King Tide and Normal Wind Setup Analysis for Monroe County, Florida

Monroe County Roadway Inundation Analysis
Monroe County, Florida
Project # 6783193178

Prepared for:

Monroe County

102050 Overseas Hwy, Ste. 246, Key Largo, FL 33037

January 10, 2020

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1.0 Introduction

The purpose of this technical brief is to outline the findings of the analysis of king tide and normal wind setup water levels, in support of the Monroe County Roadway Inundation Analysis.

1.1.1 Evaluation of Tide Gauges to Support Tidal Analysis

Historical water level and wind data were sourced for the years 1996-2018 (inclusive), from the NOAA tides and currents database at the following permanent stations with long-term hourly records that allow harmonic tidal and wind setup analysis extending to the present day:

- Key West (station 8724580)
- Vaca Key (station 8723970)
- Naples (station 8725110)

The available data at the three stations provide relatively wide coverage of the water levels observed over the latitude range, and to some extent the longitude range of the ocean domain adjacent to Monroe County. The water level data is available at 6 minute temporal resolution, providing a sufficient basis for the analysis of both astronomically induced tides, as well as atmospherically induced water level residuals.

The length of the available data period contributes to the robustness of the analysis, as it is longer than the period of the Saros cycle that characterizes the full range of astronomical tidal forcing. In order to capture the full range of tidal variability, the tidal analysis should consider the maximum and minimum water levels that occur over a period longer than the Saros cycle (when three lunar orbital periods are aligned), which includes 223 synodic months, or approximately 18 years, 11 days, 8 hours.

An additional water level dataset was considered for a limited analysis of king tides, at Key Colony Beach (inactive station 8723962) where historical data had been gathered between 1976 and 1998 (with several large gaps), in order to provide further characterization of the spatial variability of the tidal range in the region. The Key Colony Beach tide gauge is located on the Atlantic Ocean coastline in the vicinity of the Vaca Key tide gauge, therefore these two locations capture the different tidal ranges on each side of the keys.

2.0 Tidal Analysis and King Tide Predictions

The historical water level time series were used to conduct a harmonic tidal analysis and extract the astronomical tidal constituents at each of the stations, by using the UTide Matlab toolbox by Codiga (2011). The tidal analysis was performed in several stages

- Removal of the linear trends from the long-term records;
- Performing a harmonic tidal analysis to extract the amplitudes and phases of the astronomical constituents; the harmonic tidal constituents are extracted over a minimum of a 19 year period, to capture the full range of tidal variability over a Saros cycle;
- The extracted tidal constituents are used to generate a pure tidal water level signal over the recorded period;
- The predicted tides over a minimum period of 19 years are used to estimate the maximum or highest astronomical tides for each location, labeled as the King Tides;
- The predicted tidal time series is also used for subsequent analysis of the normal wind setup over the period 1996-2018, as removing the tidal signal from the raw water level time series provides the non-tidal surge residuals necessary for wind setup analysis.

The tidal analysis indicates that the tidal range at the tide gauge locations exhibits a seasonal cycle, with the highest tides occurring in the fall (during the months of September or October) of every year on record. Time series of the raw water level data, as well as the extracted tide levels, are shown in Figure 2-1, Figure 2-2 and Figure 2-3 for the three active tide gauge locations. While the maximum tides could vary slightly from one year to the next, the maximum tides predicted over a 19 year period that includes the full Saros cycle would provide an upper limit of the expected astronomical tidal levels.

The king tides predicted for the three active tide gauge locations and one historical location are shown in **Error! Reference source not found.**, presented as levels above Mean Sea Level (MSL). The predicted highest king tides range from 13.8 inches above mean sea level at Vaca Key, to 20.9 inches at Key West, and 25.6 inches at Naples. The king tides at the historical Key Colony Beach location are predicted at 22.3 inches above MSL, indicating a higher tidal range on the Atlantic Ocean coastline than on the Florida Bay side at Vaca Key. These results indicate a relatively high degree of spatial variability of the tides along the coastline of the Florida Keys, resulting in generally higher tidal ranges in the west of Florida Bay (Key West and Naples), and diminishing tidal ranges further east (Vaca Key) within Florida Bay. On the Atlantic Ocean coastline, the elevated levels at Key Colony Beach indicate a potential amplification of the tide eastward of Key West, however the full range of variability is likely not captured due to the lack of data at other locations further east along the coastline of the keys.

