TAYLOR ENGINEERING, INC.

Task 2B Hydrodynamic Modeling to Evaluate Downstream Coastal Area Water Levels Prepared for SFWMD C-8 C-9 Phase II, Deliverable 2.B

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Task 2B Hydrodynamic Modeling to Evaluate Downstream Coastal Area Water Levels Prepared for SFWMD C-8 C-9 Phase II, Deliverable 2.B

Miami-Dade County, FL

Final Report

Prepared for

South Florida Water Management District

by

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1.0 INTRODUCTION

Biscayne Bay, an estuary system that connects to the Atlantic Ocean through a multi-inlet system, has hydraulic conditions mostly influenced from south to north by the Government Cut, Bakers Haulover Inlet, and Port Everglades Inlet. In addition, the bay receives upstream water outflows from numerous canals (e.g., C-6, C-7, C-8, and C-9 canals in Figure 1.1) that connect along the bay's western shore. The South Florida Water Management District (SFWMD) commissioned a C-8 and C-9 basins Floodplain Level of Service (FPLOS) modeling study that evaluated improvements for the S-28 and S-29 structures. The FPLOS modeling evaluated three C-8 and C-9 basins flood mitigation alternatives—M2A, M2B, and M2C alternatives.

For the FPLOS modeling, the SFWMD-provided storm surge time series along Biscayne Bay that was applied as a two-dimensional (2D) overland downstream flow boundary in the FPLOS model. FPLOS model simulations of the 20-, 10-, 4-, 1-percent annual exceedance probability rainfall events with 1-ft, 2-ft, and 3-ft sea level rise scenarios provided estimates of the gate flows and pump flows across the S-28 and S-29 structures. Table 1.1 provides a summary of the features and components of M2A, M2B, and M2C flood mitigation alternatives.

However, the FPLOS modeling is limited in resolving water levels downstream of the S-28 and S-29 structures as the FPLOS model did not include the storage of Biscayne Bay and its multiple connections to the Atlantic Ocean. Thus, the SFWMD requested Taylor Engineering evaluate the downstream effects of the S-28 and S-29 structures gate and pump outflows on water levels in Biscayne Bay during normal tides and 10-yr surge event conditions. Appendix A provides the S-28 and S-29 structures gate and pump flow hydrographs.

This study employed a state-of-the-art 2D numerical model—the Biscayne Bay Model (BBM)—to evaluate water levels downstream of S-28 and S-29 with FPLOS outflows. In developing the BBM, Taylor Engineering leveraged an existing Florida Inland Navigation District (FIND) MIKE21 hydrodynamic model (henceforth called "BHIM" in this study) for Bakers Haulover Inlet, Biscayne Bay, and Intracoastal Waterway (IWW). MIKE SHE is integrated hydrological modelling software for analyzing groundwater, surface water, recharge, and evapotranspiration processes. MIKE 21 simulates processes with surface water flows, waves, sediments and ecology in rivers, lakes, estuaries, bays, coastal areas, and seas. Because of these functionalities, this tool can achieve the objective of this task. Taylor Engineering also leveraged ADCIRC+SWAN model data and output sourced from effective Federal Emergency Management Agency (FEMA) modeling (FEMA, 2021) to expand the BHIM to include upstream areas that may be inundated with a 10-yr surge flood event. Data collection and field measurements provided the input data for the BBM validation. The BHIM and the ADCIRC+SWAN model also provided the boundary conditions for normal tides and 10-yr surge event conditions BBM production runs.

Following this introduction, Chapter 2 of this report presents details of the data collection and data analyses. Chapter 3 describes the development of the BBM hydrodynamic model, including model mesh, model boundary conditions setup, and model validation. Chapter 4 describes the evaluation of the effects of S-28 and S-29 structures outflows on downstream water levels for normal tides and 10-yr flood event conditions. Finally, Chapter 5 concludes the report with a summary of the findings and recommendations.

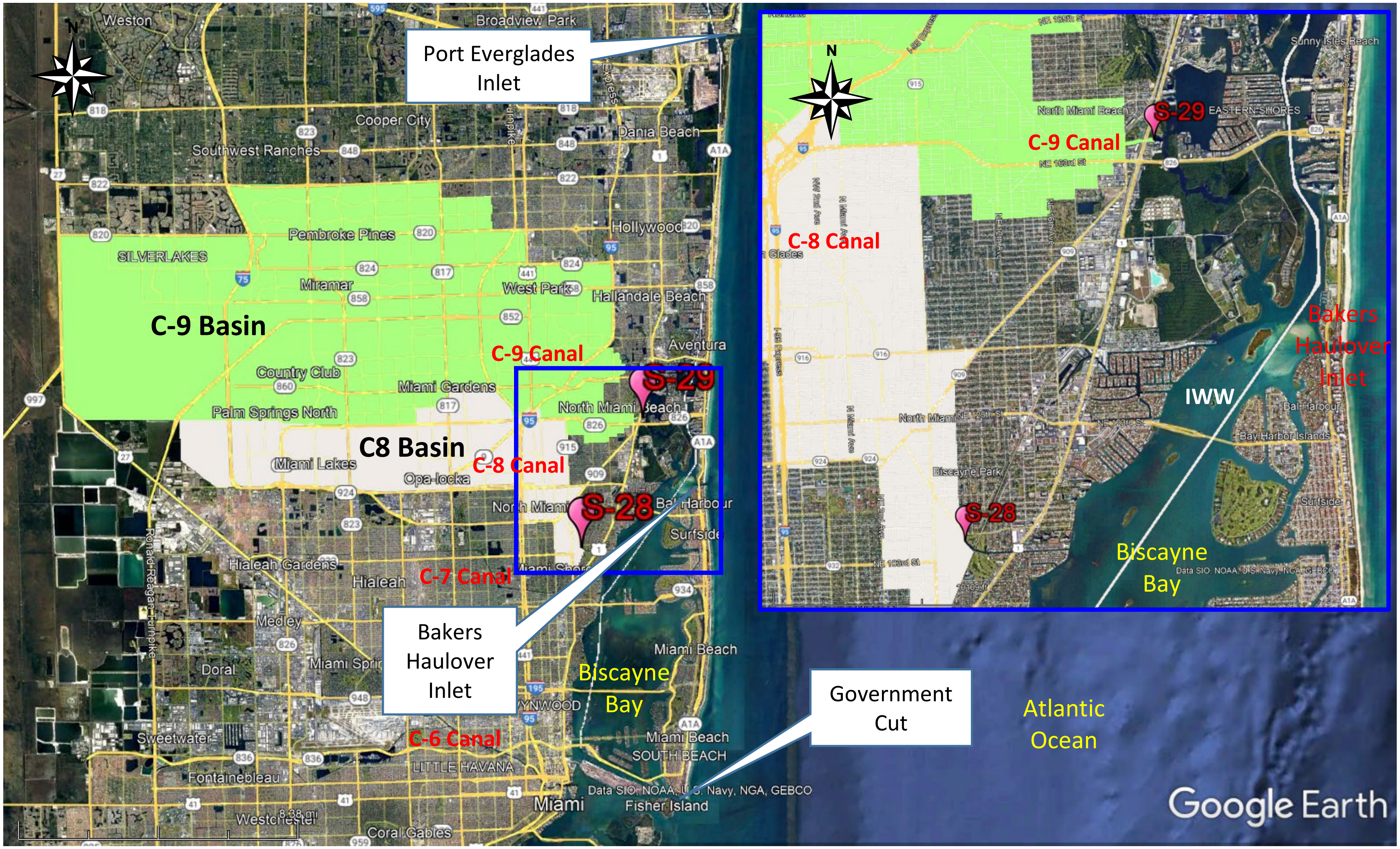

Figure 1.1 Locations of C-8 and C-9 Basins and S-28 and S-29 Structures West of Biscayne Bay

Table 1.1 Features of C-8 and C-9 Basins Flood Mitigation Alternatives M2A, M2B, and M2C

Features	**Alternatives**		
	M2A	**M2B**	**M2C**
S-28 and S-29 forward pumps capacity	1550 cfs	2550 cfs	3550 cfs
S-28 and S-29 gate improvement overtopping elevation	9.0 ft-NGVD29	9.0 ft-NGVD29	9.0 ft-NGVD29
Tieback levees/floodwalls (conceptually represented with elevation of 9.0 ft-NGVD29)	○ S-28: approximately 600 ft length for the north bank and 700 ft length for south bank ○ S-29: approximately 250 ft length for the north bank and 425 ft length for south bank	○ S-28: approximately 600 ft length for the north bank and 700 ft length for south bank ○ S-29: approximately 250 ft length for the north bank and 425 ft length for south bank	○ S-28: approximately 600 ft length for the north bank and 700 ft length for south bank ○ S-29: approximately 250 ft length for the north bank and 425 ft length for south bank
Total of 500 acre-ft distributed storage across both C-8 and C-9 combined	○ conceptually represented – gravity-driven drainage areas only	○ conceptually represented – gravity-driven drainage areas only	○ conceptually represented – gravity-driven drainage areas only
Primary canal improvements		○ improved geometry (cross-section features such as side slope, removing irregularities in channel bottom, and increasing cross-sectional area within the existing width of canal banks) as deemed appropriate along entire C-8 and C-9 canals ○ raised bank elevations to elevation 7.5 ft-NGVD29 anywhere lower than 7.5 ft-NGVD29 (this does not include freeboard)	○ improved geometry (cross-section features such as side slope, removing irregularities in channel bottom, and increasing cross-sectional area within the existing width of canal banks) as deemed appropriate in locations where the C-8 and C-9 canals were not widened ○ widened cross sections ▪ C-8 canal widened along approximately 20,000 ft by a width of 100 ft from Interstate 95 to S-28 ▪ C-9 Canal widened along approximately 79,000 ft by an average of approximately 75 ft, from the west side of the South Broward Drainage District to Interstate 95. ○ raised bank elevations to elevation 7.5 ft-NGVD29 anywhere lower than 7.5 ft-NGVD29 (this does not include freeboard)
Internal drainage system along primary canals to drain water through raised banks		○ System of "dummy" canals and one-way culverts along the perimeter of the C-8 and C-9 canals to allow water to drain into the C-8 and C-9 canals from the surrounding area ○ Can only discharge if C-8 and C-9 canals elevations are lower than water elevation in the surrounding floodplain (the same way as if the raised banks weren't there)	○ System of "dummy" canals and one-way culverts along the perimeter of the C-8 and C-9 canals to allow water to drain into the C-8 and C-9 canals from the surrounding area ○ Can only discharge if C-8 and C-9 canals elevations are lower than water elevation in the surrounding floodplain (the same way as if the raised banks weren't there)
Optimized S-28 and S-29 operational controls for SLR1, SLR2, and SLR3	Yes	Yes	Yes

2.0 DATA COLLECTION AND ANALYSIS

The study area spans portions of the Atlantic Ocean, Bakers Haulover Inlet, Stranahan River, West Lake, North Lake, South Lake, Golden Isles Lake, Dumfoundling Bay, Maule Lake, Little Arch Creek, Biscayne Bay, Indian Creek Lake, Indian Creek, Tatum Waterway, Flamingo Waterway, Surprise Lake, Surprise Waterway, Biscayne Waterway, Normandy Waterway, Sabal Lake, Little River/C7 Canal, Biscayne Canal/C-8 Canal, and C-9 Canal. Tides, waves, and winds influence these areas daily and occasionally storm winds produce elevated water levels (surge) and increase wave heights. The paragraphs below describe the data collection to support BBM development, validation, and application.

2.1 Water Level Data

Semi-diurnal tides—two high and two low per day—and mixed tides during neap period characterize the astronomical tides in the study area. Collection and review of published tide records as well as field measurements of tides contributed to a comprehensive set of tide data for this study. The following sections describe published tidal data and measured tide data.

2.1.1 NOAA Tide Data

Figure 2.1 and Table 2.1 show the locations of the National Oceanic and Atmospheric Administration (NOAA) tidal datum stations near the area of interest. Inshore tidal data from these stations indicate inshore mean tidal range equals 2.21 ft at Whiskey Creek South Entrance, FL (NOAA 8722971), 2.03 ft at Golden Beach, IWW, FL (NOAA 8723026), 2.02 ft at Dumfoundling Bay, FL (NOAA 8723044), 2.01 ft at Haulover Inside, FL (NOAA 8723073), 2.15 ft at Biscayne Creek, IWW, FL (NOAA 8723089), 2.20 ft at San Marino Island, FL (NOAA 8723156), and 2.18 ft at Miami, Biscayne Bay, FL (NOAA 8723165). Tidal data indicate ocean mean tidal range equals 2.49 ft at North Miami Beach, FL (NOAA 8723050), 2.48 ft at Haulover Pier, N. Miami Beach, FL (NOAA 8723080), and 2.46 ft at Miami Beach City Pier, FL (NOAA 8723170). Table 2.1 presents tidal datums for these stations based on the 1983 – 2001 tidal epoch referenced to North American Vertical Datum of 1988 (NAVD).

2.1.2 Field Measured Inshore Tide Level

A FIND sedimentation study deployed tide gages from August 12, 2020 to September 24, 2020 that recorded water level at six locations (Stations TB1 – TB6) and provided hydrodynamic model water level validation data for the inshore area. Figure 2.2 shows the locations of the tide measurement stations and Table 2.2 provides the locations, periods of record, and interval of the tide measurements. Inspection of the measured tides show measurements reflect mean tide ranges consistent with tidal ranges from NOAA stations. Notably, the measured water level data reflects wind setup that caused non-tidal fluctuations in the measured tides.

2.1.3 FEMA Flood Insurance Study Data for 10-yr High Water Level

The FEMA recently completed a preliminary Flood Insurance Study (FIS) for Miami Dade County and Figure 2.3 shows the east-end portions of the C-8 and C-9 basins (where S-28 and S-29 structures are located) with respect to FEMA transects in Biscayne Bay (FEMA, 2021). The FEMA transect information includes still water elevation (SWEL) values near the project sites, including the 10-yr SWELs.

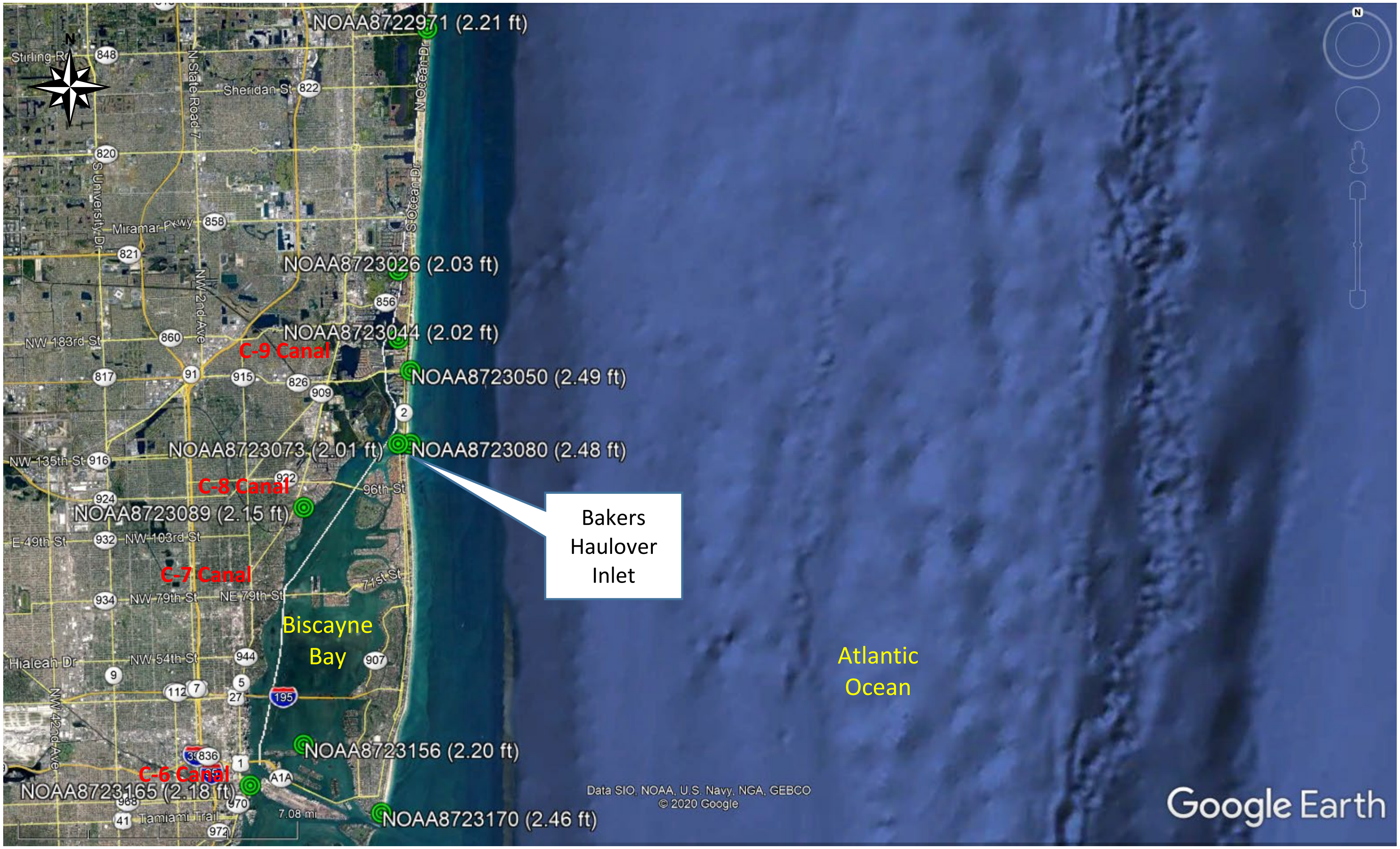

Figure 2.1 Locations of Select NOAA Tide Stations and Wind Stations (Inset) with Mean Tidal Ranges (in parentheses)

