Application of the Sea-Level Affecting Marshes Model (SLAMM 5.1) to Target Rock 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 8 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 sea-level 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, brackish 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

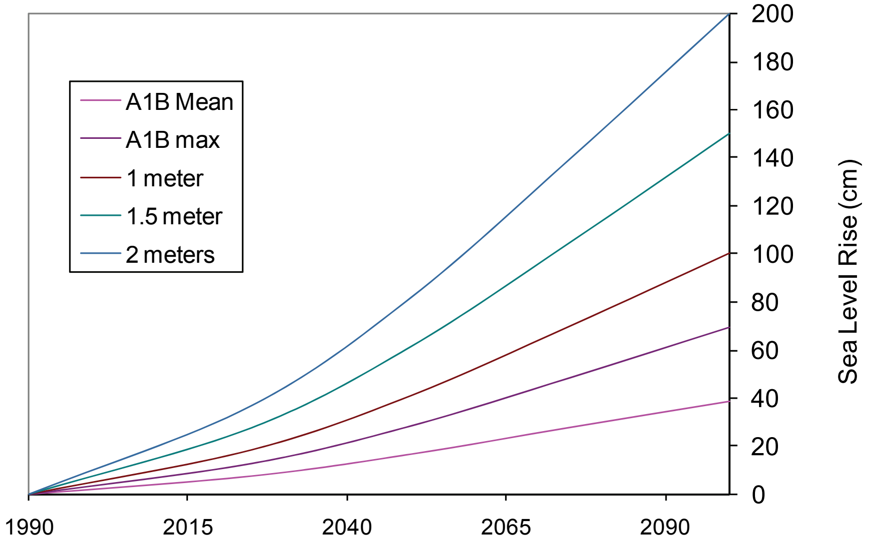
SLAMM 5 was run using scenario A1B from the Special Report on Emissions Scenarios (SRES) – mean and maximum estimates. The A1 scenario assumes that the future world includes very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of 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, 1½ 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 the SLAMM website (Clough and Park, 2008).

Methods and Data Sources

LIDAR data were not publicly available for Target Rock NWR, so the elevation data used are based entirely on National Elevation Data (NED). NED metadata indicates that this digital elevation map (DEM) was derived from a 1931 survey with 20 foot contour intervals (Figure 2). For this site, the elevation data are of particularly low quality, therefore the SLAMM elevation pre-processor was used to estimate elevation ranges for wetlands and beaches but dry land elevations were not adjusted.

