Sea Level Change Curve Calculator (2017.55)

User Manual

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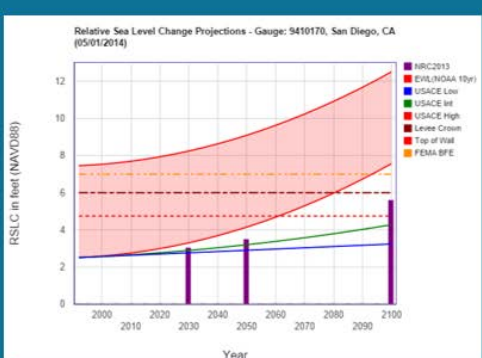
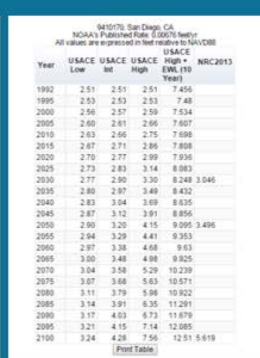
USACE Responses to Climate Change Program

July 2017

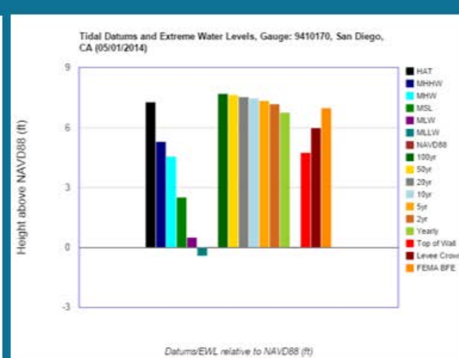




9410170, San Diego, CA
NOAA's Published Rate: 0.00676 feet/yr
All values are expressed in feet relative to NAVD88

Year	USACE Low	USACE Int	USACE High	USACE High + EWL (10 Year)	NRC2013
1992	2.51	2.51	2.51	7.456	
1995	2.53	2.53	2.53	7.48	
2000	2.56	2.57	2.59	7.534	
2005	2.60	2.61	2.66	7.607	
2010	2.63	2.66	2.75	7.698	
2015	2.67	2.71	2.86	7.808	
2020	2.70	2.77	2.99	7.936	
2025	2.73	2.83	3.14	8.083	
2030	2.77	2.90	3.30	8.248	3.046
2035	2.80	2.97	3.49	8.432	
2040	2.83	3.04	3.69	8.635	
2045	2.87	3.12	3.91	8.856	
2050	2.90	3.20	4.15	9.095	3.496
2055	2.94	3.29	4.41	9.353	
2060	2.97	3.38	4.68	9.63	
2065	3.00	3.48	4.98	9.925	
2070	3.04	3.58	5.29	10.239	
2075	3.07	3.68	5.63	10.571	
2080	3.11	3.79	5.98	10.922	
2085	3.14	3.91	6.35	11.291	
2090	3.17	4.03	6.73	11.679	
2095	3.21	4.15	7.14	12.085	
2100	3.24	4.28	7.56	12.51	5.619

Print Table



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Introduction

This manual is designed to guide the user through the U.S. Army Corps of Engineers (USACE) Sea Level Change Curve Calculator, providing step-by-step instructions for using the online tool. Version 2017.55 employs the same computations as its predecessor, yielding the same projections along with some additional functionality. A listing of the major enhancements and modifications to the superseded calculator can be found in Appendix B. The superseded version is still valid and can be accessed at: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm.

1.1 Background

USACE updated its guidance on considerations for Sea Level Change (SLC) in Civil Works programs and projects to ensure sustainable performance in the future and combine the post-Katrina recommendations around land subsidence, tidal fluctuations, and sea level change. Beginning in 2009, USACE policy and guidance required that all coastal projects be evaluated with respect to changes in sea level throughout the project life-cycle.

The need to incorporate projected changes to Local Mean Sea Level (LMSL) into the design of USACE Civil Works projects required the development of a simple, web-based tool to provide repeatable analytical results. This Sea Level Change Curve Calculator was developed under the Comprehensive Evaluation of Projects with Respect to Sea Level Change (CESL) component of the Responses to Climate Change Program. The calculator is also used in the CESL screening-level vulnerability assessments for USACE coastal projects.

The USACE Sea Level Change Curve Calculator uses the methodology described in Engineer Regulation (ER) 1100-2-8162 - Incorporating Sea Level Changes in Civil Works Programs (USACE 2013a). The tool also provides comparisons to scenarios in the National Oceanic and Atmospheric Administration Technical Report OAR CPO-1 titled *Global Sea Level Rise Scenarios for the United States National Climate Assessment* (NOAA 2012); the National Research Council's (NRC) *Sea Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* report (NRC 2012); the *NPCC2 New York City Panel on Climate Change 2015 Report, Chapter 2: Sea Level Rise and Coastal Storms* (NPCC 2015); the New York State Department of Environmental Conservation Proposed Regulation 6 NYCRR Part 490; The Maryland Climate Change Commission 2013 (MCCC 2013); the CARSWG Regional Sea Level Scenarios For Coastal Risk Management Report 2016 (CARSWG 2016); and the US Global Change Research Program 2017 (NOAA et al. 2017).

The extreme water levels are based on statistical probabilities using recorded historic monthly extreme water level values. *NOAA Technical Report NOS CO-OPS 067 - Extreme Water Levels of the United States 1893-2010* describes the methods and data used in the calculation of the exceedance probability levels using a generalized extreme value (GEV) statistical function (NOAA 2013c). The USACE method uses the same NOAA recorded monthly extreme values in a percentile statistical function. Both methods use data recorded and validated by NOAA at the tide gauges. The extreme values at the gauge can be significantly different than what may occur at the project site based on the distance from the gauge and conditions at the project site. The level of confidence in the exceedance probability decreases with longer return periods.

Additional information is available at the CO-OPS website at:
http://tidesandcurrents.noaa.gov/est/

1.1.1 Information Quality Act

This section describes the testing and validation of the computational accuracy consistent with the Information Quality Act as described in the Deputy Secretary of Defense memorandum titled *Ensuring Quality of Information Disseminated to the Public by the Department of Defense* (2003).

1.1.1.1 Utility

The calculator is designed to help with the application of the guidance found in Engineer Regulation (ER) 1100-2-8162—*Incorporating Sea Level Change in Civil Works Programs* (USACE 2013a), and Engineer Technical Letter (ETL) 1100-2-1—*Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation* (USACE 2014).

1.1.1.2 Objectivity

The calculator conforms to the guidance found in ER 1100-2-8162 (USACE 2013a). Other than using the equations in the regulation to produce tables and graphs, this tool makes no predictions or draws any conclusions. It is recommended that the user become familiar with the guidance prior to using the calculator's output for any influential decisions.

1.1.1.3 Quality

The computations for future sea levels based on ER 1100-2-8162 have been independently checked by personnel at the New Orleans, Galveston, Jacksonville, Portland, and Honolulu District offices. The computations were also reviewed by NOAA National Ocean Service Subject Matter Experts and the calculator is being used by NOAA personnel.

Honolulu District checked SLC values provided by the calculator in 2012 using random spot checks and again in April 2015 using a more rigorous process. A total of 36 NOAA gauges (a little over a third of the total) were checked in 2015; three gauges within each of the twelve identified regions. In the more rigorous process, each of the 36 gauges was checked by comparing selected values of SLC from the calculator with spreadsheets that had been previously (and independently) developed by the Honolulu District to calculate SLC curves at all listed NOAA gauges.