Table 2.1 NOAA Tide Datums and Locations of Select Stations near the Area of Interest (1983 – 2001 Tidal Epoch)

Tide Datums, Mean Tide Range, and Coordinates	NOAA 8722971 Whiskey Creek South Entrance, FL (ft-NAVD)	NOAA 8723044 Dumfoundling Bay, FL (ft-NAVD)	NOAA 8723073 Haulover Inside, FL (ft-NAVD)	NOAA 8723080 Haulover Pier, N. Miami Beach, FL (ft-NAVD)	NOAA 8723026 Golden Beach, IWW, FL* (ft-NAVD)
Mean Higher High Water (MHHW)	0.42	0.34	0.27	0.43	0.23
Mean High Water (MHW)	0.33	0.27	0.20	0.36	0.16
Mean Sea Level (MSL)	-0.79	-0.74	-0.85	-0.87	-0.86
Mean Low Water (MLW)	-1.88	-1.75	-1.81	-2.12	-1.87
Mean Lower Low Water (MLLW)	-2.04	-1.89	-1.94	-2.25	-2.01
Mean Tide Range (ft)	2.21	2.02	2.01	2.48	2.03
Latitude	26°03.3'N	25°56.5'N	25°54.2'N	25°54.2'N	25°58.0'N
Longitude	80°06.8'W	80°07.5'W	80°07.5'W	80°07.2'W	80°07.5'W

Tide Datums, Mean Tide Range, and Coordinates	NOAA 8723050 North Miami Beach, FL (ft-NAVD)	NOAA 8723089 Biscayne Creek, IWW, FL (ft-NAVD)	NOAA 8723165 Miami, Biscayne Bay, FL (ft-NAVD)	NOAA 8723170 Miami Beach City Pier, FL (ft-NAVD)	NOAA 8723156 San Marino Island, FL* (ft-NAVD)
Mean Higher High Water (MHHW)	0.37	0.24	0.26	0.33	0.29
Mean High Water (MHW)	0.27	0.17	0.20	0.25	0.22
Mean Sea Level (MSL)	-0.96	-0.91	-0.89	-0.96	-0.90
Mean Low Water (MLW)	-2.22	-1.98	-1.98	-2.20	-1.98
Mean Lower Low Water (MLLW)	-2.39	-2.11	-2.11	-2.37	-2.11
Mean Tide Range (ft)	2.49	2.15	2.18	2.46	2.20
Latitude	25°55.8'N	25°52.8'N	25°46.7'N	25°46.1'N	25°47.6'N
Longitude	80°07.2'W	80°09.8'W	80°11.1'W	80°07.9'W	80°09.8'W

Note: * From Vdatum conversion

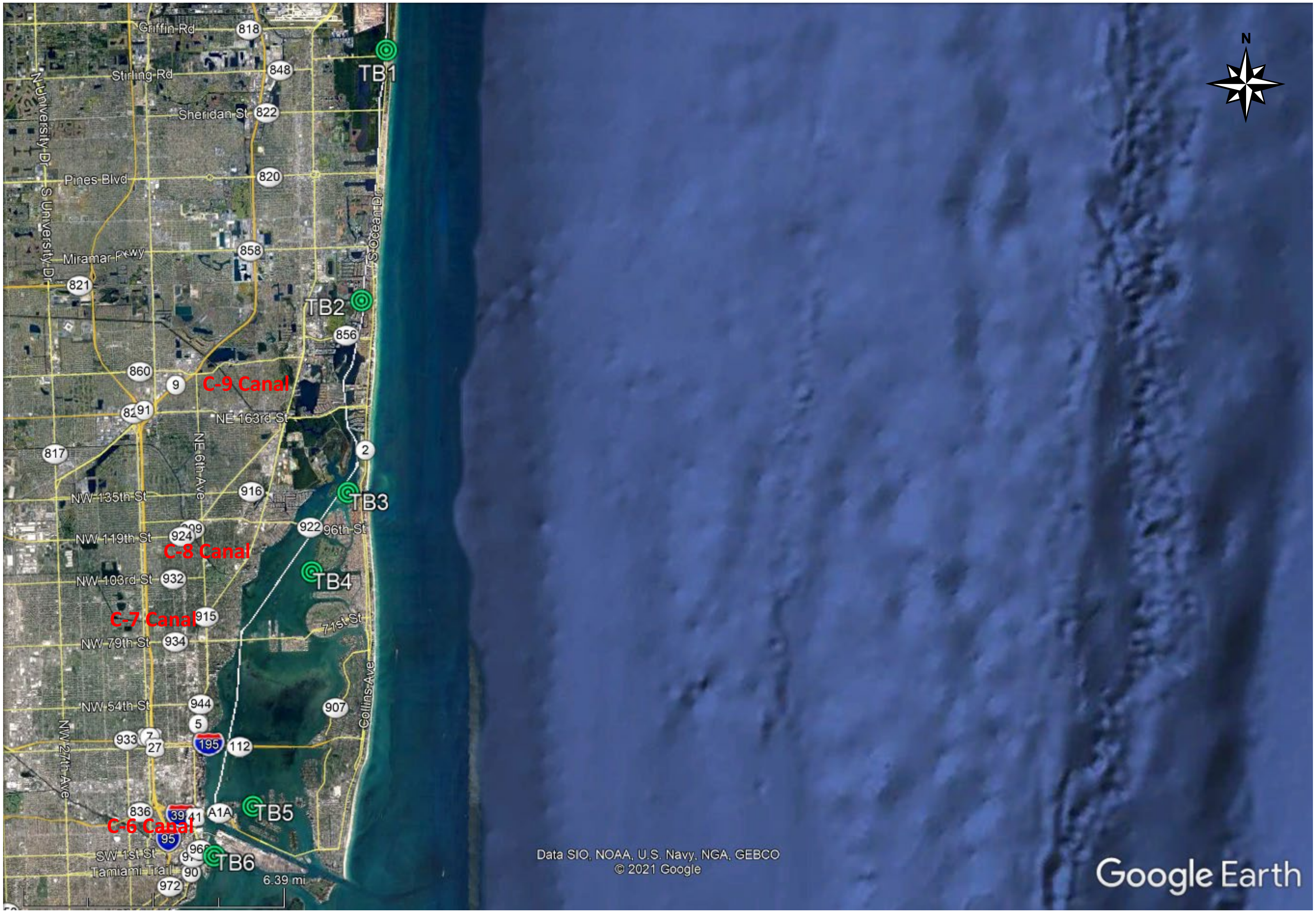

Figure 2.2 Locations of the Tide Level Measurement Stations

Table 2.2 Coordinates, Period of Record, and Time Interval of Measured Tide Level (TB) Stations

Station	Coordinates		Period of Record	Time Interval	Location/ Remarks
	Latitude	Longitude			
TB1	26°03'19.06"N	80°06'52.61"W	8/12/2020 – 9/24/2020	15 minutes	Near IWW Cut-BW52
TB2	25°58'2.02"N	80°07'26.99"W	8/12/2020 – 9/24/2020	15 minutes	Near IWW Cut-DA1
TB3	25°53'59.19"N	80°07'45.71"W	8/12/2020 – 9/24/2020	15 minutes	Between Bakers Haulover Inlet and IWW Cut-DA9
TB4	25°52'18.92"N	80° 8'36.57"W	8/12/2020 – 9/24/2020	15 minutes	0.7 mi east of IWW Cut-DA9
TB5	25°47'22.00"N	80°09'59.17"W	8/12/2020 – 9/24/2020	15 minutes	0.9 mi east of IWW Cut-DA9
TB6	25°46'18.96"N	80°10'53.72"W	8/12/2020 – 9/24/2020	15 minutes	0.4 mi east of Miami River Entrance

In addition to the FIS transects, Taylor Engineering obtained FEMA Geographic Information Systems (GIS) data for the S-28 and S-29 structures locations based on the same modeling as the FIS data. Table 2.3 provides the 10-yr SWELs for both the FIS and GIS data. The 10-yr FIS and GIS data fall within 0.1 ft at both structures. NOAA's extreme water level analysis of the recorded water level at Miami Beach City Pier (NOAA 8723170) (https://tidesandcurrents.noaa.gov/est/est_station.shtml?stnid=8723170) shows a 10-yr high water level of approximately 2.7 ft-NAVD.

2.1.4 ADCIRC+SWAN Model Provided Water Levels for 10-yr Flood Modeling

The recently completed FEMA Coastal South Florida Flood Insurance Study (SFLFIS) provides modeled offshore hydrographs that were produced from a high-resolution 2D ADCIRC+SWAN model (FEMA, 2021). The ADCIRC model was validated to astronomical tides and to five historical tropical cyclones—Hurricanes Andrew, Wilma, Georges, David, and Betsy. The SFLFIS included ADCIRC+SWAN modeling of 392 storms to produce FEMA's 1% SWELs at various locations in the ADCIRC+SWAN model domain. The 392 storm suites included several synthetic storms with different tracks, forward speeds, pressures, wind speeds, and Holland B parameters. Evaluation of the maximum water levels from each of the 392 production suite storm simulations at the downstream side of the S-28 and S-29 structures resulted in selection of candidate storms that provided highwater levels nearest to the values listed in Table 2.3. Appendix B describes the evaluation and selection of the ADCIRC+SWAN storm that provides good estimates of the water level hydrographs with highwater levels near those listed in Table 2.3.

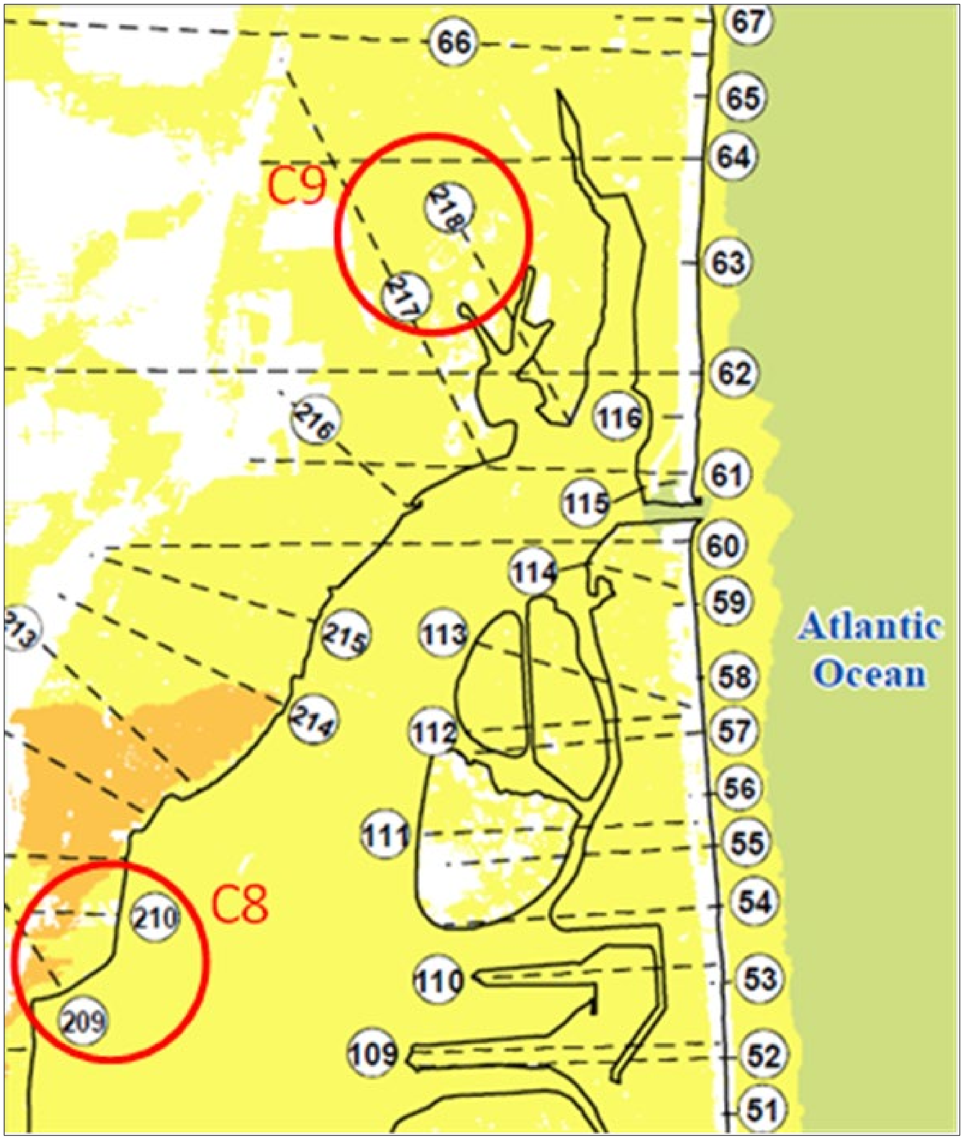

Figure 2.3 Locations of C-8 and C-9 Canals Outlets and FIS Transects (Source: FEMA, 2021)

Table 2.3 10-yr Still Water Elevations at S-28 and S-29 Structures

Station	10-yr SWEL (ft-NAVD)	
	FIS Transects	GIS Data
S-28	2.5	2.4
S-29	2.4	2.3

2.2 Bathymetric and Topographic Data

This study sourced its bathymetric and topographic data from three sources—(a) the FEMA 2016 South Florida ADCIRC+SWAN model Version 11 mesh; (b) USACE 2019 Cut-DA9, Bakers Haulover Inlet, and Biscayne Bay bathymetric survey data; and (c) 2018 FDEP survey of Broward and Miami-Dade Counties beaches. The ADCIRC+SWAN model Version 11 mesh provided the base topographic and bathymetric data in the upland areas, Atlantic Ocean, Bakers Haulover Inlet, Stranahan River, Dumfoundling Bay, Biscayne Bay, and other inshore waterways. The other survey data provided updated bed elevation data in IWW Cut-DA9 north of Broad Causeway, Bakers Haulover Inlet, Stranahan River, Dumfoundling Bay, Biscayne Bay, other inshore waterways, and Martin and Palm Beach Counties beaches and nearshore areas. Using either Surface Modeling System (SMS) Version 13.0.13, Vdatum Version 4.0.1, or USACE's Corpscon 6.0.1, this study converted the applied bed elevation data sets to horizontal control reference Universal Transverse Mercator North American Datum of 1983 (NAD83) Zone 17 and vertical control reference NAVD.

2.2.1 FEMA 2016 South Florida ADCIRC+SWAN Model Mesh Data

Figure 2.4 shows the FEMA 2016 South Florida ADCIRC+SWAN model Version 11 mesh and domain. It includes the Gulf of Mexico, Caribbean Sea, and a portion of the Atlantic Ocean. As shown in Figure 2.5, the mesh provided bed elevation data in the Atlantic Ocean, inshore areas, and upland areas. The horizontal coordinates of the FEMA 2016 South Florida ADCIRC+SWAN model Version 11 mesh are in latitude and longitude and the bed elevation is referenced to m-NAVD.

