Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0) to Elizabeth A. Morton 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 brackish 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 4 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 (Brackish) 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 when creating results for Morton NWR.

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).

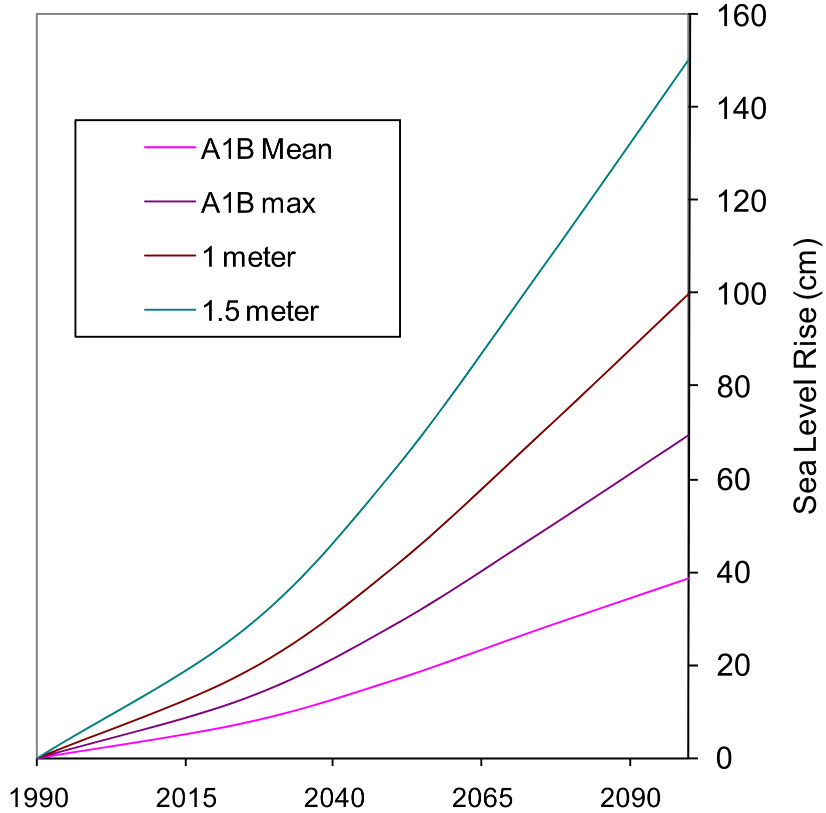
Sea-Level Rise Scenarios

The primary set of eustatic (global) sea level rise scenarios used within SLAMM was derived from the work of the Intergovernmental Panel on Climate Change (IPCC 2001). SLAMM 5 was run using the following IPCC and fixed-rate scenarios:

Scenario	Eustatic SLR by 2025 (cm)	Eustatic SLR by 2050 (cm)	Eustatic SLR by 2075 (cm)	Eustatic SLR by 2100 (cm)
A1B Mean	8	17	28	39
A1B Max	14	30	49	69
1 meter	13	28	48	100
1.5 meter	18	41	70	150

Recent 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 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. To allow for flexibility when interpreting the results, SLAMM was also run assuming 1 meter, 1½ 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



Methods and Data Sources

LIDAR elevation data are unavailable for this NWR, likely because it is inland. Therefore, elevation data used are based on National Elevation Data (NED). An examination of the NED metadata indicates that this digital elevation map (DEM) was derived from a 1956 survey (Fig. 2). The contour interval used to derive the DEM was ten feet with a five foot supplemental contour.

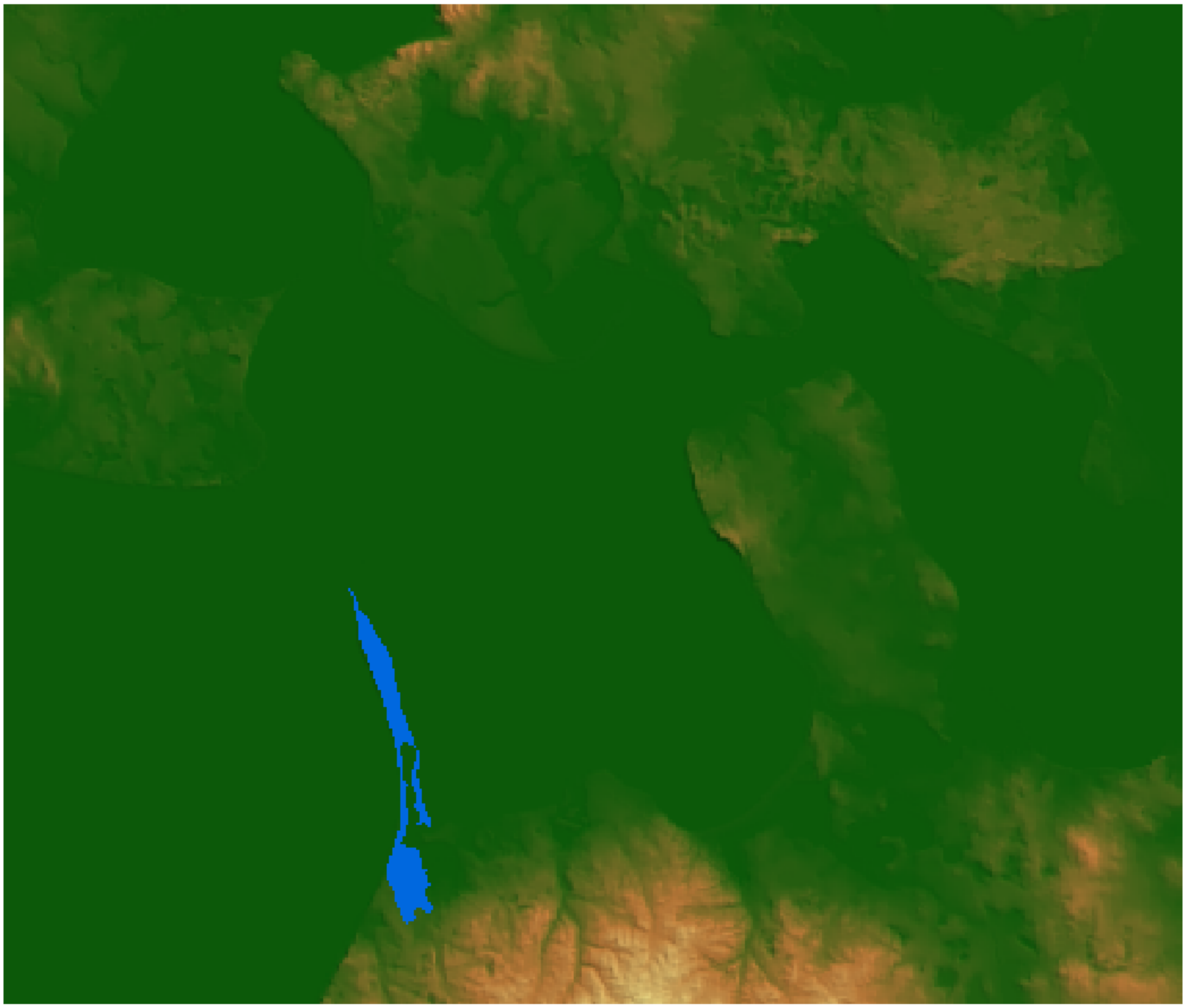


Figure 2: Morton NWR (in Blue) Over NED Map.

The National Wetlands Inventory for Morton is based on a photo date of 1994. An examination of the NWI map overlaid on recent satellite photos indicates insignificant changes in the Morton NWR wetland boundaries since that date.

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

Dry Land	64.1%
Estuarine Beach	20.6%
Estuarine Open Water	9.6%
Brackish Marsh	3.3%
Saltmarsh	1.4%
Inland Open Water	0.6%
Inland Fresh Marsh	0.3%
Swamp	0.1%

There are no diked or impounded wetlands within the Morton NWR, and none located within the surrounding land.

The historic trend for sea level rise was estimated at 2.87 mm/year (Cashin Associates, 2006). Long-term NOAA gages on Long Island measure long term sea level rise at somewhere between 2.3 and 3.0 mm/year. The rate of sea level rise on Long Island may be considered somewhat higher than the global average for the last 100 years (1.5-2.0 mm/year).

The great diurnal tidal range for the Morton NWR is estimated at 0.91 meters (Fig. 3) using NOAA tide predictions for four local sites (New Suffolk , Sag Harbor, Noyack Bay, and South Jamesport). The USGS topographical map for the site suggests an approximate mean tidal range of 2.4 feet (0.73 meters).

Figure 3: NOAA Gages Relevant to the Study Area.

Accretion rates in salt, brackish and tidal fresh marshes were set to 2.5 mm/year, the mean of accretion values from Wertheim NWR and from Barn Island Wildlife Management Area, CT (McLetchie, 2006; R.A. Orson, 1998).

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. However, the SLAMM model does track partial conversion of cells based on elevation and slope. (Note that since the LIDAR data produce a more accurate DEM, only the elevations of wetlands classes lying outside of the LIDAR data were overwritten as a function of the local tidal range using the SLAMM elevation pre-processor.)