All SLC curves reviewed by Honolulu District (approximately 432 total) were calculated and compared using 2020 as the start year and 2120 as the end year. Each of the three curves for a gauge (low, medium, and high) were evaluated at four times: years 10, 20, 50, and 100 (2030, 2040, 2070, and 2120, respectively). Values were compared for calculations done in meters, and relative to LMSL only. Curves calculated using the USACE method were evaluated. Curves calculated using the NOAA method were not evaluated. If a regionally corrected SLC rate (including the NOAA "M" value to incorporate vertical land movement) was available for a gauge, it was used (rather than the published SLC rate) to generate the curves. See section 1.3 for further information on the "M" value. In areas where the "M" value was not available (e.g. – Ocean Islands Region), the published SLC rate was used for calculations.

All of the CESL calculator values checked agreed with spreadsheet values (when rounded to 2 decimal places). A list of gauges checked is available in Appendix C.

NOAA also compared the calculator's output to their Sea Level Rise Viewer (https://coast.noaa.gov/digitalcoast/tools/slr) noting that the values agreed when rounded to 2 decimal places.

Need to add content from latest QC report (BAH)

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1.1.2 NOAA CO-OPS Data Quality

The underlying tide gauge data, NOAA sea level change rates, tidal datums, "M" values, where available, and the GEV extreme water levels were supplied by the NOAA Center for Operational Oceanographic Products and Services (CO-OPS) in batch mode. CO-OPS has an extensive QA/QC program for the collection of water levels outlined in their report titled *CO-OPS Evaluation Criteria for Water Level Station Documentation* (NOAA 2013a).

1.2 Overview

The online Sea Level Change Curve Calculator consists of a web-based tool that accepts user input such as project start date, selection of an appropriate NOAA long term tide gauge, and project life span, to produce a table and graph of the projected sea level changes for the respective project. The calculator was developed to calculate the USACE SLC scenarios, but can also be used to develop other scenarios for comparison purposes. Additional scenarios available include those developed by the NOAA (2012), the National Research Council (NRC 2012), and the New York City Panel on Climate Change (NPCC 2013b) and several others listed in Section 1.1 Background.

1.2.1 USACE Scenarios – ER 1100-2-8162 (USACE 2013)

USACE SLC scenarios are developed using the guidance in ER 1100-2-8162 and ETL 1100-2-1 (USACE 2013a, 2014). Assuming a eustatic SLC rate of 1.7 mm/year and start date of 1992 (mid-year of the NOAA National Tidal Datum Epoch (NTDE) of 1983–2001), the updated values for the variable b in the 1987 NRC report, as shown in Table 1-1 below, are equal to 2.71E-5 for modified NRC Curve I (USACE Intermediate Rate Scenario), and 1.13E-4 for modified NRC Curve III (USACE High Rate Scenario) (NRC 1987). The USACE Low Rate Scenario extrapolates the historic rate of sea level change. The tidal datums and their relationship to NAVD88 are referenced to the midpoint of the selected gauge's epoch period.

Eustatic Sea Level Change Rate	Start Date	Variable b	
		NRC Curve I	**NRC Curve III** Used for the USACE High Rate Curve

		Used for the USACE Intermediate Rate Curve	
1.7mm/year	1992[1]	2.71E-5	1.13E-4

Table 1-1: Eustatic Sea Level Change Rate

1.2.2 NOAA Scenarios - OAR CPO-1 (NOAA et al. 2012)

NOAA's scenarios also begin at 1992 but produce 4 curves based on a rise of 2.0, 1.2, 0.5, and 0.2 meters by 2100. To fit the curves to the scenarios defined above, the constant b has a value of 1.56E-04 (Highest Scenario), 8.71E-05 (Intermediate-High Scenario), and 2.71E-05 (Intermediate-Low Scenario) as shown in Table 1-2 below. The NOAA Intermediate Low Scenario is the same as the USACE Intermediate Scenario. NOAA also extrapolates the historic tide gauge rate for the NOAA Low Rate Scenario, which is the same as the USACE Low Rate Scenario.

Start Date	Variable b		
	Highest Scenario	**Intermediate-High Scenario**	**Intermediate-Low Scenario**
1992	1.56E-04	8.71E-05	2.71E-05

Table 1-2: NOAA OAR CPO-1 Scenarios

1.2.3 NRC 2012 Values (West Coast Only)

The National Research Council's 2012 report breaks the west coast into 4 regions associated with the gauges at Seattle, WA, Newport, OR, San Francisco, CA, and Los Angeles, CA. The calculator will find the closest of these four gauges to the user's selected gauge and provide the NRC 2012 values in the table and on the chart. The NRC 2012 values are relative to the year 2000. The calculator extrapolates the historic rate of SLC at the user's selected gauge from 1992 (the mid-point of the National Tidal Datum Epoch) to 2000 in order to relate the report's projected values to LMSL and NAVD88. Projections for A1B, B1, and A1FI are included.

1.2.4 NPCC 2013/2015/Part 490 Values (New York City, The Battery and Montauk Point Gauges Only)

The New York City Panel on Climate Change 2013 and 2015 reports (NPCC 2013a, Horton, R., et al. 2015) compute projected sea level for the Bronx, Brooklyn, Manhattan, Queens, and Staten Island Boroughs of New York. 10th percentile, 25th percentile, 75th percentile, and 90th percentiles are tabulated and shown on the curves graph. The 2020s (2050s, 2080s) is a ten year average of the projections from 2020-2029 (2050-2059, 2080-2089). In order to associate the projections which are based on changes starting in 2002, to either Local Mean Sea Level (83-01) or NAVD88, the 2006 historic rate was used to account for changes (0.08') between 1992

[1] The mid-year of the National Tidal Datum Epoch (NTDE) of 1983-2001.

(midpoint of the 83-01 NTDE) and 2002. The NPCC 2015 projections are shown in the table below.

Horton *et al.* NPCC 2015 Report Chapter 2

Table 2.2. New York City sea level rise projections

Baseline (2000–2004) 0 in	Low estimate (10th percentile)	Middle range (25th to 75th percentile)	High estimate (90th percentile)
2020s	2 in	4–8 in	10 in
2050s	8 in	11–21 in	30 in
2080s	13 in	18–39 in	58 in
2100	15 in	22–50 in	75 in

NOTE: Projections are based on a six-component approach that incorporates both local and global factors. The model-based components are from 24 global climate models and two representative concentration pathways. Projections are relative to the 2000–2004 base period.

The new guidelines contained in the New York Department of Environmental Conservation document “Part 490, Projected Sea-Level Rise - Regulatory Impact Statement - Regulatory Impact Statement - 6 NYCRR Part 490, Projected Sea-level Rise” are also available for gauges “The Battery” and “Montauk Point”. In order to associate the projections which are based on changes starting in 2002, to either Local Mean Sea Level (83-01) or NAVD88, the 2006 historic rate was used to account for changes (0.08’) between 1992 (midpoint of the 83-01 NTDE) and 2002.

1.2.5 Maryland’s SLC Projections based on “Updating Maryland’s Sea-level Rise Projections”, Scientific and Technical Working Group Maryland Climate Change Commission Report dated June 26, 2013 (MCCC 2013)

The Scientific and Technical Working Group Maryland Climate Change Commission’s projections for the gauges located in Maryland can be optionally graphed along with the USACE and/or NOAA SLC Curves. The option’s checkbox will appear when the user selects a gauge located in Maryland. The projections will appear on the graph as stacked bars for the years 2050 and 2100 showing the values for the Low, Best, and High projections. As with the other optional projections, the historic rate is used to relate the values to the 1983-2001 National Tidal Datum Epoch and NAVD88 where available. Maryland's projections are shown in the table below.