2.2.2 USACE 2019 Cut-DA9, Bakers Haulover Inlet, and IWW Rerouting Area Bathymetric Survey Data

Figure 2.6 shows the coverage area of the USACE June 11 – 13, 2019 IWW Cut-DA9, Bakers Haulover Inlet, and portions of Biscayne Bay bathymetric survey. The data is provided in feet horizontally projected in State Plane Florida East Zone 0901 referenced to the North American Datum of 1983 (NAD83) and vertically referenced to ft-MLLW. The data replaced the bathymetry data in Cut-DA9 north of Broad Causeway, Bakers Haulover Inlet, and portions of Biscayne Bay.

2.2.3 FDEP Bathymetric and Topographic Beaches Survey Data

This study compiled FDEP Broward County April 10, 2018 and Miami-Dade County May 23, 2016, August 16, 2016, and November 25, 2018 beach monitoring bathymetric and topographic surveys to update the bed elevations along these counties' beaches and nearshore areas. Figure 2.7 shows the Broward County 2018 (red), Miami-Dade County 2016 (teal), and Miami-Dade County 2018 (red) coverage areas of the compiled bathymetric surveys which are referenced to ft-NAVD. For the model mesh development, this study replaced the ADCIRC+SWAN model mesh bathymetry data in their common coverage area to apply recent updates on the bathymetry and topography data.

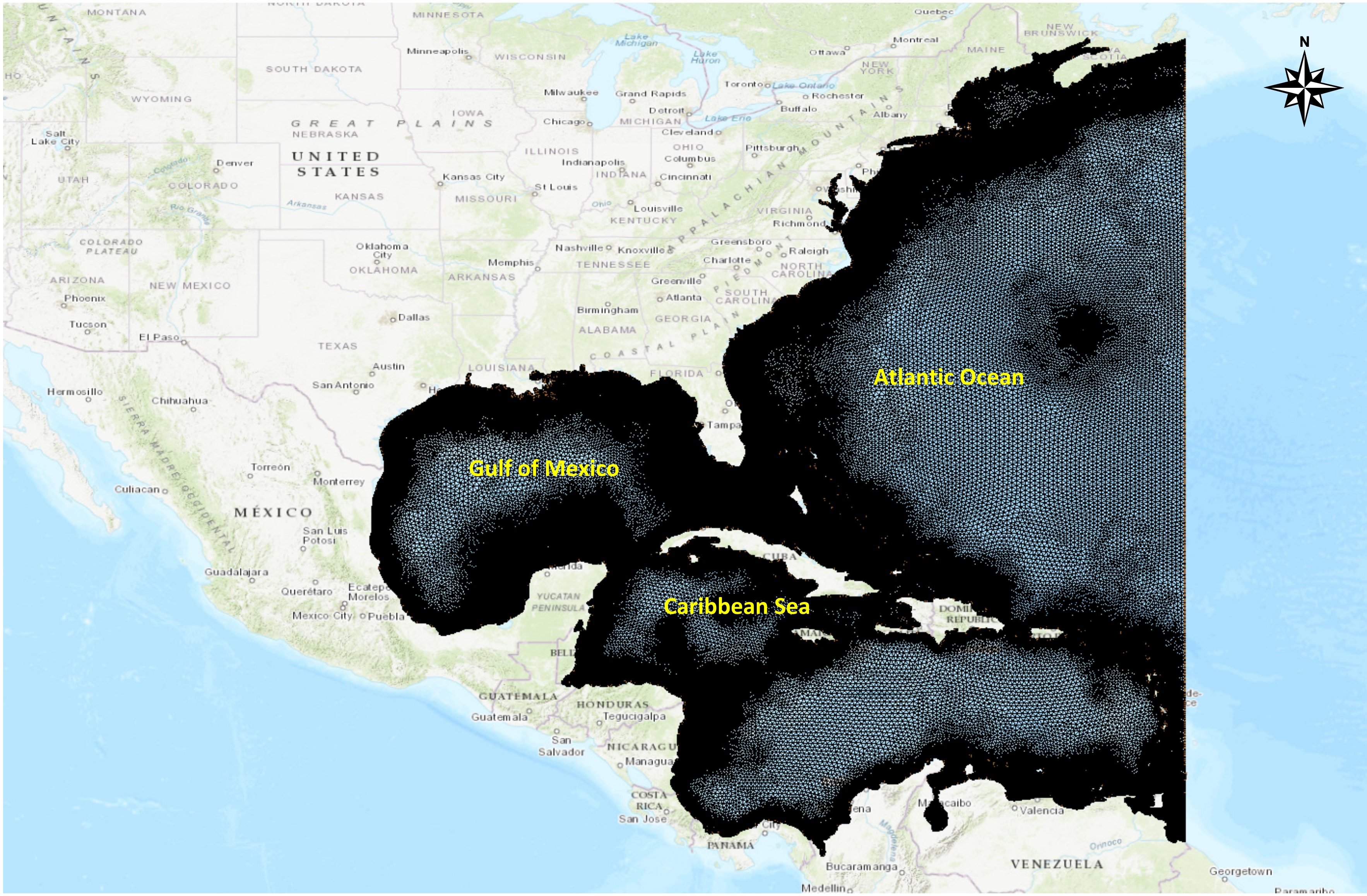

Figure 2.4 FEMA 2016 South Florida Version 11 ADCIRC+SWAN Model Mesh and Domain

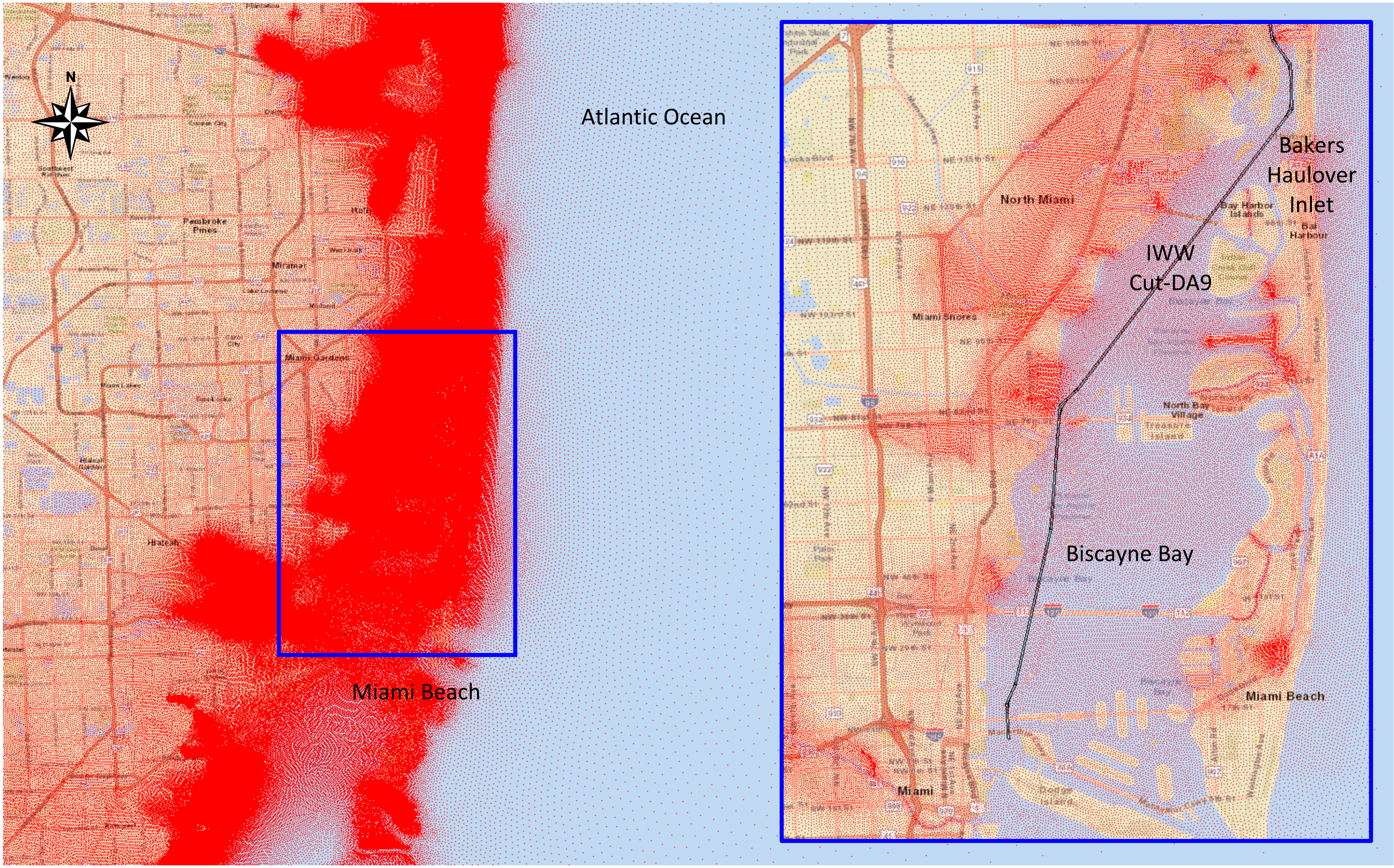

Figure 2.5 FEMA 2016 South Florida Version 11 ADCIRC+SWAN Model Bed Elevation Points

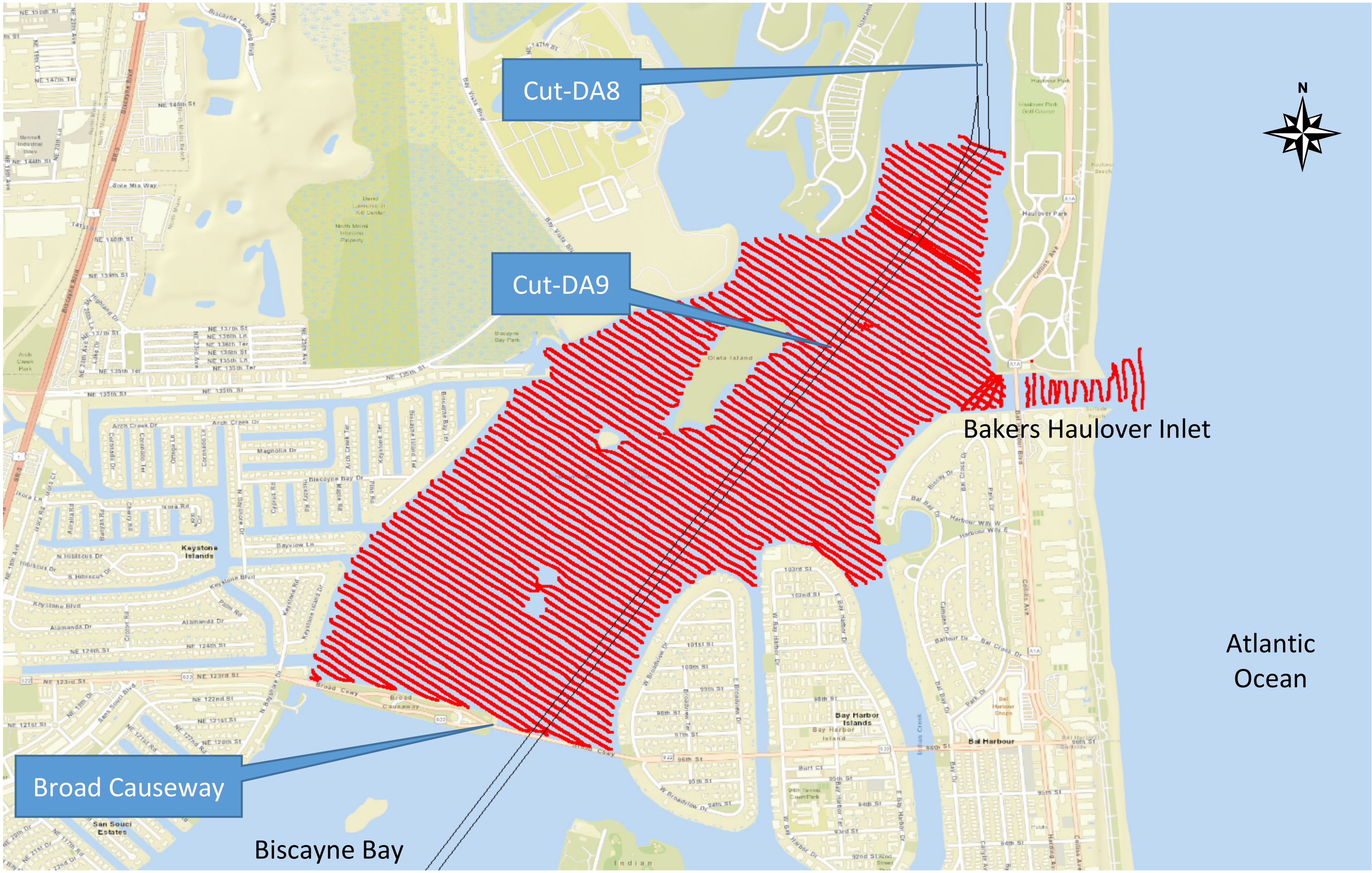

Figure 2.6 Area of 2019 Cut-DA9, Bakers Haulover Inlet, and IWW Rerouting Area Bathymetric Survey Data Update

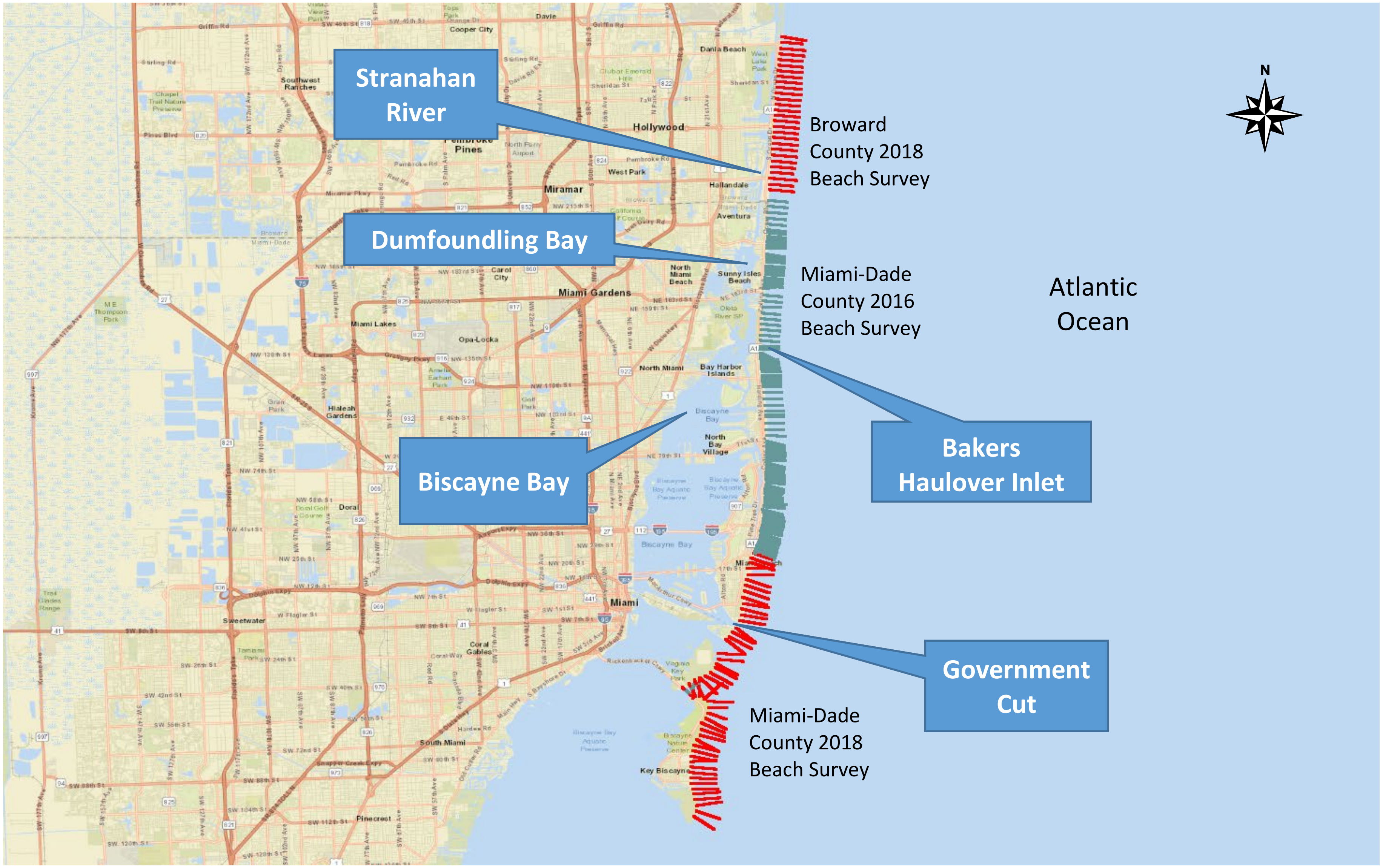

Figure 2.7 Broward and Miami-Dade Counties Bathymetry and Topography Data Update along Beaches and Nearshore Areas

3.0 BISCAYNE BAY MODEL DEVELOPMENT AND MODEL VALIDATION

The BBM applied the MIKE21 Flexible (FM) Mesh Hydrodynamic (HD) Model Version 2022. The BBM calculates water surface elevation, water depth, and flow velocity in Biscayne Bay, connected waterways, and at the area downstream of the S-28 and S-29 structures. The BBM represents portions of the Atlantic Ocean, Bakers Haulover Inlet, Stranahan River, West Lake, North Lake, South Lake, Golden Isles Lake, Dumfoundling Bay, Maule Lake, Little Arch Creek, Biscayne Bay, Indian Creek Lake, Indian Creek, Tatum Waterway, Flamingo Waterway, Surprise Lake, Surprise Waterway, Biscayne Waterway, Normandy Waterway, Sabal Lake, Little River/C-7 Canal, Biscayne Canal/C-8 Canal, C-9 Canal, and other inshore waterways as 2D waterways.

