Date: February 10, 2017
From: NJ Frames Project Team
To: Project File
Subject: Water Level Proposals for NJ FRAMES Project Team Deliberation

This memorandum serves as an account of NJ FRAMES Project Team (i.e. Rutgers, Louis Berger, NJDEP) deliberations on total water level projections for use in conducting exposure assessments to flood hazards for the NJ FRAMES project. On November 10, 2016, the NJ Frames Project Team agreed to the total water levels of 3, 7, and 12 feet above Mean Higher High Water (MHHW) to serve as the basis for exposure assessment and cost-benefit analysis for the NJ FRAMES project. The use of the high-water-level scenarios is an adaptation planning technique described in NOAA's "What Will Adaption Cost" framework (https://coast.noaa.gov/data/digitalcoast/pdf/adaptation-report.pdf), which serves as the guiding framework for this project. The use of water levels (as opposed to specific flooding or storm scenarios) allows the team to discuss the variety of conditions that might cause flooding to reach a certain water level under a given set of assumptions. For example, flooding that is currently associated with a 1% storm is estimated to be approximately 7 feet above MHHW at Sandy Hook, NJ. Under a given set of assumptions regarding sea level rise, the same 7-foot water level, is associated with a 99% storm (i.e. the Annual Flood) in 2100.

Scientific Basis

In 2016, a Science and Technical Advisory Panel (STAP) convened by Rutgers University on behalf of the New Jersey Climate Adaptation Alliance issued a report that provided estimates for sea-level rise (SLR) projections for New Jersey, which are presented in Table 1 (Kopp et al., 2016). The estimates are ranges of sea- level rise, based on Kopp et al. (2014) which uses projections for the Atlantic City tide gauge to represent the entire State of New Jersey (projections for the Sandy Hook and Cape May tide gauges differ minimally from Atlantic City).

Table 1: Projected SLR Projections for New Jersey (ft.)

	Central Estimate	'Likely' Range	1-in-20 Chance	1-in-200 Chance	1-in-1000 Chance
Year	*50% probability SLR meets or exceeds…*	*67% probability SLR is between…*	*5% probability SLR meets or exceeds…*	*0.5% probability SLR meets or exceeds…*	*0.1% probability SLR meets or exceeds…*
2030	0.8 ft	0.6 – 1.0 ft	1.1 ft	1.3 ft	1.5 ft
2050	1.4 ft	1.0 – 1.8 ft	2.0 ft	2.4 ft	2.8 ft
2100 Low emissions	2.3 ft	1.7 – 3.1 ft	3.8 ft	5.9 ft	8.3 ft
2100 High emissions	3.4 ft	2.4 – 4.5 ft	5.3 ft	7.2 ft	10 ft

Estimates are based on (Kopp et al., 2014). Columns correspond to different projection probabilities. For example, the 'Likely Range' column corresponds to the range between the 17th and 83rd percentile; consistent with the terms used by the Intergovernmental Panel on Climate Change (Mastrandrea et al., 2010). *All values are with respect to a 1991-2009 baseline. Note that these results represent a single way of estimating the probability of different levels of SLR; alternative methods may yield higher or lower estimates of the probability of high-end outcomes.*

The STAP also provided guidance for the conditions that practitioners could evaluate to assess exposure:

1. Use at least two projections, with one being a sea-level rise estimate in the likely range and one being a high-end estimate, in order to assess exposure to a range of future flood conditions.
2. Incorporate projected sea-level rise estimates to develop future water levels by adding the estimates to current or historic water levels that represent at least three flooding conditions: permanent inundation, tidal flooding, and coastal storms.

Establishing Conditions to Assess Exposure

The NJ FRAMES Project Team relied on the Rutgers partners (who had also been involved in the STAP process) to recommend an initial set of conditions to assess exposure within the STAP framework guidance. With respect to sea-level rise projections, the Rutgers partners suggested the NJ FRAMES Project Team consider building high water level scenarios using sea-level rise values that reflect the STAP central estimates for 2030, 2050, 2100 low emissions and high emissions and the 1-in-20 chance 2100 high emissions scenario. With respect to future water levels to assess the three flooding conditions, consistent with the STAP Report, the Rutgers partners noted options for determining the water levels associated with future events including NOAA's Annual Exceedance Probability (AEP) at a nearby tide gauge, FEMA's Base Flood Elevation (BFE), or in reference to an historic event storm tide (e.g., Hurricane Sandy).