SUMMARY OF SLAMM INPUT PARAMETERS FOR MORTON

Description	**Morton**
DEM Source Date (yyyy)	1956
NWI_photo_date (yyyy)	1994
Direction_OffShore (N|S|E|W)	N
Historic_trend (mm/yr)	2.87
NAVD88_correction (MTL-NAVD88 in meters)	-0.029
Water Depth (m below MLW- N/A)	2
TideRangeOcean (meters: MHHW-MLLW)	0.91
TideRangeInland (meters)	0.91
Mean High Water Spring (m above MTL)	0.605
MHSW Inland (m above MTL)	0.605
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	2.5
Brackish March vert. accretion (mm/yr) Final	2.5
Tidal Fresh vertical accretion (mm/yr) Final	2.5
Beach/T.Flat Sedimentation Rate (mm/yr)	0.5
Frequency of Large Storms (yr/washover)	35
Use Elevation Preprocessor for Wetlands	TRUE

Results

Under most of the scenarios run, Morton NWR is predicted to be fairly resilient to the effects of sea level rise. The loss of dry land – which constitutes the majority of this NWR – is not predicted to exceed one quarter of the NWR's land area even in the most extreme sea level rise scenario. Dry land elevations are somewhat uncertain due to the coarse resolution of the elevation data set, however.

In nearly every sea level rise scenario, estuarine beach – which constitutes about one-fifth of this NWR – will be lost entirely.

SLR by 2100 (m)	0.39	0.69	1	1.5
Dry Land	12%	15%	18%	22%
Estuarine Beach	91%	100%	100%	100%
Brackish Marsh	84%	100%	100%	100%
Inland Fresh Marsh	0%	0%	0%	0%
Swamp	0%	0%	0%	0%

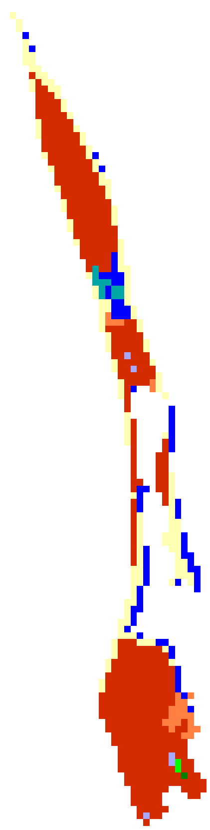
Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

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

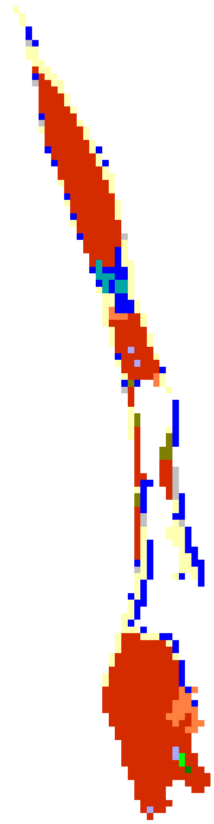
Morton NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

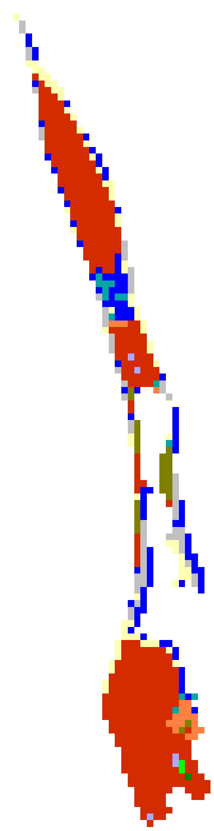
	Initial	2025	2050	2075	2100
Dry Land	113.0	110.2	105.8	102.1	99.4
Estuarine Beach	36.3	28.6	15.5	7.0	3.1
Estuarine Open Water	16.9	20.3	24.0	27.2	37.8
Brackish Marsh	5.8	5.4	4.4	2.0	0.9
Saltmarsh	2.4	2.7	3.8	9.7	14.0
Inland Open Water	1.1	1.1	1.1	0.9	0.7
Inland Fresh Marsh	0.4	0.4	0.4	0.4	0.4
Swamp	0.2	0.2	0.2	0.2	0.2
Tidal Flat	0.0	4.4	14.1	20.1	14.6
Trans. Salt Marsh	0.0	2.8	6.8	6.5	5.0
Total (incl. water)	**176.1**	**176.1**	**176.1**	**176.1**	**176.1**



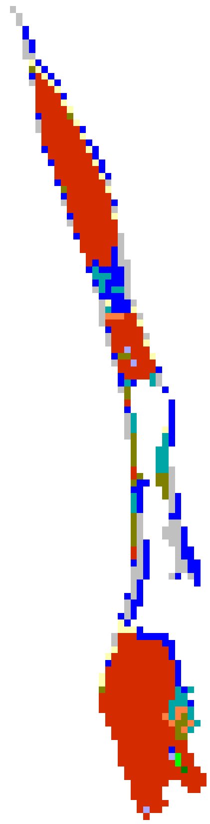
Morton NWR, Initial Condition



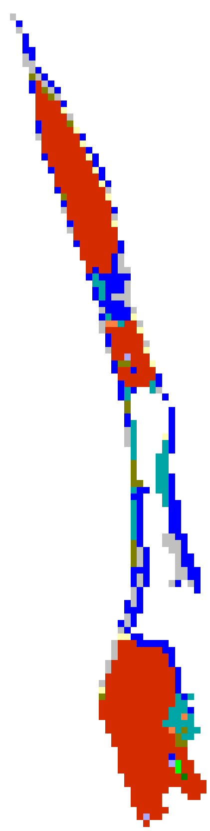
Morton NWR, 2025, Scenario A1B Mean Protect Developed Dry Land



Morton NWR, 2050, Scenario A1B Mean Protect Developed Dry Land



Morton NWR, 2075, Scenario A1B Mean Protect Developed Dry Land

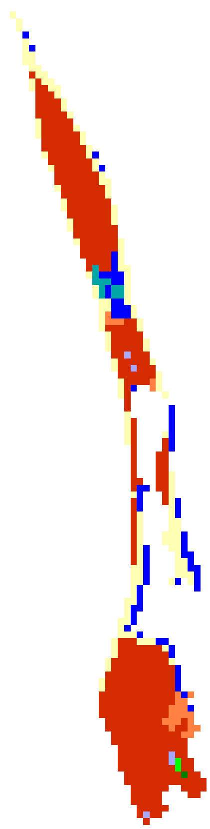


Morton NWR, 2100, Scenario A1B Mean Protect Developed Dry Land

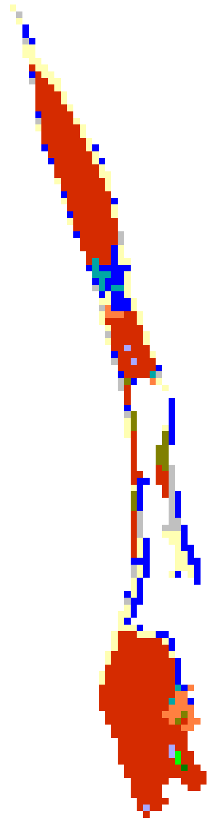
Morton NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

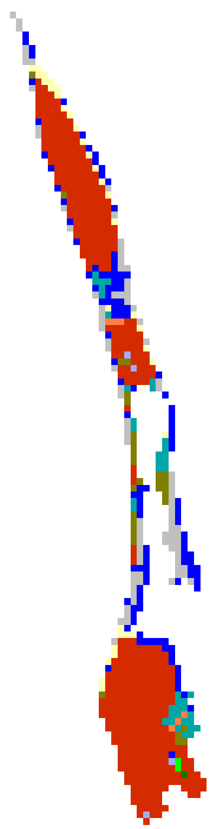
	Initial	2025	2050	2075	2100
Dry Land	113.0	108.7	102.9	98.8	95.9
Estuarine Beach	36.3	22.7	7.8	1.5	0.0
Estuarine Open Water	16.9	21.2	26.2	49.0	57.5
Brackish Marsh	5.8	4.8	1.5	0.1	0.0
Saltmarsh	2.4	3.1	9.2	13.1	13.8
Inland Open Water	1.1	1.1	0.9	0.7	0.7
Inland Fresh Marsh	0.4	0.4	0.4	0.4	0.4
Swamp	0.2	0.2	0.2	0.2	0.2
Tidal Flat	0.0	9.6	20.5	8.2	4.6
Trans. Salt Marsh	0.0	4.3	6.5	4.1	2.9
Total (incl. water)	**176.1**	**176.1**	**176.1**	**176.1**	**176.1**



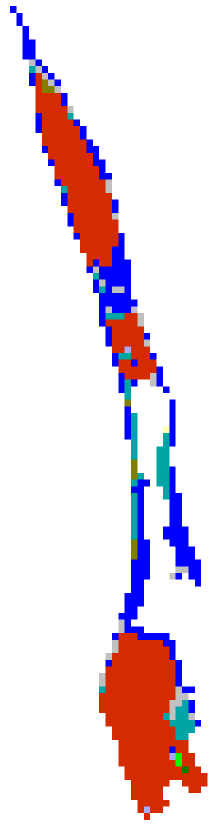
Morton NWR, Initial Condition



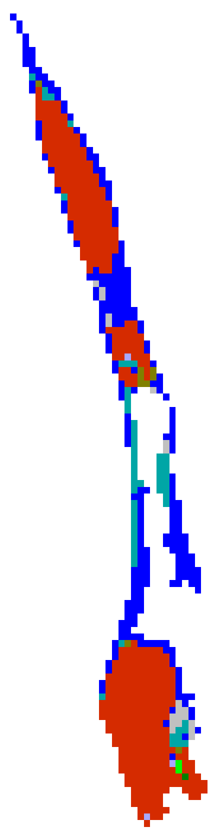
Morton NWR, 2025, Scenario A1B Maximum Protect Developed Dry Land



