Quality Assurance Project Plan
for
SLAMM Modeling in Casco Bay
by
Warren Pinnacle Consulting, Inc. (WPC)

Prepared for
Casco Bay Estuary Partnership (CBEP)
and
U.S. Environmental Protection Agency (EPA)
Region 1

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WPC Program Manager: Jonathan Clough, Warren Pinnacle Consulting, Inc.

CBEP Director: Curtis Bohlen, Ph.D., Casco Bay Estuary Partnership, University of Southern Maine

EPA Project Manager: Matthew Liebman, Ph.D. Ocean and Coastal Protection Unit, Ocean and Coastal Protection Unit, EPA Region 1

This QAPP is based on the following EPA guidance documents: *Guidance for Quality Assurance Project Plans* (EPA QA/G-5, 2002), *Guidance for Quality Assurance Project Plans for Modeling* (EPA QA/G-5M, 2002), and *QAPP Requirements for Secondary Data Research Projects* (1999).

RFA17107

A. Project Management

A1. Approval Page

8/3/2017
U.S. EPA Quality Assurance Coordinator, Nora Conlon, Ph.D. Date

August 3, 2017
U.S. EPA Region 1 Project Manager, Matthew Liebman, Ph.D. Date

8-3-2017
Casco Bay Estuary Partnership Director, Curtis Bohlen, Ph.D. Date

8-7-2017
WPC Program Manager and Quality Assurance Officer, Jonathan Clough Date

8/7/2017
WPC Model Application Manager, Marco Propato, Ph.D. Date

A2. Table of Contents

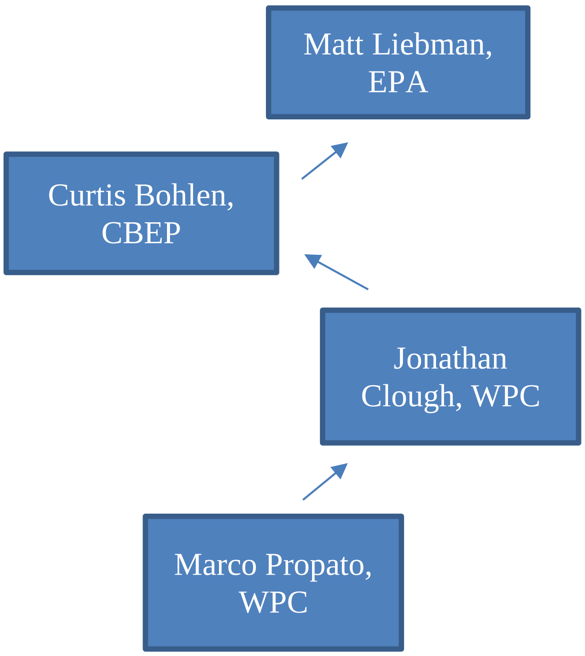
A3. Distribution List

A copy of this QAPP has been distributed to the following individuals:

Nora Conlon	U.S. EPA Quality Assurance Officer
Matthew Liebman	U.S. EPA Region 1 Project Manager
Curtis Bohlen	Casco Bay Estuary Partnership Director
Jonathan S. Clough	President, Warren Pinnacle Consulting, Inc.
Marco Propato	Model Application Manager, Warren Pinnacle Consulting, Inc.

A4. SLAMM Modeling Project Organization

Figure A1: Project Organizational Diagram



Curtis Bohlen, Casco Bay Estuary Partnership Director, will be the overall Project Manager for this project and will report annually to EPA as part of annual reporting requirements of National Estuary Program (NEP) grants. Dr. Bohlen will prepare the final report in collaboration with Mr. Clough.

Matt Liebman, EPA Region 1 Project Manager, will provide National Estuary Program support and EPA grant oversight, and review and approve the QAPP.

Jonathan Clough, Warren Pinnacle Consulting, Inc. Program Manager and Quality Assurance (QA) Officer, will direct all program activities at WPC and will be responsible for ensuring that all elements of the project at WPC comply with the QAPP.

Marco Propato, Warren Pinnacle Consulting, Inc. Research Associate, will be Model Application Manager for this project and will prepare parameter inputs, apply models, and interpret results.

A5. Problem Definition/Background

Casco Bay Estuary Partnership (CBEP) is engaged in on-going efforts to understand the potential effects of climate change on Casco Bay. In 2013, CBEP conducted a study of ten municipalities that line Casco Bay to identify potential areas of marsh migration and possible impacts to existing developed areas due to tidal inundation from sea level rise (Bohlen et al. 2012, Bohlen et al. 2013).

The objectives of this project are to utilize a Sea Level Affecting Marshes Model (SLAMM) to produce projections of the potential effects of sea level rise on the wetland communities of Casco Bay, determine adaptation strategies for marsh conservation and community resilience, and evaluate benefits of each strategy using the Dynamic Marsh Management Tool (DMMT).

