CITY OF ST. PETERSBURG

Transient Docks Wave Modeling
Draft Report

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0	09/01/2016	M. Garcia-Castano	M. Herrman	M. Herrman

1. INTRODUCTION

The City of St. Petersburg is planning to construct new floating transient docks near the entrance to the Central Basin of the Municipal Marina. The City requested Moffatt and Nichol (MN) analyze winds and waves at the prospective site to assist with finalizing the layout and to use in design of the dock system. This report summarizes the wind and wave analyses including wave modeling to transform waves to the proposed transient dock site.

This report provides an overview and analysis of existing publicly available wind and wave data and identifies design conditions for the 50 and 100 year storm event. This report also provides a description of numerical wave models developed for these analyses. These wave models are used to simulate offshore wave propagation into Tampa Bay, local, wind-generation of waves, and wave transformation from the Bay to the transient dock site.

2. EXISTING DATA ANALYSIS

Existing meteorological and oceanographic (metocean) information was obtained for the Tampa Bay region from publicly available data sources. Water levels, storm surge and wind and wave data in the St. Petersburg area and the Tampa Bay are summarized below.

2.1 WATER LEVELS

Tides in the Tampa Bay region are mixed semi-diurnal tides, with water levels typically exhibiting two high and two low tides of varying amplitude in any given day or cycle. Tidal information was obtained from NOAA Station 8726520 located at the St. Petersburg U.S. Coast Guard station. The following table provides a summary of tidal datum elevations at that station based on the current tidal epoch (19 years of measurements from 1983 to 2001).

Table 1 Tidal Datums at St. Petersburg U.S. Coast Guard station

Tidal Datum	Elevation [ft]
Highest Observed Water Level (08/31/1985)	4.80
Highest Astronomical Tide (HAT)	1.65
Mean Higher High water (MHHW)	0.80
Mean High Water (MHW)	0.51
North American Vertical Datum (NAVD88)	0.00
Mean Sea Level (MSL)	-0.27
National Geodetic Vertical Datum (NGVD29)	-0.88
Mean Low Water Level (MLW)	-1.08
Mean Lower Low Water (MLLW)	-1.47
Lowest Astronomical Tide (LAT)	-2.60
Lowest Observed Water Level (01/16/1972)	-3.94

2.2 STORM SURGE

Storm surge data from the most recent FEMA Flood Insurance Study (FIS) for Pinellas County (2003) lists the following storm surge water levels for the project vicinity.

Table 2 Storm surge for 25, 50 and 100-year return period (Pinellas County FIS)

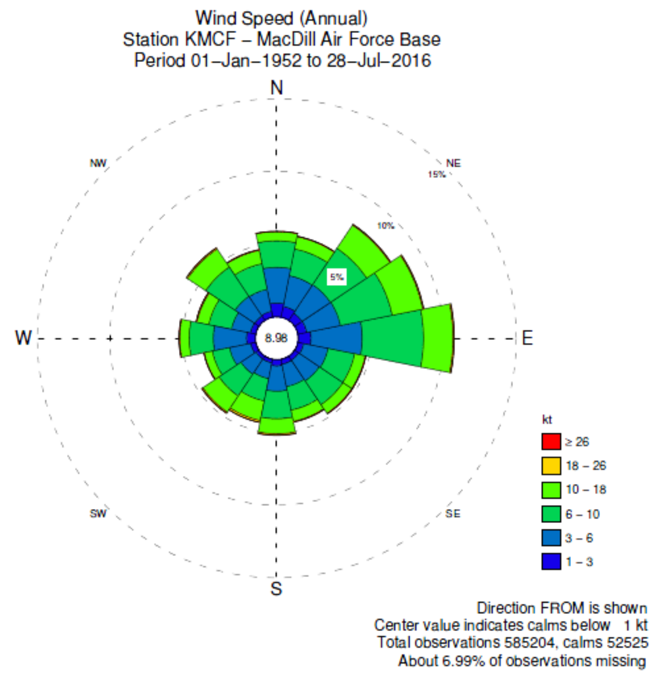
Return Period [years]	Water Level [NAVD ft.]
25	5.7
50	7.0
100	8.3

The return period listed indicates the probability of occurrence for the indicated water level in any given year as the inverse of the return period (a 100 year event has a probability of 1/100 to occur in any given year). The likelihood of the storm surge occurring jointly with wind or wave events with a similar return period is not included in the FIS.

Storm surge of these magnitudes is typically associated with tropical storms and hurricanes having sustained winds blowing from the west that act to push water into the bay.

2.3 WIND DATA

Wind data is typically available for long durations at airports and similar installations throughout a region. Wind data from MacDill Air Force Base was used for this analysis due to the exposure to overwater winds and the long period of available data (period of observation January 1952 to July 2016). The results are shown in the wind rose below.



Percentage of Occurrence

Wind Speed, kt	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	5.86	5.67	7.94	8.83	10.73	4.76	4.76	4.39	5.19	4.43	4.72	3.63	5.23	4.17	5.99	4.72	91.02
26																	
18–26									0.10	0.14							0.98
10–18	0.63	0.87	1.93	2.15	2.03	0.75	0.74	0.79	1.04	1.37	1.34	0.57	0.65	0.83	1.50	0.95	18.14
6–10	1.82	1.87	3.01	3.64	4.22	1.87	1.96	1.65	1.89	1.56	1.81	1.21	1.66	1.59	2.43	1.79	34.00
3–6	2.47	2.15	2.36	2.36	3.52	1.71	1.71	1.56	1.74	1.11	1.25	1.48	2.29	1.33	1.62	1.55	30.22
1–3	0.92	0.74	0.59	0.61	0.86	0.39	0.32	0.33	0.40	0.23	0.22	0.33	0.59	0.36	0.34	0.39	7.62

Figure 1 Wind rose at MacDill Air Force Base (1952-2016)

The wind rose at MacDill Air Force Base shows a scattered wind climate with wind approaching from all directions. The predominant wind direction is East with almost 11% of the winds approaching from this direction. Wind speeds are generally under 18 knots with less than 1% of the data showing higher wind speeds. The proposed transient dock location is partially exposed to southeast winds and waves. Wind data shows southeast and south-southeast winds occur approximately 10% of the time.

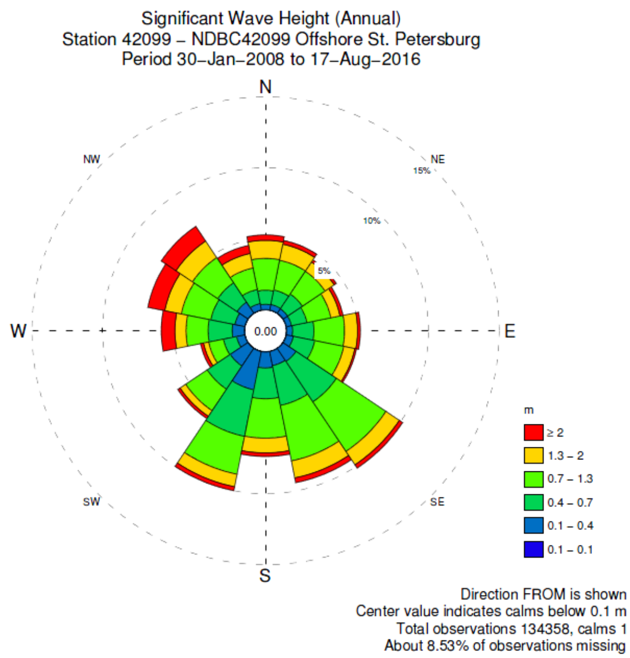
Extreme value analysis of historical wind speeds recorded at MacDill Air Force Base from 1941 through 2011 results in the following wind speeds by return period.

Table 3 10-minute wind speed for different return periods

Return Period [years]	10-minute Wind Speed [mph]
25	74
50	83
100	92

2.4 WAVE DATA

Offshore wave data was obtained from the National Data Buoy Center (NDBC) buoy 42099, located 80 miles offshore of Tampa Bay. Wave data was extracted for a period of 8 years (2008-2016) and the results are shown in the rose below.