Morton NWR, 2050, Scenario A1B Maximum Protect Developed Dry Land



Morton NWR, 2075, Scenario A1B Maximum Protect Developed Dry Land

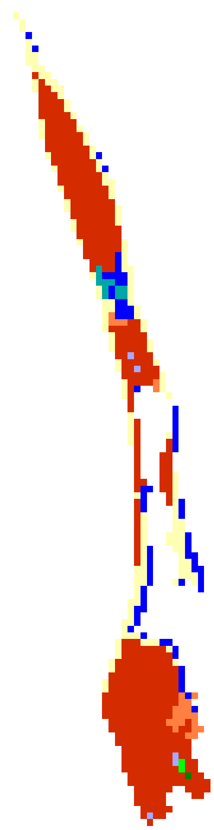


Morton NWR, 2100, Scenario A1B Maximum Protect Developed Dry Land

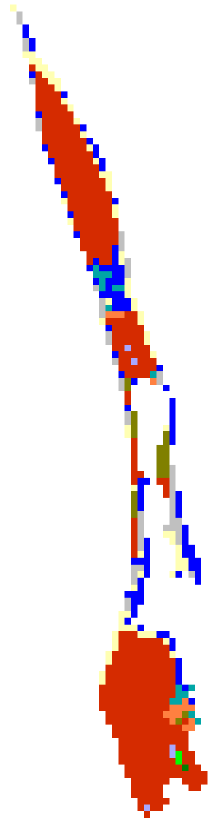
Morton NWR
1 Meter Eustatic SLR by 2100

Results in Acres

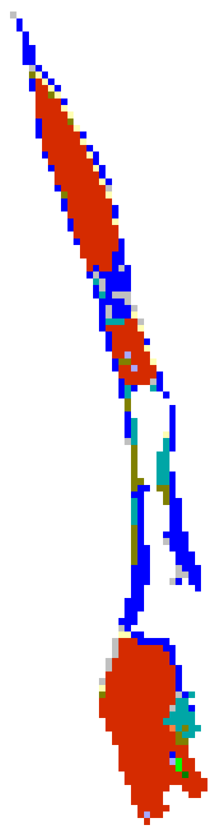
	Initial	2025	2050	2075	2100
Dry Land	113.0	107.0	100.1	96.3	92.4
Estuarine Beach	36.3	17.3	4.1	0.0	0.0
Estuarine Open Water	16.9	21.8	44.4	57.3	63.0
Brackish Marsh	5.8	3.4	0.4	0.0	0.0
Saltmarsh	2.4	4.2	10.5	12.0	5.5
Inland Open Water	1.1	1.1	0.9	0.7	0.7
Inland Fresh Marsh	0.4	0.4	0.4	0.4	0.4
Swamp	0.2	0.2	0.2	0.2	0.2
Tidal Flat	0.0	14.6	8.2	5.4	9.9
Trans. Salt Marsh	0.0	6.0	6.9	3.7	4.0
Total (incl. water)	**176.1**	**176.1**	**176.1**	**176.1**	**176.1**



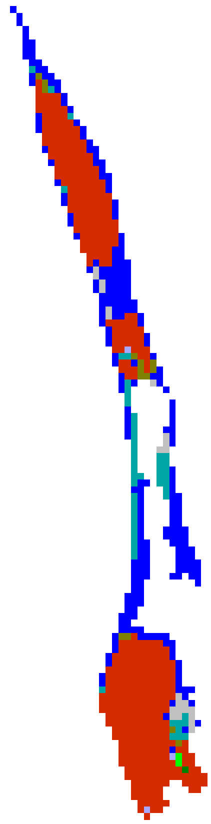
Morton NWR, Initial Condition



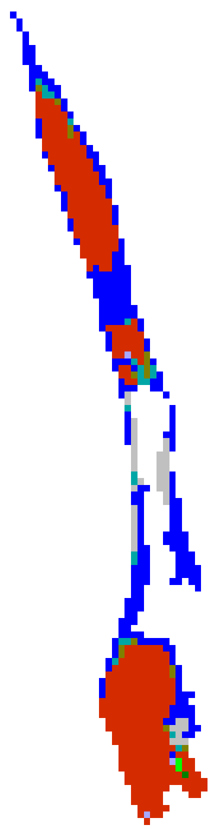
Morton NWR, 2025, 1 meter Protect Developed Dry Land



Morton NWR, 2050, 1 meter Protect Developed Dry Land



Morton NWR, 2075, 1 meter Protect Developed Dry Land

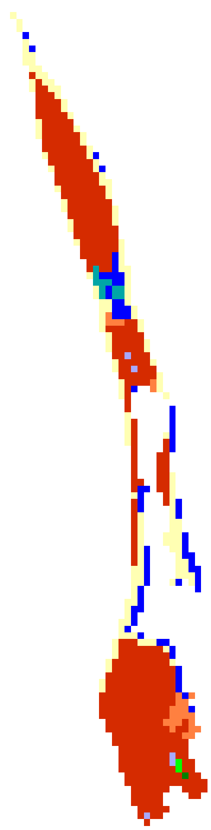


Morton NWR, 2100, 1 meter Protect Developed Dry Land

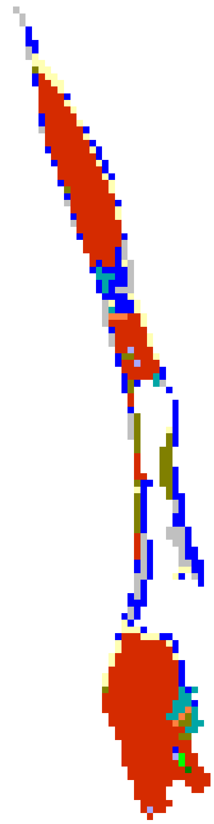
Morton NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

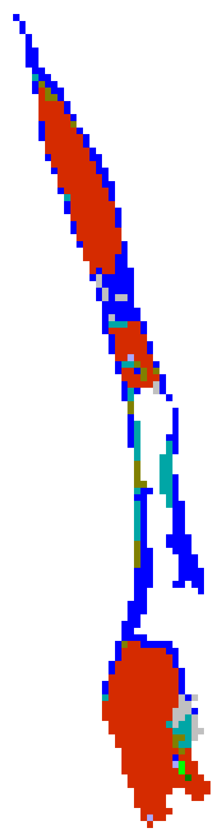
	Initial	2025	2050	2075	2100
Dry Land	113.0	104.3	97.7	92.5	87.7
Estuarine Beach	36.3	10.2	0.1	0.0	0.0
Estuarine Open Water	16.9	29.7	55.7	62.0	72.9
Brackish Marsh	5.8	1.5	0.0	0.0	0.0
Saltmarsh	2.4	5.6	10.2	6.6	5.3
Inland Open Water	1.1	0.9	0.7	0.7	0.7
Inland Fresh Marsh	0.4	0.4	0.4	0.4	0.4
Swamp	0.2	0.2	0.2	0.2	0.2
Trans. Salt Marsh	0.0	8.7	6.6	5.3	4.9
Tidal Flat	0.0	14.6	4.6	8.5	3.9
Total (incl. water)	**176.1**	**176.1**	**176.1**	**176.1**	**176.1**



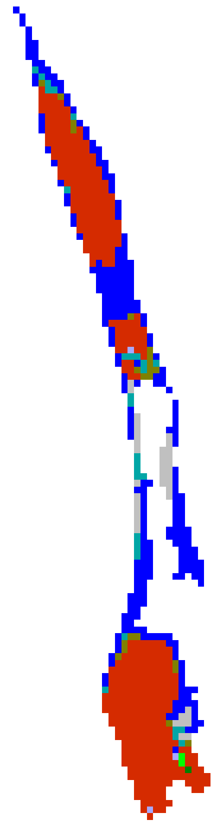
Morton NWR, Initial Condition



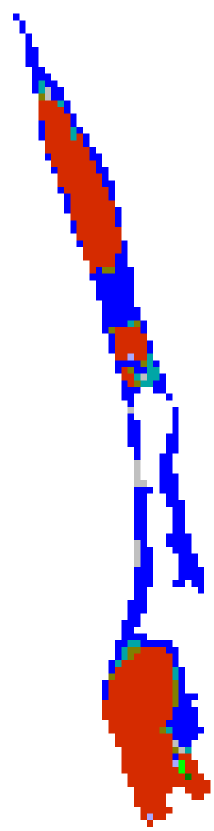
Morton NWR, 2025, 1.5 meter Protect Developed Dry Land



Morton NWR, 2050, 1.5 meter Protect Developed Dry Land



Morton NWR, 2075, 1.5 meter Protect Developed Dry Land



Morton NWR, 2100, 1.5 meter Protect Developed Dry Land

Discussion:

Model results indicate that Elizabeth A. Morton NWR will be affected by all sea level rise scenarios, but the predicted loss of estuarine beach is especially alarming. Estuarine beach elevations are uncertain, though, due to the coarse vertical resolution of the elevation data set. Enough dry-land is located above the five foot contour that dry land loss is not predicted to exceed 13% by 2100 under any scenario run.