The geographic area of coverage of this study is all of the Casco Bay shoreline and some adjacent areas along the Kennebec and along the Spurwink River. This study will also provide in-depth modelling both of sea level rise and of marsh management alternatives for approximately seven targeted study areas. (In contrast, the 2012 study focused on a slightly smaller region, did not develop system-wide statistical estimates of wetland impacts, but focused on 40 selected wetland areas, as representative of regional trends.)

Tidal marshes are among the most susceptible ecosystems to climate change, especially under accelerated sea-level rise (SLR). Rising sea levels may result in tidal marsh submergence and habitat migration as salt marshes transgress landward and replace tidal freshwater and irregularly flooded marshes. In order to identify the most appropriate adaptation strategies for areas near these marshes regarding land use and management, information on how these marshes may respond to SLR is needed.

Changes in tidal marsh area and habitat type in response to sea-level rise will be modeled using the Sea Level Affecting Marshes Model (SLAMM 6). SLAMM accounts for the dominant processes involved in wetland conversion and shoreline modifications during long-term sea-level rise (Park et al. 1989) and has been applied to numerous sites along the U.S. coast (Craft et al. 2009; Galbraith et al. 2002; Glick et al. 2013, 2007; National Wildlife Federation and Florida Wildlife Federation 2006; Park et al. 1993; Titus et al. 1991, Clough et al. 2016) SLAMM is a relatively simple, non-hydrodynamic model that relies on land elevation and tidal range to predict the future of wetland habitats given projected future SLR. It accounts for six primary processes that affect wetland fate in response rising to sea level: inundation, erosion, soil saturation, overwash, accretion, and salinity. Moreover, SLAMM has the capability to model feedbacks between marsh accretion rates and the rate of sea-level rise, considering frequency-of-flooding effects on rates of marsh accretion. The model is capable of including spatial maps of subsidence as well as including the potential effects of storm-generated overwash that may occur on barrier islands. A detailed description of model processes, underlying assumptions, and equations can be found in the SLAMM 6.7 *Technical Documentation* (available at the following URL: http://warrenpinnacle.com/prof/SLAMM).

A6. Project Objectives and Schedule

Objectives

1. SLAMM Modeling

WPC will set up and run a Sea Level Affecting Marshes Model (SLAMM) for the entirety of Casco Bay at a high spatial resolution (5-m cell size) to produce both numerical and map-based projections of the potential effects of sea-level rise on the wetland communities.

Although the base analysis will consider 4-5 unique SLR scenarios, in general SLAMM results will consider the effects of various sources of uncertainties such as input parameters and driving data. Hundreds of model realizations will be run to study the effect of uncertainties and produce predictions of wetland coverage as distributions. This approach enhances the value of the results by providing confidence intervals, worst and best case scenarios, likelihood of wetland to conversion and other statistical indicators useful to better characterize possible future outcomes and thus to assist in decision making.

Significant effort will be devoted in gathering the latest spatial data, input parameters and especially in the calibration step in which the consistency of key SLAMM modeling inputs, such as current land cover, elevations, tide ranges and hydraulic connectivity is tested by running SLAMM at "time zero" with no sea-level rise, accretion or erosion.

There are four specific assumptions included in this process:

- **a.** Previous experience suggests that a cell resolution of 5 m x 5 m is fine enough to provide an elevation layer that effectively describes water paths and captures the presence of roads that may limit or impede free water flow. Roads are typically from 18 to 30 feet wide (5.4 to 9.2 m). Therefore, a 5m resolution DEM appears to be accurate enough to characterize road elevations and thus capture their effects on hydrology. (See section A7 for technical details on the source of the elevation data used in this study).
- **b.** Model setup will consider effects when existing structures such as culverts, ridges and ditches allow tidal flow but tidal amplitude is reduced as inflow and outflow are partially restricted. Adding consideration of muted-tidal areas is important for two reasons. First, a better characterization of tide-inundation elevations improves the delineation of the wet to dry-land boundary. Second, wetlands in muted tidal areas may be more vulnerable to accelerated sea-level rise due to reduced sediment delivery and narrower wetland-elevation ranges. Both of these aspects are important for planning and management purposes. The removal or replacement of current man-made structures that are responsible for observed muted tides is a possible adaptation strategy considered here to improve marsh viability. To assign the correct tidal amplitude, in the absence of available tidal data, land cover and elevation data will be cross examined to manually identify the boundary elevation between wet and dry land. Generally, it is unclear if and how muted tides will change as a result of sea-level rise. Therefore, within the model's uncertainty analysis, the tidal variability in these muted tidal areas will account for this uncertainty by assigning a wide tidal variability.
- **c.** Accretion parameters will be modeled in a realistic fashion by considering feedback with sea level to mimic the capability of the marsh to adapt and respond to increased

inundation. As there is a lot of uncertainty around accretion response to sea level, uncertainty estimation will account for these possible accretion variabilities.

d. In order to reflect the local characteristics of the shoreline and its suitability to accommodate marsh establishment provided sufficient inundation, available information regarding substrate will be incorporated into the model. This feature will not affect current land cover but it will be important to determine future land type conversion of dry land as a result of SLR.