The MIKE21 FM HD modeling system applies the time-dependent mass and momentum conservation equations to compute transient flows and water surface elevations. The HD model requires flows, velocities, or stage hydrographs at its boundaries. Given the hydraulic conditions at the boundaries, MIKE21 FM HD—a two-dimensional, transient, and depth-averaged model—employs finite volume methods to compute flows and water surface elevations inside the model domain. The governing equations treat conservation of mass, conservation of momentum in the x- and y-directions, and turbulence closure. Model capabilities include wetting and drying, Coriolis acceleration, wind stress, bed friction assignment, eddy viscosity or Smagorinsky definition of turbulent exchange coefficients, choices for boundary conditions (including flow, velocity, or elevation), and inclusion of flow sources (inflows or outflows).

The engineering community applies the MIKE21 FM HD modeling system for riverine, estuarine, and coastal hydrodynamics purposes worldwide. The sections below focus on the BBM description, model setup including mesh generation, development of boundary conditions, and validation of the model to water levels in Biscayne Bay.

3.1 Biscayne Bay Model Setup

The application of the MIKE21 FM HD modeling system to an area requires development of a finite volume mesh to map the bathymetry and topography into the model's input format. The mesh divides the model domain into triangular and/or quadrilateral elements. The size of the elements usually varies from large sizes (e.g., model mesh element side length approximately at 400 ft) in regions far from the area of interest to very small sizes (e.g., model mesh element side length approximately at 30 ft) at the area of interest. The next step of model setup after mesh development consists of defining the model boundary conditions. The following paragraphs describe the development of the model mesh and application of the model boundary data.

3.1.1 Model Schematization

The BBM mesh development takes advantage of the existing BHIM and existing FEMA South Florida ADCIRC+SWAN model Version 11 meshes. The BHIM, developed by Taylor Engineering for a FIND sedimentation study, used available shoreline and IWW delineation data to generate the BHIM mesh in the IWW and in areas between the IWW and the Stranahan River, Dumfoundling Bay and Biscayne Bay shorelines. Multiple sources provided the topographic and bathymetric data for the BHIM—(a) the Federal Emergency Management Agency (FEMA) 2016 South Florida ADCIRC model Version 11 mesh; (b) USACE 2019 Cut-DA9, Bakers Haulover Inlet, and potential IWW rerouting area bathymetric survey data; and (c) 2018 FDEP survey of Broward and Miami-Dade Counties beaches. Section 2.2 describes the application of these data sets to the existing model mesh. Taylor Engineering added portions of the

ADCIRC+SWAN model mesh to the BHIM mesh to extend the BHIM mesh to upland and barrier island areas that would be inundated during the 10-yr flood surge event. Thus, the BBM mesh and elevation data comes from the existing BHIM for the Biscayne Bay and connected waterways areas and from the existing ADCIRC+SWAN model for upland and barrier island areas.

Requirements for computational efficiency limited the BBM mesh from the mouth of Bakers Haulover Inlet to approximately 7.7 miles (mi) west, 10.7 mi north to the south entrance of Whiskey Creek (NOAA 8722971), and 7.2 mi to San Marino Island (NOAA 8723156) in Biscayne Bay. The BBM mesh also includes smaller waterways near Stranahan River including West Lake, North Lake, South Lake, and Golden Isles Lake; and smaller waterways near Biscayne Bay including Little Arch Creek (located 0.8 mi southwest of Sandspur Island), 0.7 mi of Indian Creek Lake, 7.6 mi of Indian Creek, 0.6 mi of Tatum Waterway, 0.4 mi of Flamingo Waterway, Surprise Lake, 0.3 mi of Surprise Waterway, 1.1 mi of Biscayne Waterway, 1.1 mi of Normandy Waterway, Sabal Lake, Sunset Lake, 1.2 mi of Little River/C-7 Canal, 1.0 mi of Biscayne Canal/C-8 Canal, and 0.1 mi of C-9 Canal. Small elements provided the means to delineate and evaluate in more detail the water levels and water depths in areas downstream of the S-28 and S-29 structures.

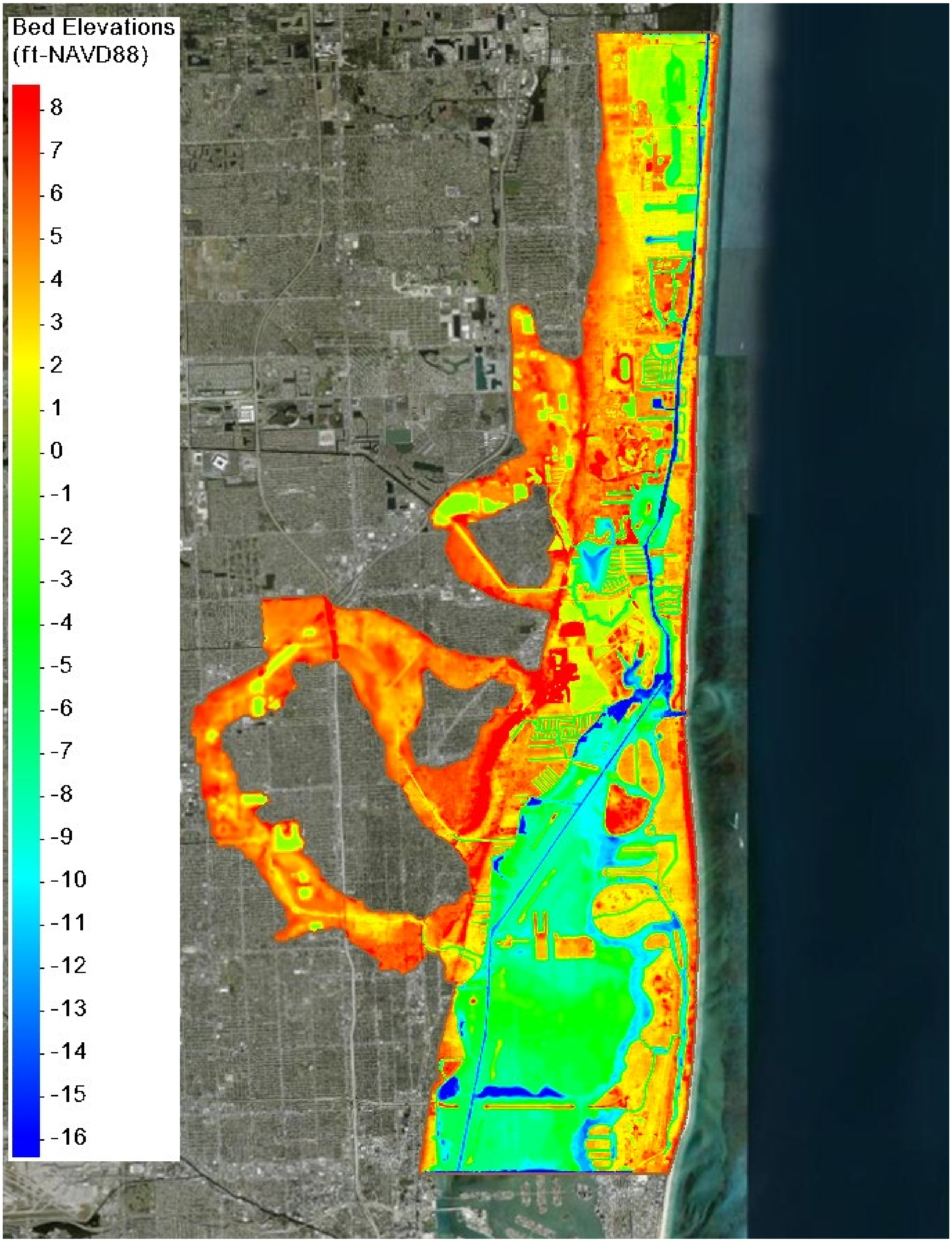

Figure 3.1 shows the BBM domain bed elevations referenced to NAVD and indicates the area of interest in the red inset. Figure 3.2 shows the bed elevations and model mesh at the area of interest that includes portions of C-8 canal, C-9 canal, areas downstream of S-28 and S-29 structures, Maule Lake, Oleta

River State Park, and Biscayne Bay. The mesh horizontal control references the Universal Transverse Mercator North American Datum of 1983 (NAD83) Zone 17.

The programs SMS Version 13.0.13 and MIKEZero Version 2022 (DHI, 2022) provided the user interface for BBM setup. The user constructs a mesh from several of the tools provided and then adds the appropriate resolution in the areas of interest. The program allows the user to input ASCII data files of digitized bathymetry and interpolate the bathymetry onto a mesh.

3.1.2 Model Boundary Conditions

The final step in the BBM setup involved specification of known boundary conditions at the external boundaries of the model mesh. The MIKE21 FM HD modeling system provides several options for external boundaries. For an unspecified mesh boundary, the program automatically assumes a land barrier with a "slip" boundary condition. In short, the flow at nodes on a slip boundary does not have velocity components perpendicular to the boundary. Specified boundary conditions include time-varying free surface elevation, flow, flux, and velocity. The BBM applies time-varying elevation boundary conditions at the mouth of Bakers Haulover Inlet, IWW North (adjacent to Whiskey Creek South Entrance near NOAA 8722971), and IWW South (San Marino Island near NOAA 8723156) model boundaries. The S-28 and S-29 outflows are specified as time-varying flow sources at locations downstream of these structures. A constant flow based on the average monthly outflow from C-7 canal is also included for future model expansion to include outflows from the C-7 canal.

For model validation runs and normal tides production runs, recorded water levels at tide gages at Stranahan River (Station TB1) and Biscayne Bay (Station TB5), and BHIM-calculated water level at the mouth of Bakers Haulover Inlet provided water level forcing data. Table 2.2 provides the coordinates and period of records and Figure 2.2 shows the locations of the water level measurement stations. For 10-yr surge event production runs, ADCIRC+SWAN model calculated water levels at the three model boundaries provided the bases for the development of the BBM boundary forcing data.

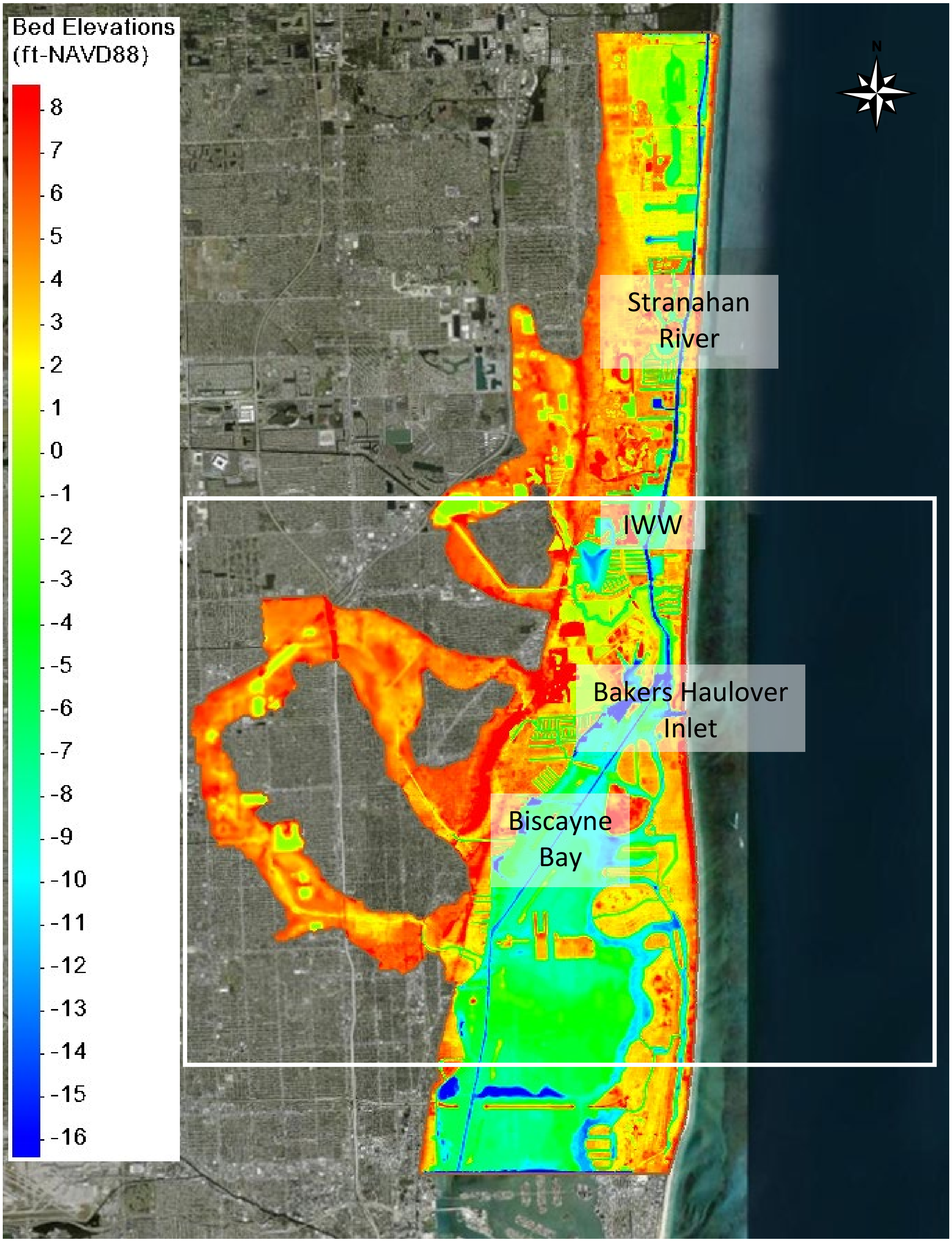

Figure 3.1 BBM Domain, Bed Elevations, and Model Mesh (Inset, shown in Figure 3.2) at the Area of Interest

