



North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk

Appendix A Engineering

Final Report
January 2015



US Army Corps
of Engineers®



APPENDIX A: ENGINEERING

NORTH ATLANTIC COAST COMPREHENSIVE STUDY: RESILIENT ADAPTATION TO INCREASING RISK



Table of Contents

I. Joint Probability Study of Coastal Storm Forcing Parameters 1

II. Extreme Water Levels 1

III. Relative Sea Level Changes 2

IV. References 10

List of Tables

Table III-1.Gauge: 8410140, ME, Eastport: 78 yrs 2

Table III-2. Gauge: 8418150, ME, Portland: 95 yrs 2

Table III-3.Gauge: 8419870, ME, Seavey Island: 76 yrs *Inactive..... 3

Table III-4.Gauge: 8443970, MA, Boston: 86 yrs 3

Table III-5.Gauge: 8447930, MA, Woods Hole: 75 yrs 3

Table III-6.Gauge: 8452660, RI, Newport: 77 yrs 3

Table III-7.Gauge: 8454000, RI, Providence: 69 yrs 4

Table III-8.Gauge: 8461490, CT, New London: 69 yrs 4

Table III-9.Gauge: 8467150, CT, Bridgeport: 43 yrs..... 4

Table III-10.Gauge: 8510560, NY, Montauk: 60 yrs 4

Table III-11.Gauge: 8518750, NY, The Battery: 151 yrs..... 5

Table III-12.Gauge: 8531680, NJ, Sandy Hook: 75 yrs 5

Table III-13.Gauge: 8534720, NJ, Atlantic City: 96 yrs..... 5

Table III-14.Gauge: 8536110, NJ, Cape May: 42 yrs 5

Table III-15.Gauge: 8545240, PA, Philadelphia: 107 yrs..... 6

Table III-16.Gauge: 8551910, DE, Reedy Point: 51 yrs..... 6

Table III-17.Gauge: 8557380, DE, Lewes: 88 yrs..... 6

Table III-18.Gauge: 8571892, MD, Cambridge: 64 yrs 6

Table III-19.Gauge: 8574680, MD, Baltimore: 105 yrs 7

Table III-20.Gauge: 8575512, MD, Annapolis: 79 yrs..... 7

Table III-21.Gauge: 8577330, MD, Solomons Island: 70 yrs 7

Table III-22.Gauge: 8594900, DC, Washington: 83 yrs 8

Table III-23.Gauge: 8632200, VA, Kiptopeke: 56 yrs 8



North Atlantic Coast Comprehensive Study (NACCS)

United States Army Corps of Engineers

Table III-24.Gauge: 8637624, VA, Gloucester Point: 54 yrs *Inactive	8
Table III-25.Gauge: 8638610, VA, Sewells Point: 80 yrs.....	8
Table III-26.Gauge: 8638660, VA, Portsmouth: 53 yrs *Inactive	9



I. Joint Probability Study of Coastal Storm Forcing Parameters

This study will compute the coastal storm hazard for the east coast region from Maine to Virginia as a primary requirement for project performance evaluation. The primary focus is on storm winds, waves and water levels along the coast for both tropical and extra-tropical storm events. The method for computing winds, waves and water levels is by applying a suite of high-fidelity numerical models within the Coastal Storm Modeling System (CSTORM-MS). Products from this work include simulated winds, waves and water levels for 1,050 synthetic tropical events and 100 extra-tropical events computed at over 3 million computational locations. A smaller number of high frequency collocation points (18,000) will save the same information at higher frequency for more convenient/concise data handling. These storm events are determined so that they span the range of practical probabilities. The water levels are modeled in such a way that the effects of storm surge, waves, tide, and sea level change can be assessed.

This work helps to close the gap with respect to flood risk management by providing statistical wave and water level information for the entire North Atlantic coast. The statistical database can potentially be revised based on estimates of future climatology. The CSTORM platform that will contain the raw model data (winds, waves, and water levels) as well as processed data (visualization products and statistics) will be available through the Coastal Hazards System. These data will be available for engineering analysis and project design for coastal projects from Maine to Virginia.

II. Extreme Water Levels

Following Hurricane Sandy, NOAA published Technical Report NOS CO-OPS 067, "Extreme Water Levels of the United States 1893-2010" in September 2013, including an updated Appendix VIII, "Effect of Hurricanes Irene and Sandy on High Water Exceedance Probability Levels for Bridgeport, the Battery, and Sandy Hook." The NACCS required a post-Sandy extreme water level analysis that included all of the long-term NOAA water level gages that are within the NACCS. As a result, USACE Engineering Research and Development Center (ERDC) conducted a study similar in nature to the 2013 NOAA Technical Report. The results of this study are shown to agree well with those published in the 2013 NOAA Technical Report.