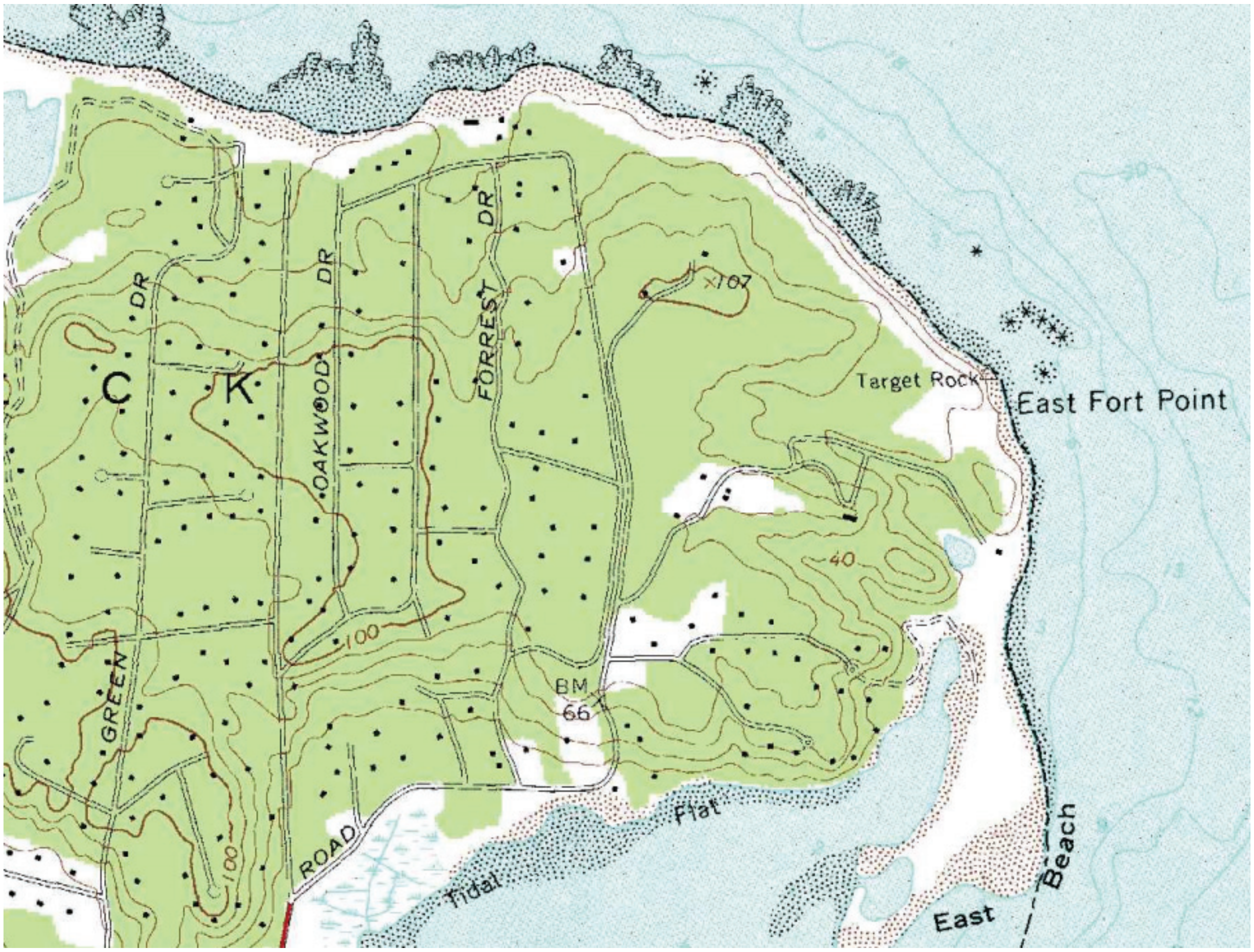


Figure 2: Detail of Target Rock NWR from USGS topographic map.

The National Wetlands Inventory for Target Rock is based on a photo date of 1981 (Figure 3).

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

Dry Land	94.0%
Estuarine Beach	2.6%
Irregularly Flooded Marsh	2.0%
Estuarine Open Water	0.9%
Dev. Dry Land	0.3%
Regularly Flooded Marsh	0.3%

The irregularly flooded (brackish) marshes in the Target Rock NWR are protected by dikes according to the National Wetlands Inventory (Figure 3).

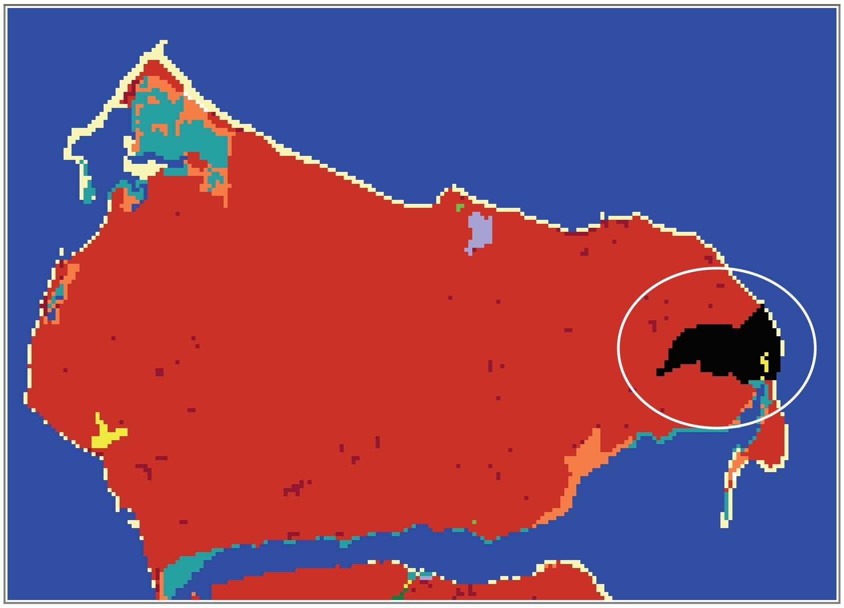


Figure 3: Target Rock Refuge in Black. Diked Wetlands in Yellow.

The historic trend for sea level rise was estimated at 2.44 mm/year (8514560, Port Jefferson, New York). This rate is slightly higher than the global average for the last 100 years (approximately 1.5-2.0 mm/year).

The tidal range for the Target Rock NWR is estimated at 2.318 meters (Figure 4) using tidal data from the closest gages (8515921, Lloyd Harbor Lighthouse, NY).

