Application of the Sea-Level Affecting Marshes Model (SLAMM 5.1) to Martin NWR

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Introduction

Tidal marshes are among the most susceptible ecosystems to climate change, especially accelerated sea level rise (SLR). The International Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) suggested that global sea level will increase by approximately 30 cm to 100 cm by 2100 (IPCC 2001). Rahmstorf (2007) suggests that this range may be too conservative and that the feasible range by 2100 could be 50 to 140 cm. Pfeffer et al. (2008) suggests that 200 cm by 2100 is at the upper end of plausible scenarios due to physical limitations on glaciological conditions. Rising sea level may result in tidal marsh submergence (Moorhead and Brinson 1995) and habitat migration as salt marshes transgress landward and replace tidal freshwater and Irregularly Flooded marsh (Park et al. 1991).

In an effort to address the potential effects of sea level rise on United States national wildlife refuges, the U. S. Fish and Wildlife Service contracted the application of the SLAMM model for most Region 5 refuges. This analysis is designed to assist in the production of comprehensive conservation plans (CCPs) for each refuge along with other long-term management plans.

Model Summary

Changes in tidal marsh area and habitat type in response to sea-level rise were modeled using the Sea Level Affecting Marshes Model (SLAMM 5.0) that accounts for the dominant processes involved in wetland conversion and shoreline modifications during long-term sea level rise (Park et al. 1989; www.warrenpinnacle.com/prof/SLAMM).

Successive versions of the model have been used to estimate the impacts of sea level rise on the coasts of the U.S. (Titus et al., 1991; Lee, J.K., R.A. Park, and P.W. Mausel. 1992; Park, R.A., J.K. Lee, and D. Canning 1993; Galbraith, H., R. Jones, R.A. Park, J.S. Clough, S. Herrod-Julius, B. Harrington, and G. Page. 2002; National Wildlife Federation et al., 2006; Glick, Clough, et al. 2007; Craft et al., 2009.

Within SLAMM, there are five primary processes that affect wetland fate under different scenarios of sea-level rise:

| • | Inundation: | The rise of water levels and the salt boundary are tracked by reducing elevations of each cell as sea levels rise, thus keeping mean tide level (MTL) constant at zero. The effects on each cell are calculated based on the minimum elevation and slope of that cell. |
|---|-------------|---|
| • | Erosion: | Erosion is triggered based on a threshold of maximum fetch and the proximity of the marsh to estuarine water or open ocean. When these conditions are met, horizontal erosion occurs at a rate based on site- specific data. |
| • | Overwash: | Barrier islands of under 500 meters width are assumed to undergo overwash during each 25-year time-step due to storms. Beach migration and transport of sediments are calculated. |
| • | Saturation: | Coastal swamps and fresh marshes can migrate onto adjacent uplands as a response of the fresh water table to rising sea level close to the coast. |

• Accretion: Sea level rise is offset by sedimentation and vertical accretion using average or site-specific values for each wetland category. Accretion rates may be spatially variable within a given model domain.

SLAMM Version 5.0 is the latest version of the SLAMM Model, developed in 2006/2007 and based on SLAMM 4.0. SLAMM 5.0 provides the following refinements:

- The capability to simulate fixed levels of sea-level rise by 2100 in case IPCC estimates of sealevel rise prove to be too conservative;
- Additional model categories such as "Inland Shore," "Irregularly Flooded (Irregularly Flooded) Marsh," and "Tidal Swamp."
- *Optional.* In a defined estuary, salt marsh, Irregularly Flooded marsh, and tidal fresh marsh can migrate based on changes in salinity, using a simple though geographically-realistic salt wedge model. This optional model was not used in this model application.

Model results presented in this report were produced using SLAMM version 5.0.1 which was released in early 2008 based on only minor refinements to the original SLAMM 5.0 model. Specifically, the accretion rates for swamps were modified based on additional literature review. For a thorough accounting of SLAMM model processes and the underlying assumptions and equations, please see the SLAMM 5.0.1 technical documentation (Clough and Park, 2008). This document is available at http://warrenpinnacle.com/prof/SLAMM

All model results are subject to uncertainty due to limitations in input data, incomplete knowledge about factors that control the behavior of the system being modeled, and simplifications of the system (CREM 2008).