Table 2: Projected Water Levels Relative to Current MHHW

	2000	2030	2050	2100
Low Emissions Central Estimate - 2.3 Ft. SLR by 2100				
Hurricane Sandy	8.3	9.1	9.7	10.6
1% Chance Flood (100-year flood)	6.7	7.5	8.1	9
10% Chance Flood (10-year flood)	3.9	4.7	5.3	6.2
99% Chance Flood (Annual flood)	1.6	2.4	3	3.9
Permanent Inundation (MHHW)	0	0.8	1.4	2.3
High Emissions Central Estimate - 3.4 Ft. SLR by 2100				
Hurricane Sandy	8.3	9.1	9.7	11.7
1% Chance Flood (100-year flood)	6.7	7.5	8.1	10.1
10% Chance Flood (10-year flood)	3.9	4.7	5.3	7.3
99% Chance Flood (Annual flood)	1.6	2.4	3	5
Permanent Inundation (MHHW)	0	0.8	1.4	3.4
High Emissions 1-in-20 Chance Estimate - 5.3 Ft. SLR by 2100				
Hurricane Sandy	8.3	9.4	10.3	13.6
1% Chance Flood (100-year flood)	6.7	7.8	8.7	12
10% Chance Flood (10-year flood)	3.9	5	5.9	9.2
99% Chance Flood (Annual flood)	1.6	2.7	3.6	6.9
Permanent Inundation (MHHW)	0	1.1	2	5.3

The Rutgers partners used three SLR estimates from Table 1 to develop future water levels by adding the estimates to current or historic water levels that represent at least three flooding conditions: permanent inundation, tidal flooding, and coastal storms. The Rutgers partners chose to use the:

- Low Emissions Central Estimate - 2.3 Ft. SLR by 2100
- High Emissions Central Estimate - 3.4 Ft. SLR by 2100
- High Emissions 1-in-20 Chance Estimate - 5.3 Ft. SLR by 2100

The Rutgers partners projected water levels associated with future events by adding the SLR value for each of the 3 projections above to NOAA's Annual Exceedance Probability (AEP) levels and historic storm

tide records using the Sandy Hook, NJ Tide gauge (See Table 2). Sandy Hook was chosen as per the STAP guidance that it is the gauge nearest to the Two Rivers Region. Given the range of values in Table 2, it is possible to round water levels to each whole foot between 1 ft. and 14 ft. above current MHHW to assess exposure to the various conditions through 2100 (Table 3).

In keeping with the recommendations of the Science and Technical Advisory Panel, chosen water levels must represent three types of flooding – permanent inundation, tidal flooding, and flooding related to coastal storms. Additionally, the project team considered central estimates for the Low Emissions and High Emissions scenarios, and the 1-in-20 chance estimate for the High emissions scenario. Table 3 presents the ranges of water levels representing each flooding condition under the exposure assessment scenarios and the left hand side visualizes how these conditions overlap:

- Water levels between 1 foot and 5 feet reflect the range of current and future permanent inundation (blue).
- Water levels between 2 feet and 9 feet reflect the range of current and future Annual and 10-year floods (orange).
- Water levels between 7 feet and 14 feet represent the range of current and future 100-year floods, as well as observed Hurricane Sandy storm tide and future Hurricane Sandy storm tide incorporating sea-level rise (green).

In order to choose a subset of water levels, the Rutgers partners reviewed the points where the three ranges overlap at 2, 3, 5, 7, and 9 feet. These critical points represent boundary levels, for example, where current annual floods become future inundation, or where current 100-year floods become more regular future flood events (Hinkel et al., 2015). The Rutgers partners also chose to include a 12-foot water level to represent the 2100 projection of Hurricane Sandy and the 100-year flood. The Rutgers partners considered several issues in light of preliminary discussions with the NJ FRAMES Project Team including:

1. The NJ FRAMES Project Team may also choose to include a 14-foot water level to represent the 2100 projection of Hurricane Sandy using the 1-in-20 chance high-emissions as a boundary.
2. The NJ FRAMES Project Team may select 3 feet as the water level lower bound to facilitate more protective projections using the central estimate of SLR for 2100 under the High Emissions scenario.
3. The project resources are not unlimited and thus the scope of work may limit the number of analyses that the NJ FRAMES Project Team can complete for the planning and cost benefit analyses. The NJ FRAMES Project Team could choose four (4) water levels in order to be able to create three (3) ranges of scenarios that reflect the STAP recommendation to plan for permanent inundation, tidal flooding, and coastal storms.
4. While the chosen water levels will reflect scientific data around the height of sea- level rise, the assessments may not be adequate for those assets that are most sensitive to the rate of sea- level rise. Additional consideration of sea-level rise rates is important to natural systems like coastal wetlands including emergent marsh species. As lower water levels (1 or 2 feet) may be of particular concern for ecological systems, the NJ FRAMES Project Team should also include maps assessing wetland health and resilience. The NJFloodMapper.org site uses an assessment of marsh vulnerability from NOAA Coastal Services Center[1]

[1] http://www.njfloodmapper.org/slr_old/index.html?ll=-242880.501313;4917338.963854&level=7&basemap=streetMap&CurTab=3&CurSLR=3

Table 3: Sandy Hook, NJ - Water Levels Above Current MHHW for Exposure Assessment

		Rounded Water Level	What High Water Level Condition Does This Height Represent?
Permanent Inundation (MHHW)		1 ft.	• 2030 Permanent Inundation - LE/HE – 0.8ft • 2030 Permanent Inundation - 1-in-20 chance HE – 1.1ft • 2050 Permanent Inundation - LE/HE - 1.4ft • Nuisance Flood Level - 1.48 ft. (NOAA National Weather Service)
	Coastal Flooding (Annual flood (99% Chance Flood), 10-year flood (10% Chance Flood)	2 ft.	• Current Annual Flood - 1.6ft • 2030 Annual Flood -LE/HE - 2.4ft • 2050 Permanent Inundation - 1-in-20 chance HE – 2ft • 2100 Permanent Inundation – - LE - 2.3ft
		3 ft.	• 2030 Annual Flood - 1-in-20 chance HE – 2.7ft • 2050 Annual Flood - LE/HE - 3.0ft • 2100 Permanent Inundation – HE - 3.4ft
		4 ft.	• Current 10% Chance Flood – 3.9ft • 2050 Annual Flood - 1-in-20 chance HE – 3.6ft • 2100 Annual Flood - LE - 3.9ft
		5 ft.	• 2030 10% Chance Flood - 1-in-20 chance HE – 5.0ft • 2050 10% Chance Flood – LE/HE - 5.3ft • 2100 Permanent Inundation - 1-in-20 chance HE – 5.3ft • 2100 Annual Flood - HE - 5.0ft
		6 ft.	• 2050 10% Chance Flood - 1-in-20 chance HE – 5.9ft • 2100 10% Chance Flood - LE - 6.2ft
	Coastal Strom Related Flooding (100-year flood (1% AEP), Hurricane Sandy)	7 ft.	• Current 100 Year Flood – 6.7ft • 2100 10% Chance Flood – HE - 7.3ft • 2100 Annual Flood - 1-in-20 chance HE – 6.9ft
		8 ft.	• Observed Hurricane Sandy water level – 8.3ft • 2030 1% Chance Flood - 1-in-20 chance HE – 7.8ft • 2050 1% Chance Flood – LE -/HE - 8.1ft
		9 ft.	• 2030 Hurricane Sandy water level -LE/HE - 9.1ft • 2050 1% Chance Flood - 1-in-20 chance HE– 8.7ft • 2100 10% Chance Flood 1-in-20 chance HE – 9.2ft • 2100 1% Chance Flood with LE - 9ft
		10 ft.	• 2050 Hurricane Sandy water level - LE /HE – 9.7ft • 2050 Hurricane Sandy water level - 1-in-20 chance HE – 10.3ft • 2100 1% Chance Flood with HE – 10.1ft
		11 ft.	• 2100 Hurricane Sandy water level - LE – 10.6ft
		12 ft.	• 2100 1% Chance Flood - 1-in-20 chance HE – 12ft. • 2100 Hurricane Sandy water level - HE – 11.7ft
		13 ft.	• N/A
		14 ft.	• 2100 Hurricane Sandy water level - 1-in-20 chance HE – 13.6ft

Notes: Blue = Permanent Inundation Range / Orange = Flood Range / Green = Coastal Storm Range. HE = High Emissions. LE = Low Emissions. 1-in-20 Chance Estimate = High Emissions Estimate.