Percentage of Occurrence

Significant Wave Height, m	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	5.27	5.00	4.51	4.08	5.20	5.05	10.15	9.42	7.37	10.00	5.95	3.17	5.87	6.98	7.36	4.64	100.00
> 2	0.38	0.27	0.17	0.22	0.20	0.12	0.28	0.35	0.25	0.28	0.19	0.21	0.96	1.22	1.25	0.58	6.92
1.3 – 2	1.27	1.15	0.78	0.66	0.92	0.80	1.14	1.22	1.04	0.90	0.48	0.37	0.79	1.19	1.40	1.04	15.16
0.7 – 1.3	2.25	2.13	1.93	1.72	2.16	2.09	4.21	3.99	2.78	2.72	1.82	1.06	1.56	2.12	2.14	1.55	36.24
0.4 – 0.7	0.99	1.05	1.25	1.11	1.51	1.54	3.43	2.86	2.18	3.35	1.96	0.95	1.70	1.73	1.64	1.01	28.27
0.1 – 0.4	0.37	0.39	0.37	0.37	0.41	0.50	1.10	1.01	1.12	2.74	1.50	0.58	0.86	0.71	0.93	0.46	13.41
0.1 – 0.1																	

Figure 2 Wave rose at NDBC42099 (2008-2016)

The wave rose at NDBC42099 shows a scattered wave climate with waves approaching from all directions. The predominant wave direction quadrant is South South-East through South South-West with almost 27% of the waves approaching from this direction. Significant wave heights are generally under 2.0 meters with less than 7% of the data showing higher values.

3. WAVE MODELING

Waves in Tampa Bay consist of locally-generated seas, offshore swells, or a combination of both. Locally-generated seas are waves that are directly formed from local winds blowing over the water surface. Locally-generated seas are primarily influenced by fetch distance (the water surface distance over which the wind blows), wind speed, wind duration, and water depth. As these parameters increase in value, the locally-generated waves increase in wave height and wavelength. After the wind ceases or the waves travel outside of the influence of the winds, the resultant wind-generated waves are called swells. Offshore swells are waves that are no longer – or minimally – affected by local winds that continue to propagate until their energy is dissipated by friction, wave breaking, or other means.

In Tampa Bay, locally-generated seas are waves formed by the wind blowing across the surface of Tampa Bay from various directions. Offshore swells formed in the Gulf of Mexico may propagate into Tampa Bay, and the impact of swell on wave energy at specific sites diminishes with distance longitudinally and laterally with respect to the mouth of Tampa Bay and deeper water along the federal navigation channel. Offshore swells and locally-generated seas were modeled separately to determine their potential influence at the project site individually.

3.1 TAMPA BAY REGIONAL MODELING

Two wave models were developed for the analysis of Tampa Bay and the vicinity of St. Petersburg Central Basin. Waves in Tampa Bay were simulated using the MIKE 21 SW numerical modeling software suite. This numerical model calculates offshore swell propagation into Tampa Bay and the development and transformation of wind-generated waves within the bay. MIKE 21 SW (DHI, 2011) is a spectral wind-wave model developed by DHI that simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas. The model includes wave growth by action of wind, non-linear wave-wave interaction, dissipation by white-capping, dissipation by wave breaking, dissipation due to bottom friction, shoaling and refraction due to depth variations, and wave-current interaction. The primary model input includes bathymetry, water levels, wind data, and offshore boundary conditions (e.g. offshore wave heights, periods, and incident wave directions).

The bathymetry for the Tampa Bay model is based on the Digital Elevation Model (DEM) of the region compiled by the USGS.

3.1.1 Offshore Swells

Analysis of NDBC buoy 42099 shows that waves greater than 4.0 meters are within the highest 1 percent of waves measured. This wave height was selected as the initial offshore boundary condition to determine the wave transmission characteristics from the Gulf of Mexico into Tampa Bay. Three wave period values (8, 10, and 12 seconds) were modeled to determine the relationship between wave length and maximum wave transmission, and the incident wave directions were varied in 15-degree increments. No storm surge elevation was applied but the results with storm surge are expected to be similar.

Results indicate that the offshore swell achieved maximum transmission into Tampa Bay when the waves approached from 225 degrees (southwest). The largest resultant significant wave height at the project site for these offshore swell conditions is 0.03 meters, which is a reduction of 99.25 percent from an offshore significant wave height of 4.0 meters (transmission coefficient of 0.0075). Figure 3 shows the graphical results of the offshore swell transmission into Tampa Bay for these conditions. (barrier island land masses are reflected in the bathymetry but may not show in the background aerial image)

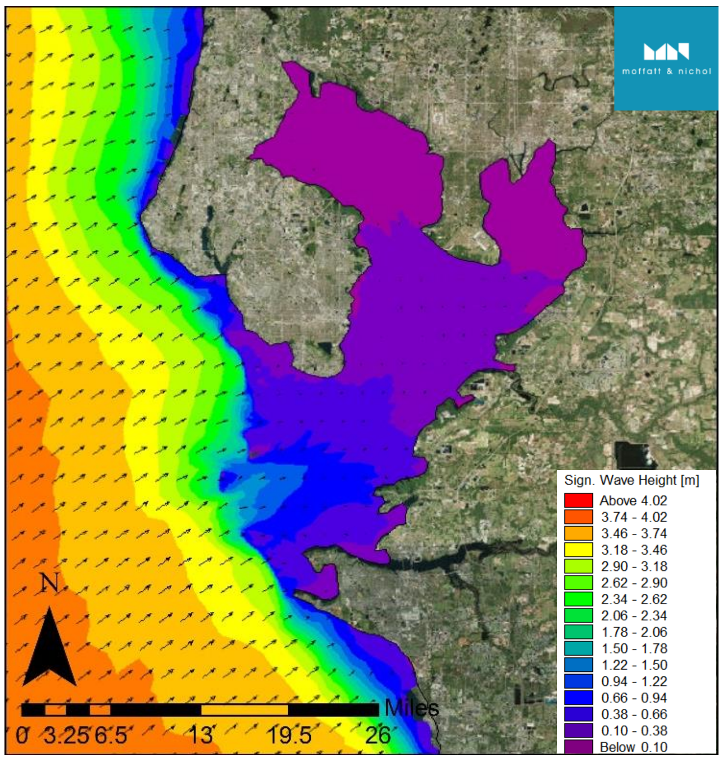


Figure 3 Example of offshore swells propagation throughout Tampa Bay

3.1.2 Locally-Generated Seas

Locally-generated seas, generated by winds over the bay, were modeled using input wind and water level conditions for the 50-, and 100-year return period events, as described in Table 4. The model was run in quasi-steady state mode to allow seas to fully develop within the Bay. Separate cases were run for incident wind direction in 15-degree increments over the full 360-degree compass range to represent the potential fetch distances from all directions.

Water currents in Tampa Bay were not included in the numerical model. Diffraction was also not included in the model after a diffraction sensitivity analysis was conducted and found to have minimal effect on the resultant waves approaching the project vicinity. The 25-, 50-, and 100-year return period wind speeds were applied to the model, both with and without the effects of storm surge (Figure 4 to Figure 7).

