TAYLOR ENGINEERING, INC.

ADCIRC Storm Event Modeling for the Broward County Flood Study

Broward County, FL

August 2018

Final Report

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ADCIRC Storm Event Modeling for the Broward County Flood Study

Broward County, Florida

Final Report

Prepared for

U.S. Army Corps of Engineers

Jacksonville District

by

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1.0 INTRODUCTION

The U.S. Army Corps of Engineers (USACE), Jacksonville District, in partnership with Broward County, Florida, is conducting a Flood Risk Management (FRM) Study to address flooding problems in specific tidally influenced coastal areas (not direct oceanfront) within the county. The Broward County FRM Study is evaluating nuisance flooding in the Hollywood Lakes area in the City of Hollywood, Florida and the Las Olas Boulevard area in the City of Ft. Lauderdale, Florida. Figure 1.1 shows the focus areas for the study. In all report figures, North is oriented to the top of the page. These areas are experiencing damaging nuisance or "sunny day" flooding events. These nuisance-flooding events can cause damage to residential neighborhood homes, and local business and commerce centers. The events can also interrupt critical county services and damage county and municipal infrastructure (evacuation routes, utility systems and structures, etc.). These damaging flooding events are compounded by the combined influence of higher than normal high tides coupled with rising sea levels. As a result, during abnormally high tides, coastal waters overtop existing sea walls in the study area.

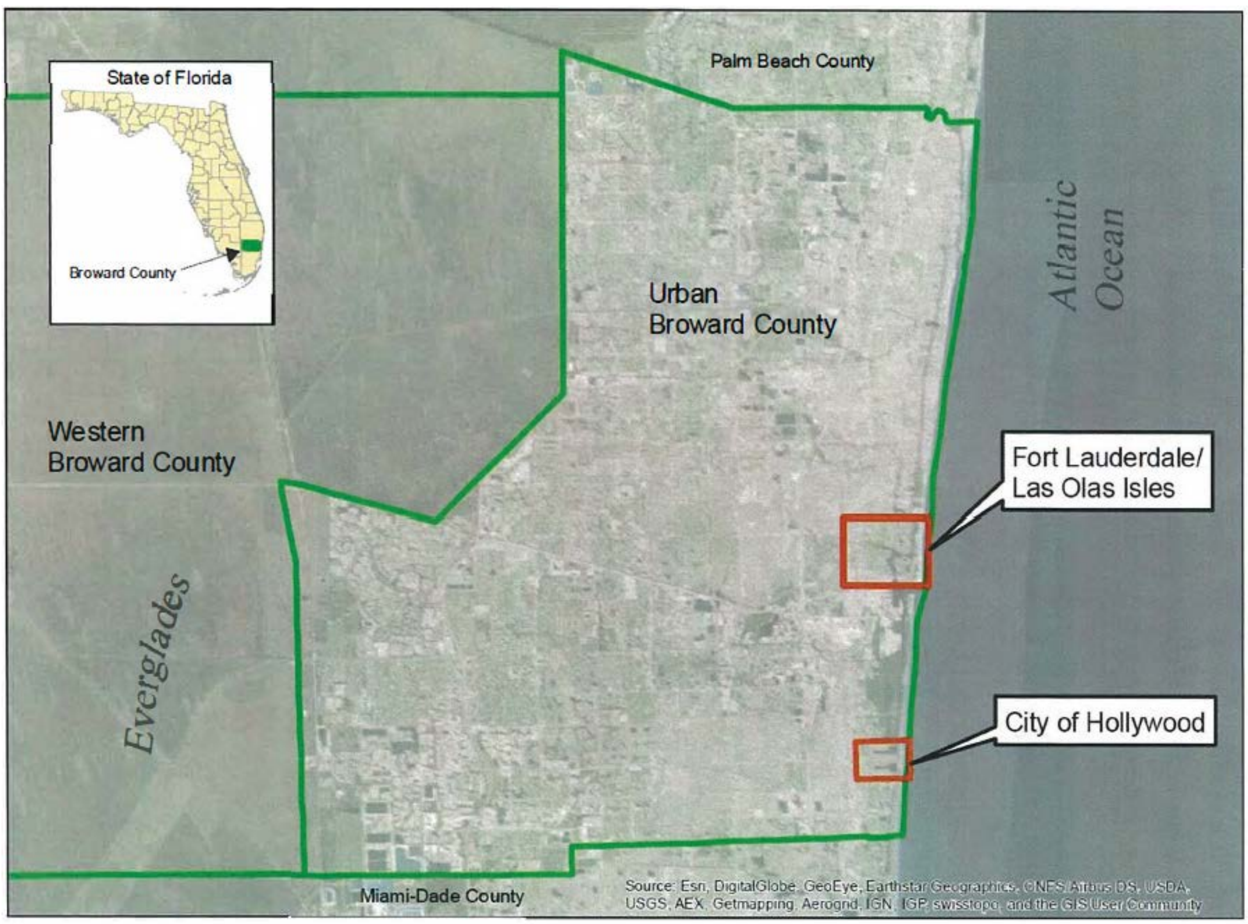

Figure 1.1 Broward County FRM Study Focus Areas (USACE Jacksonville)

Taylor Engineering provided support to the Broward County FRM by developing and applying SWAN+ADCIRC model mesh configurations and storm conditions to evaluate flooding and inundation patterns for various seawall configurations. The SWAN+ADCIRC modeling applied the validated mesh and storm forcing from the Federal Emergency Management Agency (FEMA) Region IV South Florida Storm

Surge Study (SFLSSS) (FEMA, 2017). The SWAN+ADCIRC modeling suite developed for this study allows examination of how different seawall elevations influence simulated flooding and inundation patterns for different storm forcing conditions. A comparison of the modeled maximum water level results for the existing seawall condition to the water level results for a raised seawall configuration allows examination of any potential effects of the seawall height on the storm surge inundation patterns.

Following this introduction, Section 2 describes the development of the SWAN+ADCIRC mesh alternatives. Section 3 describes the selection of the storm forcing. Section 4 provides the model results and discussion. Section 5 summarizes the findings from the study.

2.0 ALTERNATIVE MESH DEVELOPMENT

This portion of the study established the SWAN+ADCIRC mesh configurations, including the Existing Conditions mesh as well as the three seawall alternatives meshes (Alternatives 1, 2, and 3). The Broward FRM Study based its SWAN+ADCIRC meshes from the FEMA SFLSSS mesh, editing both mesh geometry and nodal attributes. The following sections detail the data used to guide mesh updates, the mesh geometry and nodal attribute edits for the Existing Conditions mesh, the nodal elevation interpolation scheme, and seawall alternatives mesh development.

2.1 Available Data

Data sources available within the Las Olas Boulevard area include 2015 LiDAR collected by the City of Fort Lauderdale as well as 3D polylines from the USACE delineating seawall alignments and elevations (FtLauderdale3DSeawalls20171206.shp). The USACE also created buffered polylines offset 5ft upland from the original polylines (FtLauderdale5ftOffset3DGenerated.shp). The buffered polylines extracted local maximum elevations from LiDAR data along areas of the seawall where no recent survey data are available.

Data available for the Hollywood Lakes area include point survey data along the seawalls (SAJ-Seawall_Survey_17-038.xyz) and a 2D polyline layer file delineating seawall alignments (Seawalls_FloodAreas_Hollywood_RMS.lpk). Data availability guided the extents of the project area and mesh edit boundaries. Where new data were not available, the Digital Elevation Model (DEM) developed for the FEMA SFLSSS provided topographic and bathymetric elevation data. Figures 2.1 and 2.2 show polyline data and survey point data available in the Las Olas Boulevard area (east and west portions). Figure 2.3 shows polyline data and survey point data available in the in the Hollywood Lakes area.

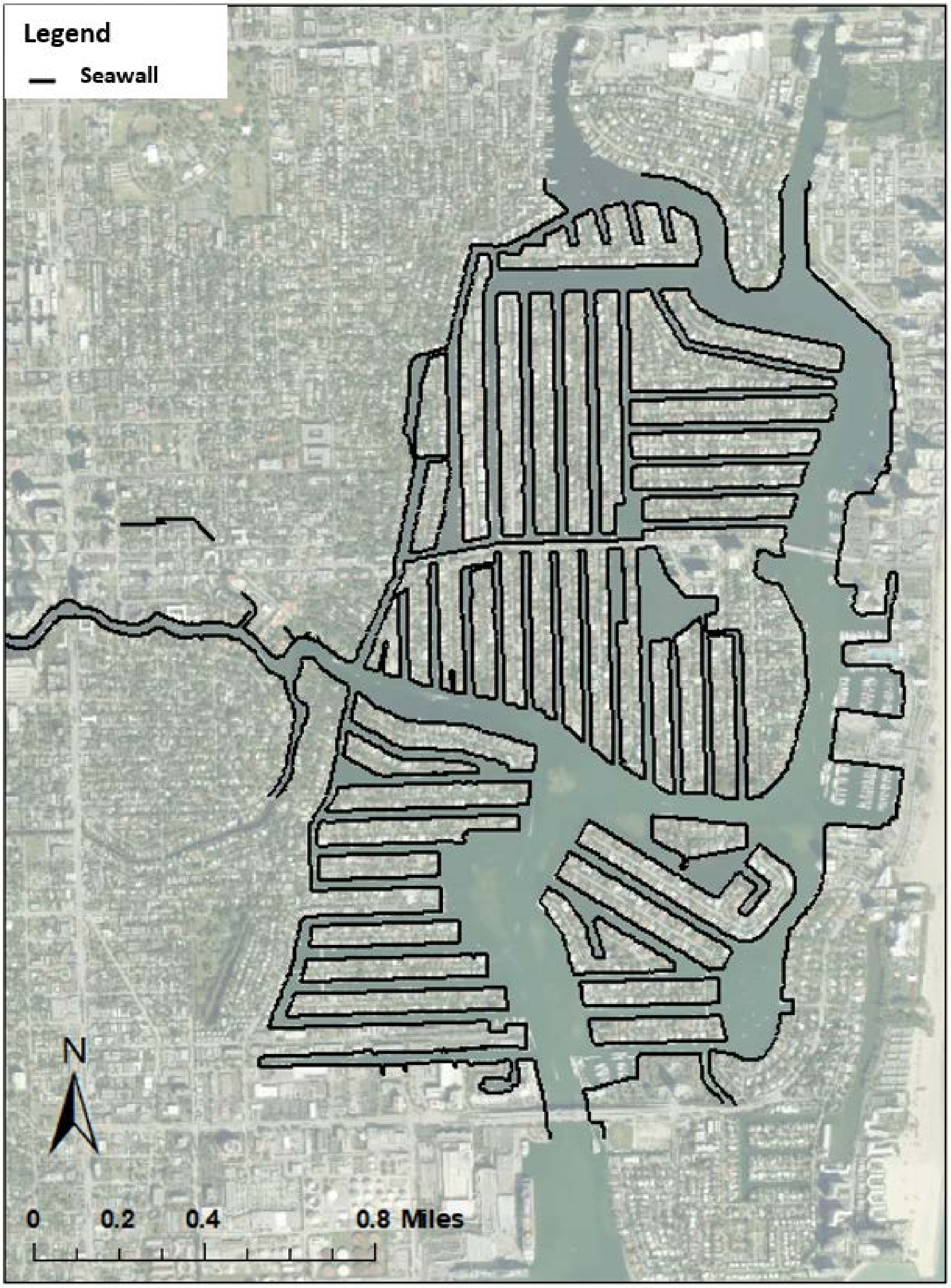

Figure 2.1 3D Polyline Seawall Data in Las Olas Boulevard Area (Eastern Area)

Figure 2.2 3D Polyline Seawall Data in Las Olas Boulevard Area (Western Area)

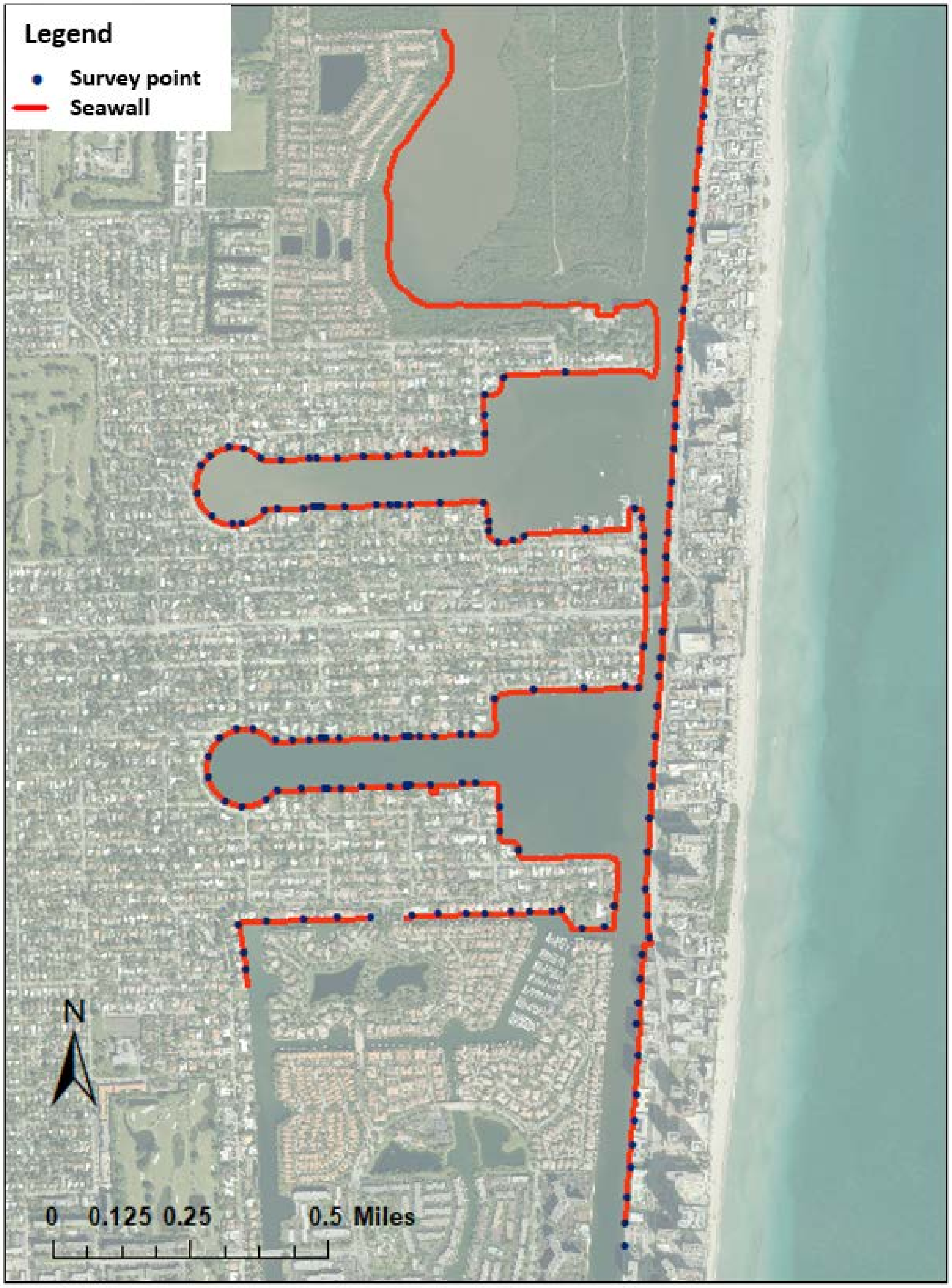

Figure 2.3 Survey Point Data and Seawall Alignments in Hollywood Lakes Area

2.2 Mesh Resolution Changes

In the SWAN+ADCIRC model, all three of an element's nodes must compute as "wet" for the element to become wet and to conduct storm surge and tidal flow. Because channels whose elements become dry at mean lower low water (MLLW) cause unrealistic hydraulic disruptions and numerical instabilities, the FEMA SFLSSS mesh aimed to include as many wet elements across narrow channels as possible. This goal necessitated placing lines of connected nodes just inside of the channel banks rather than on top of banks. Figures 2.4 and 2.5 show plan view and cross-section of this geometric configuration for a narrow channel that can accommodate two wet elements across the channel.

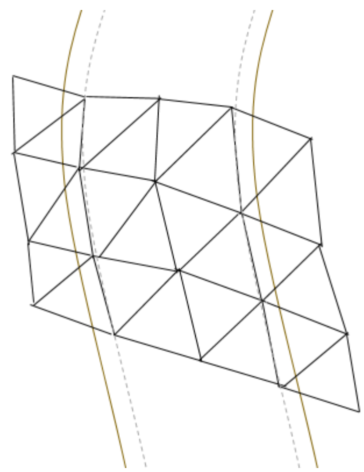

Figure 2.4 Plan View of Mesh Configuration in Narrow Channel as Applied in FEMA SFLSSS Mesh

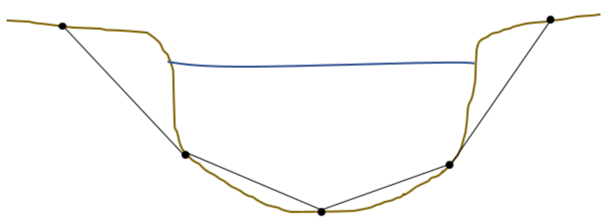

Figure 2.5 Cross-section of Mesh Configuration in Narrow Channel as Applied in FEMA SFLSSS Mesh

The FEMA SFLSSS mesh applied nodal spacing of 40 – 60 ft in the Las Olas Boulevard and Hollywood Lakes regions. The Broward FRM Study mesh edits typically preserved this resolution but altered horizontal mesh geometry to better represent seawalls. Specifics on mesh geometry changes vary throughout the project area depending on the terrain and canal alignments. Due to the narrow nature of the navigational canals throughout greater Fort Lauderdale, the Broward FRM Study generally captured canals with one or two wet elements across the canals, then placed seawalls upland of, but as close as possible to, the wet element inside the channel. This report will refer to such configuration as "adjusted seawalls." Figures 2.6 and 2.7 show plan and cross-sectional views of mesh geometry in an example of the narrowest channel the mesh can capture (~40 ft wide) with adjusted seawalls. In the plan view image, the dotted lines show wetted area within the channel with tide phase at MLLW.

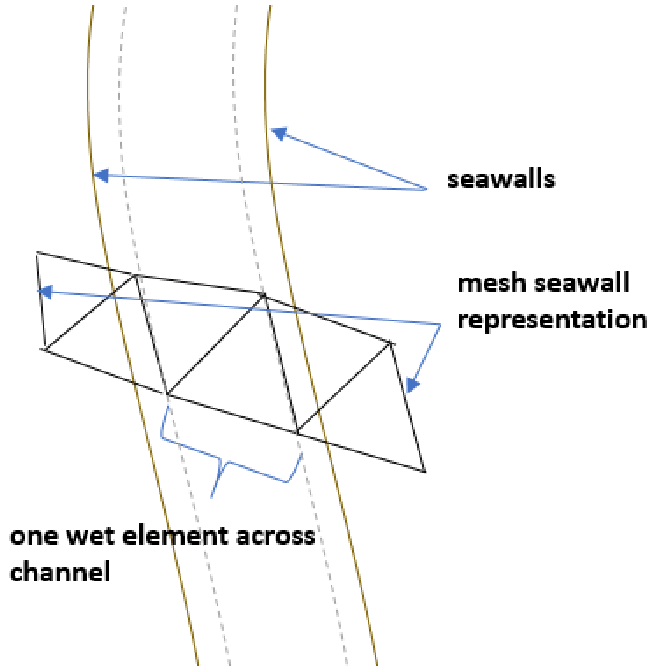

Figure 2.6 Plan View of Mesh Configuration in Narrow Channel with Adjusted Seawall

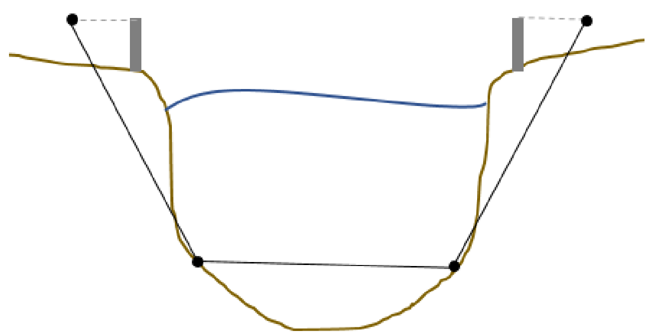

Figure 2.7 Cross-section of Mesh Configuration in Narrow Channel with Adjusted Seawall

Channels that can accommodate five full elements across at maximum resolution (hence minimum nodal spacing) place continuous lines of nodes on top of seawalls at their precise alignments as indicated by the input data polylines. In this scenario, the channels feature three wet elements and two dry elements across at MLLW; when water levels rise above the seawall nodes, the two dry elements become wet and allow flow to overtop into the floodplain. Figures 2.8 and 2.9 show plan and cross-sectional views of this mesh configuration.

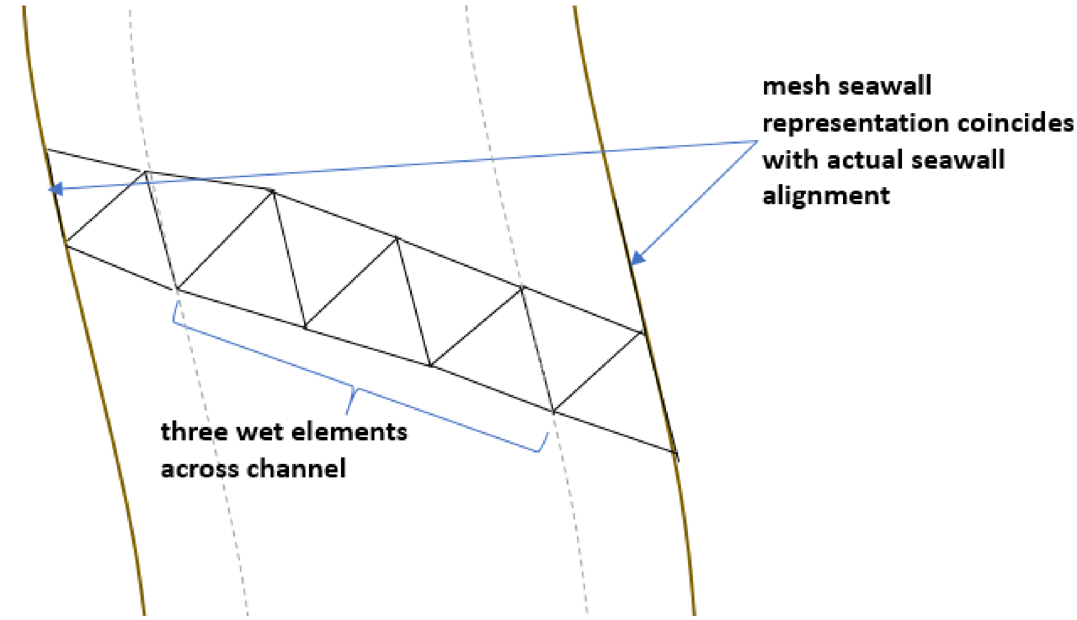

Figure 2.8 Plan View of Mesh Configuration in Wide Channel with Seawall

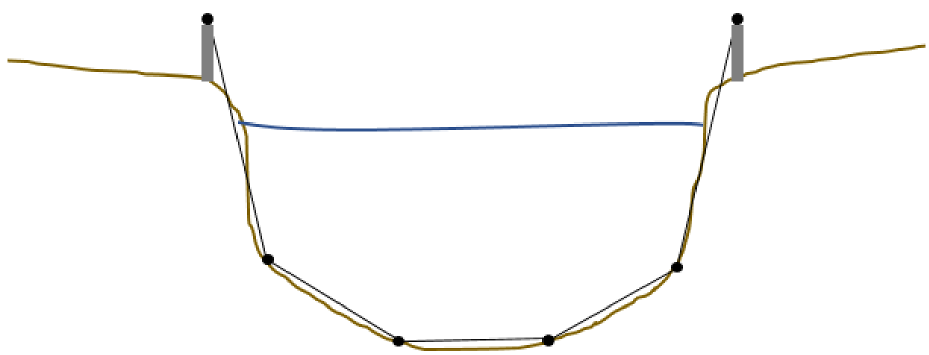

Figure 2.9 Cross-section of Mesh Configuration in Wide Channel with Seawall

The Broward FRM Study selected either adjusted seawall configuration as shown in Figure 2.6 or regular seawall configuration as shown in Figure 2.8 for channels wide enough to accommodate three or four elements across. The selection depended on demonstrated local instabilities occurring during the FEMA SFLSSS. If the area previously exhibited numerical instabilities, then the Broward FRM Study team maximized wet elements inside of the channel via the adjusted seawall configuration (Figure 2.6); otherwise, the team chose the Figure 2.8 configuration.

2.3 Interpolation Scheme

The Broward FRM Study updated the FEMA SFLSSS DEM with 2015 LiDAR data in downtown Fort Lauderdale/Las Olas Boulevard region of the project area. Hydrographic breaklines provided with the LiDAR data guided the boundary for insertion of the updated topography into the DEM. Due to the sparse nature of point and line survey data as compared to the density of the continuous surface of the DEM, the team did not incorporate discrete point and line survey datasets directly into the DEM; instead, varying interpolation schemes applied these elevation data onto the nodes. The interpolation schemes include six categories as presented in Table 2.1. Three of the six pertain to nodes that represent seawalls; applying different interpolation types among seawall nodes provided the most accurate elevation mapping given the varying data sources and alignments.

Table 2.1 Mesh Node Interpolation Code

Code	Node Type	Data Source	Interpolation Method
1	Topographic	DEM	Area average based on element size
2	Bathymetric	DEM	Linear interpolation
3	Dune crest	DEM	Local maximum (10 ft radius)
4	Nodes < 60 ft from a survey point	Survey data	Near function
5	Nodes >= 60 ft from a survey point	Seawall TIN	Linear interpolation
6	Nodes falling outside a concave hull formed by survey dataset points	DEM	Local maximum (10 ft radius)

If a seawall node falls within one element length of a survey point, then the node directly assigns its elevation via Near function in ArcGIS. If a seawall node lies farther away, then elevation is interpolated from a triangulated irregular network (TIN) formed by seawall point/polyline data as well as by breaklines that prevent triangulation across canals or across islands. Seawall nodes lying completely outside of the area of survey data collection derive their elevations from the DEM. Figures 2.10 and 2.11 present node types within the Las Olas Boulevard area (east and west areas). Figure 2.12 presents the node types for the Hollywood Lakes area. Figures 2.13 and 2.14 present final interpolated mesh configuration for the Existing Conditions mesh.

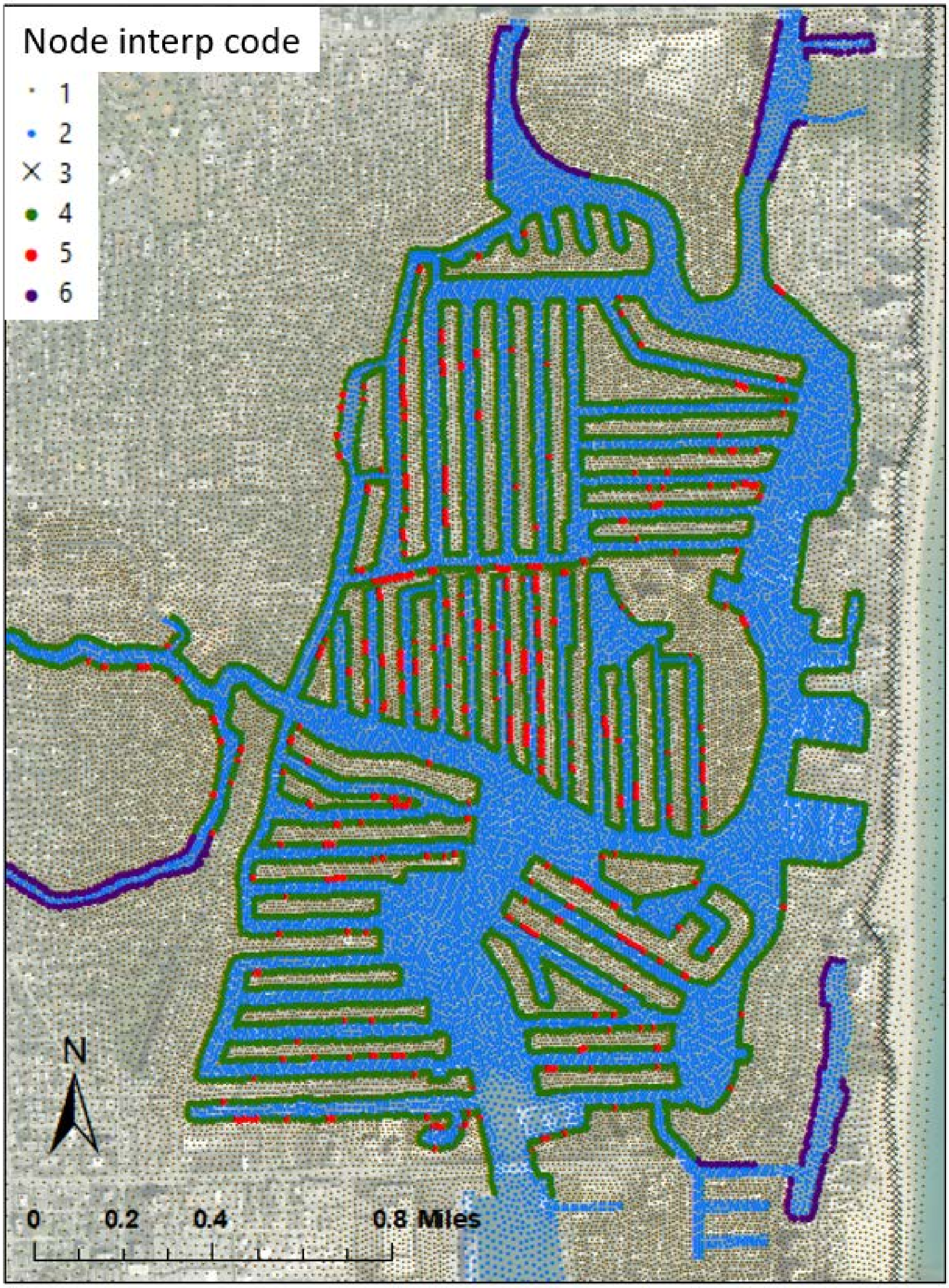

Figure 2.10 Mesh Node Elevation Interpolation Codes, Las Olas Boulevard (Eastern Area)

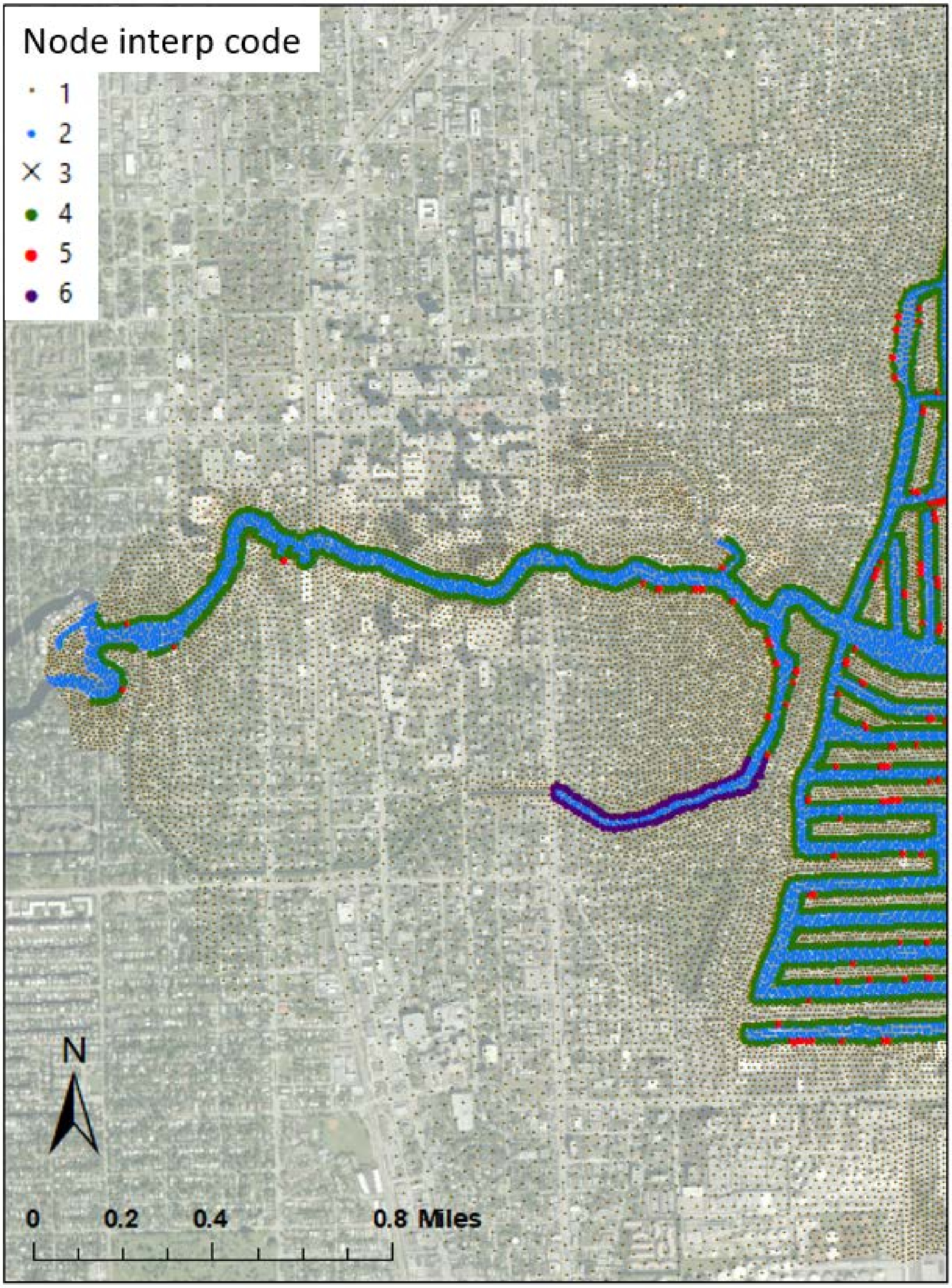

Figure 2.11 Mesh Node Elevation Interpolation Codes, Las Olas Boulevard (Western Area)