Maryland Relative Sea-level Rise	Thermal (m)	Glaciers (m)	Greenland (m)	Antarctica (m)	Dynamic (m)	VLM (m)	Relative SLR meters	Relative SLR feet
2050 best	0.10	0.05	0.03	0.09	0.09	0.075	0.4	1.4
2050 low	0.04	0.05	0.02	0.04	0.07	0.065	0.3	0.9
2050 high	0.19	0.06	0.05	0.16	0.10	0.085	0.7	2.1
2100 best	0.24	0.13	0.10	0.30	0.17	0.15	1.1	3.7
2100 low	0.10	0.12	0.08	0.10	0.13	0.13	0.7	2.1
2100 high	0.46	0.17	0.17	0.58	0.19	0.17	1.7	5.7
Land ice change fingerprint scale factors		0.9	0.5	1.25				

1.2.6 CARSWG's Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme

Water Levels for Department of Defense Coastal Sites Worldwide (CARSWG 2016)

The CARSWG 2016 projections are broken into 5 scenarios starting in 1992 ranging from 0.2 meters to 2.0 meters. The acceleration coefficients are shown in table 3.4 below. The CARSWG 2016 curves may be shown along with other projections for comparison purposes.

Table 3.4 Values for a and b Coefficients in Equation 3–1

Scenario (m)	*a* (m/yr)	*b* (m/yr^2)
0.5	1.7×10^{-3}	2.7126200×10^{-5}
1.0	1.7×10^{-3}	6.9993141×10^{-5}
1.5	1.7×10^{-3}	$1.12860082 \times 10^{-4}$
2.0	1.7×10^{-3}	$1.55727023 \times 10^{-4}$

1.2.7 NOAA Technical Report NOS CO-OPS 083 (NOAA et al. 2017)

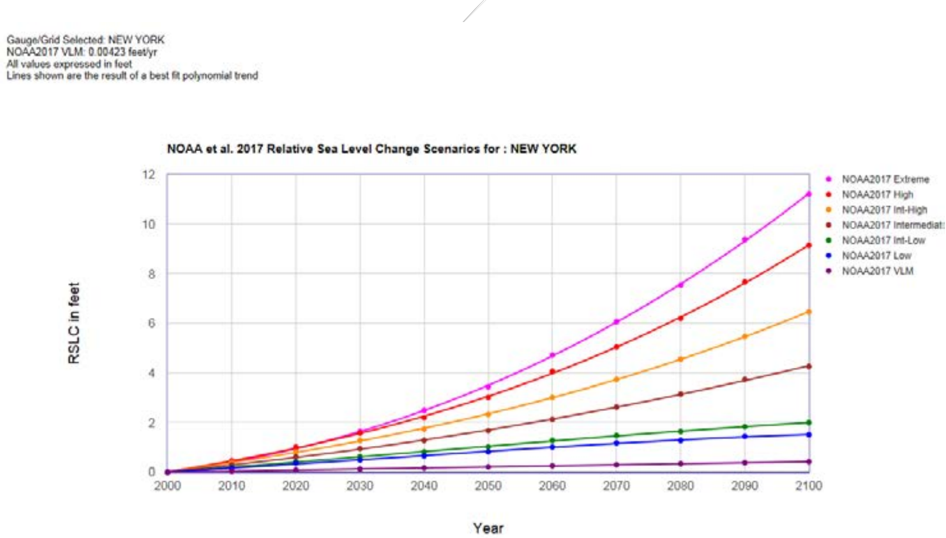
The recently released NOAA et al. 2017 projections contained in the report, Global and Regional Sea Level Rise Scenarios for the United States provide projected MSL centered at each decade between 2010 and 2100. The projections also include Local Vertical Land Movement and are modeled on a 1 degree grid along the coastline throughout the US and territories. The NOAA

2017 projections for Global Meal Sea Level are shown in the table below. The values shown below do not include any local land movement.

Table 5. GMSL rise scenario heights in meters for 19-year averages centered on decade through 2200 (showing only a subset after 2100) initiating in year 2000. Only median values are shown.

GMSL Scenario (meters)	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2120	2150	2200
Low	0.03	0.06	0.09	0.13	0.16	0.19	0.22	0.25	0.28	0.30	0.34	0.37	0.39
Intermediate-Low	0.04	0.08	0.13	0.18	0.24	0.29	0.35	0.4	0.45	0.50	0.60	0.73	0.95
Intermediate	0.04	0.10	0.16	0.25	0.34	0.45	0.57	0.71	0.85	1.0	1.3	1.8	2.8
Intermediate-High	0.05	0.10	0.19	0.30	0.44	0.60	0.79	1.0	1.2	1.5	2.0	3.1	5.1
High	0.05	0.11	0.21	0.36	0.54	0.77	1.0	1.3	1.7	2.0	2.8	4.3	7.5
Extreme	0.04	0.11	0.24	0.41	0.63	0.90	1.2	1.6	2.0	2.5	3.6	5.5	9.7

The projections begin in 2000 therefore they are not connected to the National Tidal Datum Epoch 83-01. The historic rate is applied to the projections to reference the values to the 83-01 epoch.



1.3 Sample Curve Calculations

Global SLC for any of the accelerating scenarios can be calculated using Equation 2 in ER 1100-2-8162 (USACE 2013a). For example, the projected USACE High Rate SLR for 2060 can be computed by:

$$E(t) = 0.0017t + bt^2$$

Where:

- t = years since 1992, so for this example, t= 2060 – 1992 = 68
- generally accepted eustatic sea level rise rate = 1.7 mm/yr or 0.0017 m/yr
- b = 0.0001130 from ER 1100-2-8162 (high rate)
- E = the change in global mean sea level between 1992 and 2060 (for this example) using the high rate scenario

$E = (0.0017*68) + (0.0001130*68^2)$
$E = (0.1156) + (0.0001130*4624)$
E = 0.638112 meters in this example

Equation 2, in ER 1100-2-8162, does not contain the local Vertical Land Movement (VLM) (USACE 2013a). The rate used to develop the local relative SLC is a combination of the generally accepted eustatic rate of 1.7 mm/yr plus the VLM ("M"). The "0.0017" in Equation 2 of the ER would be substituted with the appropriate rate of relative SLC for the gauge selected. To account for local VLM, we substitute 0.017 with either the published or regionally corrected rates, both of which are provided by NOAA CO-OPS. The published rates are available from the CO-OPS Sea Level Trends website (NOAA 2013b). The regionally corrected rates can be developed with the information contained in *NOAA Technical Report NOS CO-OPS 065* (NOAA 2013d).

Modifying Equation 2 to substitute either the published or the regionally corrected rate as "M" we get:

$$E(t) = Mt + bt^2$$

Where

- t = years since 1992, so for this example, t= 2060 – 1992 = 68
- M = the generally accepted eustatic sea level rise rate 1.7 mm/yr plus the VLM (subsidence) of 1.23 mm/yr at the Montauk gauge in New York (Table 1 from NOAA 2013d's regional rates) = 2.93 mm/yr
- b = 0.0001130 from ER 1100-2-8162 (high rate)

$E = (0.00293*68) + (0.0001130*68^2)$
$E = (0.19924) + (0.0001130*4624)$
E = 0.721752 meters in this example

The calculator also produces a chart and table showing the projected change between the project start and end. The is done by manipulating equation (2) to account for the fact that it was developed for eustatic sea level rise starting in 1992, while projects will actually be constructed at some date after 1992, resulting in equation (3):

$$E(t_2) - E(t_1) = 0.0017(t_2 - t_1) + b(t_2^2 - t_1^2)$$

Where

- t_1 = the difference in time between the project's construction date and 1992
- t_2= the difference in time between a future date at which one wants an estimate, beyond t_1, for sea level change and 1992

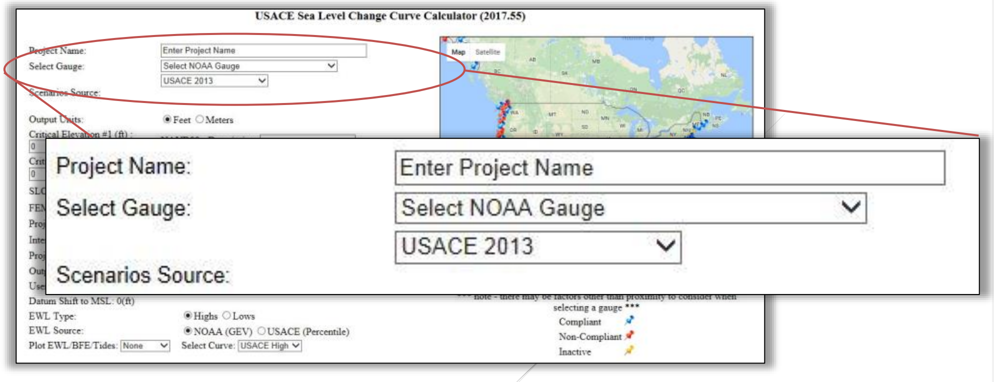
This shows only the changes in sea level, and does not reference a particular datum, which is why it does not plot any user entered BFE or critical elevations.