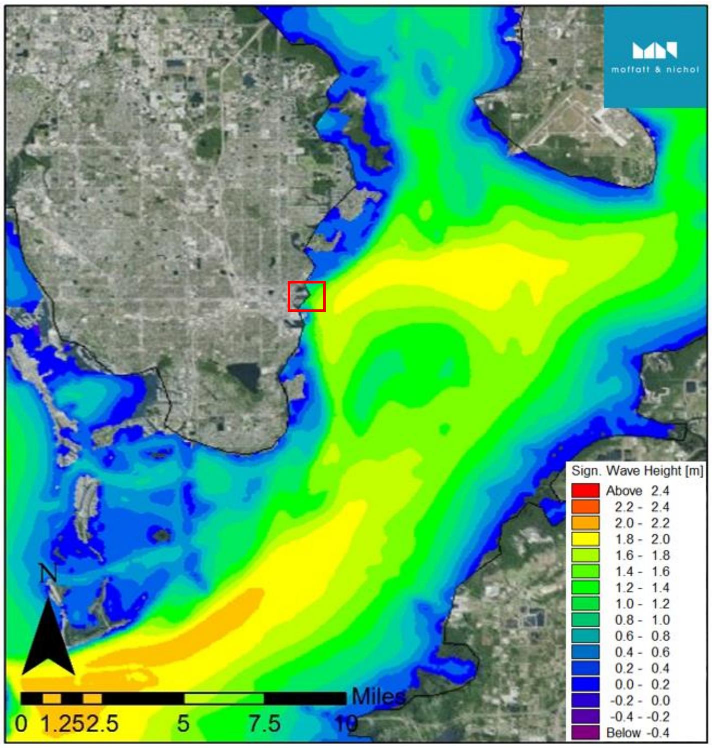


Figure 4 Locally-generated waves for 50-year return period winds (no storm surge)

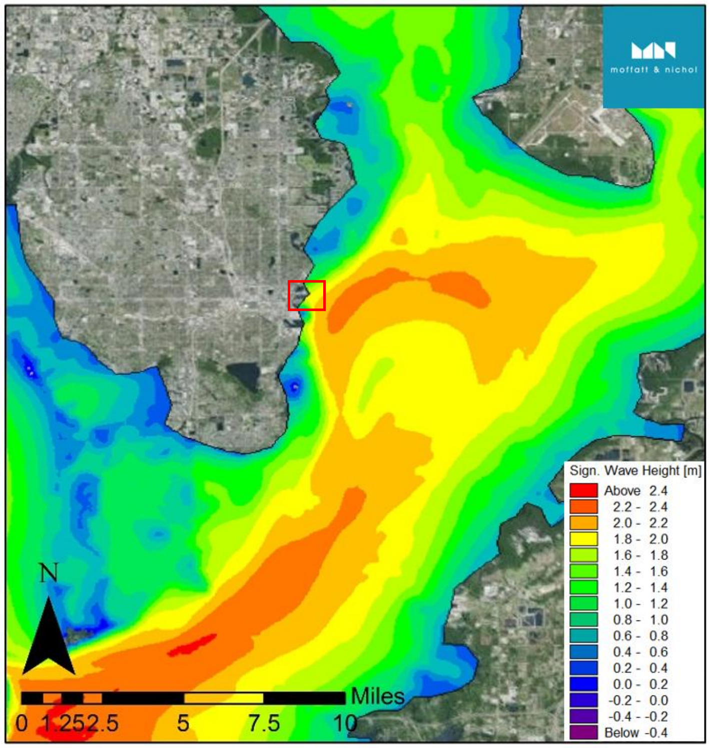


Figure 5 Locally-generated waves for 50-year return period winds (includes storm surge)

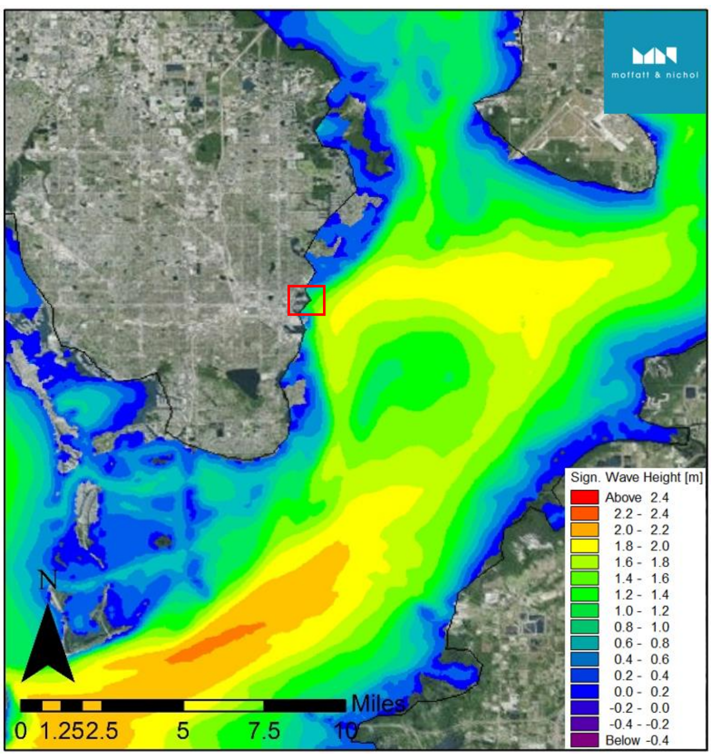


Figure 6 Locally-generated waves for 100-year return period winds (no storm surge)

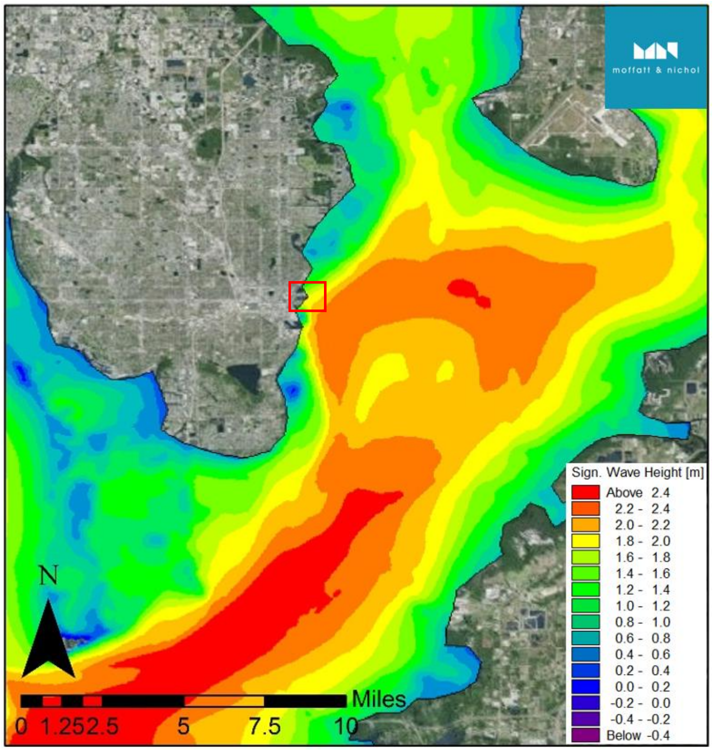


Figure 7 Locally-generated waves for 100-year return period winds (includes storm surge)

The maximum wind-generated waves occurred from the East sector, which provides a long, uninterrupted fetch distance within Tampa Bay to the project site. The largest waves resulted from an incident wind direction of 105 degrees with respect to North (N=0°). These wave heights are listed in Table 4 for the 25-, 50-, and 100-year return period wind speeds.

Table 4 Wave conditions for the 25, 50 and 100 year event

Return Period [years]	Storm Surge [ft]	H_{mo} [ft]	H_{max} [ft]	T_p [sec]
25	0.0	2.6	5.3	2.7
	5.7	6.2	10.7	4.7
50	0.0	4.6	7.9	4.2
	7.0	6.6	11.8	4.8
100	0.0	4.9	8.2	4.2
	8.3	7.2	12.5	4.9

Analysis of the results shows that bottom friction is significant in limiting wave height. This is reflected in the increased wave heights with storm surge and the direction that generates the highest wave heights.

H_{mo} represents the significant wave height with wave breaking included. H_{max} represents the average of the highest 1% of wave heights within the random wave climate. T_p represents the peak wave period.

3.2 LOCAL BW MODELING

Waves entering the St. Petersburg Central Basin, were simulated using the MIKE 21 BW numerical modeling software. This numerical model calculates nearshore wave propagation by using offshore propagation results from the regional SW model. MIKE 21 BW simulates the growth, decay and transformation of wind-generated waves and swells in coastal areas. This model includes non-linear wave-wave interaction, dissipation by wave breaking and bottom friction, shoaling, refraction, reflection and diffraction.