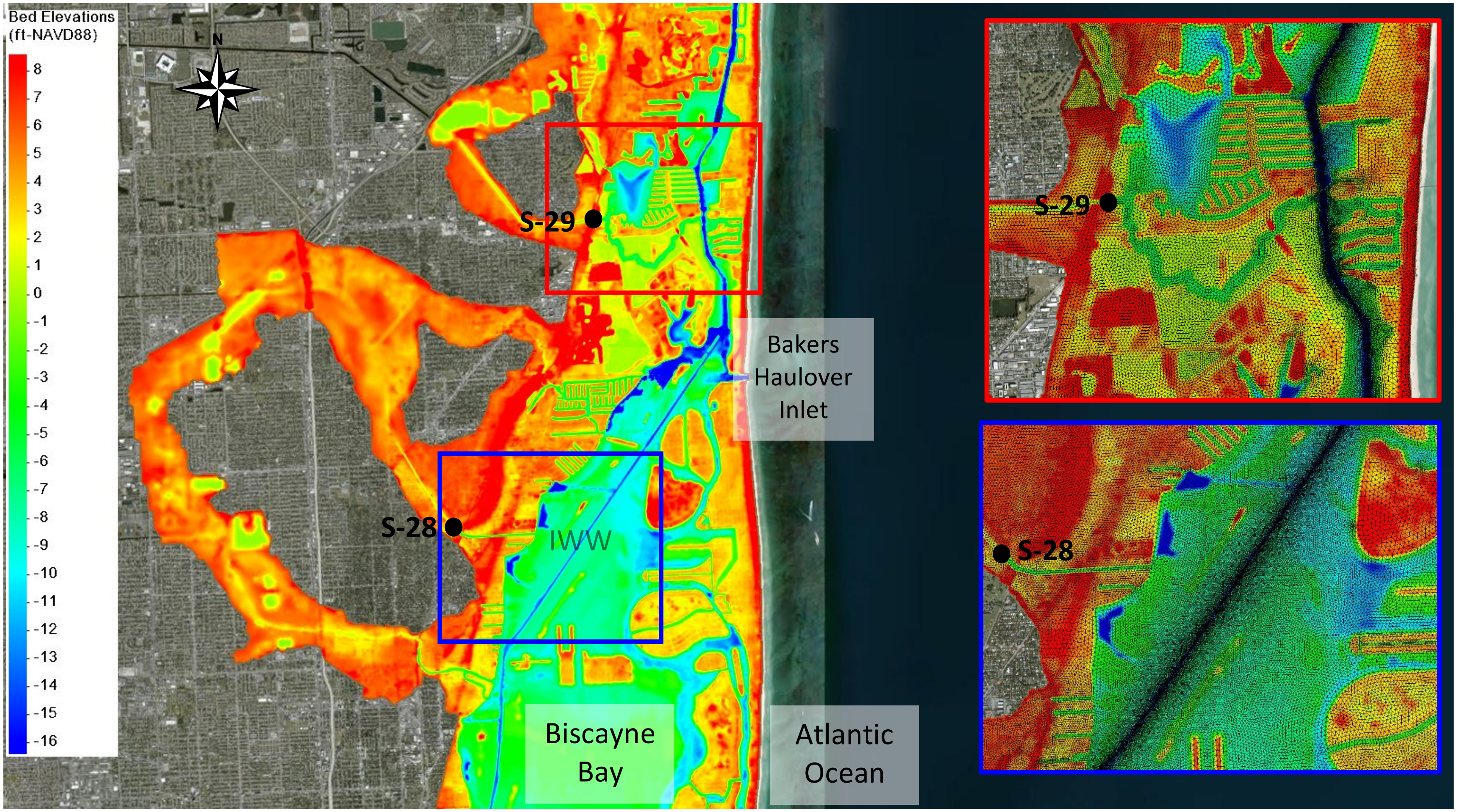

Figure 3.2 BBM Bed Elevations and Mesh at the Area of Interest

3.2 Biscayne Bay Model Validation

Model validation demonstrates a model’s capability to reproduce observed hydrodynamic conditions in the study area. BBM validation for this study consisted of application of model parameters sourced from the BHIM and ADCIRC+SWAN, BBM simulation of water levels for a BHIM validation period, and comparison of modeled and measured water levels at Stations TB2, TB3, and TB4 to check if the BBM model provides good estimation of measured water levels. Thus, this study performed the BBM validation using measured water level data in August 2020.

This study used several statistical tools like the mean error (ME), root mean square error (RMSE), and correlation coefficient (CORREL) to quantify the goodness-of-fit of model results with measured data. The ME (Equation 3.1) measures the average difference between the modeled and measured values, the RMSE (Equation 3.2) measures the absolute differences between the modeled and measured values with large RMSE values indicating data outliers, and CORREL (Equation 3.3) quantifies the quality of fit of the model values to measured values (or the degree to which the variation of model values reflects the variation of the measured values):

$$\boldsymbol{ME(X_m, X_c) = \frac{1}{n}\sum_{i=1}^{n}(X_{m,i} - X_{c,i})}$$

Equation 3.1

$$RMSE(X_m, X_c) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_{m,i} - X_{c,i})^2}$$

Equation 3.2

$$CORREL(X_m, X_c) = \frac{\sum_{i=1}^{n}\left(X_{m,i} - \frac{1}{n}\sum_{i=1}^{n} X_{m,i}\right)\left(X_{c,i} - \frac{1}{n}\sum_{i=1}^{n} X_{c,i}\right)}{\sqrt{\sum_{i=1}^{n}\left(X_{m,i} - \frac{1}{n}\sum_{i=1}^{n} X_{m,i}\right)^2 \sum_{i=1}^{n}\left(X_{c,i} - \frac{1}{n}\sum_{i=1}^{n} X_{c,i}\right)^2}}$$

Equation 3.3

where X_m are the measured values and X_c are the model calculated values. Correlation coefficients of -1 and 1 indicate a perfect negative and positive relationship between two data sets.

3.2.1 Validation of BBM Calibration and Verification

The BHIM used initial Manning’s n values based on land use and land cover classifications as defined by the SFWMD 2014 – 2016 Land Cover and Land Use dataset. Then, BHIM calibration evaluated bed resistance Manning’s n at 0.025, 0.030, 0.035, and 0.040 for Bakers Haulover Inlet, Stranahan River, Biscayne Bay, and smaller inshore waterways and found a Manning’s n value of 0.035 at inshore waterways provided the best agreement with measurements. Thus, the BBM applied Manning’s n values based on BHIM’s Manning’s n spatial distribution in Biscayne Bay and the ADCIRC+SWAN model’s Manning’s n spatial distribution in upland areas.

The BBM validation period was August 15 – 29, 2020. Measured water level at Stations TB2 (near NOAA 8723026 at Golden Beach), TB3 (near NOAA 8723073 at Bakers Haulover Inlet), and TB4 (near NOAA 8723089 at Biscayne Creek) provided the BBM validation data. Figure 2.2 shows the locations of these water level measurements stations. This study applied 1-hr moving averaging to the measured tide data to remove short-term water level oscillations caused by local boat traffic and winds. The measured 1-hr moving averaged water levels at Stranahan River in Station TB1 and Biscayne Bay (Station TB5) provided the BBM boundary conditions. The BBM model's correlation with water level measurements taken at Stations TB2, TB3, and TB4 are important because these locations are near the S-28 and S-29 structures downstream areas. The BBM ability to accurately estimate water levels in this portion of Biscayne Bay is essential.

Table 3.1 provides the ME, RMSE, and CORREL that relate BBM modeled and measured water levels at Stations TB2, TB3, and TB4. The comparison of the modeled and measured water levels in Table 3.1 shows mean error ME of -0.090 to 0.056 ft. Local wind effects and boat wakes contributed to this ME between measured and modeled water level. Given a mean tidal range of approximately 2.03 ft (Station TB2 derived from NOAA 8723026), 2.01 ft (Station TB3 derived from NOAA 8723073), and 2.15 ft (Station TB4 derived from NOAA 8723089), the small ME values comprise less than 2.6% to 4.5% of the mean tidal ranges at these stations. The model-calculated water level compares very well with recorded measurements—with a small RMSE range of 0.087 – 0.153 ft for the 15-day long validation data set. The calibrated water level parameters—when compared to the measured water levels—resulted in correlation coefficients greater than 0.991. A positive correlation coefficient means modeled water levels increase with increasing measured water levels and vice-versa.

Table 3.1 ME, RMSE, and CORREL for Water Levels Comparisons at Select Stations for BBM Validation

Location	Mean Error, ME (ft)	Root Mean Square Error, RMSE (ft)	Correlation Coefficient, CORREL
Station TB2	0.056	0.087	0.998
Station TB3	-0.080	0.104	0.998
Station TB4	-0.090	0.153	0.991

Figure 3.3 shows comparison of the calibration model-calculated (red line) and measured (blue line) water level time series (hydrographs) at Stations TB2, TB3, and TB4 over the BBM validation period. In general, except for slight underestimation of low tides at Stations TB3 and TB4 (likely due to unknown changes in bathymetry and deviations due to local wind setups), Figure 3.3 shows very good agreement between data and model-calculated water levels.

Based on favorable comparison statistics and very good visual comparisons of the model and measured water level, this study deemed the BBM well validated to estimate water levels and water depths in Biscayne Bay and nearby waterways.

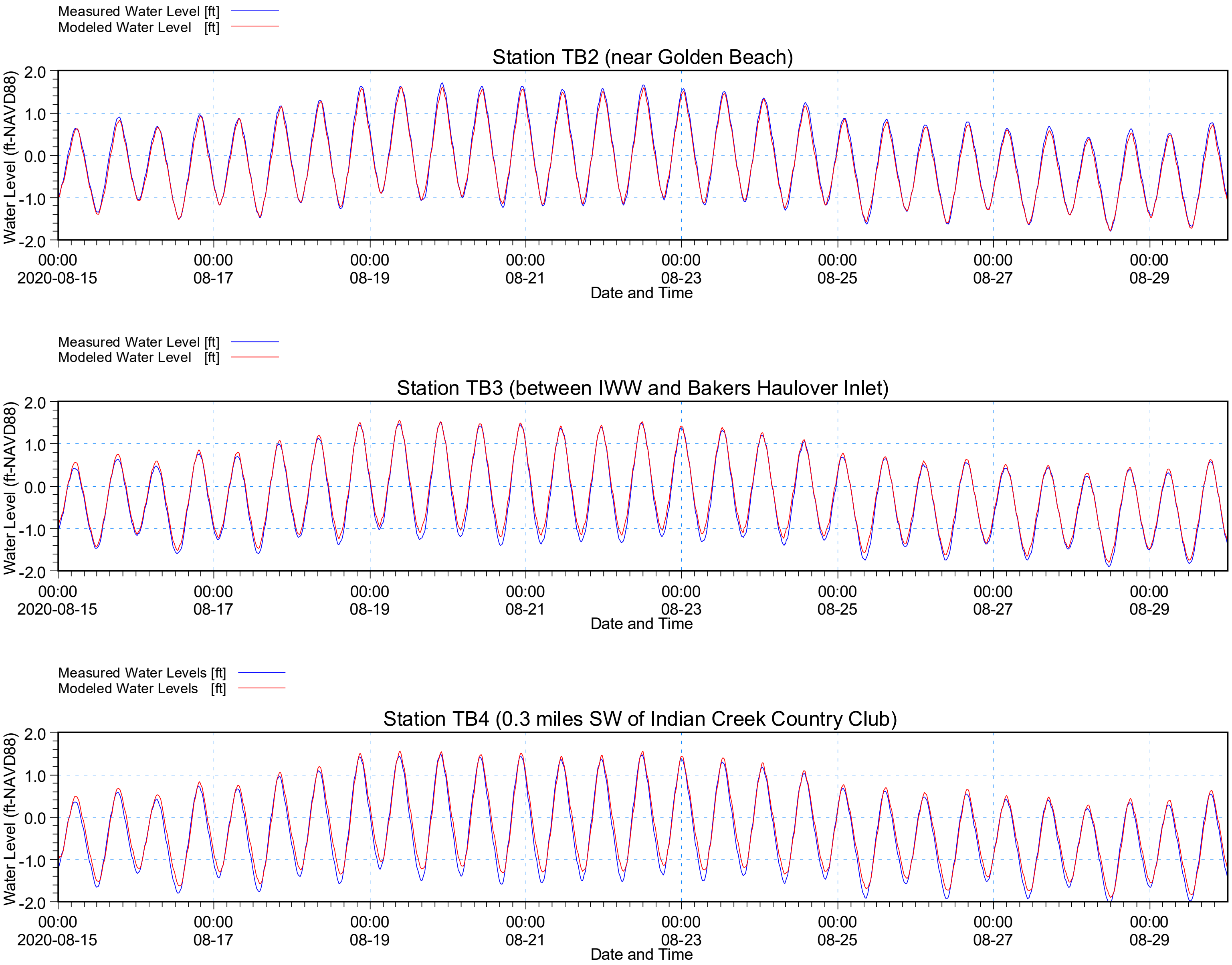

Figure 3.3 Comparison of Modeled and Measured Water Levels at Stations TB2, TB3, and TB4 for BBM Validation

4.0 EVALUATION OF EFFECTS OF S-28 AND S-29 STRUCTURES OUTFLOWS

The evaluation of the effects of outflows from the S-28 and S-29 structures requires (a) an understanding of the various alternatives modeled in FPLOS, (b) an understanding of the flow distribution in the area immediately downstream of the structures, through the canals that connects to Biscayne Bay, and to waterways connected to the bay; and (c) accurate estimation of the water levels in Biscayne Bay. Table 1.1 summarizes alternatives M2A, M3B, and M2C modeled in FPLOS. The BBM presents the flow distribution in areas downstream of the S-28 and S-29 structures, Biscayne Bay, and waterways connected to the bay. The BBM validation in Section 3.2.1 showed the BBM accurately estimates water level in Biscayne Bay and connected waterways. The BBM includes FPLOS source inflows at locations immediately downstream of the structures to evaluate the effects of the structure outflows on Biscayne Bay water level.

This chapter details the magnitude of changes in the peak water levels and the specific areas where such changes would likely occur. The paragraphs below describe the evaluation of the effect of structure outflows on maximum water depths under (1) normal tides, (2) 10-yr surge, and (3) sea level rise conditions.

4.1 Normal Tides Conditions

Recorded water levels at tide gages at Stranahan River (Station TB1) and Biscayne Bay (Station TB5), and BHIM-calculated water level at the mouth of Bakers Haulover Inlet provided BBM water level forcing data. Appendix A provides the FPLOS gate flow and pump flow hydrographs at S-28 and S-29 structures. Temporal translation of these hydrographs allowed consistent tide phasing of the flow hydrographs with the observed tide phase applied in the BBM. Table 4.1 lists the structure outflows and sea level rise conditions applied in the 16-day BBM normal tides conditions simulation period. Baseline (M0) runs characterize conditions without the C-8 and C-9 basins flood mitigation projects (thus no pump flows at the structures). With concurrence of the SFWMD, this study evaluated the effects of Alternative M2C outflows on Biscayne Bay water levels because this alternative provides the largest structure outflows (and therefore the largest potential effect on water levels) when compared to Alternatives M2A and M2B (see Table 1.1).

Table 4.1 Normal Tides Conditions BBM Runs (see Appendix A Figures)

Run	Condition	S-28 Structure Flow		S-29 Structure Flow		Sea Level Rise (ft)
		Gate Flow	Pump Flow	Gate Flow	Pump Flow	
M0-SLR0	Baseline	Figure A.1	none	Figure A.1	none	0
M0-SLR1	Baseline	Figure A.3	none	Figure A.3	none	1
M0-SLR2	Baseline	Figure A.5	none	Figure A.5	none	2
M0-SLR3	Baseline	Figure A.7	none	Figure A.7	none	3
M2C-SLR0	M2C	Figure A.2	Figure A.2	Figure A.2	Figure A.2	0
M2C-SLR1	M2C	Figure A.4	Figure A.4	Figure A.4	Figure A.4	1
M2C-SLR2	M2C	Figure A.6	Figure A.6	Figure A.6	Figure A.6	2
M2C-SLR3	M2C	Figure A.8	Figure A.8	Figure A.8	Figure A.8	3

4.1.1 Effects on Normal Tides with No Sea Level Rise

This study calculated the maximum water depths for each BBM cell in model runs M0-SLR0 and M2C-SLR0 for the normal tides model simulation period. Subtraction of M0-SLR0 element maximum water depth from the corresponding M2C-SLR0 element maximum water depth provided estimates of the effect of Alternative M2C structure outflows on downstream water levels. Figure 4.1 shows the difference in the modeled maximum water depths between M2C-SLR0 and M0-SLR0. The figure shows S-28 structure outflows can increase maximum depths by 0.25 – 1.0 ft in a limited area downstream of S-28 structure. The figure also shows S-29 structure outflows can increase maximum depths by up to 0.25 ft in a small area downstream of S-29 structure (around Maule Lake and Oleta River State Park). Notably, model results do not show substantial change in water levels in Biscayne Bay with M2C-SLR0 structure outflows because the tidal prism flows from the ocean are very much larger than the structure outflows.