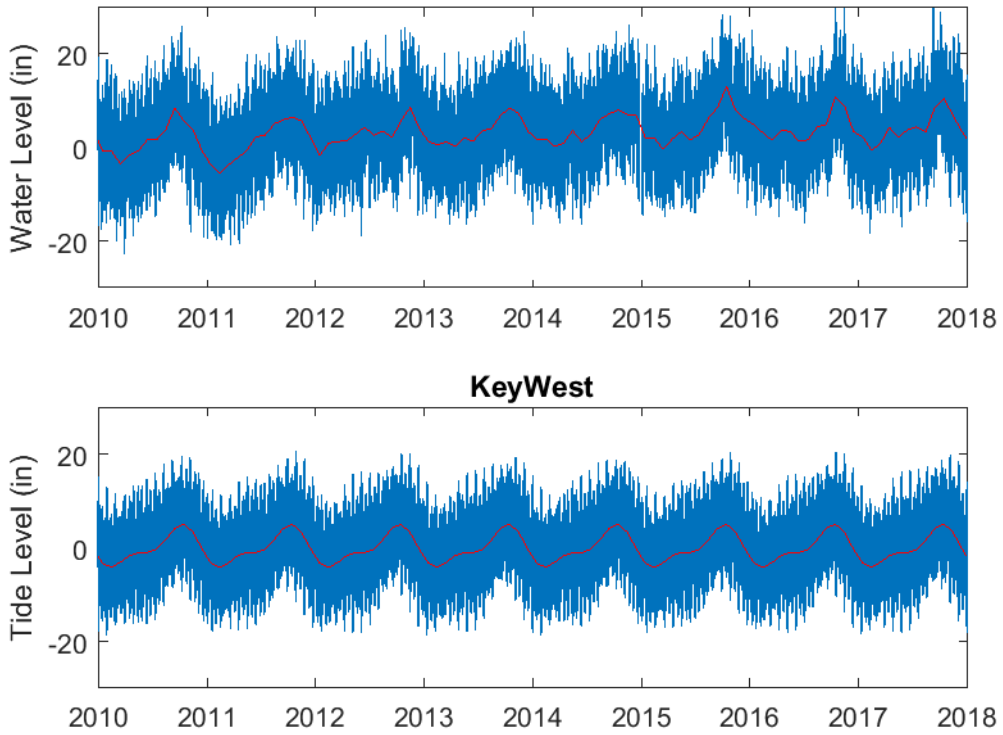

Figure 2-1 Raw water level and tide-only levels for Key West, with monthly averages (red line).