The primary model input includes bathymetry, water levels, wind data, and wave conditions obtained from regional model. The bathymetry is based on the USGS DEM and on hydrographic survey data of the St. Petersburg Municipal Marina.

A smaller grid resolution was adopted to obtain a better representation of the area of interest near the central basin entrance. This allows inclusion of wave transformation phenomena such as wave breaking, reflection, refraction and diffraction. The wave analysis for the St. Petersburg Transient Docks includes operational regime analysis and extreme regime analysis. A description as well as a summary of the results obtained for both regimes is provided in the next sections.

3.2.1 Operational Regime

Regular operational conditions are simulated for 2 different representative wave peak periods (4 and 7 seconds) and 5 wave directions encompassing the East to South South-East quadrant. A unitary significant wave height was applied at the model boundary and the model results reflect wave height reduction coefficients throughout the domain. A point result of 0.5 suggests that 50% of the offshore energy reaches that location.

The following plots show the wave height reduction coefficients for different peak periods and propagation directions.

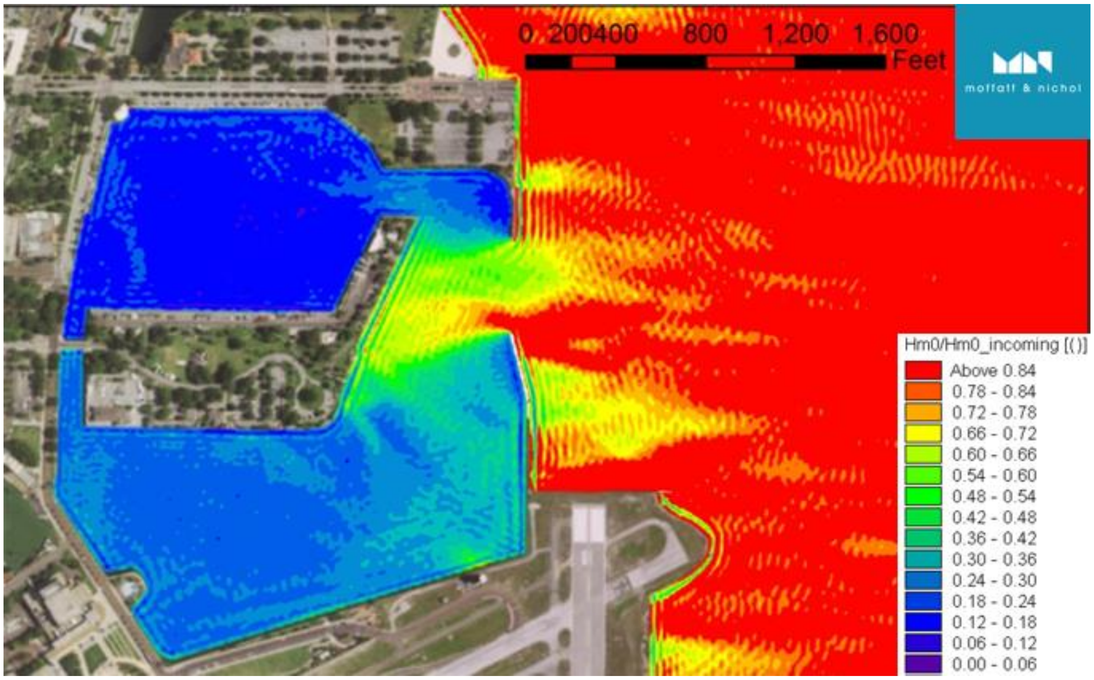


Figure 8 H_s reduction factor (T_p=4sec. θ=90°)

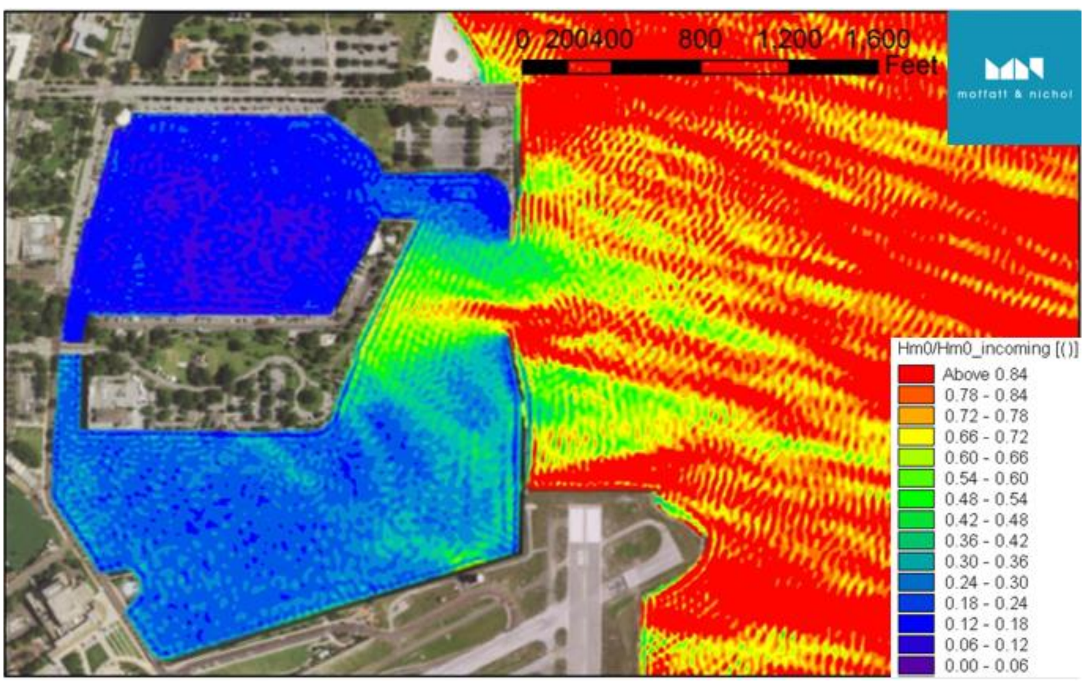


Figure 9 H_s reduction factor (T_p=4sec. θ=105°)

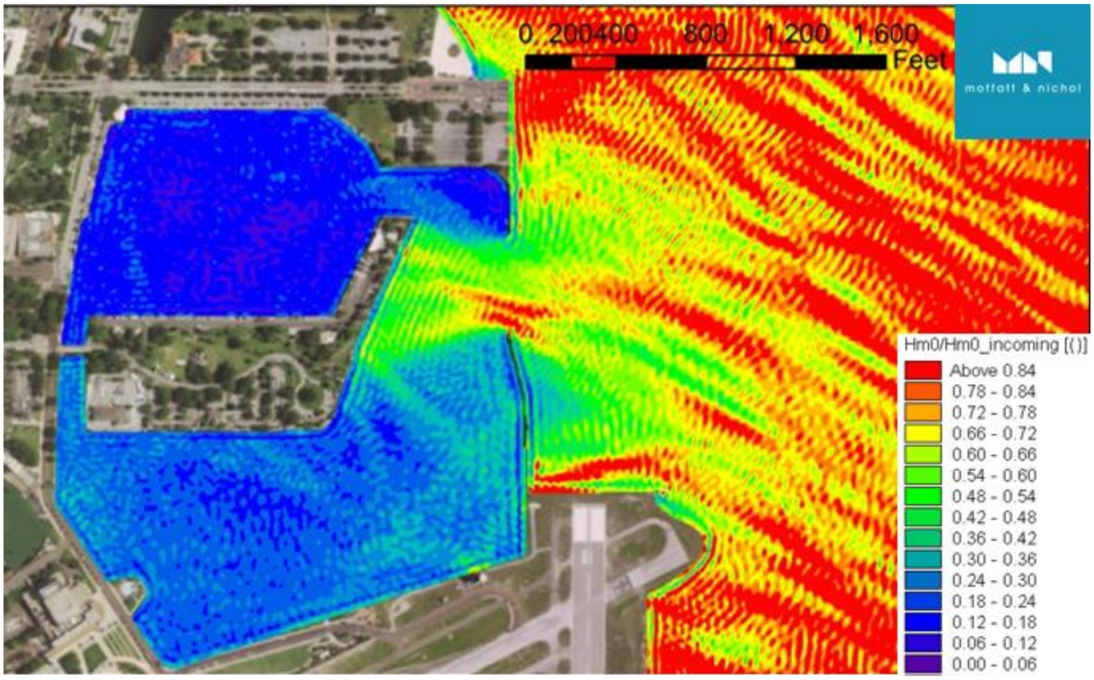


Figure 10 H_s reduction factor (T_p=4sec. θ=120°)