2. Evaluate adaptation strategies

WPC will identify methods that effectively integrate the SLAMM results with other decision making factors to determine proper adaptation strategies for marsh conservation and community resilience. The benefits of each strategy will be evaluated using the Dynamic Marsh Management Tool (DMMT) recently developed by WPC. This tool allows accounting for stakeholder-benefit evaluation, to modify ecosystem benefit quantification, to assess parcels and strategies in an integrated manner, and to include uncertainty in the evaluation process with a flexible time management horizon. Expected-benefit results will be calculated based on several hundred SLAMM realizations with varying input parameters reflecting future SLR uncertainties and also data and model uncertainties.

The projected benefits of three possible adaptation strategies will be considered:

i. *Protection of existing tidal wetlands* – Changes in marsh area ("marsh evolution") will be studied to differentiate marsh systems that are more vulnerable to future SLR from those that are less vulnerable, and thus more likely to continue to provide ecosystem services;

ii. *Protection of land adjacent to wetlands* – The “migration marsh footprint” will be evaluated by allowing marsh to migrate into adjacent area today not occupied by salt marsh. The benefits for allowing marsh migration within parcels will be quantified;

iii. *Restore tidal flow* – Evaluate new benefits as a result of restoring flow by modeling muted-tidal areas using a tide range estimated as the tide before the restriction. By removing these restrictions, it is expected that the additional ecosystem benefits will exist both for the existing marsh footprint (resilience to SLR) and for the areas of marsh migration (potentially expanded).

3. Reporting and Technology Transfer

- WPC will provide tables figures and text required to make transparent all model inputs and assumptions going in to this analysis.
- In addition, WPC will provide the results tables, figures, and maps (listed above and summarized in the figures and tables below) for the entire study area and/or selected sites provided input from CBEP.
- In addition, WPC will provide text for a “conclusions” section of a report that emphasizes two to five “lessons” or “take home messages” from the analysis. CBEP will prepare the final report.
- WPC will ensure that ample time remains on the contract to review and edit any project reporting by CBEP, to answer questions from CBEP, and to assist in presentations.

- WPC will provide training in use of SLAMM and DMMT if requested by CBEP.

Schedule

- WPC will provide initial project results by early September 2017 so they can be made available in a presentation to the CBEP Management Committee.
- WPC will complete all modeling and initial technology transfer by December of 2017.
- WPC will retain some hours to be able to answer questions, to assist in report preparation and presentations following its December 2017 delivery, and to provide training to CBEP.

A7. Quality Objectives and Criteria

It is the intent of this project to use the best available data. Data discovery and evaluation are an implied part of the scope. Quality objectives for input data are described below by Task.

WPC will use an adaptive approach to selecting data for use in SLAMM models. For most model inputs, WPC has a default data source derived from nationally available data (e.g., the National Wetlands Inventory). Where related local data is available (e.g., CBEP's Fringing Marsh Data), WPC evaluates the quality of that data and considers whether and how best to use it to improve model performance. After review, local data may be used in lieu of the default data, combined with it, used to guide interpretation of model results, or not used at all. The decision on whether and how to use local data is based on review of the data, comparison with other data (considering area of coverage, resolution, timespan, consistency with aerial imagery, and local knowledge), and best professional judgment. Local data will be incorporated into the modeling effort when, in the judgment of WPC, its use will enhance model performance.

Task 1: Collection of Input Parameter Data

WPC shall collect precise and recently derived input parameters to apply to SLAMM for all Study Areas.

Subtask 1.1: Collection of Input Parameter Data

WPC shall use local NOAA gauges as a primary source of data regarding tide ranges, frequency-of-inundation analysis, and historic SLR rates. Where appropriate, these shall be supplemented with other tide gauge data when available. Supplemental (local) data will be used only when its incorporation improves model performance. Where feasible, taking into consideration the time involved in incorporating alternative data sources into SLAMM model runs, relative model performance can be judged by comparing "time zero" model outputs with aerial imagery, site visits or local knowledge.

WPC shall gather erosion and accretion rates through a literature search and a search of data-sources from local agencies and researchers. High quality modern data on accretion rates in tidal wetlands (for example, multi-year data records collected with RSETs) is rare in Maine. WPC will search for the best available data from the Gulf of Maine region, and select data to use to guide modeling efforts based on quality and length of the data record, and geographic proximity to Casco Bay. WPC has so far identified high quality accretion data from Plum Island and Acadia National Park.

Task 1 Deliverables:

- List of model-input parameters, and data sources used

Task 2: Collection and Preparation of Spatial Input Data

WPC shall collect recent and precise spatial data covering the Study Areas, and shall then prepare the raster inputs for subsequent SLAMM analysis.

Subtask 2.1: Creation of Precise and Up-to-Date Input Rasters
WPC shall collect the necessary spatial data and create the following data layers. The data sources listed shall be used unless otherwise directed by CBEP.