Operation of Sea Level Change Curve Calculator Tool

2.1 User Controls

The tool uses the appropriate equation to produce a graph and table of the projected SLC Curves based on the user selected controls and desired output.

Figure 2-1: USACE Sea Level Change Curve Calculator User Controls



A. **Project Name:** The user can enter a project name to be displayed on top of the curves chart and table.

Gauge Selection: There are two ways that a user can select the appropriate NOAA gauge: (1) gauge: (1) Clicking on the project area on the map (

B. Figure 2-1) in the location of the project, or (2) Selecting a gauge from the drop-down menu (Figure 2-2). If the user chooses option (1), the calculator will choose the gauge closes to the area clicked on the map.
   Selecting a gauge via the drop-down menu in option (2) will cause the calculator to zoom the Google Map insert to the selected gauge. There may be additional factors other than proximity to consider when selecting a gauge.

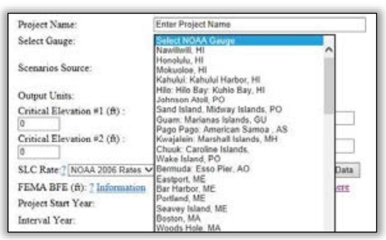


Figure 2-2: Gauge Selection

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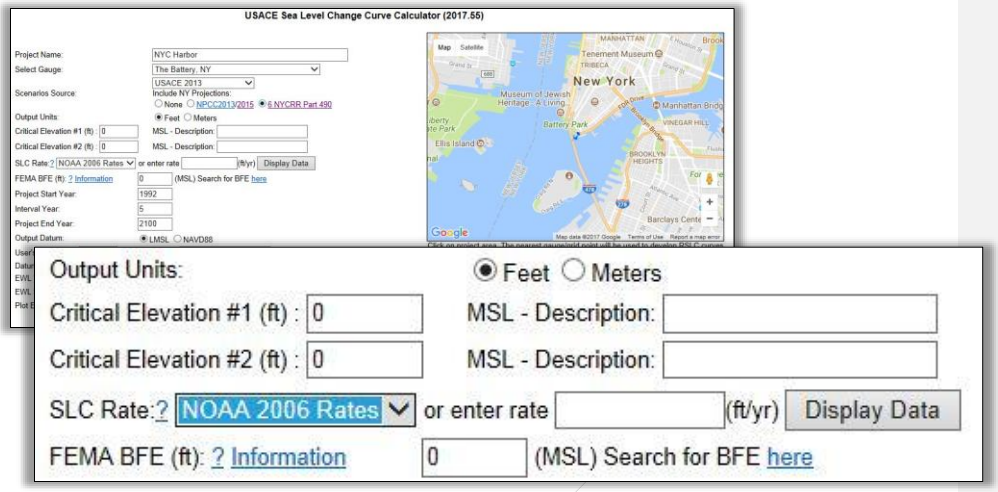
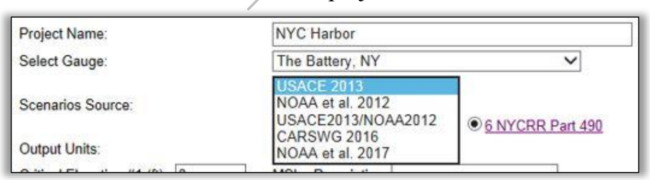
Figure 2-3: USACE Sea Level Change Curve Calculator User Controls cont'd



C. Output Agency: USACE and NOAA projections are available at any tide gauge location, and any combination may be selected by clicking on the desired checkboxes. Note: For the gauges in California, Oregon, and Washington, you may also elect to show the NRC2012 projections. For "The Battery" in New York, you may also elect to show the either the NPCC2013/2015 projections or the New York State Department of Environmental Conservation's Part 490 ClimAID projections. Selecting Montauk Point will allow the user to also select the New York State Department of Environmental Conservation's Part 490 ClimAID projections.



D. FEMA Base Flood Elevation: If desired, the user may enter a FEMA Base Flood Elevation. If the selected gauge is not connected to NAVD88, the BFE will have to be converted to LMSL before being entered. Select BFE in the "Plot EWL and/or BFE" pull-down to plot the BFE on top of the selected SLC curve. Links are provided to more information and locating the area's BFE. This capability was requested by some users and is not meant to imply that the BFE is a USACE design standard.

E. Project Start Year Enter the project's starting year. This will determine what the curves and tables will use as a starting point. Relative sea level change will always begin its computations in 1992; however, the project start year will determine when to start displaying the values.

F. **Year Interval** Enter the interval of years desired for the output tables. Any value entered other than five will compute all years relative to the starting year. If the value is 5, all years will be computed as even intervals of 5 (i.e. 2005, 2010, 2015, etc.).

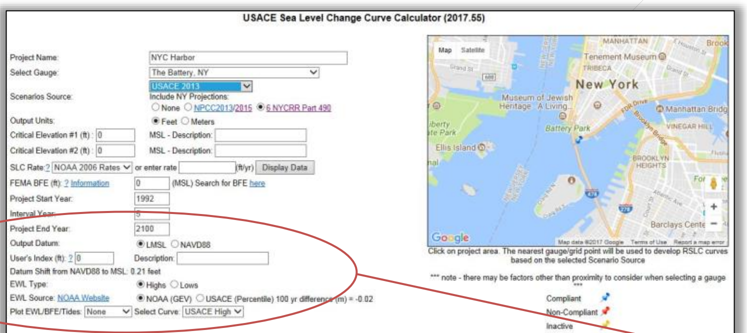
G. **Project End Year:** Enter the project's ending year (1992-2150). Use caution when projecting out beyond 2120.

H. **Output Units:** The user may optionally change the unit of measure. The default unit of measure is feet.

I. **Output Datum:** The output datum may also be selected by clicking on the desired checkbox. Local Mean Sea Level (LMSL) or the North American Vertical Datum of 1988 (NAVD88) are available. Note: NAVD88 is not available for all gauges.

Figure 2-4: USACE Sea Level Change Curve Calculator User Controls cont'd

J. **SLC Rate:** Select either the (1) NOAA 2006 published rate of Sea Level Change, which



are published on the CO-OPS website, or (2) the regionally corrected rates from *NOAA Technical Report NOS CO-OPS 065* (NOAA 2013d). The user may optionally enter in an alternate rate and click on the [Display Data] button.

Note: Per NOAA, long term sea level trends observed in tide station records include a component due to oceanographic variables and a component due to local Vertical Land Motion (VLM). The oceanographic component includes the global (eustatic) sea level trend, plus tide station location specific sea level variations acting on different scales (local to regional) and at different frequencies (storm surge to seasonal to decadal scale). In the past, local VLM has been estimated simply by subtracting the global sea level trend from the local mean sea level trend developed from local tide station records. NOAA Technical Report NOS CO-OPS 065, Estimating Vertical Land Motion from Long-Term Tide Gauge Records, dated May 2013 provides improved estimates of local VLM through a process which references regional long-term tide stations and removes regional oceanographic variability. These regionally corrected VLM estimates added to the global sea level trend provide more technically accurate local mean sea level trends.