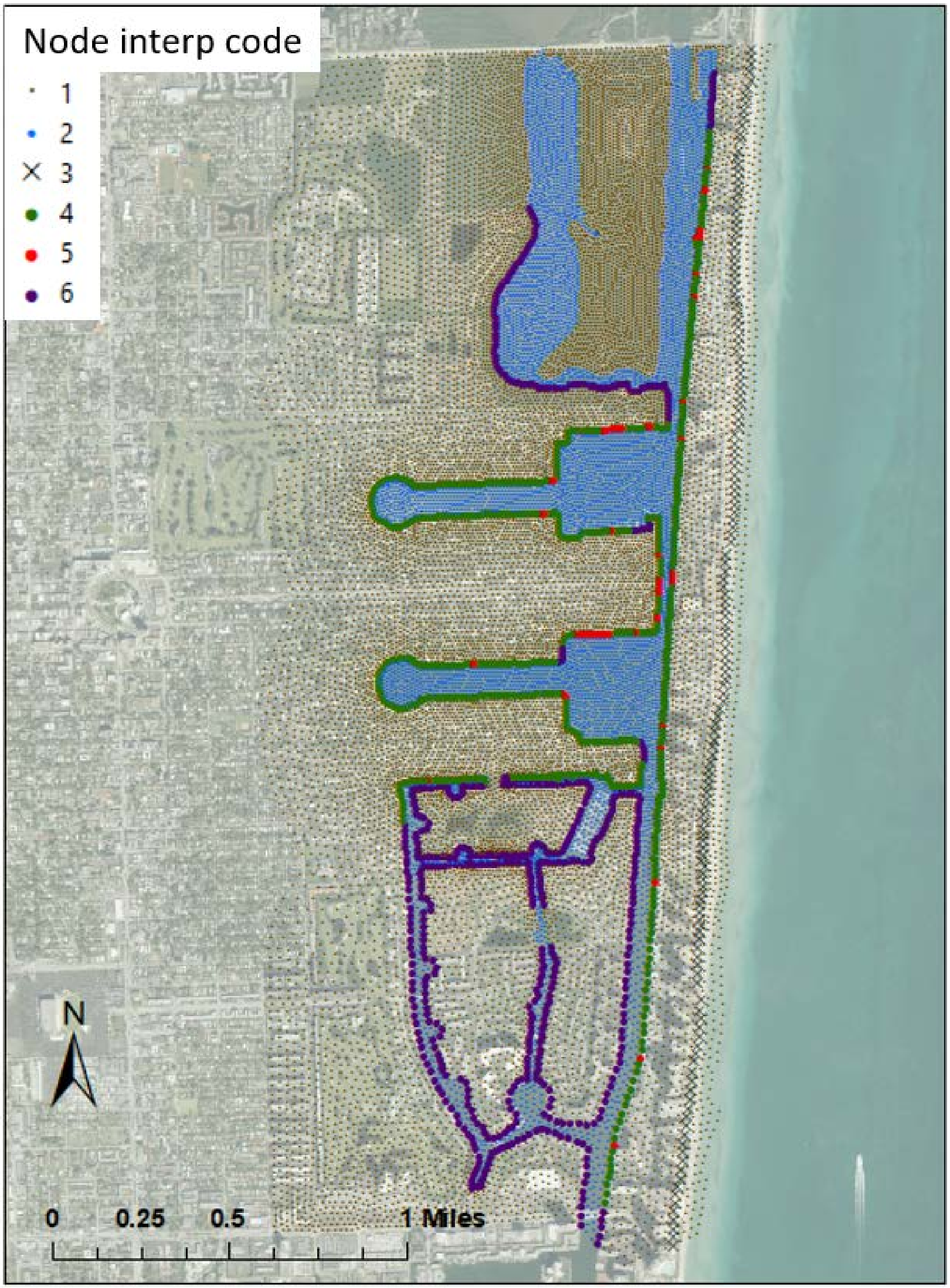

Figure 2.12 Mesh Node Elevation Interpolation Codes, Hollywood Lakes

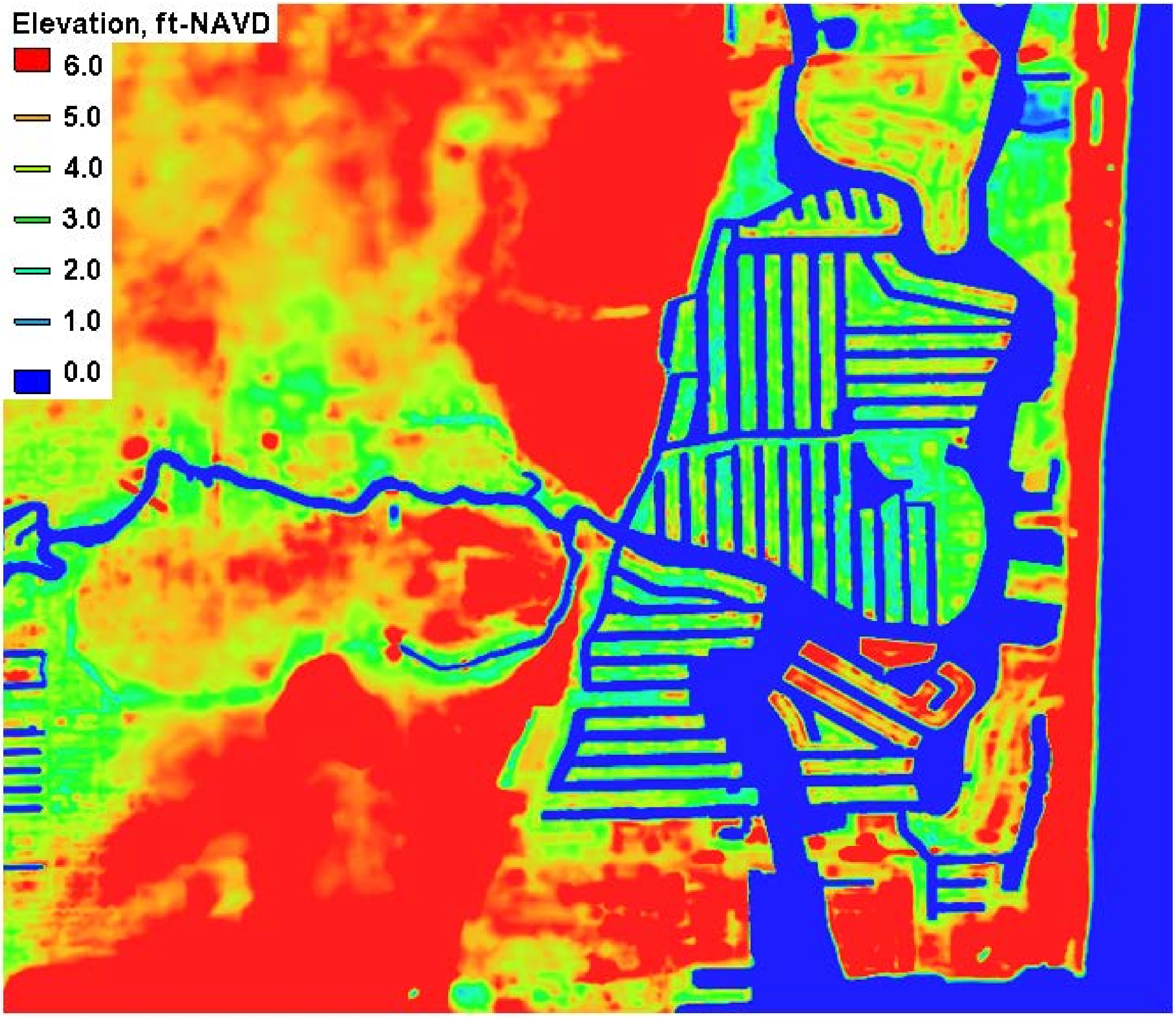

Figure 2.13 Existing Conditions Mesh Configuration, Las Olas Boulevard

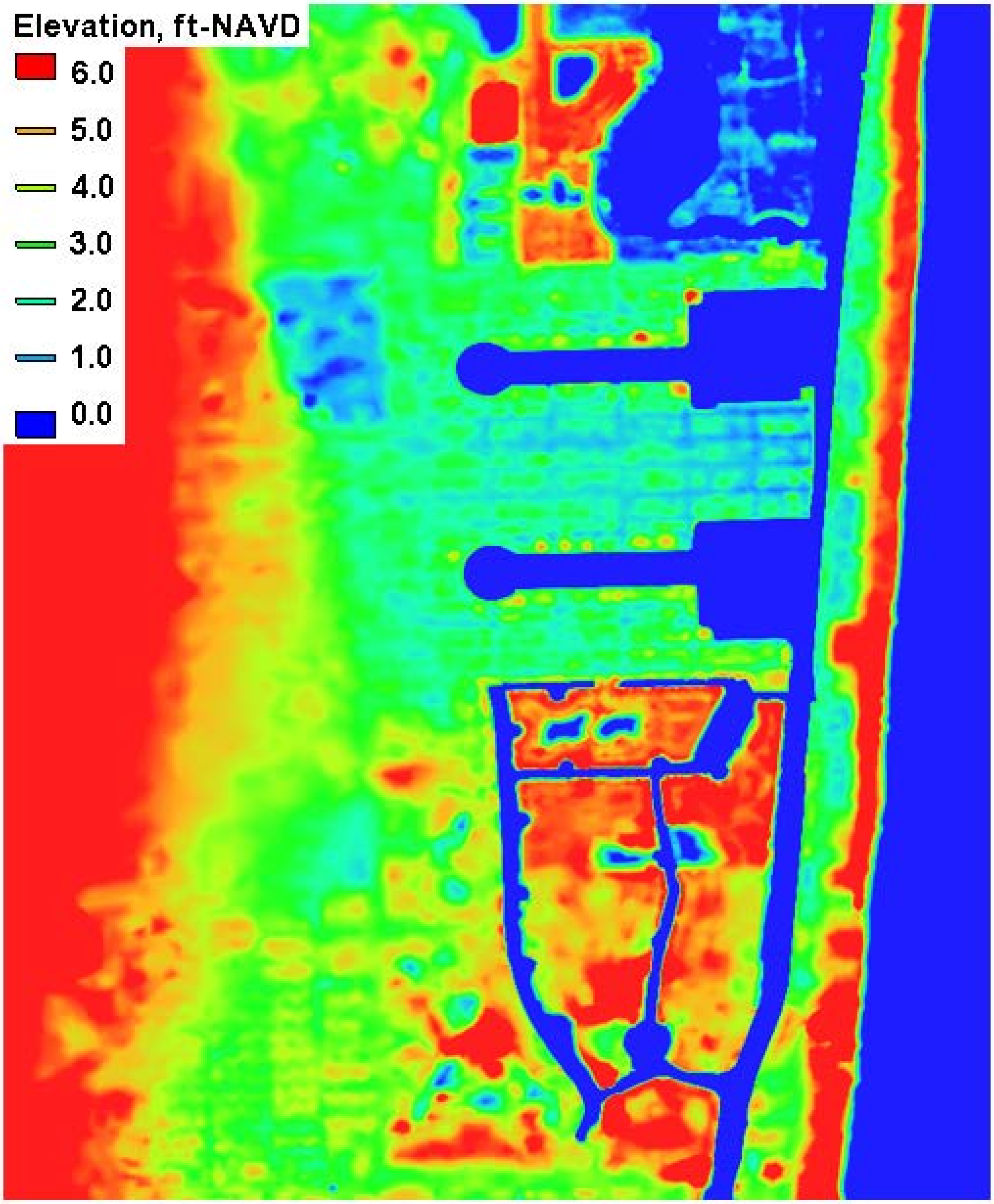

Figure 2.14 Existing Conditions Mesh Configuration, Hollywood Lakes

2.4 Seawall Alternatives

The Broward County FRM Study Existing and Alternative meshes applied identical horizontal mesh geometry. The seawall alternative meshes raised seawall nodes as indicated by Table 2.2 if their Existing Conditions configuration elevations were less than the seawall alternative elevation. Figures 2.15 through 2.20 show elevation contours of the Alternative 1, 2, and 3 mesh configuration in the Las Olas Boulevard and the Hollywood Lakes areas.

Table 2.2 Seawall Alternative Mesh Configurations

Seawall Alternative	Minimum Elevation (ft-NAVD)	
	Las Olas Boulevard	Hollywood Lakes
1	4	2.5
2	4	4
3	6	6

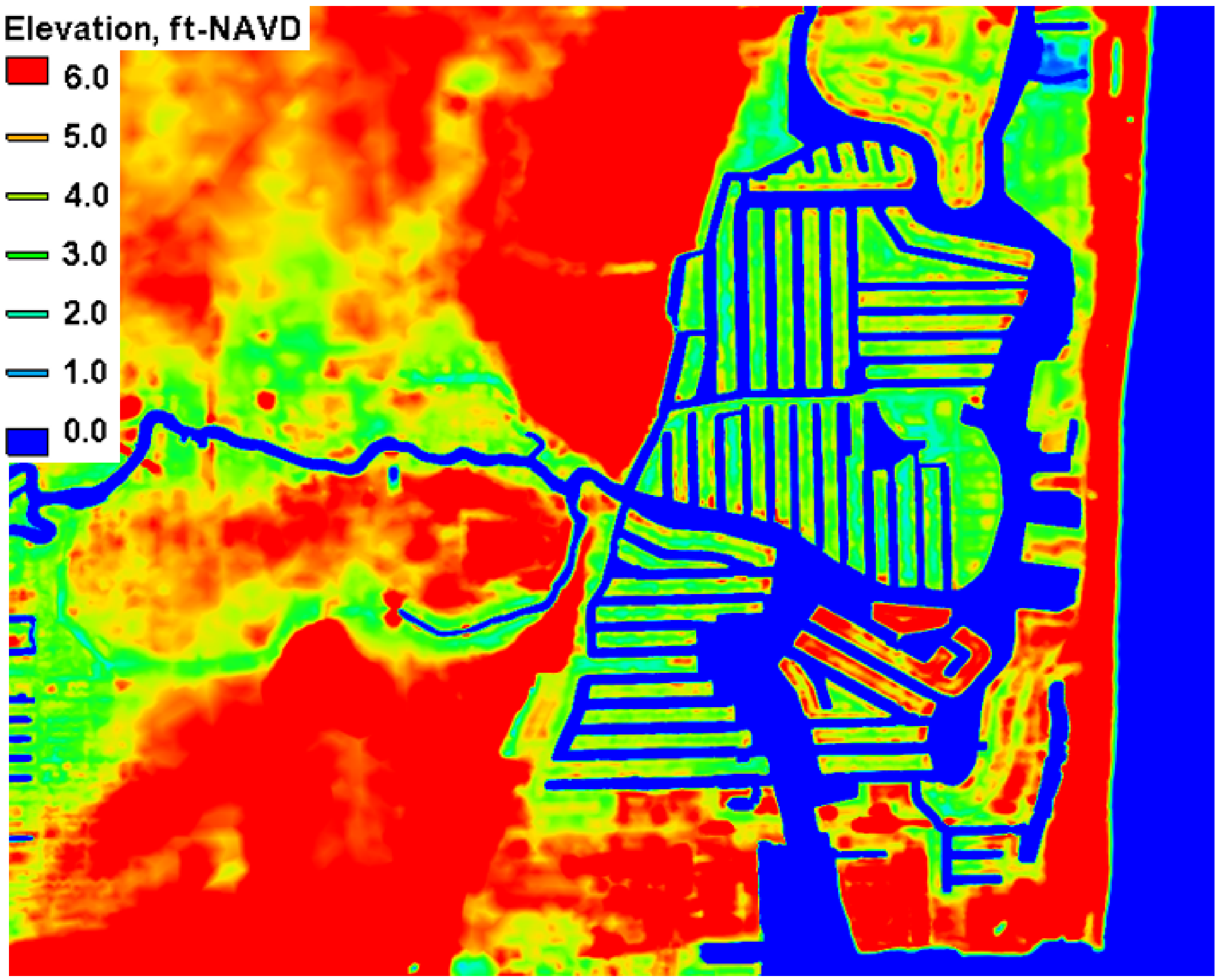

Figure 2.15 Alternative 1 Mesh Configuration, Las Olas Boulevard

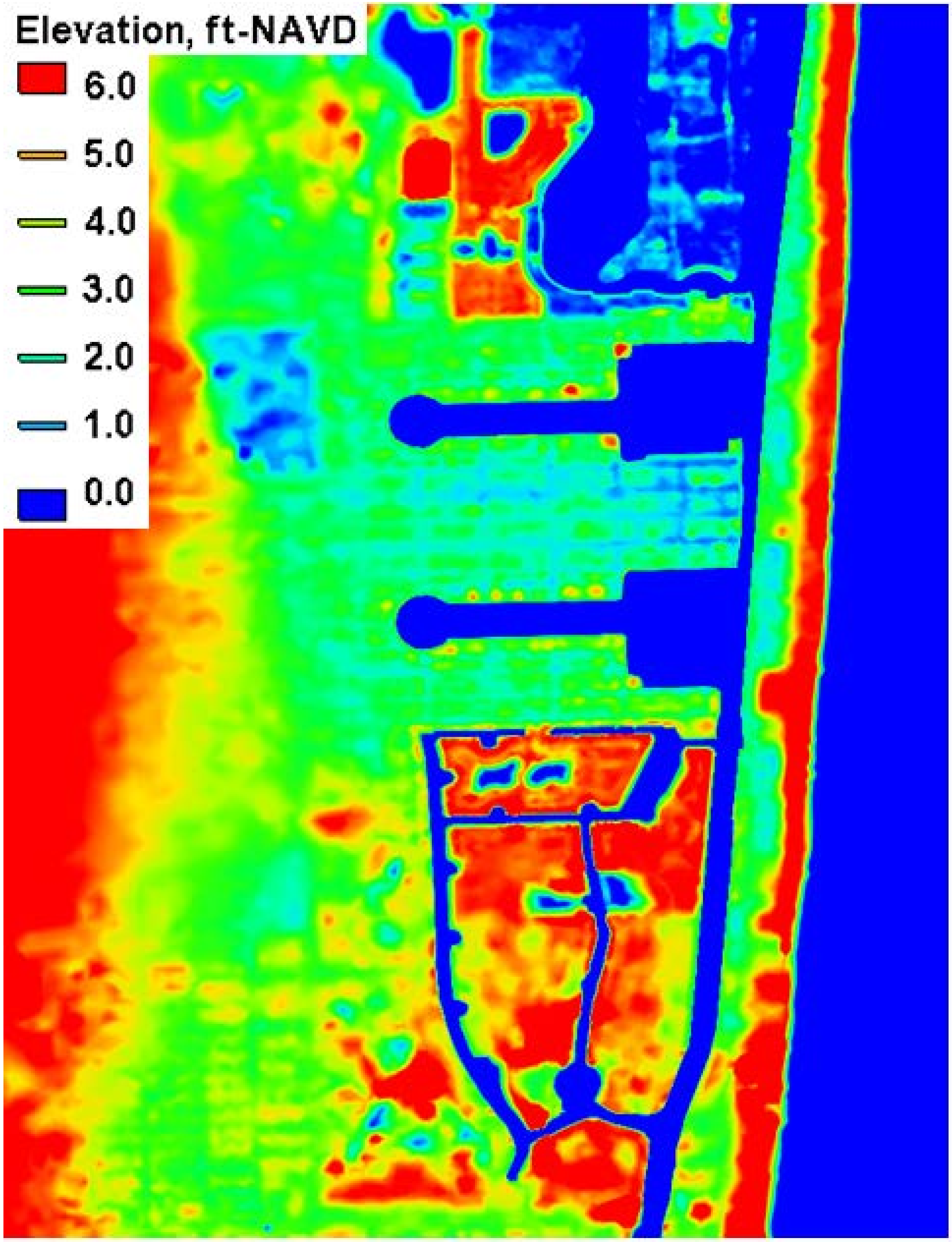

Figure 2.16 Alternative 1 Mesh Configuration, Hollywood Lakes

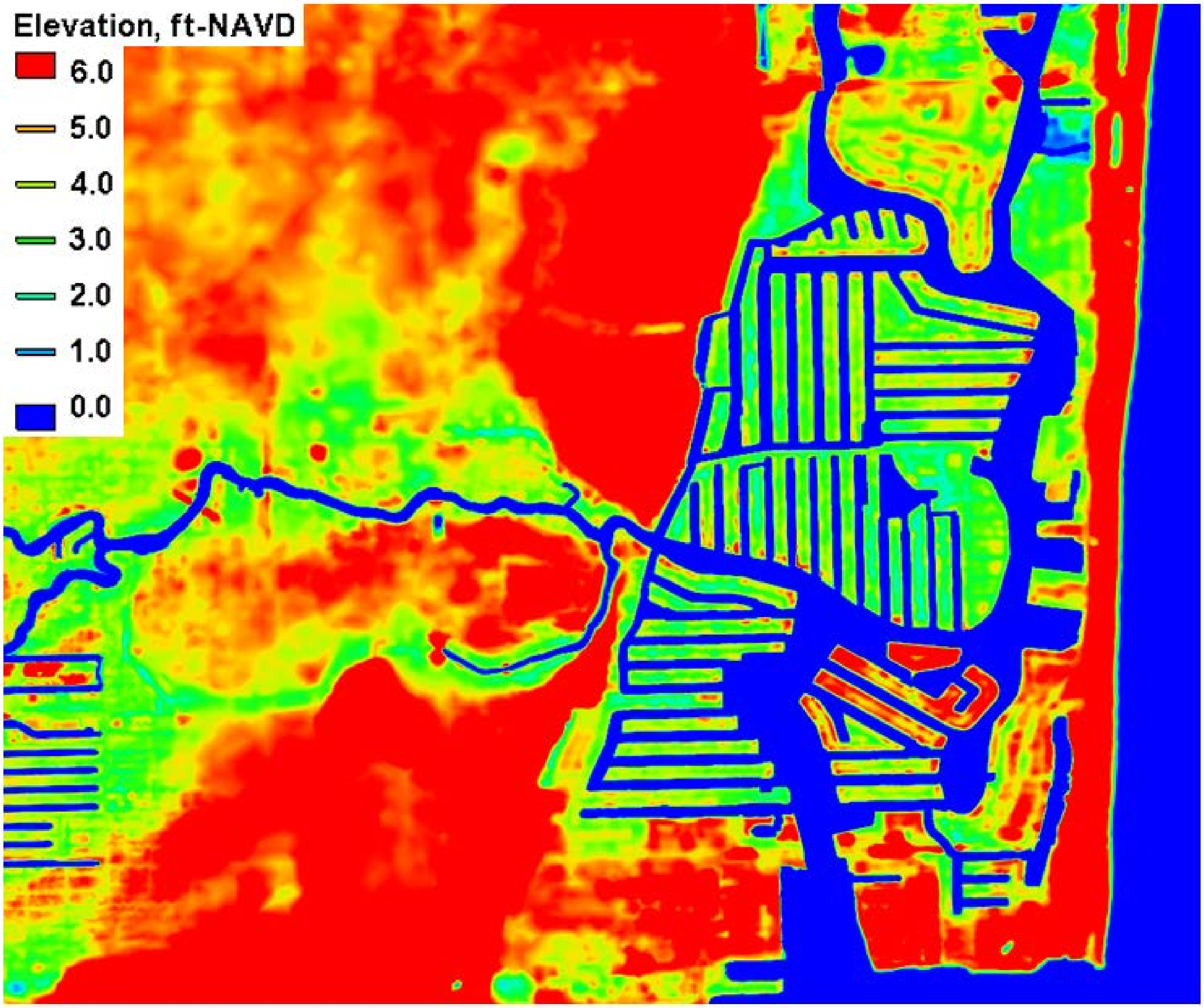

Figure 2.17 Alternative 2 Mesh Configuration, Las Olas Boulevard

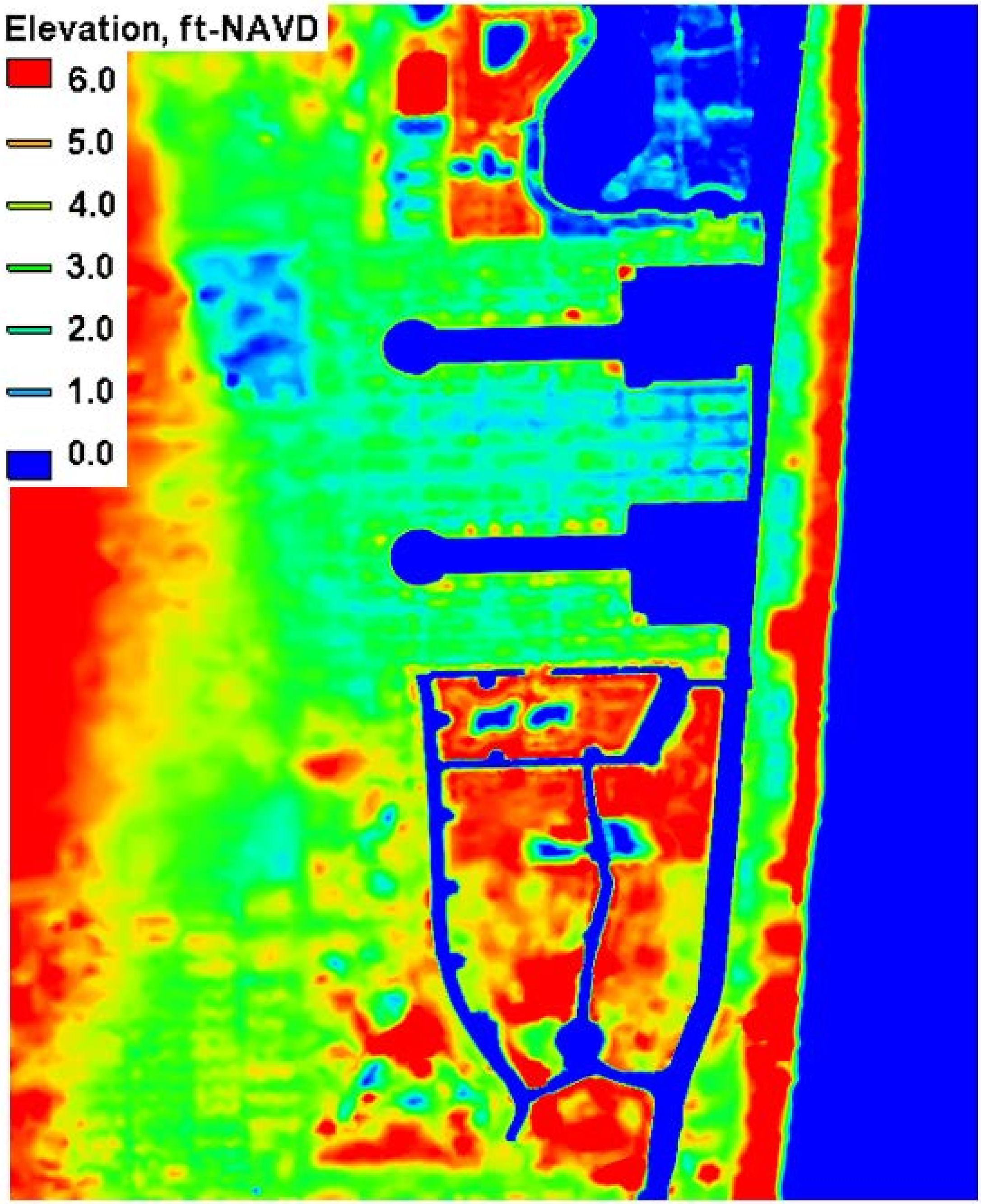

Figure 2.18 Alternative 2 Mesh Configuration, Hollywood Lakes

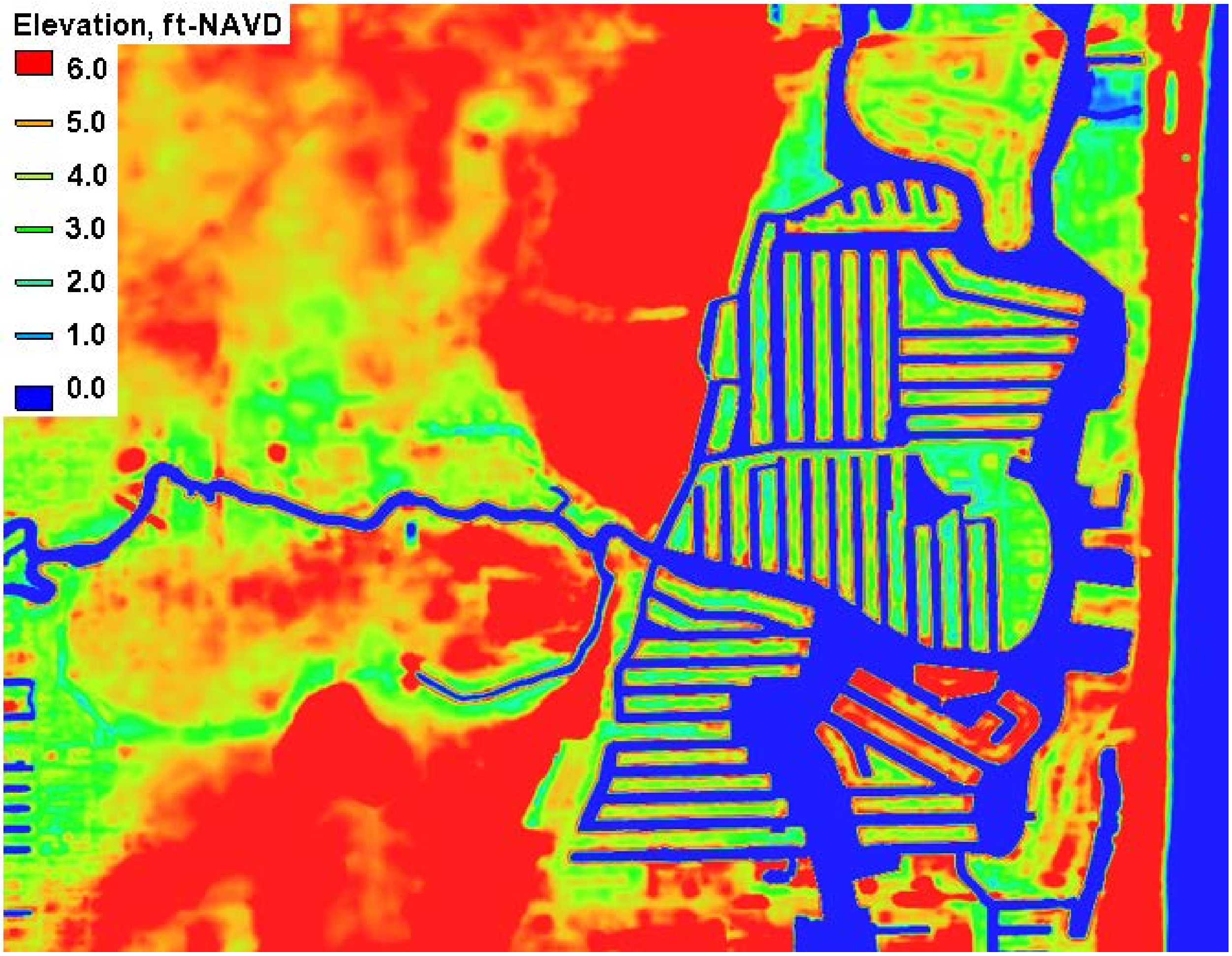

Figure 2.19 Alternative 3 Mesh Configuration, Las Olas Boulevard

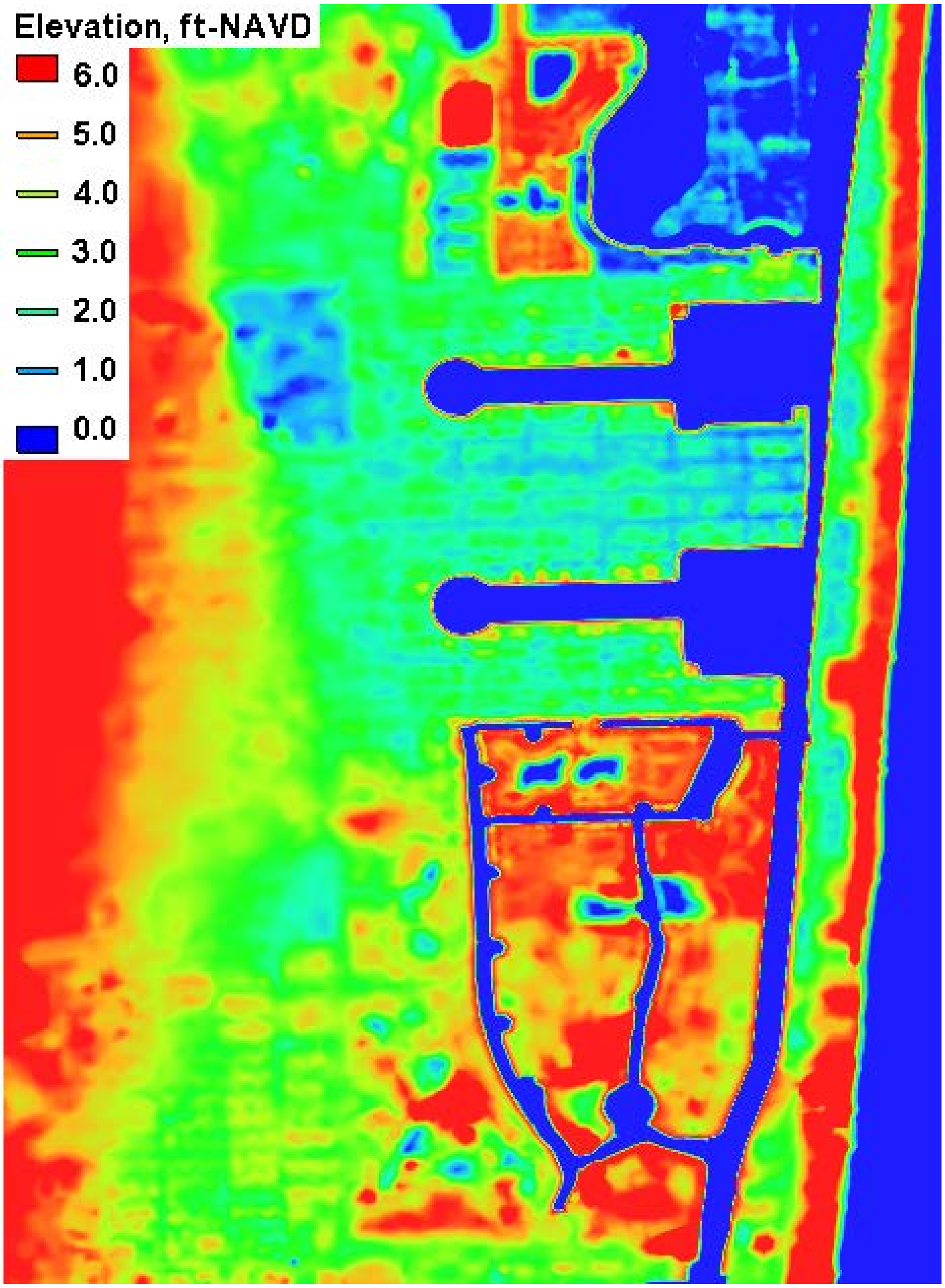

Figure 2.20 Alternative 3 Mesh Configuration, Hollywood Lakes

2.5 Nodal Attributes

Altering the SWAN+ADCIRC model mesh geometry requires corresponding updates to the nodal attribute data. Nodal attributes updated for the Broward FRM Study include *Manning's n*; the wind stress reduction parameter *surface canopy coefficient*; and the *elemental slope limiter*.

The ADCIRC model inputs Manning's *n* values to parameterize bottom friction; typically, values derive from land use data compiled by the NOAA Coastal Change Analysis Program (C-CAP). Figures 2.21 and 2.22 present Manning's *n* in the Las Olas Boulevard and Hollywood Lakes areas. The surface canopy coefficient is mostly derived from NOAA C-CAP land use data, as is common to SWAN+ADCIRC modeling.

Surface canopy coefficient allows the user to turn off wind stress in heavily vegetated areas; the FEMA SFLSSS found that using this parameter to disable wind stress over select overland locations prone to wetting and drying oscillations improved numerical stability. With wind stress disabled, storm surge inundation can still occur through local hydrodynamics; wind stress is never disabled within interior waterways. The Broward FRM Study disabled wind stress in specific areas to promote stability in several model runs. However, these areas lie west of the areas of interest in the study. Figures 2.23 and 2.24 show the existing and modified surface canopy coefficient settings for the existing and modified modeling conditions.