This study consists of a statistical analysis of historical water level measurements to compute extreme water levels and was completed for 23 National Oceanic and Atmospheric Administration's (NOAA's) National Ocean Service's Center for Operational Oceanographic Products and Services gauges along the North Atlantic Coast. The criteria used to select the 23 gauges across the North Atlantic Coast Comprehensive Study (NACCS) study area as well as locations in Maine were coastal location, a minimum of 30 years of continuous record length, and modern instrumentation. Extreme water levels as well as future extreme water levels for each of the sea level change scenarios for the 1-, 0.1-, 0.04-, 0.02-, 0.01-, and 0.002- annual-percent-chance recurrence intervals for all 23 gauges were computed as part of the analysis. The results of the study are included in the North Atlantic Coast Comprehensive Study Phase I: Statistical Analysis of Historical Extreme Water Levels with Sea Level Change report, dated October 2013. The document was published as ERDC/CHL TR-14-7 (Nadal-Caraballo and Melby, 2014).



III. Relative Sea Level Changes

The NACCS addresses sea level change in accordance with the recently updated guidance document USACE Engineer Regulation (ER) 1100-2-8162, *Incorporating Sea Level Change in Civil Works Programs* (USACE 2013). The USACE Sea Level Change ER refers to sea level change (rather than sea level rise) because it is meant to be applicable in all areas, including those locations where local relative sea levels are *falling* due to local/regional land uplift. In the case of the NACCS, relative sea levels are rising throughout the entire study area. The USACE Low/NOAA Low, USACE Intermediate/NOAA Intermediate-Low, USACE High, and NOAA High relative sea level change (RSLC) scenarios were developed for the 26 NOAA gauge locations across the study area that have a measurement record equal to or greater than 40 years for each sea level change scenario for four planning horizons: 2018, 2068, 2100, and 2118. These values were used to evaluate the post-Sandy landscape as it relates to potential future hazards to coastal communities. Additional information is included in Appendix C – Planning Analyses. The following tables present the results of the NACCS sea level change analysis.

Maine

Table III-1. Gauge: 8410140, ME, Eastport: 78 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	-0.1	0.0	0.2	0.3
2068	0.3	0.8	2.4	3.2
2100	0.5	1.5	4.8	6.4
2118	0.6	2.0	6.5	8.7

Table III-2. Gauge: 8418150, ME, Portland: 95 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	-0.2	-0.1	0.1	0.2
2068	0.1	0.7	2.3	3.1
2100	0.3	1.4	4.7	6.3
2118	0.5	1.9	6.3	8.6



*Table III-3. Gauge: 8419870, ME, Seavey Island: 76 yrs
Inactive

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	-0.1	0.0	0.2	0.3
2068	0.2	0.7	2.3	3.1
2100	0.3	1.4	4.7	6.3
2118	0.4	1.8	6.3	8.5

Massachusetts

Table III-4. Gauge: 8443970, MA, Boston: 86 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	-0.1	0.0	0.2	0.3
2068	0.3	0.9	2.5	3.3
2100	0.6	1.6	4.9	6.6
2118	0.8	2.2	6.6	8.9

Table III-5. Gauge: 8447930, MA, Woods Hole: 75 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	-0.1	-0.1	0.1	0.2
2068	0.3	0.8	2.4	3.3
2100	0.6	1.6	4.9	6.5
2118	0.7	2.2	6.6	8.8

Rhode Island

Table III-6. Gauge: 8452660, RI, Newport: 77 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	-0.1	0.0	0.2	0.3
2068	0.3	0.9	2.5	3.3
2100	0.6	1.7	4.9	6.6
2118	0.8	2.2	6.7	8.9



Table III-7. Gauge: 8454000, RI, Providence: 69 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	-0.1	0.0	0.2	0.3
2068	0.3	0.8	2.4	3.2
2100	0.5	1.5	4.8	6.5
2118	0.6	2.0	6.5	8.7

Connecticut

Table III-8. Gauge: 8461490, CT, New London: 69 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	-0.1	0.0	0.2	0.3
2068	0.3	0.8	2.4	3.2
2100	0.5	1.6	4.9	6.5
2118	0.7	2.1	6.6	8.8

Table III-9. Gauge: 8467150, CT, Bridgeport: 43 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	0.0	0.1	0.2	0.3
2068	0.4	0.9	2.5	3.3
2100	0.7	1.7	5.0	6.6
2118	0.8	2.2	6.7	8.9

New York

Table III-10. Gauge: 8510560, NY, Montauk: 60 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	-0.1	0.0	0.2	0.3
2068	0.4	0.9	2.5	3.4
2100	0.7	1.8	5.0	6.7
2118	0.9	2.3	6.8	9.0



Table III-11. Gauge: 8518750, NY, The Battery: 151 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	0.1	0.1	0.3	0.4
2068	0.5	1.0	2.7	3.5
2100	0.8	1.9	5.2	6.8
2118	1.0	2.4	6.9	9.1