It should also be noted that the elevation data set is more than 50 years old. A future analysis would considerably benefit from higher resolution elevation data.

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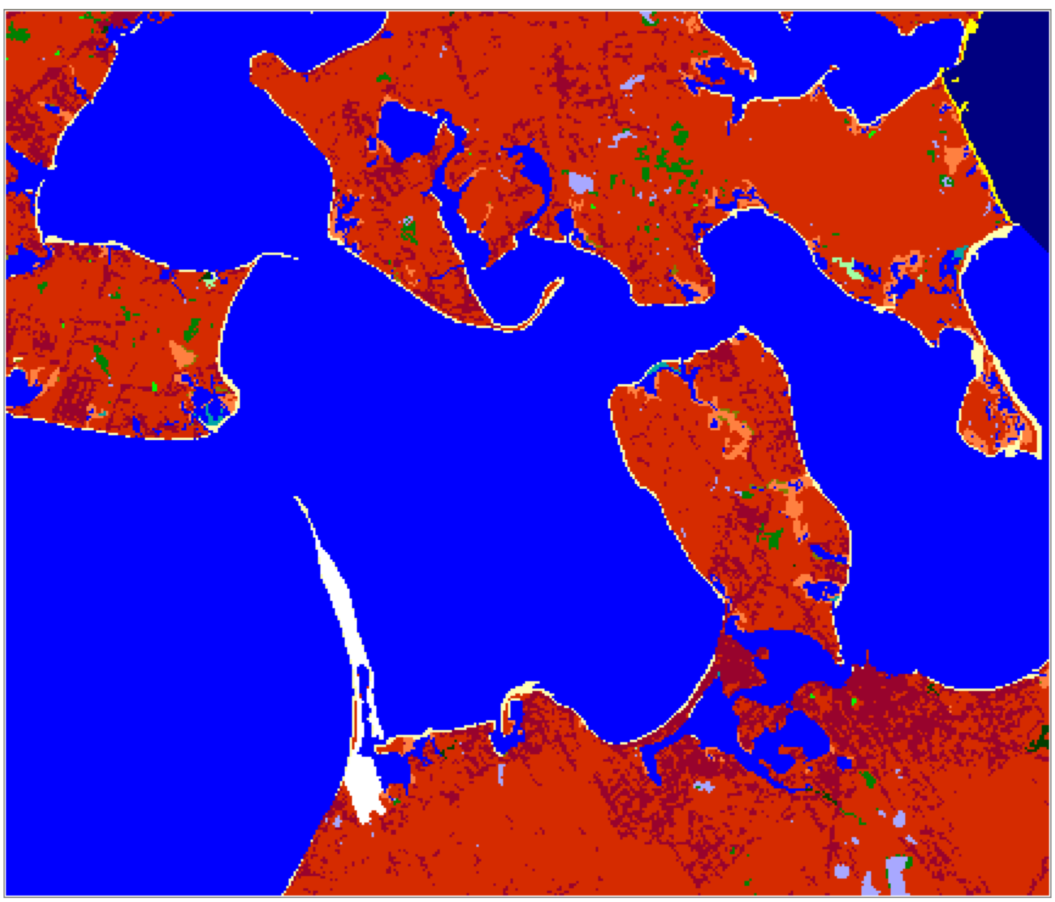
Appendix A: Contextual Results

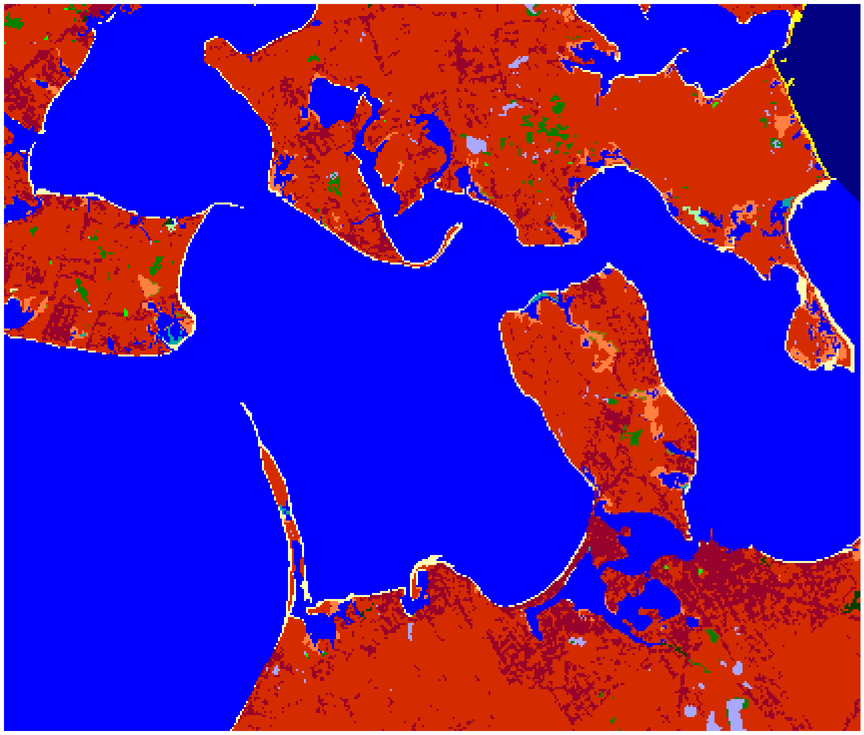
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

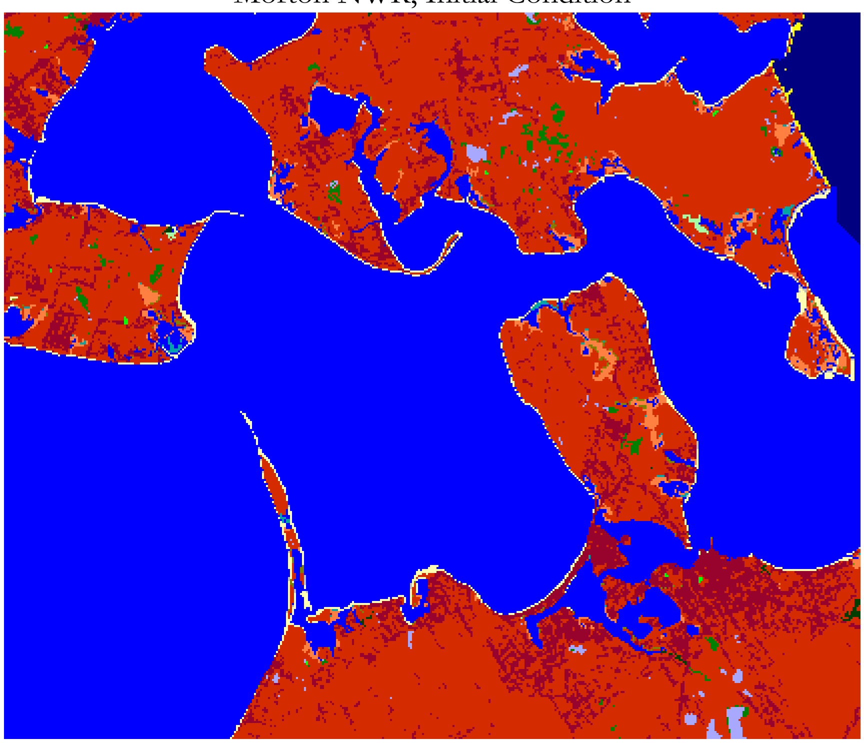
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



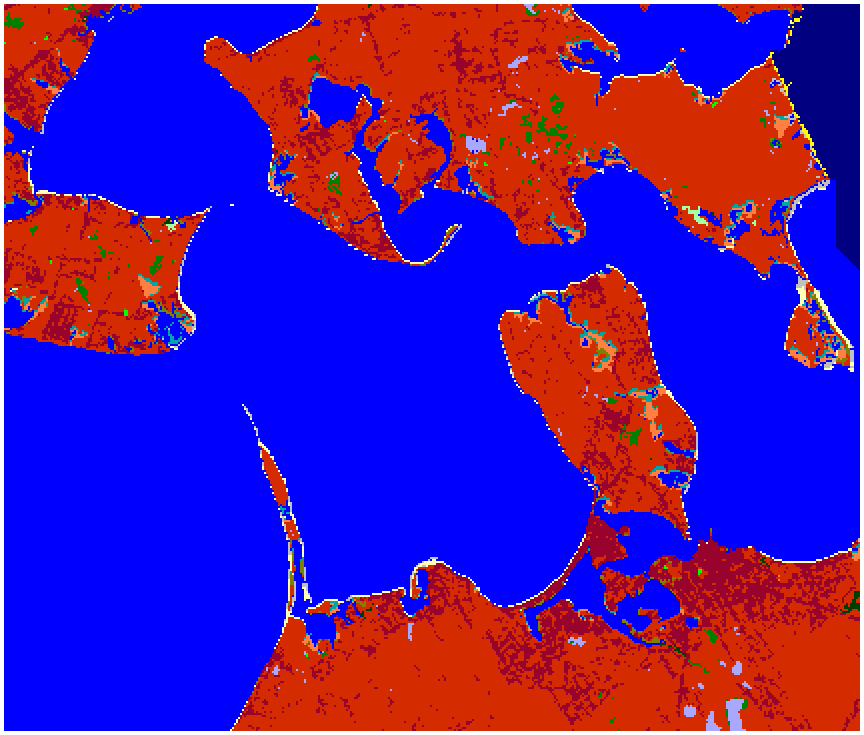
Location of Morton National Wildlife Refuge (white area) within simulation context