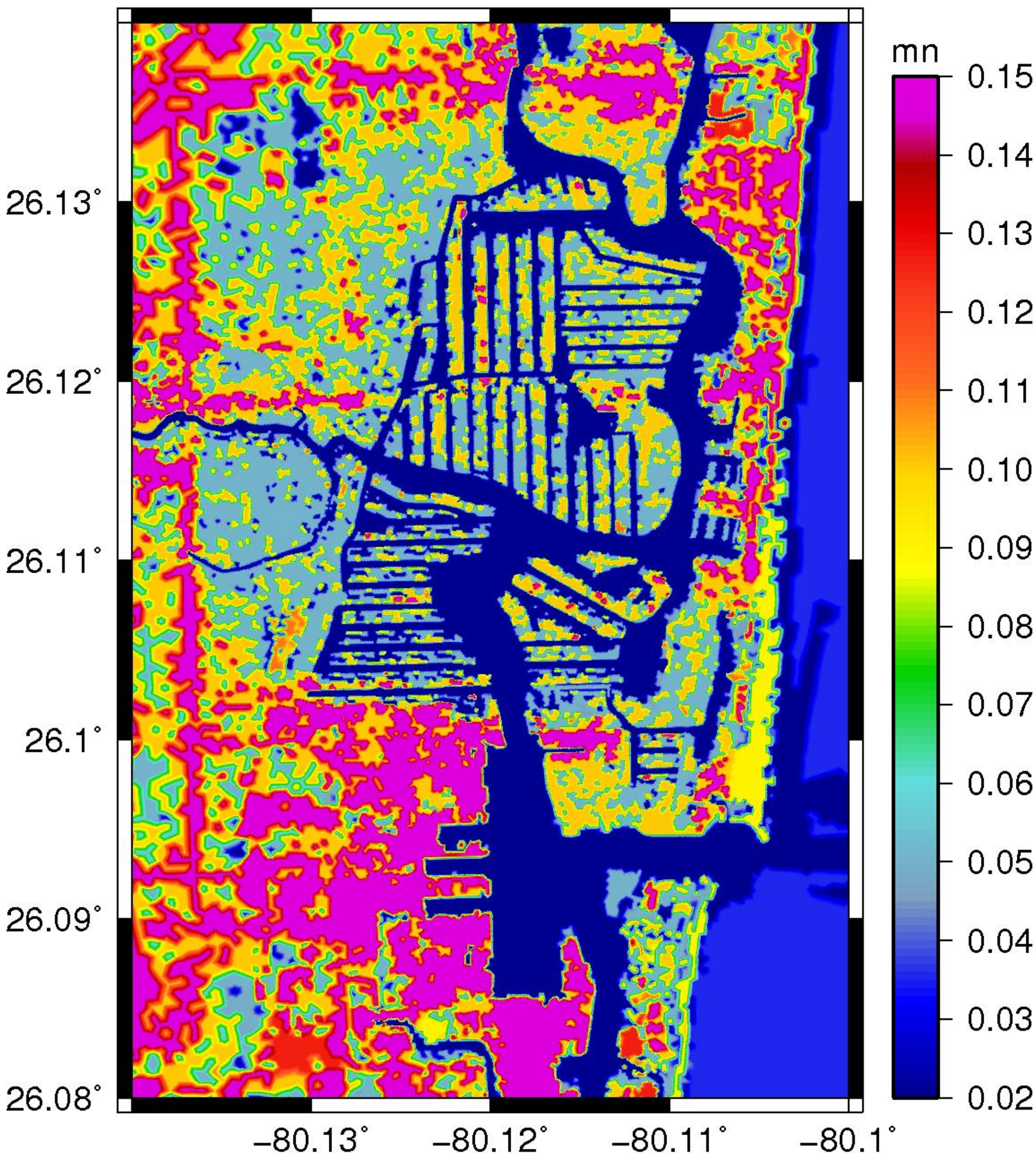

Figure 2.21 Manning's *n*, Las Olas Boulevard

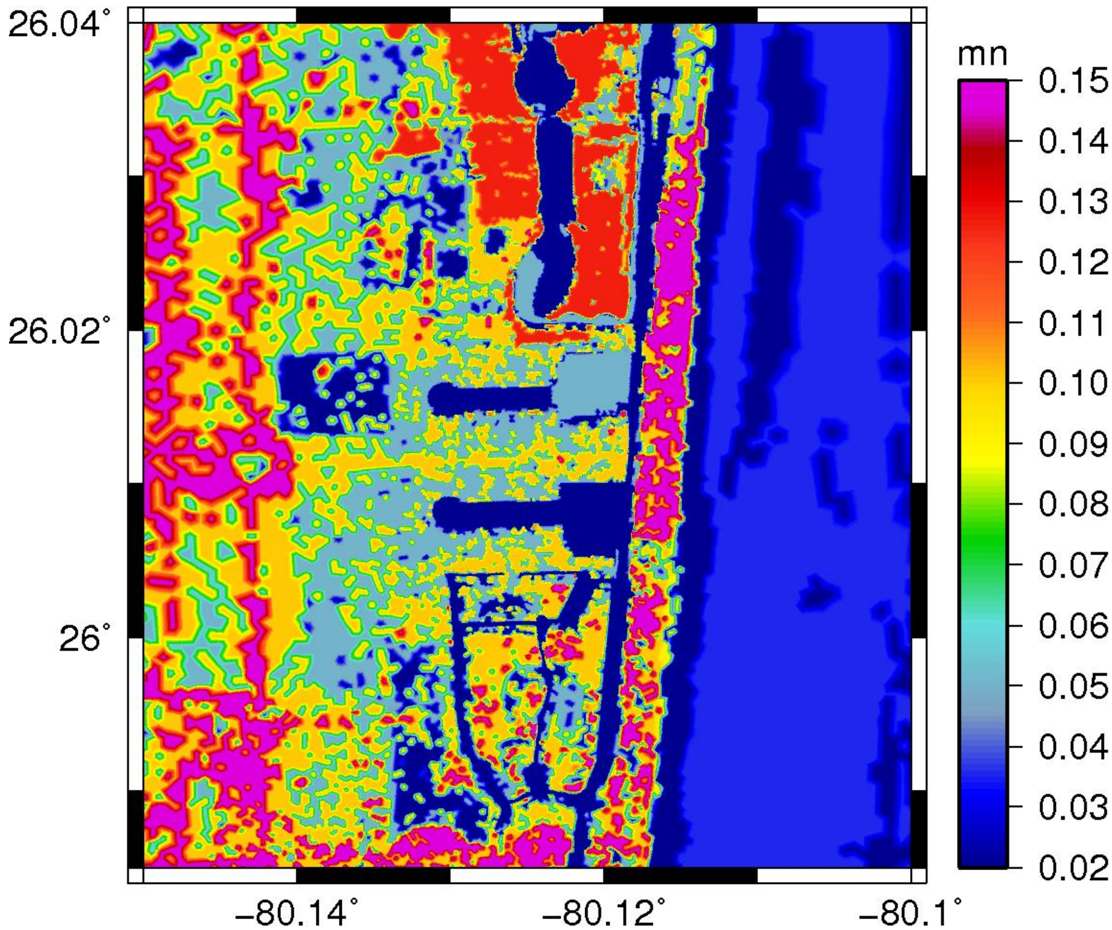

Figure 2.22 Manning's *n*, Hollywood Lakes

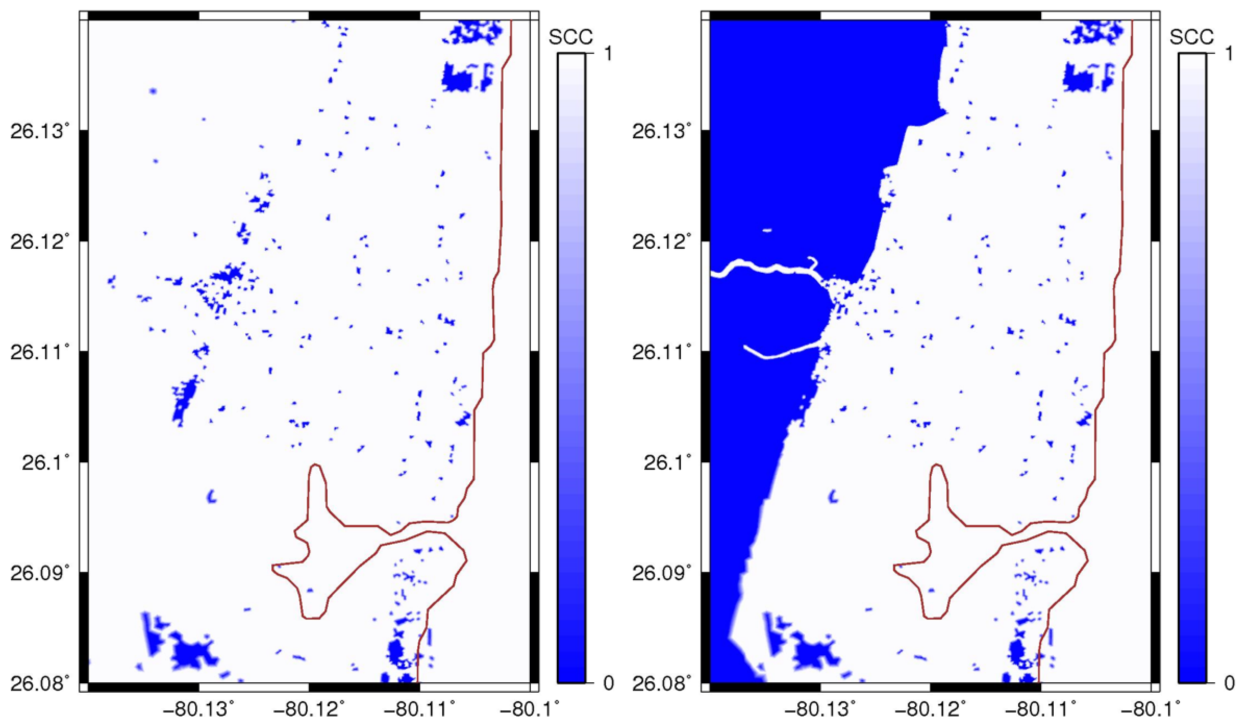

Figure 2.23 Surface Canopy Coefficient, Las Olas Boulevard; Existing Condition (left) and Modified (right)

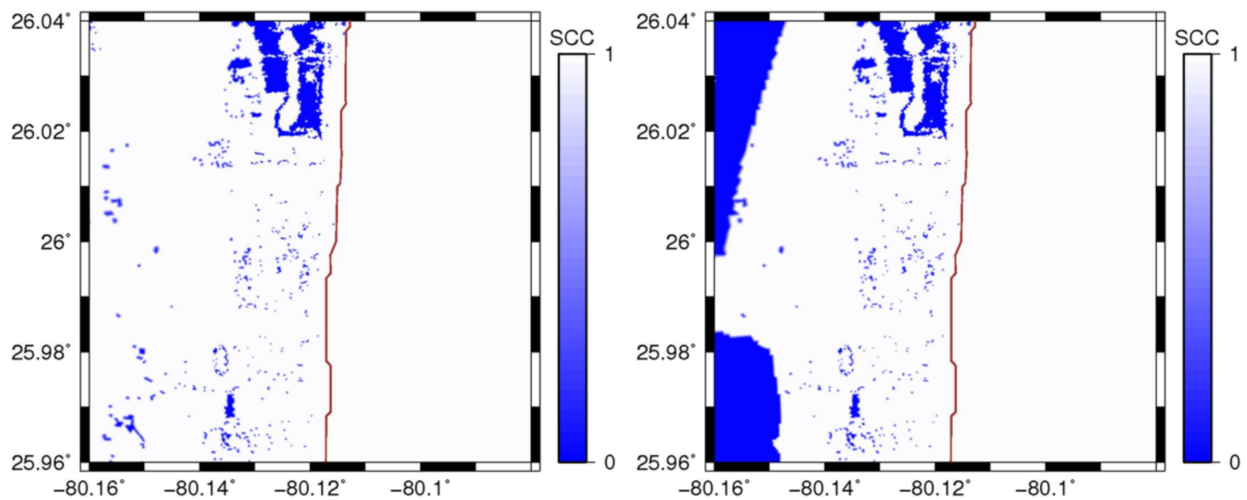

Figure 2.24 Surface Canopy Coefficient, Hollywood Lakes; Existing Condition (left) and Modified (right)

Finally, the SWAN+ADCIRC model user can apply the elemental slope limiter (ESL) nodal attribute to selectively limit the maximum water surface elevation gradient that can occur across an element. This nodal attribute improves numerical stability. The Broward FRM Study team initially applied ESL in the same locations as applied by the FEMA SFLSSS. Additional localized instabilities prompted the Broward FRM Study to further activate ESL in select locations. Section 5 further discusses application of ESL as well as sensitivity tests conducted to ensure that ESL only dampened instabilities rather than artificially dampening the surge signal. Figures 2.25 and 2.26 present ESL settings in the Las Olas Boulevard and Hollywood Lakes areas; red areas indicate that ESL was not applied, and the black line shows the inshore waterway delineation to provide location reference. Notably, ESL only activates if the specified water surface elevation gradient is exceeded at any point during the simulation; if the gradient is not exceeded, the solution remains unchanged.

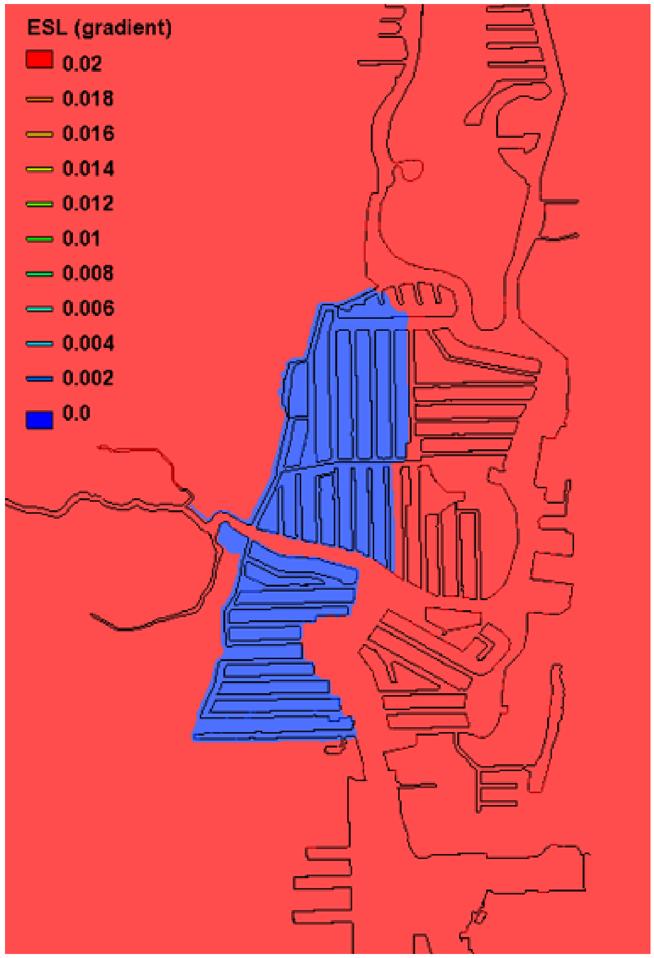

Figure 2.25 Elemental Slope Limiter (ESL), Las Olas Boulevard

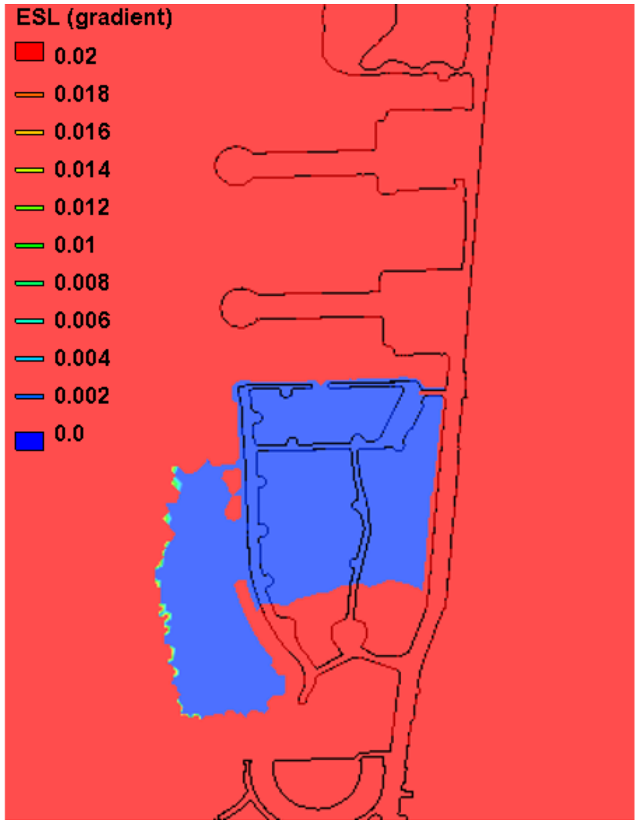

Figure 2.26 Elemental Slope Limiter (ESL), Hollywood Lakes

3.0 STORM SELECTION

3.1 Storm Selection Criterion

This portion of the study established the SWAN+ADCIRC model forcing conditions acting on the mesh alternatives described in Section 2. The study team applied the selected storm forcing conditions within the SWAN+ADCIRC model to allow examination of how different water levels (produced by different storms) interacted with various seawall height configurations in the Hollywood Lakes and Las Olas Boulevard areas. Discussions with USACE Jacksonville District and Broward County staff developed an approach for the storm selection process that included several considerations:

- Storms with various water levels ranging from an approximate 10% Annual Exceedance Probability (AEP) to an approximate 1% AEP
- Maximum storm surge occurs near high tide (approximately within 1 hour of high tide)
- Storm track places the storm landfall near Broward County (approximately 40 miles)

To examine the water level versus frequency conditions in the Hollywood Lakes and Las Olas Boulevard areas the study team reviewed several data sources. Historical measured data from NOAA Stations at Miami Beach (8723170), Virginia Key (Station 8723214), and Lake Worth Pier (8722670) allowed for examination of water levels around the 4% AEP and 10% AEP levels. Notably, the Miami Beach station record stops at approximately the same time the Virginia Key station record starts, so, due to their proximity, their records were combined into a single record. The NOAA data must be used with caution as the NOAA gages are located relatively far from the Broward FRM Study area and do not occur in inland areas similar to the Hollywood Lakes and Las Olas Boulevard focus areas. Examination of the draft SFLSSS SWAN+ADCIRC production run results (FEMA, 2018a; FEMA, 2018b) allowed extraction of the 1%, and 2% AEP stillwater levels from the draft water level surfaces. These values, while not the final FEMA study values, provided a general value for the frequency associated with various water levels in the Hollywood Lakes and Las Olas Boulevard focus areas. The study team also reviewed water level data from the Florida Department of Environmental Protection (FDEP) (Wang, 2014) study that developed combined total storm tide frequency levels along coastal Broward County. However, the study team found the Wang (2014) water levels, developed to provide a basis for the regulatory Florida Coastal Construction Control Line (CCCL), provide much higher water levels as compared to the FEMA SFLSSS and NOAA data. Therefore, the Wang (2014) water levels were not applied within the storm selection process.

Table 3.1 presents the results of the water level versus annual exceedance probability analysis for the study. The NOAA data analysis, due to the record lengths available, provides estimates of the high-frequency water levels (20% to 5% AEP). The NOAA data analysis applied a multi-step process. The first step applied a sea level rise correction with the second step declustering the data. The next steps included application of a peak-over-threshold filter with the resulting data set fit to various distributions to determine the water level versus annual exceedance probability. The SFLSSS SWAN+ADCIRC model results, designed to provide low-frequency water level data, provide estimates of the 2% and 1% AEP levels. Tide data collected by the contractors for local government organizations in Broward County near Ft Lauderdale, FL show measured water levels near the highest predicted high-tide (“King Tides”) in October and November that exceed 2 ft-NAVD near the project area; however, review of local conditions indicates relatively strong local winds during these times that can elevate local water levels.

Table 3.1 Water Level (ft-NAVD88) Versus Annual Exceedance Probability (AEP) for NOAA and FEMA SFLSSS Draft Stillwater Elevation (SWEL) Data

	NOAA Data Analysis (ft-NAVD)		**FEMA SFLSSS Draft Stillwater Level (ft-NAVD)**	
Annual Exceedance Probability (AEP %)	**Miami / Virginia Key**	**Lake Worth Inlet**	**Las Olas Boulevard (Average of 4 stations)**	**Hollywood Lakes (Average of 6 stations; 0.3 ft higher in South than North)**
1	N/A	N/A	6.2	6.4
2	N/A	N/A	5.4	5.6
5	2.9	3	N/A	N/A
10	2.5	2.8	N/A	N/A
20	2.1	2.6	N/A	N/A

The study team determined tide phase associated with the landfall of each of the 392 synthetic tropical storms simulated during the SFLSSS SWAN+ADCIRC modeling. First the team identified the timing of simulated local maximum water level for each storm, and then identified water level at the corresponding time step within a tide-only simulation. The tide-only simulation applied identical astronomical tidal forcing as that applied during the 392 tropical storms. The study team thus identified storms that featured maximum water levels (including tide and storm effects) occurring near the tide-only high tide. This process allowed the selection of storms that featured maximum water level occurring near time of high tide (approximately within one hour of high tide).

The study team also examined the storm track for each of the 392 synthetic tropical storms in the SFLSSS SWAN+ADCIRC production run storm suite. The study team identified storms with tracks that placed landfall within Broward County or northern Miami-Dade County. Due to the counter-clockwise nature of tropical storm winds, tracks making landfall in these locations produce maximum storm surge in the project focus area. This step removed from consideration very strong (and rare) storms that made landfall at significant distances from the focus areas and maintained for consideration storms with tracks more relevant to Broward County. Importantly, the focus areas occur in inland areas with interior water bodies and channels providing conduits for water to move into both the Hollywood Lakes and Las Olas Boulevard focus areas; therefore, many different storm tracks and paths can produce elevated water levels in the focus areas.

3.2 Selection of Storms

Discussions with USACE Jacksonville and Broward County staff indicated that having storms that produced water levels near 3 ft-NAVD, 4.5 ft-NAVD, and 6 ft-NAVD would allow for examination of the effectiveness of the seawall height alternatives targeted for the study (existing conditions, 2.5 ft-NAVD, 4 ft-NAVD, and 6 ft-NAVD as discussed in Section 2). Based on the review of the three selection criteria in Section 3.1, the study team identified four storms from the SFLSSS SWAN+ADCIRC production run storm suite as the best candidates for application in models to evaluate the seawall configurations. The study team evaluated these four candidate storms as providing a range of maximum water levels that would allow evaluation of the seawall height alternatives, while meeting the tide and track considerations. The storms produced water levels ranging from approximately 3.3 ft-NAVD to 6.3 ft-NAVD in the Hollywood Lakes and Las Olas Boulevard focus areas. Importantly, the areas near Hollywood Lakes and Las Olas Boulevard feature numerous small canals, low-lying elevation areas, and connections to the Intra-coastal Waterway (ICWW) and the areas are separated by approximately 5.5 miles; these features allow for the same storm to have water levels that can differ by three to six inches within one of the focus areas and over six inches between the two study areas.

The water level values include an adjustment made to the SFLSSS initial water level to develop a Broward County-focused SWAN+ADCIRC initial water level that accounts for bringing the water levels up to the estimated 2018 mean sea level (MSL) condition near the focus areas. The Broward County FRM initial water level started with MSL for the North Dania Sound NOAA Benchmark Station (-0.87 ft-NAVD) and accounted for a steric effect from the NOAA SA and SSA tidal constituents equal to 0.45 ft which raises the local water level during hurricane season. The initial water level calculation also applied 0.31 ft of sea level rise based on the NOAA Lake Worth Pier sea level rise value (0.145 in/yr) to bring the water level up from the mid-point of the recent NOAA tidal epoch to 2018 conditions (25.7 years; 2018.2-1992.5). Thus, the Broward County FRM Study applied SWAN+ADCIRC model initial water level equal to -0.11 ft-NAVD [MSL (-0.87 ft-NAVD) + Steric Effect (0.45 ft) + Sea Level Rise since MSL Epoch (0.31 ft) = -0.11 ft-NAVD]. For reference, the South Florida region-wide SFLSSS applied an initial water level equal to -0.51 ft-NAVD

The study team selected SFLSSS Storms 276, 122, 61, and 60 for the Broward County FRM Study (storms listed in order of storm surge height produced near Las Olas Boulevard, from lowest to highest). Table 3.2 provides details on the storm features and water levels developed in the focus areas. Figure 3.1 shows the storm tracks.

- Storm 276 features a storm track that moves in a westerly direction, makes landfall approximately 13 miles south of the Hollywood Lakes focus area, and produces water levels of 3.7 ft-NAVD near Las Olas Boulevard and 3.2 ft-NAVD in Hollywood Lakes.

- Storm 122 features a storm track that moves in a westerly direction, makes landfall approximately 20 miles south of the Hollywood Lakes focus area, and produces water levels near 5.0 ft-NAVD near Las Olas Boulevard and 4.5 ft-NAVD in Hollywood Lakes. Storm 122 makes landfall further south of the project area than Storm 276 but features stronger wind speeds.
- Storm 60 features a storm track that moves in a northwesterly direction, makes landfall in central Biscayne Bay approximately 27 miles south of the Hollywood Lakes focus area, and produces water levels near 5.4 ft-NAVD near Las Olas Boulevard and 6.1 ft-NAVD in Hollywood Lakes.
- Storm 61 features a storm track that moves in a northwesterly direction, makes landfall in northern Biscayne Bay approximately 20 miles south of the Hollywood Lakes focus area, and produces water levels near 6.3 ft-NAVD near Las Olas Boulevard and 5.7 ft-NAVD in Hollywood Lakes.

Table 3.2 Storm Parameters and Approximate Maximum Water Levels Associated with Storm Selected for SWAN+ADCIRC Model Simulations

Storm	Forward Velocity	Radius to Maximum Wind	Maximum Wind Speed	Approximate Maximum Water Level Las Olas Boulevard	Approximate Maximum Water Level Hollywood Lakes
	(knots)	(nmi)	(knots)	(ft-NAVD)	(ft-NAVD)
276	10	25	58	3.7	3.2
122	10	13	114	5.0	4.5
60	10	14	114	5.4	6.1
61	10	14	114	6.3	5.7

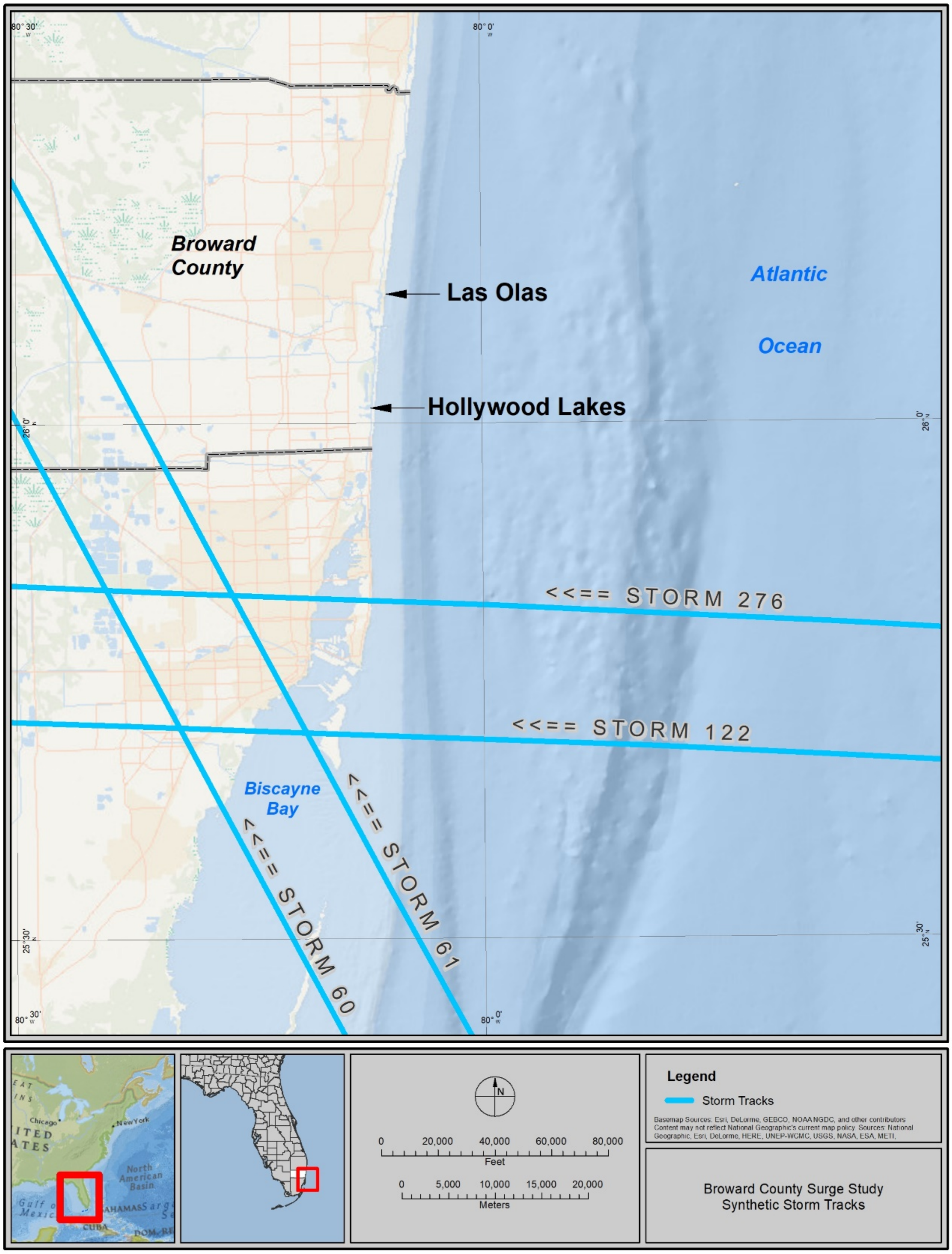

Figure 3.1 Storm Track for Each of the Storms Selected for Analysis in SWAN+ADCIRC Model

4.0 SWAN+ADCIRC MODEL VERIFICATION

The Broward County FRM applied a SWAN+ADCIRC model mesh and forcing that included both a validation phase and verification phase. The validation phase consisted of comparisons of simulated data to measured data for historical tropical storms, while the verification consisted of comparing model results from different computing resources. The validation phase for the mesh and model settings that provided the foundation for the Broward County FRM SWAN+ADCIRC model occurred during the FEMA Region IV SFLSSS (FEMA, 2017). The SFLSSS executed five historical tropical storms as part of the SWAN+ADCIRC model validation. For each validation storm, the SWAN+ADCIRC model results were compared with measured water level data (hydrographs and high-water marks (HWM)). Due to the absence of fixed wave measurement buoys in south Florida, the SFLSSS did not locate any wave measurements during the validation storms. The model-to-measurement water level comparisons showed the SFLSSS SWAN+ADCIRC model reasonably reproduced the measured water levels across the study area and the validation passed the multi-level FEMA review process.

The Broward County FRM also executed a model verification procedure to document that, with similar initial water level and storm forcing, the SWAN+ADCIRC model simulation results conducted on Taylor Engineering's high-performance computer (HPC) "Merlin" closely matched the SFLSSS results conducted on FEMA's "LiveOak" cluster hosted by WorldWinds, Inc. in Slidell, LA. The study team executed Storm 276 for the Broward County FRM on the Existing Conditions mesh using the Merlin HPC and compared the water level results to the SFLSSS results for Storm 276 (executed on the LiveOak HPC).

Figure 4.1 shows the model verification results near Las Olas Boulevard for Storm 276 executed on Merlin with the Broward County FRM Existing Conditions mesh and on LiveOak with the SFLSSS model mesh. Figure 4.1 shows almost identical results for the pre-storm tidal oscillations and storm surge, with maximum differences near 0.05 ft. Given the differences in HPC architecture and changes to the Broward County FRM mesh based on new seawall survey data, the small changes were expected. Figure 4.2 shows the model verification results in Hollywood Lakes for Storm 276 executed on Merlin with the Broward County FRM Existing Conditions mesh and on LiveOak with the SFLSSS model mesh. Figure 4.2 shows almost identical results for the pre-storm tidal oscillations and storm surge, with maximum differences near 0.05 ft. The verification results demonstrate the Broward County FRM SWAN+ADCIRC model with the Existing Conditions mesh and executed on the Merlin HPC produces similar results to the validated SFLSSS SWAN+ADCIRC model and mesh. With this testing complete, the study team moved on to simulate the different Broward County FRM mesh alternatives with the selected storm forcing conditions.

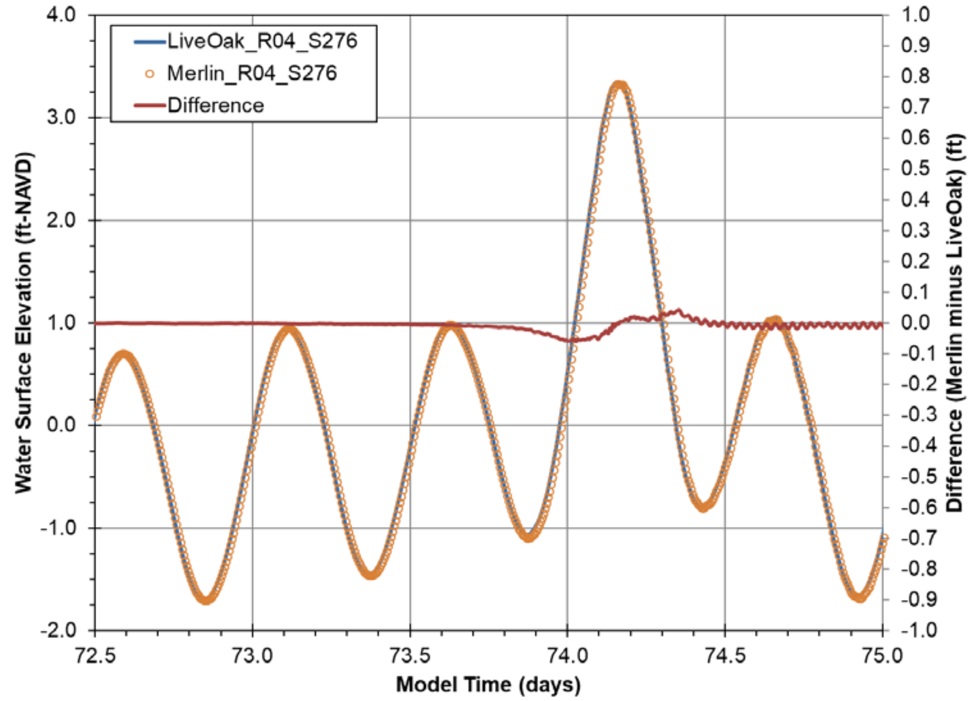

Figure 4.1 Verification for Broward County FRM SWAN+ADCIRC Model, Las Olas Boulevard Area

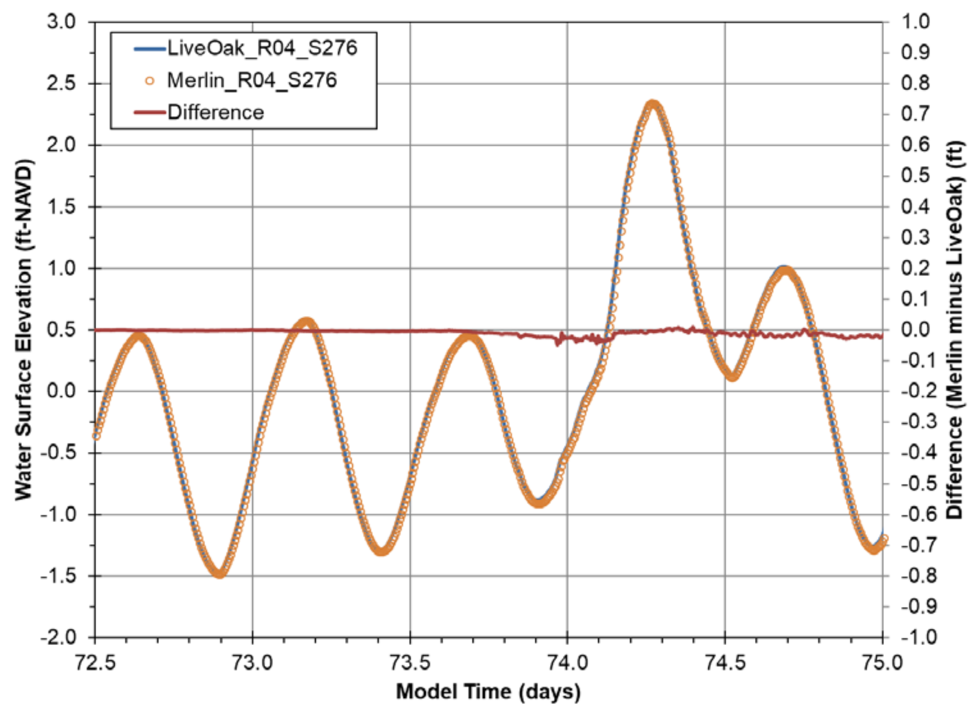

Figure 4.2 Verification for Broward County FRM SWAN+ADCIRC Model, Hollywood Lakes Area

5.0 SWAN+ADCIRC MODEL RESULTS AND DISCUSSION

With alternative seawall configurations developed as detailed in Section 2 and the storms selected in Section 3, the study team developed a model run matrix to assign the mesh configuration and storm forcing for a series of 12 simulations. The simulations were designed to provide water levels and inundation extents produced by various storms with different seawall heights (mesh alternatives) applied. Table 5.1 presents the SWAN+ADCIRC model simulation matrix with information on the storm forcing, mesh configuration, model attributes (surface canopy coefficient and ESL), and brief notes on the model results near Las Olas Boulevard and Hollywood Lakes.

Table 5.1 SWAN+ADCIRC Model Simulation Matrix with Notes on Results

Storm Number	Mesh Configuration	Surface Canopy Attribute Setting	ESL Attribute Setting	Seawall Overtopping Notes Las Olas Boulevard	Seawall Overtopping Notes Hollywood Lakes
Storm 276	Existing	base	sofl_v10	Overtopping	Overtopping
Storm 276	Alternative 1	base	sofl_v10	No overtopping	Overtopping
Storm 276	Alternative 2	base	sofl_v10	No overtopping	No overtopping
Storm 122	Existing	scc-v3c	sofl_v10g	Overtopping	Overtopping
Storm 122	Alternative 2	scc-v3c	sofl_v10g	Overtopping	Overtopping
Storm 122	Alternative 3	scc-v3c	sofl_v10d	No overtopping	No overtopping
Storm 60	Existing	scc-v3c	sofl_v10g	Overtopping	Overtopping
Storm 60	Alternative 2	scc-v3c	sofl_v10g	Overtopping	Overtopping
Storm 60	Alternative t3	scc-v3c	sofl_v10d	No overtopping	Unstable in ICWW south of South Lake
Storm 61	Existing	scc-v3c	sofl_v10g	Overtopping	Overtopping
Storm 61	Alternative 2	scc-v3c	sofl_v10g	Overtopping	Overtopping
Storm 61	Alternative 3	scc-v3c	sofl_v10g	Some overtopping, greatly reduced from Alternative 2	No overtopping, surge enters from south

During execution of the model simulations, the project team observed that some model simulations of Alternative 2 (4-ft minimum) and Alternative 3 (6-ft minimum) seawall elevations produced unstable SWAN+ADCIRC model behavior at the point of overtopping in specific mesh locations. The unstable model behavior caused a rapid increase in water level over a single 6-minute output time step; such results indicated unrealistic water levels changes. Importantly, this model behavior was not observed in the original SFLSSS simulations that applied the SFLSSS mesh (based on existing conditions from best-available data at the time of that study). The study team believes the model behavior resulted from the effect of water rushing over the narrow, elevated seawall and down the backslope created in the model mesh as water levels exceed the seawall elevation. For the areas near the ICWW, the instabilities likely relate to Courant–Friedrichs–Lewy (CFL) conditions (related to model time step, element size, and wave speed). However, near the one-element canals, the instabilities likely relate to wetting and drying oscillations. To achieve stability within the SWAN+ADCIRC model for those areas near seawall overtopping, the study team modified two nodal attributes – elemental slope limiter (ESL) and surface canopy coefficient (SCC). The study team had initially applied nodal attributes reflecting those applied to most production simulations in the SFLSSS SWAN+ADCIRC modeling. These included SCC deriving from NOAA C-CAP land use data as detailed in Section 2, and ESL applied in select locations throughout the mesh to dampen instabilities experienced during early SFLSSS production run simulations. The initially applied ESL locations did not coincide with areas of interest in the Broward FRM Study. During the Broward FRM Study storm simulations, overtopping instabilities necessitated expansion in the application area of ESL; the final set of numerically stable storm simulations included several versions of the ESL nodal attribute application extent. The team began with SFLSSS dataset "sofl_v10", with subsequent edits labeled sofl_v10a, sofl_v10b, etc. These edits were cumulative, with unstable nodes added to the ESL dataset with each consecutive edit. Sofl_v10g represents the most comprehensive ESL activation applied as displayed in Figures 2.25 – 2.26.

