µg/L)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**4.1** (1.9-6.4)	**3.9** (1.7-6.1)	**3.4** (1.2-5.6)	**2.5** (0.3-4.7)	**4.0** (1.8-6.3)	**3.8** (1.6-6.0)	**3.1** (0.9-5.3)	**4.2** (2.3-6.8)	**3.9** (1.9-6.3)	**3.0** (1.3-5.8)	**4.6** (2.3-6.8)	**4.1** (1.9-6.3)	**3.6** (1.3-5.8)
10 Year	**4.5** (2.3-6.8)	**4.3** (2.1-6.5)	**3.8** (1.5-6.0)	**2.9** (0.7-5.1)	**4.5** (2.3-6.7)	**4.2** (2.0-6.5)	**3.7** (1.4-5.9)	**4.7** (2.9-7.3)	**4.3** (2.5-6.9)	**3.6** (1.7-6.2)	**5.1** (2.9-7.3)	**4.7** (2.5-6.9)	**4.0** (1.7-6.2)
25 Year	**5.7** (3.5-7.9)	**5.4** (3.2-7.7)	**4.9** (2.7-7.1)	**4.0** (1.8-6.2)	**5.6** (3.4-7.8)	**5.3** (3.1-7.5)	**4.8** (2.6-7.0)	**5.9** (4.1-8.5)	**5.5** (3.7-8.1)	**4.9** (3.4-7.9)	**6.3** (4.1-8.5)	**5.9** (3.7-8.1)	**5.6** (3.4-7.9)
100 Year	**6.8** (4.6-9.1)	**6.6** (4.4-8.8)	**6.1** (3.9-8.3)	**5.1** (2.9-7.3)	**6.9** (4.7-9.1)	**6.6** (4.4-8.8)	**6.1** (3.8-8.3)	**7.2** (5.7-10.2)	**6.9** (5.4-9.8)	**6.3** (5.0-9.5)	**8.0** (5.7-10.2)	**7.6** (5.4-9.8)	**7.2** (5.0-9.5)

Dissolved Oxygen Concentration Estimates with 95% Confidence Intervals (mg/L)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**5.1** (3.9-6.3)	**5.2** (4.0-6.5)	**5.5** (4.3-6.7)	**5.8** (4.6-7.1)	**5.2** (3.9-6.4)	**5.3** (4.1-6.5)	**5.7** (4.4-6.9)	**5.1** (3.7-6.2)	**5.3** (3.9-6.4)	**5.7** (4.2-6.7)	**4.9** (3.7-6.2)	**5.2** (3.9-6.4)	**5.5** (4.2-6.7)
10 Year	**4.9** (3.7-6.2)	**5.1** (3.8-6.3)	**5.3** (4.1-6.5)	**5.6** (4.4-6.9)	**5.0** (3.7-6.2)	**5.1** (3.9-6.3)	**5.4** (4.2-6.6)	**4.9** (3.4-5.9)	**5.0** (3.6-6.1)	**5.4** (4.0-6.5)	**4.7** (3.4-5.9)	**4.9** (3.6-6.1)	**5.3** (4.0-6.5)
25 Year	**4.3** (3.1-5.6)	**4.5** (3.3-5.7)	**4.7** (3.5-6.0)	**5.1** (3.9-6.3)	**4.4** (3.2-5.6)	**4.5** (3.3-5.8)	**4.8** (3.6-6.0)	**4.3** (2.8-5.3)	**4.5** (3.0-5.5)	**4.8** (3.2-5.7)	**4.1** (2.8-5.3)	**4.3** (3.0-5.5)	**4.4** (3.2-5.7)
100 Year	**3.8** (2.6-5.0)	**3.9** (2.7-5.1)	**4.2** (2.9-5.4)	**4.5** (3.3-5.7)	**3.8** (2.6-5.0)	**3.9** (2.7-5.2)	**4.2** (3.0-5.4)	**3.6** (2.0-4.5)	**3.8** (2.2-4.7)	**4.1** (2.4-4.9)	**3.3** (2.0-4.5)	**3.5** (2.2-4.7)	**3.7** (2.4-4.9)

Total Nitrogen Concentration Estimates with 95% Confidence Intervals (mg/L)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**0.8** (0.6-1.0)	**0.8** (0.6-0.9)	**0.7** (0.5-0.8)	**0.5** (0.4-0.7)	**0.8** (0.6-0.9)	**0.7** (0.6-0.9)	**0.6** (0.5-0.8)	**0.8** (0.7-1.0)	**0.7** (0.6-0.9)	**0.6** (0.5-0.8)	**0.9** (0.7-1.0)	**0.8** (0.6-0.9)	**0.7** (0.5-0.8)
10 Year	**0.9** (0.7-1.0)	**0.8** (0.7-1.0)	**0.7** (0.6-0.9)	**0.6** (0.5-0.8)	**0.9** (0.7-1.0)	**0.8** (0.7-1.0)	**0.7** (0.5-0.9)	**0.9** (0.8-1.1)	**0.8** (0.7-1.0)	**0.7** (0.6-0.9)	**1.0** (0.8-1.1)	**0.9** (0.7-1.0)	**0.8** (0.6-0.9)
25 Year	**1.1** (0.9-1.2)	**1.0** (0.9-1.2)	**0.9** (0.8-1.1)	**0.8** (0.6-1.0)	**1.0** (0.9-1.2)	**1.0** (0.8-1.2)	**0.9** (0.7-1.1)	**1.1** (1.0-1.3)	**1.0** (0.9-1.3)	**0.9** (0.9-1.2)	**1.2** (1.0-1.3)	**1.1** (0.9-1.3)	**1.0** (0.9-1.2)
100 Year	**1.3** (1.1-1.4)	**1.2** (1.1-1.4)	**1.1** (1.0-1.3)	**1.0** (0.9-1.2)	**1.3** (1.1-1.4)	**1.2** (1.1-1.4)	**1.1** (1.0-1.3)	**1.3** (1.3-1.6)	**1.3** (1.2-1.5)	**1.2** (1.2-1.5)	**1.4** (1.3-1.6)	**1.4** (1.2-1.5)	**1.3** (1.2-1.5)