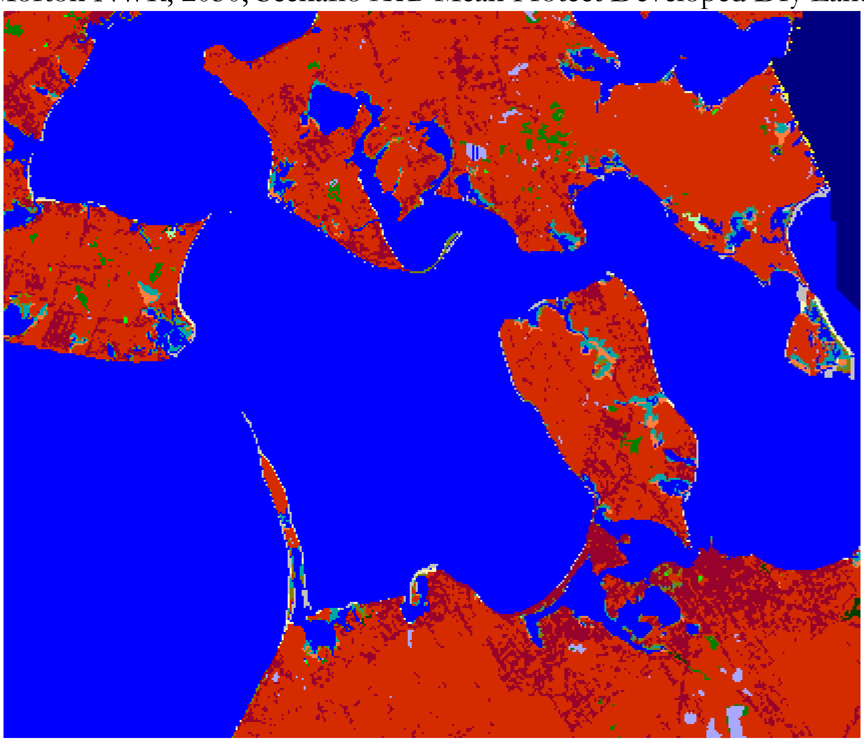
Morton NWR, Initial Condition



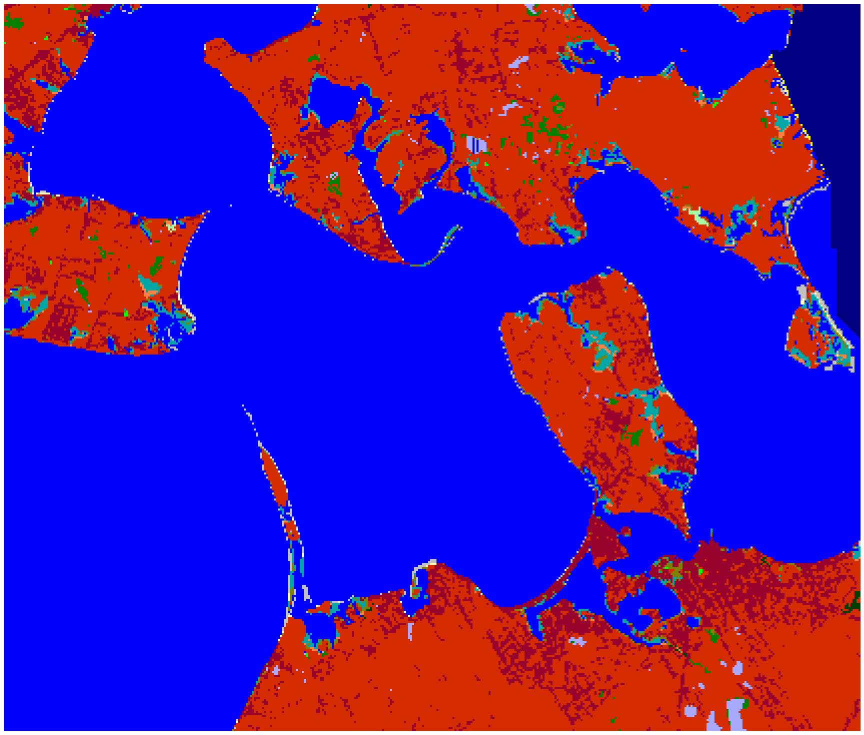
Morton NWR, 2025, Scenario A1B Mean Protect Developed Dry Land



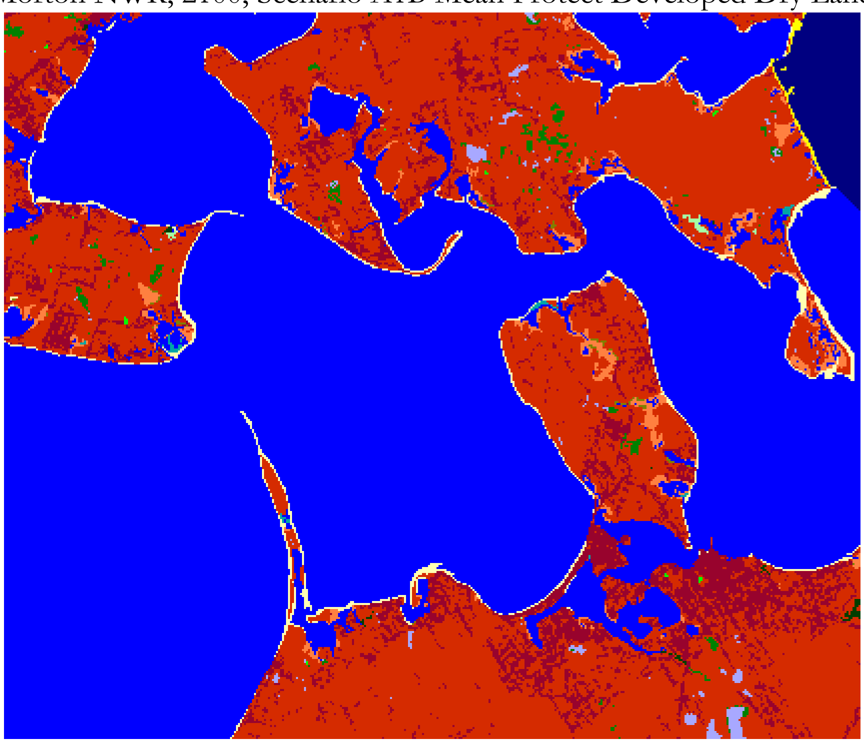
Morton NWR, 2050, Scenario A1B Mean Protect Developed Dry Land



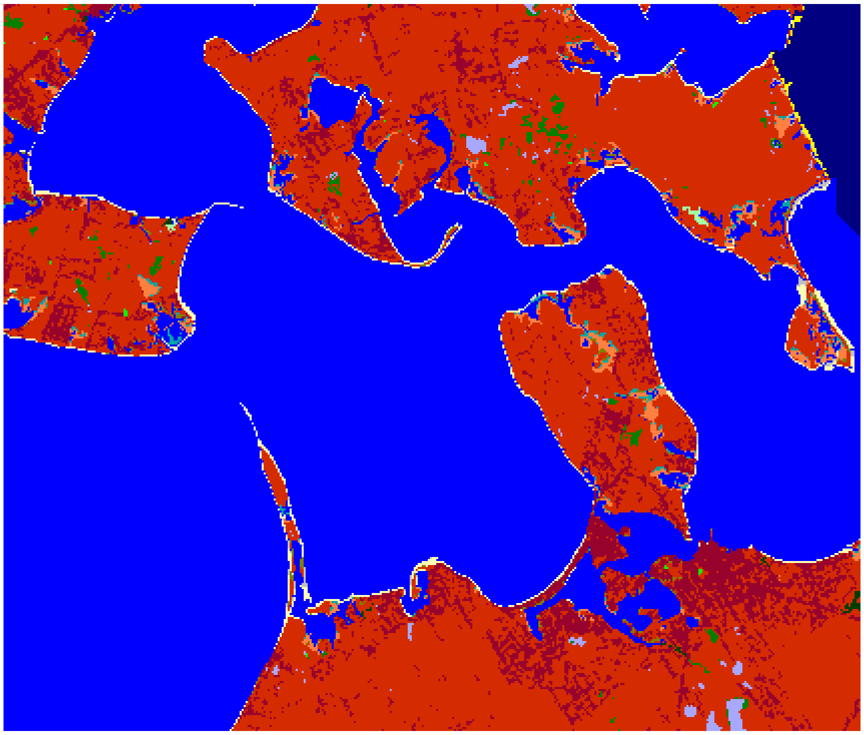
Morton NWR, 2075, Scenario A1B Mean Protect Developed Dry Land