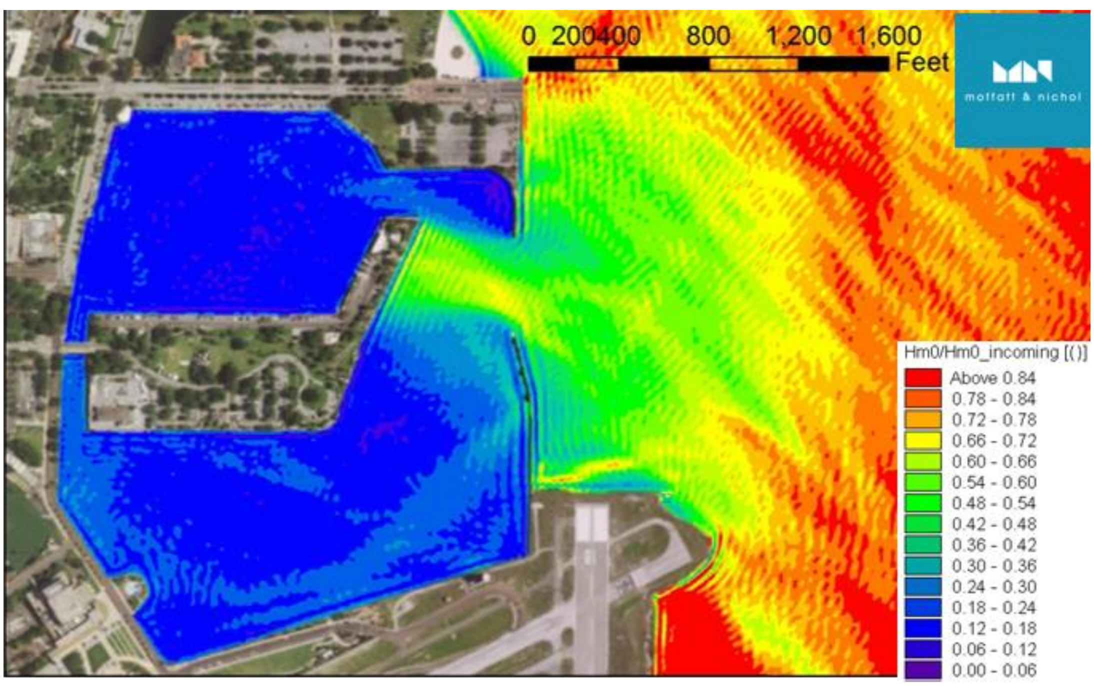


Figure 11 H_s reduction factor (T_p=4sec. θ=135°)

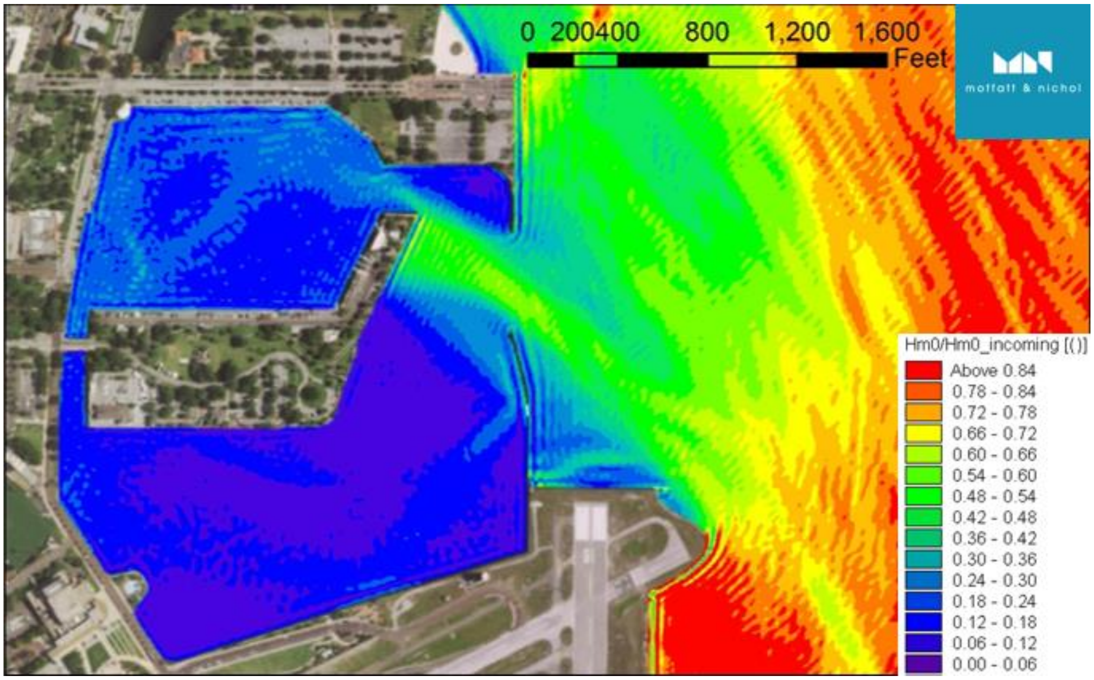


Figure 12 H_s reduction factor (T_p=4sec. θ=150°)

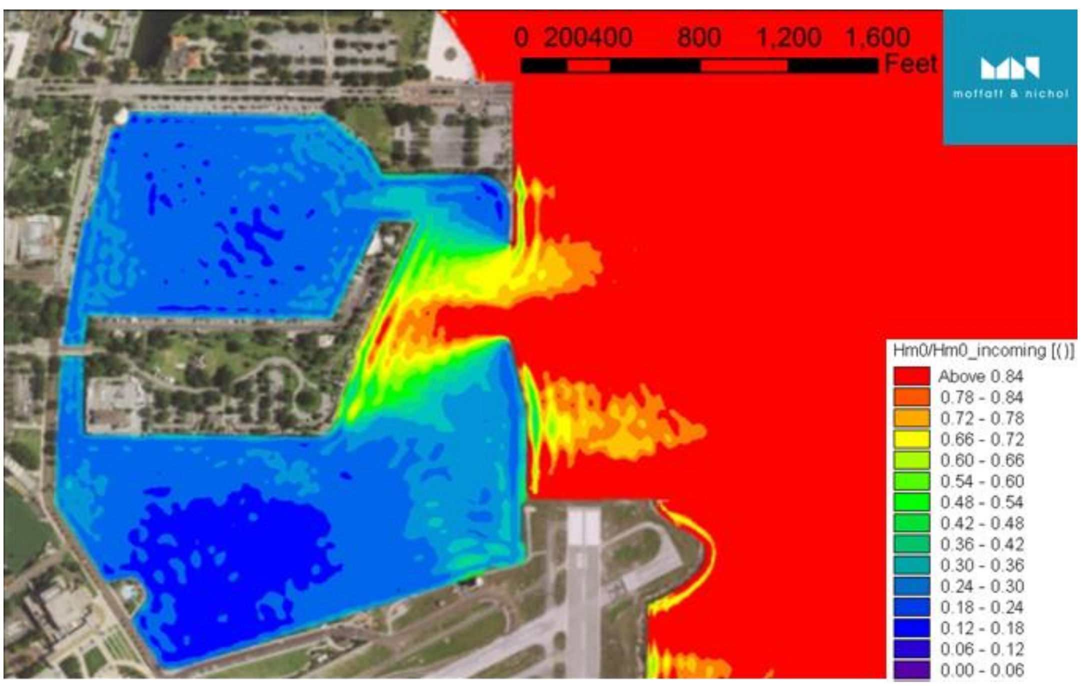


Figure 13 H_s reduction factor (T_p=7sec. θ=90°)