K. EWL Type: Select the desired type of Extreme Water Levels (EWL) to display. Low water extremes are not available using the USACE Percentile method

L. EWL Source: Select the desired source of the EWLs, the USACE produced Percentile or NOAA produced Generalized Extreme Value (GEV).

M. Chart Size: The chart height and width may be changed by adding the desired values in the text boxes. Note: The [Display Data] button must be clicked to re-plot the charts.

N. Plot EWL, BFE, or Tides: From the pull-down, select the desired return period, base flood elevation (BFE), or tides along with the curve upon which to display them.

O. Download CSV: Click on the Download CSV button to create and download a .csv file of the selected table.

Note: CSV download is only available when using the Firefox browser.

P. Critical Elevations: The user may also include 2 critical elevations to plot on the SLC curve and gauge datums graphs. ETL 1100-2-1 describes a critical elevation or threshold as, "… intended to identify a water surface elevation at which a structural condition changes or system performance changes. For example, a structure can either fail or be overtopped at a certain water elevation, and a drainage system might start to back up at a certain water elevation. A tipping point refers to a critical point, after the threshold, when stability and/or performance begin to rapidly decline and impacts increase dramatically. Determining tipping points that would generate a necessary action in the future is an essential element of alternative development with respect to SLC" (USACE 2014). The user-entered thresholds may also be described by entering a description in the text boxes provided. These descriptions will appear on the chart legends. The range of tipping points produced between the low and high SLC curves defines the future time uncertainty of performance changes referenced to the critical elevation.

Keep in mind the various water surfaces when determining the critical elevation. As MSL approaches the critical elevation, high tide must be considered. If in this scenario, Mean High Water (MHW) or high tide is 2 feet higher than MSL, a structure with an elevation of 5 feet will be inundated almost daily when MSL gets to 3.1'. The calculator provides the years at which the Mean Lower Low Water (MLLW), LMSL, and MHHW all reach the critical elevation(s). The user can also select an Extreme Water Level such as a 100 yr event to be included in the tabulation of intersections of water levels and critical elevations.

Q. User Entered Index: The user may optionally enter in a value to be added to the calculated curves. This may be used for Flood Risk Reduction Standards as described in ECB 2013-33, overbuild, etc. (USACE 2013b). Caution… this does not perform any computations based on water depth; it simply adds the entered value as a constant to the water surface calculated for the selected scenarios. A description of the index value can also be entered.

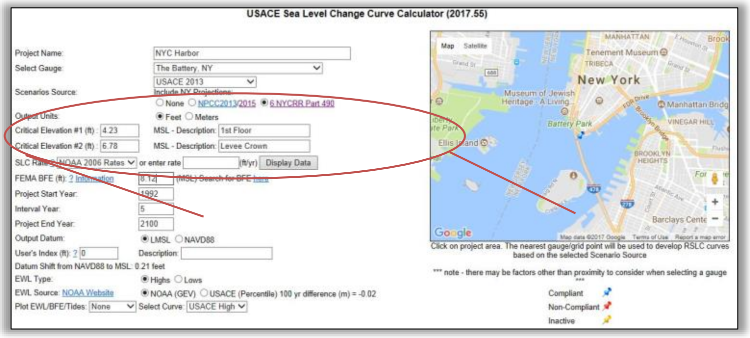


Figure 2-5: USACE Sea Level Change Curve Calculator User Controls cont'd

2.2 Gauge Map

Along with the output curve table and graph, an interactive Google map is produced showing the location of the user selected gauge. The user can zoom in, zoom out, and pan the map. The example below shows the location of the San Diego gauge, as represented by the blue push pin.

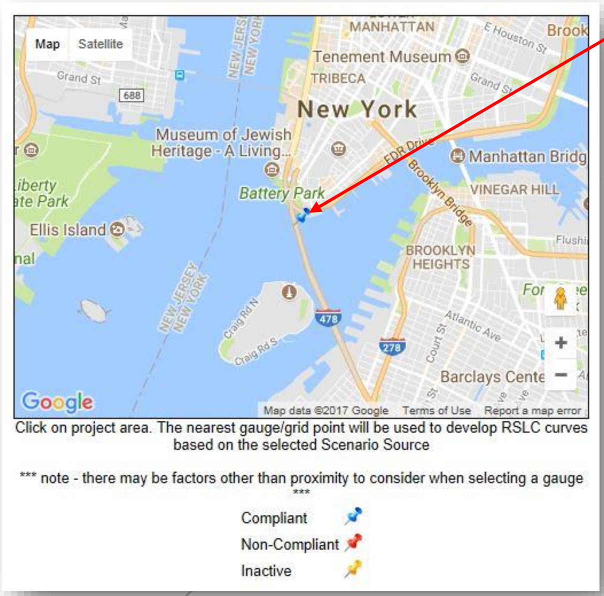


Figure 2-6: Gauge Map

2.3 Output Table

The projected water level heights relative to either LMSL or NAVD88 are tabulated for each of the requested scenarios at a 5 year interval. The tabulated heights will be displayed in the selected unit of measure, either feet or meters and relative to the selected output datum. In the example shown below, the USACE, NOAA, and NRC scenarios were selected for the Santa Monica tide gauge.

9410840, Santa Monica, CA
NOAA's 2006 Published Rate: 0.00479 feet/yr
All values are expressed in feet relative to LMSL

Year	USACE Low	USACE Int	USACE High	NRC2012 B1	NRC2012 A1B	NRC2012 A1FI
2010	0.086	0.115	0.206			
2015	0.110	0.157	0.306			
2020	0.134	0.204	0.425			
2025	0.158	0.255	0.562			
2030	0.182	0.310	0.717	0.189	0.520	1.022
2035	0.206	0.370	0.891			
2040	0.230	0.435	1.084			
2045	0.254	0.504	1.295			
2050	0.278	0.577	1.525	0.455	0.970	2.033
2055	0.302	0.655	1.773			
2060	0.326	0.737	2.040			
2065	0.350	0.823	2.325			
2070	0.374	0.915	2.629			
2075	0.398	1.010	2.952			
2080	0.422	1.110	3.292			
2085	0.445	1.214	3.652			
2090	0.469	1.323	4.030			
2095	0.493	1.437	4.426			
2100	0.517	1.554	4.842	1.488	3.092	5.501

Figure 2-7: Example Output Table

2.4 Graph of Projected Relative Sea Level Change Curves

An interactive Google graph is produced along with the output table. The graph displays the relative sea level change curves according to the user supplied inputs and options. The user can hover over a node of the curve to display the value at that point. Zooming is also possible using the button's scroll wheel. In the example shown in Figure 2-8 below, the USACE, NOAA, and NRC scenarios were selected for the Santa Monica tide gauge. Two different elevation thresholds were input, labeled Emergency Generators and Levee Crown. A BFE was also selected. Finally, an extreme water level (100-yr recurrence interval calculated by NOAA using the GEV) is plotted on the USACE high curve.