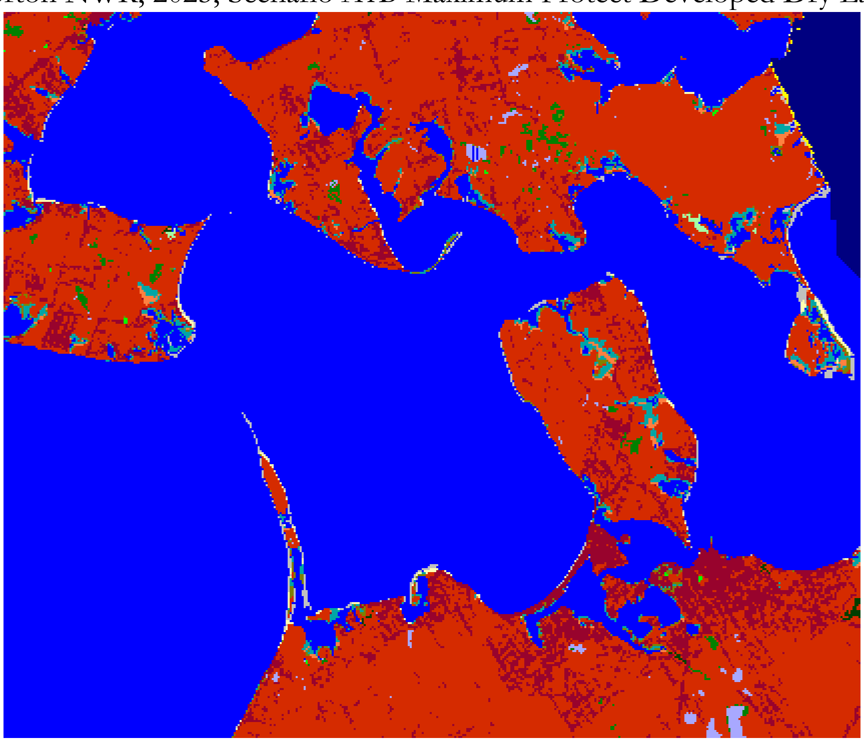
Morton NWR, 2100, Scenario A1B Mean Protect Developed Dry Land



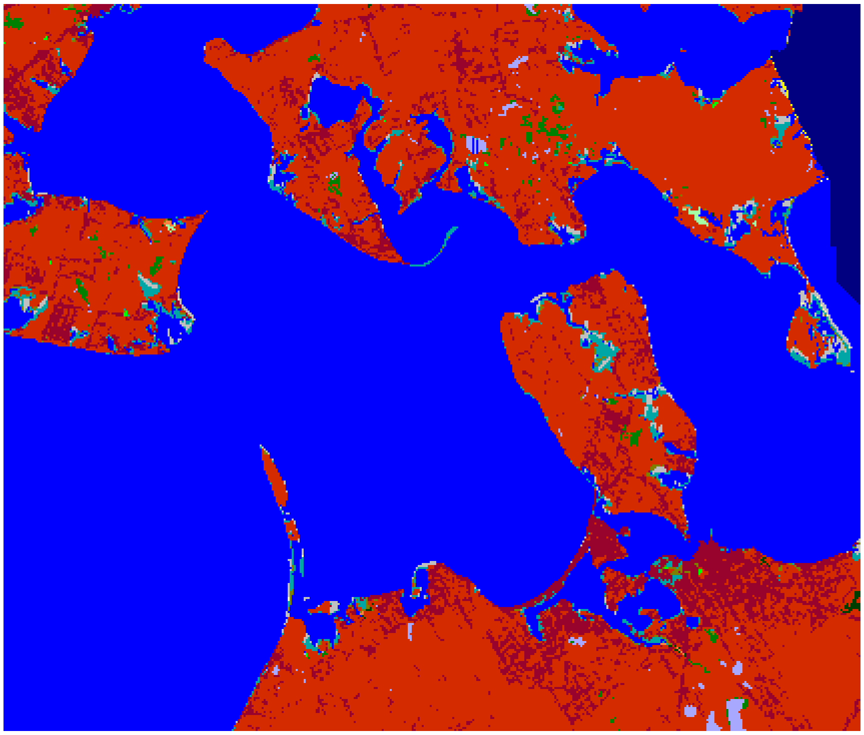
Morton NWR, Initial Condition



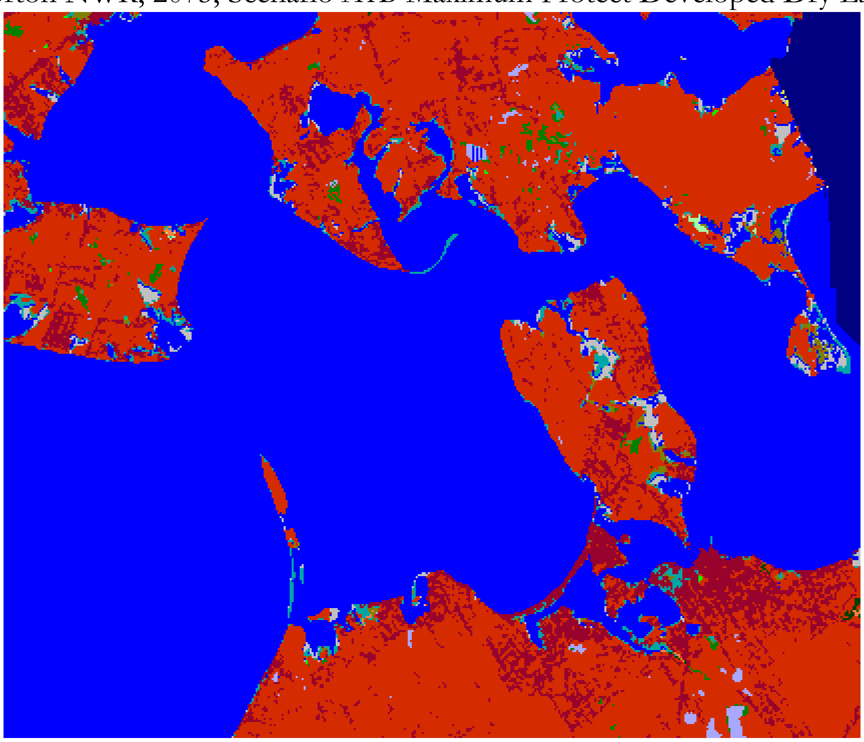
Morton NWR, 2025, Scenario A1B Maximum Protect Developed Dry Land



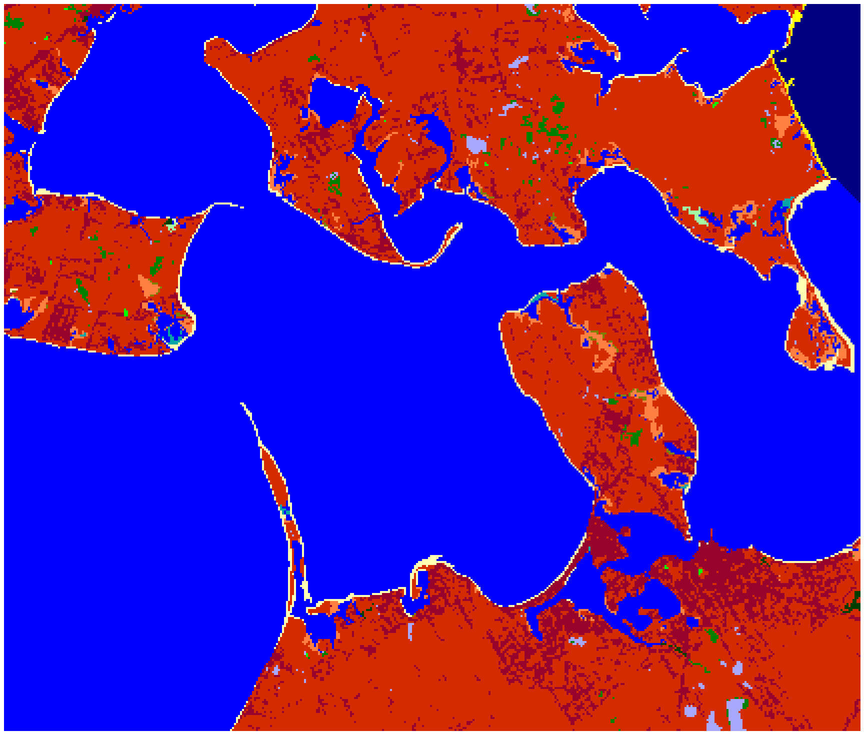
Morton NWR, 2050, Scenario A1B Maximum Protect Developed Dry Land