Sea Level Rise Scenarios

SLAMM 5 was run using scenario A1B from the Special Report on Emissions Scenarios (SRES) – mean and maximum estimates. The A1 scenario assumes that the future world includes very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. In particular, the A1B scenario assumes that energy sources will be balanced across all sources. Under the A1B scenario, the IPCC WGI Fourth Assessment Report (IPC, 2007) suggests a likely range of 0.21 to 0.48 meters of sea level rise by 2090-2099 "excluding future rapid dynamical changes in ice flow." The A1B-mean scenario that was run as a part of this project falls near the middle of this estimated range, predicting 0.40 meters of global sea level rise by 2100.

The latest literature (Chen et al., 2006, Monaghan et al., 2006) indicates that the eustatic rise in sea levels is progressing more rapidly than was previously assumed, perhaps due to the dynamic changes in ice flow omitted within the IPCC report's calculations. A recent paper in the journal *Science* (Rahmstorf, 2007) suggests that, taking into account possible model error, a feasible range by 2100 might be 50 to 140 cm. Pfeffer et al. (2008) suggests that 2 meters by 2100 is at the upper end of plausible scenarios due to physical limitations on glaciological conditions. A recent US intergovernmental report states "Although no ice-sheet model is currently capable of capturing the glacier speedups in Antarctica or Greenland that have been observed over the last decade, including these processes in models will very likely show that IPCC AR4 projected sea level rises for the end of the 21st century are too low." (US Climate Change Science Program, 2008) A recent paper by

Grinsted et. al. (2009) states that "sea level 2090-2099 is projected to be 0.9 to 1.3 m for the A1B scenario, with low probability of the rise being within Intergovernmental Panel on Climate Change (IPCC) confidence limits."

To allow for flexibility when interpreting the results, SLAMM was also run assuming 1 meter, $1\frac{1}{2}$ meters, and 2 meters of eustatic sea-level rise by the year 2100. The A1B- maximum scenario was scaled up to produce these bounding scenarios (Figure 1).



Figure 1: Summary of SLR Scenarios Utilized

Additional information on the development of the SLAMM model is available in the technical documentation, which may be downloaded from <u>the SLAMM website</u> (Clough and Park, 2008).

Methods and Data Sources

For the model simulation of Martin NWR the best elevation data were a combination of high vertical resolution LiDAR data and lower resolution data derived from USGS topo maps. Both LiDAR and non-LiDAR data were gathered from the one-arc-second National Elevation Dataset (NED). The LiDAR data have a flight date of 2003 and the topo data are based on a 1997 map. The USGS quad for the refuge indicates that all the land in the map is below 5 feet of elevation meaning there is high uncertainty as to elevations in that region. LiDAR data covers some western and southern portions of the refuge (Figure 1). However, high resolution elevation data does not actually cover all areas indicated within the metadata (Figure 2). As a result, any land that was not covered with LiDAR was "preprocessed" by SLAMM using wetland types and tidal ranges.



Figure 1: Indicated LiDAR coverage (darker green polygon)



Figure 2: Actual LiDAR coverage (white within green polygon). All other data are derived from USGS contours.

The National Wetlands Inventory for Martin is based on photo dates of 1981, 1988 and 1990.

Converting the NWI survey into 30 meter cells indicates that the approximately four thousand three hundred acre refuge (approved acquisition boundary including water) is composed of the categories as shown below:

| Regularly Flooded Marsh | 41.5% |
|---------------------------|-------|
| Irregularly Flooded Marsh | 39.0% |
| Estuarine Open Water | 13.6% |
| Estuarine Beach | 4.0% |

There are no diked wetlands in the Martin NWR according to the National Wetlands Inventory.

The historic trend for sea level rise was estimated 4.97 mm/year using a NOAA gage (8636760, Lewisetta, VA). The rate of sea level rise for this refuge is more than twice the global average for the last 100 years (approximately 1.7 mm/year).

Eustatic projections of future sea level rise were further increased by 0.5 mm/year as a result of a study performed by Dr. Victoria Coles of University of Maryland (Figure 3). This study suggests that sea level rise in Chesapeake Bay will increase faster than eustatic trends due to regional heating, freshwater effects, or mass adjustments. Based on this analysis an additional 0.5 mm/year were added to eustatic sea level rise trends. (This adjustment was performed by adding 0.5 mm/year to the historic SLR trend parameter.)