Based on the need to reduce the overall number of exposure scenarios for assessment from 5 values to 4 values (See listed point 3 above), the Rutgers partners proposed four water levels of 2, 5, 8, and 12 feet to the full NJ FRAMES Project Team to serve as the basis for exposure analysis and benefit cost analysis (See Table 3):

- 2 feet and 5 feet to reflect potential exposures from permanent inundation,
- 2, 5, and 8 feet to represent potential exposure from coastal flooding, and
- 8 feet and 12 feet to represent potential exposures from coastal storm related flooding.

At a meeting held on November 10, 2016, the NJ FRAMES Project Team met to discuss the proposed 2, 5, 8, and 12-foot water levels. The NJ FRAMES Project Team concluded that the scope of work and level of analysis required for each scenario would only permit the use of three water level scenarios. The project team then discussed the best approaches for reducing the water level recommendation to three levels while capturing key exposures of concern based on best professional judgment and experiences in the field.

The Rutgers partners suggested that the 2-foot water level above MHHW is already a common occurrence in this region and as such does not merit recording by the National Weather Service in listing of historical flooding events at the Sandy Hook tide gauge.[2] The National Weather Service records water levels of 2.6 feet above MHHW, which are associated with more substantive impacts (2.7 feet above MHHW is the moderate flooding threshold). Following the same rounding conventions used to determine representative whole foot flood levels for various flooding events in Table 3, the NJ FRAMES Project Team can approximate these events by mapping 3 feet above MHHW. The most recent events at 3 feet above MHHW took place in early 2016 on January 10, January 23, and February 8 (records last updated in May 2016) related to Nor'easters and coastal storms[3]. In addition, the NJ FRAMES Project Team referenced a preliminary exposure analysis conducted by NJDEP to understand the exposure at 3 feet above MHHW, approximated by using the exposure assessment of 5 feet above NAVD88 (See Appendix A). After assessing the storm history and the draft exposure assessment, the NJ FRAMES Project Team decided to raise the water level from 2 feet to 3 feet because this level is a practical lower bound for future planning and has more consequential asset exposures (12 Total) than lower water levels that could be used for exposure assessment (4 Total) (See Appendix A, Figures 3 and 5).

The NJ FRAMES Project Team also confirmed the 12-foot water level as an accurate assessment for a reasonable upper bound of exposure. This water level represents a projection of the water level associated with Hurricane Sandy under a high emissions central estimate scenario in the year 2100, in addition to a 1% chance flood in 2100 under a 1-in-20 chance estimate of sea-level rise under a high emissions scenario. The NJ FRAMES Project Team considers this water level to reflect the assessment of low probability, high consequence events that are concerning for stakeholders with critical assets (e.g. transportation infrastructure, electrical substations, etc.).

The NJ FRAMES Project Team discussed the 7-foot water level as a reasonable central water level that reflects the current lower bound of coastal storms and a reasonable subset of future coastal flooding events that may not be caused by large coastal storms. In particular, the 7-foot water level reflects the

[2] http://www.weather.gov/media/phi/monmou.pdf
[3] http://nj.usgs.gov/hazards/flood/flood1601/

point at which the current 1% Chance (100-year) flood becomes the 2100 10% Chance (10-year) flood under the high emissions central estimate for sea- level rise.