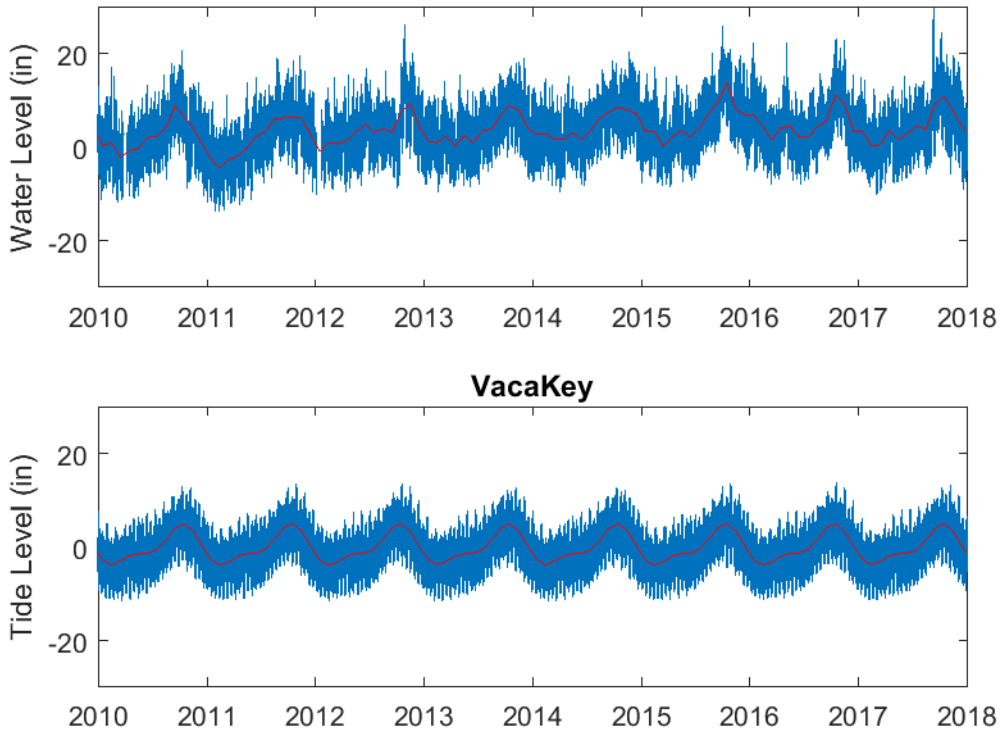

Figure 2-2 Raw water level and tide-only levels for Vaca Key, with monthly averages (red line).

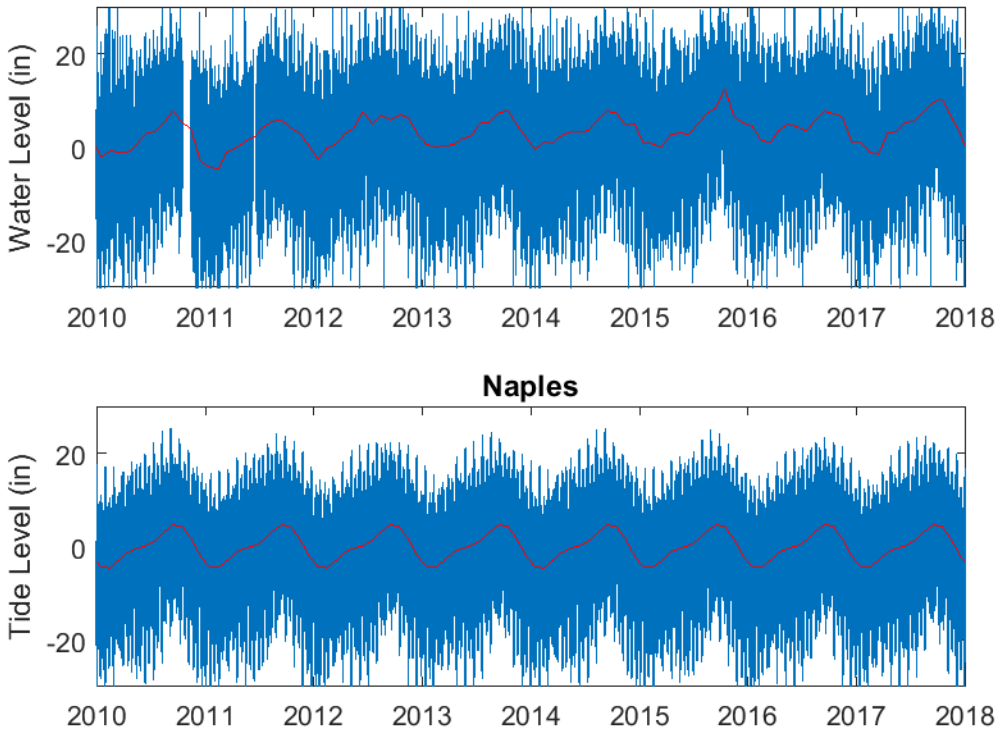

Figure 2-3 Raw water level and tide-only levels for Naples, with monthly averages (red line).

Table 2-1: King tide levels above mean sea level at the tide gauge locations.

Location	King tides (highest astronomical tides), inches above MSL
Key West	20.9
Vaca Key	13.8
Naples	25.6
Key Colony Beach (limited analysis)	22.3

3.0 Normal Wind Setup Analysis

Following the tidal analysis of the water level time series for the period 1996-2018 at the long-term active tide gauge locations, the non-tidal surge residual was extracted for further analysis of the normal wind setup water levels. The derived statistics were based on the positive surge values, selectively reflecting the wind setup during conditions when winds and atmospheric pressure forcing are contributing to elevated water levels at the coastline of the Florida Keys.

The normal wind setup conditions were computed based on the mean value over the period of 1996-2018, with mean positive wind setup in the range of 2.4-2.8 inches across the sites (Table 3-1). The maximum wind setup values reflect the recorded coastal water levels during storm events. The time series of the extracted positive wind setup, shown in Figure 3-1, indicates that while there is considerable seasonal and interannual variability of the wind setup, no clear and consistent trend is observed in the historical time series of wind setup to date that could be used to predict longer-term normal wind setup increases.

Table 3-1: Wind setup levels for the three active tide gauge locations.