Figure 3: Adjustment of Eustatic SLR in SLAMM illustrated as red line. Source of model results, Dr. Victoria Coles Research Web Page, 11/15/2009, <u>http://hpl.umces.edu/vcoles/cbayclim-sl.htm</u>.

Several different erosion values were used for this site, varying spatially (Figure 4, Figure 5). Marsh and tidal flat erosion values for the majority of the site, were set to 1.8 meters per year and 1.6 meters per year, respectively (Reed et al., 2008). Based on available data, erosion values were set to 2.43 meters per year for sub-sites 12 and 14 and to 1.83 meters per year for sub-sites 13 and 15.



Figure 4: Erosion values used for Martin. Source of erosion values are Towson University, Coastal Atlas v1.1, Center for GIS at Towson University, http://cgis.towson.edu.

The tidal range for the Martin NWR was determined to be 0.552 meters using a NOAA gage (8572955, Ewell, Smith Island, MD) (Figure 6).



Figure 5: Model sub-sites.



Figure 6: NOAA Gage Relevant to the Study Area.

Accretion rates in regularly flooded marshes were set to 5.2 mm/year, irregularly flooded marshes to 5.33 mm/year and tidal fresh to 7.2 mm/year. The regularly flooded marsh accretion value was determined using local study in the Deal Island Management Area, which is located northeast of Martin NWR (Rooth et al, 2000). The irregularly flooded marsh accretion value was determined from three studies, two from Monie Bay and one from Nanticoke River Estuary (Rooth et al., 2000; Kearney, 1986, Kearney et al., 1991; Ward et al., 1998).

The MTL to NAVD correction was derived using the NOAA VDATUM modeling product. The correction varies by sub-site, and was determined to range from -0.063 meters to -0.085 meters.

Modeled U.S. Fish and Wildlife Service refuge boundaries for Maryland are based on Approved Acquisition Boundaries as published on the FWS National Wildlife Refuge Data and Metadata website. The cell-size used for this analysis was 30 meter by 30 meter cells. The SLAMM model also tracks partial conversion of cells based on elevation and slope.

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As mentioned above, in areas where LiDAR coverage does not exist (the majority of the site), the SLAMM pre-processor was used to estimate elevation ranges for wetlands. This is important because the non-LiDAR elevations for the site were based on very little input data (essentially, interpolation between contour lines that did not exist.) The SLAMM processor sets elevation ranges based on known relationships between wetlands elevations and tidal ranges. However, based on the site's LiDAR data, the elevation ranges of regularly flooded and irregularly flooded marshes were allowed to range to twice the SLAMM-default elevations.

The relationship between tidal ranges and vertical marsh elevation ranges tends to be more uncertain within microtidal environments. Fortunately LiDAR data were present to examine and refine these assumptions.

| Parameter | Global | Sub-site 2 | Sub-site 9 | Sub-site 10 | Sub-site 15 |
|-------------------------------------|--------------|------------|------------|-------------|-------------|
| Description | Chessy North | Martin | Martin1 | Martin2 | Sub-site 15 |
| NWI Photo Date (YYYY) | 2000 | 1981 | 1988 | 1990 | 1981 |
| DEM Date (YYYY) | 2000 | 1997 | 2003 | 1997 | 2003 |
| Direction Offshore [n,s,e,w] | East | East | East | East | North |
| Historic Trend (mm/yr) | 4.8 | 5.47 | 5.47 | 5.47 | 5.47 |
| MTL-NAVD88 (m) | -0.05 | -0.063 | -0.07 | -0.085 | -0.085 |
| GT Great Diurnal Tide Range (m) | 0.58 | 0.552 | 0.552 | 0.552 | 0.552 |
| Salt Elev. (m above MTL) | 0.385 | 0.367 | 0.367 | 0.367 | 0.367 |
| Marsh Erosion (horz. m /yr) | 1.8 | 1.8 | 1.8 | 1.8 | 1.8288 |
| Swamp Erosion (horz. m /yr) | 1 | 1 | 1 | 1 | 1 |
| T.Flat Erosion (horz. m /yr) | 6 | 6 | 6 | 6 | 1.8288 |
| Reg. Flood Marsh Accr (mm/yr) | 6 | 5.2 | 5.2 | 5.2 | 5.2 |
| Irreg. Flood Marsh Accr (mm/yr) | 4.8 | 5.33 | 5.33 | 5.33 | 5.33 |
| Tidal Fresh Marsh Accr (mm/yr) | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 |
| Beach Sed. Rate (mm/yr) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Freq. Overwash (years) | 25 | 25 | 25 | 25 | 25 |
| Use Elev Pre-processor [True,False] | TRUE | TRUE | FALSE | TRUE | TRUE |