4.1.2 Effects on Normal Tides with 1-, 2-, and 3-ft Sea Level Rises

BBM simulations with sea level rises added a constant 1 ft, 2 ft, and 3 ft respectively to each of the three BBM external water level boundaries for the SLR1, SLR2, and SLR3 sea level rise conditions. The evaluation of the effect of S-28 and S-29 structure outflows on downstream water levels followed the same procedure as described in the above section. The calculated differences between the maximum water depths of M2C-SLR1 and M0-SLR1, M2C-SLR2 and M0-SLR2, M2C-SLR3 and M0-SLR3 show (see Figure 4.2 to Figure 4.4 respectively):

a) M2C-SLR1 S-28 outflows can increase maximum water depths by 0.5 – 1.0 ft over a limited area downstream of S-28 structure.

b) M2C-SLR1 S-29 outflows can increase maximum depths by up to 0.25 ft in a small area downstream of S-29 structure (around Maule Lake and Oleta River State Park).

c) M2C-SLR2 and M2C-SLR3 S-28 outflows can increase maximum water depths by 0.1 – 1.0 ft over a slightly larger area (compared to M2C-SLR1) downstream of S-28 structure.

d) M2C-SLR2 and M2C-SLR3 S-29 outflows can increase maximum depths by up 0.1 to 0.25 ft in a slightly larger small area (compared to M2C-SLR1) downstream of S-29 structure. Additionally, water depths are increased in Oleta River north to and including Enchanted Lake of up to 1 ft. (west of US1).

e) The increase in the sea level rise did not substantially increase the difference between baseline and M2C modeled maximum water depths but only slightly enlarges the area affected by M2C structures outflows. This is not surprising as rising sea levels will dampen the effect of any structure outflows on downstream water levels. Thus, normal tides conditions model results generally indicate rising sea levels decrease the effect of S-28 and S-29 outflows on water levels.

f) Normal tides conditions model results indicate the effect of S-28 and S-29 outflows is limited to downstream areas near the structures and do not reach the main Biscayne Bay area.

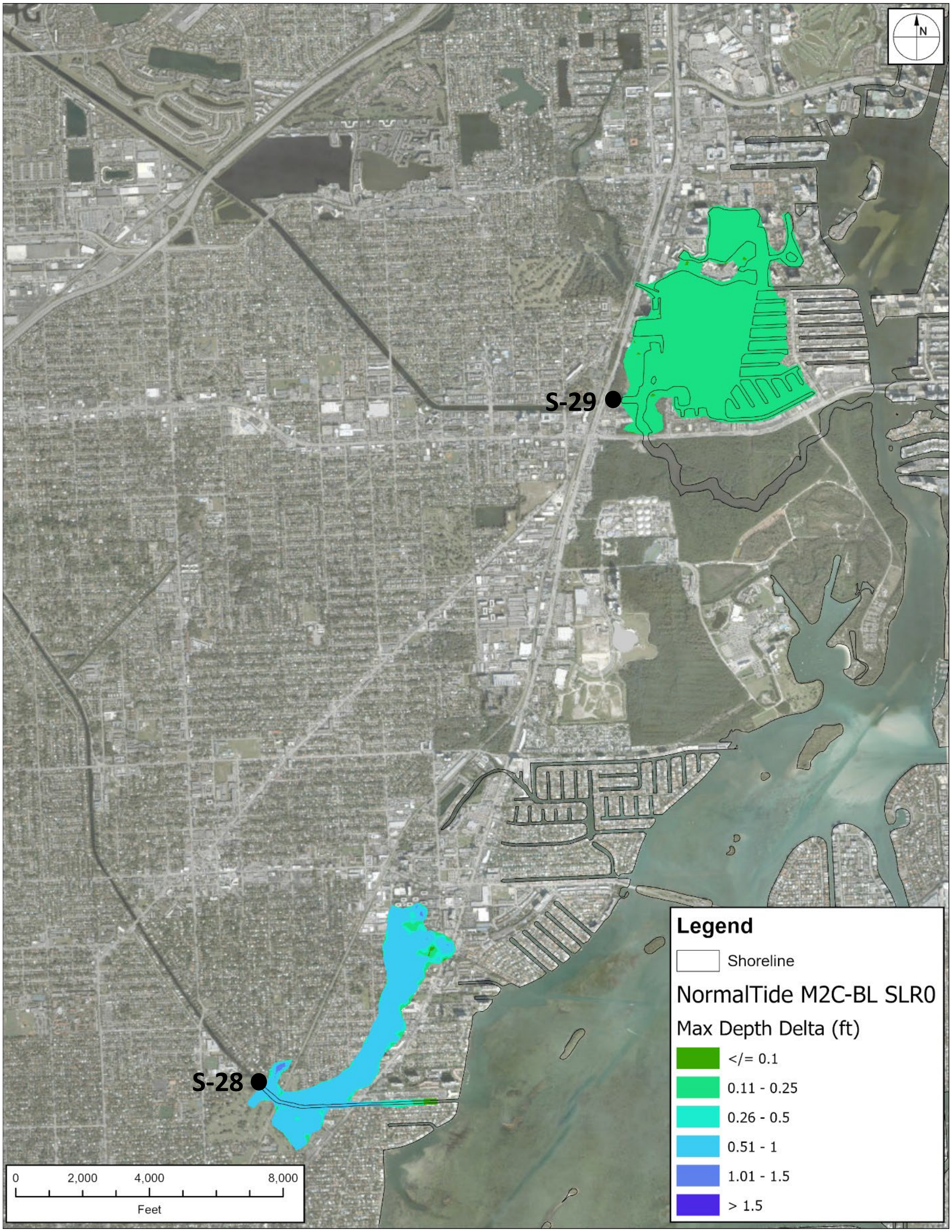

Figure 4.1 S-28 and S-29 Structures Downstream Difference in Normal Tides Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 0 ft)

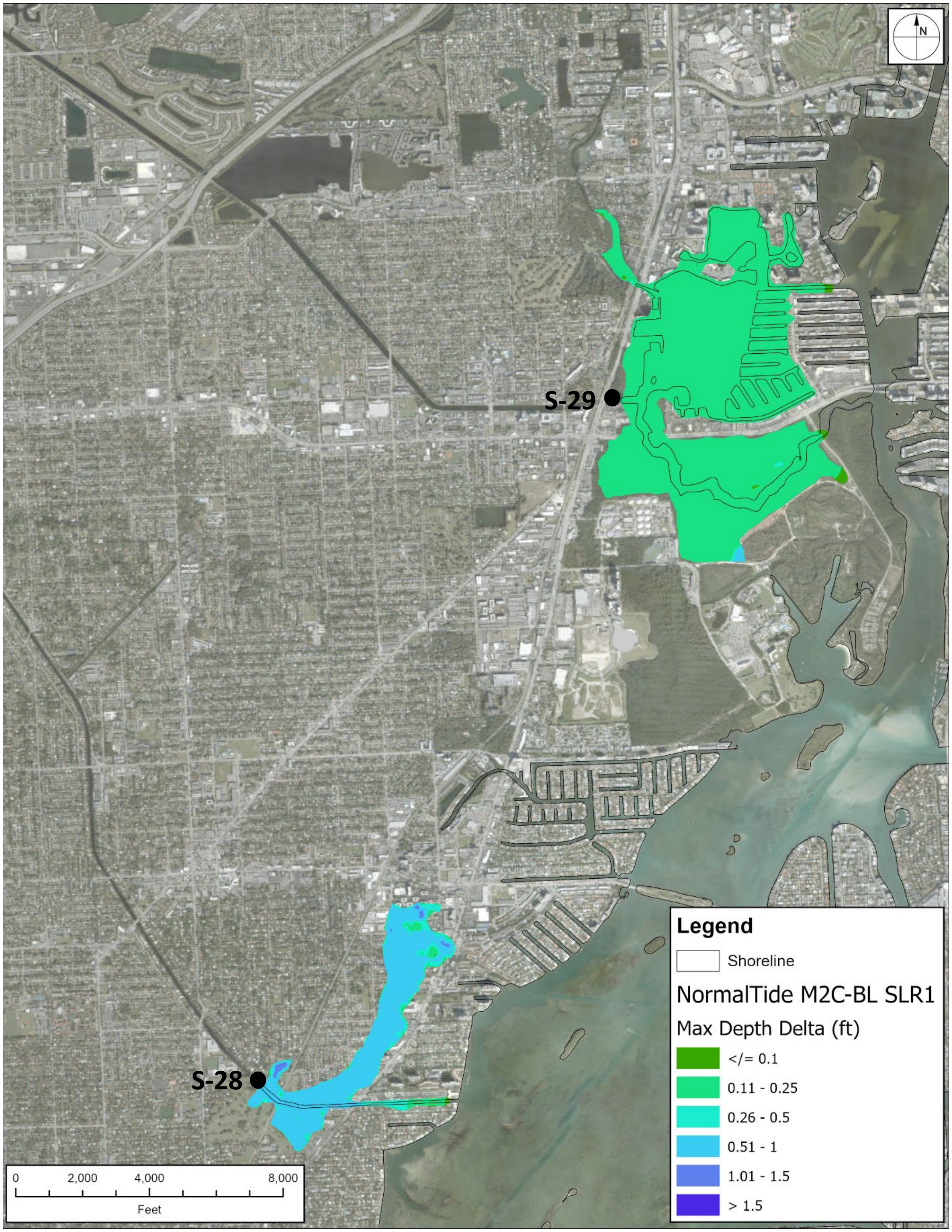

Figure 4.2 S-28 and S-29 Structures Downstream Difference in Normal Tides Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 1 ft)

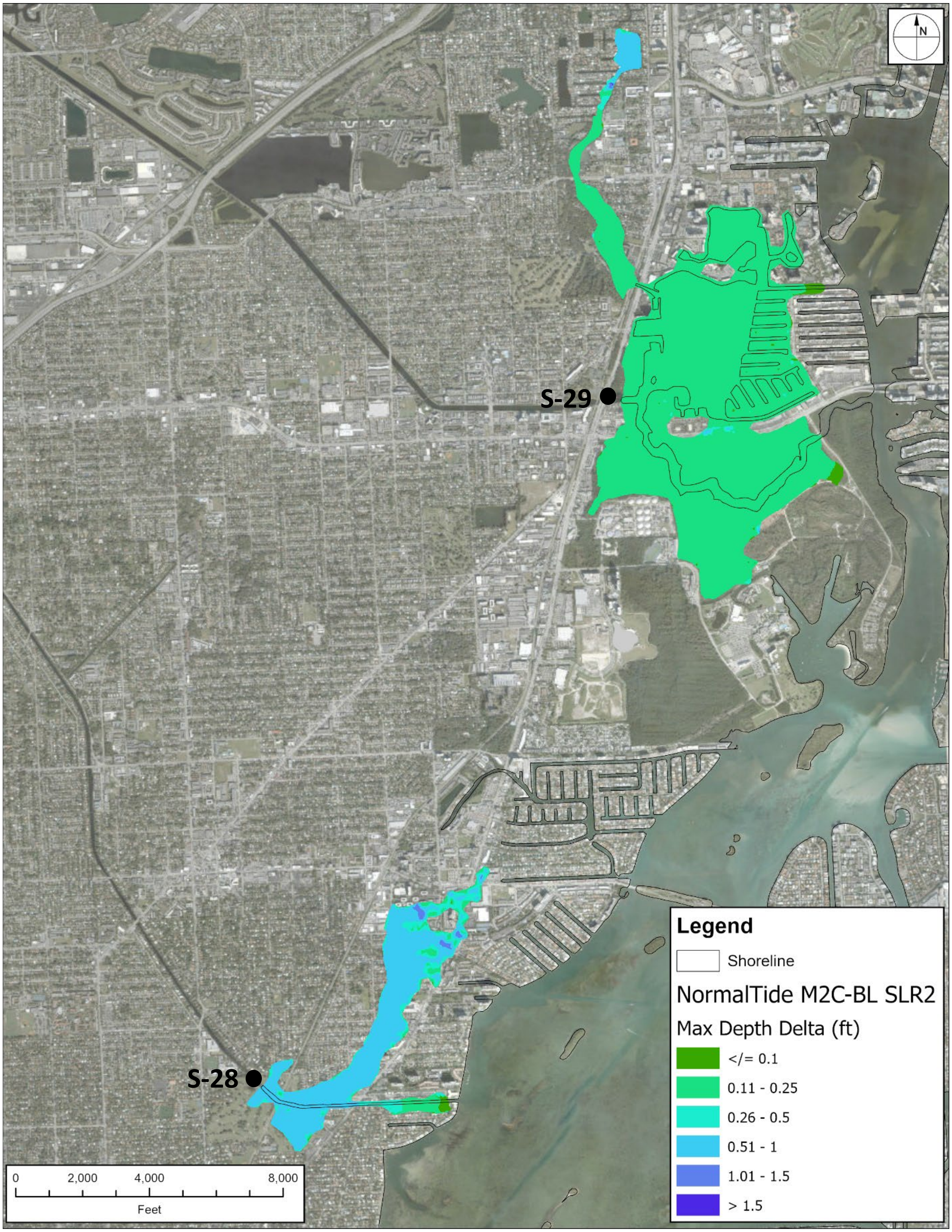

Figure 4.3 S-28 and S-29 Structures Downstream Difference in Normal Tides Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 2 ft)

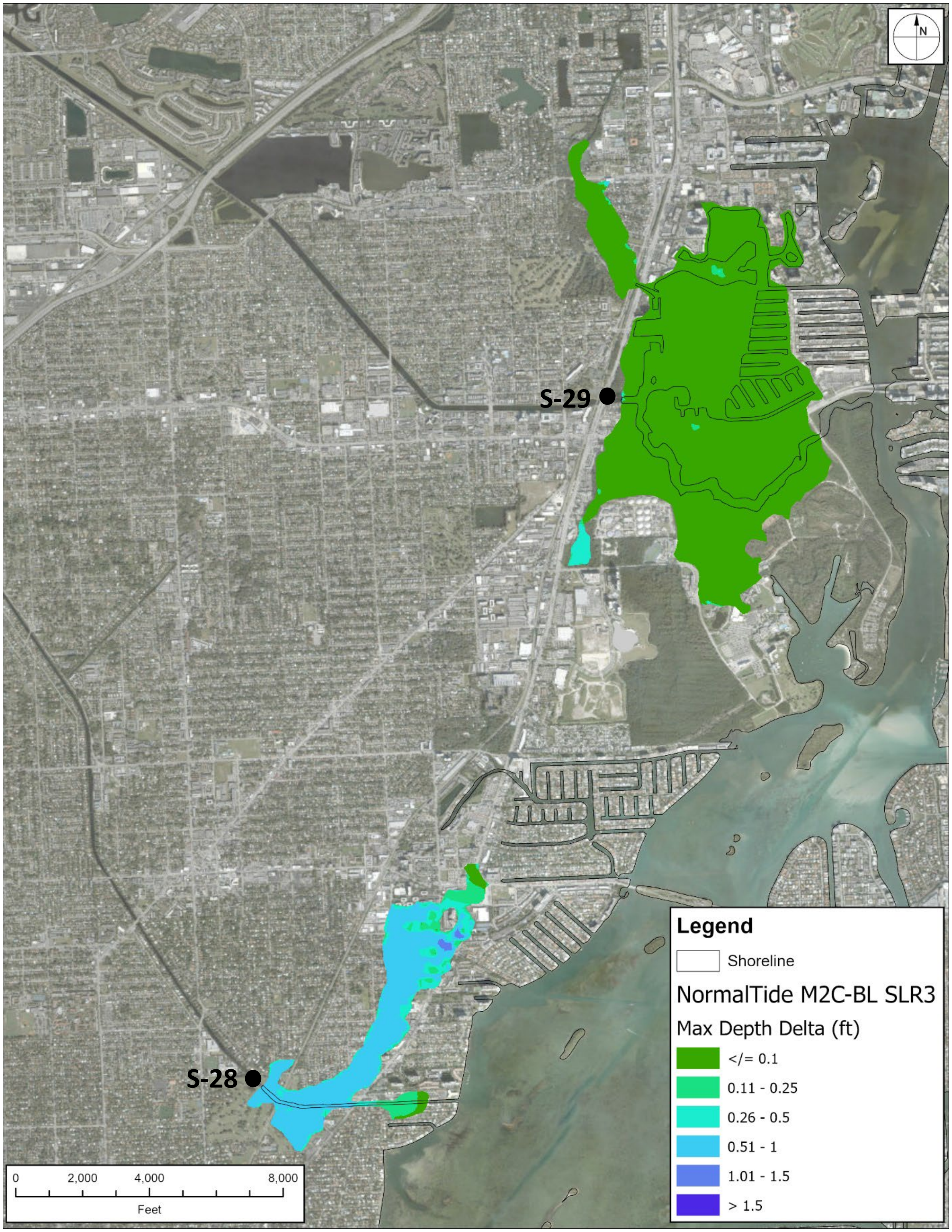

Figure 4.4 S-28 and S-29 Structures Downstream Difference in Normal Tides Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 3 ft)

4.2 10-yr Surge Event Conditions

Appendix B describes the development of BBM water level boundary conditions at the mouth of Bakers Haulover, IWW North, and IWW South boundaries. Table 4.2 lists the structure outflows and sea level rise conditions applied in the 6.4-day BBM 10-yr surge conditions simulation period. Baseline (M0) runs characterize conditions without the C-8 and C-9 basins flood mitigation projects (thus no pump flows at the structures). With concurrence of the SFWMD, this study evaluated the effects of Alternative M2C outflows on Biscayne Bay water levels because this alternative provides the largest structure outflows (and therefore the largest effect on water levels) when compared to Alternatives M2A and M2B (see Table 1.1). The SFWMD also added Alternatives M2A with 1-ft sea level rise and M2B with 2-ft sea level rise to specifically evaluate S-28 and S-29 structure outflows for alternatives that are likely to be constructed in the near the future. Appendix A provides the FPLOS gate flow and pump flow hydrographs at S-28 and S-29 structures.