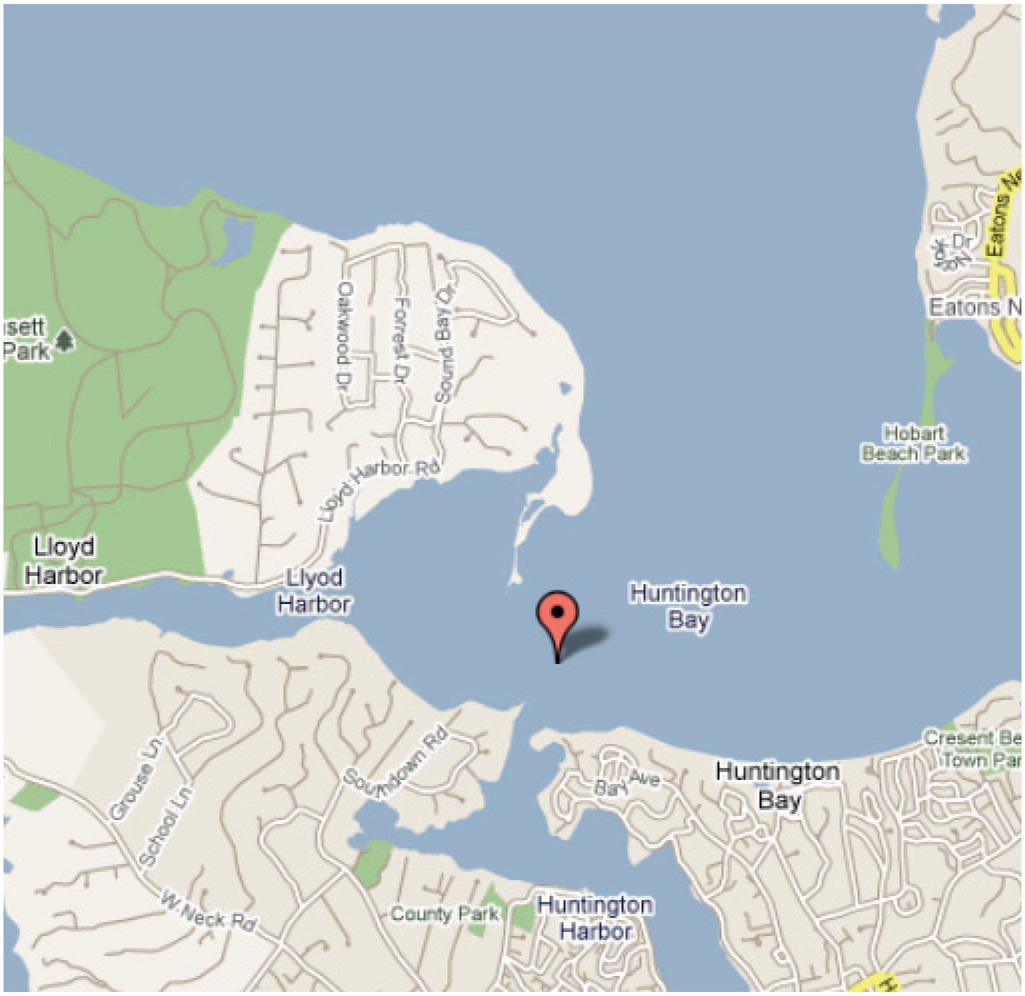


Figure 4: NOAA Gage Relevant to the Study Area.

Accretion rates in regularly flooded and irregularly flooded marshes were set to 3.05 mm/year (Clark & Patterson, 1984). This value was taken from a study done in nearby Fresh Pond – about 11 kilometers east along the shore of Long Island Sound -- where accretion rates for regularly flooded marsh measured between 1.8 and 4.3 mm/year.

The MTL to NAVD correction was derived using the NOAA VDATUM modeling product. Multiple geographic points were input into VDATUM to produce several corrections in the study area. These ranged from between -0.0596 and -0.0598 meters. The resulting datum adjustment is an average of these values.

Contact with the refuge manager did not reveal any additional sources of local parameter data.

Modeled U.S. Fish and Wildlife Service refuge boundaries for New York 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. Additionally, the SLAMM model does track partial conversion of cells based on elevation and slope.