SUMMARY OF SLAMM INPUT PARAMETERS FOR MARTIN NWR

| Parameter | Sub-site 11 | Sub-site 12 | Sub-site 13 | Sub-site 14 |
|-------------------------------------|-------------|-------------|-------------|-------------|
| Description | Martin3 | Sub-site 12 | Sub-site 13 | Sub-site 14 |
| NWI Photo Date (YYYY) | 1981 | 1981 | 1981 | 1981 |
| DEM Date (YYYY) | 2003 | 2003 | 2003 | 2003 |
| Direction Offshore [n,s,e,w] | South | West | West | West |
| Historic Trend (mm/yr) | 5.47 | 5.47 | 5.47 | 5.47 |
| MTL-NAVD88 (m) | -0.085 | -0.085 | -0.085 | -0.085 |
| GT Great Diurnal Tide Range (m) | 0.552 | 0.552 | 0.552 | 0.552 |
| Salt Elev. (m above MTL) | 0.367 | 0.367 | 0.367 | 0.367 |
| Marsh Erosion (horz. m /yr) | 1.8 | 2.4384 | 1.8288 | 2.4384 |
| Swamp Erosion (horz. m /yr) | 1 | 1 | 1 | 1 |
| T.Flat Erosion (horz. m /yr) | 6 | 2.4384 | 1.8288 | 2.4384 |
| Reg. Flood Marsh Accr (mm/yr) | 5.2 | 5.2 | 5.2 | 5.2 |
| Irreg. Flood Marsh Accr (mm/yr) | 5.33 | 5.33 | 5.33 | 5.33 |
| Tidal Fresh Marsh Accr (mm/yr) | 7.2 | 7.2 | 7.2 | 7.2 |
| Beach Sed. Rate (mm/yr) | 0.5 | 0.5 | 0.5 | 0.5 |
| Freq. Overwash (years) | 25 | 25 | 25 | 25 |
| Use Elev Pre-processor [True,False] | FALSE | FALSE | FALSE | FALSE |

Results

SLAMM predicts Martin NWR to be extremely vulnerable to the effects of sea level rise. In a scenario of under 70cm of eustatic SLR, 95% of regularly flooded marsh is predicted lost; 100% is predicted lost in scenarios of 1 meter or more. Loss for irregularly flooded marsh, which comprises roughly 40% of the refuge, is predicted to be even more extreme, with 90% loss in the least extreme scenario and 100% loss in all other scenarios.

| SLR by 2100 (m) | 0.39 | 0.69 | 1 | 1.5 | 2 |
|---------------------------|------|------|------|------|------|
| Regularly Flooded Marsh | 30% | 95% | 100% | 100% | 100% |
| Irregularly Flooded Marsh | 90% | 100% | 100% | 100% | 100% |
| Estuarine Beach | 100% | 100% | 100% | 100% | 100% |

Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

Maps of SLAMM input and output to follow will use the following legend:



Martin Raster IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

| | Initial | 2025 | 2050 | 2075 | 2100 |
|---------------------------|---------|--------|--------|--------|--------|
| Dry Land | 1311.7 | 1296.9 | 1263.0 | 1198.1 | 1128.7 |
| Irregularly Flooded Marsh | 585.3 | 557.3 | 552.1 | 550.6 | 546.6 |
| Estuarine Open Water | 101.0 | 113.3 | 129.0 | 137.0 | 147.2 |
| Swamp | 44.7 | 44.1 | 43.8 | 43.1 | 40.7 |
| Tidal Swamp | 18.7 | 18.7 | 18.3 | 16.9 | 15.2 |
| Inland Open Water | 17.3 | 17.3 | 17.1 | 16.2 | 13.6 |
| Dev. Dry Land | 4.2 | 4.2 | 2.9 | 0.7 | 0.1 |
| | | | | | |
| Trans. Salt Marsh | 3.3 | 11.9 | 41.4 | 74.6 | 80.9 |
| Inland Fresh Marsh | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 |
| Regularly Flooded Marsh | 2.4 | 23.6 | 18.3 | 49.8 | 115.6 |
| Tidal Flat | 0.0 | 1.4 | 2.9 | 1.7 | 0.1 |
| Total (incl. water) | 2091.8 | 2091.8 | 2091.8 | 2091.8 | 2091.8 |