The Broward FRM Study instabilities also prompted disabling wind stress in select overland areas as described in Section 2. For these runs, the study team applied an SCC dataset with overland wind stress disabled as applied in model reruns to correct unstable results during the SFLSSS SWAN+ADCIRC modeling. The Broward FRM Study team did not further edit this dataset (titled "scc_v3"). Note that the overland areas with wind stress disabled are located west of areas of interest in the present study. Table 5.1 indicates the various SCC and ESL settings applied for each of the 12 simulations in the SWAN+ADCIRC Model Simulation Matrix.

5.1 Storm Surge Model Results; Las Olas Boulevard

Figures 5.1 to 5.24 present the maximum water level and maximum water depth in the Las Olas Boulevard area for the 12 simulations in the SWAN+ADCIRC model simulation matrix (order shown in Table 5.1). The plots allow for examination of how each seawall alternative affects the water levels and inundation areas for each of the four storms. The water depth plots calculate the depth as the maximum water level minus the ground elevation; therefore, the open ocean and small channels present as a depth over six ft.

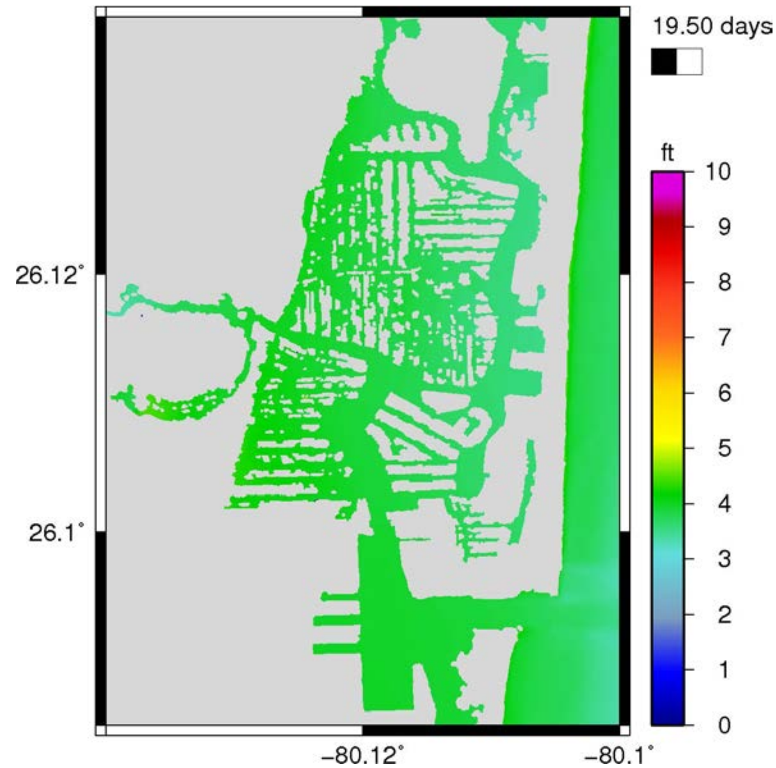

Figure 5.1 Maximum Water Surface Elevation (ft-NAVD), Las Olas Boulevard; Storm 276; Existing Mesh Configuration

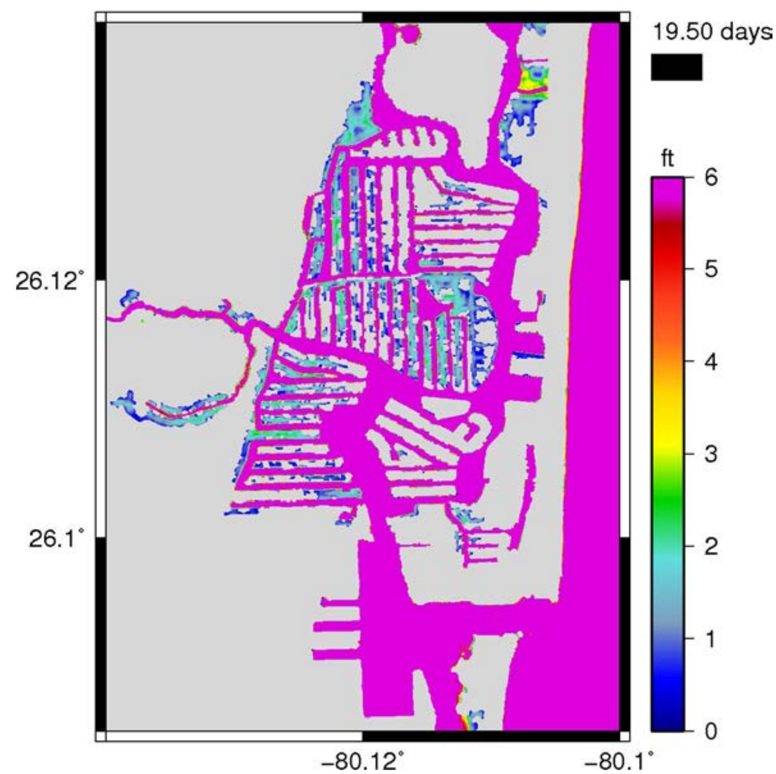

Figure 5.2 Maximum Water Depth, Las Olas Boulevard; Storm 276; Existing Mesh Configuration

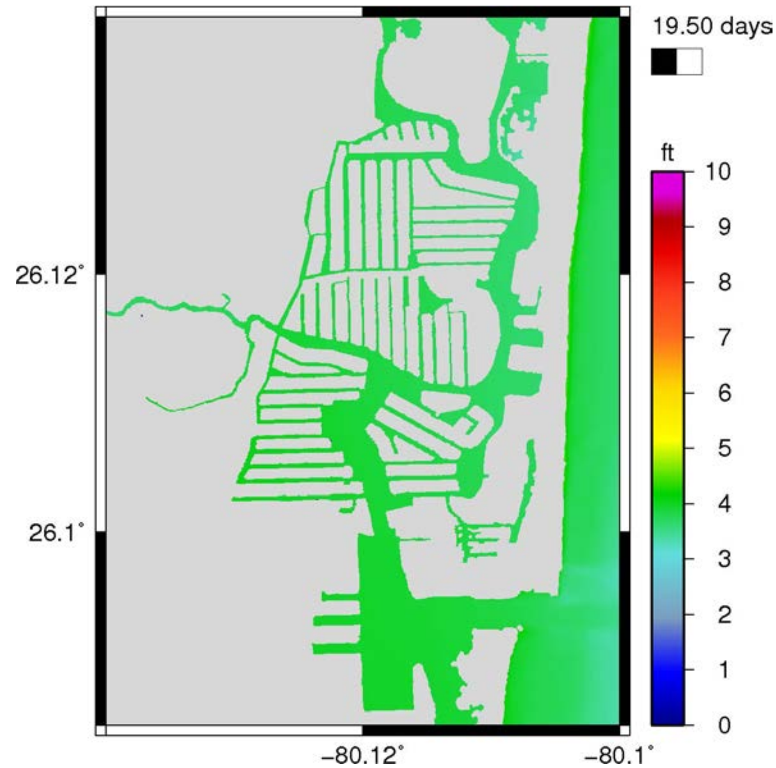

Figure 5.3 Maximum Water Surface Elevation (ft-NAVD), Las Olas Boulevard; Storm 276; Alternative 1 Mesh Configuration

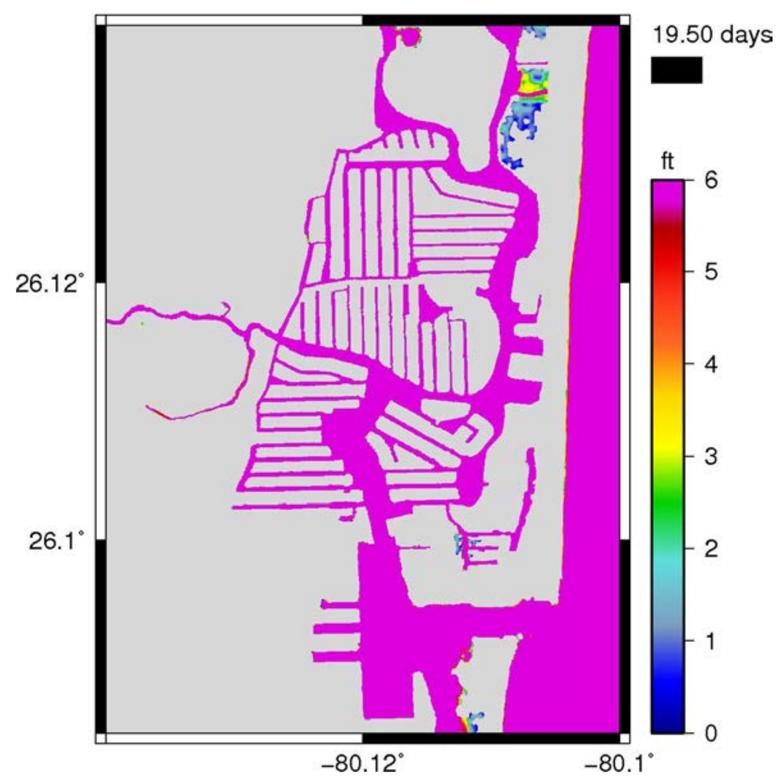

Figure 5.4 Maximum Water Depth, Las Olas Boulevard; Storm 276; Alternative 1 Mesh Configuration

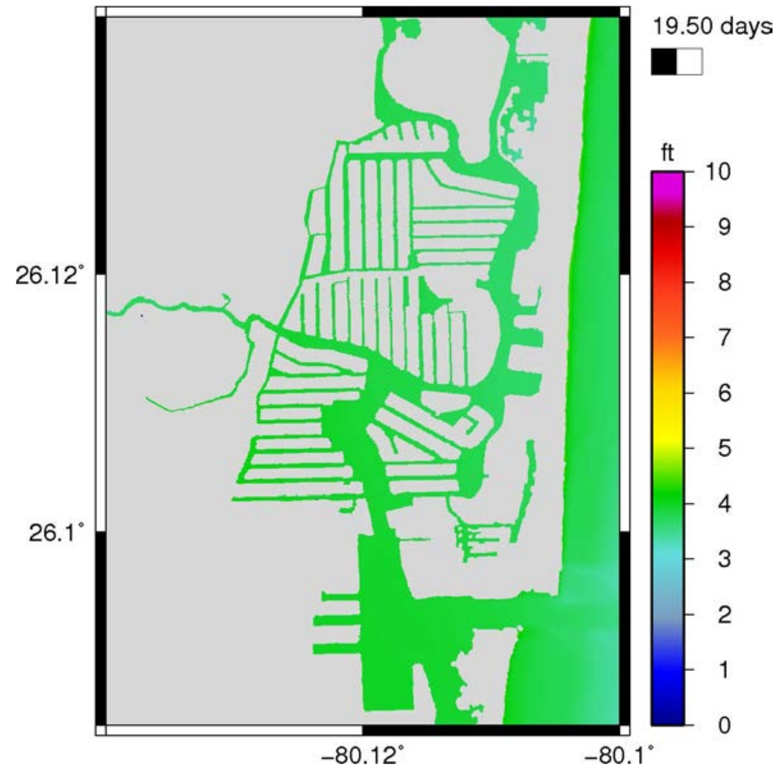

Figure 5.5 Maximum Water Surface Elevation (ft-NAVD), Las Olas Boulevard; Storm 276; Alternative 2 Mesh Configuration

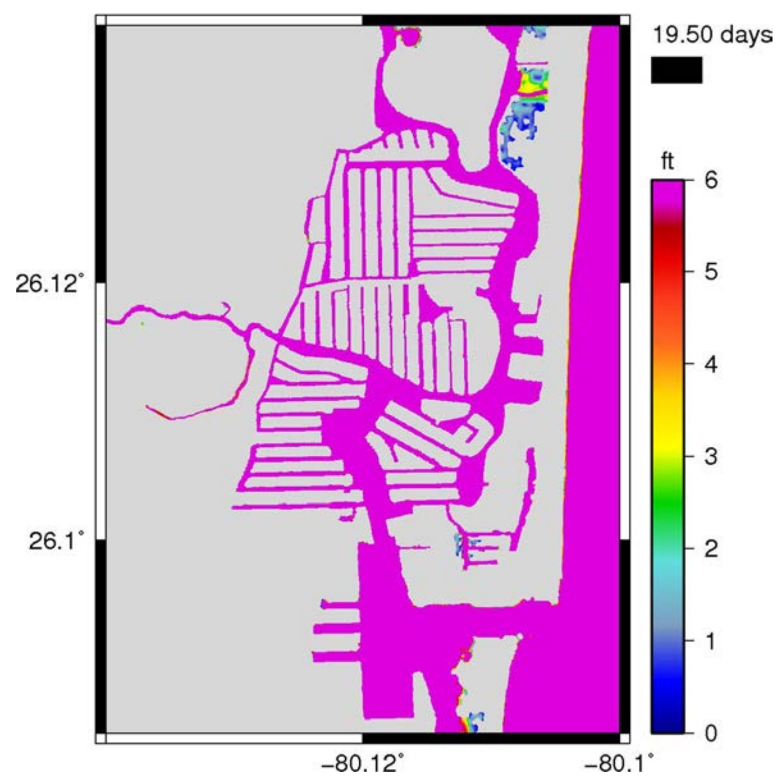

Figure 5.6 Maximum Water Depth, Las Olas Boulevard; Storm 276; Alternative 2 Mesh Configuration

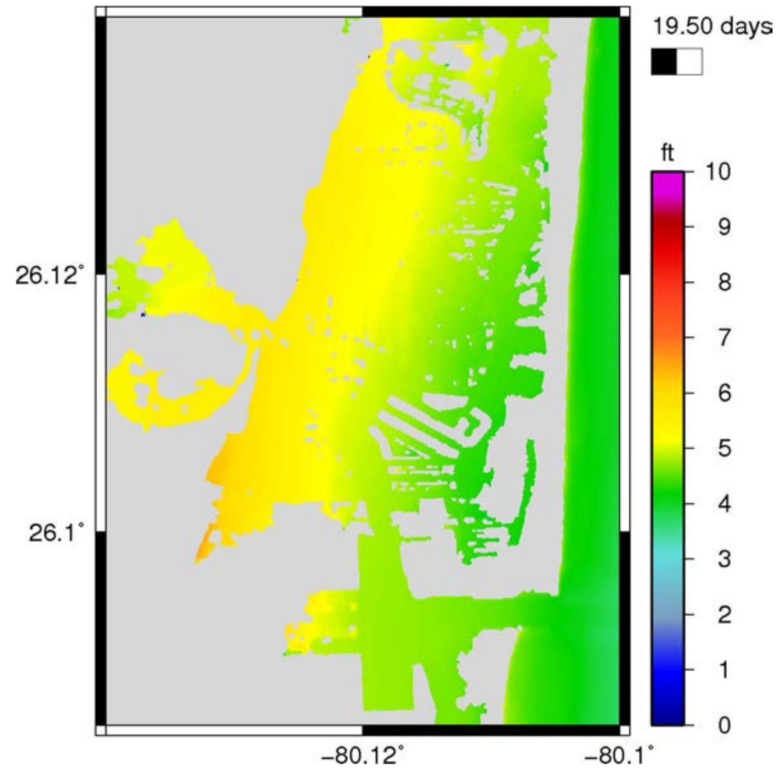

Figure 5.7 Maximum Water Surface Elevation (ft-NAVD), Las Olas Boulevard; Storm 122; Existing Mesh Configuration

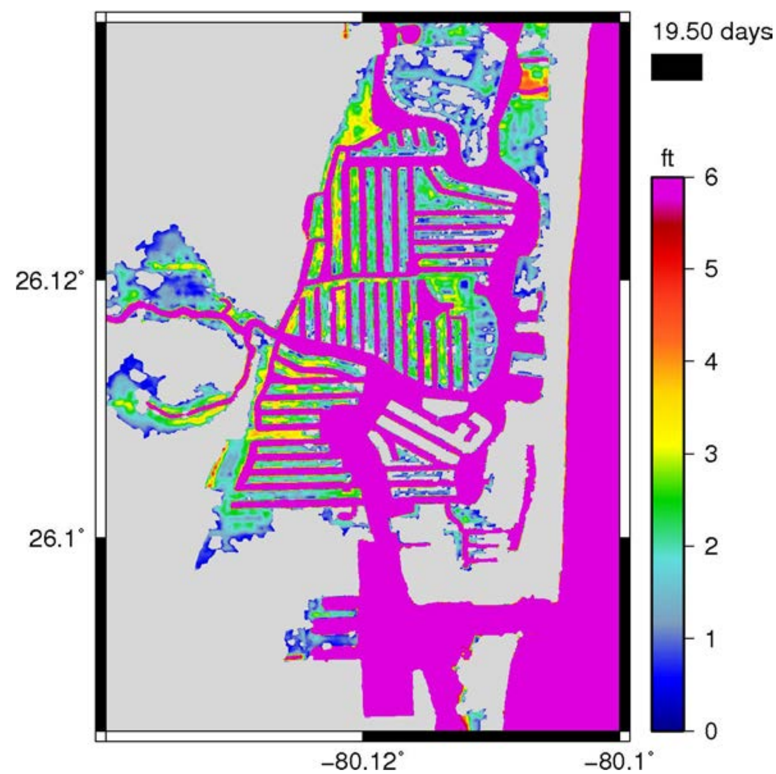

Figure 5.8 Maximum Water Depth, Las Olas Boulevard; Storm 122; Existing Mesh Configuration

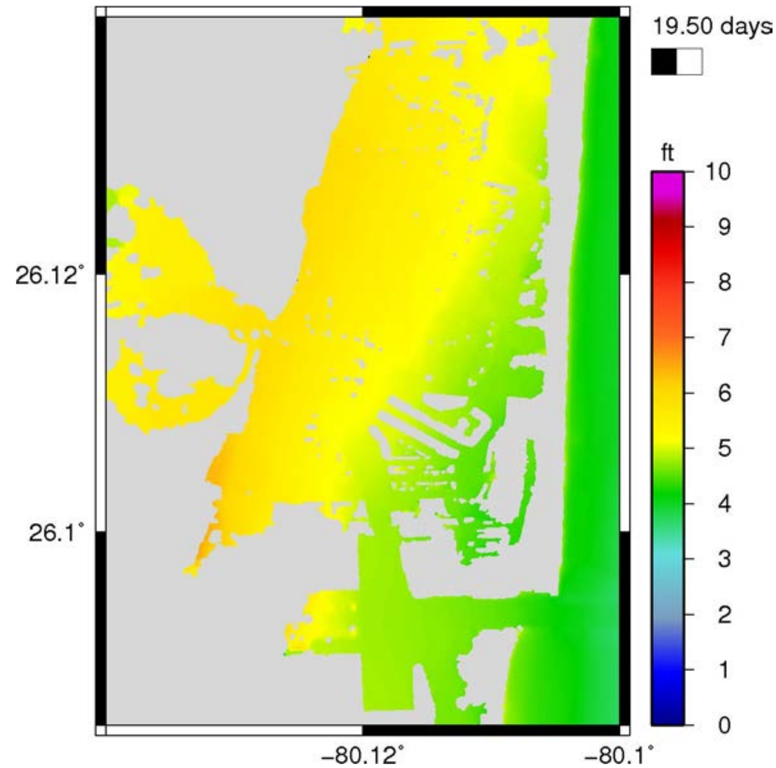

Figure 5.9 Maximum Water Surface Elevation (ft-NAVD), Las Olas Boulevard; Storm 122; Alternative 2 Mesh Configuration

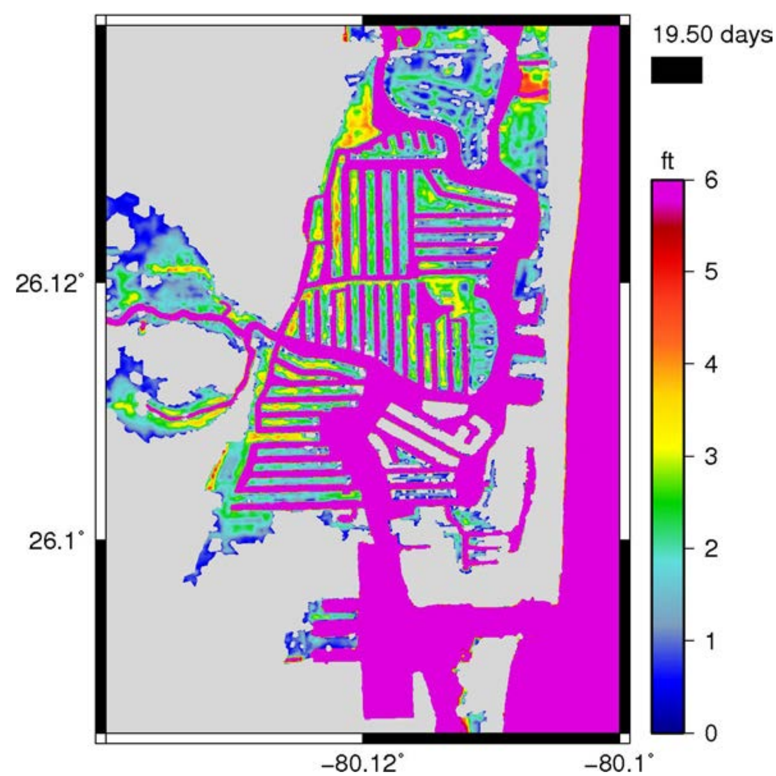

Figure 5.10 Maximum Water Depth, Las Olas Boulevard; Storm 122; Alternative 2 Mesh Configuration

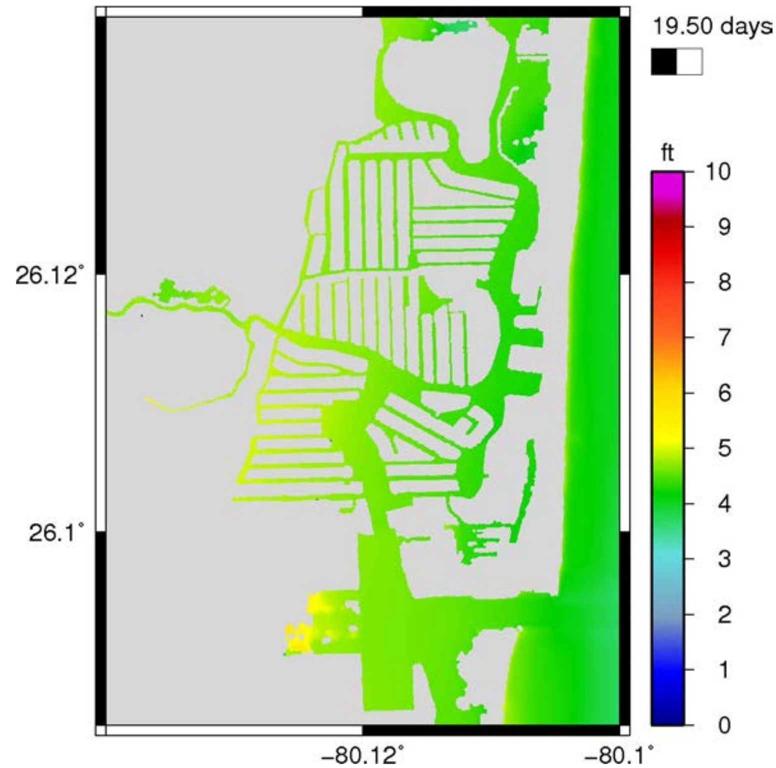

Figure 5.11 Maximum Water Surface Elevation (ft-NAVD), Las Olas Boulevard; Storm 122; Alternative 3 Mesh Configuration

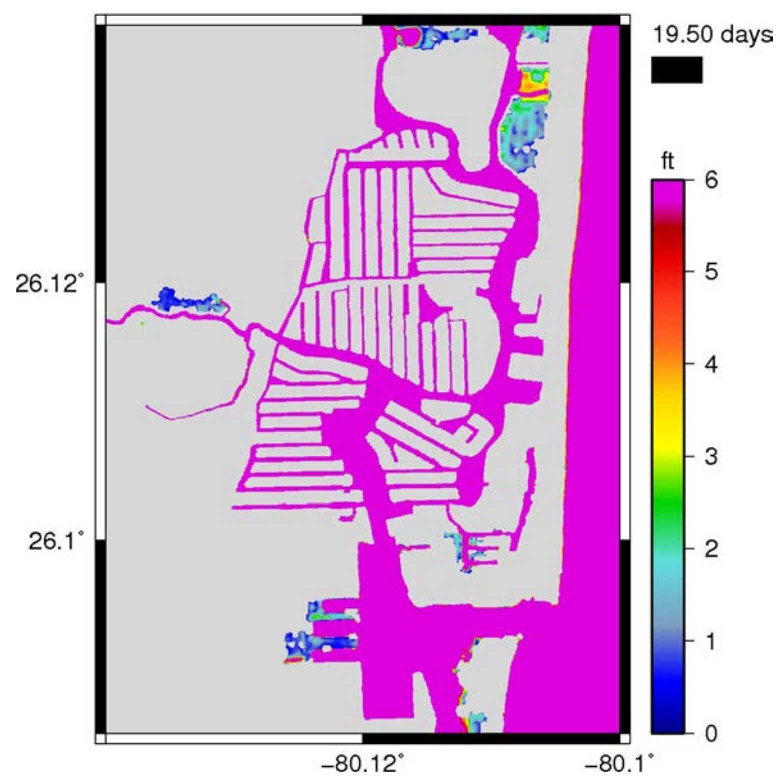

Figure 5.12 Maximum Water Depth, Las Olas Boulevard; Storm 122; Alternative 3 Mesh Configuration

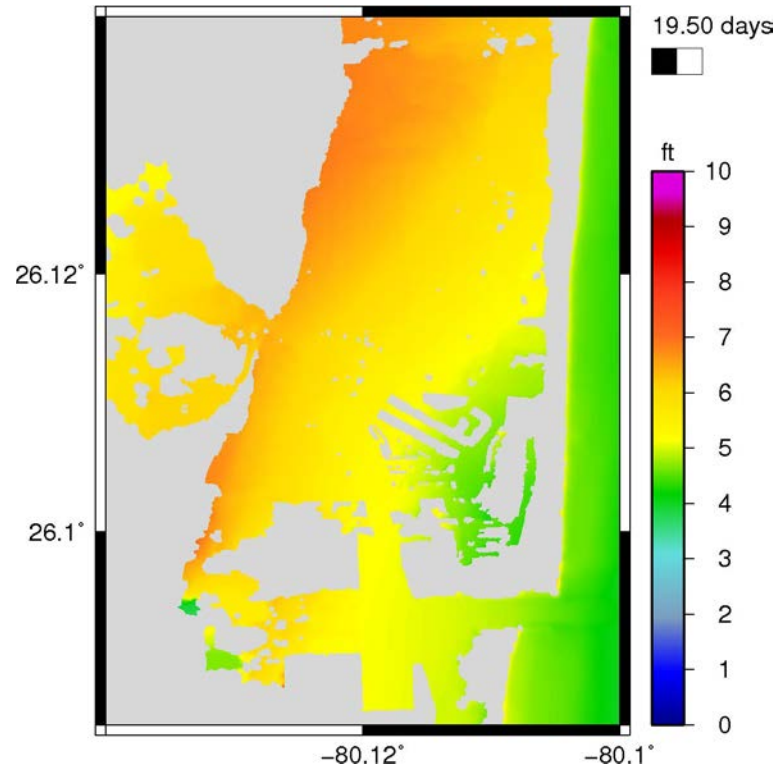

Figure 5.13 Maximum Water Surface Elevation (ft-NAVD), Las Olas Boulevard; Storm 60; Existing Mesh Configuration

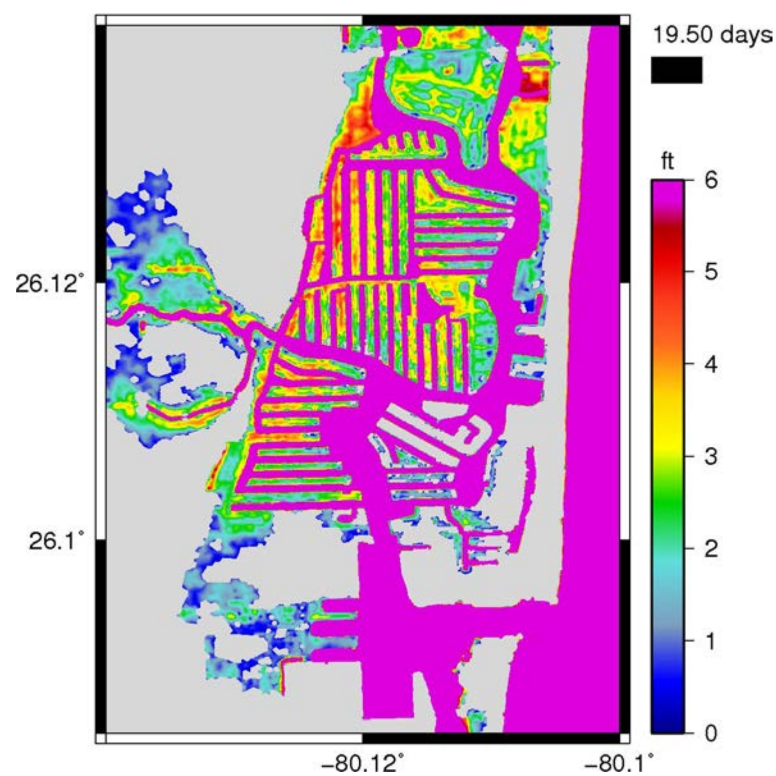

Figure 5.14 Maximum Water Depth, Las Olas Boulevard; Storm 60; Existing Mesh Configuration

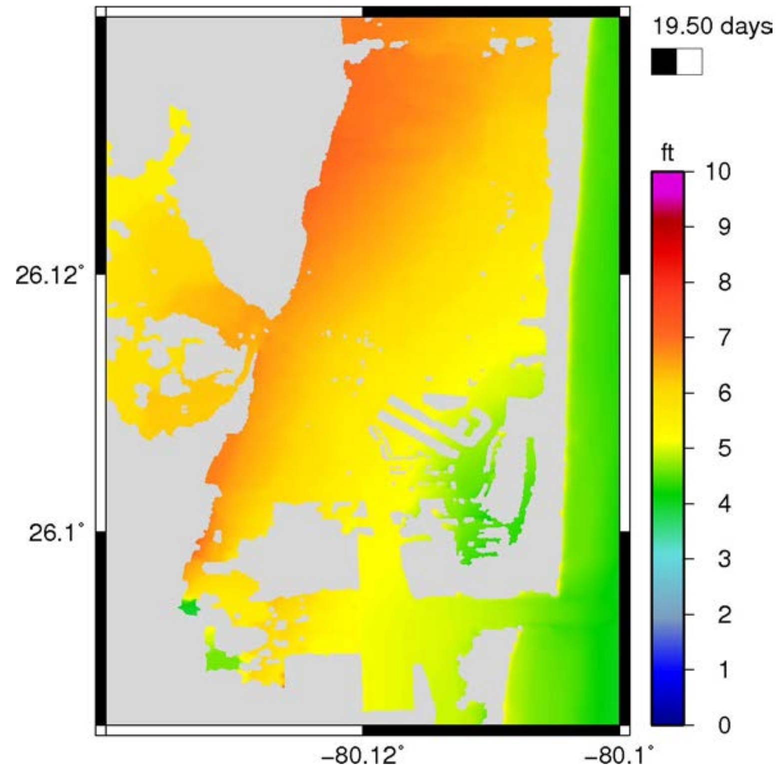

Figure 5.15 Maximum Water Surface Elevation (ft-NAVD), Las Olas Boulevard; Storm 60; Alternative 2 Mesh Configuration

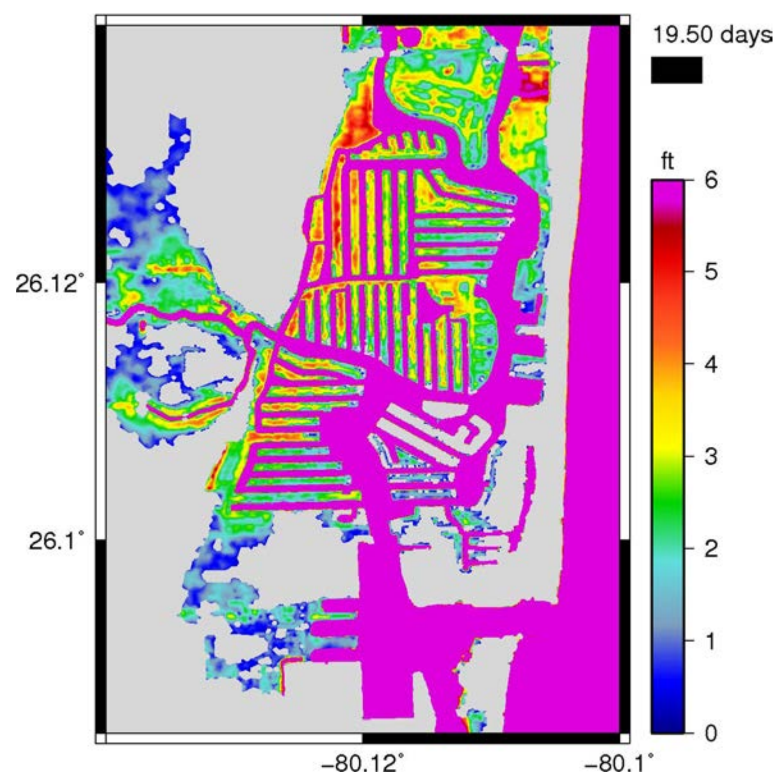

Figure 5.16 Maximum Water Depth, Las Olas Boulevard; Storm 60; Alternative 2 Mesh Configuration

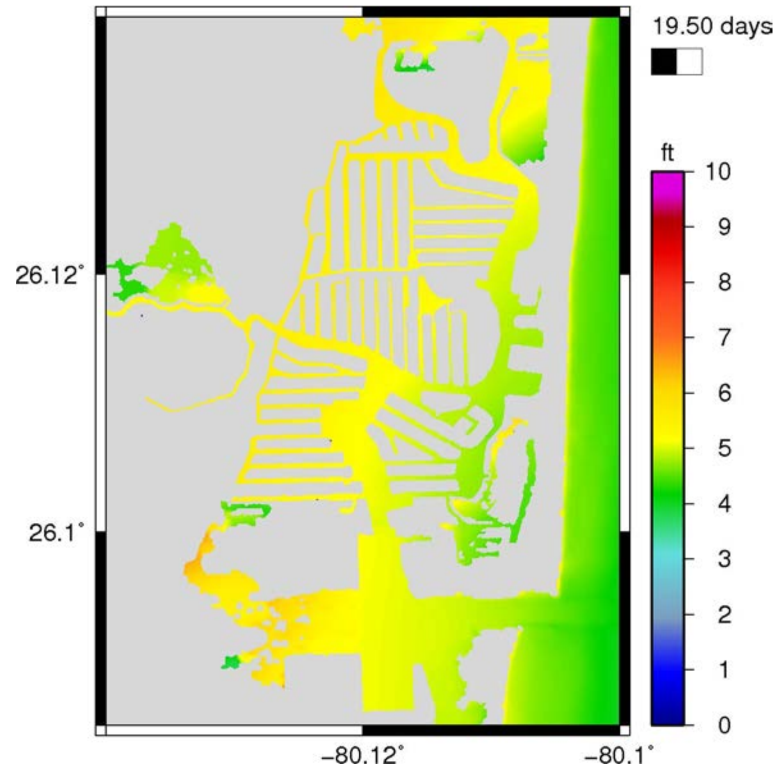

Figure 5.17 Maximum Water Surface Elevation (ft-NAVD), Las Olas Boulevard; Storm 60; Alternative 3 Mesh Configuration

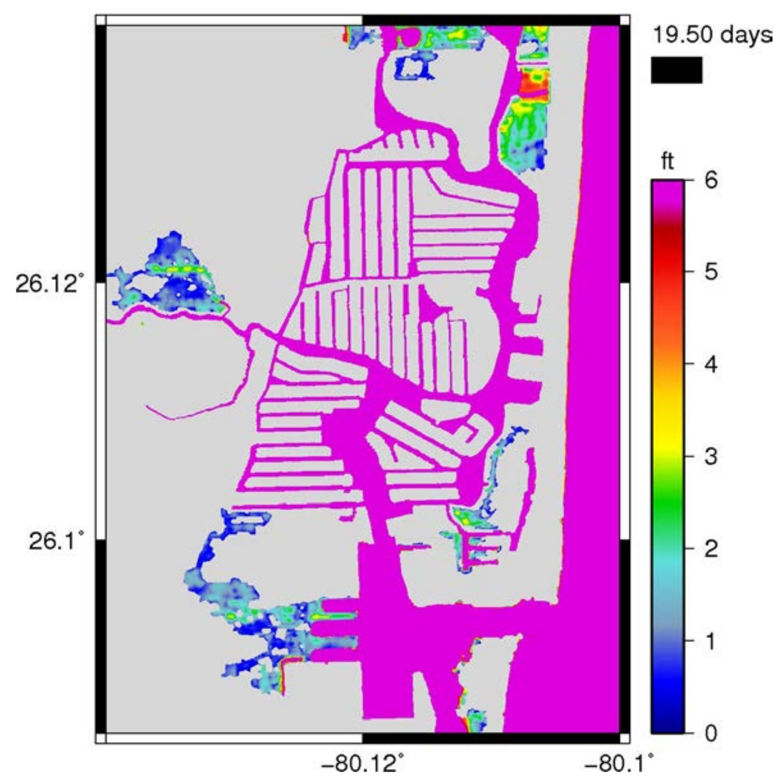

Figure 5.18 Maximum Water Depth, Las Olas Boulevard; Storm 60; Alternative 3 Mesh Configuration