Wetland Layer. WPC shall derive the SLAMM wetland layer from the National Wetland Inventory (NWI), supplemented by CBEP's 'Fringing Marsh" data (Hayes et al. 2008) and the Maine Tidal Marshes layer to better define the areas covered by wetland.

Elevation Layer. WPC seeks the most recent and comprehensive LiDAR elevation data available for the Study Area. LiDAR Coverage for Casco Bay and surrounding areas were accessed from the NOAA Data Access viewer (https://coast.noaa.gov/dataviewer/#/lidar/search/). The NOAA data viewer was used to download 5 m resolution digital elevation models (DEM) for the region based on multiple sources of LiDAR data. WPC assembled those layers into a single DEM. Nominal vertical accuracy of the source data ranged from 5 to 20 cm RMSE, with 16.5 cm RMSE for the majority of the study area.

Slope Layer. WPC shall use the digital elevation models constructed from the LiDAR data to create the data layer describing slope profiles of the Study Areas.

Dikes and Impoundments. WPC shall discern any wetlands protected by dikes and impoundments from the NWI data layer and other local data sources. CBEP will share both local knowledge and an existing catalog of known tidal restrictions (unpublished data) with WPC. The tidal restrictions data identifies known impoundments adjacent to Casco Bay. WPC shall further contact local agencies to ensure completeness.

Impervious Layer. WPC shall derive this layer from the 1 m resolution imperviousness layer based on 2007 imagery integrated with road and railroad data, all available from the Maine Office of GIS

Elevation Datum correction. WPC shall use the NOAA VDATUM product to convert elevation data from an NAVD88 to a tidal vertical datum.

Subtask 2.2: Preparation of Input Rasters
Once the spatial layers are assembled and updated, WPC shall convert all the datasets collected above to a common raster format using GIS Software with a 5 m cell-size.

Task 2 Deliverables:
- Input GIS maps/data layers (GeoTIFF) for the study area
- Metadata for each spatial layer

Task 3: SLAMM Simulations

WPC shall run a series of SLAMM deterministic and uncertainty simulations.

Subtask 3. 1: Model Calibration
WPC shall test the consistency between the conceptual model and available wetland, elevation, and tidal data. WPC shall run an elevation analysis producing histograms of wetland elevations as a function of tide ranges to evaluate the consistency with SLAMM model assumptions.

In particular, tidal muted areas (areas with reduced tidal amplitude due to restricted tidal flow) will be closely examined and calibrated.

Muted areas will be identified based on (1) local knowledge, (2) CBEP's existing catalog of tidal restriction sites (unpublished data), and (3) comparison of base land cover data and aerial photography (showing existing conditions) with land cover predicted for present sea level conditions during preliminary model runs. Significant discrepancies between observed and modeled conditions suggest locations where inundation does not match expectation based on elevation, a strong indicator of tidal muting.

To assign the correct tidal amplitude in tidal muted areas, WPC will make use of local data where available. Where local data is not available, land cover and elevation data will be cross examined to manually identify the boundary elevation between wet and dry land. Model calibrations will be set to match.

Local data may include data derived from the Casco Bay Fish Passage Survey (Craig and Abbott. 2012; data available on-line through the Maine Stream Habitat Viewer), and prior CBEP studies of tidal restriction (unpublished data), and CBEP studies of tidal hydrology at selected tidal restriction sites (also unpublished). These data may include:
- hydrological records derived from placement of pressure transducers ("data loggers") into tidal channels, whether referenced to a vertical datum or not;
- Physical characteristics of culverts or other structures crossing tidal wetlands or tidal channels;
- Other data as available.

Subtask 3.2: Evaluation of Input Data Uncertainties

WPC shall record the uncertainty of input parameters and data layers during the model set-up phase. WPC shall assess and numerically characterize the uncertainty in all model parameters, along with uncertainty in future rates of SLR and elevation-data errors.

Subtask 3.3: Model Simulations

WPC shall run simulation scenarios under up to five different SLR projections, as directed by CBEP, with predicted outputs for years as directed by CBEP (e.g. 2030, 2050, 2080, and 2100). Specific SLR values shall be determined upon consultation with CBEP prior to running the model simulations. Three sets of model simulations will be produced:

i. Protection of existing tidal wetlands
ii. Protection of land adjacent to wetlands
iii. Restore tidal flow

Subtask 3.4: Set Up and Run Model Simulations in Uncertainty Analysis Mode

WPC shall undertake a stochastic uncertainty analysis, producing hundreds of model outputs. WPC shall then assemble the individual model realizations into probability distributions of possible wetland coverage. WPC shall run uncertainty simulations with predicted outputs for the years 2030, 2050, and 2080. WPC shall produce maps showing the likelihood of land-cover change and the predicted vulnerability of each model cell. Confidence intervals shall be derived for all model acreage predictions. Uncertainty Analysis simulations will be run for each of the three model simulation sets listed in 3.3 above (Protect existing tidal wetlands, Protect adjacent land, and Restore tidal flow).