Martin NWR, Initial Condition





Martin NWR, 2025, Scenario A1B Mean





Martin NWR, 2050, Scenario A1B Mean





Martin NWR, 2075, Scenario A1B Mean





Martin NWR, 2100, Scenario A1B Mean

Martin Raster IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

| | Initial | 2025 | 2050 | 2075 | 2100 |
|---------------------------|---------|--------|--------|--------|--------|
| Dry Land | 1311.7 | 1288.7 | 1214.8 | 1105.6 | 1016.3 |
| Irregularly Flooded Marsh | 585.3 | 552.5 | 548.5 | 502.6 | 251.9 |
| Estuarine Open Water | 101.0 | 120.2 | 137.9 | 159.7 | 286.2 |
| Swamp | 44.7 | 43.9 | 43.3 | 39.6 | 36.0 |
| Tidal Swamp | 18.7 | 18.7 | 17.0 | 13.9 | 8.2 |
| Inland Open Water | 17.3 | 17.3 | 16.5 | 13.6 | 9.6 |
| Dev. Dry Land | 4.2 | 4.1 | 1.3 | 0.0 | 0.0 |
| | | | | | |
| Trans. Salt Marsh | 3.3 | 19.6 | 80.4 | 117.1 | 94.0 |
| Inland Fresh Marsh | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 |
| Regularly Flooded Marsh | 2.4 | 21.5 | 26.3 | 136.3 | 375.6 |
| Tidal Flat | 0.0 | 2.2 | 2.7 | 0.4 | 10.9 |
| Total (incl. water) | 2091.8 | 2091.8 | 2091.8 | 2091.8 | 2091.8 |





Martin NWR, Initial Condition





Martin NWR, 2025, Scenario A1B Maximum





Martin NWR, 2050, Scenario A1B Maximum





Martin NWR, 2075, Scenario A1B Maximum





Martin NWR, 2100, Scenario A1B Maximum

Martin Raster 1 Meter Eustatic SLR by 2100

Results in Acres

| | Initial | 2025 | 2050 | 2075 | 2100 |
|---------------------------|---------|--------|--------|--------|--------|
| Dry Land | 1311.7 | 1272.8 | 1158.4 | 1029.2 | 940.5 |
| Irregularly Flooded Marsh | 585.3 | 550.3 | 525.8 | 201.3 | 44.0 |
| Estuarine Open Water | 101.0 | 122.4 | 143.9 | 209.3 | 586.1 |
| Swamp | 44.7 | 43.8 | 41.6 | 36.4 | 33.1 |
| Tidal Swamp | 18.7 | 18.3 | 15.4 | 8.4 | 5.5 |
| Inland Open Water | 17.3 | 17.3 | 15.3 | 9.6 | 9.1 |
| Dev. Dry Land | 4.2 | 3.5 | 0.1 | 0.0 | 0.0 |
| | | | | | |
| Trans. Salt Marsh | 3.3 | 36.3 | 122.8 | 135.3 | 93.5 |
| Inland Fresh Marsh | 3.1 | 3.1 | 3.1 | 2.9 | 1.6 |
| Regularly Flooded Marsh | 2.4 | 21.5 | 63.6 | 454.9 | 295.4 |
| Tidal Flat | 0.0 | 2.4 | 1.7 | 4.6 | 83.0 |
| Total (incl. water) | 2091.8 | 2091.8 | 2091.8 | 2091.8 | 2091.8 |