Table 4: Sandy Hook, NJ: Water Levels Above Current MHHW for Proposed for Exposure Assessment and Cost-Benefit Analysis

			Rounded Water Level	What High Water Level Condition Does This Height Represent?
Permanent Inundation	Coastal Flooding		3 ft.	• 2030 Annual Flood - 1-in-20 chance HE – 2.7ft • 2050 Annual Flood - LE/HE - 3.0ft • 2100 Permanent Inundation – HE - 3.4ft
		Coastal Storm Flooding	7 ft.	• Current 100 Year Flood – 6.7ft • 2100 10% Chance Flood – HE - 7.3ft • 2100 Annual Flood - 1-in-20 chance HE – 6.9ft
			12 ft.	• 2100 1% Chance Flood - 1-in-20 chance HE – 12ft. • 2100 Hurricane Sandy water level - HE – 11.7ft

References

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Appendix A: NJDEP Draft Deliberative Exposure Analysis for Discussion

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Date: November 10, 2016
From: NJDEP Coastal Management Program
To: NJ FRAMES Project Team
Subject: Inundation Level Analysis

This document presents mapping and analysis for the impacted community locations/assets based on projected water levels (2'ft – 14'ft) above NAVD88 in the Two Rivers Region. These locations include:

- Solid Waste Landfills
- Pump Stations
- Schools (Elementary, Middle, HS)
- Nursing Homes
- Law Enforcement
- Hospitals
- Gas Stations
- Fire Stations

Information included in this document is for informational/discussion purposes and may only be distributed to the NJFRAMES Project Team.

Two Rivers Region Study Area

Figure 1: Water Level w/ Projected Inundated Study Area (Acres)

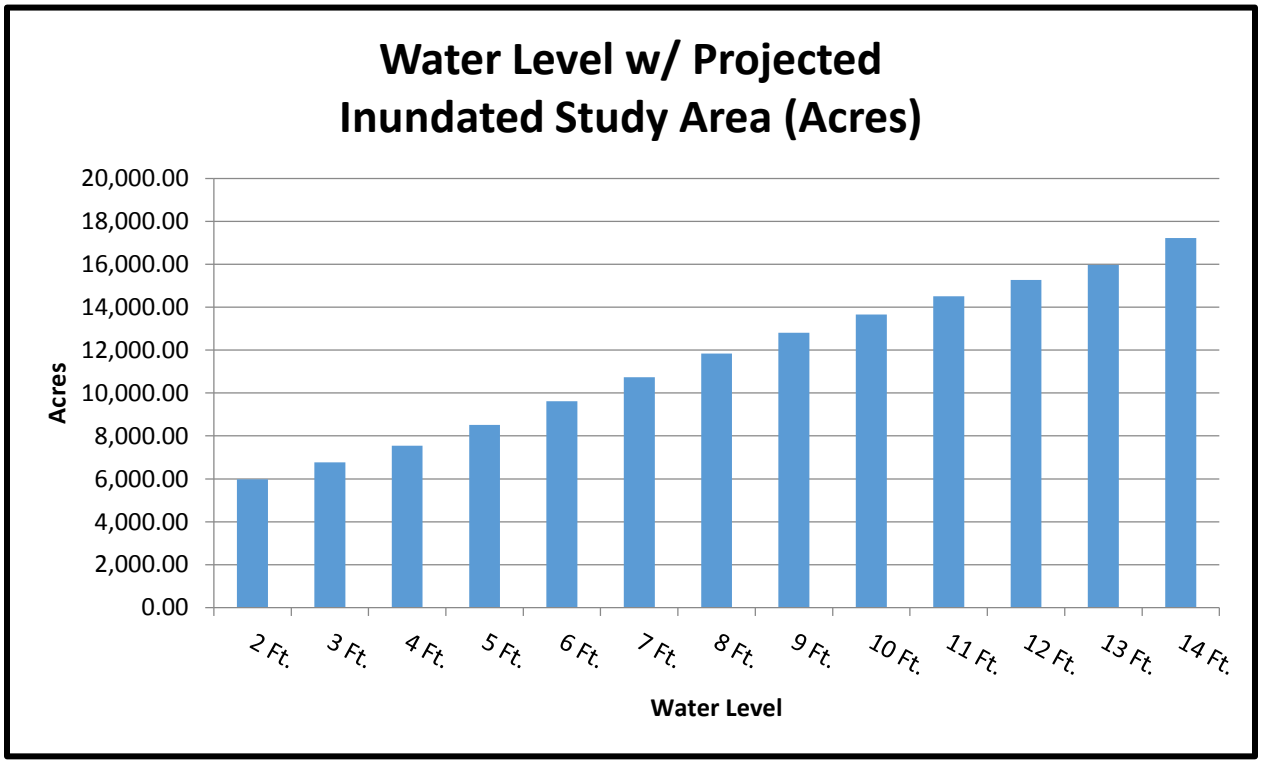

Figure 2: Water Level Depth Maps - 2, 5, 8, 12 Ft.