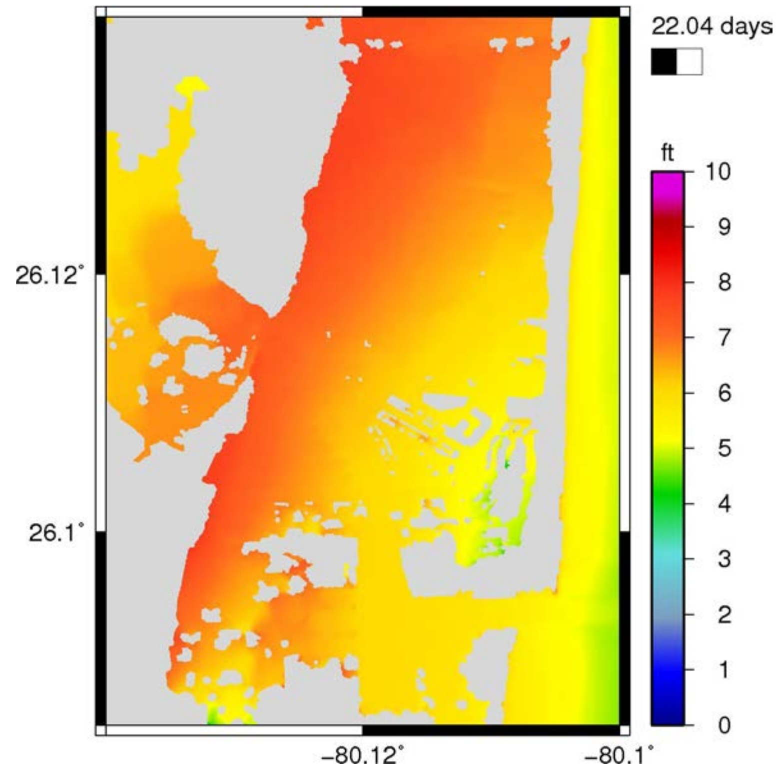

Figure 5.19 Maximum Water Surface Elevation (ft-NAVD), Las Olas Boulevard; Storm 61; Existing Mesh Configuration

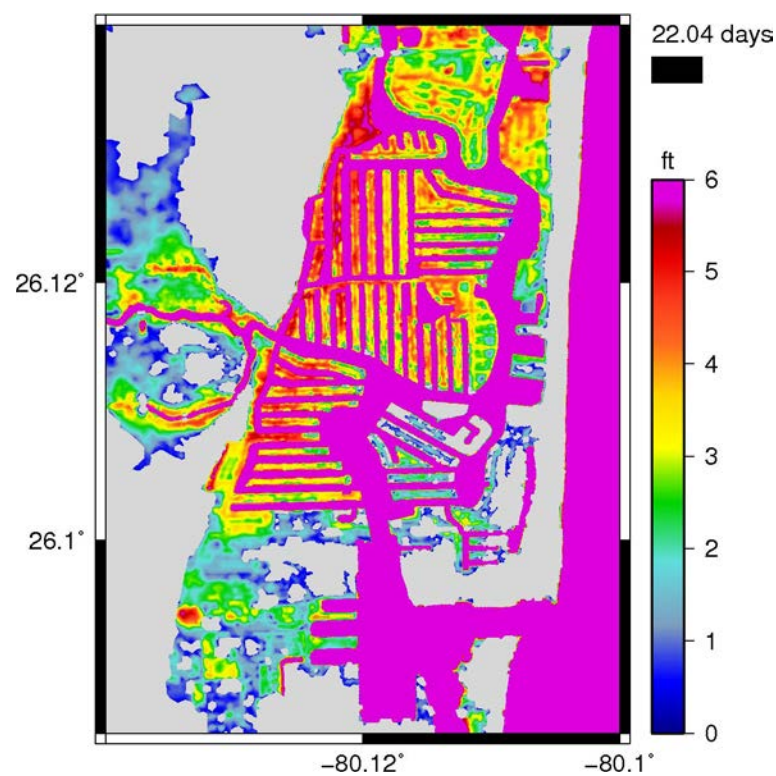

Figure 5.20 Maximum Water Depth, Las Olas Boulevard; Storm 61; Existing Mesh Configuration

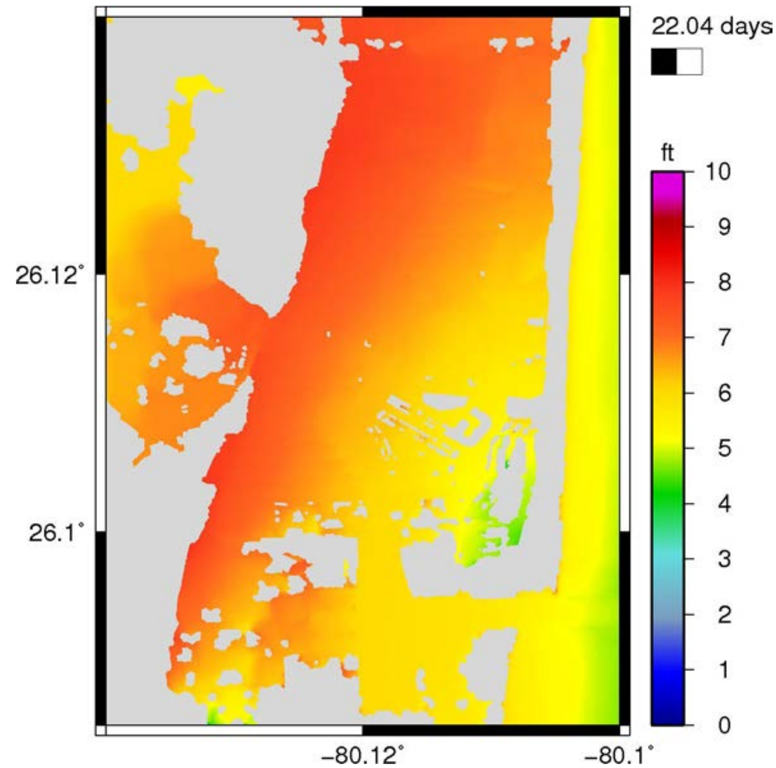

Figure 5.21 Maximum Water Surface Elevation (ft-NAVD), Las Olas Boulevard; Storm 61; Alternative 2 Mesh Configuration

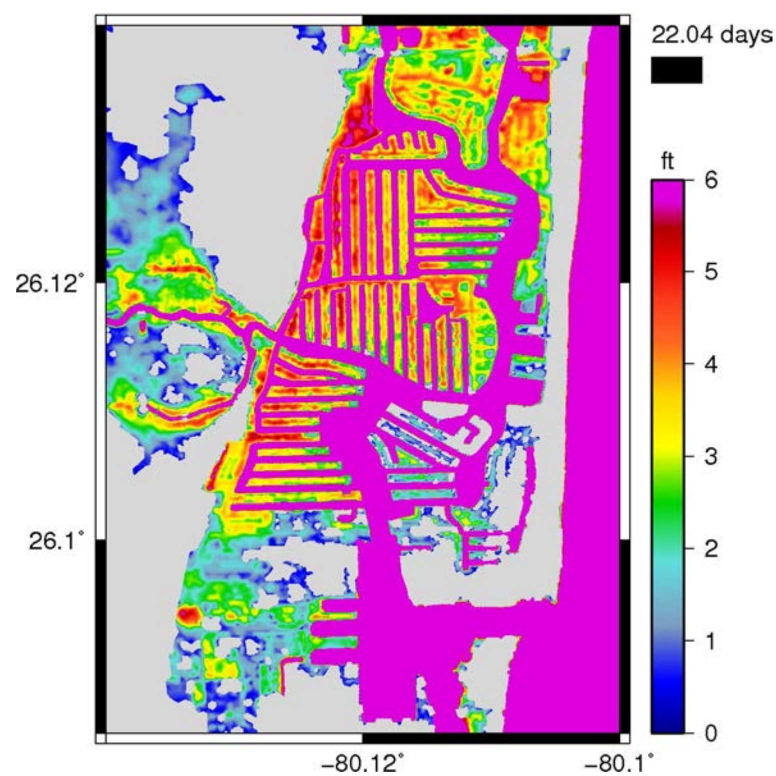

Figure 5.22 Maximum Water Depth, Las Olas Boulevard; Storm 61; Alternative 2 Mesh Configuration

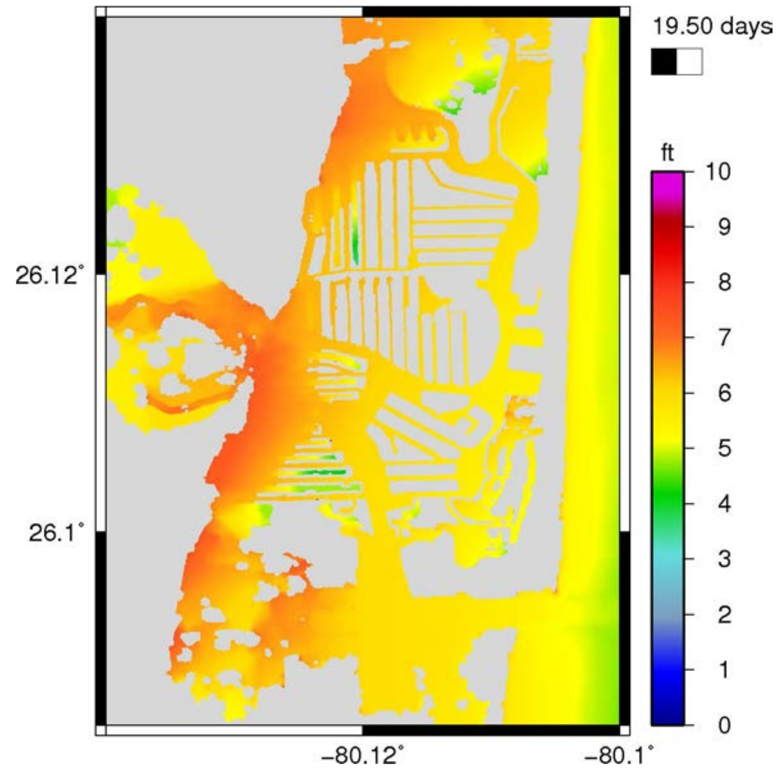

Figure 5.23 Maximum Water Surface Elevation (ft-NAVD), Las Olas Boulevard; Storm 61; Alternative 3 Mesh Configuration

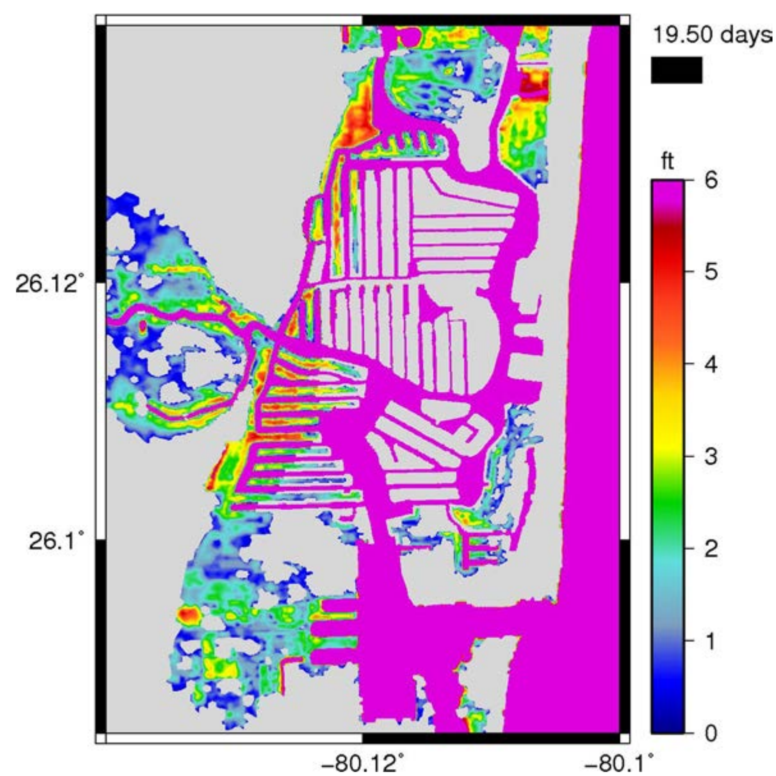

Figure 5.24 Maximum Water Depth, Las Olas Boulevard; Storm 61; Alternative 3 Mesh Configuration

5.2 Storm Surge Model Results; Hollywood Lakes

Figures 5.25 to 5.46 present the maximum water level and maximum water depth in the Hollywood Lakes area for the 12 simulations in the SWAN+ADCIRC model simulation matrix (order shown in Table 5.1). The plots allow for examination of how each seawall alternative affects the water levels and inundation areas for each of the four storms. The water depth plots calculate the depth as the maximum water level minus the ground elevation; therefore, the open ocean and small channels present as a depth over six ft.

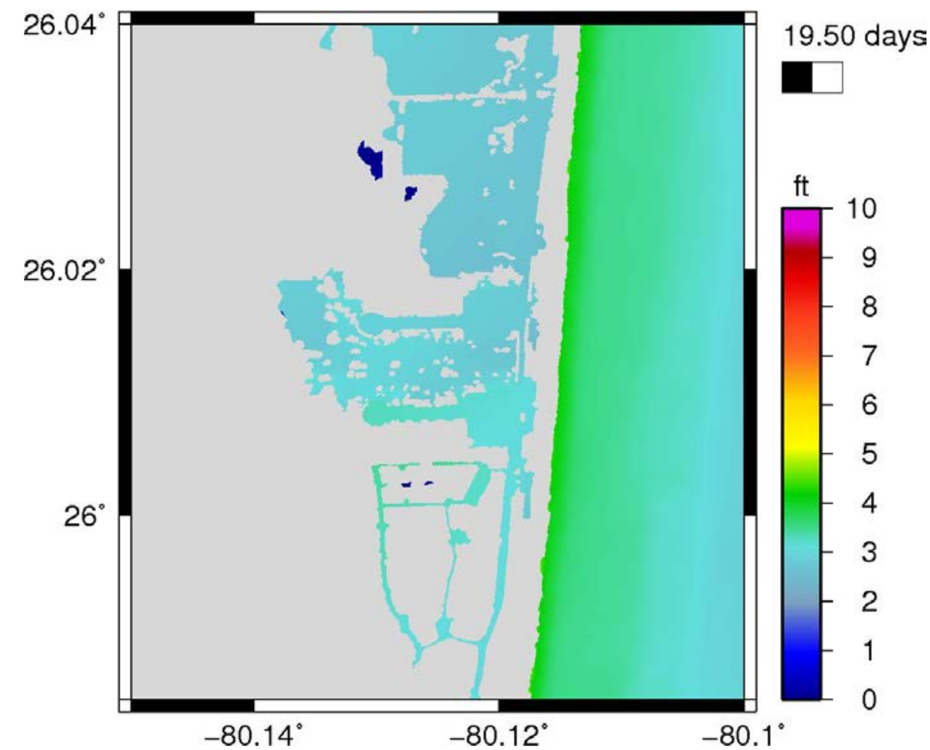

Figure 5.25 Maximum Water Surface Elevation (ft-NAVD), Hollywood Lakes; Storm 276; Existing Mesh Configuration

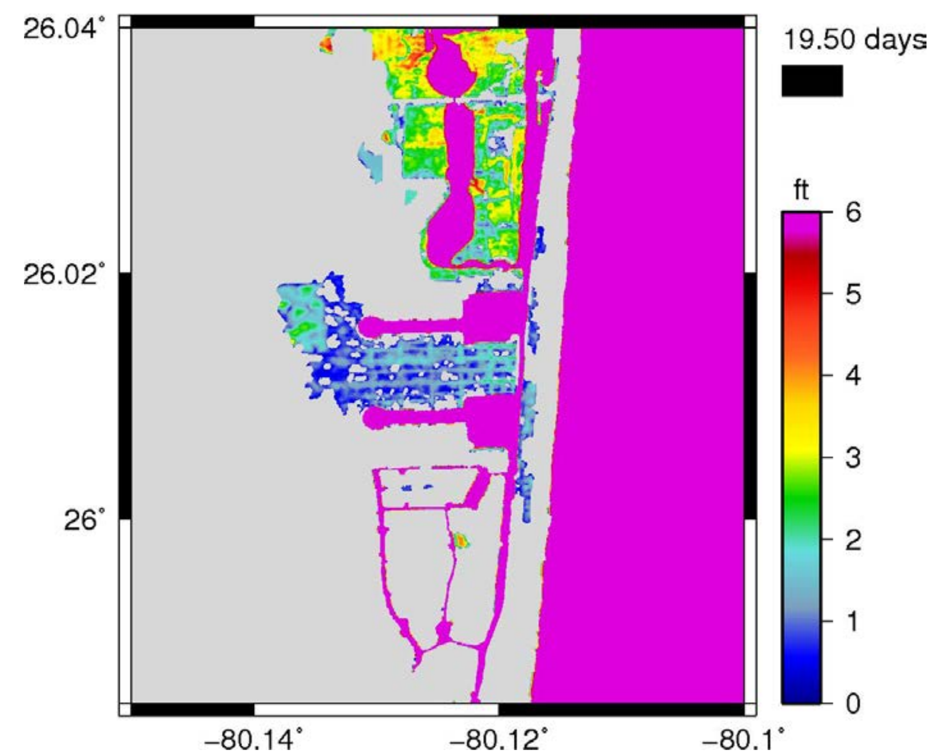

Figure 5.26 Maximum Water Depth, Hollywood Lakes; Storm 276; Existing Mesh Configuration

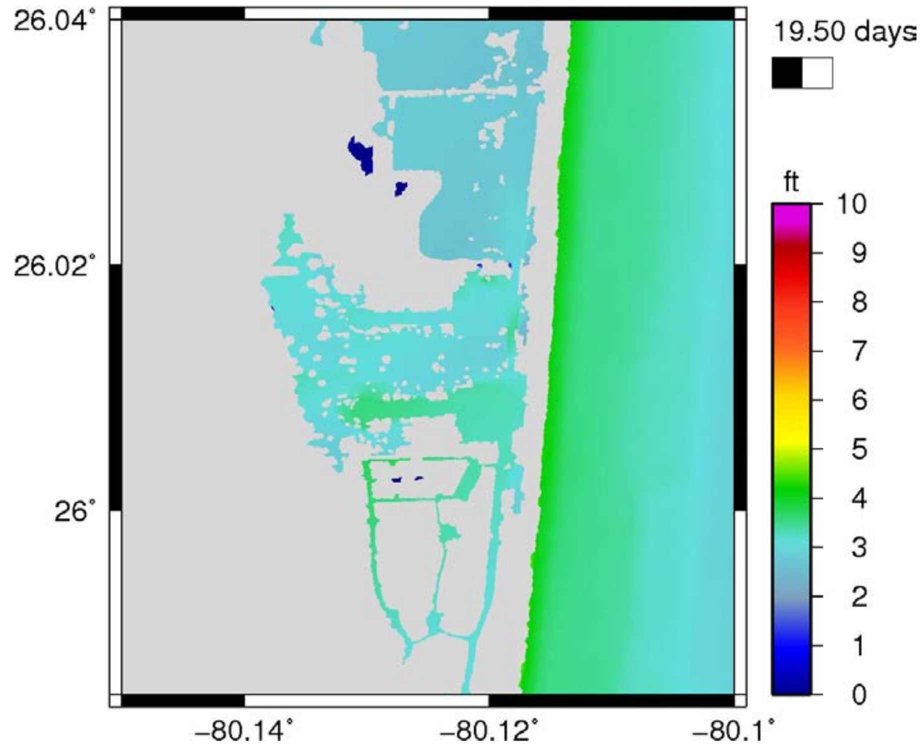

Figure 5.27 Maximum Water Surface Elevation (ft-NAVD), Hollywood Lakes; Storm 276; Alternative 1 Mesh Configuration

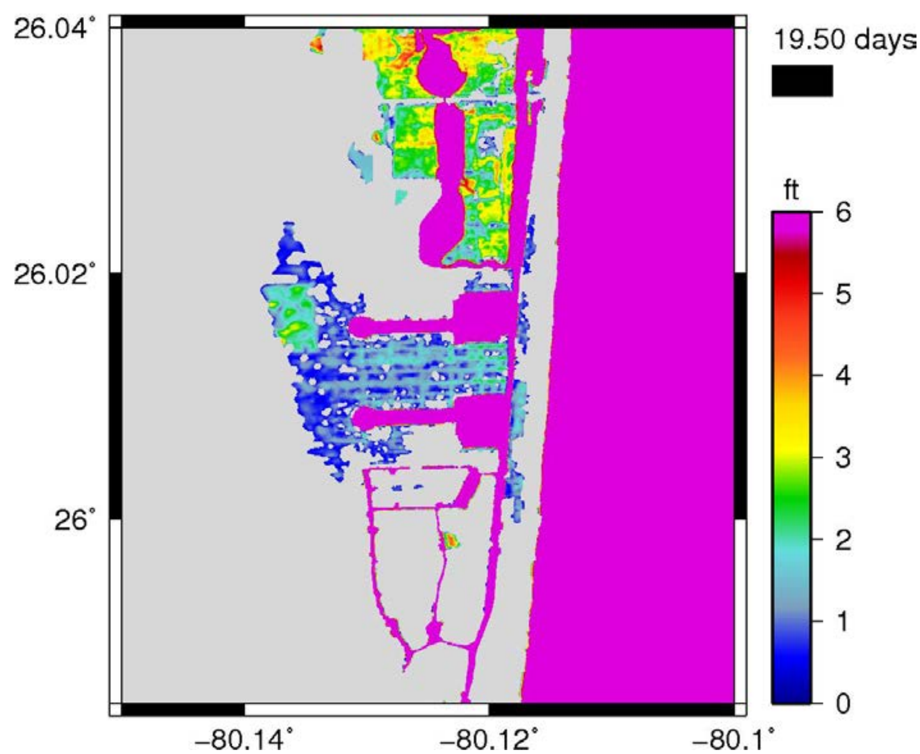

Figure 5.28 Maximum Water Depth, Hollywood Lakes; Storm 276; Alternative 1 Mesh Configuration

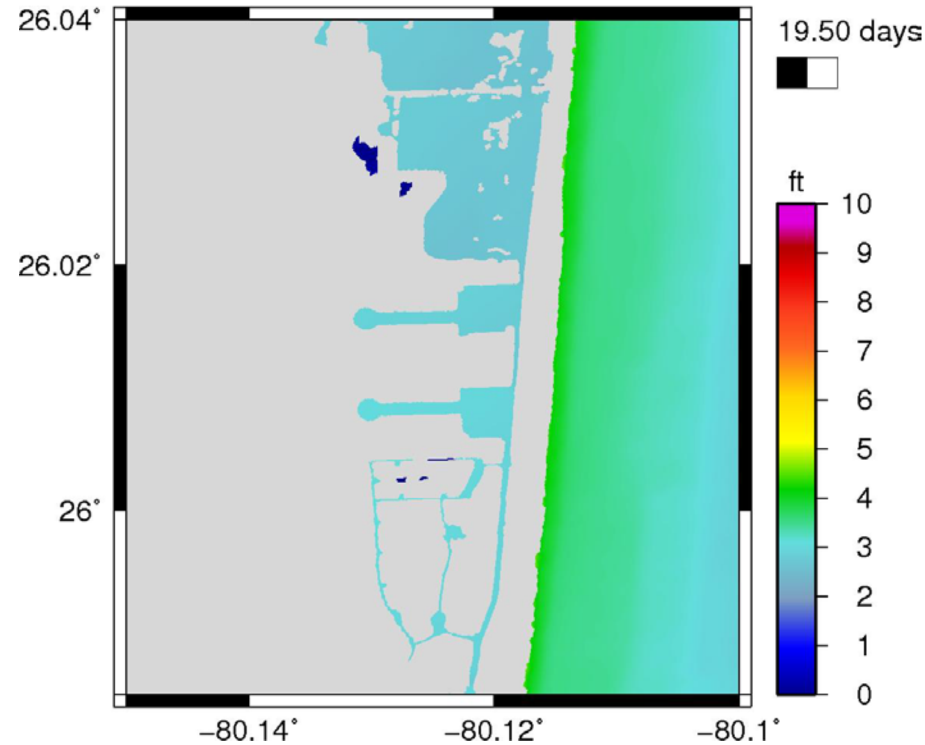

Figure 5.29 Maximum Water Surface Elevation (ft-NAVD), Hollywood Lakes; Storm 276; Alternative 2 Mesh Configuration

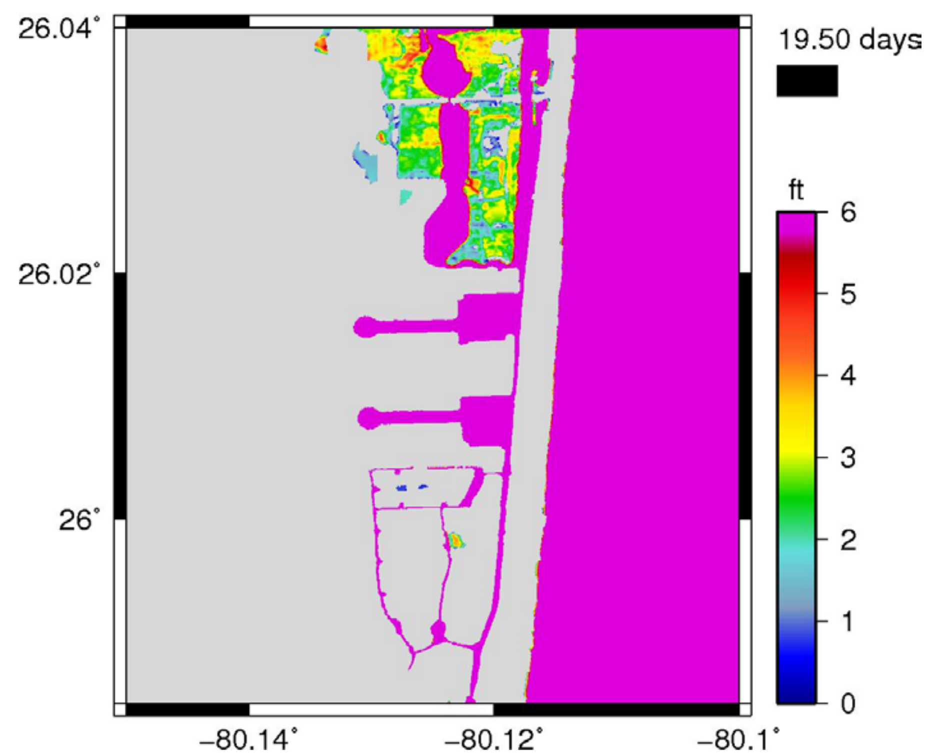

Figure 5.30 Maximum Water Depth, Hollywood Lakes; Storm 276; Alternative 2 Mesh Configuration

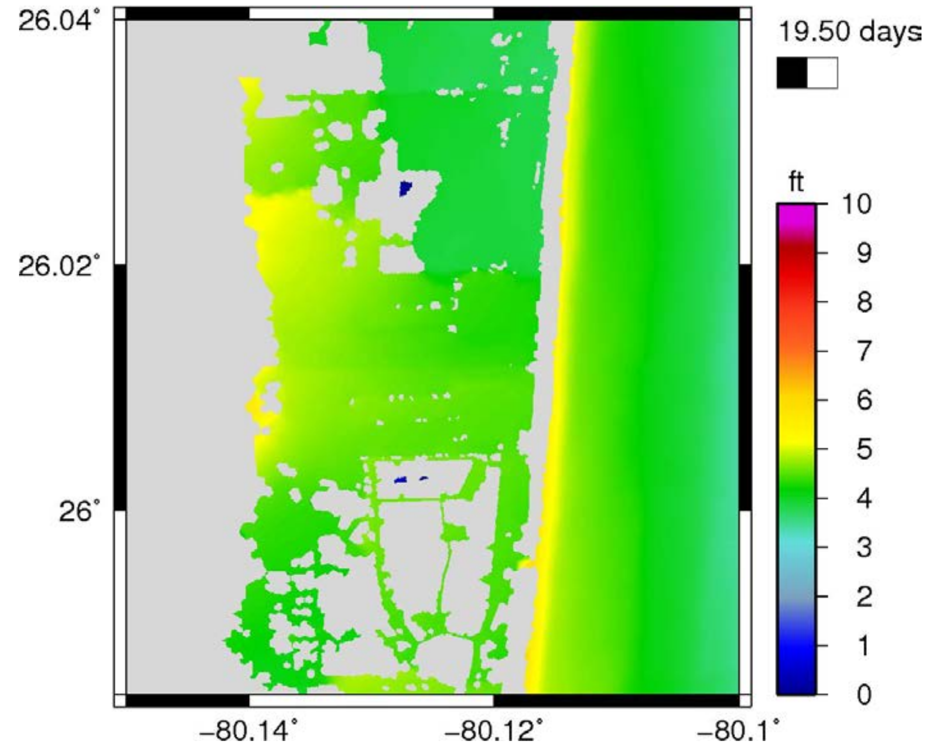

Figure 5.31 Maximum Water Surface Elevation (ft-NAVD), Hollywood Lakes; Storm 122; Existing Mesh Configuration

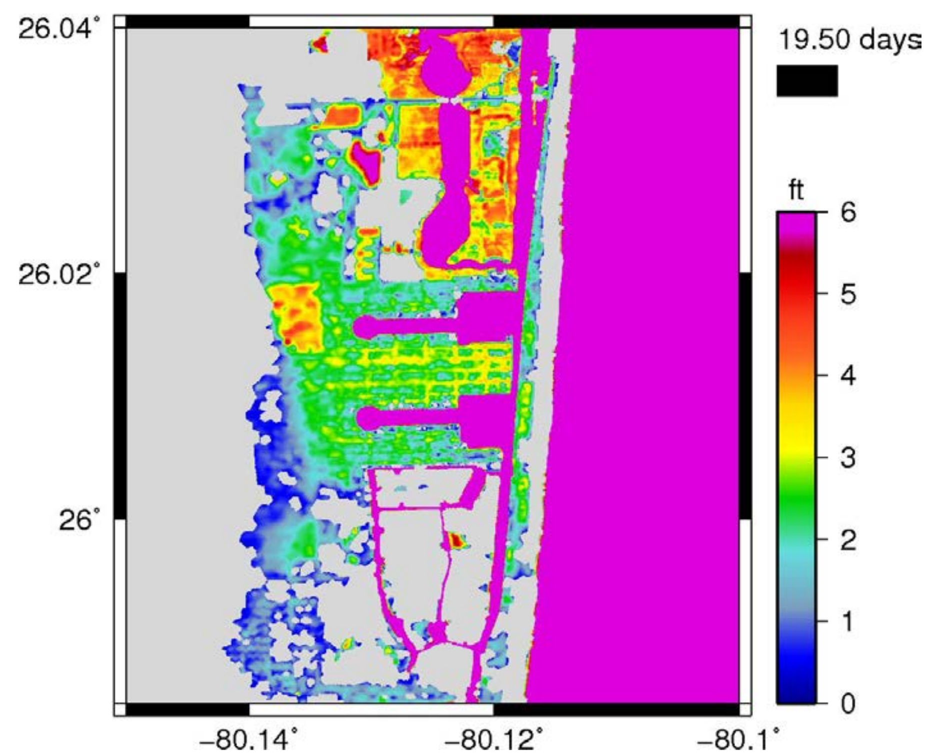

Figure 5.32 Maximum Water Depth, Hollywood Lakes; Storm 122; Existing Mesh Configuration

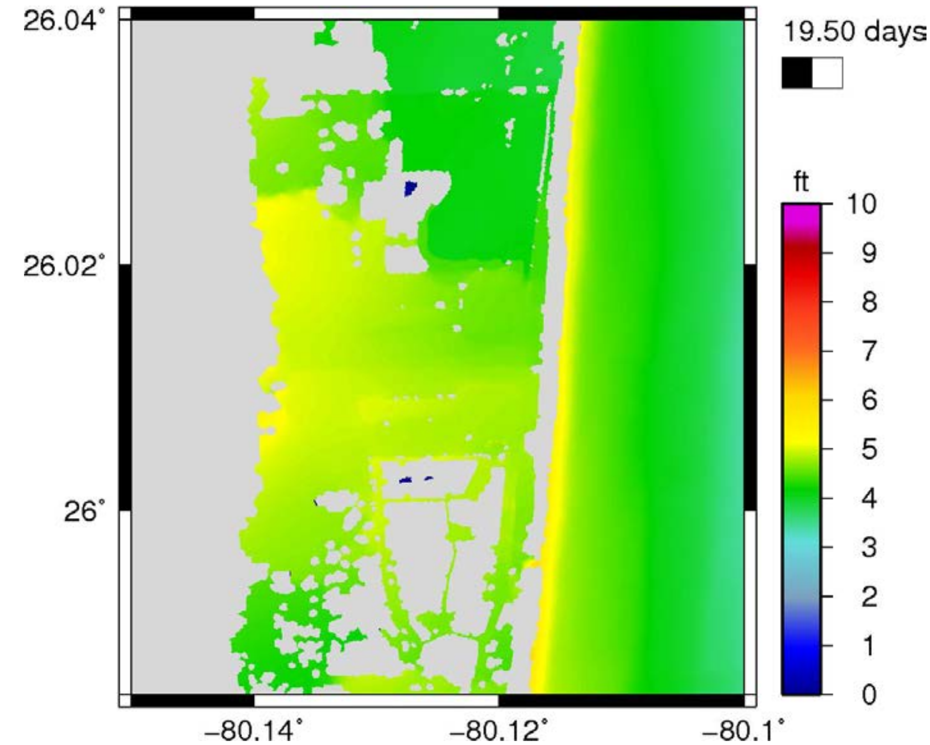

Figure 5.33 Maximum Water Surface Elevation (ft-NAVD), Hollywood Lakes; Storm 122; Alternative 2 Mesh Configuration

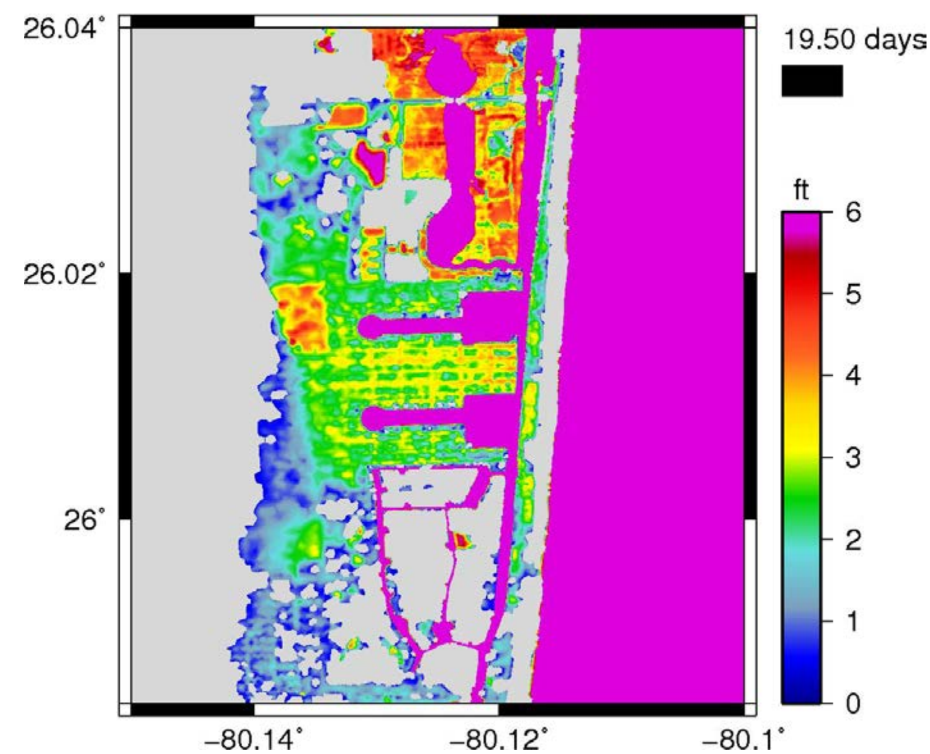

Figure 5.34 Maximum Water Depth, Hollywood Lakes; Storm 122; Alternative 2 Mesh Configuration