SUMMARY OF SLAMM INPUT PARAMETERS FOR TARGET ROCK NWR

Description	**,**	Target Rock
DEM Source Date (yyyy)	,	2004
NWI_photo_date (yyyy)	,	1931
Direction_OffShore (N|S|E|W)	,	E
Historic_trend (mm/yr)	,	2.44
NAVD88_correction (MTL-NAVD88 in meters)	,	-0.0597
Water Depth (m below MLW- N/A)	*,*	2
TideRangeOcean (meters: MHHW-MLLW)	,	2.318
TideRangeInland (meters)	,	2.318
Mean High Water Spring (m above MTL)	,	1.541
MHSW Inland (m above MTL)	,	1.541
Marsh Erosion (horz meters/year)	,	1.8
Swamp Erosion (horz meters/year)	,	1
TFlat Erosion (horz meters/year) [from 0.5]	,	0.5
Salt marsh vertical accretion (mm/yr) Final	,	3.05
Irregularly Flooded March vert. accretion (mm/yr) Final	,	3.05
Tidal Fresh vertical accretion (mm/yr) Final	,	5.9
Beach/T.Flat Sedimentation Rate (mm/yr)	,	0.5
Frequency of Large Storms (yr/washover)	,	35
Use Elevation Preprocessor for Wetlands	,	TRUE

Results

Effects of sea level rise vary across land categories. Loss of dry land, which constitutes the majority of this site, is not predicted to be more than 4% in the most extreme sea level rise scenario. Loss of estuarine beach, which makes up roughly 3% of the refuge, is predicted between 6% and 68% across all scenarios. Irregularly flooded marsh is not predicted to suffer any losses as the dike that protects it is assumed to be sufficiently maintained or built up if required.

SLR by 2100 (m)	0.39	0.69	1	1.5	2
Dry Land	0%	1%	2%	3%	4%
Estuarine Beach	6%	14%	24%	43%	68%
Irregularly Flooded Marsh	0%	0%	0%	0%	0%

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:

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

Results in Acres

	Initial	2025	2050	2075	2100
Undev. Dry Land	73.6	73.6	73.6	73.5	73.3
Estuarine Beach	2.0	2.0	2.0	1.9	1.9
Irregularly Flooded Marsh	1.6	1.6	1.6	1.6	1.6
Estuarine Open Water	0.7	0.7	0.7	0.8	0.8
Dev. Dry Land	0.2	0.2	0.2	0.2	0.2
Regularly Flooded Marsh	0.2	0.2	0.2	0.2	0.2
Trans. Salt Marsh	0.0	0.0	0.1	0.2	0.3
Total (incl. water)	**78.3**	**78.3**	**78.3**	**78.3**	**78.3**

Target Rock NWR, Initial Condition

Target Rock NWR, 2025, Scenario A1B Mean

Target Rock NWR, 2050, Scenario A1B Mean

Target Rock NWR, 2075, Scenario A1B Mean

Target Rock NWR, 2100, Scenario A1B Mean

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

Results in Acres

	Initial	2025	2050	2075	2100
Undev. Dry Land	73.6	73.6	73.5	73.2	72.9
Estuarine Beach	2.0	2.0	1.9	1.8	1.7
Irregularly Flooded Marsh	1.6	1.6	1.6	1.6	1.6
Estuarine Open Water	0.7	0.7	0.8	0.9	1.0
Dev. Dry Land	0.2	0.2	0.2	0.2	0.2
Regularly Flooded Marsh	0.2	0.2	0.2	0.2	0.2
Trans. Salt Marsh	0.0	0.0	0.1	0.4	0.7
Total (incl. water)	**78.3**	**78.3**	**78.3**	**78.3**	**78.3**

Target Rock NWR, Initial Condition

Target Rock NWR, 2025, Scenario A1B Maximum

Target Rock NWR, 2050, Scenario A1B Maximum

Target Rock NWR, 2075, Scenario A1B Maximum

Target Rock NWR, 2100, Scenario A1B Maximum

Target Rock Raster
1 Meter Eustatic SLR by 2100

Results in Acres

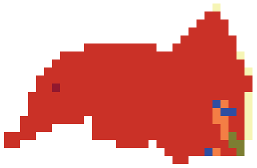
	Initial	2025	2050	2075	2100
Undev. Dry Land	73.6	73.6	73.3	72.9	72.4
Estuarine Beach	2.0	2.0	1.9	1.7	1.5
Irregularly Flooded Marsh	1.6	1.6	1.6	1.6	1.6
Estuarine Open Water	0.7	0.7	0.8	1.0	1.3
Dev. Dry Land	0.2	0.2	0.2	0.2	0.2
Regularly Flooded Marsh	0.2	0.2	0.2	0.2	0.5
Trans. Salt Marsh	0.0	0.1	0.3	0.6	0.9
Total (incl. water)	**78.3**	**78.3**	**78.3**	**78.3**	**78.3**