Subtask 3.5: Analysis of Results

WPC shall use a series of semi-automated data processing steps to efficiently consolidate and visualize the data output by SLAMM, developing other required tools as needed. These include numerical processing of the projections using spreadsheets that calculate the overall percentage of wetland lost/gain under each scenario for the entire time period of simulation and the total area covered by each wetland category at each time step for each scenario. In addition, maps shall be produced to visually analyze projected coverage for each time step and scenario.

Task 3 Deliverables:

- GIS maps/data layers (GeoTIFF) corresponding to each model simulation for each of the following:
  - SLAMM base simulation results
  - Percent likelihood maps derived from uncertainty simulations
- Tables summarizing:
  - Numerical results of land cover and predicted changes of each wetland category
  - Uncertainty statistics

Task 4: Assess Ecosystem Benefits of Management Strategies

The Dynamic Marsh Management Tool (DMMT – recently developed by WPC) will be used to provide policymakers with a way to integrate data with respect to sea-level rise, marsh migration pathways and relative costs, and social impacts of each marsh parcel. Information in the tool will be derived based on stakeholder values, which will be obtained through a survey that is designed by WPC but will be filled out by or administered by CBEP in a workshop or on line.

The DMMT can summarize results from individual marshes or geographic locations and comparatively examine marsh fate, ecosystem benefits, and the effects of management strategies on each location in the list. If CBEP wishes to do this, CBEP will provide WPC with 5-10 unique locations to evaluate comparatively in the DMMT. This will be provided by shapefile (preferentially) or by written demarcations on a map.

SLAMM-results data for all adaptation strategies derived in task 3 will be fed back through the DMMT to assess the relative increase in value produced by each of the management techniques examined.

Task 4 Deliverables:

- WPC will design an on-line survey to ascertain stakeholder values regarding the importance of ecosystem services and site-specific information regarding ecosystem services (e.g. https://www.surveymonkey.com/r/NYSERDASLAMM_NYC)
- A spreadsheet-based tool that allows users to examine different stakeholder values or different input assumptions on outputs will be created and delivered (e.g. the draft tool for New York City available at: http://warrenpinnacle.com/prof/SLAMM/NYSERDA2015/NYSERDA_Tool_42_NYC.xlsm)
- WPC will render a number of informative graphics and graphs from the DMMT tool and provide text helping to interpret their meaning. At a minimum, graphs to examine ecosystem benefits over time will be produced and the relative effects of different adaptation strategies on ecosystem benefits.
- Written discussion will be produced regarding the relative increase in wetland value predicted under each management tool, using the metrics defined in the creation of the DMMT.

Quality objectives for output data:
Output data (model results) should be free of gross error, as confirmed via QA/QC review. In addition, results should lie within reasonable ranges, and be free of unexplained artifacts. GIS data layers will be rendered and examined to identify, and either correct or document any artifacts or discrepancies from typical model results encountered in other runs of the model. Practices for achieving these quality objectives are described in section C1 and Appendix B.

A8. Training & Experience

All key personnel have extensive training and experience in their respective roles and responsibilities.

A9. Documentation

The Project Manager/CBEP Director will be responsible for assuring that all project personnel have the most recent version of the QAPP, any amendments to the QAPP and any updates. All project personnel will be notified by email by the Project Manager when changes are made to the QAPP.

During the project, it is possible that changes will occur and amendments or revisions to the QAPP may be required. Revisions may be necessary to reflect changes in project organization, tasks, schedules, objectives, and methods; address deficiencies and nonconformance; to improve operational efficiency; and/or to accommodate unique or unanticipated circumstances. Requests for Amendments/Revisions will be made by CBEP to EPA via email. Any changes that significantly affect the technical and quality objectives of the project will require a revision and re-approval of the QAPP, and a revised copy will be sent to all persons on the distribution list.

B. Data Acquisition

This section will discuss secondary data and quality control with respect to the data requirements; the acceptance criteria for data; and the importance of data tracking and archiving. It is important to note that this project does not propose any primary data acquisition, data development, sampling, or measurement. All the project inputs will be derived from secondary (existing) data.

B1. Data Requirements

Detailed descriptions of the input data required are listed in both the SLAMM technical documentation (http://warrenpinnacle.com/prof/SLAMM6/SLAMM_6.7_Technical_Documentation.pdf) and the SLAMM user's manual (http://warrenpinnacle.com/prof/SLAMM6/SLAMM_6.7_Users_Manual.pdf). The level of precision, accuracy, completeness, representativeness, and comparability (for definitions see Section F, Appendix) achievable for the model inputs is dictated by the available data.

There is no specific set of thresholds for data acceptability. The SLAMM model has been under development since the mid-1980s and is therefore capable of running in data rich or data poor environments. However, with the uncertainty-analysis procedure we will quantify the effects of data precision on model predictions and output-data uncertainty. Furthermore, initial examination finds the proposed study area to have high-quality data for the most important data sources for the model (land elevations, wetlands maps, and tide range information.)

