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SUBJECT: Using Non-NOAA Tide Gauge Records for Computing Relative Sea Level Change

CATEGORY: Guidance

1. References:

- a. Engineer Regulation (ER) 1100-2-8162, Incorporating Sea Level Change in Civil Works Programs, 31 December 2013
- b. ER 1110-2-8160, Policies for Referencing Project Elevation Grades to Nationwide Vertical Datums, 1 March 2009
- c. Engineer Technical Letter (ETL) 1100-2-1, Procedures to Evaluate Sea Level Change, 30 June 2014
- d. Intergovernmental Oceanographic Commission, IOC Manual on Sea Level Measurement and Interpretation (1985-2006) Volumes I-IV, http://www.psmsl.org/train_and_info/training/manuals/
- e. Zervas, C.E. (2009) Sea Level Variations of the United States, 1854-2006. National Oceanic and Atmospheric Administration, U.S. Department of Commerce, National Ocean Service, Center for Operational Oceanographic Products and Services, http://www.co-ops.nos.noaa.gov/publications/Tech_rpt_53.pdf
- f. Veatch, W.C. (2017) 2015 Updated Atlas of U.S. Army Corps of Engineers Historic Daily Tide Data in Coastal Louisiana. Mississippi River Geomorphology and Potamology Report No. 14, <https://erdc-library.erdc.dren.mil/xmlui/bitstream/handle/11681/25484/MRG%26P%20Report%20No%2014.pdf?sequence=1&isAllowed=y>

2. **Purpose.** This ECB outlines concepts and goals, provides guidance, and introduces a tool for estimating relative sea level change (RSLC) using long-term tide gauge records other than National Oceanic and Atmospheric Administration (NOAA) National Water Level Observation Network (NWLON) tide gauges. Examples of long-term non-NOAA tide gauges are those operated by the U.S. Army Corps of Engineers (USACE) or the US Geological Survey (USGS) within the coastal zone.

3. **Background.** ER 1100-2-8162, 31 December 2013, provides detailed procedures for computing RSLC rates based on long-term tidal data, preferably using a tide gauge with at least 40 years of tidal data. Three scenarios of future sea level change are required. These are a low scenario that is the extrapolation of the historical rate of local relative sea level change at the most appropriate tide gauge of the NWLON Stations with at least 40 years of tidal data available

for United States coastal areas, an intermediate scenario, and a high scenario. A web tool that computes the three RSLC scenarios for each of the NWLON stations is available at <http://corpsclimate.us/ccaceslcurves.cfm>. Selection of the station used to compute RSLC is most often based on length of record and proximity to the project area. Where RSLC is highly variable due to complex geological conditions, or for large project areas, the local coverage of NWLON stations may not be sufficient to develop explicit estimates of RSLC at the project area. In these cases, long-term tide gauge records, such as those operated by the USGS or the USACE within the coastal zone, may be used to augment the NWLON stations using the guidelines presented in this ECB.

4. **Objective.** Adaptation to sea level change is a critical component of USACE climate change resilience. Methods and tools such as the one introduced here help reduce uncertainty, improve consistency, and simplify work processes. This ECB establishes a procedure to develop future RSLC scenarios from non-NOAA tide gauges approved for use in USACE CONUS coastal areas where necessary to augment the NWLON gauges with at least 40 years of tidal data. At present, all such gauges are located in the State of Louisiana, though coverage is expected to increase over the next several years. An accompanying web tool (http://www.corpsclimate.us/ccaceslcurves_nn.cfm) is provided to facilitate computation.

5. **Future Expansion.** Future expansion: Additional non-NOAA gauges will be added to this tool over time, after a technical quality evaluation by NOAA. For technical assistance, and to recommend addition of new gauges to the tool, please contact Mark Huber, CE-AGC-GSA, 571-216-0365, Mark.W.Huber@usace.army.mil or Will Veatch, CE-MVN-ED-H, 504-862-2858, William.C.Veatch@usace.army.mil.

6. **Guidance.** For all coastal Civil Works designs and studies that require computations of RSLC through augmentation of NWLON tide gauges, Engineering & Construction (E&C) staff should access the web tool (http://www.corpsclimate.us/ccaceslcurves_nn.cfm) to identify the latest approved non-NOAA tide gauges and to calculate RSLC. If E&C staff plan to augment the NWLON with a tide gauge that is not available in the web tool, the procedures for computing RSLC included as an appendix to this document should be followed. Any questions regarding the appropriateness of tide gauges for use for a specific project area should be referred to the regional NOAA expert.