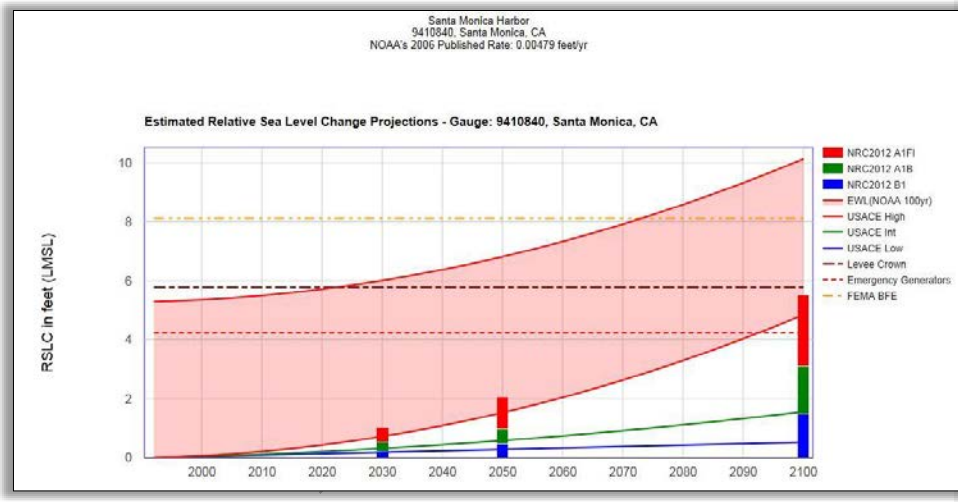


Figure 2-8: Projected Relative Sea Level Change Curves

2.5 Curve Intersections Table

The year at which the selected curve (item M) intersects the user entered critical elevations and/or base flood elevation is produced. The curves from the selected agency and the critical elevations and BFE are shown by default. The user can select an EWL to be included in the tabulation as described in K, L, and N as shown in Figure 1-4. In the example shown in Figure 2-8 above, intersections are shown for two different elevation thresholds input, labeled Levee Crown and Emergency Generators.

Curve Intersections	Emergency Generators (yr)	Levee Crown (yr)	BFE (yr)
USACE High	2092	2110	2133
USACE Int	2184	2221	2268
USACE Low	2874	3197	3685

Print Intersections Table

2.6 Graph and Table of Gauge Datums, EWLs, Critical Elevations, and BFE

The established datums and the user selected EWLs, along with any user entered critical elevations and/or a BFE, are tabulated and graphed as shown in Figure 2-9 below. The graph shows the relationship between the various datums and elevations. Note that because the EWLs are computed based on de-trended data, they can be applied to any year or scenario. The EWLs have the historic rate of the selected gauge applied to account for SLC from the midpoint of the gauge's epoch period to the project start year.

Deleted: Figure 2-9

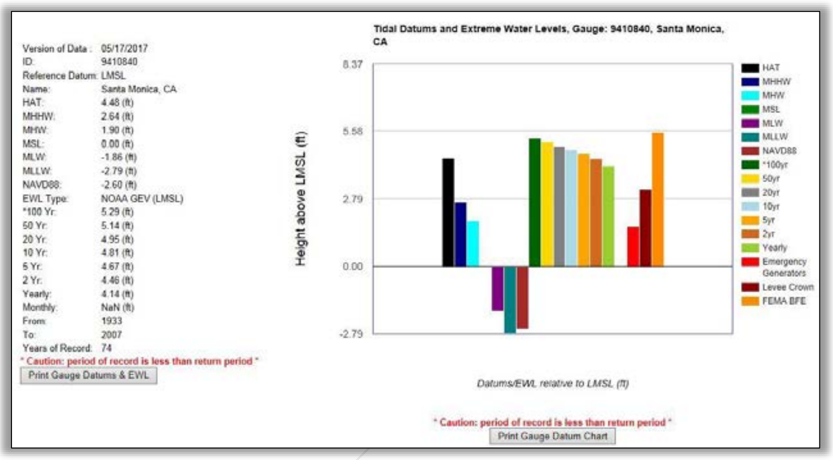


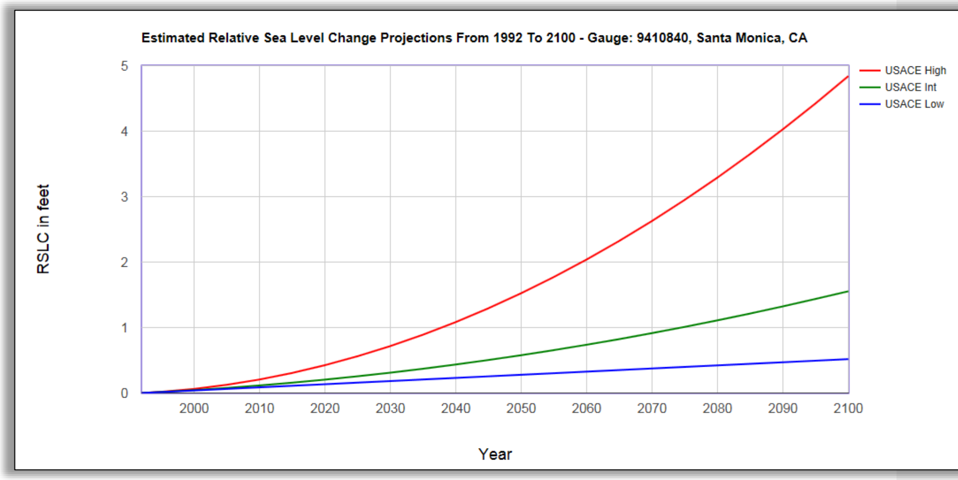
Figure 2-9: Gauge Datums, EWLs, Critical Elevations, and BFE

2.7 Graph and Table of the Relative Sea Level Change Between Dates

The table and graph shown in Figure 2-10 below shows the relative differences in the water level between the user entered project's start and end dates for the USACE and NOAA scenarios. Both the graph and table start at zero in the project start year.

Deleted: Figure 1-10

Associating these curves with a particular datum is not possible unless an assumed rate/curve is used to transfer the datums developed for the NTDE to the project start year. This calculator does not make that determination; therefore, no critical elevations or BFE will be shown on this graph. The Sea Level Change Curve Calculator simply shows the change in height between the project's start and end dates.



Estimated Relative Sea Level Change Projections From 1992 To 2100 - Gauge: 9410840, Santa Monica, CA
RSLC in feet
Year
0
1
2
3
4
5
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
USACE High
USACE Int
USACE Low

2.8 NOAA Plots

NOAA plots of extreme water levels are shown at the bottom of the tool's output display. These plots use the GEV function and display the period of record water levels. Clicking on either plot brings up the NOAA CO-OPS webpage for the selected gauge.

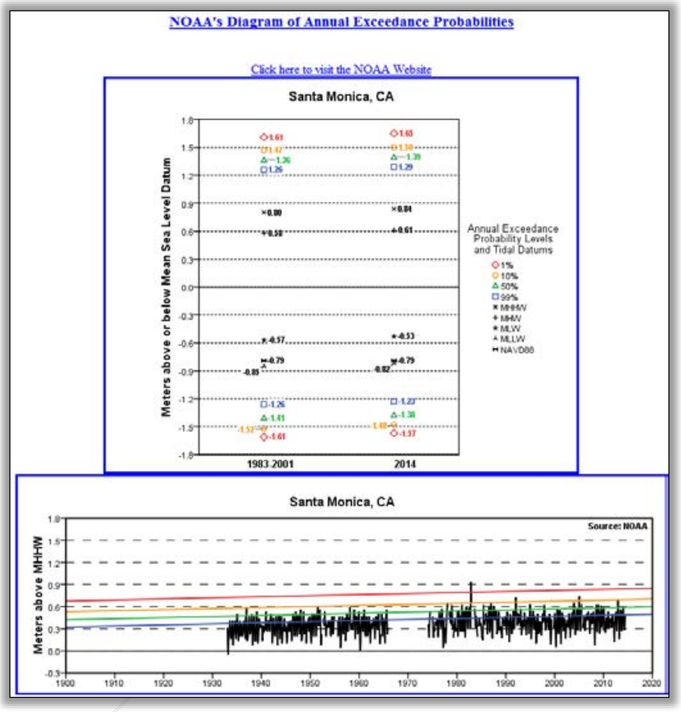


Figure 2-10: NOAA Plots

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Appendix B: List of Enhancements