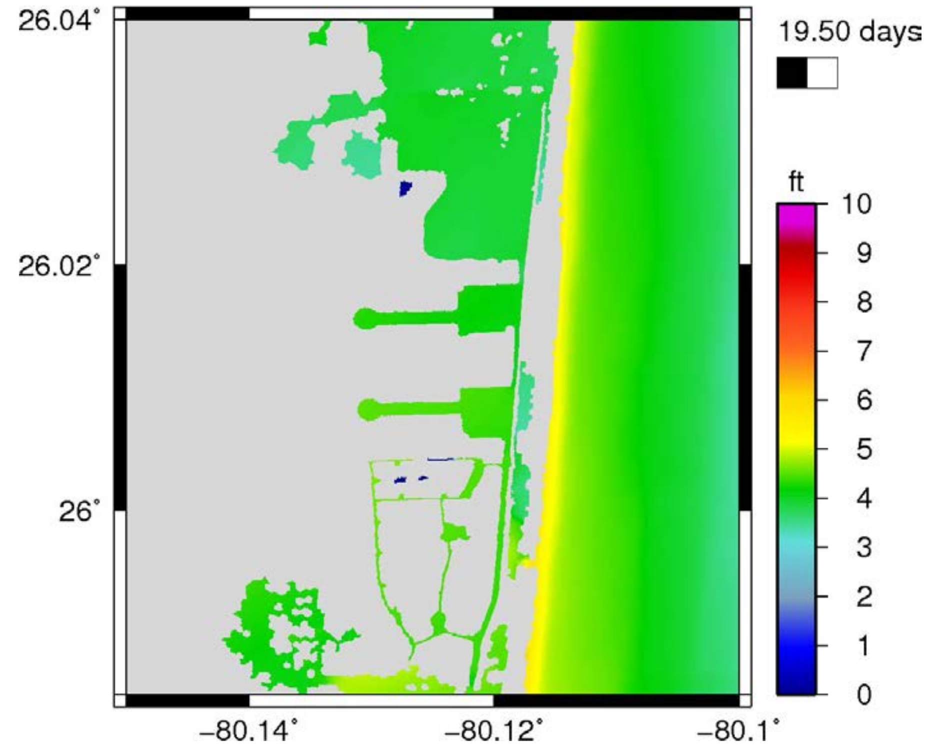

Figure 5.35 Maximum Water Surface Elevation (ft-NAVD), Hollywood Lakes; Storm 122; Alternative 3 Mesh Configuration

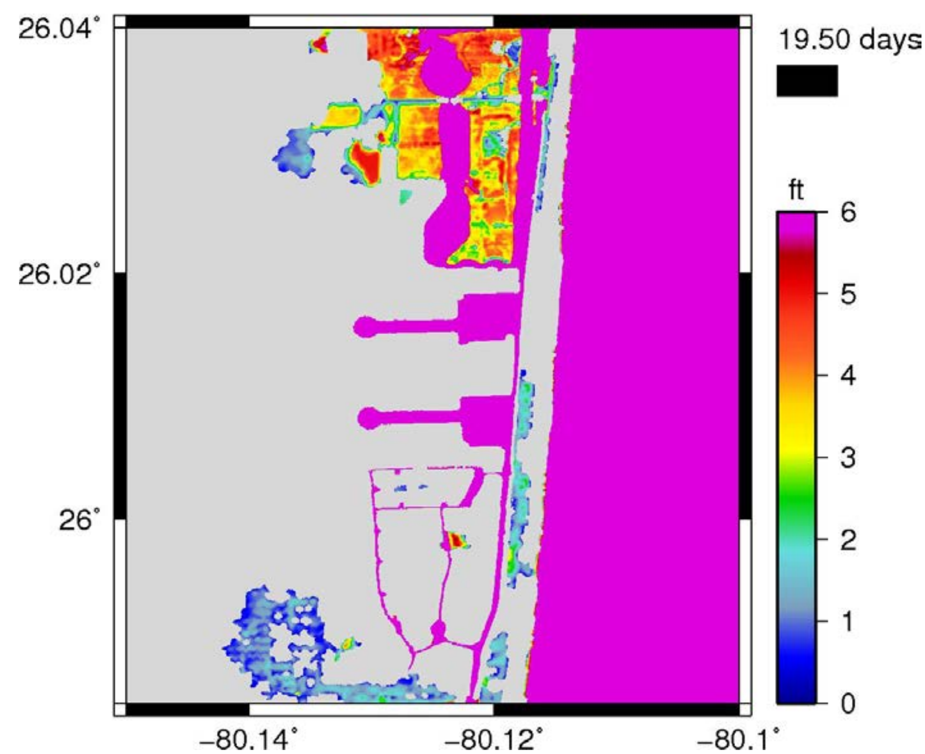

Figure 5.36 Maximum Water Depth, Hollywood Lakes; Storm 122; Alternative 3 Mesh Configuration

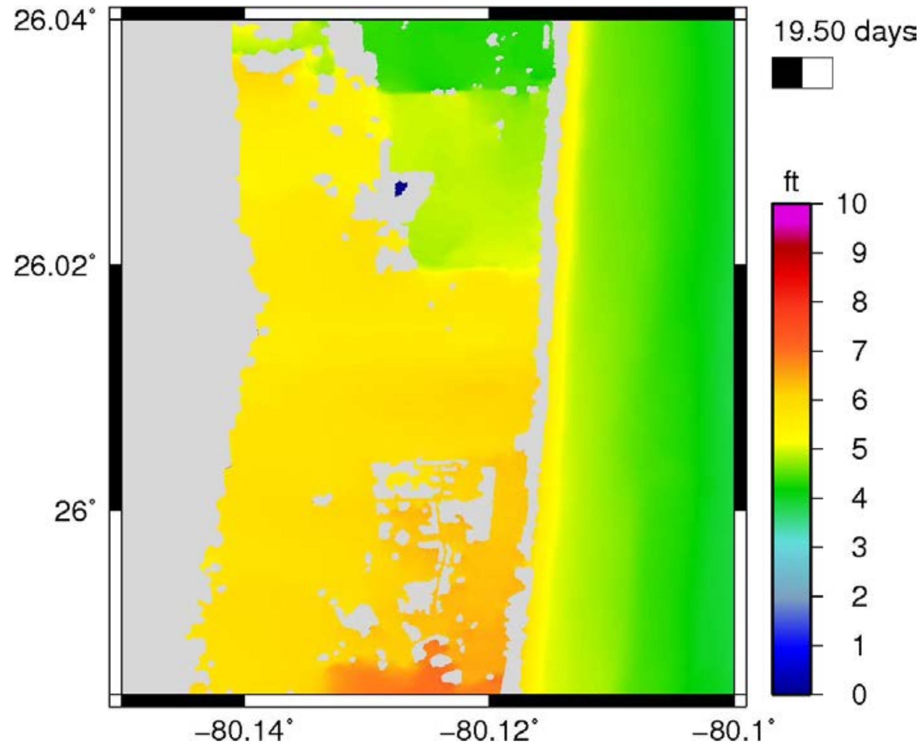

Figure 5.37 Maximum Water Surface Elevation (ft-NAVD), Hollywood Lakes; Storm 60; Existing Mesh Configuration

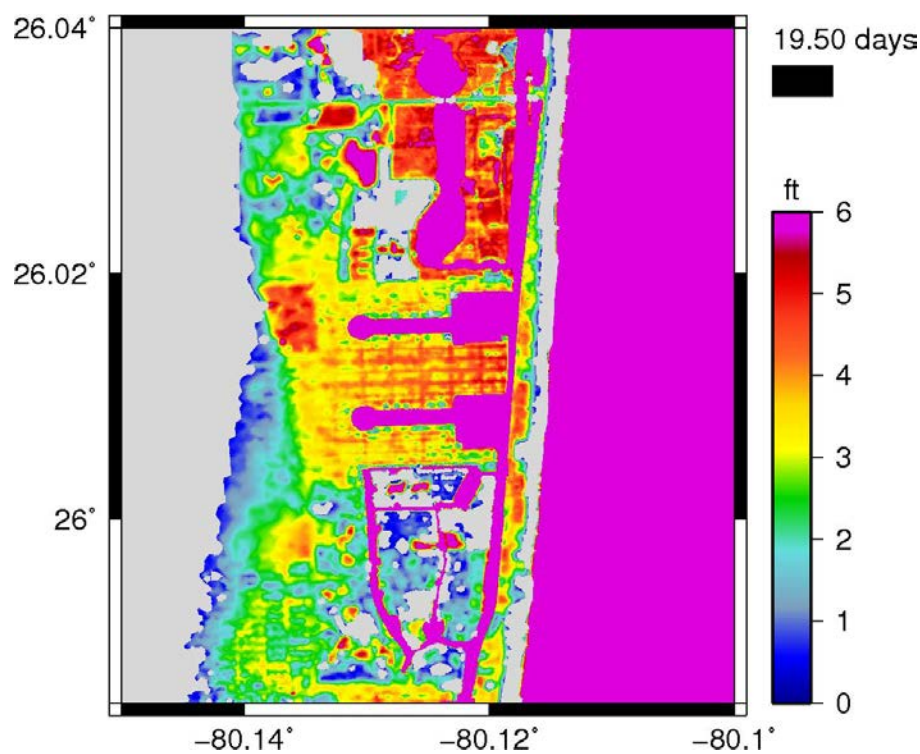

Figure 5.38 Maximum Water Depth, Hollywood Lakes; Storm 60; Existing Mesh Configuration

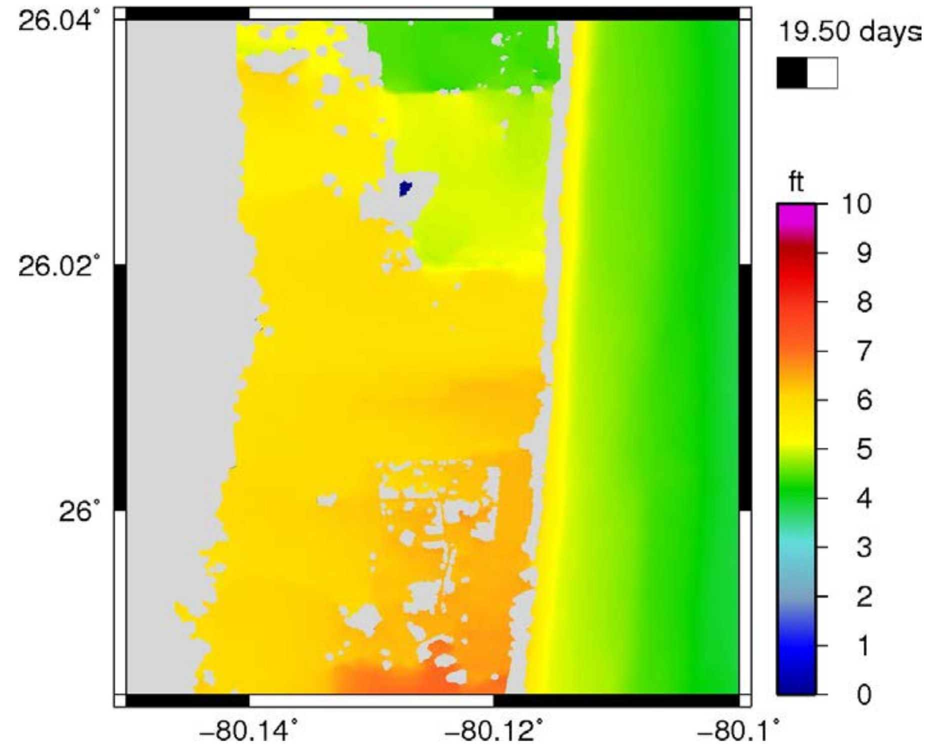

Figure 5.39 Maximum Water Surface Elevation (ft-NAVD), Hollywood Lakes; Storm 60; Alternative 2 Mesh Configuration

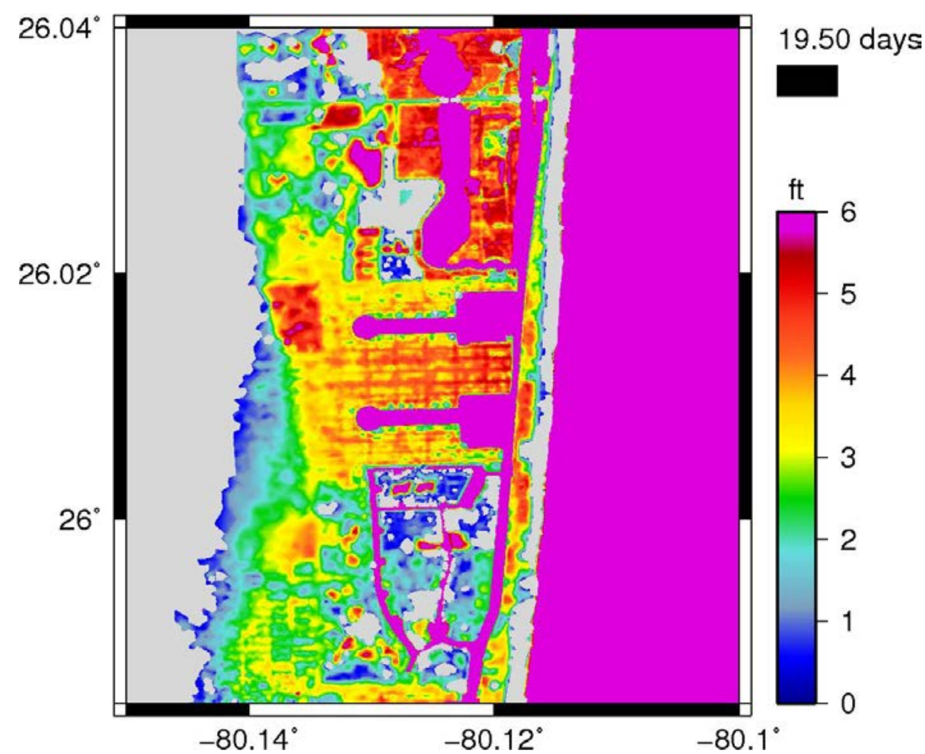

Figure 5.40 Maximum Water Depth, Hollywood Lakes; Storm 60; Alternative 2 Mesh Configuration

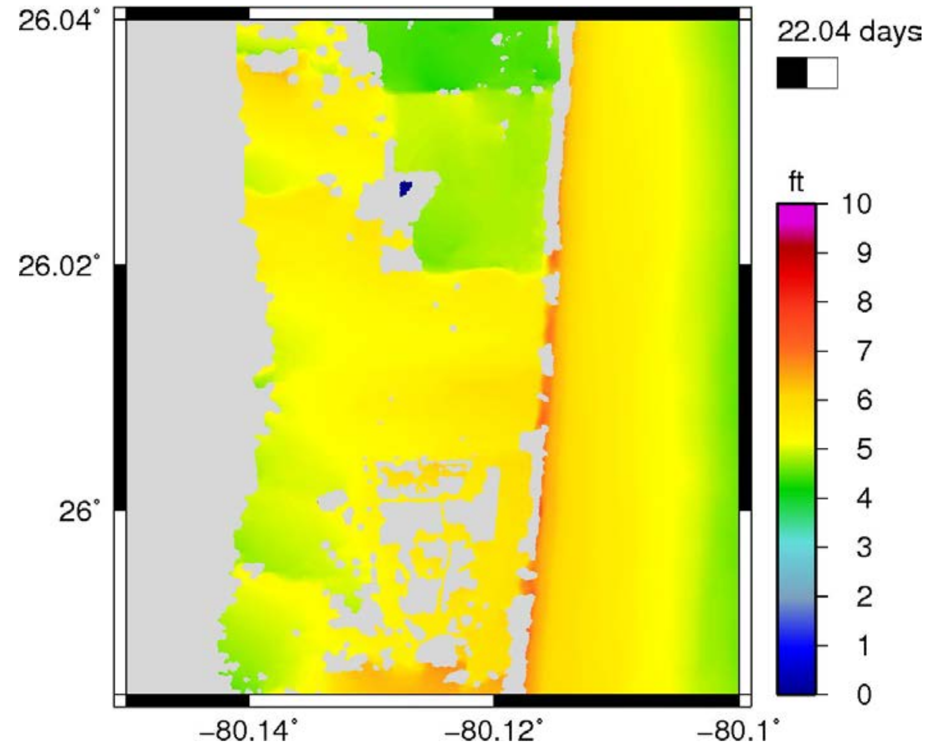

Figure 5.41 Maximum Water Surface Elevation (ft-NAVD), Hollywood Lakes; Storm 61; Existing Mesh Configuration

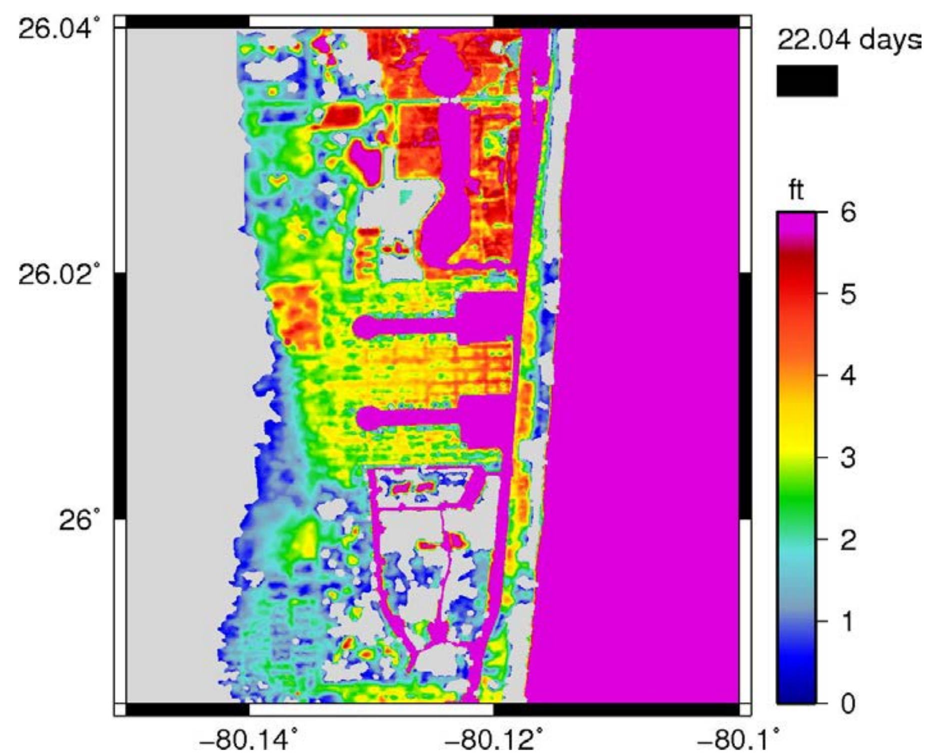

Figure 5.42 Maximum Water Depth, Hollywood Lakes; Storm 61; Existing Mesh Configuration

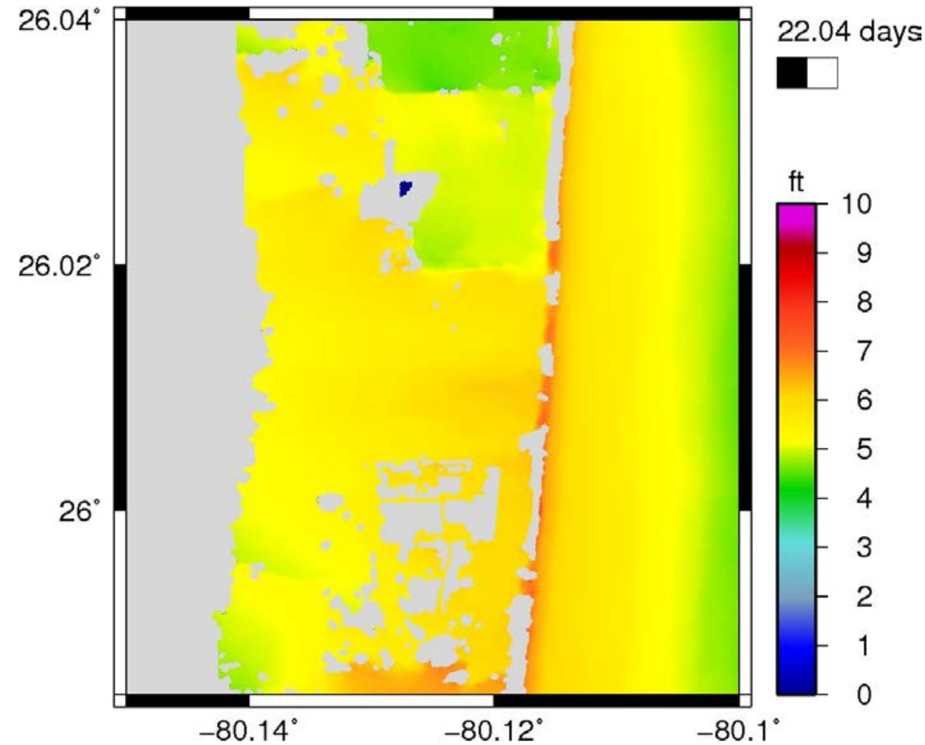

Figure 5.43 Maximum Water Surface Elevation (ft-NAVD), Hollywood Lakes; Storm 61; Alternative 2 Mesh Configuration

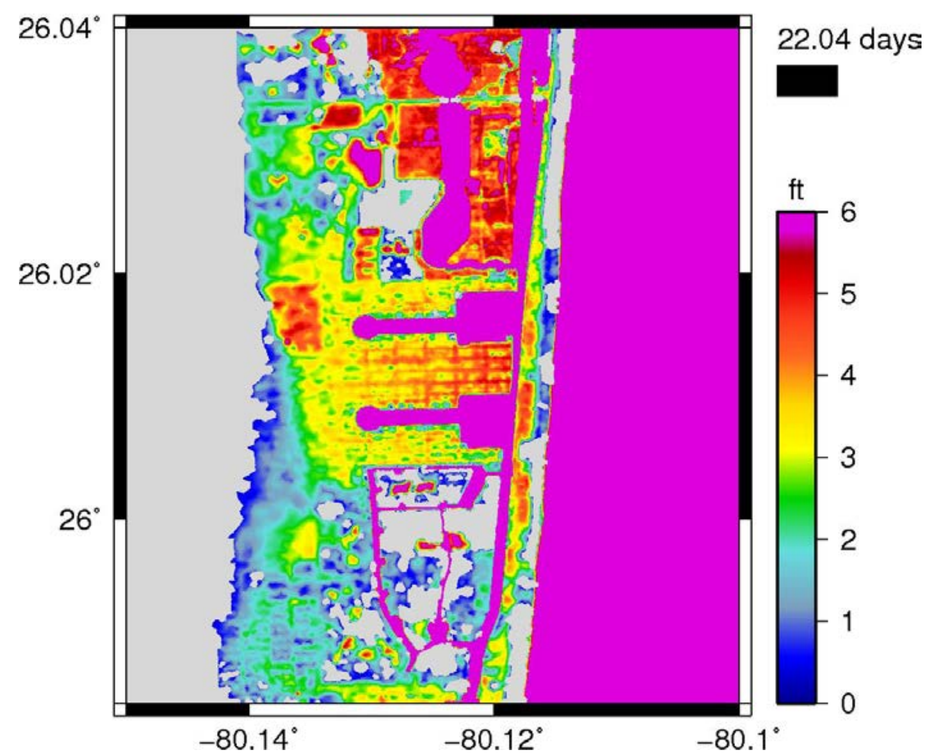

Figure 5.44 Maximum Water Depth, Hollywood Lakes; Storm 61; Alternative 2 Mesh Configuration

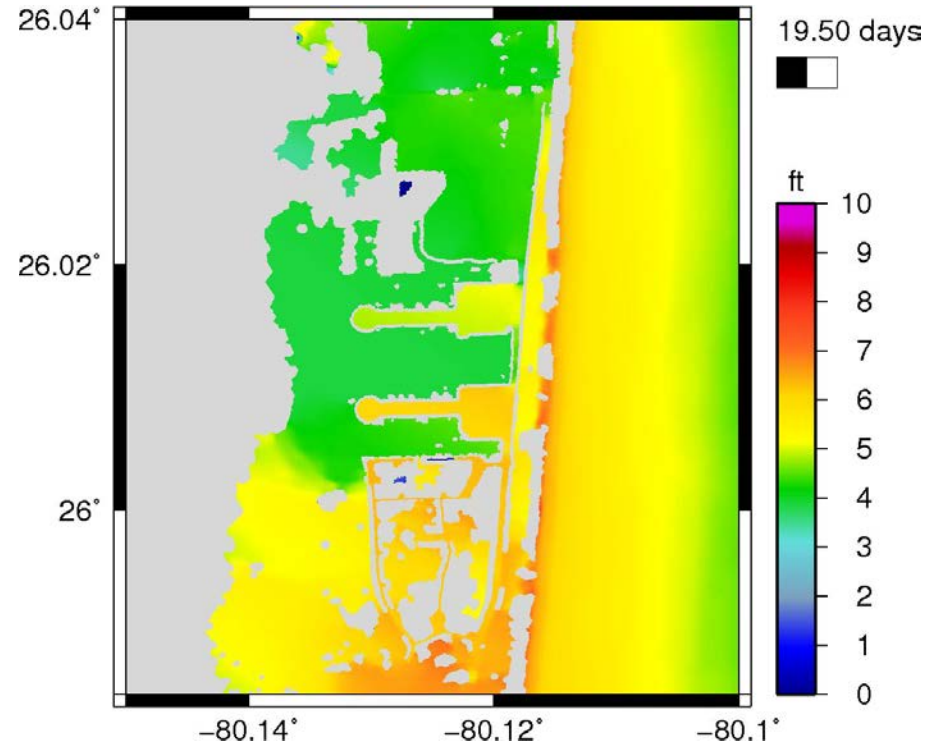

Figure 5.45 Maximum Water Surface Elevation (ft-NAVD), Hollywood Lakes; Storm 61; Alternative 3 Mesh Configuration

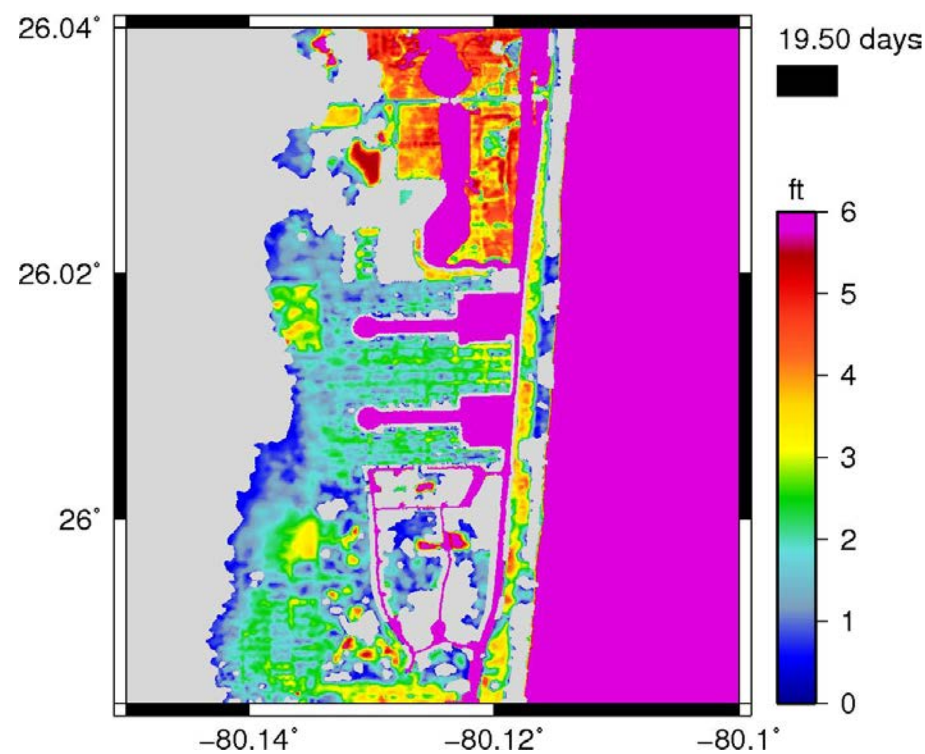

Figure 5.46 Maximum Water Depth, Hollywood Lakes; Storm 61; Alternative 3 Mesh Configuration

5.3 Storm Surge Model Results; Summary Plots

Examination of the SWAN+ADCIRC model results for a single storm across all simulated seawall elevation alternatives demonstrates how the various seawall elevations influence the inundation patterns. Plotting both Las Olas Boulevard and Hollywood Lakes on a single plot shows how different alternatives can create different water levels in the two Broward County FRM focus areas. Figure 5.47 shows the maximum water levels produced by Storm 276 for the Existing, Alternative 1, and Alternative 2 seawall elevations. Both Alternative 1 and Alternative 2 seawall configurations stop the inland inundation observed in the Existing Conditions Mesh simulation. For Storm 122, Figure 5.48 shows that only Alternative 3 can limit the inland inundation as both the Existing and Alternative 2 conditions have significant areas of inundation during this strong storm. Notably, Alternative 2 worsens the flooding in Hollywood Lakes when compared to Existing Conditions. Storm 60 (Figure 5.49) and Storm 61 (Figure 5.50) create water levels that produce significant inundation on both Las Olas Boulevard and Hollywood Lakes for the Existing Conditions and Alternative 2. For Storm 60, Alternative 3 provides seawall elevations that stop the inland inundation of Las Olas Boulevard; however, in Hollywood Lakes overtopping of the seawall occurs that produces a SWAN+ADCIRC model instability. For Storm 61, Alternative 3 seawall elevations greatly reduce, but do not completely stop the inland inundation of Las Olas Boulevard. Alternative 2 causes greater flood depths in Hollywood Lakes than Existing Conditions. For Storm 61, the inundation in the Hollywood Lakes area is not caused by seawall overtopping but is caused by flooding that propagates from south to north through overland areas and small canals as the storm produces a very large surge in northern Biscayne Bay that then moves north and “behind” the Hollywood Lakes seawalls. Additional animations for Storm 61 created to examine the water levels south of Hollywood Lakes indicate that the storm track and landfall location create a situation where surge piles up in Biscayne Bay on storm approach, with the elevated water levels then moving north through low-lying areas near the ICWW as the storm moves inland and features very strong winds directed to the north. Appendix A provides information on the maximum water level produced by each storm and seawall configuration at four locations (open water and inland for both Las Olas and Hollywood Lakes).

Examination of the SWAN+ADCIRC model results across all storms for a single seawall elevation alternative shows the “signature” of inundation for each specific storm. Figures 5.51 through 5.53 present the maximum water level conditions for the Existing Conditions, Alternative 2, and Alternative 3 for each storm simulated and showing both Las Olas Boulevard and Hollywood Lakes results. Figures 5.51 through 5.53 indicate the specific seawall alternatives may limit or stop inland inundation for a specific storm, but not provide protection from other storms. Notably, a plot for Alternative 1 is not presented because only Storm 276 was simulated with Alternative 1.

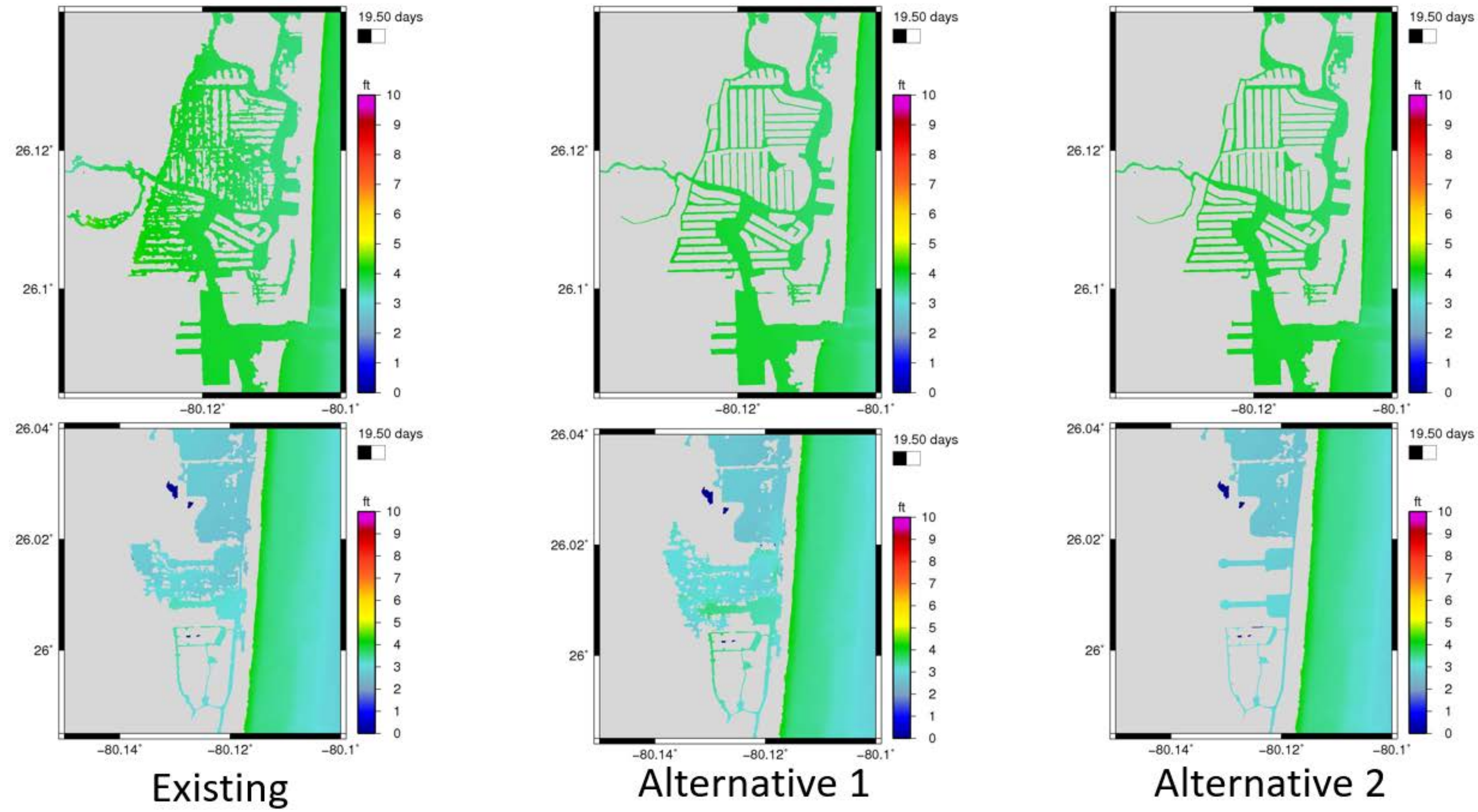

Figure 5.47 Maximum Water Surface Elevation (ft-NAVD) for Storm 276, Existing, Alternative 1, and Alternative 2 Mesh Configuration for Las Olas Boulevard (Top) and Hollywood Lakes (Bottom) Focus Areas.

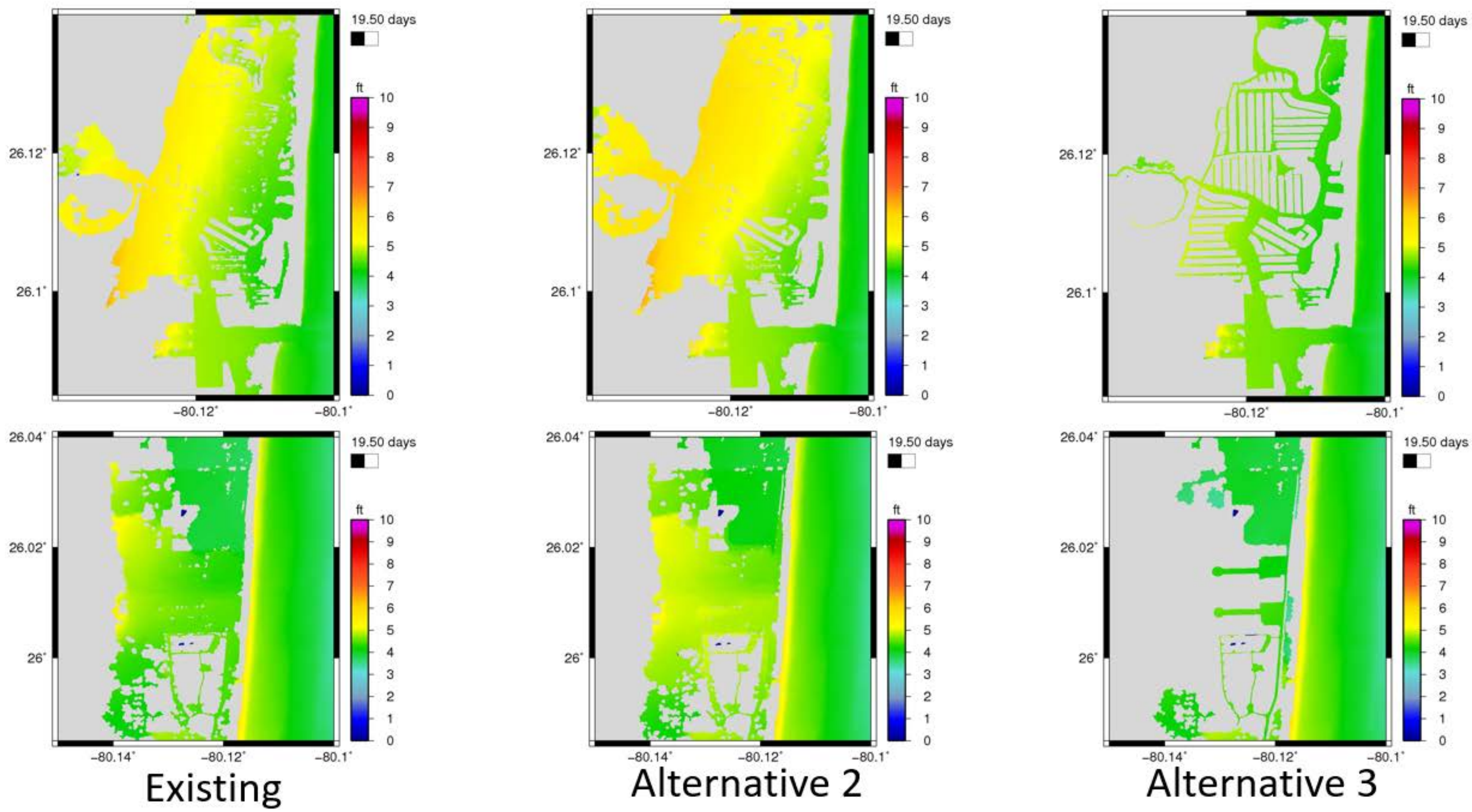

Figure 5.48 Maximum Water Surface Elevation (ft-NAVD) for Storm 122, Existing, Alternative 2, and Alternative 3 Mesh Configuration for Las Olas Boulevard (Top) and Hollywood Lakes (Bottom) Focus Areas.