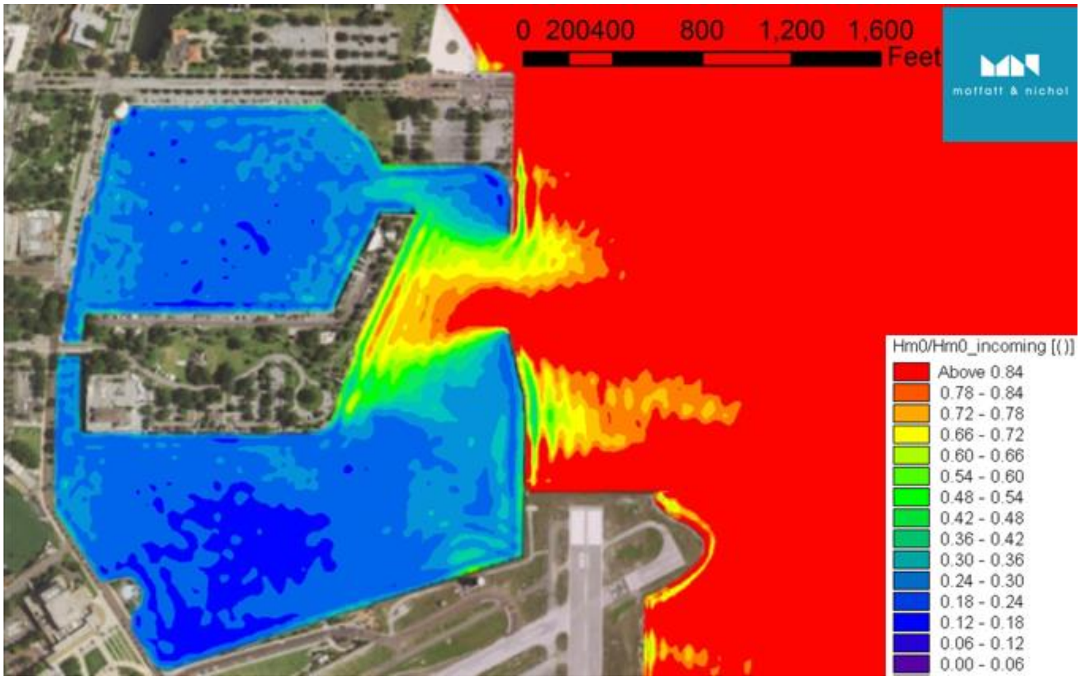


Figure 14 H_s reduction factor (T_p=7sec. θ=105°)

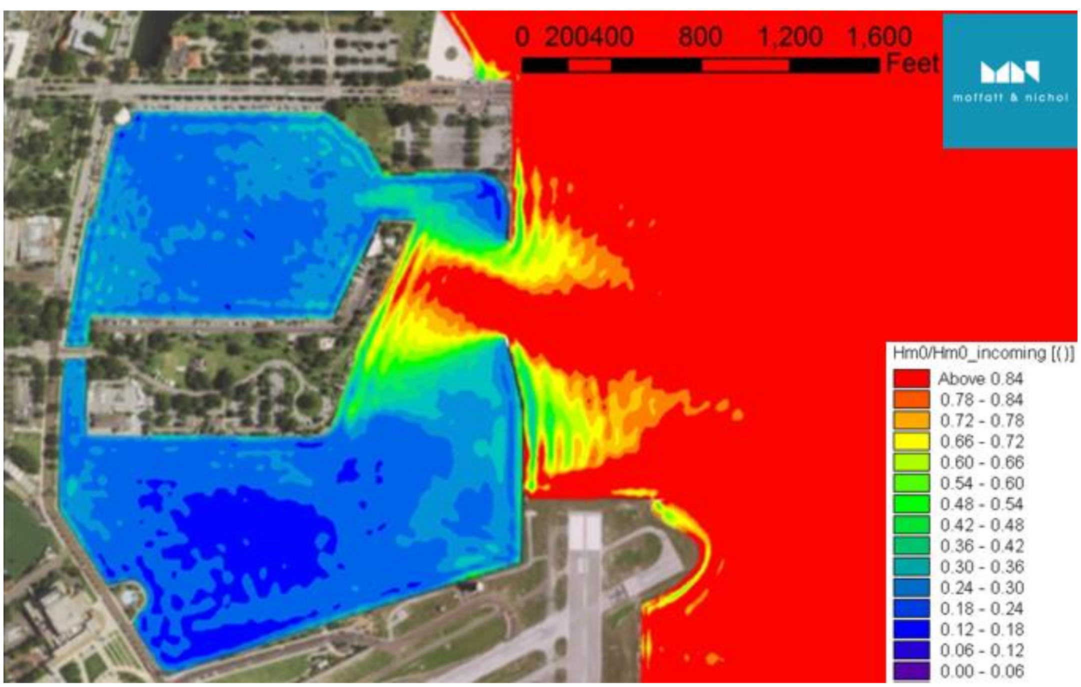


Figure 15 Hs reduction factor (T_p=7sec. θ=120°)

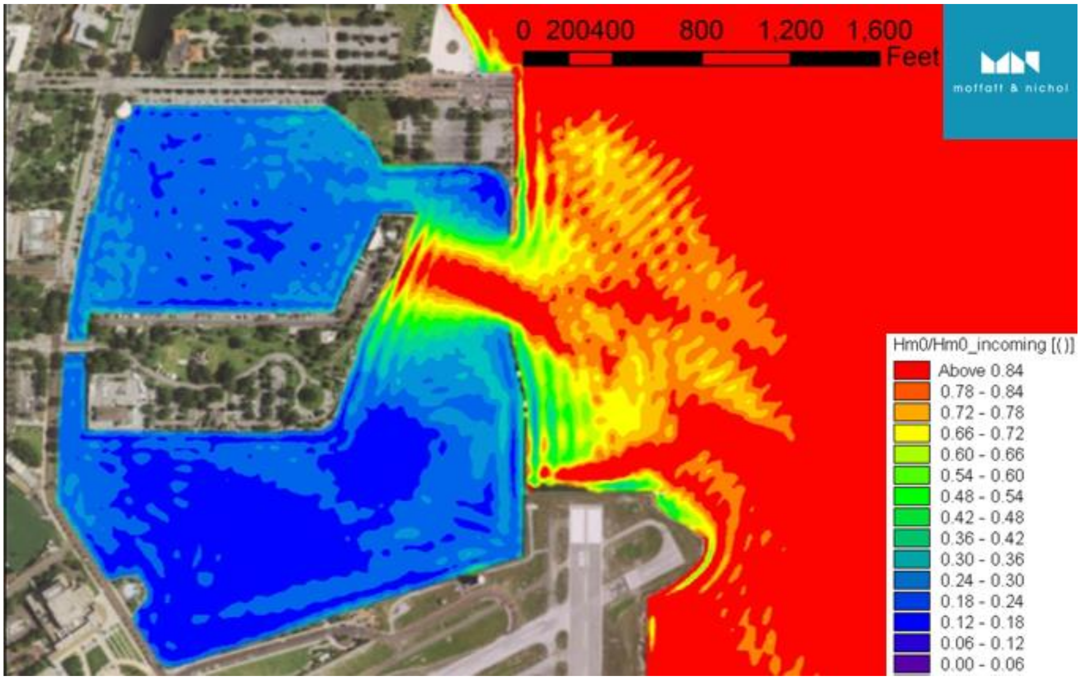


Figure 16 H_s reduction factor (T_p=7sec. θ=135°)