Location	Positive surge (wind setup) during the period 1996-2018		
	Mean (inches)	STD (inches)	Max (inches)
Key West	2.4	2.0	37.0
Vaca Key	2.4	2.0	75.2
Naples	2.8	2.8	55.1

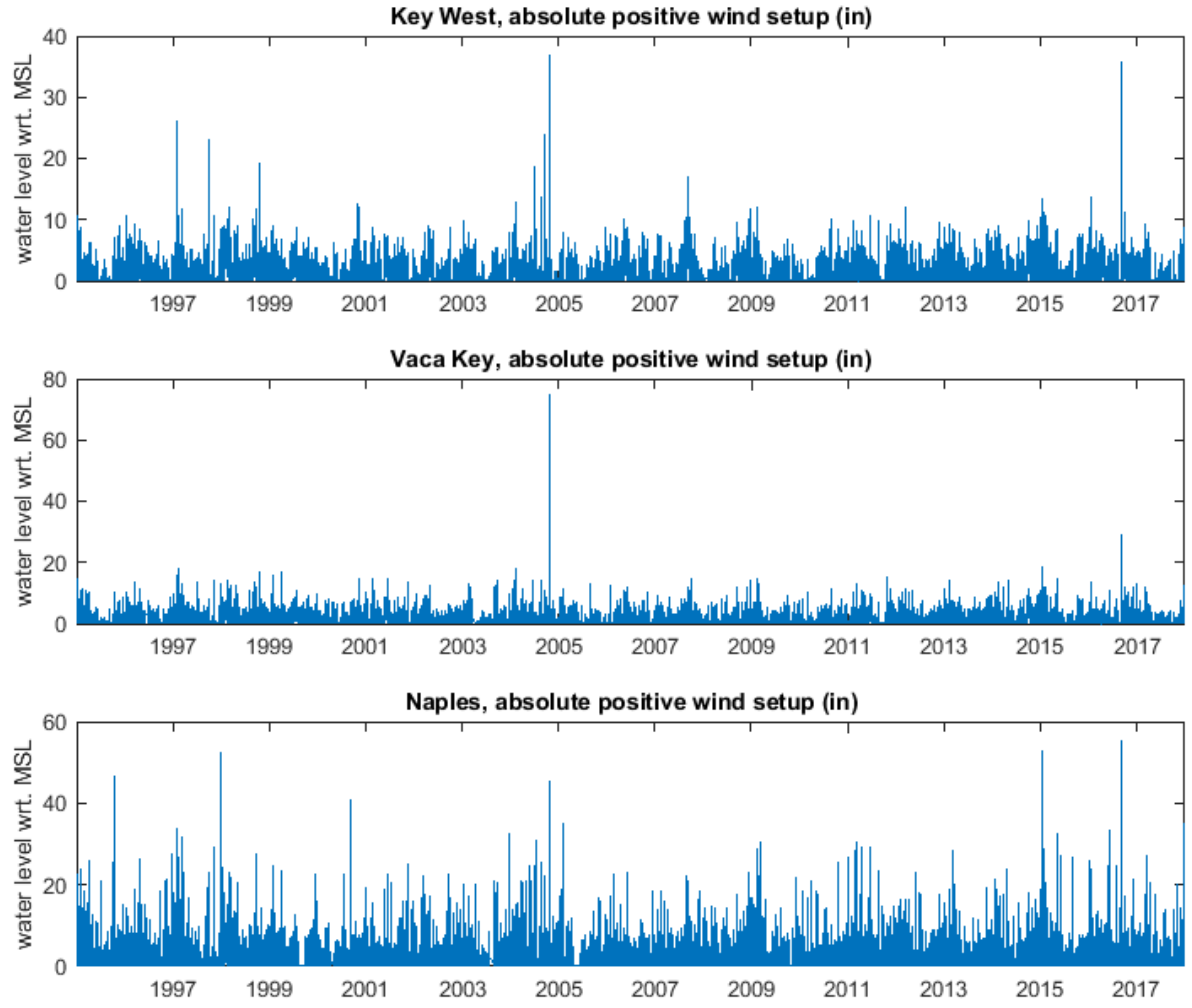

Figure 3-1 Positive wind setup time series at the tide gauge locations for the period 1996-2018.