Table 4.2 10-yr Surge Conditions BBM Runs (see Appendix A Figures)

Run	Condition	S-28 Structure Flow		S-29 Structure Flow		Sea Level Rise (ft)
		Gate Flow	Pump Flow	Gate Flow	Pump Flow	
10-yr M0-SLR0	Baseline	Figure A.9	none	Figure A.9	none	0
10-yr M0-SLR1	Baseline	Figure A.11	none	Figure A.11	none	1
10-yr M0-SLR2	Baseline	Figure A.13	none	Figure A.13	none	2
10-yr M0-SLR3	Baseline	Figure A.15	none	Figure A.15	none	3
10-yr M2C-SLR0	M2C	Figure A.10	Figure A.10	Figure A.10	Figure A.10	0
10-yr M2C-SLR1	M2C	Figure A.12	Figure A.12	Figure A.12	Figure A.12	1
10-yr M2C-SLR2	M2C	Figure A.14	Figure A.14	Figure A.14	Figure A.14	2
10-yr M2C-SLR3	M2C	Figure A.16	Figure A.16	Figure A.16	Figure A.16	3
10-yr M2A-SLR1	M2C	Figure A.17	Figure A.17	Figure A.17	Figure A.17	1
10-yr M2B-SLR1	M2C	Figure A.18	Figure A.18	Figure A.18	Figure A.18	2

4.2.1 Effect of M2C S-28 and S-29 Structures Outflows with No SLR on 10-yr Surge Highwater Levels

This study calculated the maximum water depths for each BBM element in model runs 10-yr M0-SLR0 and 10-yr M2C-SLR0. Subtraction of 10-yr M0-SLR0 element maximum water depth from the corresponding 10-yr M2C-SLR0 element maximum water depth provided estimates of the effect of Alternative M2C S-28 and S-29 structure outflows on 10-yr surge downstream water levels. Figure 4.5 shows the difference in the modeled maximum water depths between 10-yr M2C-SLR0 and 10-yr M0-SLR0. The figure shows S-28 structure outflows can increase maximum depths by mostly 0.25 – 1.5 ft in a limited area downstream of S-28 structure. The figure also shows S-29 structure outflows can increase maximum depths by mostly up to 0.10 ft in a small area downstream of S-29 structure (around Maule Lake and Oleta River State Park). Notably, model results do not show substantial change in water levels in Biscayne Bay with M2C-SLR0 structure outflows because the surge prism flows from the ocean are very much larger than the structure outflows.

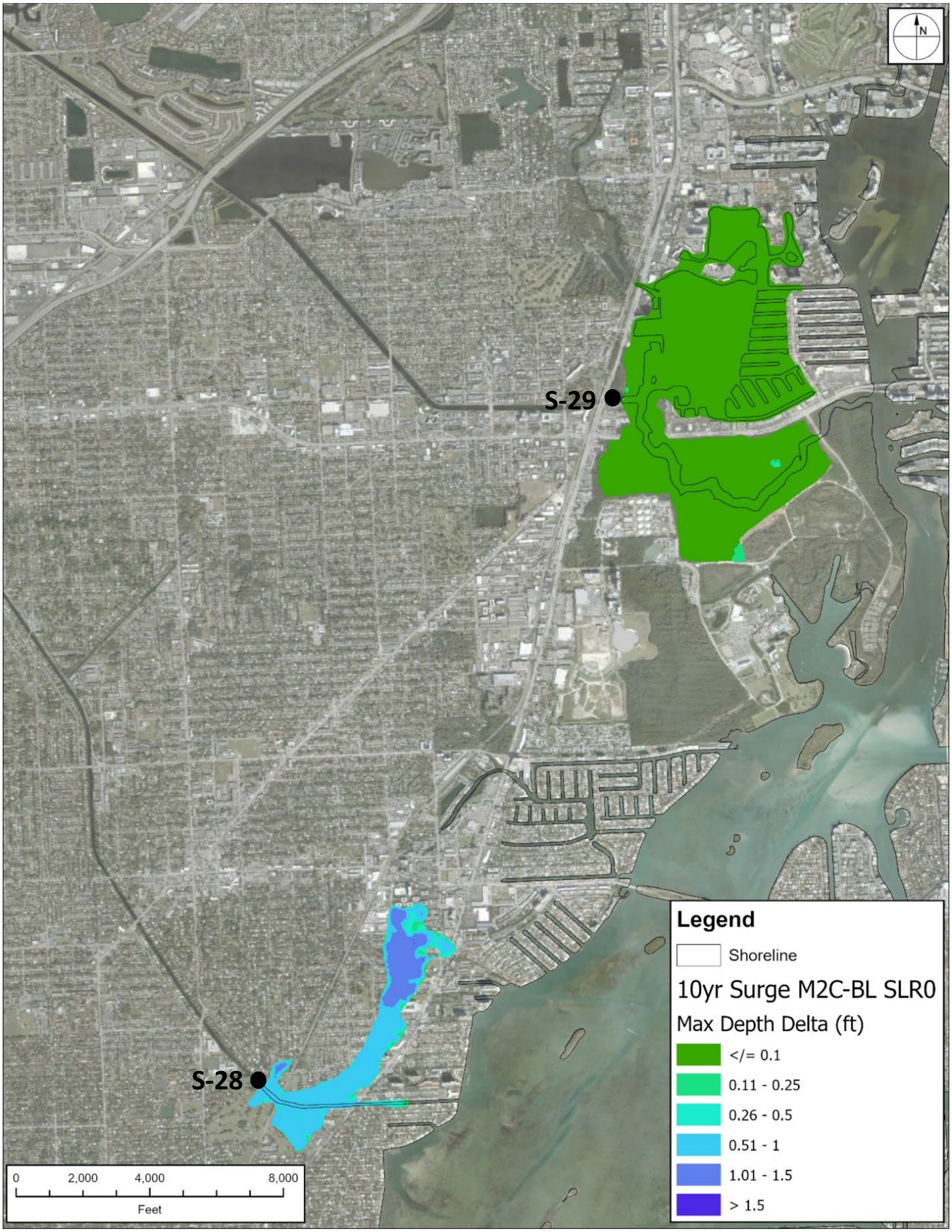

Figure 4.5 S-28 and S-29 Structures Downstream Difference in 10-yr Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 0 ft)

4.2.2 Effect of M2C S-28 and S-29 Structures Outflows with SLR on 10-yr Surge Highwater Levels

BBM M2C 10-yr surge simulations with sea level rises added a constant 1 ft, 2 ft, and 3 ft respectively to each of the three BBM external water level boundaries for the SLR1, SLR2, and SLR3 sea level rise conditions. The evaluation of the effect of S-28 and S-29 structure outflows on downstream water levels followed the same procedure as described in the above section. The calculated differences between the maximum water depths of 10-yr M2C-SLR1 and 10-yr M0-SLR1, 10-yr M2C-SLR2 and 10-yr M0-SLR2, 10-yr M2C-SLR3 and 10-yr M0-SLR3 show (see Figure 4.6 to Figure 4.8 respectively):

a) 10-yr M2C-SLR1 S-28 outflows can increase maximum water depths by mostly 0.5 – 1.5 ft over a limited area downstream of S-28 structure.

b) 10-yr M2C-SLR1 S-29 outflows can increase maximum depths by mostly up to 0.1 – 0.25 ft in a small area downstream of S-29 structure (around Maule Lake and Oleta River State Park) and increased in Oleta River north and west of US1 of up to 1 ft.

c) 10-yr M2C-SLR2 S-28 outflows can increase maximum water depths by mostly 0.25 – 1.0 ft over the same area (compared to 10-yr M2C-SLR1) downstream of S-28 structure.

d) 10-yr M2C-SLR2 and 10-yr M2C-SLR3 S-29 outflows will likely not substantially change maximum depths downstream of S-28 and S-29 structures.

e) 10-yr M2C-SLR3 S-28 outflows can increase maximum water depths by mostly 0.1 – 0.5 ft over a slightly larger area (compared to 10-yr M2C-SLR1 and 10-yr M2C-SLR2) downstream of S-28 structure.

f) As with normal tides conditions wherein rising sea levels dampen the effect of any structure outflows on downstream water levels, the increase in the sea level rise did not substantially increase the difference between 10-yr surge baseline and M2C modeled maximum water depths but only slightly enlarges the area affected by M2C structure outflows. Thus, 10-yr surge conditions model results generally indicate rising sea levels decrease the effect of S-28 and S-29 outflows on water levels.

g) 10-yr surge conditions model results indicate the effect of S-28 and S-29 outflows is limited to downstream areas near the structures and do not reach the main Biscayne Bay area.

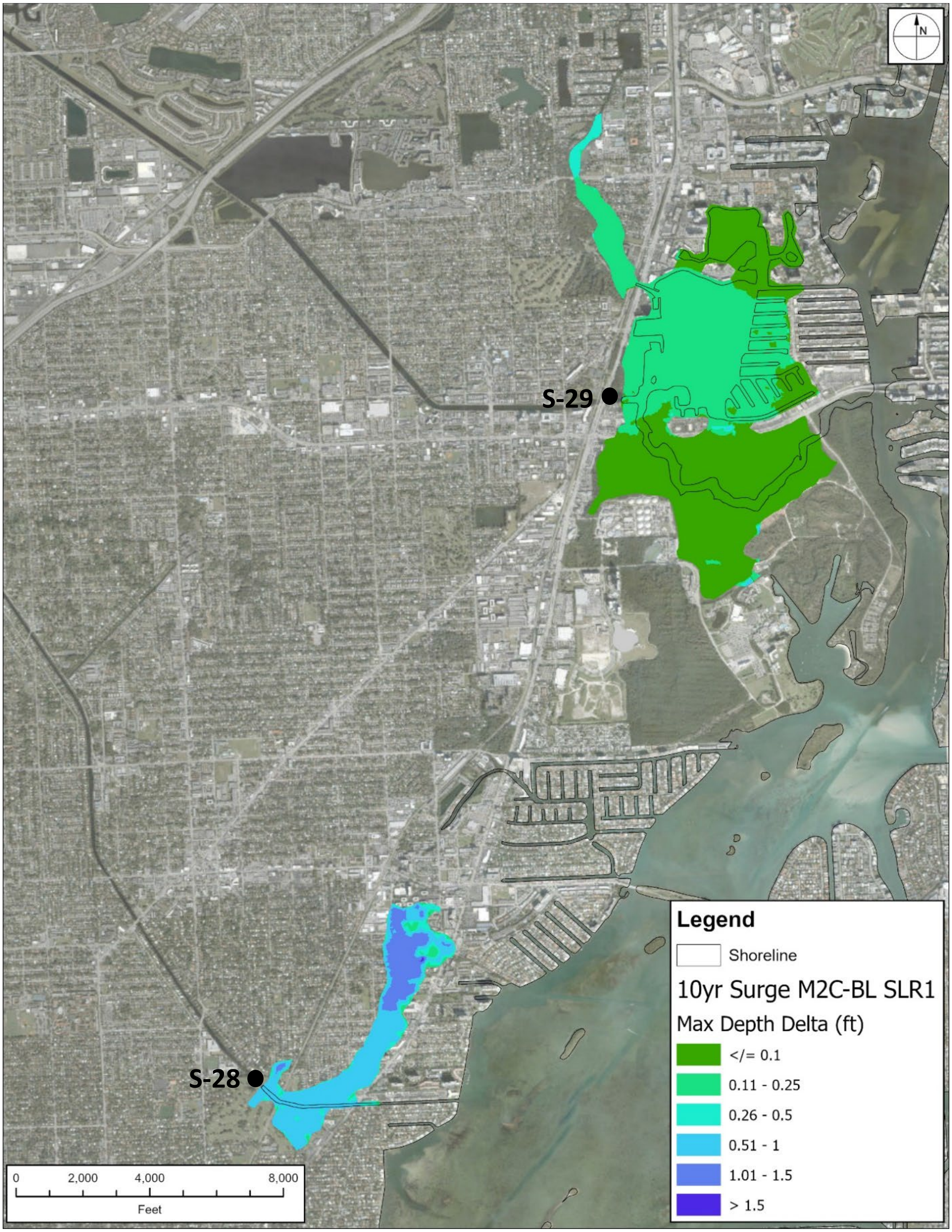

Figure 4.6 S-28 and S-29 Structures Downstream Difference in 10-yr Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 1 ft)

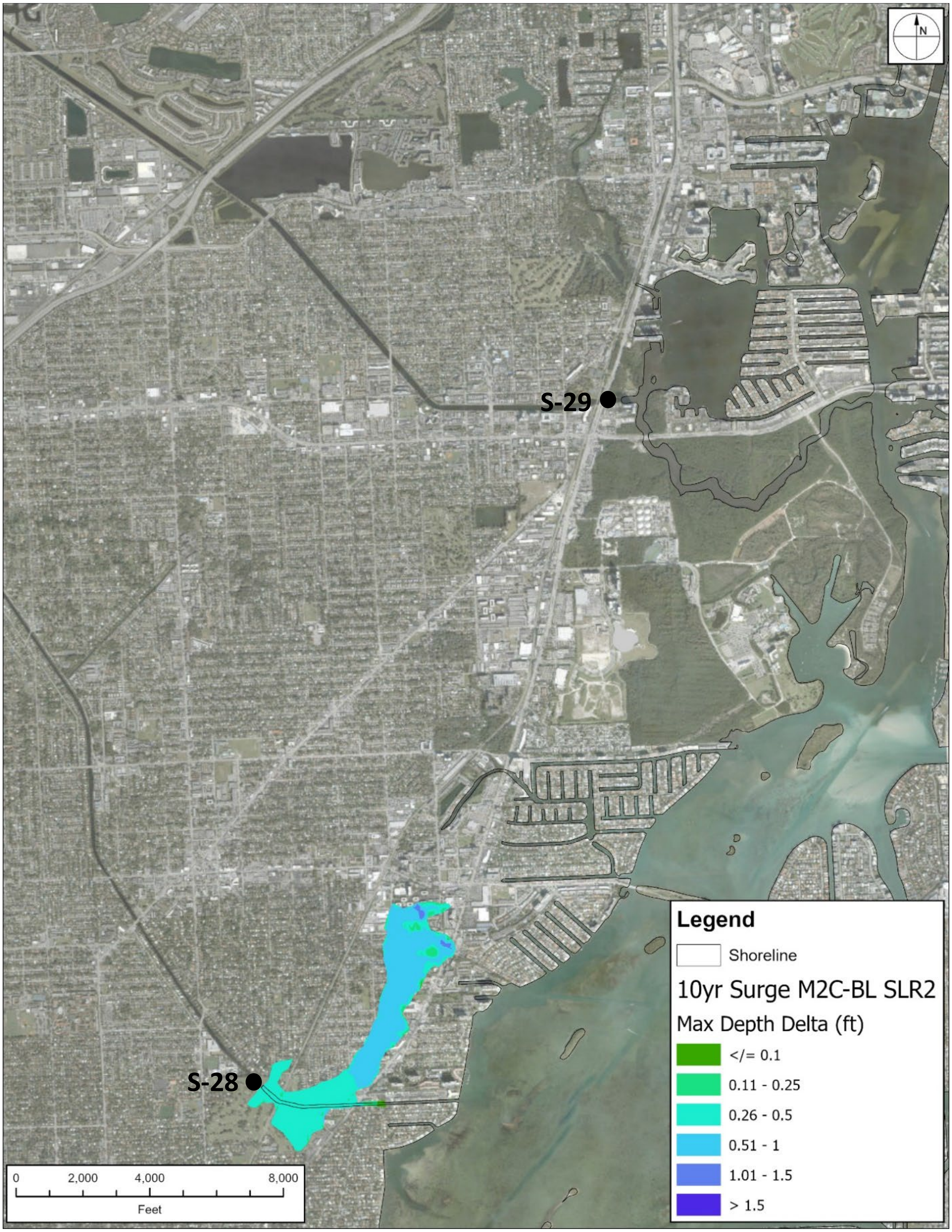

Figure 4.7 S-28 and S-29 Structures Downstream Difference in 10-yr Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 2 ft)

Figure 4.8 S-28 and S-29 Structures Downstream Difference in 10-yr Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 3 ft)

4.2.3 Effect of M2A S-28 and S-29 Structures Outflows with 1-ft SLR on 10-yr Surge Highwater Levels

Figure 4.9 shows the difference in the modeled maximum water depths between 10-yr M2A-SLR1 and 10-yr M0-SLR1. The figure shows S-28 structure outflows can decrease maximum depths by mostly 0.0 – 1.5 ft in a limited area downstream of S-28 structure. The figure also shows S-29 structure outflows can increase maximum depths mostly up to 0 – 0.25 ft in a small area (around Maule Lake and Oleta River State Park) downstream of S-29 structure. Notably, model results do not show substantial change in water levels in Biscayne Bay with M2A S-28 and S-29 structure outflows because the surge prism flows from the ocean are very much larger than the structure outflows.