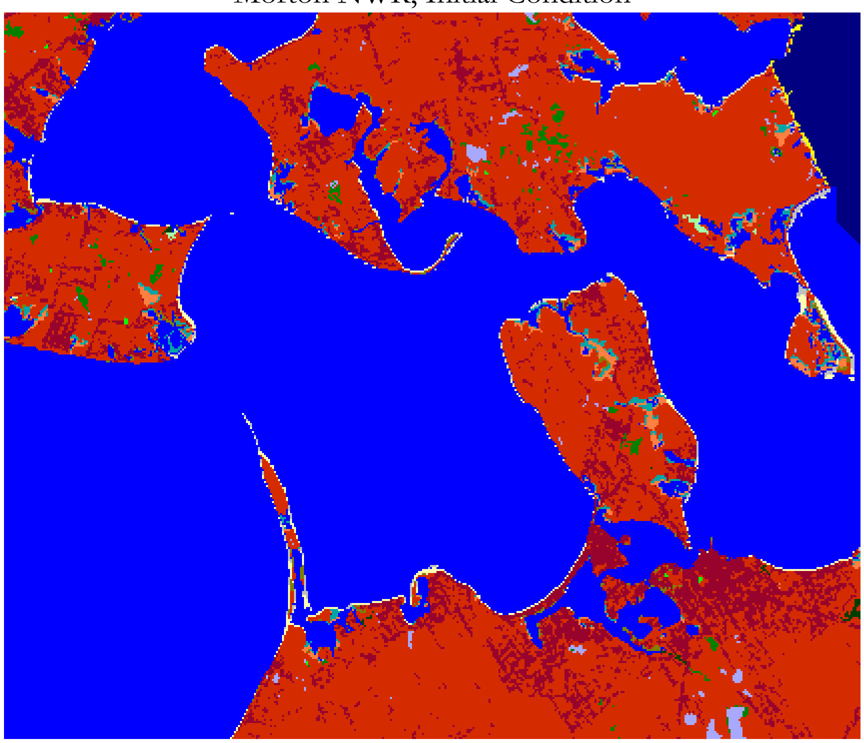
Morton NWR, 2075, Scenario A1B Maximum Protect Developed Dry Land



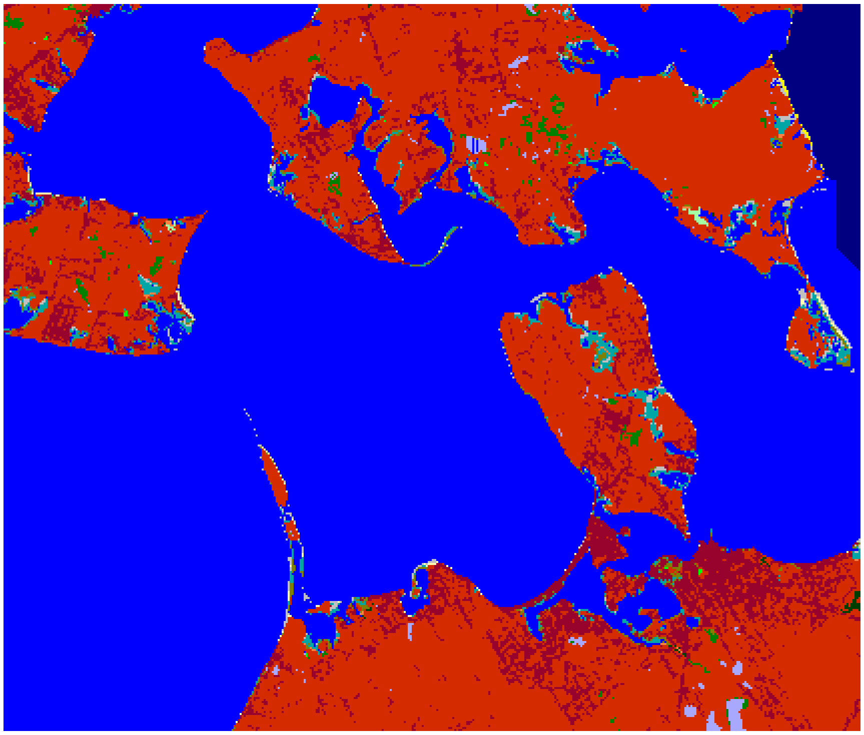
Morton NWR, 2100, Scenario A1B Maximum Protect Developed Dry Land



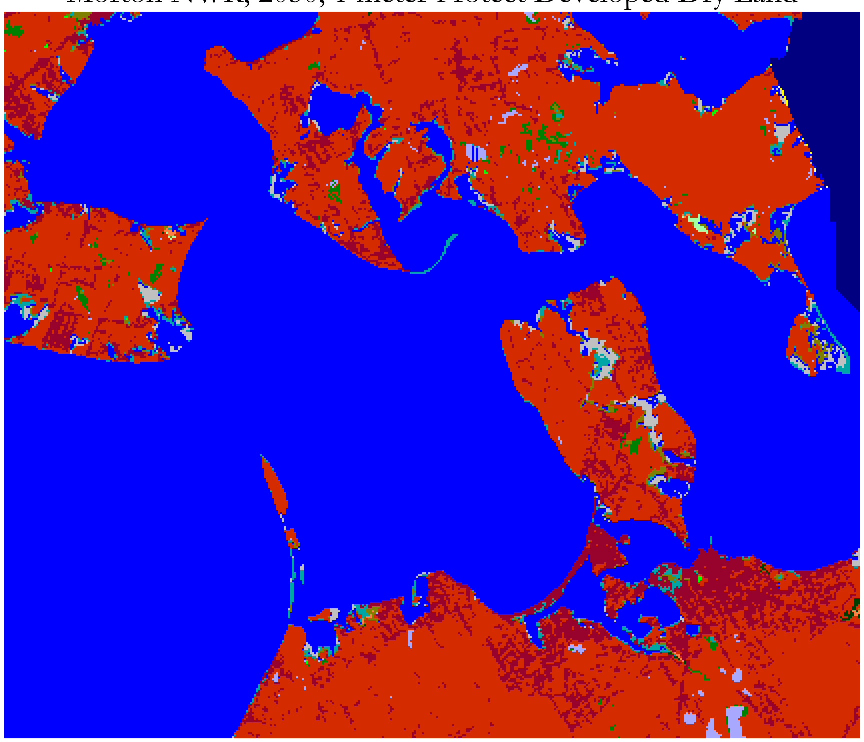
Morton NWR, Initial Condition



Morton NWR, 2025, 1 meter Protect Developed Dry Land



Morton NWR, 2050, 1 meter Protect Developed Dry Land



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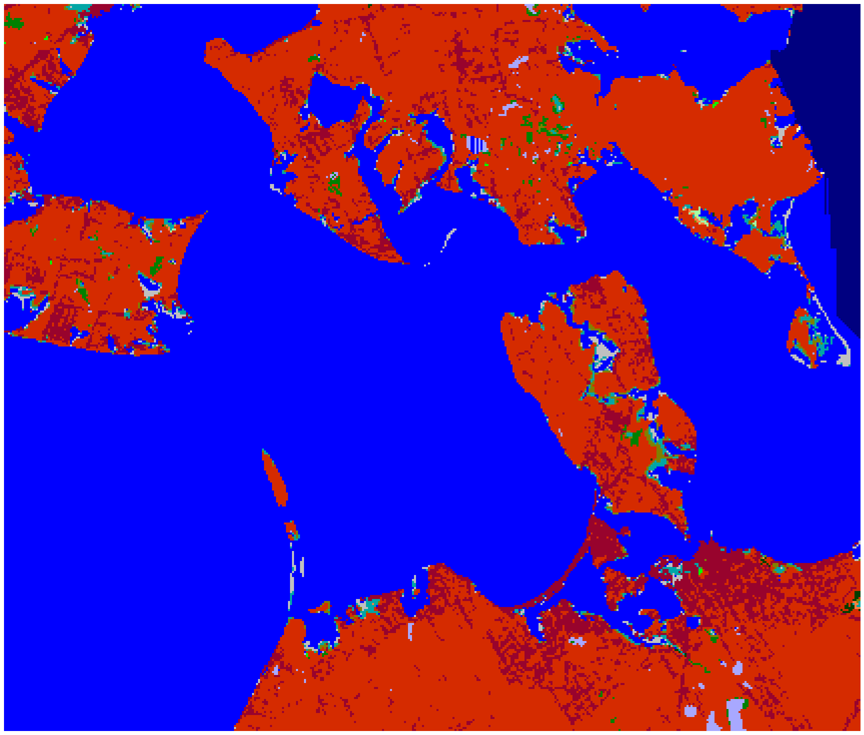