New Jersey

Table III-12. Gauge: 8531680, NJ, Sandy Hook: 75 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	0.1	0.2	0.4	0.4
2068	0.8	1.3	2.9	3.7
2100	1.2	2.2	5.5	7.1
2118	1.4	2.8	7.3	9.5

Table III-13. Gauge: 8534720, NJ, Atlantic City: 96 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	-0.1	0.0	0.2	0.3
2068	0.6	1.1	2.7	3.5
2100	1.0	2.0	5.3	6.9
2118	1.2	2.6	7.1	9.3

Table III-14. Gauge: 8536110, NJ, Cape May: 42 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	-0.1	-0.1	0.1	0.2
2068	0.5	1.0	2.6	3.5
2100	0.9	1.9	5.2	6.9
2118	1.1	2.5	7.0	9.2



North Atlantic Coast Comprehensive Study (NACCS)

United States Army Corps of Engineers

Pennsylvania

Table III-15. Gauge: 8545240, PA, Philadelphia: 107 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	0.6	0.7	0.9	1.0
2068	1.1	1.6	3.2	4.0
2100	1.4	2.4	5.7	7.3
2118	1.5	2.9	7.4	9.6

Delaware

Table III-16. Gauge: 8551910, DE, Reedy Point: 51 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	0.2	0.3	0.5	0.6
2068	0.8	1.3	2.9	3.8
2100	1.2	2.2	5.5	7.1
2118	1.4	2.8	7.3	9.5

Table III-17. Gauge: 8557380, DE, Lewes: 88 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	-0.1	-0.1	0.1	0.2
2068	0.4	1.0	2.6	3.4
2100	0.8	1.8	5.1	6.8
2118	1.0	2.4	6.9	9.1

Maryland

Table III-18. Gauge: 8571892, MD, Cambridge: 64 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	0.2	0.3	0.5	0.6
2068	0.8	1.3	3.0	3.8
2100	1.2	2.2	5.5	7.1
2118	1.4	2.8	7.3	9.5



Table III-19. Gauge: 8574680, MD, Baltimore: 105 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	0.2	0.3	0.5	0.6
2068	0.7	1.2	2.9	3.7
2100	1.0	2.1	5.4	7.0
2118	1.2	2.6	7.1	9.3

Table III-20. Gauge: 8575512, MD, Annapolis: 79 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	0.2	0.3	0.5	0.6
2068	0.8	1.3	2.9	3.7
2100	1.1	2.2	5.5	7.1
2118	1.3	2.7	7.2	9.4

Table III-21. Gauge: 8577330, MD, Solomons Island: 70 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	0.2	0.3	0.5	0.6
2068	0.8	1.3	2.9	3.7
2100	1.2	2.2	5.5	7.1
2118	1.4	2.8	7.3	9.5



North Atlantic Coast Comprehensive Study (NACCS)

United States Army Corps of Engineers

District of Columbia

Table III-22. Gauge: 8594900, DC, Washington: 83 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	0.4	0.5	0.7	0.8
2068	0.9	1.4	3.1	3.9
2100	1.2	2.3	5.6	7.2
2118	1.4	2.8	7.3	9.5

Virginia

Table III-23. Gauge: 8632200, VA, Kiptopeke: 56 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	-0.2	-0.1	0.1	0.2
2068	0.4	0.9	2.6	3.4
2100	0.8	1.8	5.1	6.8
2118	1.0	2.4	6.9	9.1

Table III-24. Gauge: 8637624, VA, Gloucester Point: 54 yrs
**Inactive*

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	0.0	0.1	0.3	0.4
2068	0.7	1.2	2.9	3.7
2100	1.2	2.2	5.5	7.1
2118	1.4	2.8	7.3	9.5

Table III-25. Gauge: 8638610, VA, Sewells Point: 80 yrs

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	0.1	0.2	0.4	0.5
2068	0.8	1.3	3.0	3.8
2100	1.3	2.3	5.6	7.2
2118	1.5	2.9	7.4	9.6



*Table III-26. Gauge: 8638660, VA, Portsmouth: 53 yrs
Inactive

All values are in feet (NAVD88)				
Year	USACE	USACE	USACE	NOAA
	Low	Int	High	High
2018	0.1	0.1	0.3	0.4
2068	0.7	1.2	2.8	3.6
2100	1.1	2.1	5.4	7.0
2118	1.3	2.7	7.2	9.4



IV. References

- Nadal-Caraballo, N. C., and J. A. Melby. 2014. North Atlantic Coast Comprehensive Study: Phase I: Statistical Analysis of Historical Extreme Water Levels with Sea Level Change. ERDC/CHL TR-14-7. Vicksburg, MS: U.S. Army Engineer Research and Development Center.
- USACE. 2013. Incorporating Sea Level Change in Civil Works Programs. Engineer Regulation 1100-2-8162. U.S. Army Corps of Engineers.