B2. Types, Sources, and Quality of Input Data

SLAMM accepts several types of input data, which may come from a variety of sources, often requiring unit conversions, and with differing quality assurance, even in the same study.

At a minimum the project will use the most current public-domain datasets as described in A.7. above, augmented or replaced with data that may be discovered by the project team or made available to the project by Stakeholders or other related/interested parties that is determined to be of higher quality or otherwise enhances the project. The rationale for using the listed data sources is that the data are of known consistency and origin, and in many cases have a proven utility for

SLAMM modeling on previous projects. The rationale for augmenting with additional data is that such data may be more recent, more descriptive, of higher spatial resolution, and/or may reflect more local knowledge of environmental conditions that are not reflected in the more "standardized" public domain data. Ultimately, this project can be run and the model can be developed from datasets identified through the public domain as discussed above, but our team remains interested in augmenting this dataset with higher-quality data whenever possible.

Input data can be divided into parameter and spatial categories:

Parameter Input Data:

- Local NOAA gauges are the primary source of data regarding tide ranges, frequency-of-inundation analyses, and historic SLR rates. These shall be supplemented with other tide gauge data where available. In order to keep track of the potential applicability of the tide data available through NOAA, the analysis period /period of record will be recorded for each tidal measurement used. Frequency of inundation analyses will be carried out using multiple years of the most recent high/low water level data available.
- Erosion and accretion rates will be determined through a literature search and a search of data-sources from local agencies and researchers.
- Nearly all parameters may be represented by distributions when the model is run in uncertainty mode. Distributions may be based on multiple values to be found in parameter sources.

Data selection shall be quality controlled via WPC's internal peer-review and contact with local experts. WPC shall use peer-reviewed data exclusively and data from federal databases unless given direction from the CBEP Project Manager to use an alternative. All input data shall be subject to quality assurance as defined in this QAPP.

Spatial Input Data:

As discussed in A.7, the spatial data requirements to support this project include:

- Wetland,
- Elevation,
- Slope,
- Dikes and impoundments, and
- Impervious (developed) regions.

In general, data that is more recent is preferred; however, data consistency across the study area and the richness of content may occasionally have higher priority than temporal accuracy. For example, wetlands data with rich attribution may be preferred over very accurate high resolution wetlands data with only rudimentary attribution.

B3. Acceptance Criteria for Data

The identified sources and peer-reviewed scientific literature will be reviewed based on their relevance to the task. Selected sources will include well established organizations, academic institutions, or government agencies in the field of water resources management.

As datasets are compiled and post-processed, an independent technical review of each dataset shall be performed to ensure that there are no visible errors in the input data.

Each input data source, including any additional or supplemental data discovered during the course of the project, will be evaluated by at least two different members of the project team to determine the appropriateness for use of the data, including an evaluation of the spatial and temporal resolution, completeness of the data (i.e., gaps in coverage or level of content detail).

All geospatial input datasets shall be reviewed in accordance with the following QC checklist:

- Metadata availability and completeness
- Unit Consistency
- Spatial Reference System
- Spatial coverage/extent (i.e., data gaps)
- Grid size and tiling consistency
- NODATA values in Rasters
- Attribute consistency

All final geospatial input datasets will be derived from existing sources. In some cases inputs may represent a combination or hybrid of existing data. As such both the final input and the final output GIS data will adhere to the requirements set by the EPA's National Geospatial Data Policy (NGDP). Specifically, each digital data layer will be accompanied by supporting documentation that includes data source information (i.e., scale and accuracy, map projection, coordinate system, etc.), and specific information about the data layer itself (i.e., method used, geographic extent of data layer, file format, date of creation, staff contact, description and definition of data fields and their contents, related files, if any, and description of data quality and quality assurance methods used). The EPA Metadata Editor (EME) will be used as the tool for streamlining production of required metadata.

<u>DISCLAIMER</u>

In accordance with the QAPP REQUIREMENTS FOR SECONDARY DATA RESEARCH PROJECTS, a disclaimer similar to the following should be used for all derived input and model output data:

> *"These data are derived from source data of varying quality to include accuracy, precision, and completeness. As such no warrantee or representation is made as to the applicability or suitability of this data for any implied or specified use other than that for which it was originally intended."*

B4. Model Calibration

Initially, SLAMM simulates a "time zero" step, in which the consistency of model assumptions for wetland elevations is validated with respect to available wetland coverage information, elevation data, and tidal frames. This step allows for site-specific calibration/validation of the SLAMM conceptual model.

Due to simplifications within the SLAMM conceptual model, DEM and wetland layer uncertainty, or other local factors, some cells may fall below their lowest allowable elevation category and would be immediately converted by the model to a different land cover category (e.g. an area categorized in the wetland layer as swamp where water has a tidal regime according to its elevation and tidal information will be converted to a tidal marsh). These cells represent outliers on the distribution of elevations for a given land-cover type.