List of 2014.88 Enhancements

2014.88 major enhancements and modifications to the superseded calculator—available at http://www.corpsclimate.us/ccaceslcurves(superseded).cfm—include:

- Ability to click on gauge map to select project gauge
- Table and graph of gauge datums and Extreme Water Levels
- Option for output datum (LMSL or NAVD88)
- Option to output values from NRC 2012 for locations on the west coast
- Option to output values from NPCC 2013/2015 for New York City (The Battery)
- Option for published or regionally corrected SLC rates
- Option to include Extreme Water Levels
- Option for EWL source (USACE Percentile or NOAA GEV)
- Graph and table of curves using ER 1100-2-8162 equation 3
- Optional critical elevations
- Displayed CO-OPS EWL and Period of Record images for selected gauge
- Use of JSON formatted data. Will allow for future transition to real-time data
- Development of Intersection Table of water levels to critical elevations
- Option for user to enter an index to add to projected water surfaces
- CSV output option for Firefox browser
- Print option for tables and graphs

List of 2015.46 Enhancements

2015.46 major enhancements and modifications to the 2014.88 calculator—available at http://www.corpsclimate.us/ccaceslcurves_2014_88.cfm —include:

- Ability to click on gauge map to select project gauge
- Table and graph of gauge datums and Extreme Water Levels
- Option for output datum (LMSL or NAVD88)
- Option to output values from NRC 2012 for locations on the west coast
- Option to output values from NPCC 2013/2015 for New York City (The Battery)

- Option for published or regionally corrected SLC rates
- Option to include Extreme Water Levels
- Option for EWL source (USACE Percentile or NOAA GEV)
- Graph and table of curves using ER 1100-2-8162 equation 3
- Optional critical elevations
- Displayed CO-OPS EWL and Period of Record images for selected gauge
- Use of JSON formatted data. Will allow for future transition to real-time data
- Development of Intersection Table of water levels to critical elevations
- Option for user to enter an index to add to projected water surfaces
- CSV output option for Firefox browser
- Print option for tables and graphs
- Correction of abbreviation for the state of Maine

List of 2015.xx Enhancements (not published)

2015.xx major enhancements and modifications to the 2015.46 calculator—available at http://www.corpsclimate.us/ccaceslcurves_2015_46.cfm —include:

- Gauge map tool tips – hover over a gauge to show gauge's information
- Addition of 11 new gauges with 30+ years of data
- Ability to select NOAA's Regional, 2006, or 2014 SLC rates
- Gauge map and pull-down selection display gauges relevant to selected rate type
- Added links to CO-OPS' webpages for selected gauge
  - Gauge's Extreme Water Levels page
  - Gauge's Tidal Datums page
  - Gauge's Home Page
  - Gauges Average Seasonal Cycle page
  - Gauge's Interannual Variation page
- Gauges using a 5 year epoch will not produce curves relative to a datum.

List of 2016.xx Enhancements (includes 2015.xx items not published)

2016.xx major enhancements and modifications to the 2015.46 calculator—available at http://www.corpsclimate.us/ccaceslcurves_2015_46.cfm —include:

- Added capability to plot the New York State Department of Environmental Conservation's proposed ClimAID projections for Montauk Point and The Battery using Table 1. ClimAID sea-level rise projections (inches of rise relative to 2000-2004 baseline), Part 490, Projected Sea-Level Rise - Regulatory Impact Statement at http://www.dec.ny.gov/regulations/103889.html
- Added capability to plot Maryland's projected Relative Sea Level Rise for gauges in Maryland using the table on pg 15 of the Scientific and Technical Working Group

Maryland Climate Change Commission (2013), Updating Maryland's Sea-level Rise Projections at http://www.umces.edu/sites/default/files/pdfs/SeaLevelRiseProjections.pdf

- Added links to CO-OPS' webpages for selected gauge
  - Gauges Average Seasonal Cycle page
  - Gauge's Interannual Variation page
- Modified the legend's order of curves to be more intuitive
- Added NRC2012's B1 and A1FI projections

List of 2017.55 Enhancements (includes 2016.xx items not published)

2017.55 major enhancements and modifications to the 2015.46 calculator—available at

- Added capability to plot the NOAA et al. 2017 projections. This dataset includes many additional gauges and a one degree gridded model of projections.
- Added gauge at Bergen Point, NY (using NOAA published 2010 rate; 2006 rate not available)
- Deleted user options to mask various graphs and tables
- Changed reference from NYCRR Proposed Part 490 to accepted publication. Also changed legend from percentiles to High through Low Scenarios for the Part 490 projections.
- Added code to mask the NOAA EWL images when they are not available. The icon for a missing image should no longer appear for those gauges where NOAA does not have published Extreme Water Levels.

Appendix C: List of NOAA Gauges Locations Where Checks Were Performed by Honolulu District:

	Station	Notes
Mid-Atlantic Region	Nantucket	
	Port Jefferson	No published M value
	Cape May	
W Gulf of Mexico Region	Grand Isle	
	Galv Pleasure Pie	
	Port Mansfield	No published M value
South/Central California	La Jolla	
	Rincon Island	No published M value
	San Francisco	
N Cal/OR/WA	North Spit	
	Astoria	
	Seattle	
Hawaii	Honolulu	
	Kahului	
	Hilo	
E Gulf of Mexico	Key West	
	Clearwater Beach	
	Panama City	
Gulf of Maine	Eastport	
	Portland	
	Boston	
S Alaska/Aleutian Is	Valdez	* note that post-EQ values used for Alaska
	Kodiak Island	
	Unalaska	
SE Alaska	Ketchikan	* note that post-EQ values used for Alaska
	Juneau	
	Yakutat	
South Atlantic Bight	Wilmington	
	Charleston	
	Miami Beach	No published M value
Puerto Rico/USVI	Lime Tree Bay	* missing Guantanamo gage
	San Juan	
	Magueyes Island	
Ocean Islands	Guam	* missing Johnson and Midway gages
	Pago Pago	* note pre-EQ used for Guam
	Bermuda	No published M value (all Ocean Islands)

Notes on calculator:

1. Pre- and Post- earthquake values. Noted that post-earthquake curves were used for Alaska in the calculator at the time of the review and pre-earthquake values were used for Guam. Website has been updated to show post-earthquake values only for these gauges.

2. Missing Gauges. Noted that Johnson Island, Midway Island, and Guantanamo Bay gauges did not appear on the calculator at the time of review. The Johnson Island and Midway Island gauge records are now

compliant and are included in the calculator. The tide gauge at Guantanamo is non-compliant and thus is not included.

Appendix D: Acronyms Used

Acronym	Name
BFE	Base Flood Elevation
CARSWG	Coastal Assessment Regional Scenario Working Group
CESL	Comprehensive Evaluation of Projects with Respect to Sea Level Change
CO-OPS	Center for Operational Oceanographic Products and Services
CPO	Climate Program Office
ECB	Engineering and Construction Bulletin
ER	Engineer Regulation
ETL	Engineer Technical Letter
EWL	Extreme Water Level
GEV	Generalized Extreme Value
LMSL	Local Mean Sea Level
MSL	Mean Sea Level
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
NOS	National Oceanographic Service
NRC	National Research Council
NTDE	National Tidal Datum Epoch
NPCC	New York City Panel on Climate Change
OAR	Oceanic & Atmospheric Research
SLC	Sea Level Change
USACE	U.S. Army Corps of Engineers
VLM	Vertical Land Movement

Appendix E: Source Tables

These tables are taken from the reference documents listed in Appendix A.