Martin NWR, Initial Condition





Martin NWR, 2025, 1 meter





Martin NWR, 2050, 1 meter





Martin NWR, 2075, 1 meter





Martin NWR, 2100, 1 meter

Martin Raster 1.5 Meters Eustatic SLR by 2100

Results in Acres

| | Initial | 2025 | 2050 | 2075 | 2100 |
|---------------------------|---------|--------|--------|--------|--------|
| Dry Land | 1311.7 | 1236.0 | 1072.0 | 939.9 | 846.3 |
| Irregularly Flooded Marsh | 585.3 | 546.3 | 277.9 | 36.4 | 12.3 |
| Estuarine Open Water | 101.0 | 122.5 | 153.7 | 445.8 | 860.4 |
| Swamp | 44.7 | 43.5 | 38.1 | 33.0 | 29.9 |
| Tidal Swamp | 18.7 | 17.2 | 11.0 | 5.4 | 2.6 |
| Inland Open Water | 17.3 | 17.3 | 11.6 | 9.1 | 8.7 |
| Dev. Dry Land | 4.2 | 2.1 | 0.0 | 0.0 | 0.0 |
| | | | | | |
| Trans. Salt Marsh | 3.3 | 74.6 | 173.0 | 139.6 | 97.4 |
| Inland Fresh Marsh | 3.1 | 3.1 | 3.0 | 0.8 | 0.1 |
| Regularly Flooded Marsh | 2.4 | 26.7 | 349.4 | 420.3 | 166.6 |
| Tidal Flat | 0.0 | 2.4 | 2.0 | 61.6 | 67.5 |
| Total (incl. water) | 2091.8 | 2091.8 | 2091.8 | 2091.8 | 2091.8 |





Martin NWR, Initial Condition





Martin NWR, 2025, 1.5 meter




Martin NWR, 2050, 1.5 meter





Martin NWR, 2075, 1.5 meter





Martin NWR, 2100, 1.5 meter

Martin Raster 2 Meters Eustatic SLR by 2100

Results in Acres

| | Initial | 2025 | 2050 | 2075 | 2100 |
|---------------------------|---------|--------|--------|--------|--------|
| Dry Land | 1311.7 | 1196.5 | 1005.3 | 873.0 | 774.9 |
| Irregularly Flooded Marsh | 585.3 | 528.8 | 80.7 | 15.7 | 5.3 |
| Estuarine Open Water | 101.0 | 122.8 | 173.9 | 577.0 | 978.5 |
| Swamp | 44.7 | 42.9 | 35.4 | 30.9 | 24.4 |
| Tidal Swamp | 18.7 | 16.4 | 7.0 | 3.2 | 1.3 |
| Inland Open Water | 17.3 | 17.1 | 9.6 | 8.7 | 8.7 |
| Dev. Dry Land | 4.2 | 0.7 | 0.0 | 0.0 | 0.0 |
| | | | | | |
| Trans. Salt Marsh | 3.3 | 115.8 | 200.3 | 139.1 | 105.0 |
| Inland Fresh Marsh | 3.1 | 3.1 | 2.5 | 0.1 | 0.0 |
| Regularly Flooded Marsh | 2.4 | 45.4 | 573.4 | 269.1 | 151.4 |
| Tidal Flat | 0.0 | 2.4 | 3.9 | 175.0 | 42.5 |
| Total (incl. water) | 2091.8 | 2091.8 | 2091.8 | 2091.8 | 2091.8 |





Martin NWR, Initial Condition





Martin NWR, 2025, 2 meters





Martin NWR, 2050, 2 meters





Martin NWR, 2075, 2 meters





Martin NWR, 2100, 2 meters

Discussion

The future existence of Martin NWR is called into question based on these model results. A combination of low marsh elevations and a microtidal regime make this refuge particularly vulnerable to sea level rise.

Marsh vertical accretion rates may respond positively to an increase in Sea Level Rise which could result in some additional marsh resilience. However, such resilience may be limited by sediment supply. Stevenson and Kearney write (2008) "Coastal wetlands on the western shore of Chesapeake Bay generally have more potential for input of sediment due to higher elevations of surrounding landscape resulting in a greater energy gradient. The generalization has been that the marshes on the western shore of Chesapeake Bay have been keeping abreast of relative sea-level rise." This is not true, however, for sites closer to the eastern shore such as Martin NWR.

The majority of this study site is not covered with LiDAR data and this increases model uncertainty. However, elevation ranges for marshes were estimated based on LiDAR data and the portion of the refuge covered with LiDAR data appears to be equally vulnerable.