Model calibration will be completed for each of the project sites. A threshold tolerance of up to 5% change will be allowed for in major land cover categories (those comprising over five percent of initial land cover). When initial calibration results are inconsistent with available wetland coverage, the model is adjusted as follows. First, wetland coverages are amended where satellite imagery shows that inundation has already occurred, or where site-specific knowledge confirms that wetland coverage should be indeed amended. Second, the tidal range domain in the affected area can be adjusted to better reflect the local conditions. The layer designating which areas are protected by dikes may also be replaced if more high-quality local data is available.

Future predictions of wetland changes will be compared to SLAMM time-zero results so that model results are showing the predicted effect of a sea-level rise signal, and are not reflective of model and data uncertainty.

Uncertainty will not be assessed during model calibration; instead a stochastic uncertainty analysis will be carried out on model projections to provide uncertainty bounds on model results.

B5. System Documentation and Archiving

Through the use of text-based log files, the draft report, and the final report, the following information will be documented, as applicable:

- underlying model assumptions
- parameter values and sources
- boundary conditions used in the model
- limiting conditions on model applications, including details on where the model is or is not suited
- actual input data (type and format) used
- overview of the immediate (non-manipulated or -post processed) results of the model runs
- output of model runs and interpretation
- documentation of significant changes to the model (not likely relevant)

Model inputs will be organized through: databases of parameters, GIS-based parameter projects as well as log files and reports describe parameter sources and selection rationale.

Model inputs and outputs will be archived in .zip directories at both the draft and final model implementation phases. These directories will be placed on an FTP site maintained by WPC as well on local WPC backup for a minimum of 7 years.

C. Model Application

C1. Assessment and Response Actions

A QC checklist shall be completed by the QA Officer and shall include the steps described in Appendix B. An electronic Quality Control Log will be generated and stored in a directory with the SLAMM project file. The QC Log will document the findings of each of the steps described in Appendix B with actions need and taken to rectify any issues discovered. The log files will be archived with the SLAMM projects and available upon request.

All model forecast results shall be investigated prior to the data analysis step. GIS data layers will be rendered and examined to ensure they are artifact free. Visible model artifacts will be corrected if possible. If it is not possible to correct these artifacts they will be identified and explained.

Any results that fall outside of typical model results encountered from previous runs of the model will be examined and the reason for these differences will be identified. These outlying model results will either be remedied or fully documented as to why they represent the most likely outcome given the SLR being simulated.

Observations noted in this step will be shared with key project personnel. A summary of this assessment will be included in the modeling report. GIS data layers will be rendered and examined to ensure they are artifact free.

Both maps and numeric data will be used to assess the “time zero” step for model calibration as described in section B4.

CBEP may implement, at their discretion, various audits or reviews of this project to assess conformance and compliance to the Quality Assurance Project Plan (QAPP).

D. Data Validation and Usability

D1. Data Review, Verification, and Usability

Model results will be examined for consistency and accepted based on the criteria outlined in Section A7 of this QAPP. Any questionable results shall be identified and investigated prior to the data analysis step. GIS data layers will be rendered and examined to ensure they are artifact free.

Uncertainty in model results will be assessed through the application of the SLAMM uncertainty module. Maps and tables of output data, along with the confidence statistics for model results provided by the uncertainty-analysis module will be provided to CBEP. Given substantial uncertainty in SLR forecasts, model results are inherently contingent. Appropriate use of model results will be tempered by understanding of model uncertainties. Documenting model uncertainty can minimize risk of over- or under-interpreting deterministic model results. Furthermore, understanding uncertainty has value in its own right. Knowledge of sources and magnitude of uncertainty may also suggest areas for future data collection that would have the most substantial impact on reducing uncertainty or guiding future policy choices.

D2. Reconciliation with User Requirements

Quality objectives are addressed in this QAPP for both data acquisition (Section B) and modeling development and application (Section C). Acceptance criteria for data and model calibration were selected to ensure achievement of the quality objectives. If there are irreconcilable discrepancies from the quality criteria, the ability of the model to achieve quality objectives and provide accurate output might be compromised. Under such circumstances, the consultant will confer with EPA to determine if the quality discrepancies could still allow user requirements to be met. If not, then a plan to address the issue will be developed to ensure model quality and user satisfaction.

E. Literature Cited

Bohlen, C., Stelk, M., Craig, M., Redmond, L., and Gerber, C. (2012) Geomorphology and the effects of sea level rise on tidal marshes in Casco Bay. Casco Bay Estuary Partnership. http://www.cascobayestuary.org/publication/geomorphology-effects-sea-level-rise-tidal-marshes-casco-bay/

Bohlen, C., Stelk, M., Craig, M., and Gerber, C. (2013). Sea level rise and Casco Bay's wetlands: A look at potential impacts. Casco Bay Estuary Partnership (10 reports, by coastal municipality). http://www.cascobayestuary.org/resources/publications/2013-sea-level-rise-and-casco-bays-wetlands-reports/

Clough, J., Polaczyk, A., and Propato, M. (2016). “Modeling the potential effects of sea-level rise on the coast of New York: Integrating mechanistic accretion and stochastic uncertainty.” *Environmental Modelling & Software*, 84, 349–362.