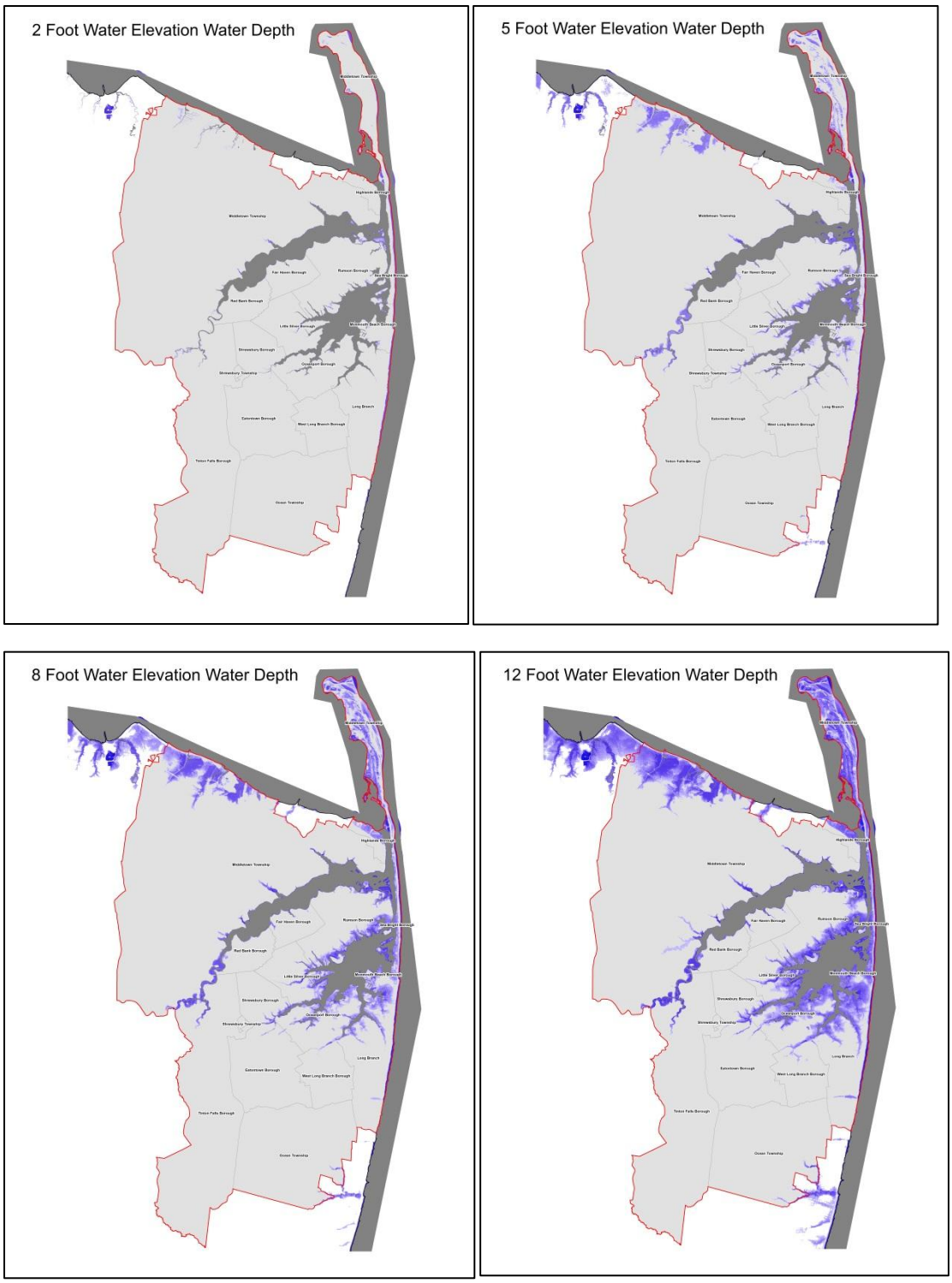

Figure 3: Projected Water Levels with Inundated Locations

Location	2 Ft.	3 Ft.	4 Ft.	5 Ft.	6 Ft.	7 Ft.	8 Ft.	9 Ft.	10 Ft.	11 Ft.	12 Ft.	13 Ft.	14 Ft.	Total Number of Inundated Locations at 14 Ft.
Solid Waste Landfill		1					1		1					3
Pump Stations	1	1	1	5	10	9	9	1	4	2	4	4	8	59
Schools (Elementary, Middle, HS)				1	1				4	2	2		1	11
Nursing Homes									1					1
Law Enforcement						1	2	1	1				1	6
Hospitals										1	1			2