Within SLAMM initial condition maps, the sharp linear boundaries between regularly and irregularly flooded marsh are apparently the result of different NWI coverages in different USGS quads. This inconsistency adds some uncertainty to model results, as it is unclear whether regularly or irregularly flooded marsh should be dominant in this NWR.



References

- Boesch, D.R., Greer, J., (Eds.), 2003. *Chesapeake Futures, Choices for the 21st Century*. Scientific and Technical Advisory Committee publ. no. 03-001, Chesapeake Research Consortium, Edgewater, Maryland, USA.
- Cahoon, D.R., J. W. Day, Jr., and D. J. Reed, 1999. "The influence of surface and shallow subsurface soil processes on wetland elevation: A synthesis." *Current Topics in Wetland Biogeochemistry*, 3, 72-88.
- Chen, J. L., Wilson, C. R., Tapley, B. D., 2006 "Satellite Gravity Measurements Confirm Accelerated Melting of Greenland Ice Sheet" *Science* 2006 0: 1129007
- Clark, J. S. and W. A. Patterson III. 1984. Pollen, Pb-210 and sedimentation in the intertidal environment. Journal of Sedimentary Petrology 54(4):1249-1263.
- Clough, J.S. and R.A. Park, 2007, *Technical Documentation for SLAMM 5.0.1* February 2008, Jonathan S. Clough, Warren Pinnacle Consulting, Inc, Richard A. Park, Eco Modeling. http://warrenpinnacle.com/prof/SLAMM
- Craft C, Clough J, Ehman J, Guo H, Joye S, Machmuller M, Park R, and Pennings S. Effects of Accelerated Sea Level Rise on Delivery of Ecosystem Services Provided by Tidal Marshes: A Simulation of the Georgia (USA) Coast. *Frontiers in Ecology and the Environment.* 2009; 7, doi:10.1890/070219
- Council for Regulatory Environmental Modeling, (CREM) 2008. Draft guidance on the development, evaluation, and application of regulatory environmental models P Pascual, N Stiber, E Sunderland -Washington DC: Draft, August 2008
- Erwin, RM, GM Sanders, DJ Prosser, and DR Cahoon. 2006. High tides and rising seas: potential effects on estuarine waterbirds. Pages 214-228 in: Terrestrial Vertebrates of Tidal Marshes: Evolution, Ecology, and Conservation (R. Greenberg, J. Maldonado, S. Droege, and M.V. McDonald, eds.). Studies in Avian Biology No. 32, Cooper Ornithological Society.
- Glick, Clough, et al. Sea-level Rise and Coastal Habitats in the Pacific Northwest An Analysis for Puget Sound, Southwestern Washington, and Northwestern Oregon July 2007 http://www.nwf.org/sealevelrise/pdfs/PacificNWSeaLevelRise.pdf
- IPCC, 2001: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K.Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.
- Kearney, M.S. and L.G. Ward. 1986. Accretion rates in brackish marshes of a Chesapeake Bay estuarine tributary. Geo-Marine Letters 6: 41–49.
- Kearney, M.S. and J.C. Stevenson. 1991. Island land loss and marsh vertical accretion rate evidence for historical sea-level changes in Chesapeake Bay. Journal of Coastal Research 7(2): 403– 415.