7. **Update.** All new requirements will be included in the next appropriate policy document update prior the expiration of this ECB.

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8. **Point of Contact.** The point of contact for this ECB is Dr. Kate White, P.E., Lead, Climate Preparedness and Resilience Community of Practice, USACE Headquarters, 202-761-4163, email: Kathleen.D.White@usace.army.mil.

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Appendix A - Instructions for Computing Relative Sea Level Change From Long-Term Non-NOAA Tide Gauges That Are Not Yet Included In The Web Tool

Appendix B - Process to Add Long-Term Non-NOAA Tide Gauges To Web Tool

APPENDIX A

INSTRUCTIONS FOR COMPUTING RELATIVE SEA LEVEL CHANGE FROM LONG-TERM NON-NOAA TIDE GAUGES THAT ARE NOT YET INCLUDED IN THE WEB TOOL

1. Computation of sea level rise from non-NOAA tide gauges that are not yet incorporated in the web tool will incorporate the following concepts:

a. Period of record. The Manual on Sea Level Measurement and Interpretation ([Intergovernmental Oceanographic Commission](#) Volumes I-IV) suggests that a tidal record should be of at least two-tidal epoch duration (about 40 years) before being used to estimate RSLC. Continuous data are preferred, and computing trends from stations with long time gaps in the data record should be avoided if possible. The NOAA [Sea Levels Online](#) web pages and the NOAA Sea Level Variations reports document the effect of record length on the error in the estimated trend. If no gauge near the project area exists with the recommended tidal record, a gauge with a shorter record may be used, but decisions based on such data must recognize the potential for significant uncertainty relative to the computed trend. Please consult a regional NOAA expert for further guidance and recommendations.

b. Consistent Project Datum. For determination of trends, it is critical that the data time series are referenced to a common “zero” datum for the entire time period prior to the calculation. NOAA tidal stations typically compute mean sea level (and changes thereto) relative to an arbitrary station datum, which may be surveyed periodically to determine its relationship to a terrestrial datum (such as NAVD88 or to a tidal datum such as Mean High Water or Mean Sea Level. This relationship may change, but the gauge station datum will be left unchanged to maintain a consistent data record. NOAA documents vertical stability of the water level sensors relative to the station datum using annual leveling surveys to nearby bench marks. USGS gauges are often managed using similar procedures. USACE gauges, in contrast, are often maintained to ensure that they report water level relative to a given terrestrial datum (e.g. NGVD29 or NAVD88). As a result, these gauges may be re-set at a new height when they are referenced to a new datum (e.g. moved from one NGVD adjustment to another or moved from NGVD29 to NAVD88), when a new datum epoch is published (e.g. NAVD88 2004.65), or when surveys indicate that the gauge was previously set in error. To obtain a consistent data record for the purposes of computing changes in mean sea level, it is necessary to properly account for these datum shifts and produce a consistent record relative to a common vertical reference “0” datum.

c. When the dates and magnitudes of the shifts in the record are known and documented as part of the station operations, removal assumes a constant shift, subtracting the change from all data points before the first shift occurred. The same procedure is followed if subsequent shifts occurred. This will result in a continuous record of data measured relative to the datum used in the final recorded time period (the present, in most cases). While there is legitimate reason to be cautious when using older data transformed into a datum plane that did not exist at the time it was collected, review of USACE time series has shown this is acceptable for the purposes of measuring changes in mean sea level (see EM 1110-2-6056 Standards and Procedures for Referencing Project Evaluation Grades to Nationwide Vertical Datums, 31 December 2010). All shifts in datum over the historical record shall be fully documented as part of the background support information for using the gauge.

(1) When the approximate date of a shift is known, but the magnitude is not (e.g. a break in the data is apparent, but no survey records of such a shift exist), the magnitude of the shift may be estimated by fitting best-fit linear trend lines to the data before and after the suspected shift. The difference in value between the two trend lines at the time of the suspected shift may be used as the magnitude of the shift, and then the procedure in the paragraph above may be followed to remove it. Estimating the trend in this way introduces added uncertainty, but is generally superior to ignoring the older data, which was effectively reported relative to an unknown datum. Comparisons with nearby stations can sometimes be used as a quality control check to ensure that no unwanted vertical step changes remain in the time series and to validate measurement system performance over time.