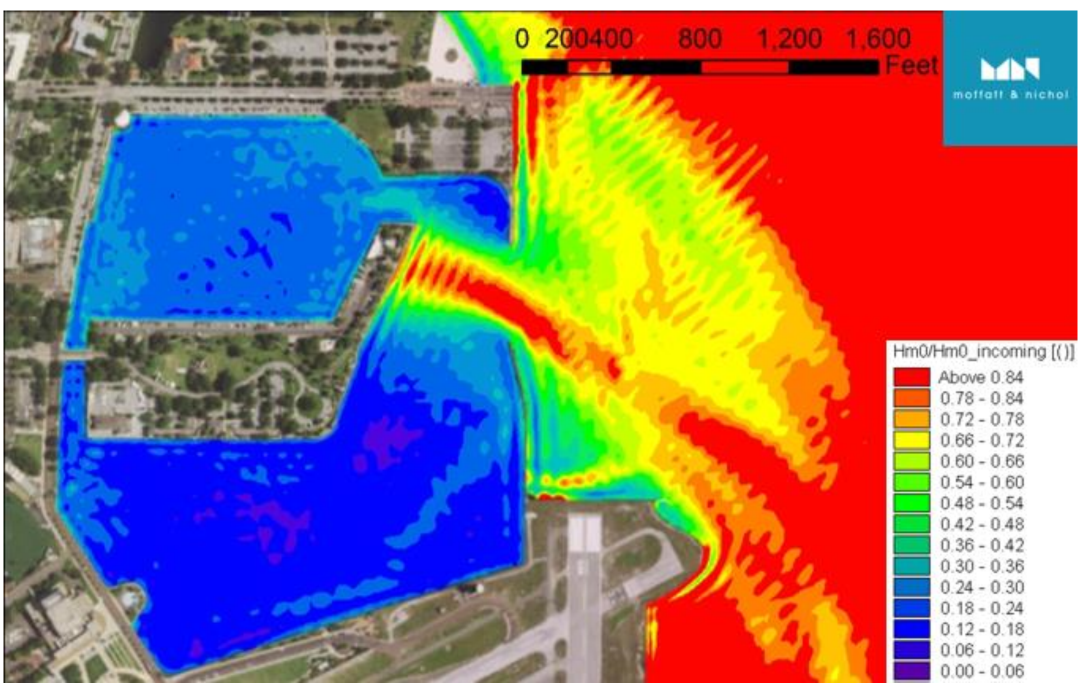


Figure 17 H_s reduction factor (T_p=7sec. θ=150°)

As the waves propagate from offshore, different wave transformation phenomena (shoaling, refraction, reflection and diffraction) dictate how the wave height changes. Figure 8 to Figure 17 show the significant wave height reduction for each case. These plots can be used to estimate the significant wave height at any point in the domain for a given set of offshore conditions (significant wave height, peak period and wave direction).

For a given offshore wave height, the resulting wave agitation in the central basin is mainly influenced by the offshore wave direction and the wave reflection off the walls of the basin. Waves approaching from the southeast (150 degrees) propagate between the existing breakwaters and generate a localized region with low wave height reduction but are somewhat blocked by the airport peninsula resulting in overall lower wave agitation compared to other cases. Waves from the East result in the highest wave agitation in the area immediately seaward from the existing breakwater due to wave reflection and lack of sheltering by the adjacent airport runway.

Figure 18 and Figure 19 show the maximum wave height in the transient dock area for waves approaching from the East with a peak period of 4 and 7 seconds respectively. The breakwater results in a sheltered area immediate adjacent with wave height reduction of up to 83%. West along the seawall the area becomes less protected by the breakwater. The sheltered area extends further in Figure 18 than in Figure 19 due to the fact that longer waves shoal more than shorter waves.

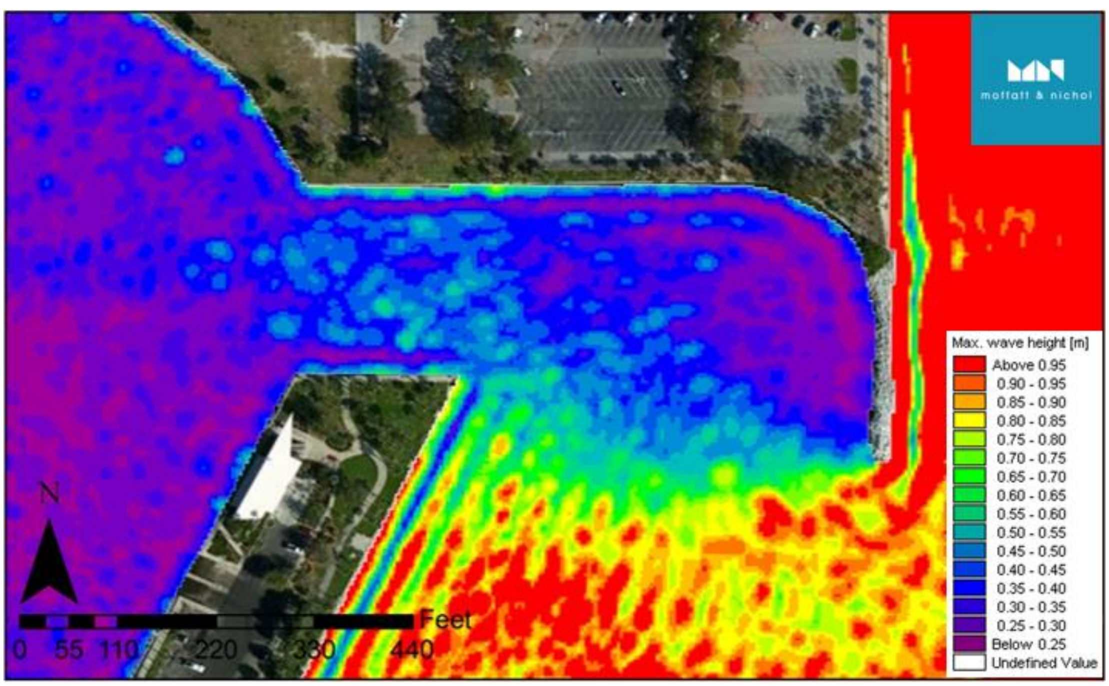


Figure 18 Maximum wave height at the location of the transient docks (T_p=4sec. θ=90°)

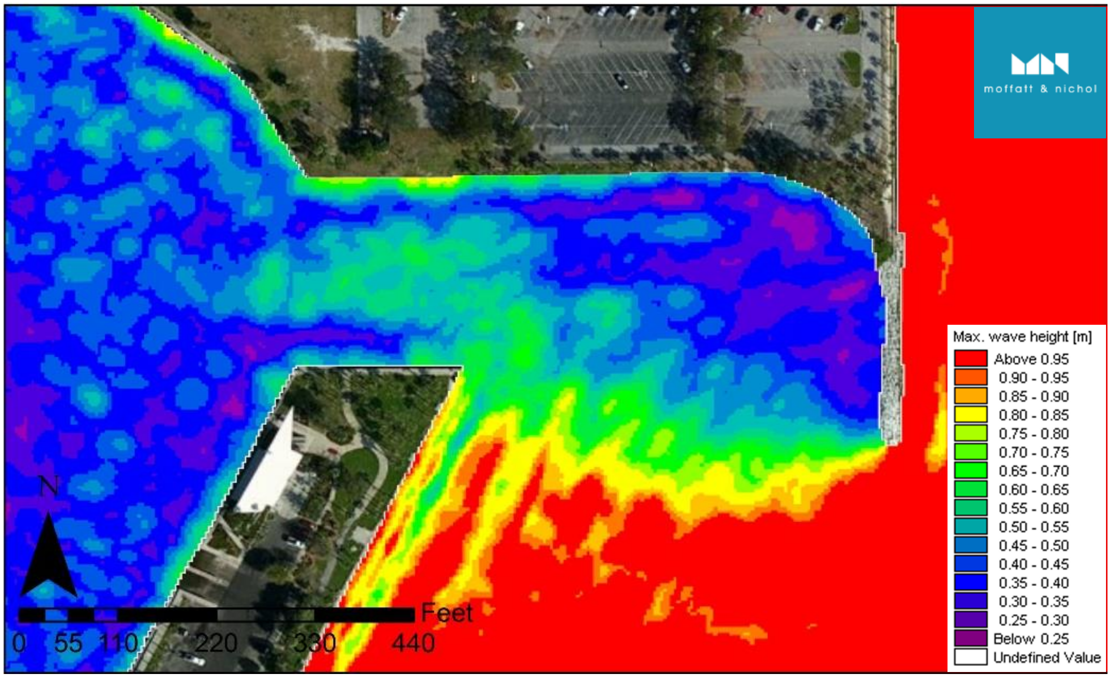


Figure 19 Maximum wave height at the location of the transient docks (T_p=7sec. θ=90°)

3.2.2 Extremal Regime

Extreme wave conditions were modeled simulating wave propagation for the 50 and 100 year return period storm event scenarios. The Tampa Bay model was fed with wind data for the 50 and 100-year return period storm (Table 3) and produced the offshore wave conditions (Figure 4 to Figure 7) that were used as input for the local model.