Gas Stations				2	4	1		1				3	1	12
Fire Stations						3		1	3	2	1	1	2	13
Evacuation Routes														0
Known Contamination Sites														0
Number of locations per Inundation Level	1	2	1	8	15	14	12	4	14	7	8	8	13	107
Cumulative Number of Inundated Locations	1	3	4	12	27	41	53	57	71	78	86	94	107	107

Figure 4: Number of Inundated Locations per Water Level

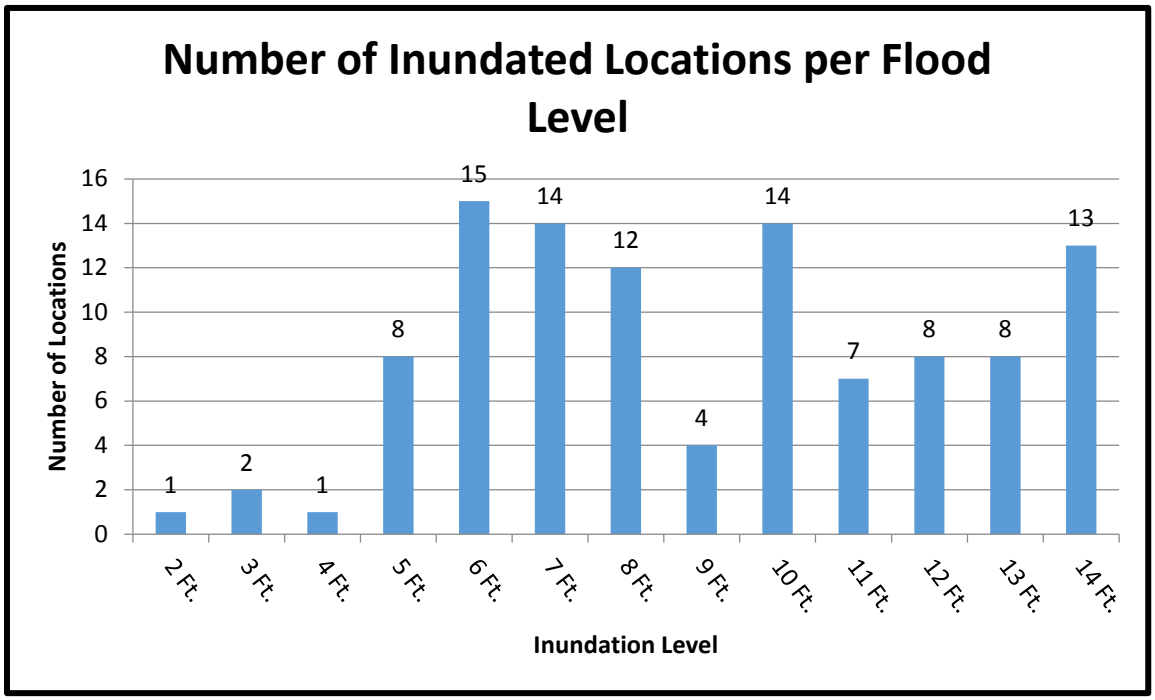

Figure 5: Cumulative Number of Inundated Locations at 14'