(2) Removal of Hydrologic Influence from Historic Record. Some tidal gauges are located on rivers, estuaries, bays, bayous, or other water bodies that are influenced by discharge from upland runoff, in addition to tidal influence. To compute a rate of change in sea level over time at these locations, the riverine signal must be removed from the data. This is achieved by first creating a stage-discharge rating curve for the gauge of interest. Because stage-discharge relationships can change over time due to factors such as changing channel cross-section, this rating curve should also change over time, for example by computing it over a moving window centered on the observation of interest. The stage-discharge relationship is then used along with discharge measurements to compute the expected value of a given stage observation as a function of river discharge and this value is subtracted from the data record. Once the river signal has been subtracted from each data point, the remaining tidal data record can be assessed for trend in mean sea level. This technique is described in-depth in the latest version of the Atlas of U.S. Army Corps of Engineers Historic Daily Tide Data in Coastal Louisiana (e.g., Veatch 2017), which is also linked from the tool web site (the gauges listed in the tool have already been adjusted for hydrologic influence).

(3) Computation of Sea Level Trends. It is recommended that sea level trends be calculated using the NOAA procedures found in Zervas (2009, page 15-17). Monthly means provide trends with lower standard errors than annual means.

(4) Project Start Date. ER 1100-2-8162 provides equations for computing future sea level change scenarios relative to the year 1992, the midpoint of the most recent published tidal epoch. When using NOAA tide gauges, it is preferable to compute sea level rise relative to 1992, since that is the mean sea level of the current National Tidal Datum Epoch that is related to the station datum, and thus to the terrestrial datum. When using gauges that are already surveyed in to a terrestrial datum, as most USACE gauges are, this is not as important. Nevertheless, the start date of projected sea level change should be consistent throughout a project. If needed, the RSLC between two years can always be computed by subtracting the change since 1992 in one year from the other. Any calculation made for estimating future RSLC must be checked for reasonableness.

APPENDIX B

PROCESS TO ADD LONG-TERM NON-NOAA TIDE GAUGES TO WEB TOOL

1. Additional gauges proposed for inclusion in the long-term tide gauge records used to augment the NWLON stations using the guidelines presented in this ECB shall provide the following metadata for evaluation by the Climate Preparedness and Resilience Community of Practice. Upon acceptance, the gauge information shall be added to the web tool. Here, * indicated required data for the evaluation:

- a. Name*: common name
- b. PID*: unique identifier
- c. State: two-letter state abbreviation
- d. Latitude/Longitude*: position of gauge in decimal degrees (Example: 30.1234/-90.1234)
- e. Relative Sea Level Change Rate*: the total relative sea level change rate including local land movement, expressed in millimeters per year
- f. Local Land Movement: the rate of local land movement expressed in millimeters per year
- g. NAVD88: value of NAVD88 relative to station datum expressed in meters
- h. HAT: value of highest astronomical tide (HAT) relative to station datum expressed in meters
- i. MHHW*: value of mean higher high water (MHHW) relative to station datum expressed in meters
- j. MSL*: value of mean sea level (MSL) relative to station datum expressed in meters
- k. MLLW*: value of mean lower low water (MLLW) relative to station datum expressed in meters
- l. Begin Date*: date at which the period of record begins (dd/mm/yyyy)
- m. End Date*: date at which the period of record ends (dd/mm/yyyy)
- n. Years of Record*: number of years contained in the period of record expressed in decimal years (Example 45.6 yrs)
- o. EWL 100yr: projected 1% probability extreme water level (EWL) high water event expressed in meters

- p. EWL 50yr: projected 2% probability high water event expressed in meters
- q. EWL 20yr: projected 5% probability high water event expressed in meters
- r. EWL 10yr: projected 10% probability high water event expressed in meters
- s. EWL 2yr: projected 50% probability high water event expressed in meters
- t. EWL 1yr: projected 100% probability high water event expressed in meters
- u. EWL Monthly: projected 100% probability high water event expressed in meters
- v. EWL Method: method used to develop EWL probabilities (i.e. model, statistical function such as Generalized Extreme Value distribution)

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