Figure 20 and Figure 21 show the wave agitation in the prospective dock location for the 50 and 100-year storm event respectively, with no storm surge. The offshore wave conditions for the 50 year and 100 year wind conditions are almost identical. For these two scenarios, regional water depths and fetch across the bay limit the wave heights.

Table 4 shows the wave conditions for the 50- and 100-year return period storm event. According to Pinellas County FIS, the storm surge at the city of St. Petersburg is expected to be 7.0 and 8.3 NAVD ft. for the 50 and 100-year return period storm event respectively. However the link between storm surge and wind events that would generate waves at St. Petersburg is not defined and may not occur simultaneously.

The elevations surrounding the project site range from +3.6 to +6.3 NAVD ft. The area around the Municipal Marina (including the breakwaters) would be submerged under these storm surge conditions. When the breakwater is submerged, the docks will be exposed to breaking waves from the bay.

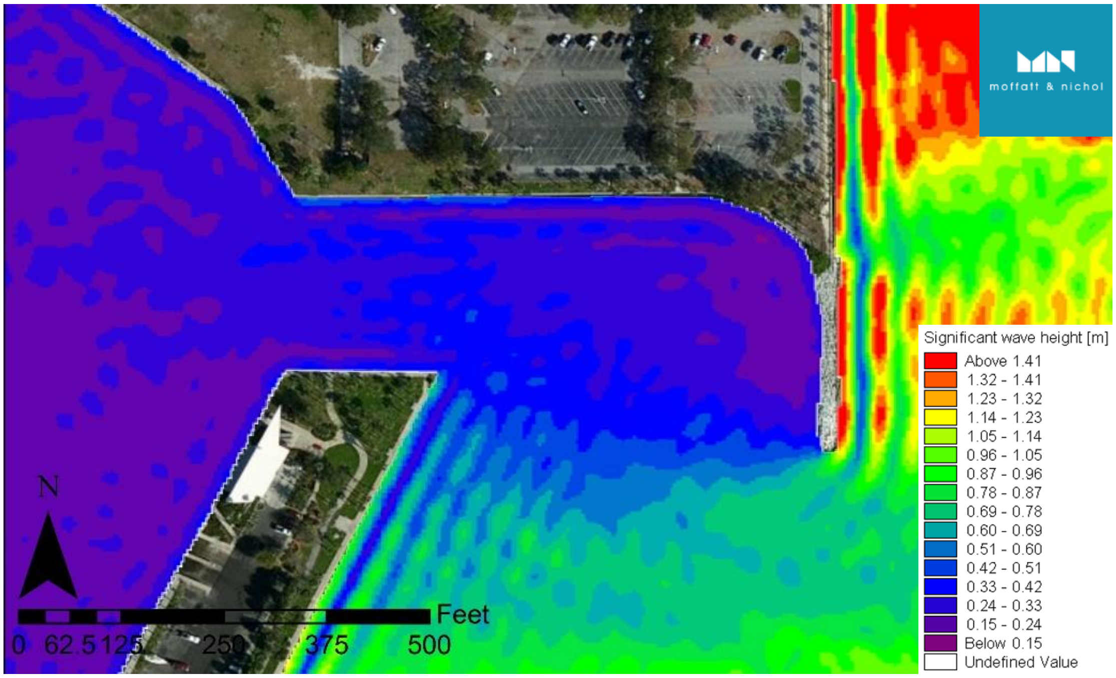


Figure 20 Maximum wave height at the location of the transient docks for the 50-year storm event ($H_{s\ offshore}$=1.4m., T_p=4.2sec. θ=90°)

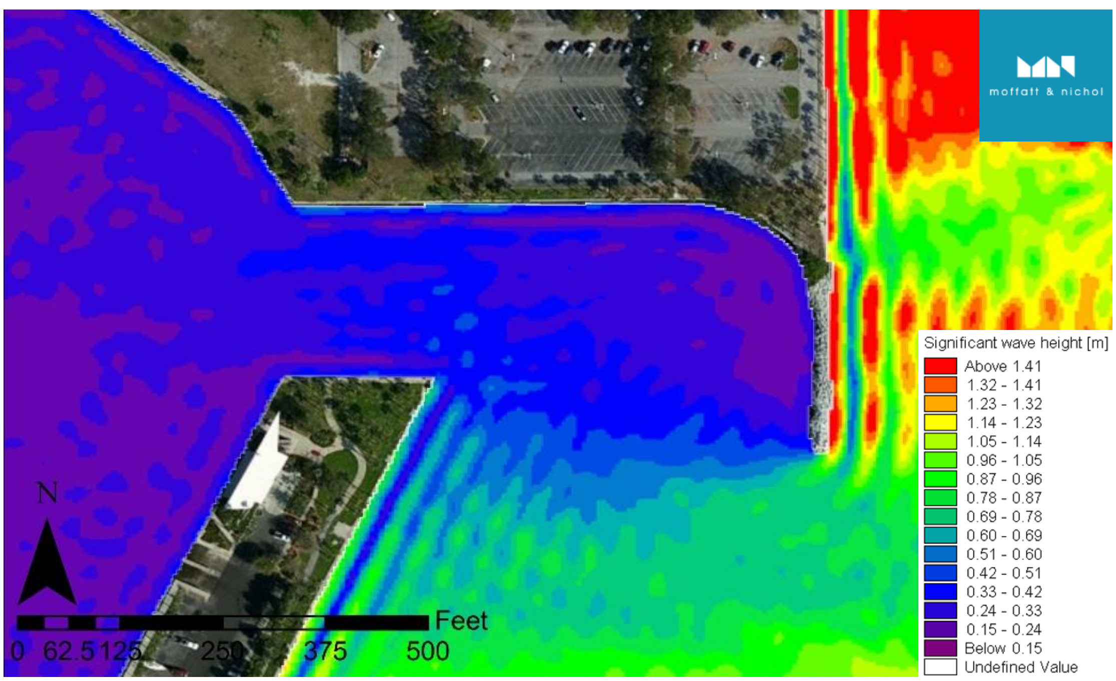


Figure 21 Maximum wave height at the location of the transient docks for the 100-year storm event ($H_{s\ offshore}$=1.5m., T_p=4.2sec. θ=90°)

4. CONCLUSIONS

This report summarizes winds and waves in Tampa Bay and in the vicinity of the Central Basin of the Municipal Marina in the City of St. Petersburg. A wave model was developed to transform waves to the proposed transient dock site. The results obtained in this report can be used to adjust the overall dock configuration and also in the developing performance specification criteria for the floating docks.

This report analyses existing publicly available wind and wave data and identifies design conditions for the 50 and 100 year storm event.

- The Tampa Bay model shows that offshore swells are not expected to have a significant influence in the Central Basin wave climate.
- The plots resulting from the operational wave analysis can be used to identify areas meeting industry standards for good docking during operational conditions.
- The 50 and 100-year return period storm surge event has a predicted surge of 7.0 and 8.3 NAVD ft., respectively. The marina breakwater is expected to be submerged, exposing the proposed transient dock area to breaking waves during these storm surge events.