- Lee, J.K., R.A. Park, and P.W. Mausel. 1992. Application of Geoprocessing and Simulation Modeling to Estimate Impacts of Sea Level Rise on the Northeast Coast of Florida. *Photogrammetric Engineering and Remote Sensing* 58:11:1579-1586.
- Meehl GA, Stocker TF, Collins WD, Friedlingstein P, Gaye AT, Gregory JM, Kitoh A, Knutti R, Murphy JM, Noda A, Raper SCB, Watterson IG, Weaver AJ and Zhao ZC. 2007. Global climate projections. Pp. 747-845. In: Solomon S, Qin, D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor, M and Miller HL, (eds.) *Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.
- Monaghan, A. J. *et al*, 2006 "Insignificant Change in Antarctic Snowfall Since the International Geophysical Year" *Science* 2006 313: 827-831.
- National Wildlife Fed 'n et al., An Unfavorable Tide: Global Warming, Coastal Habitats and Sportfishing in Florida 4, 6 (2006). http://www.targetglobalwarming.org/files/AnUnfavorableTideReport.pdf
- Park, R.A., J.K. Lee, and D. Canning. 1993. Potential Effects of Sea Level Rise on Puget Sound Wetlands. *Geocarto International* 8(4):99-110.
- Park, R.A., M.S. Trehan, P.W. Mausel, and R.C. Howe. 1989a. The Effects of Sea Level Rise on U.S. Coastal Wetlands. In *The Potential Effects of Global Climate Change on the United States: Appendix B - Sea Level Rise,* edited by J.B. Smith and D.A. Tirpak, 1-1 to 1-55. EPA-230-05-89-052. Washington, D.C.: U.S. Environmental Protection Agency.
- Park, RA, JK Lee, PW Mausel and RC Howe. 1991. Using remote sensing for modeling the impacts of sea level rise. *World Resources Review* 3:184-220.
- Pfeffer, Harper, O'Neel, 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. *Science*, Vol. 321, No. 5894. (5 September 2008), pp. 1340-134
- Rahmstorf, Stefan 2007, "A Semi-Empirical Approach to Projecting Future Sea-Level Rise," *Science* 2007 315: 368-370.
- Reed, D.J., D.A. Bishara, D.R. Cahoon, J. Donnelly, M. Kearney, A.S. Kolker, L.L. Leonard, R.A. Orson, and J.C. Stevenson, 2008: "Site-Specific Scenarios for Wetlands Accretion in the Mid-Atlantic Region. Section 2.1" in *Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise*, J.G. Titus and E.M. Strange (eds.), EPA430R07004, Washington, DC: U.S. EPA. http://www.epa.gov/climatechange/effects/downloads/section2_1.pdf
- Rooth, J.E. and J.C. Stevenson. 2000. Sediment deposition patterns in Phragmites australis communities: Implications of coastal areas threatened by rising sea- level. Wetland Ecology and Management 8:173–183.
- Stevenson and Kearney, 2008, "Impacts of Global Climate Change and Sea-Level Rise on Tidal Wetlands" Pending chapter of manuscript by University of California Press.

- Stevenson, Rooth, Sundberg, and Kearney, 2002, "The Health and Long Term Stability of Natural and Restored Marshes in Chesapeake Bay" in *Concepts and Controversies in Tidal Marsh Ecology*, Springer Netherlands.
- Titus, J.G., R.A. Park, S.P. Leatherman, J.R. Weggel, M.S. Greene, P.W. Mausel, M.S. Trehan, S. Brown, C. Grant, and G.W. Yohe. 1991. Greenhouse Effect and Sea Level Rise: Loss of Land and the Cost of Holding Back the Sea. *Coastal Management* 19:2:171-204.
- United States Fish and Wildlife Service. 2009. Martin National Wildlife Refuge: Draft Comprehensive Conservation Plan and Environmental Assessment.
- Ward, L.G., M.S. Kearney, and J C. Stevenson. 1998. Variations in sedimentary environments and accretionary patterns in estuarine marshes undergoing rapid submergence, Chesapeake Bay. Marine Geology 151: 111–134.

Appendix A: Contextual Results

The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated dry lands will convert to marshes or ocean beach depending on their proximity to open ocean.

For this reason, an area larger than the boundaries of the USFWS refuge was modeled. These results maps are presented here with the following caveats:

- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to assess the probable location and effects of dikes for USFWS refuges, but this effort was not made for surrounding areas.

Application of the Sea-Level Affecting Marshes Model (SLAMM 5.1) to Martin NWR



Location of Martin National Wildlife Refuge (white area) within simulation context









Martin NWR, 2075, Scenario A1B Mean



Martin NWR, 2100, Scenario A1B Mean





Martin NWR, 2025, Scenario A1B Maximum



Martin NWR, 2050, Scenario A1B Maximum



Martin NWR, 2075, Scenario A1B Maximum



Martin NWR, 2100, Scenario A1B Maximum





Martin NWR, 2025, 1 meter



Martin NWR, 2050, 1 meter



Martin NWR, 2075, 1 meter







Martin NWR, 2025, 1.5 meter



Martin NWR, 2050, 1.5 meter



Martin NWR, 2075, 1.5 meter






Martin NWR, 2025, 2 meter



Martin NWR, 2050, 2 meter





Martin NWR, 2100, 2 meter