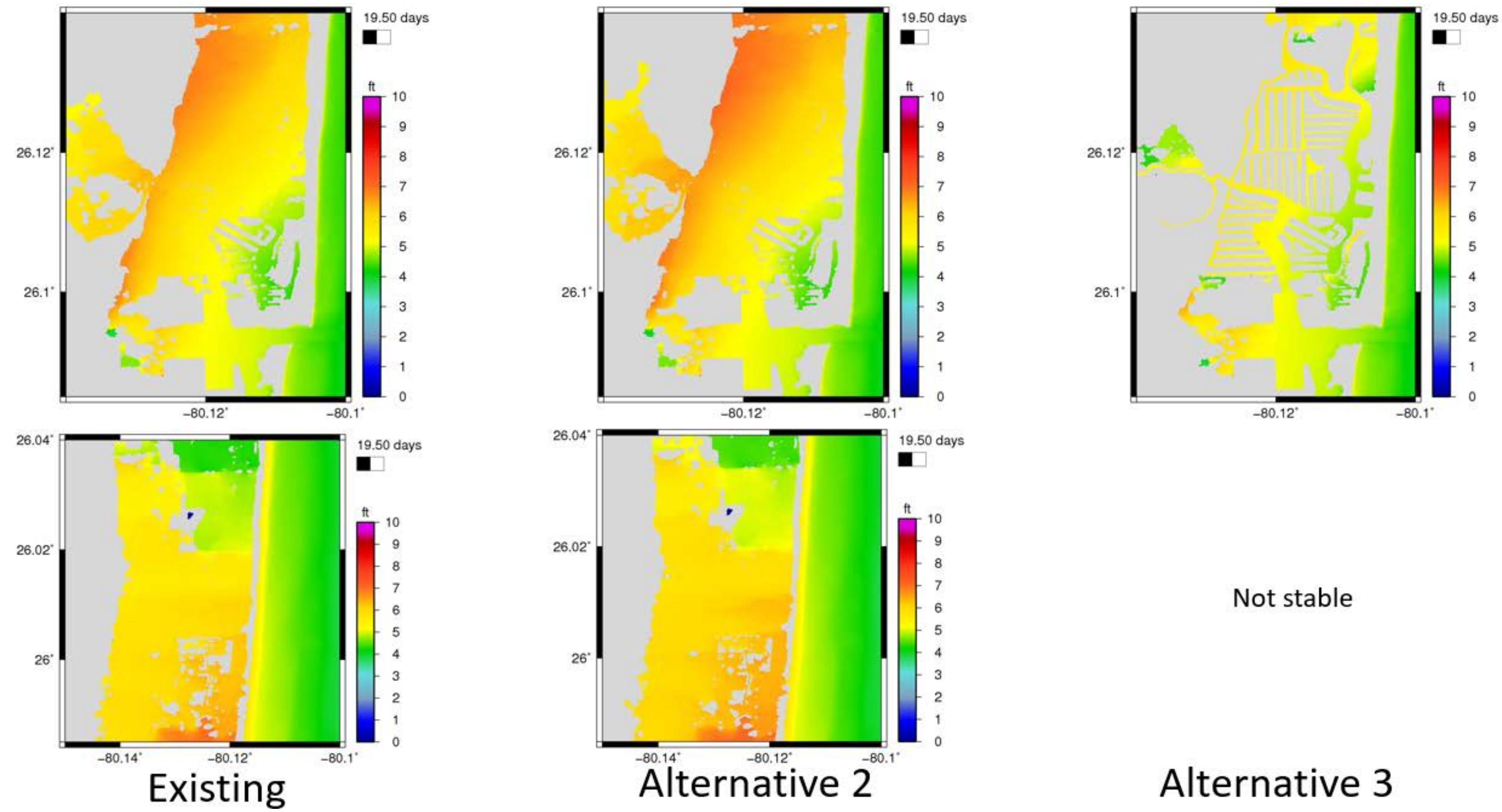

Figure 5.49 Maximum Water Surface Elevation (ft-NAVD) for Storm 60, Existing, Alternative 2, and Alternative 3 Mesh Configuration for Las Olas Boulevard (Top) and Hollywood Lakes (Bottom) Focus Areas.

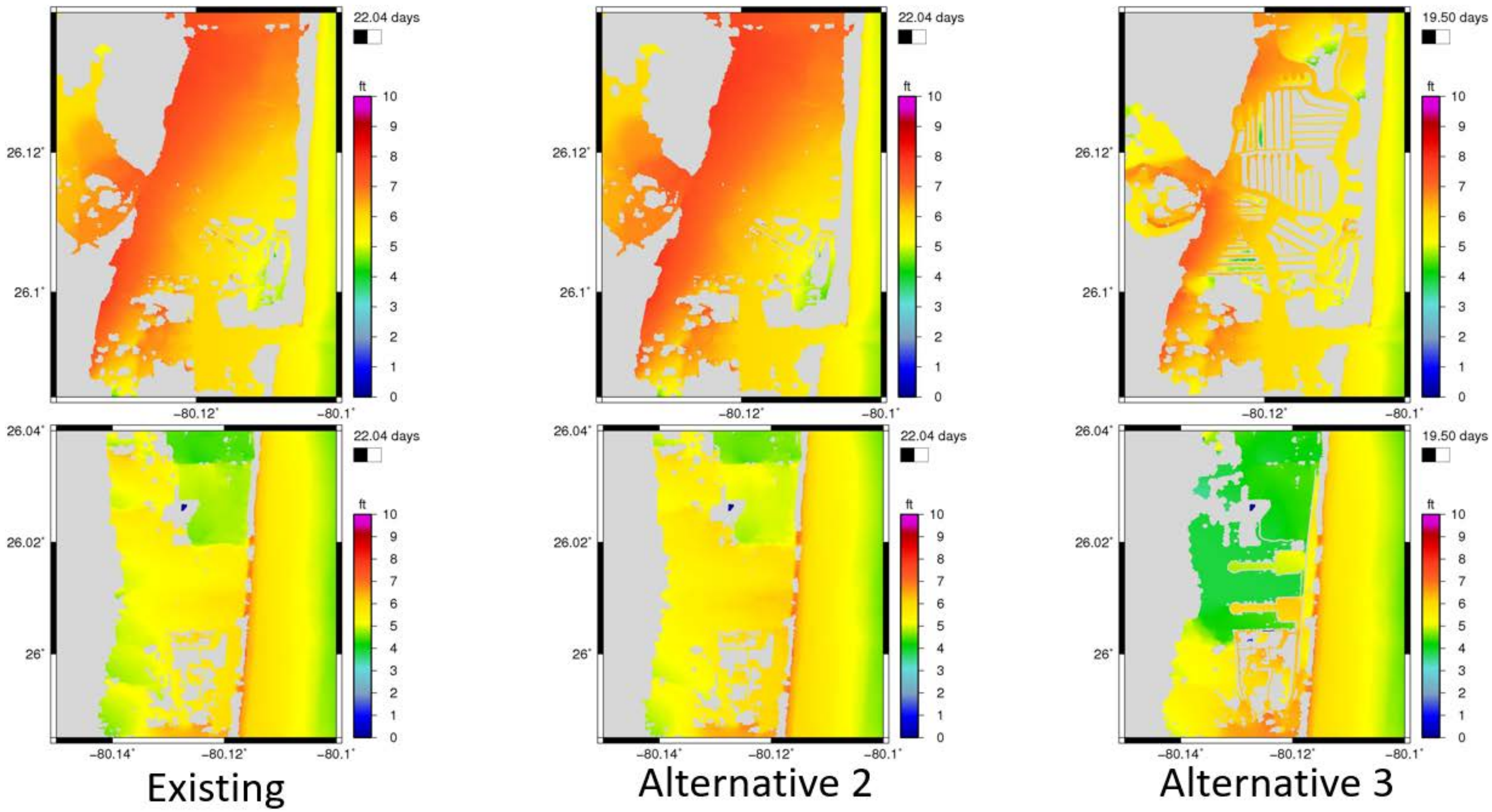

Figure 5.50 Maximum Water Surface Elevation (ft-NAVD) for Storm 61, Existing, Alternative 2, and Alternative 3 Mesh Configuration for Las Olas Boulevard (Top) and Hollywood Lakes (Bottom) Focus Areas.

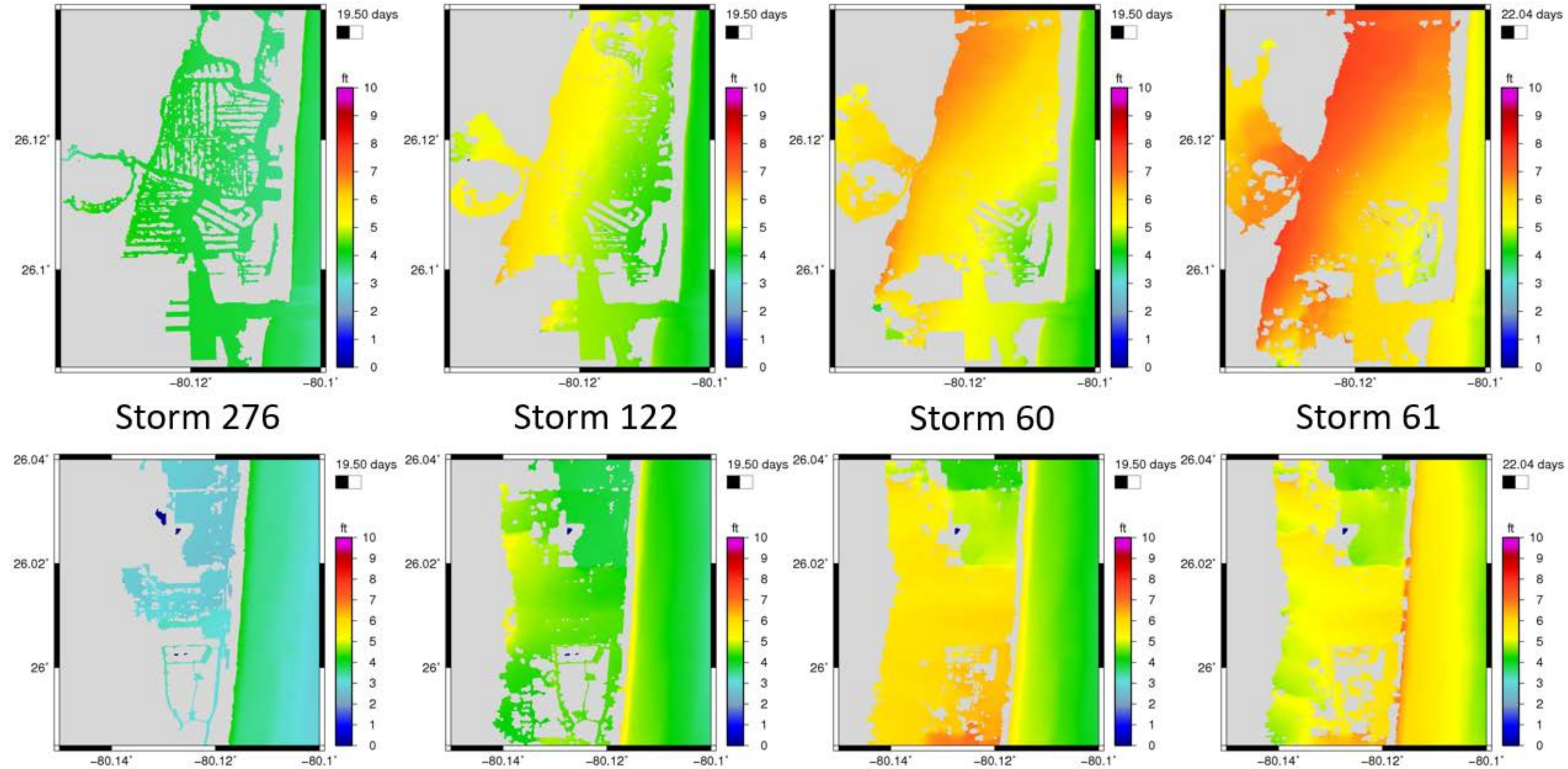

Figure 5.51 Maximum Water Surface Elevation (ft-NAVD) for Existing Mesh Configuration for Storms 276, 122, 60, and 61, Las Olas Boulevard (Top) and Hollywood Lakes (Bottom) Focus Areas.

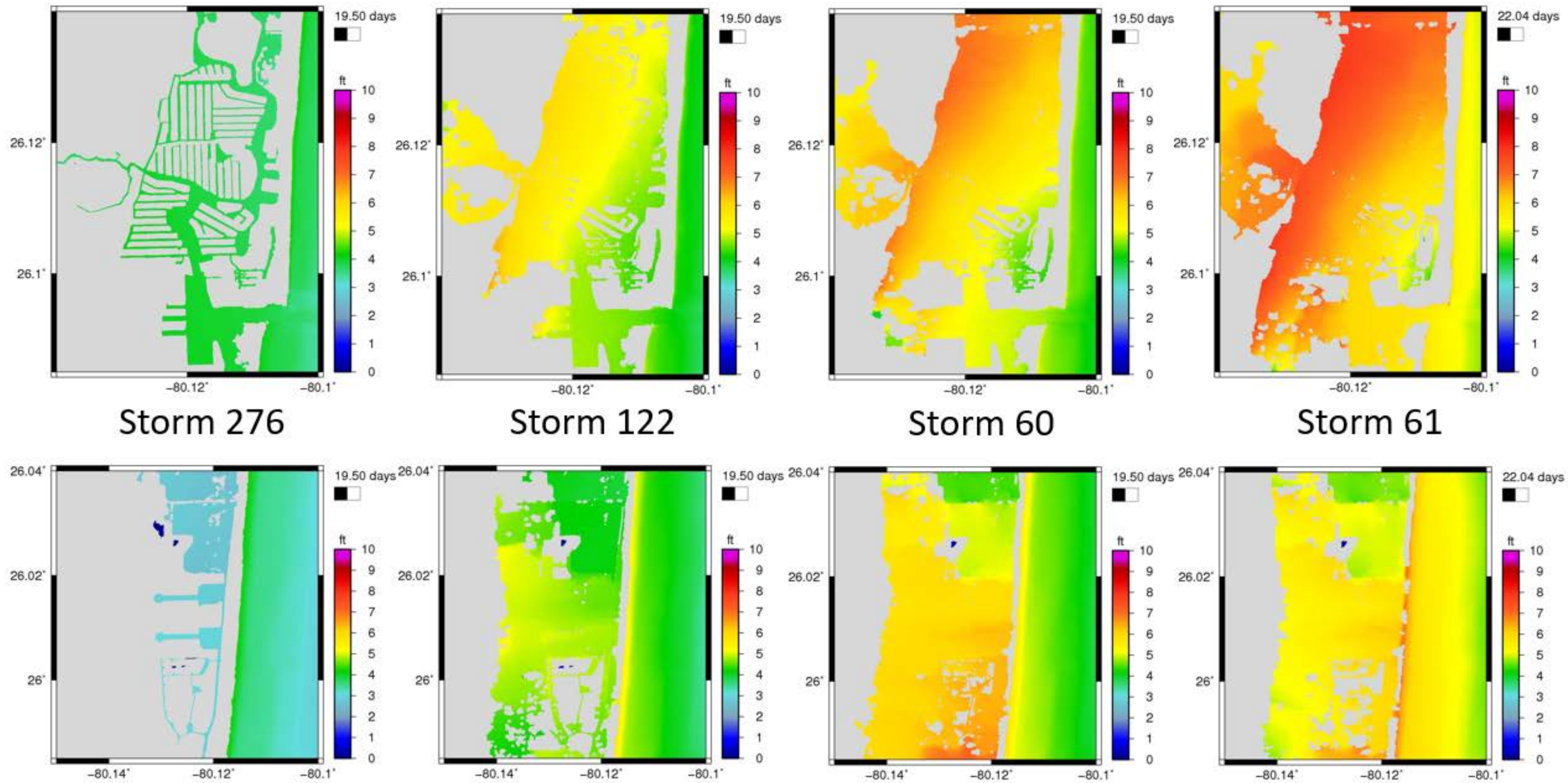

Figure 5.52 Maximum Water Surface Elevation (ft-NAVD) for Alternative 2 Mesh Configuration for Storms 276, 122, 60, and 61, Las Olas Boulevard (Top) and Hollywood Lakes (Bottom) Focus Areas.

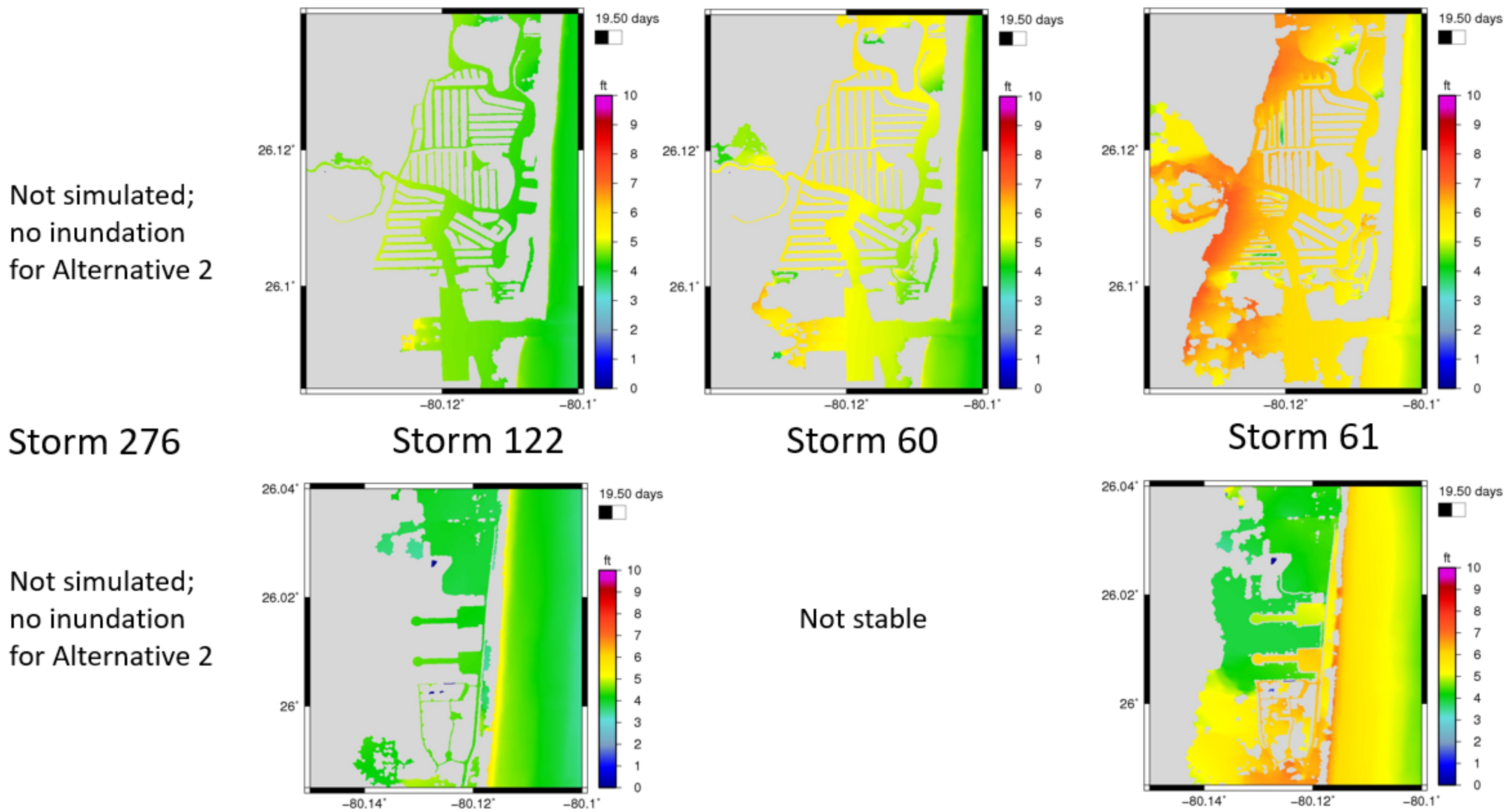

Figure 5.53 Maximum Water Surface Elevation (ft-NAVD) for Alternative 3 Mesh Configuration for Storms 276, 122, 60, and 61, Las Olas Boulevard (Top) and Hollywood Lakes (Bottom) Focus Areas.

5.4 Storm Surge Model Results; Quality Control

The technical team applied a multi-step review for each of the SWAN+ADCIRC model simulations. The first layer of review examined the model input and output files to verify the study team applied the correct SWAN+ADCIRC model mesh, mesh settings, and storm forcing. For the next level of review, the study team examined maximum water level and maximum depth plots for the Broward County area with focus on the water levels and depths near the Las Olas Boulevard and Hollywood Lakes areas. Figures 5.1 to 5.53 provide examples of the maximum water level and maximum depth plots. For the last level of review, for each storm the study team examined animations of the water levels and plots of water level time series at multiple locations. Many storm/seawall combinations required multiple simulations to obtain stable model results as overtopping of the raised seawall elevations in Alternative 2 and Alternative 3 produced some unstable model behavior at the commencement of flow over the seawall. To review these simulations, the technical team produced focused plots of water level, depth, and current velocity along with additional animations of water level and wind vectors to allow additional levels of detail for the review. Appendix B contains more details of model review process and results with additional figures.

6.0 SUMMARY

The U.S. Army Corps of Engineers (USACE), Jacksonville District, in partnership with Broward County, Florida is conducting a Flood Risk Management (FRM) Study to address flooding problems in specific tidally influenced coastal areas (not direct oceanfront) within the county. The Broward County FRM Study is specifically evaluating flooding in the Hollywood Lakes area in the City of Hollywood, Florida and the Las Olas Boulevard area in the City of Ft. Lauderdale, Florida. This report presents results of SWAN+ADCIRC model simulations executed to provide information on water levels and inundation produced by different combinations of storm forcing and seawall configurations. The simulation results indicate how the various storm forcing (chosen to provide different water levels in the focus areas) interact with four different seawall elevation configurations and what, if any, inland inundation occurs near Las Olas Boulevard and Hollywood Lakes. The results show that the various seawall height alternatives influence inundation patterns differently depending on the storm forcing and the seawall heights applied. Some seawall configurations stop inland inundation for the storms that produce the lower water levels, but do not stop inland inundation for the storms with the highest water levels. Another effect observed in the simulation results is that, after a storm passes, elevated seawalls can delay, or block, the flow of water out of inundated areas thereby increasing the duration of flooding (with recognition that the SWAN+ADCIRC model does not feature drains in the seawalls or stormwater system and pump effects that will promote drainage). Additional numerical modeling that accounts for inland stormwater system effects or drainage from areas landward of the seawalls could provide additional information on how inundation patterns change after strong storms pass by the project area.

7.0 REFERENCES

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Federal Emergency Management Agency (FEMA). (2018a, in review). *South Florida Storm Surge Study: Intermediate Data Submittal (IDS) Report 3, Section 1: Production Runs.* Prepared for FEMA Region IV. BakerAECOM.

Federal Emergency Management Agency (FEMA). (2018b, in review). *South Florida Storm Surge Study: Intermediate Data Submittal (IDS) Report 3, Section 2: Low Frequency Analysis.* Prepared for FEMA Region IV. BakerAECOM.

Wang. S.Y. (2014). Inclusion of Tropical Storms for the Combined Total Storm Tide Frequency Restudy for Broward County, Florida. Engineering, Hydrology & Geology Program, Division of Water Resource Management, Florida Department of Environmental Protection. October 2014.

Appendix A: Maximum Water Depth at Selected Stations for Storm and Seawall Combinations

This Appendix contains additional information on the maximum water depth produced at four locations for each simulation of the various storm and seawall configurations. Figures A.1 to A.4 show the detailed location for each station applied in the analysis. The stations were selected so that an inland and open water location was applied for both the Las Olas and Hollywood Lakes areas (4 total stations). Table A.1 presents the detailed information for each station and storm and seawall configuration. The table lists the ground elevation for each station along with the maximum water depth that occurred for each simulation. Table A.1 shows, for each storm, how each of the seawall configurations influences the maximum water level that occurs. Importantly, the effect of the seawall configuration varies by location and Table A.1 provides snapshot at an inland and open water location for both the Las Olas Blvd area and the Hollywood Lakes area. The contour plots of maximum water depth in Chapter 5 provide more information on how the different seawall configurations influence the water levels for each storm simulation.

Figure A.1 Maximum Water Depth Analysis Station 1 Location; Las Olas Boulevard, Inland

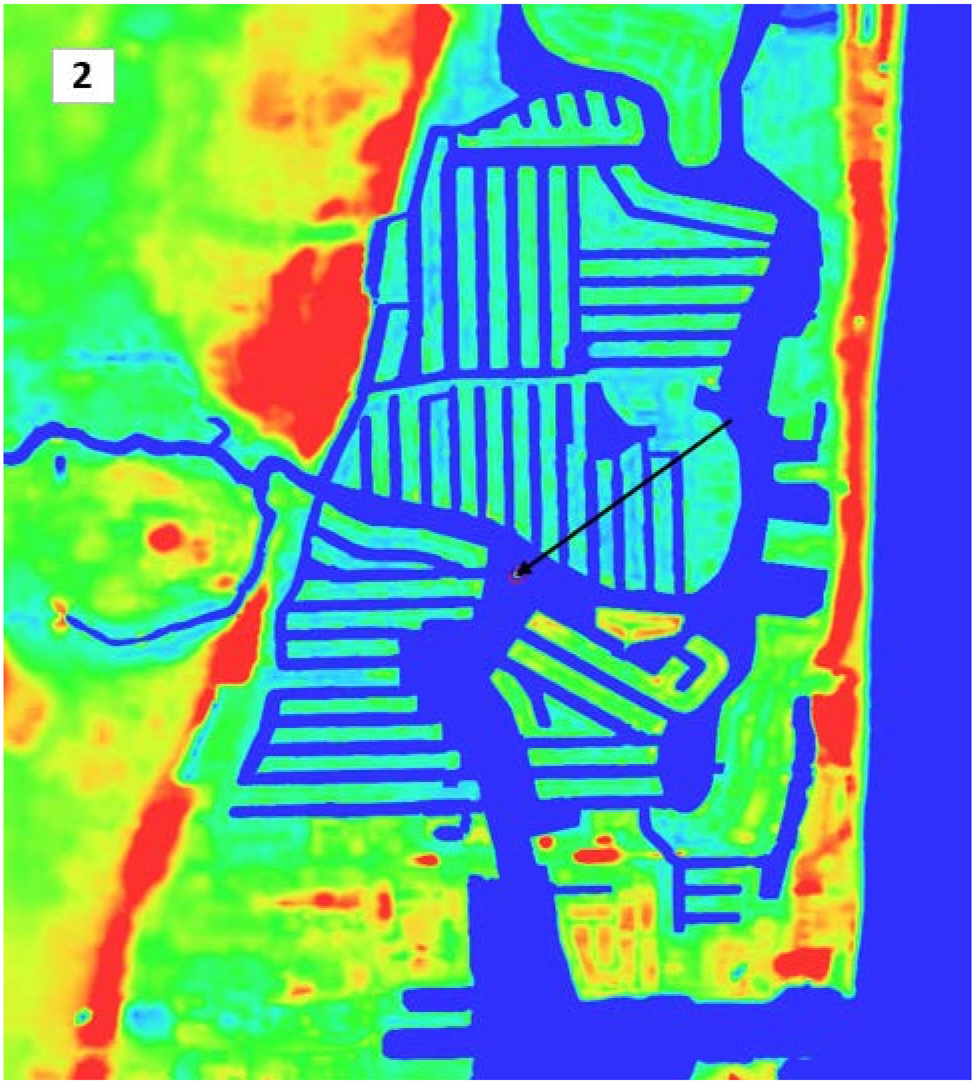

Figure A.2 Maximum Water Depth Analysis Station 2 Location; Las Olas Boulevard, Open Water

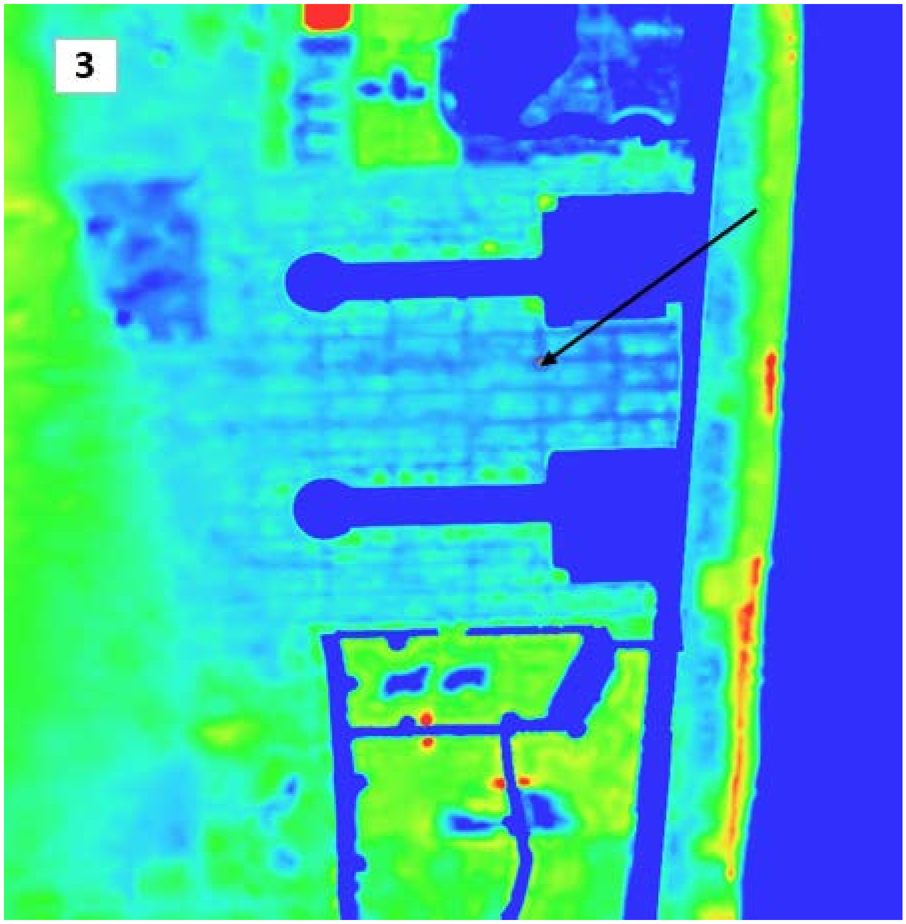

Figure A.3 Maximum Water Depth Analysis Station 3 Location; Hollywood Lakes, Inland

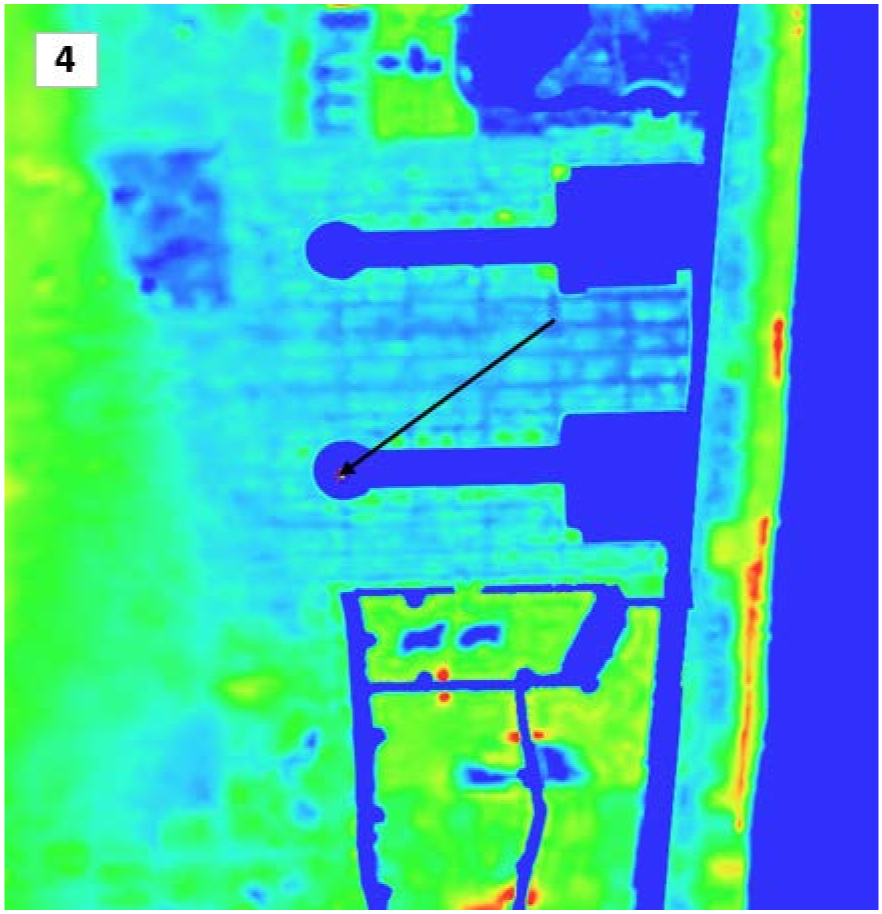

Figure A.4 Maximum Water Depth Analysis Station 4 Location; Hollywood Lakes, Open Water

Table A.1 Elevation and Maximum Water Depth for Select Stations and Storm and Seawall Configurations

Storm	Seawall Alternative	Maximum Water Depth (ft)			
		Station 1	Station 2	Station 3	Station 4
276	Existing	0.8	6.1	1.9	16.6
276	Alt 1	DRY	6.1	2.1	16.9
276	Alt 2	DRY	6.2	DRY	16.4
122	Existing	2.0	7.2	3.5	18.0
122	Alt 2	2.3	7.4	3.8	18.3
122	Alt 3	DRY	6.9	DRY	17.8
60	Existing	2.9	7.8	4.8	19.2
60	Alt 2	3.0	7.9	5.0	19.4
61	Existing	3.7	8.5	4.5	18.7
61	Alt 2	3.8	8.6	4.7	19.0
61	Alt 3	DRY	8.4	3.0	19.4
Elevation (ft-NAVD)		3.1	-2.3	0.9	-13.3

Appendix B:
Quality Control Review Procedure and Figures

This Appendix contains additional information on aspects of the technical team's multi-step review for each of the SWAN+ADCIRC model simulations. As stated in the Main Report, the technical team applied a multi-step review for each of the SWAN+ADCIRC model simulations. The first layer of review examined the model input and output files to ensure the study team applied the correct SWAN+ADCIRC model mesh, mesh settings, and storm forcing. For the next level of review, the study team examined maximum water level and maximum depth plots for the Broward County area with focus on the water levels and depths near the Las Olas Boulevard and Hollywood Lakes areas. For the last level of review, for each storm the study team examined animations of the water levels and plots of water level time series at multiple locations.

Examination of the water level animations allowed the study team to understand how different mesh alternatives influenced the inundation timing and location for the various storm forcing. As an example, Figures B.1 and B.2 show the difference in location and timing of the inland inundation that occurs for the Storm 276 simulation with the existing seawall condition (Figure B.1) and the Alternative 1 seawall elevation (Figure B.2). For the existing conditions, the inundation in Hollywood Lakes starts earlier in the storm and at the south wall of North Lake (circled in red). For the Alternative 1 seawall condition, the inundation starts later in the storm (approximately 1.7 hours later when compared to existing seawall condition), at a higher water elevation, and along the north wall of South Lake (circled in red).