APPENDIX B

C-9 Regression Analysis Decision Table

Parameter	Regression Analysis Performed	No statistically significant correlation trends. p > 0.05 for cumulative volume correlations within the modeling period	Parameter within Class III Marine Water Criteria. Not identified as a COC. Further analysis not warranted	Insufficient/No data received
Salinity	X			
Chlorophyll *a*	X			
Total Nitrogen		X		
Total Phosphorus		X		
Dissolved Oxygen	X			
Turbidity		X		
Fecal Coliform				X
Copper		X		
Cadmium, Total			X	
Selenium, Total			X	
Silver, Total			X	
Lead			X	

C-8 Regression Analysis Decision Table

Salinity	X			
Chlorophyll *a*	X			
Total Nitrogen	X			
Total Phosphorus				X
Dissolved Oxygen	X			
Turbidity		X		
Fecal Coliform			X	
Copper				X
Cadmium, Total				X
Selenium, Total				X
Silver, Total				X
Lead				X

APPENDIX C

C-8/C-9 Water Quality Data Request Log

Last Updated: **2/6/2023**

Date Requested	Data Requested	Requested From	Contact	Received Date	Parameter	Data Period (Provided by County)
8/11/2022	SK01 (all parameters)	Georgio Tachiev	georgio.tachiev@miamidade.gov	8/13/2022		
8/11/2022	BS01 (all parameters)	Georgio Tachiev	georgio.tachiev@miamidade.gov	8/13/2022		
8/11/2022	BB02 (all parameters)	Georgio Tachiev	georgio.tachiev@miamidade.gov	8/13/2022		
8/12/2022	BB09 (all parameters)	Valentina Caccia	valentina.caccia@miamidade.gov	8/23/2022	Chlorophyll a	1980 - 2022
				8/23/2022	Fecal Coliform	1979 - 2017
				8/23/2022	Total Coliform	1979 - 2009
				8/23/2022	Copper	1989, 2019
				8/23/2022	DO	1979 - 2022
				8/23/2022	Lead	1989, 2019
				8/23/2022	TN	2020 - 2022
					TKN	None
					N-N	None
				8/23/2022	TP	1979 - 2022
				8/23/2022	Salinity	1979 - 2022
				8/23/2022	Turbity	1979 - 2022
				8/23/2022	Zinc	1989
					Temperature	None
8/26/2022	BB10 (TN)	Valentina Caccia	valentina.caccia@miamidade.gov	9/12/2022	TN	2020-2022
				9/16/2022	TKN	2018-2022
				9/16/2022	N-N	2018-2022
8/29/2022	S28 S29 M0 and M2C Model Flows	Michael Del Charco	mdelcharco@taylorengineering.com	9/13/2022		
8/30/2022	BS04 (all parameters)	Valentina Caccia	valentina.caccia@miamidade.gov	9/21/2022		
8/30/2022	SK02 (all parameters)	Valentina Caccia	valentina.caccia@miamidade.gov	9/21/2022		
8/30/2022	BB03 (all parameters)	Valentina Caccia	valentina.caccia@miamidade.gov	9/21/2022		
9/7/2022	WQ Standards	Valentina Caccia	valentina.caccia@miamidade.gov	9/16/2022		
9/23/2022	BB09 (TN, TKN, N-N, Temperature)	Sherea Higgs	Sherea.Higgs@miamidade.gov	9/30/2022	TN	2020-2022
				9/30/2022	TKN	2020-2022
				9/30/2022	N-N	2020-2022
				9/30/2022	Temperature	2020-2022
10/24/2022	•BB09 (TKN, NOx, TN, TP, Copper, Lead, Zinc, Temperature) •BS04 (TP) •BB02 (Chlorophyll a, TP, Copper) •BB03 (TKN, NOx, TN, TP, Copper, Lead, Zinc, Temperature) •SK02 (TP)	Omar Abdelrahman	Omar.Abdelrahman@miamidade.gov	10/25/2022	BB02 (Chlorophyll a, Copper, TP) BB03 (Temperature) BB09 (TKN, NOx, TN, Copper, Lead, Temperature) BSO4 (TP) SK02 (TP)	BB02: 1996-2022 (Chlorophyll a, TP) 1996-2019 (Copper) BB09: 1996-2022 (NOX, Temperature) 2009-2022 (TKN) 2020-2022 (TN) 2019 (Copper, Lead) BB03: 1996-2009 BS04: 1996-2022 SK02: 1996-2022
10/26/2022	BB09 (TP)	David Chin	dchin@miami.edu	11/19/2022	TP (Geometric means only)	2008 - 2018
1/13/2023	S28 S29 M2A Model Flows	Joseph Wilder	jwilder@taylorengineering.com	1/19/2023		