Target Rock NWR, Initial Condition

Target Rock NWR, 2025, 1 meter

Target Rock NWR, 2050, 1 meter

Target Rock NWR, 2075, 1 meter



Target Rock NWR, 2100, 1 meter

Target Rock Raster
1.5 Meters Eustatic SLR by 2100

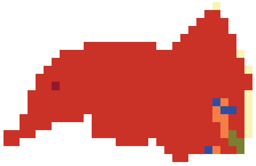
Results in Acres

	Initial	2025	2050	2075	2100
Undev. Dry Land	73.6	73.5	73.1	72.3	71.6
Estuarine Beach	2.0	1.9	1.8	1.5	1.1
Irregularly Flooded Marsh	1.6	1.6	1.6	1.6	1.6
Estuarine Open Water	0.7	0.8	1.0	1.3	1.7
Dev. Dry Land	0.2	0.2	0.2	0.2	0.2
Regularly Flooded Marsh	0.2	0.2	0.2	0.5	1.3
Trans. Salt Marsh	0.0	0.1	0.5	0.9	0.7
Total (incl. water)	**78.3**	**78.3**	**78.3**	**78.3**	**78.3**

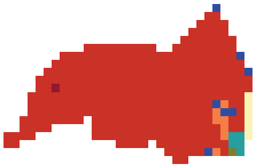
Target Rock NWR, Initial Condition

Target Rock NWR, 2025, 1.5 meter

Target Rock NWR, 2050, 1.5 meter



Target Rock NWR, 2075, 1.5 meter

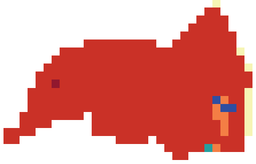


Target Rock NWR, 2100, 1.5 meter

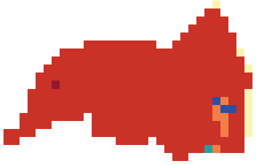
Target Rock Raster
2 Meters Eustatic SLR by 2100

Results in Acres

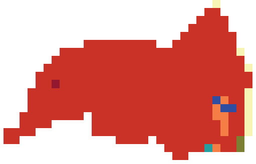
	Initial	2025	2050	2075	2100
Undev. Dry Land	73.6	73.4	72.7	71.8	70.7
Estuarine Beach	2.0	1.9	1.7	1.2	0.6
Irregularly Flooded Marsh	1.6	1.6	1.6	1.6	1.6
Estuarine Open Water	0.7	0.8	1.1	1.6	2.4
Dev. Dry Land	0.2	0.2	0.2	0.2	0.2
Regularly Flooded Marsh	0.2	0.2	0.3	0.9	1.7
Trans. Salt Marsh	0.0	0.2	0.7	1.0	1.1
Total (incl. water)	**78.3**	**78.3**	**78.3**	**78.3**	**78.3**



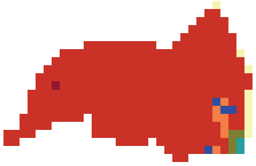
Target Rock NWR, Initial Condition



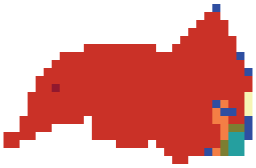
Target Rock NWR, 2025, 2 meters



Target Rock NWR, 2050, 2 meters



Target Rock NWR, 2075, 2 meters



Target Rock NWR, 2100, 2 meters

Discussion

Target Rock National Wildlife Refuge is not predicted to be susceptible to the effects of sea level rise except in the most extreme scenarios. Outside of regions in the southeast of the NWR, high dry-land elevations throughout the refuge ensure minimal inundation effects during most SLR scenarios. The refuge is not predicted to lose any irregularly flooded marsh – as much of this is diked -- and regularly flooded marsh is predicted to increase in scenarios of 1-meter-eustatic SLR and higher.

These predictions are based on 1930s elevation data with a large contour interval. The resulting uncertainty over cell elevations introduces considerable uncertainty into model predictions. However, areas located above the twenty foot contour in the original USGS contour map (see Figure 2) may be safely assumed to be free from any direct effects of projected sea level rise.