Craft, C., Clough, J. S., Ehman, J., Joye, S., Park, R. A., Pennings, S., Guo, H., and Machmuller, M. (2009). “Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services.” *Frontiers in Ecology and the Environment*, 7(2), 73–78.

Craig, M., and Abbott, A. (2012). Casco Bay Watershed Fish Passage Barrier Priorities Atlas. Casco Bay Estuary Partnership. http://www.cascobayestuary.org/wp-content/uploads/2014/08/2012_fish_barrier_atlas_final.pdf

Galbraith, H., Jones, R., Park, R., Clough, J., Herrod-Julius, S., Harrington, B., and Page, G. (2002). “Global Climate Change and Sea Level Rise: Potential Losses of Intertidal Habitat for Shorebirds.” *Waterbirds*, 25(2), 173.

Glick, P., Clough, J., and Nunley, B. (2007). *Sea-level Rise and Coastal Habitats in the Pacific Northwest: An Analysis for Puget Sound, Southwestern Washington, and Northwestern Oregon*. National Wildlife Federation.

Glick, P.; Clough, J.; Polaczyk, A.; Couvillion, B., and Nunley, B., 2013. Potential effects of sea-level rise on coastal wetlands in southeastern Louisiana. In: Brock, J.C.; Barras, J.A., and Williams, S.J. (eds.), Understanding and Predicting Change in the Coastal Ecosystems of the Northern Gulf of Mexico, Journal of Coastal Research, Special Issue No. 63, pp. 211–233, Coconut Creek (Florida), ISSN 0749-0208.

Hayes, P., Carr, R., Dionne, M. (2008). Project Report: Mapping and Restoration Inventory of Fringing Marshes in the Casco Bay Estuary. Wells National Estuarine Research Reserve, prepared for Casco Bay Estuary Partnership. http://www.cascobayestuary.org/wp-content/uploads/2014/08/2008_fringing_marsh_report.pdf

National Wildlife Federation and Florida Wildlife Federation. (2006). *An Unfavorable Tide: Global Warming, Coastal Habitats and Sportfishing in Florida*.

Park, R. A., Lee, J. K., and Canning, D. J. (1993). “Potential Effects of Sea-Level Rise on Puget Sound Wetlands.” *Geocarto International*, 8(4), 99.

Park, R. A., Trehan, M. S., Mausel, P. W., and Howe, R. C. (1989). “The Effects of Sea Level Rise on U.S. Coastal Wetlands.” *The Potential Effects of Global Climate Change on the*

United States: Appendix B - Sea Level Rise, U.S. Environmental Protection Agency, Washington, DC, 1–1 to 1–55.

Titus, J. G., Park, R. A., Leatherman, S. P., Weggel, J. R., Greene, M. S., Mausel, P. W., Brown, S., Gaunt, C., Trehan, M., and Yohe, G. (1991). "Greenhouse effect and sea level rise: the cost of holding back the sea." *Coastal Management*, 19(2), 171–204.

F. Appendices

Appendix A – Definition of Terms

Because it is not always clear how QAPP terms are defined, the following is taken from a memo by Solomon et al. (2001) on the terms and definitions from the EPA Guidance for Quality Assurance Project Plans, EPA QA/G-5 EPA/600/R-98/018:

> Accuracy — The measure of the closeness of an individual measurement or the average of a number of measurements to the true value. Accuracy includes a combination of random error (precision) and systematic error (bias) components that are due to sampling and analytical operations; the EPA recommends using the terms "precision" and "bias", rather than "accuracy," to convey the information usually associated with accuracy.
>
> Bias — The systematic or persistent distortion of a measurement process, which causes errors in one direction (i.e., the expected sample measurement is different from the sample's true value).
>
> Precision — A measure of mutual agreement among individual measurements of the same property, usually under prescribed similar conditions expressed generally in terms of the standard deviation.
>
> Representativeness — Representativeness is a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point or for a process condition or environmental condition. Representativeness is a qualitative term that should be evaluated to determine whether in-situ and other measurements are made and physical samples collected in such a manner that the resulting data appropriately reflect the media and phenomenon measured or studied.
>
> Comparability — Comparability is the qualitative term that expresses the confidence that two data sets can contribute to a common analysis and interpolation. Comparability must be carefully evaluated to establish whether two data sets can be considered equivalent in regard to the measurement of a specific variable or groups of variables.

Appendix B—Quality Assurance Checklist

QA/QC Checklist:

- examination of derived wetland layers as compared to satellite photography
- examination of all derived parameters and spatial averaging techniques
- examination of "time-zero" model results (model calibration/validation)
- analysis of wetland elevation ranges against conceptual model
- quality assurance of output to ensure model results are reasonable and logical given the interplay between accretion rates and rates of sea-level rise
- examination of maps for any artifacts from the model or input data
- review of maps and tables of output data from the uncertainty analysis