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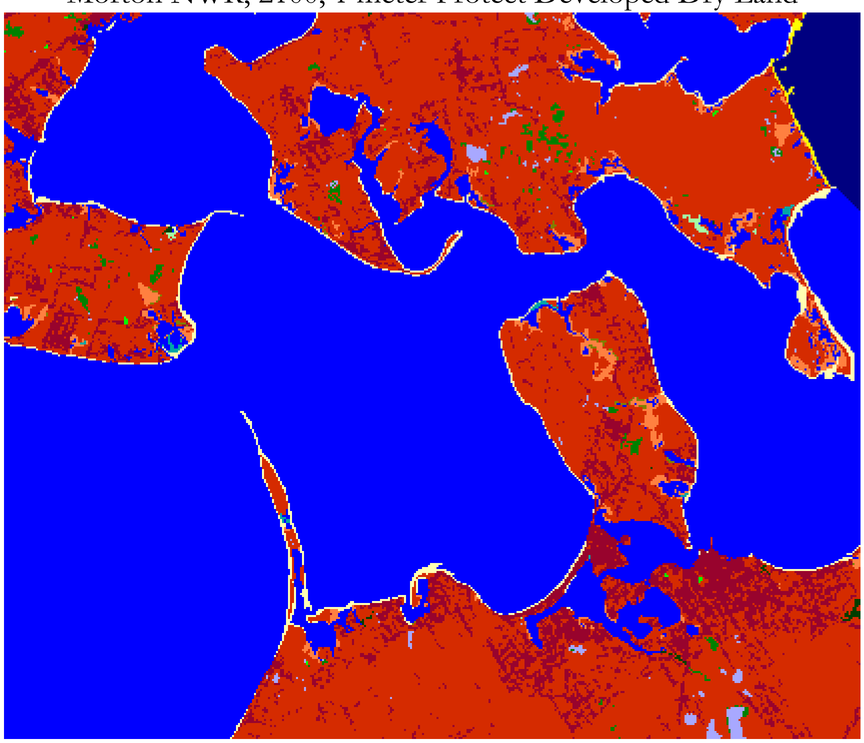
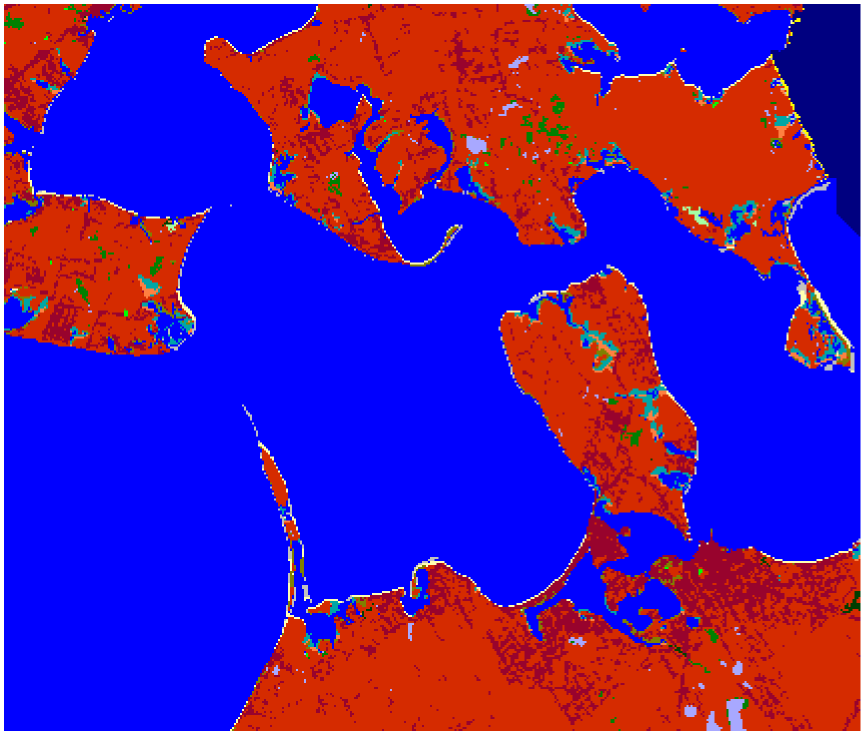
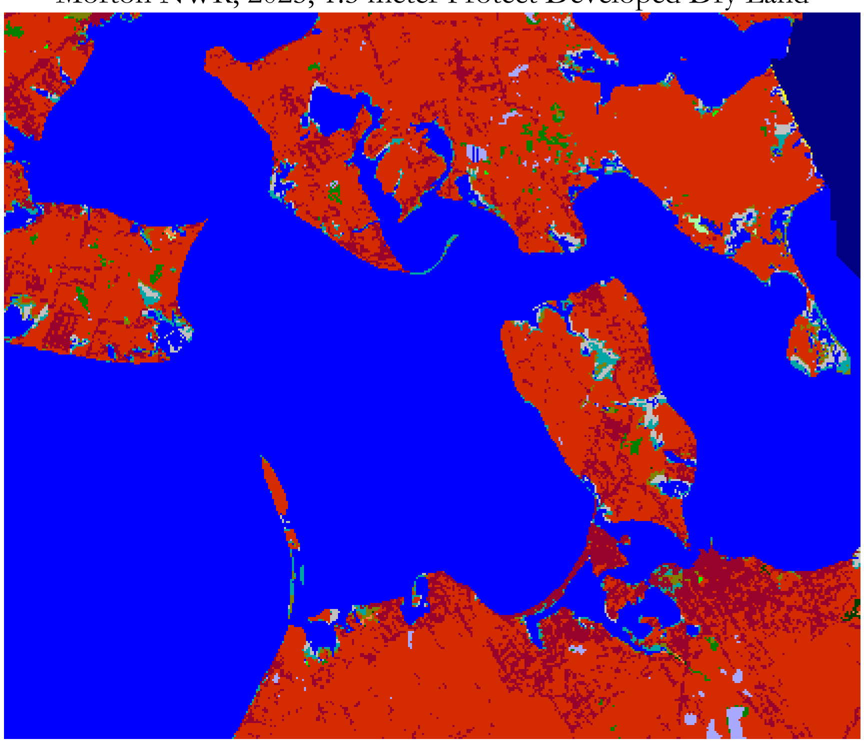


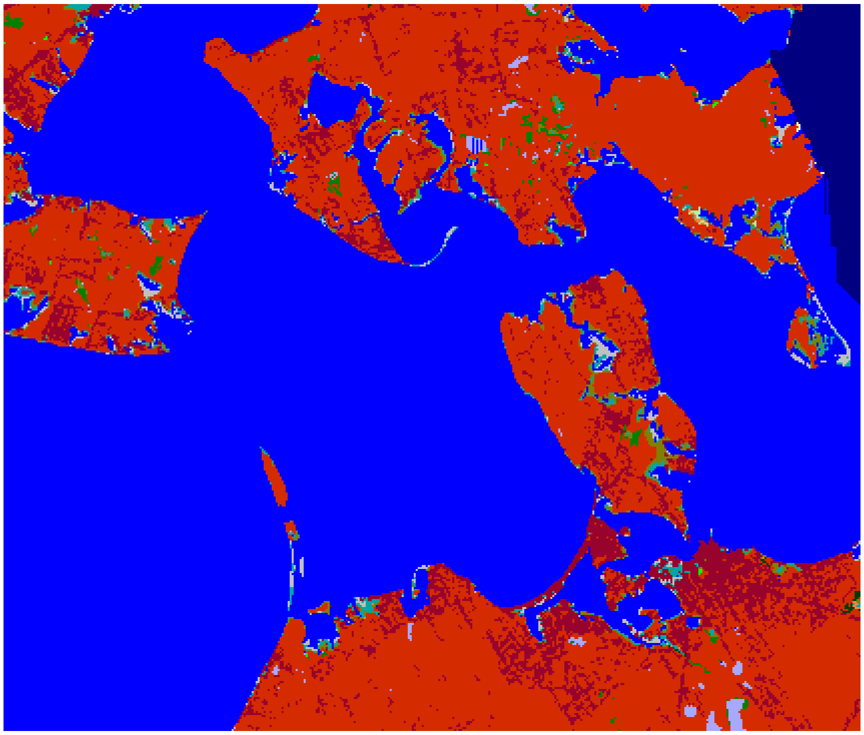
Morton NWR, Initial Condition



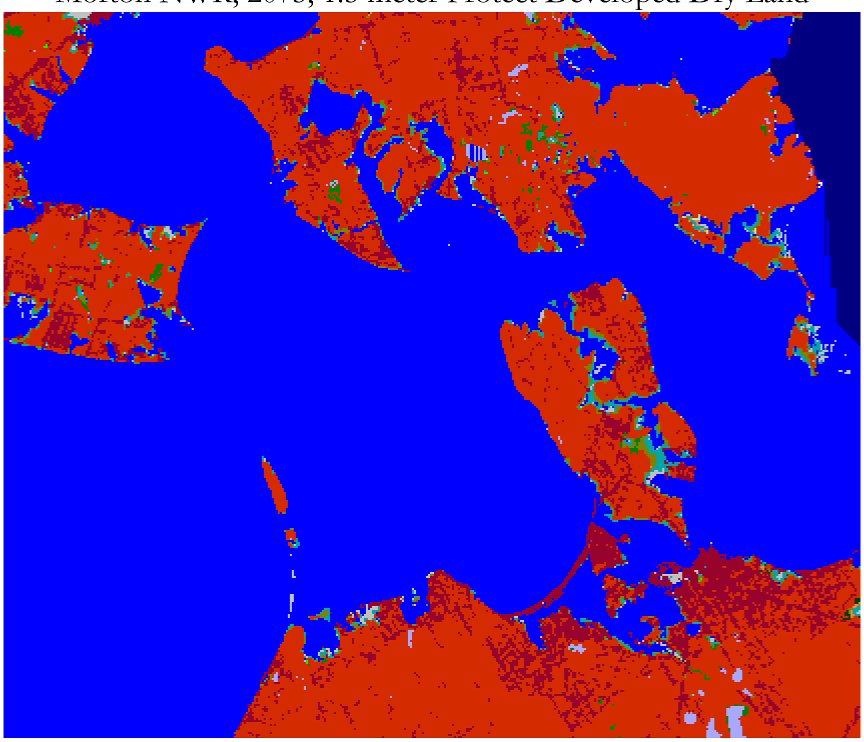
Morton NWR, 2025, 1.5 meter Protect Developed Dry Land



Morton NWR, 2050, 1.5 meter Protect Developed Dry Land



Morton NWR, 2075, 1.5 meter Protect Developed Dry Land



Morton NWR, 2100, 1.5 meter Protect Developed Dry Land