4.0 Projections of Stillwater Levels including Sea Level Rise, King Tides and Normal Wind Setup

The king tide and wind setup levels derived in the present analysis are recommended to be used in conjunction with future sea level rise projections, to provide a baseline high water level for inundation analysis that does not include severe storm events. The recommended sea level rise projections for a range of climate change scenarios have been presented in the accompanying memorandum (Table 3-1, in Sea Level Rise Projections for Monroe County, Florida, by Wood, 2020), based on NOAA (2017), which is reflected in the 2019 Compact projections (released in December 2019) and incorporates a broader range of uncertainty with higher extreme values, with consideration for the latest IPCC Median projections. These projections are presented relative to 2000 mean sea levels and were sourced from the USACE Sea-Level Change Curve Calculator (Version 2019.21) (available at http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html).

The following Table 4-1, Table 4-2 and Table 4-3 provide a summary of the sea level rise projections with added king tides and normal wind setup, to illustrate the total projected normal (non-storm conditions) stillwater levels for each of the permanent tide gauge locations.

Table 4-1: Recommended Sea Level Rise Projections for Key West, FL (from NOAA, 2017), with added King Tides (highest astronomical tides) and normal wind setup.

Scenario	SLR Projections (inches) Including King Tides and Normal Wind Setup						
	2025	2030	2035	2040	2045	2060	2100
IPCC Median (per Compact, 2019)	29.3	30.8	32.0	33.3	35.0	40.0	55.9
NOAA 2017 Int-High	32.4	35.0	37.4	39.8	43.1	53.9	96.9
NOAA 2017 High	34.4	37.4	40.7	44.1	48.4	63.8	125.9

*Relative to 2000 mean sea level

Table 4-2: Recommended Sea Level Rise Projections for Vaca Key, FL (from NOAA, 2017), with added King Tides (highest astronomical tides) and normal wind setup.

Scenario	SLR Projections (inches) Including King Tides and Normal Wind Setup						
	2025	2030	2035	2040	2045	2060	2100
IPCC Median (per Compact, 2019)	22.3	23.7	25.0	26.2	28.0	32.9	48.8
NOAA 2017 Int-High	25.3	27.9	30.3	32.7	36.0	46.8	89.8
NOAA 2017 High	27.3	30.3	33.6	37.0	41.3	56.7	118.8

*Relative to 2000 mean sea level

Table 4-3: Recommended Sea Level Rise Projections for Naples, FL (from NOAA, 2017), with added King Tides (highest astronomical tides) and normal wind setup.

Scenario	SLR Projections (inches) Including King Tides and Normal Wind Setup						
	2025	**2030**	**2035**	**2040**	**2045**	**2060**	**2100**
IPCC Median (per Compact, 2019)	34.5	35.9	37.2	38.4	40.2	45.1	61.0
NOAA 2017 Int-High	37.5	40.1	42.5	44.9	48.2	59.0	102.0
NOAA 2017 High	39.5	42.5	45.8	49.2	53.5	68.9	131.0

*Relative to 2000 mean sea level

5.0 Conclusions

Based on the observed tide range variability across the available data locations, both within Florida Bay (between Key West, Naples and Vaca Key) and along the Atlantic Ocean coastline of the keys (Key Colony Beach), it is apparent that there is a relatively high degree of spatial variability of the tidal range, while normal wind setup levels are generally similar across locations. Given that the relatively few long-term tide gauges do not resolve the tidal and normal wind setup range along much of the shoreline between and beyond the measurement locations, it is recommended that the highest tidal range and normal wind setup levels, measured at the Naples location, be applied as a reasonably conservative indicator of stillwater levels during non-storm conditions along the coastline of the Florida Keys within Monroe County.

Table 5-1: Recommended Sea Level Rise Projections for Naples, FL (from NOAA, 2017), with added King Tides (highest astronomical tides) and normal wind setup.

Scenario	SLR Projections (inches) Including King Tides and Normal Wind Setup						
	2025	2030	2035	2040	2045	2060	2100
IPCC Median (per Compact, 2019)	34.5	35.9	37.2	38.4	40.2	45.1	61.0
NOAA 2017 Int-High	37.5	40.1	42.5	44.9	48.2	59.0	102.0
NOAA 2017 High	39.5	42.5	45.8	49.2	53.5	68.9	131.0

*Relative to 2000 mean sea level

7.0 References

Codiga, D.L., 2011. Unified Tidal Analysis and Prediction Using the UTide Matlab Functions. Technical Report 2011-01. Graduate School of Oceanography, University of Rhode Island, Narragansett, RI. 59pp

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