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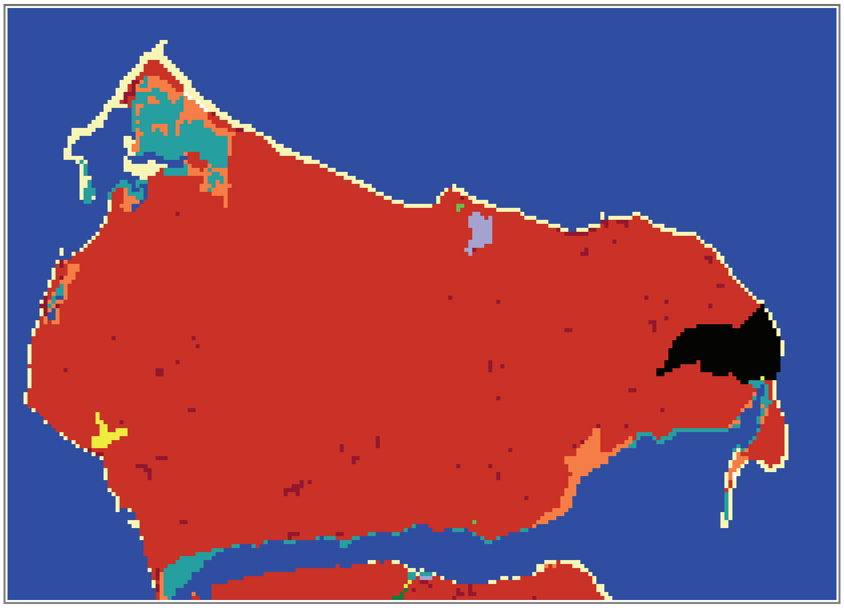
Appendix A: Contextual Results

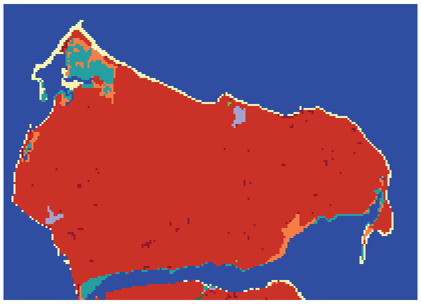
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

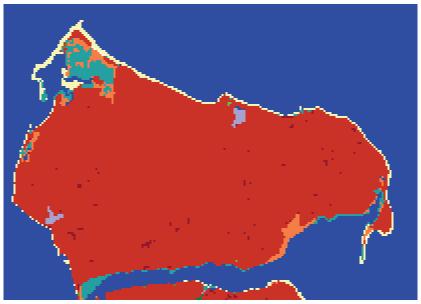
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



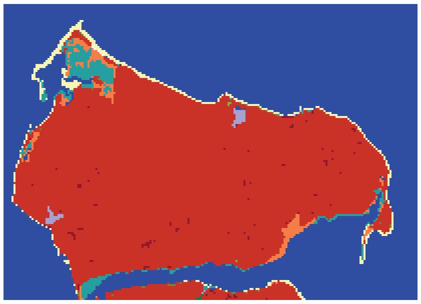
Location of Target Rock National Wildlife Refuge (black area) within simulation context



Target Rock NWR, Initial Condition



Target Rock NWR, 2025, Scenario A1B Mean



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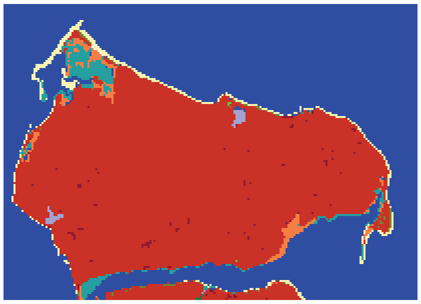
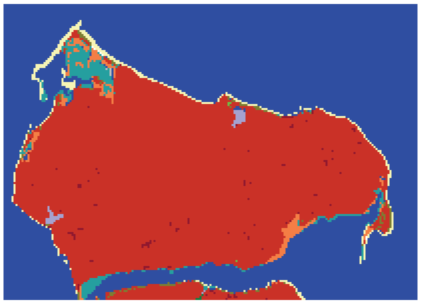
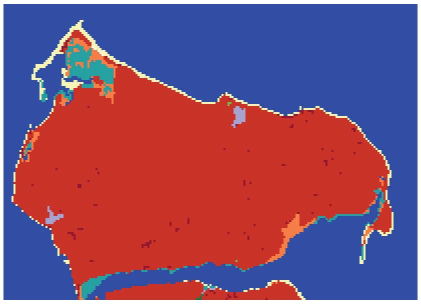