The study team reviewed water level animations for each of the final storm simulations and seawall alternatives. These reviews allowed the study team to view the propagation of the storm surge through the Broward County area and focus areas of Las Olas Boulevard and Hollywood Lakes. Each of the four storms had a different storm surge "signature" due to the differences in the landfall location, track angle, storm strength, and storm size. For each of the four storms applied in this study, some of the animations included the wind speed vectors to allow the reviewers to examine how the changing wind fields caused the surge to propagate through the focus areas. Storm 61 features a storm track that causes significant amounts of water to propagate from Biscayne Bay towards the north as the storms push water into Biscayne Bay before landfall and then northward after the storm moves inland and the winds shift to a north-northeast direction. Figure B.3 shows a sequence for the storm surge caused by Storm 60 (Alternative 2 mesh conditions) with wind vectors. The sequence shows how the storm pushes water in Biscayne Bay, and then north along the interior water ways into southern Broward County (where the water influences Hollywood Lakes, Figure 5.39)

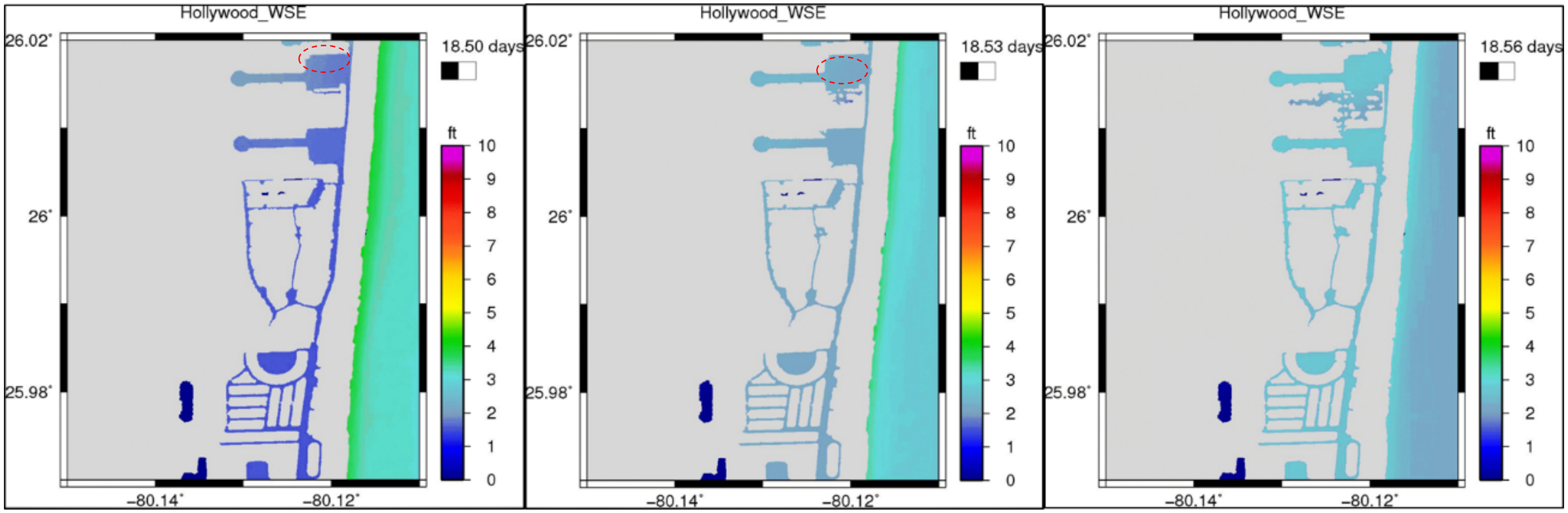

Figure B.1 Sequence of Inundation in Hollywood Lakes for Storm 276 with Existing Seawall Conditions

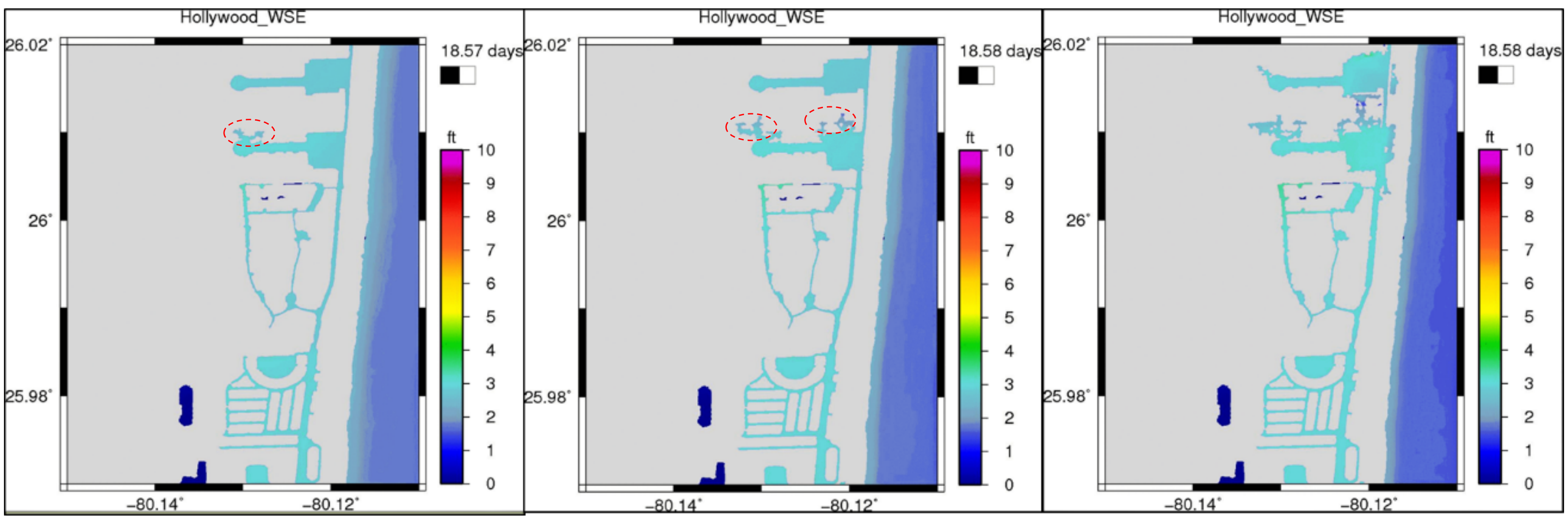

Figure B.2 Sequence of Inundation in Hollywood Lakes for Storm 276 with Alternative 1 Seawall Conditions

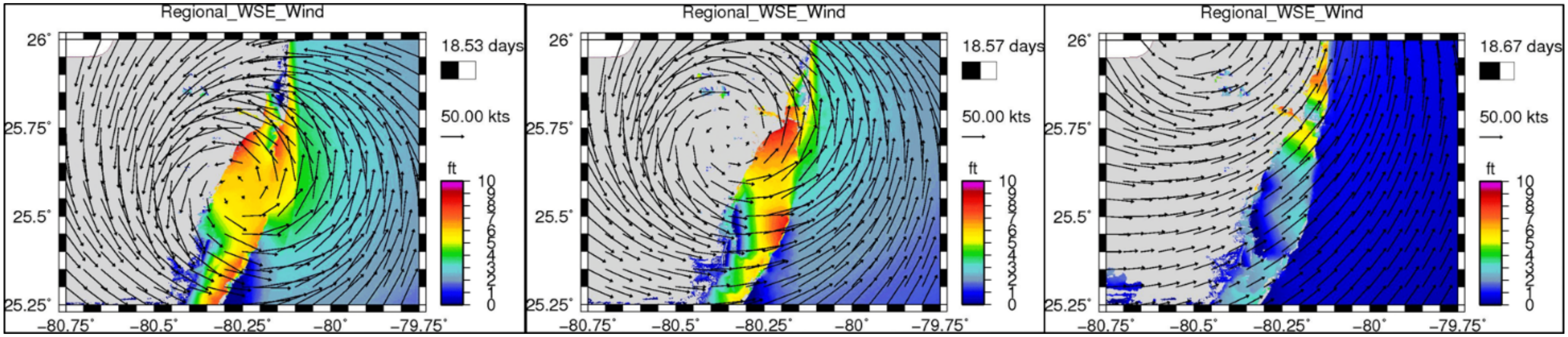

Figure B.3 Sequence of Inundation Biscayne Bay and Northern Miami-Dade County for Storm 60

Additionally, the study team also reviewed the volume of inundation that occurred within specific regions near the Las Olas Boulevard and Hollywood Lakes focus areas. First, the study team developed volume calculation areas for the Las Olas Boulevard and Hollywood Lakes areas (Figure B.4). The study team developed the extents of the calculation areas to capture the inland inundation caused by the storm systems within the two focus areas. Notably, the volume calculations include mass added to and removed (i.e., net accumulated flood volume) from the system through ADCIRC's wetting and drying algorithm. ADCIRC does not strictly locally conserve mass during this process, but rather computes water depth at each node for each time step and changes the node state from dry to wet if the minimum calculated depth criterion is met. When all nodes within an element compute to wet, the element becomes wet and its volume is added to the local inundation.

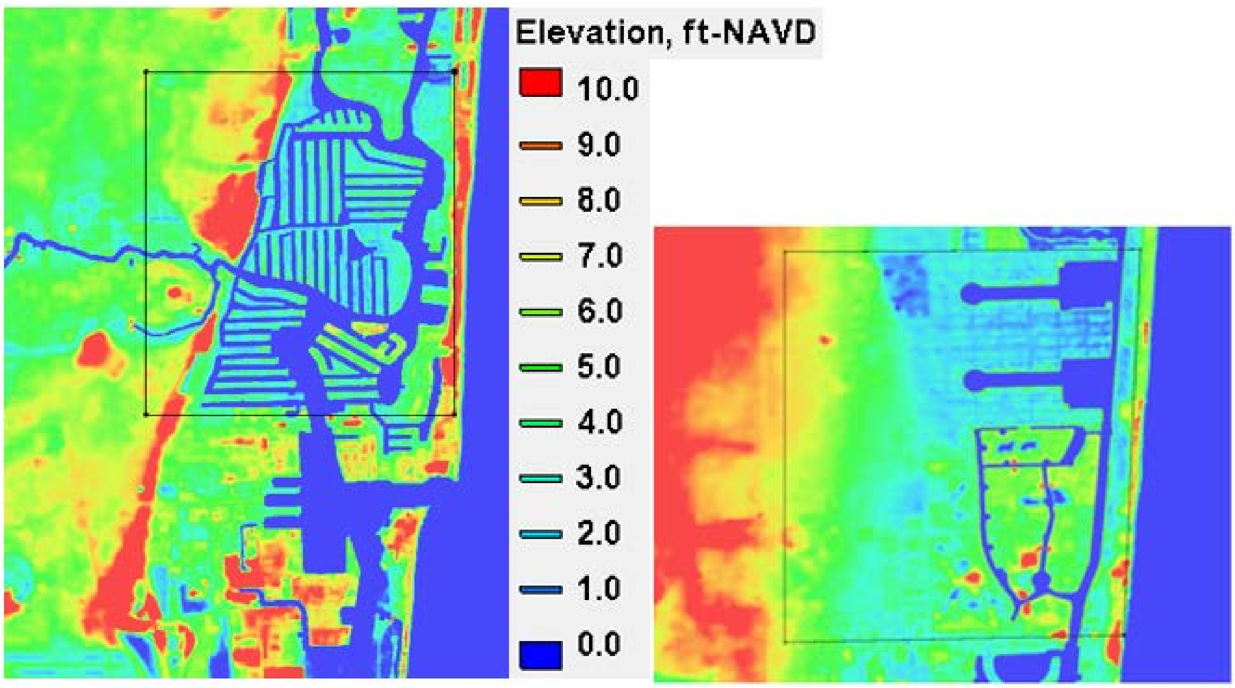

Figure B.4 Areas for Volume Analysis for Las Olas Boulevard (Left) and Hollywood Lakes (Right)

The elevated ridge that occurs just west of the Las Olas Boulevard area canals limits the westward propagation of surge, while the Hollywood Lakes area features a large distance between the lakes/canals and the closest inland elevated ridge. The study team developed plots that show the total volume within the calculation area for all alternatives simulated for each of the four storms. Figure B.5 shows the total volume with time for the three simulations with Storm 276 for the Las Olas Boulevard area. The plot shows that the pre-storm volumes match for all three seawall alternatives. For Alternative 1 and Alternative 2 (which feature the same 4 ft-NAVD minimum seawall elevation), as there is no seawall overtopping and inland inundation, the total volumes are identical and lower than the Existing Condition results which features inland inundation. Figure B.6 shows the results for the Hollywood Lakes calculation area. The plot shows that substantial flood volume from overtopping and inland inundation occurs both for the Existing Condition and Alternative 1 (2.5 ft-NAVD minimum seawall height). The Alternative 1 result shows the delay in inundation caused by the Alternative 1 configuration versus the Existing Condition. For Alternative 2, as there is no seawall overtopping, the calculated flood volume is much smaller compared to the Existing and Alternative 1 Conditions (this is not the case for Storm 122 and Storm 61). Notably, the Hollywood Lakes plot shows the presence of the Alternative 1 seawalls (that allow for some overtopping) cause more water volume to be retained in the volume calculation area than the Existing Conditions. This observation is made with the recognition that the SWAN+ADCIRC model setup for all simulations does not allow for any vents or drains in the seawalls and there is no stormwater system representation in the model.

Figure B.7 shows the total volume with time for the three simulations with Storm 122 for the Las Olas Boulevard calculation area. The plot shows almost similar calculated volumes for the Existing Conditions and Alternative 2 (4 ft-NAVD minimum seawall elevation) as there is overtopping and inland inundation for these conditions and reduced volume for Alternative 3 (6 ft-NAVD minimum seawall elevation) because there is no inland inundation for this condition. The Alternative 2 results show a smaller volume immediately before and after seawall overtopping which indicate a slight change on how the volume gets distributed over time with a sharper peak and slightly higher maximum with Alternative 2. Figure B.8 shows the results for the Hollywood Lakes calculation area have the same features as the Las Olas Boulevard figure (Figure B.7). When compared with the Existing Conditions, the results show Alternative 2 delays (by about 1.5 hours) the volume increase as flood level is initially below seawall crest. However, when flood level overtops the seawall, results show Alternative 2 produces significantly more flood volume than the Existing Condition as more volume is retained behind the Alternative 2 seawalls. For Alternative 3, calculated volume is much smaller than that for Existing Condition because there is no seawall overtopping and inland inundation.

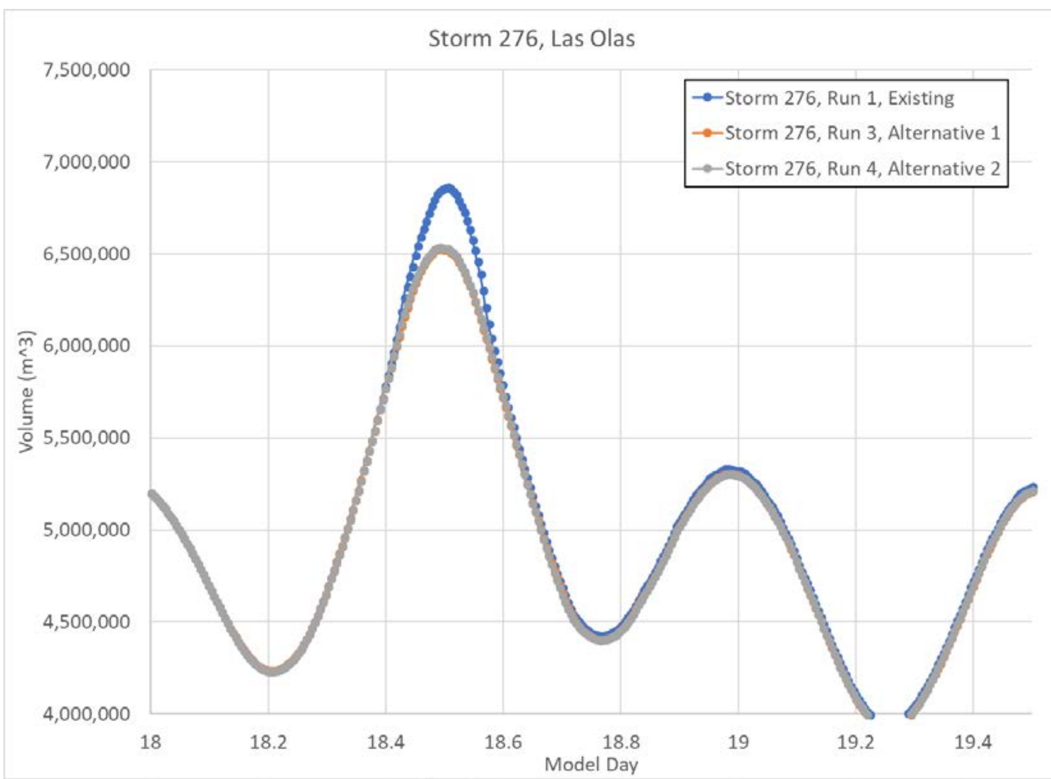

Figure B.5 Volume Calculated Within Las Olas Boulevard Calculation Area for Storm 276 Simulations

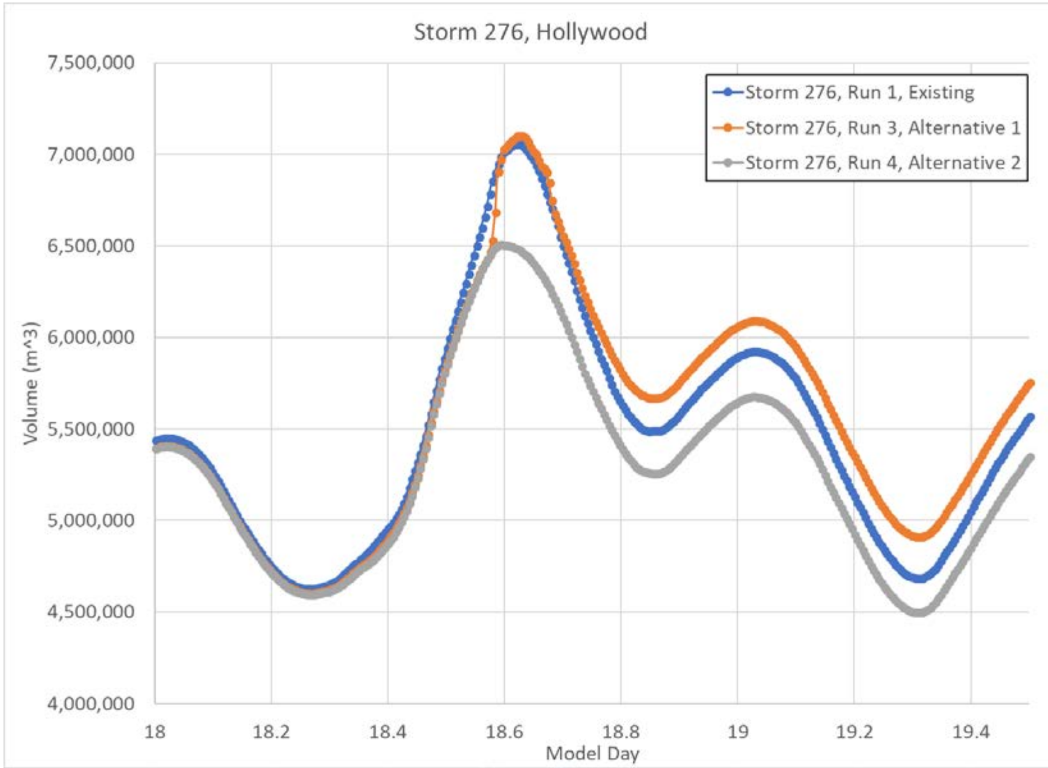

Figure B.6 Volume Calculated Within Hollywood Lakes Calculation Area for Storm 276 Simulations

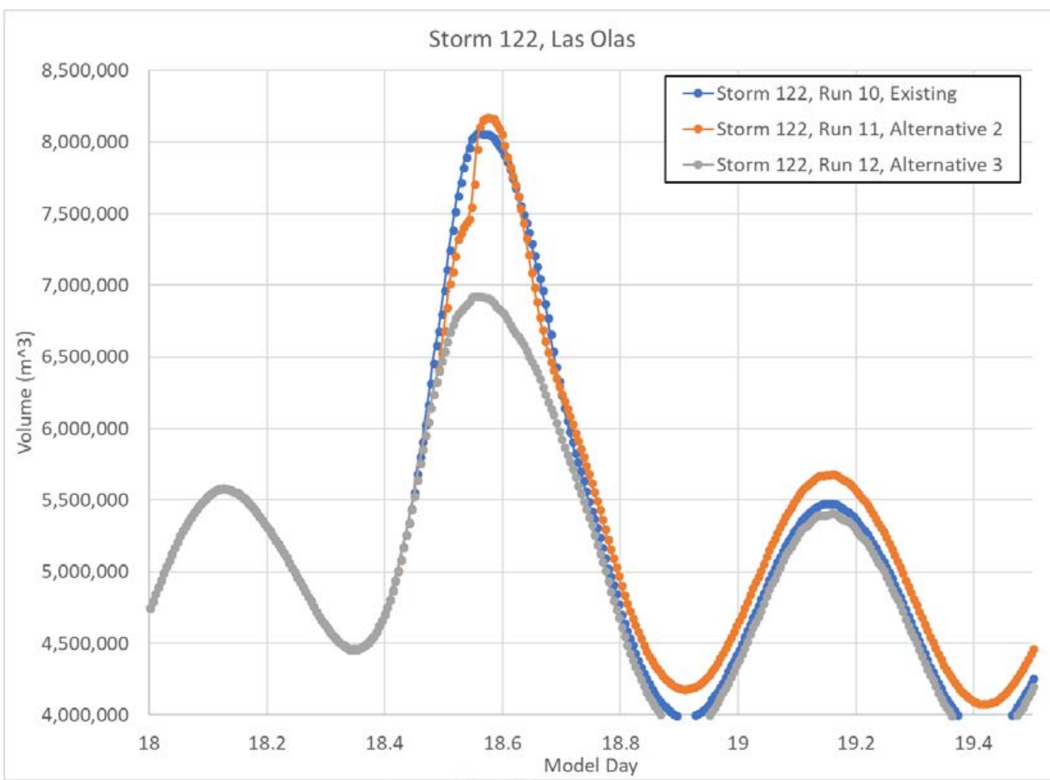

Figure B.7 Volume Calculated Within Las Olas Boulevard Calculation Area for Storm 122 Simulations

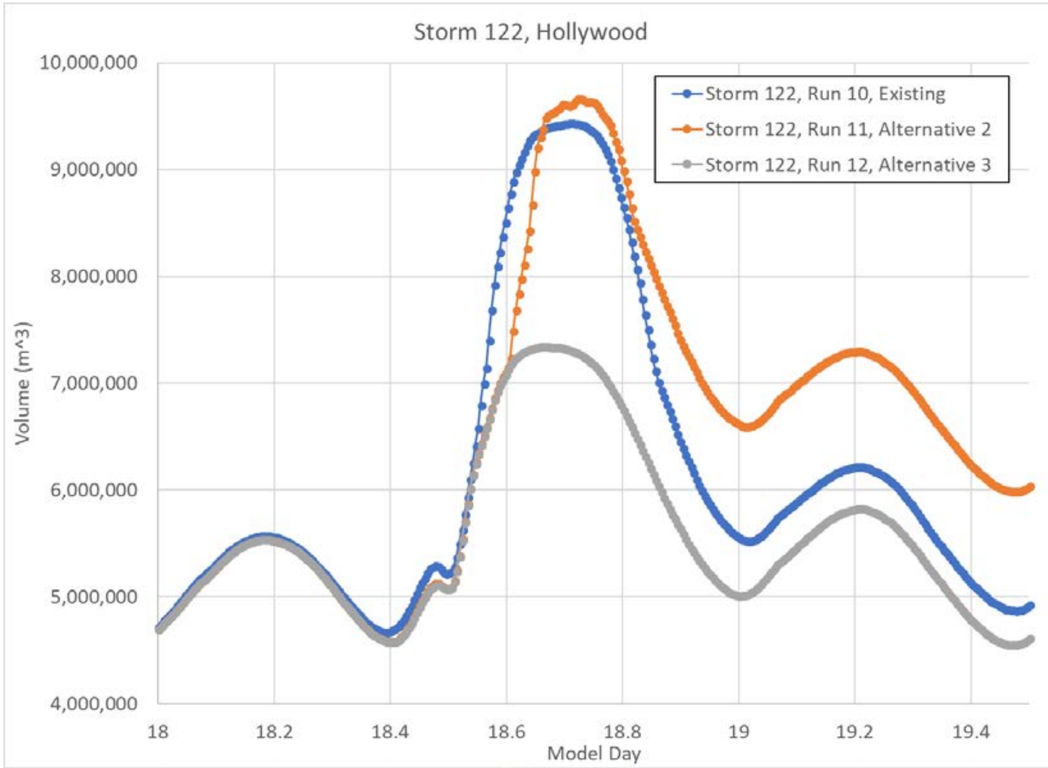

Figure B.8 Volume Calculated Within Hollywood Lakes Calculation Area for Storm 122 Simulations

Figure B.9 shows the total volume with time for the three simulations with Storm 60 for the Las Olas Boulevard calculation area. The plot shows features similar to the Storm 122 results almost similar volumes for the Existing Conditions and Alternative 2 (4 ft-NAVD minimum seawall elevation) as seawall overtopping and inland inundation occurs for both conditions and substantially reduced volume for Alternative 3 (6 ft-NAVD minimum seawall elevation) as there is no inland inundation for this condition. Figure B.10 shows the results for the Hollywood Lakes calculation area. The Alternative 2 result shows a slight delay in volume increase compared to the Existing Condition configuration because the seawall initially prevented inundation in Hollywood Lakes. However, Figure B.10 shows that after seawall overtopping, Alternative 2 produces flood volume that is slightly more than that for the Existing Condition. The Alternative 3 simulation did not produce a stable result and is not plotted.

Figure B.11 shows the total volume with time for the three simulations with Storm 61 for the Las Olas Boulevard calculation areas. The figure shows a substantially reduced flood volume for Alternative 3 because examination of the maximum elevations shown in Figure 5.52, indicate significant overtopping and inland inundation occurring for the Existing Conditions and Alternative 2 (4 ft-NAVD minimum seawall elevation) and limited inland inundation for Alternative 3 (6 ft-NAVD minimum seawall elevation). Figure B.12 shows the results for the Hollywood Lakes calculation area with many of the same features as Las Olas Boulevard figure. The Alternative 2 result shows a slight delay in volume increase compared to the Existing Condition configuration. Notably, more volume is retained behind the Alternative 2 seawalls compared to the Existing Conditions. The Alternative 3 simulation and review of water level animations indicate the 6 ft-NAVD seawalls are not overtopped from the water side, but significant water volume propagates from the south and into the Hollywood Lakes volume calculation area by moving northward inland of the seawalls (flanking the seawalls). This volume is retained behind the seawalls as the storm passes as indicated by the larger volumes after the storm peak for Alternative 3 as compared to the

Existing Condition (This observation is made with the recognition that the SWAN+ADCIRC model setup for all simulations does not allow for any vents or drains in the seawalls and there is no stormwater system representation in the model).

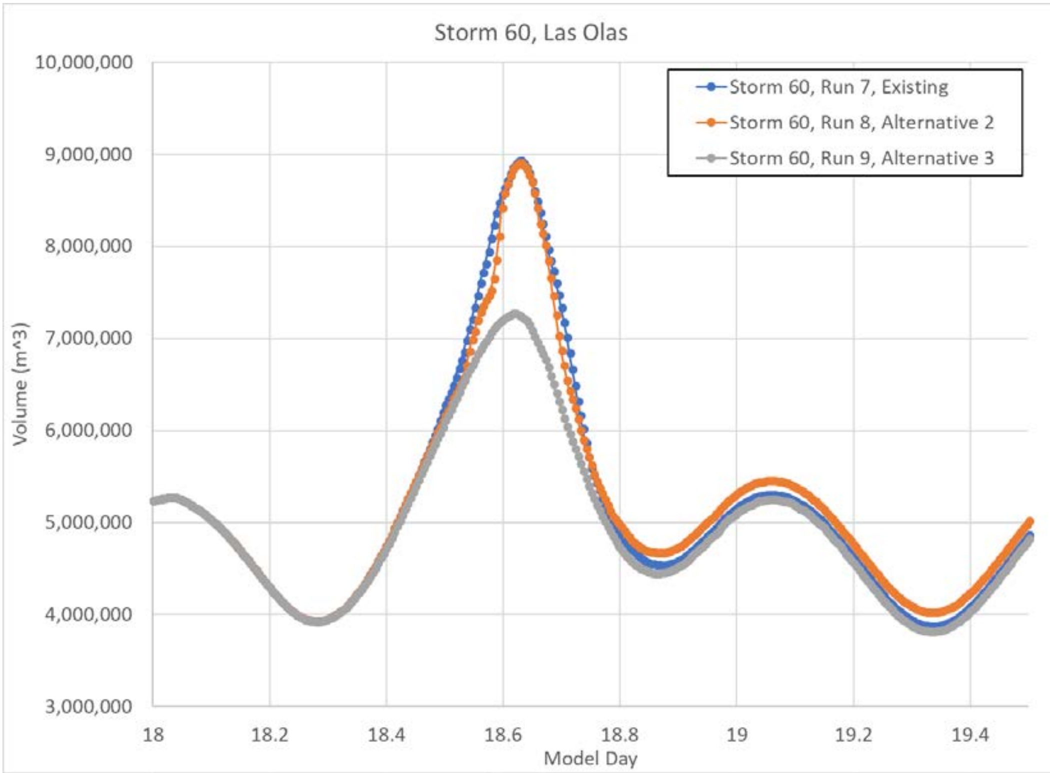

Figure B.9 Volume Calculated Within Las Olas Boulevard Calculation Area for Storm 60 Simulations

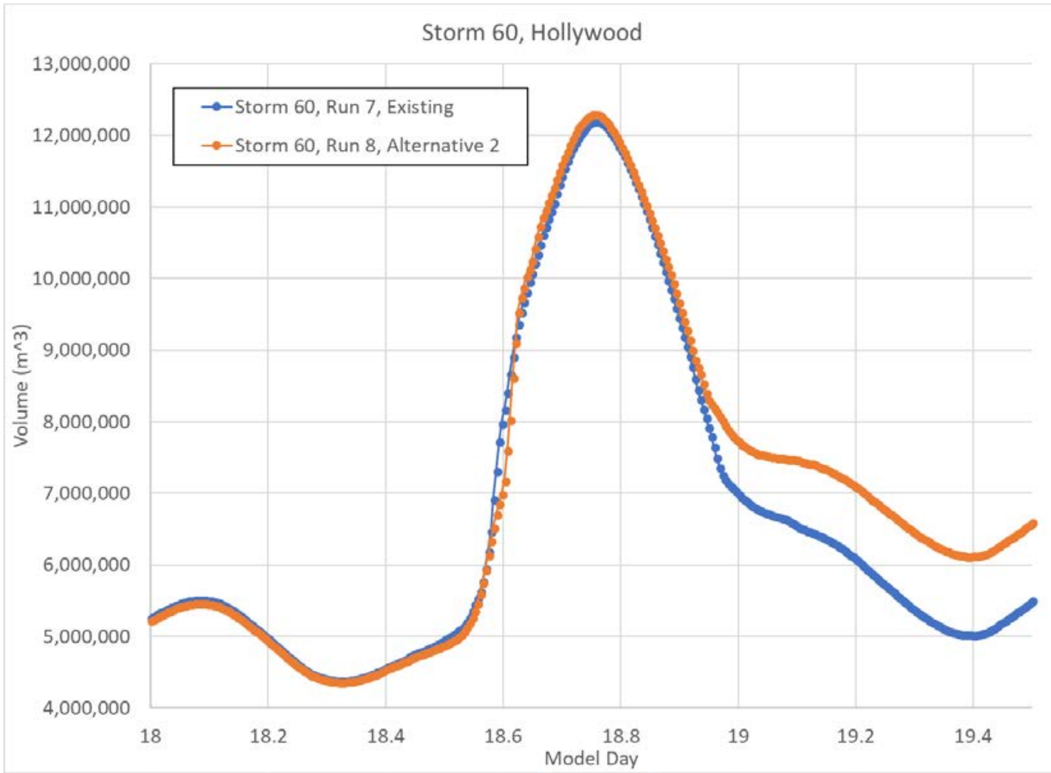

Figure B.10 Volume Calculated Within Hollywood Lakes Calculation Area for Storm 60 Simulations

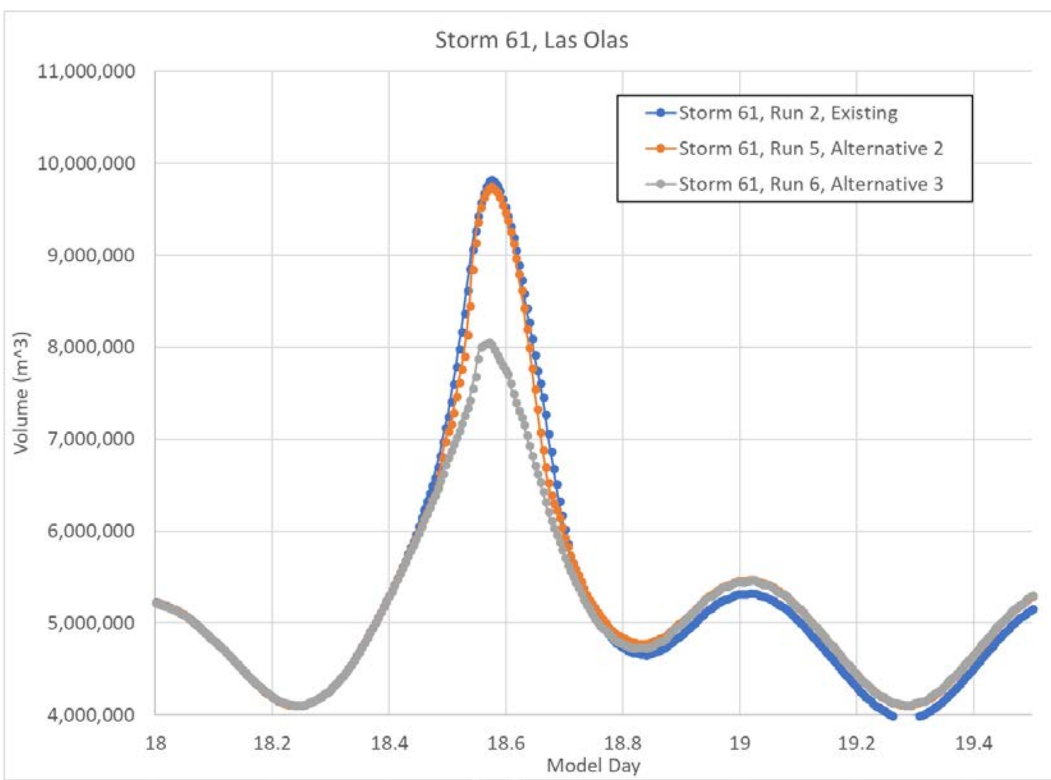

Figure B.11 Volume Calculated Within Las Olas Boulevard Calculation Area for Storm 61 Simulations

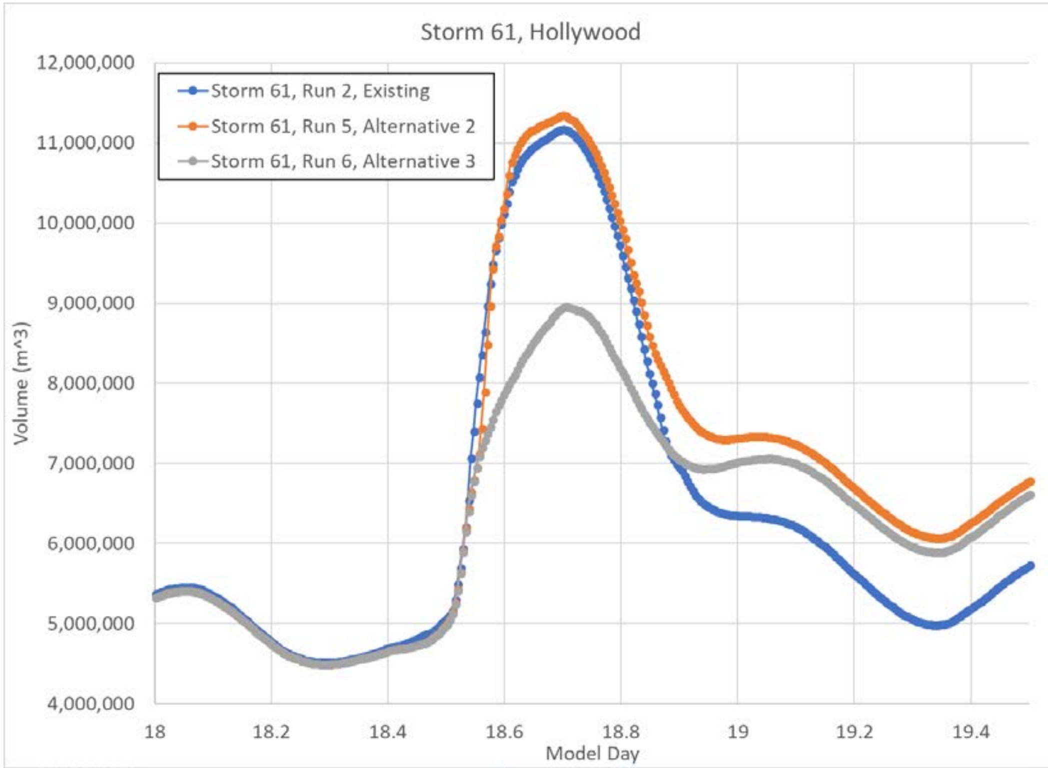

Figure B.12 Volume Calculated Within Hollywood Lakes Calculation Area for Storm 61 Simulations