4.2.4 Effect of M2B S-28 and S-29 Structures Outflows with 2-ft SLR on 10-yr Surge Highwater Levels

Figure 4.10 shows the difference in the modeled maximum water depths between 10-yr M2B-SLR2 and 10-yr M0-SLR2. The figure shows S-28 structure outflows can increase maximum depths by mostly 0.1 – 0.25 ft in a smaller area (compared to 10-yr M2C SLR1, SLR2, and SLR3) downstream of S-28 structure. The figure also shows S-29 structure outflows will likely not substantially change maximum depths downstream of S-29 structure. Notably, model results do not show substantial change in water levels in Biscayne Bay with M2B S-28 and S-29 structure outflows because the surge prism flows from the ocean are very much larger than the structure outflows.

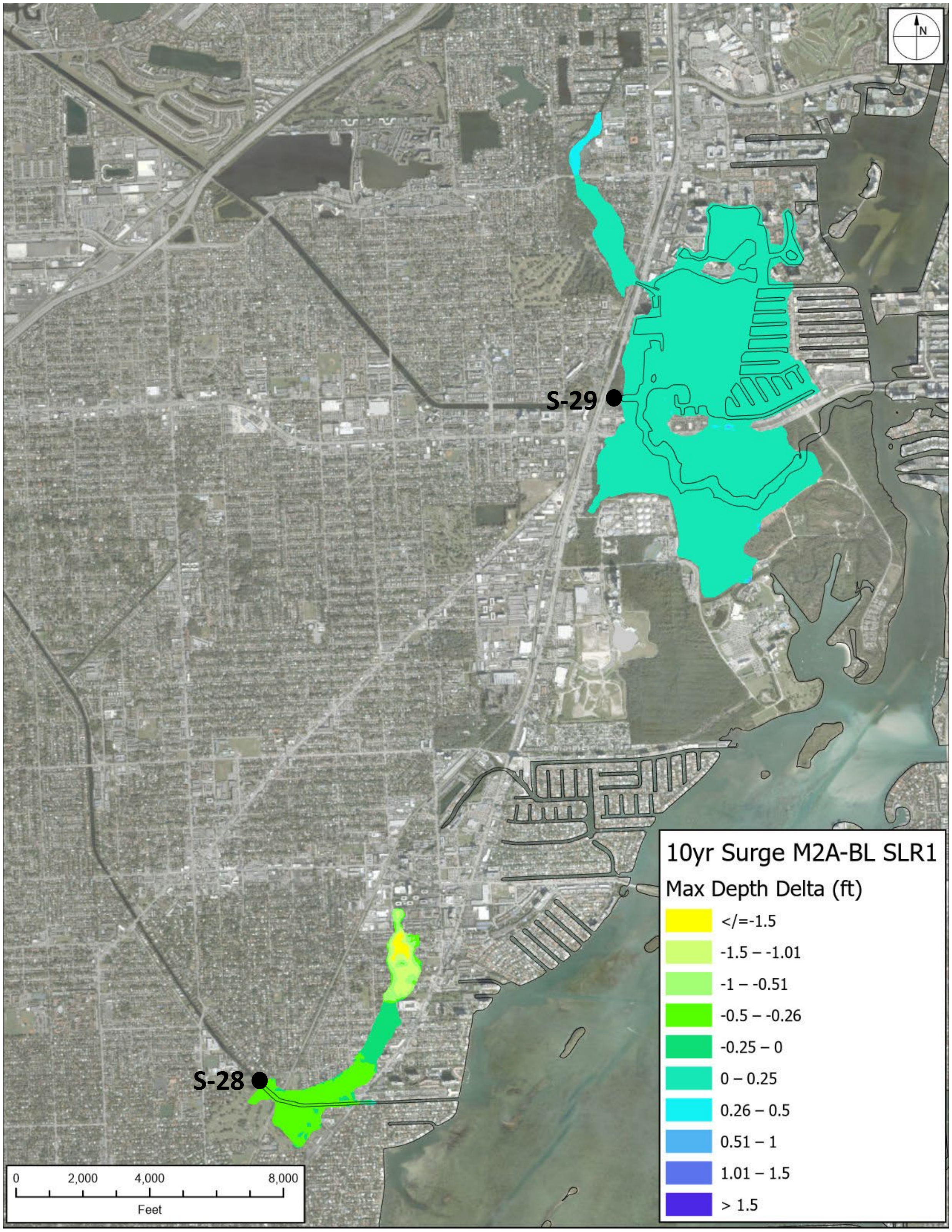

Figure 4.9 S-28 and S-29 Structures Downstream Difference in 10-yr Maximum Depths Between With and Without M2A Alternative Conditions (Sea level Rise = 1 ft)

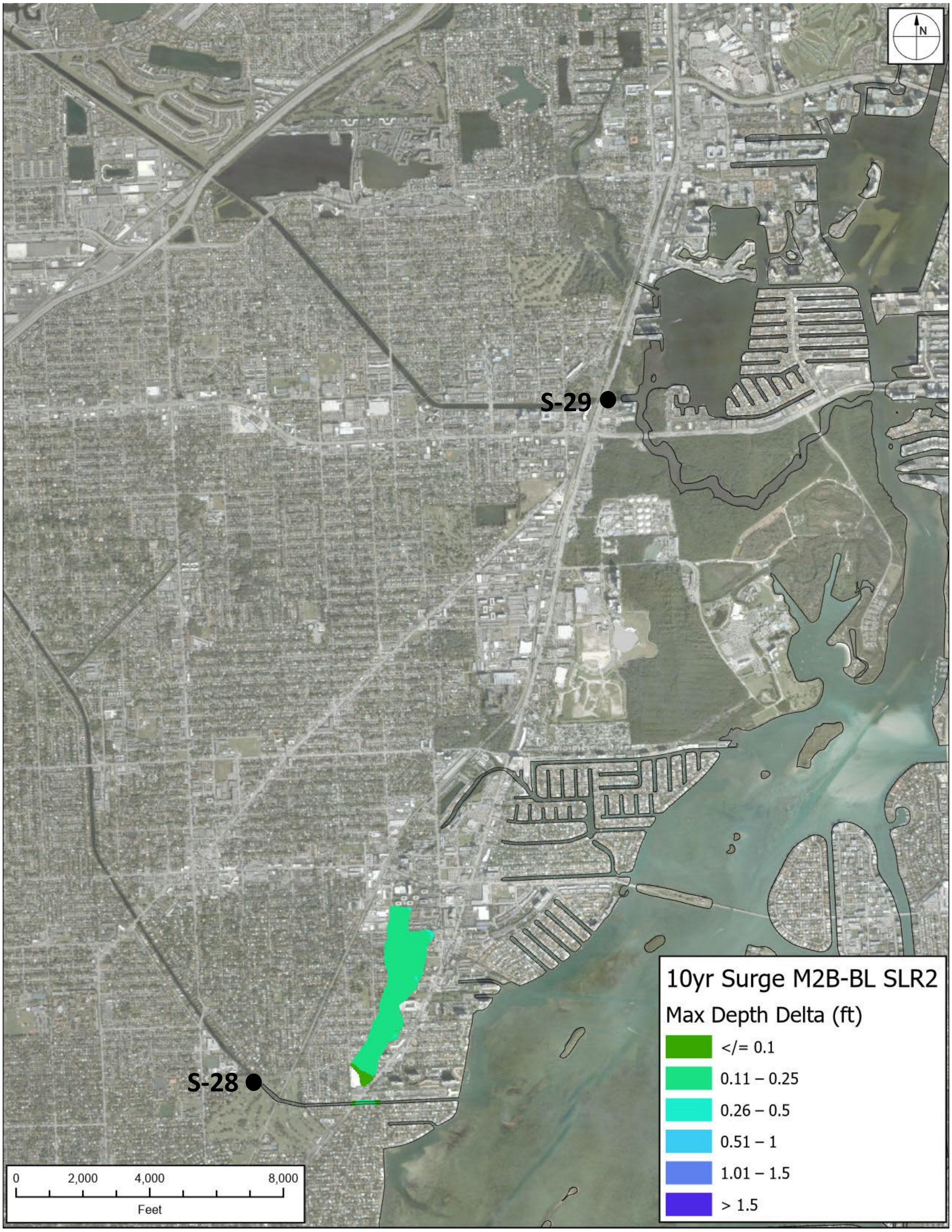

Figure 4.10 S-28 and S-29 Structures Downstream Difference in 10-yr Maximum Depths Between With and Without M2B Alternative Conditions (Sea level Rise = 2 ft)

5.0 CONCLUSIONS AND RECOMMENDATIONS

This study developed the BBM—a two-dimensional depth-averaged hydrodynamic model—to evaluate the effects on downstream water levels of FPLOS outflows at S-28 and S-29 structures. The BBM mesh development takes advantage of an existing FIND MIKE21 hydrodynamic model and existing FEMA South Florida ADCIRC+SWAN model Version 11 meshes. The BBM applies time-varying elevation boundary conditions at the mouth of Bakers Haulover Inlet, IWW North (adjacent to Whiskey Creek South Entrance near NOAA 8722971), and IWW South (San Marino Island near NOAA 8723156) model boundaries. The S-28 and S-29 outflows are specified in the BBM as time-varying flow sources at locations downstream of these structures. The BBM was successfully validated through visual and statistics comparisons of modeled water level with measured data at select locations in Biscayne Bay. Based on favorable comparison of statistics and very good visual comparisons of the model and measured water levels, this study deemed the BBM well validated to estimate water levels and water depths in Biscayne Bay and connected waterways.

Comparison of the calculated maximum modeled water depths for each model element for baseline (no flood mitigation alternatives) conditions and with flood mitigation alternatives (i.e., M2C with 1-ft, 2-ft, and 3-ft sea level rise; M2A with 1-ft sea level rise; and M2B with 2-ft sea level rise) provided estimates of the effect of C-8 and C-9 basins flood mitigation alternatives outflows at S-28 and S-29 on downstream maximum water depths. Table 5.1 summarizes the effects of the S-28 and S-29 structures outflows on downstream maximum water depths.

5.1 Conclusions on Effects of S-28 and S-29 Structures Outflows

Alternative M2C can cause larger peak depth increases downstream of S-28 structure than at downstream of S-29 structure. In contrast to Alternative M2C-SLR1 conditions, Alternative M2A-SLR1 decreases maximum water depths downstream of S-28 structure and has smaller maximum water depth increase downstream of S-29 structure when compared with M2C-SLR1 results. Alternative M2B-SLR2 has smaller maximum water depth increases downstream of S-28 and S-29 structures when compared with M2C-SLR2 results.

Model results show the effects of FPLOS structure outflows are limited to water depths in the downstream areas near the structures and maximum water depths in the main Biscayne Bay area are not substantially affected by the FPLOS S-28 and S-29 structure outflows. Model results also indicate rising sea levels generally decrease the effect of the FPLOS S-28 and S-29 structure outflows on normal tides and 10-yr surge maximum water depths (or water levels). In addition to the net differences in terms of flood depth, our simulations have indicated that Scenarios 2A and 2B will result in little to no increase in the peak stage profiles' for the canal segment downstream of the tidal structures, thereby preserving the conveyance from the secondary and tertiary systems to the primary system. However, it must be noted that Scenario 2C has the potential to negatively impact the downstream urban areas. If the proposed M2C is advanced to the implementation phase, it is crucial that additional mitigation strategies be developed to address the downstream impacts.

Including the effect of rainfall- induced flooding is extremely critical in characterizing the flood risk across South Florida and was the focus of the work done for the FPLOS study. This is reflected in the different return frequencies applied in that study. For determining the potential impact of proposed course of action or adaptation measures downstream of the coastal structures, a parsimonious strategy was employed that started with a simple representation and gradually introduced complexity as needed. This initial analysis excluded rainfall in the area downstream of the structures, but included surge, to understand the impact on canal stages and tailwater conditions. The result in this case indicates de-minimis changes in tailwater conditions and supports the conclusion that no adverse impact will result in the ability of these basins to discharge due to implementing the study recommended measures in M2A and 2B. This suggests that while additional modeling to include rainfall in tidal basins would be important to quantify extent of flooding, it would not change the conclusion that the recommended measures would not cause elevated tailwater conditions. This conclusion may not apply to all projects or basins, or even different recommended measures within the same basin. We consider the application as described in the report sufficiently demonstrates that the recommended measures from this study will not raise tailwater levels and cause adverse downstream flooding.

5.2 Recommendations

Based on the model simulations performed and analyses of model results, this study makes the below recommendation.The current model setup relies on the outflow from the decoupled FPLOS model as an inflow to the BBM. This setup does have its limitations. To better capture the interaction of the headwater and tailwater at the structures, we suggest the District develop a compound rainfall and surge hydrodynamic model simulating the overland flooding from simultaneous or overlapped rainfall and surge events for upstream basins and Biscayne Bay. Couple the FPLOS model (i.e., MIKE-SHE and MIKE overland model) with the compound rainfall and surge hydrodynamic model to evaluate flooding in C-6, C-7, C-8, C-9 basins and Biscayne Bay flooding under different flood mitigation alternatives and storm conditions.

Table 5.1 Summary of Effects of FPLOS Outflows at S-28 and S-29 Structures on Normal Tides and 10-yr Surge Maximum Water Depths

Conditions	Flood Mitigation Alternative	Sea Level Rise (ft)	Effect on Downstream Water Depths		Notes
			S-28 (ft)	S-29 (ft)	
Normal Tides	M2C-SLR0	0	+0.25 to +1.0	up to +0.25	larger increases at S-28
Normal Tides	M2C-SLR1	1	+0.5 to +1.0	up to +0.25	larger increases at S-28
Normal Tides	M2C-SLR2	2	+0.1 to +1.0	up to +0.25	slightly larger area downstream of S-28 structure (compared to M2C-SLR1)
Normal Tides	M2C-SLR3	3	+0.1 to +1.0	up to +0.1	slightly larger area downstream of S-28 structure (compared to M2C-SLR1)
10-yr Surge	M2C-SLR0	0	+0.25 to +1.5	up to +0.1	larger increases at S-28
10-yr Surge	M2C-SLR1	1	+0.5 to +1.5	+0.1 to +0.25	larger increases at S-28
10-yr Surge	M2C-SLR2	2	+0.25 to +1.0	0.0	same area downstream of S-28 structure (compared to M2C-SLR1)

10-yr Surge	M2C-SLR3	3	0.1 to +0.5	0.0	a slightly larger area downstream of S-28 structure (compared to 10-yr M2C-SLR1 and 10-yr M2C-SLR2)
10-yr Surge	M2A-SLR1	1	0.0 to -1.5	0.0 to +0.25	decrease maximum depths downstream of S-28
10-yr Surge	M2B-SLR2	2	+0.1 to +0.25	0.0	smaller area downstream of S-28 (compared to 10-yr M2C SLR1, SLR2, and SLR3)

6.0 REFERENCES

Danish Hydraulic Institute (DHI). 2022. *MIKE 21 Flow Model FM Hydrodynamic Module User Guide*. Horsholm, Denmark.

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