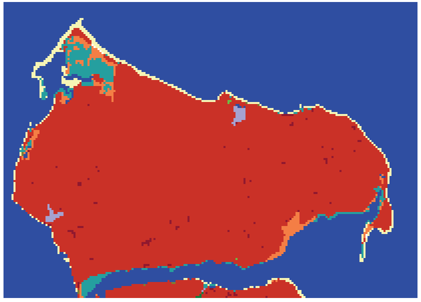
Target Rock NWR, 2075, Scenario A1B Mean



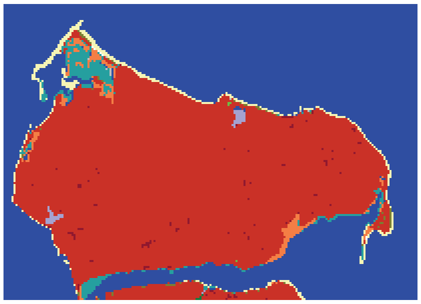
Target Rock NWR, 2100, Scenario A1B Mean



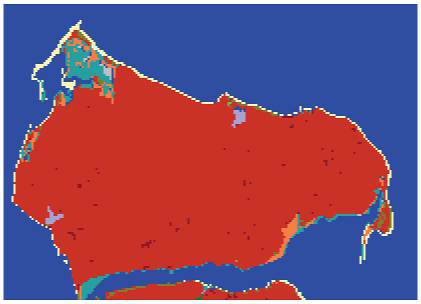
Target Rock NWR, Initial Condition



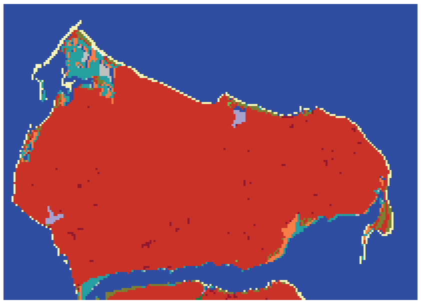
Target Rock NWR, 2025, Scenario A1B Maximum



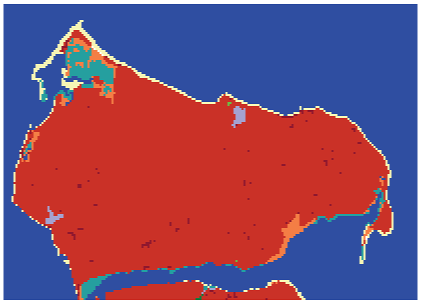
Target Rock NWR, 2050, Scenario A1B Maximum



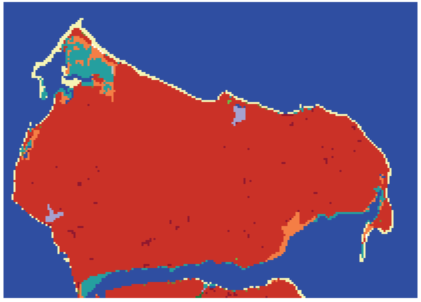
Target Rock NWR, 2075, Scenario A1B Maximum



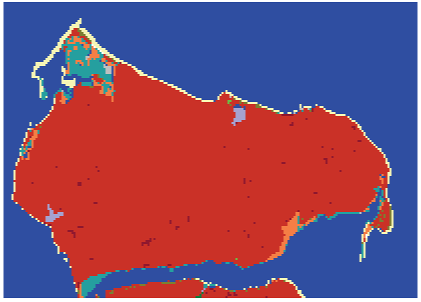
Target Rock NWR, 2100, Scenario A1B Maximum



Target Rock NWR, Initial Condition



Target Rock NWR, 2025, 1 meter



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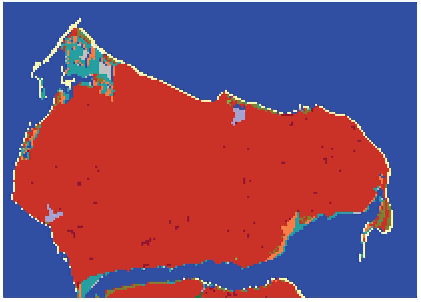

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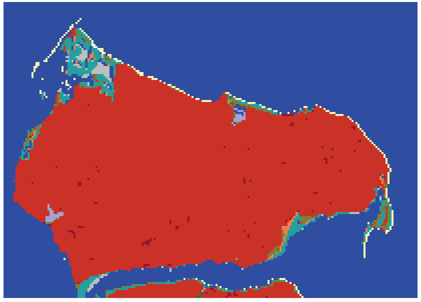