Table 1c. Sea level rise projections for 2100*

	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
Approach 1	7 inches	9 to 18 inches	24 inches
Approach 2	6 inches	9 to 19 inches	26 inches
Model-based component average	6 inches	9 to 18 inches	25 inches
2100 Total SLR Projections (Average of Approaches 1 and 2)	**15 inches**	**22 to 50 inches**	**75 inches**

Based on 24 GCMs and two Representative Concentration Pathways. Projections are relative to the 2000 - 2004 base period.

Figure 11 - New York City Panel on Climate Change, New York City Mayor's Office of Sustainability

Table 2a. November 2013 NPCC2 Sea Level Rise Projections – Updated

Sea Level Rise	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
2020s	+ 2 inches	+ 4 in to 8 in	+ 10 inches
2050s	+ 8 inches	+ 11 in to 21 in	+ 30 inches
2080s	+ 13 inches	+ 18 in to 39 in	+ 58 inches

Based on 24 GCMs and two Representative Concentration Pathways. Shown are the low-estimate (10th percentile), middle range (25th percentile to 75th percentile), and high-estimate (90th percentile).

Table 2b. June 2013 NPCC2 Sea Level Rise Projections

Sea Level Rise	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
2020s	+ 2 inches	+ 4 in to 8 in	+ 11 inches
2050s	+ 7 inches	+ 11 in to 24 in	+ 31 inches
2080s	+ 13 inches	+ 18 in to 39 in	+ 58 inches

Based on 24 GCMs and two Representative Concentration Pathways. Shown are the low-estimate (10th percentile), middle range (25th percentile to 75th percentile), and high-estimate (90th percentile).

Figure 12 - New York City Panel on Climate Change, New York City Mayor's Office of Sustainability

Table 2.2. New York City sea level rise projections

Baseline (2000–2004) 0 in	Low estimate (10th percentile)	Middle range (25th to 75th percentile)	High estimate (90th percentile)
2020s	2 in	4–8 in	10 in
2050s	8 in	11–21 in	30 in
2080s	13 in	18–39 in	58 in
2100	15 in	22–50 in	75 in

NOTE: Projections are based on a six-component approach that incorporates both local and global factors. The model-based components are from 24 global climate models and two representative concentration pathways. Projections are relative to the 2000–2004 base period.

Figure 13 - New York City Panel on Climate Change 2015 Report

TABLE 5.3 Regional Sea-Level Rise Projections (in cm) Relative to Year 2000

	2030		2050		2100	
Component	Projection	Range	Projection	Range	Projection	Range
Steric and dynamic ocean[a]	3.6 ± 2.5	0.0–9.3 (B1–A1FI)	7.8 ± 3.7	2.2–16.1 (B1–A1FI)	20.9 ± 7.7	9.9–37.1 (B1–A1FI)
Non-Alaska glaciers and ice caps[b]	2.4 ± 0.2		4.4 ± 0.3		11.4 ± 1.0	
Alaska, Greenland, and Antarctica with sea-level fingerprint effect[c]						
Seattle, WA	7.1	5.4–9.5	16.0	11.1–22.1	52.7	32.7–74.9
Newport, OR	7.4	5.6–9.5	16.6	11.7–22.2	54.5	34.1–75.3
San Francisco, CA	7.8	6.1–9.6	17.6	12.7–22.3	57.6	37.3–76.1
Los Angeles, CA	8.0	6.3–9.6	17.9	13.0–22.3	58.5	38.6–76.4
Vertical land motion[d]						
North of Cape Mendocino	-3.0	-7.5–1.5	-5.0	-12.5–2.5	-10.0	-25.0–5.0
South of Cape Mendocino	4.5	0.6–8.4	7.5	1.0–14.0	15.0	2.0–28.0
Sum of all contributions						
Seattle	6.6 ± 5.6	-3.7–22.5	16.6 ± 10.5	-2.5–47.8	61.8 ± 29.3	10.0–143.0
Newport	6.8 ± 5.6	-3.5–22.7	17.2 ± 10.3	-2.1–48.1	63.3 ± 28.3	11.7–142.4
San Francisco	14.4 ± 5.0	4.3–29.7	28.0 ± 9.2	12.3–60.8	91.9 ± 25.5	42.4–166.4
Los Angeles	14.7 ± 5.0	4.6–30.0	28.4 ± 9.0	12.7–60.8	93.1 ± 24.9	44.2–166.5

[a] Projection indicates the mean and ± standard deviation computed for the Pacific coast from the gridded data presented in Pardaens et al. (2010) for the A1B scenario. Ranges are the means for B1 and A1Fl using the scaling in Table 10.7 of IPCC (2007; see also Table 5.1 of this report): (B1/A1B) = (0.1/0.13); (A1Fl/A1B) = (0.17/0.13).
[b] Extrapolated based on ice loss rates for glaciers and ice caps except Alaska, Greenland, and Antarctica. No ranges are given because these sources are assumed to have a small or uniform effect on the gradient in sea-level change along the U.S. west coast (see "Sea-Level Fingerprints of Modern Land Ice Change" in Chapter 4).
[c] Extrapolation based on ice loss rates and gravitational attraction effects for Alaska, Greenland, and Antarctica. Ranges reflect uncertainty in ice loss rates.
[d] Assumes constant rates of vertical land motion of 1.0 ± 1.5 mm yr^{-1} for Cascadia and -1.5 ± 1.3 mm yr^{-1} for the San Andreas region. The signs were reversed to calculate relative sea level. Uncertainties are 1 standard deviation.

Figure 14 - Sea-level rise for the coasts of California, Oregon, and Washington: past, present, and future, National Research Council

Table 1. ClimAID sea-level rise projections (inches of rise relative to 2000-2004 baseline).

Tide Gauge	Montauk Point				New York City				Troy			
	Percentile											
Time Interval	10th	25th	75th	90th	10th	25th	75th	90th	10th	25th	75th	90th
2020s	2	4	8	10	2	4	8	10	1	3	7	9
2050s	8	11	21	30	8	11	21	30	5	9	19	27
2080s	13	18	39	58	13	18	39	58	10	14	36	54
2100	15	21	47	72	15	22	50	75	11	18	46	71

Figure 15 - New York State Department of Environmental Conservation - Part 490, Projected Sea-Level Rise - Regulatory Impact Statement

Maryland Relative Sea-level Rise	Thermal (m)	Glaciers (m)	Greenland (m)	Antarctica (m)	Dynamic (m)	VLM (m)	Relative SLR meters	Relative SLR feet
2050 best	0.10	0.05	0.03	0.09	0.09	0.075	0.4	1.4
2050 low	0.04	0.05	0.02	0.04	0.07	0.065	0.3	0.9
2050 high	0.19	0.06	0.05	0.16	0.10	0.085	0.7	2.1
2100 best	0.24	0.13	0.10	0.30	0.17	0.15	1.1	3.7
2100 low	0.10	0.12	0.08	0.10	0.13	0.13	0.7	2.1
2100 high	0.46	0.17	0.17	0.58	0.19	0.17	1.7	5.7
Land ice change fingerprint scale factors		0.9	0.5	1.25				

Figure 16 - Scientific and Technical Working Group Maryland Climate Change Commission (2013), Updating Maryland's Sea-level Rise Projections

Table 3.4 Values for a and b Coefficients in Equation 3–1

Scenario (m)	*a* (m/yr)	*b* (m/yr^2)
0.5	1.7×10^{-3}	2.7126200×10^{-5}
1.0	1.7×10^{-3}	6.9993141×10^{-5}
1.5	1.7×10^{-3}	$1.12860082 \times 10^{-4}$
2.0	1.7×10^{-3}	$1.55727023 \times 10^{-4}$

Figure 17 - CARSWG - SERDP (2016), Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme Water Levels for Department of Defense Coastal Sites Worldwide