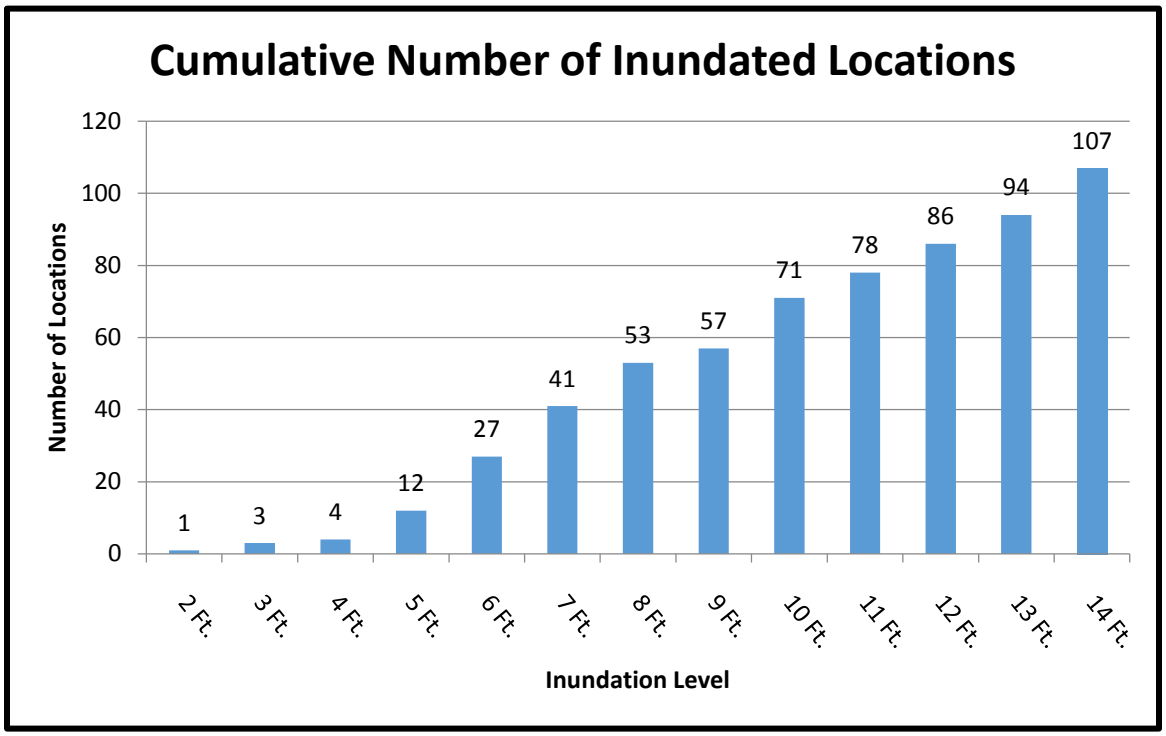

Figure 6: Projected Inundation for each Water Level

Location	2 Ft.	3 Ft.	4 Ft.
Solid Waste Landfill		1	
Pump Stations	1	1	1
Schools (Elementary, Middle, HS)			
Nursing Homes			
Law Enforcement			
Hospitals			
Gas Stations			
Fire Stations			
Evacuation Routes			
Known Contamination Sites			
Number of locations per Inundation Level	1	2	1
Cumulative Number of Inundated Locations	1	3	4

Location	5 Ft.	6 Ft.	7 Ft.
Solid Waste Landfill			
Pump Stations	5	10	9
Schools (Elementary, Middle, HS)	1	1	
Nursing Homes			
Law Enforcement			1
Hospitals			
Gas Stations	2	4	1
Fire Stations			3
Evacuation Routes			
Known Contamination Sites			
Number of locations per Inundation Level	8	15	14
Cumulative Number of Inundated Locations	12	27	41

Location	8 Ft.	9 Ft.	10 Ft.	11 Ft.
Solid Waste Landfill	1		1	
Pump Stations	9	1	4	2
Schools (Elementary, Middle, HS)			4	2
Nursing Homes			1	
Law Enforcement	2	1	1	
Hospitals				1
Gas Stations		1		
Fire Stations		1	3	2
Evacuation Routes				
Known Contamination Sites				
Number of locations per Inundation Level	12	4	14	7
Cumulative Number of Inundated Locations	53	57	71	78

Location	12 Ft.	13 Ft.	14 Ft.
Solid Waste Landfill			
Pump Stations	4	4	8
Schools (Elementary, Middle, HS)	2		1
Nursing Homes			
Law Enforcement			1
Hospitals	1		
Gas Stations		3	1
Fire Stations	1	1	2
Evacuation Routes			
Known Contamination Sites			
Number of locations per Inundation Level	8	8	13
Cumulative Number of Inundated Locations	86	94	107