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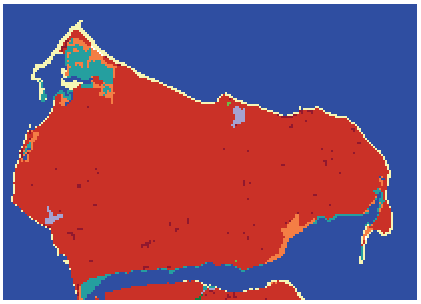
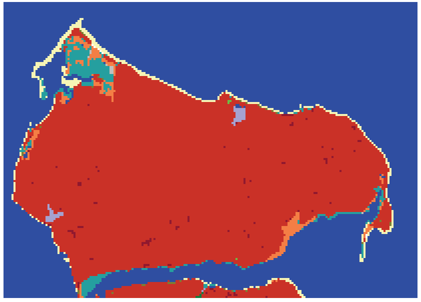
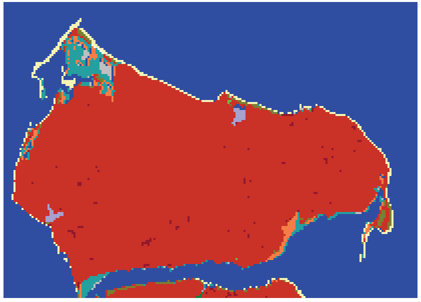


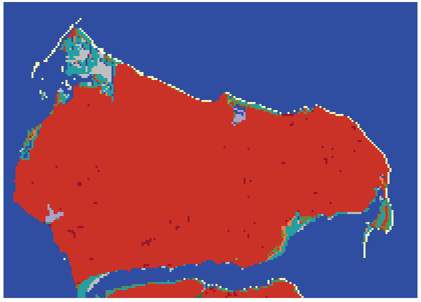
Target Rock NWR, Initial Condition



Target Rock NWR, 2025, 1.5 meter

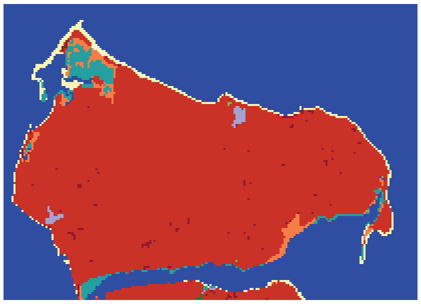


Target Rock NWR, 2050, 1.5 meter

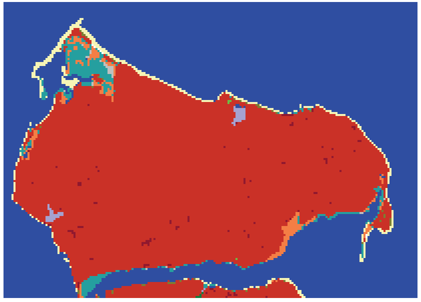


Target Rock NWR, 2075, 1.5 meter

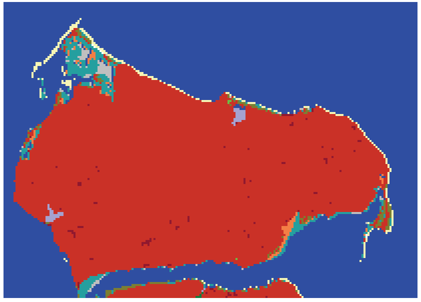
Target Rock NWR, 2100, 1.5 meter



Target Rock NWR, Initial Condition



Target Rock NWR, 2025, 2 meter



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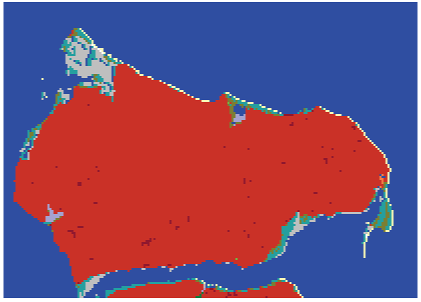

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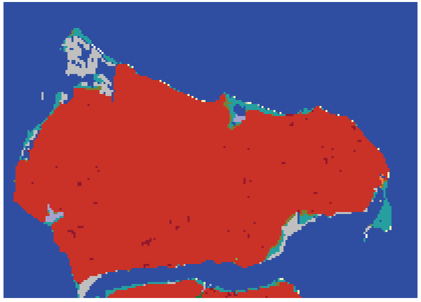

Target Rock NWR, 2100, 2 meter