Application of the Sea-Level Affecting Marshes Model (SLAMM 5.1) to Oyster Bay 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 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

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 parameters.
- **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 water table to rising sea level close to the coast.
- **Salinity:** In a defined estuary, the effects of salinity progression up an estuary and the resultant effects on marsh type may be tracked. This optional sub-model assumes an estuarine salt-wedge and calculates the influence of the freshwater head vs. the saltwater head in a particular cell. The "classic" estuary geometry is not present in Jefferson County, TX, so this model was not used in this analysis.

For a thorough accounting of each of these processes and the underlying assumptions and equations see the SLAMM 5.0 technical documentation (Clough and Park, 2008).

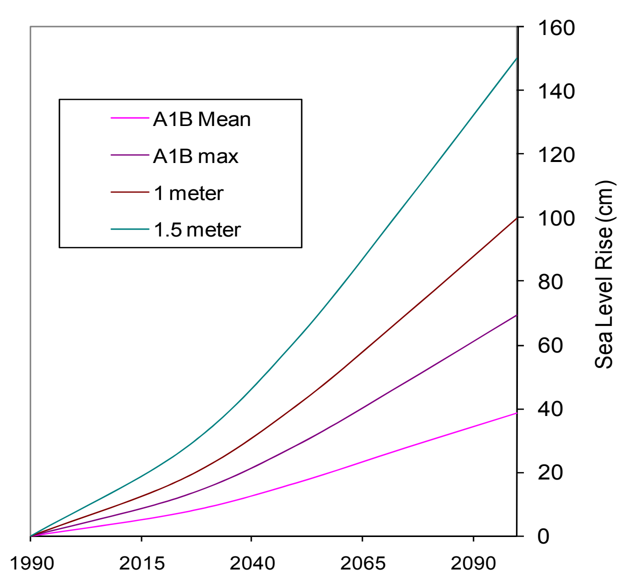
Sea Level Rise Scenarios

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 in this report, SLAMM was also run assuming 1 meter and 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



For simplicity sake, this application report will focus on the A1B-Mean, A1B-Max, and 1½-meter scenarios but a complete set of model results are available for all four scenarios discussed above.

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 available for Oyster Bay 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 1943 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.

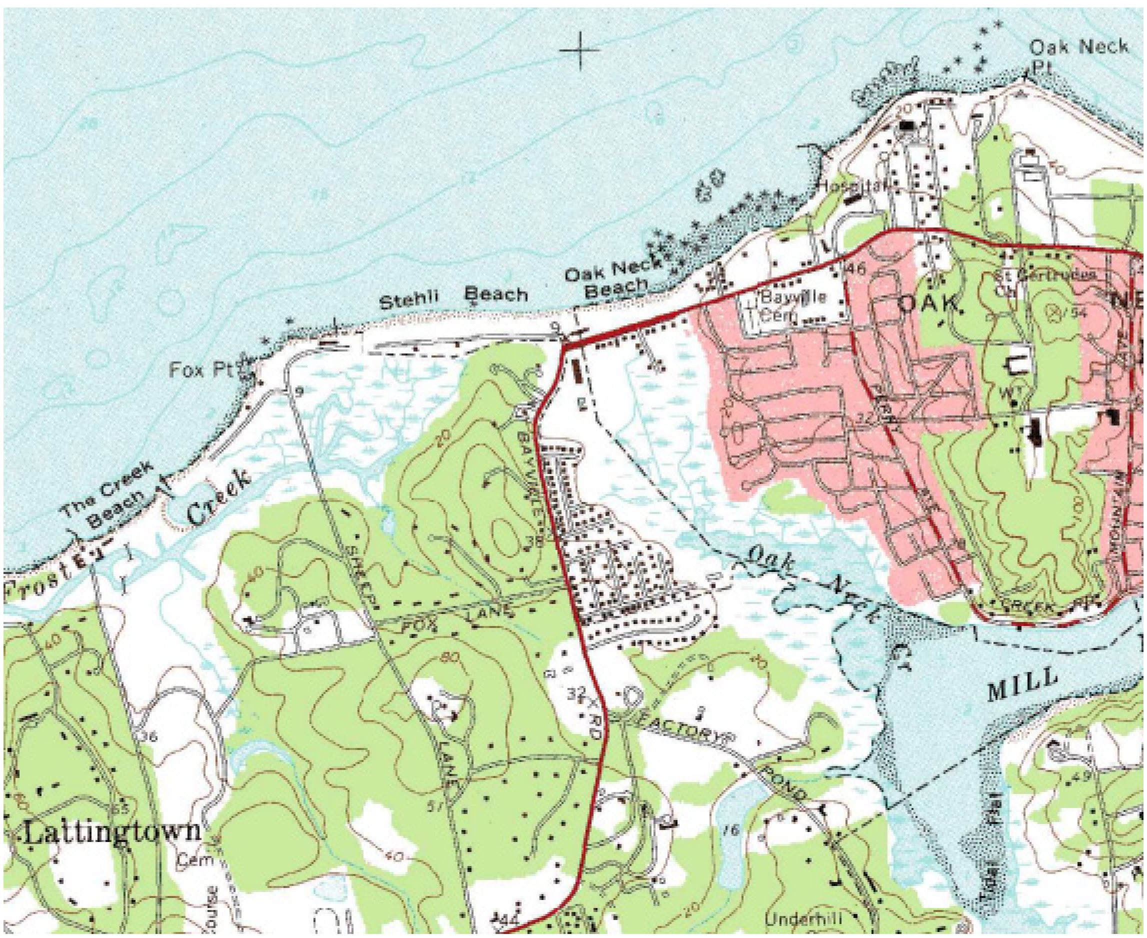


Figure 2: Detail of Northwestern Oyster Bay NWR from USGS topographic map.

The National Wetlands Inventory for Oyster Bay is based on a photo date of 2004 (Figure 3).

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

Estuarine Open Water	97.0%
Irregularly Flooded Marsh	0.7%
Saltmarsh	0.5%
Estuarine Beach	0.5%
Tidal Flat	0.4%
Undeveloped Dry Land	0.3%
Inland Open Water	0.2%
Swamp	0.2%
Trans. Salt Marsh	0.1%

There are several diked or impounded wetlands in the region of the Oyster Bay NWR according to the National Wetlands Inventory. Only one diked area lies within the refuge boundary, however (Figure 3).

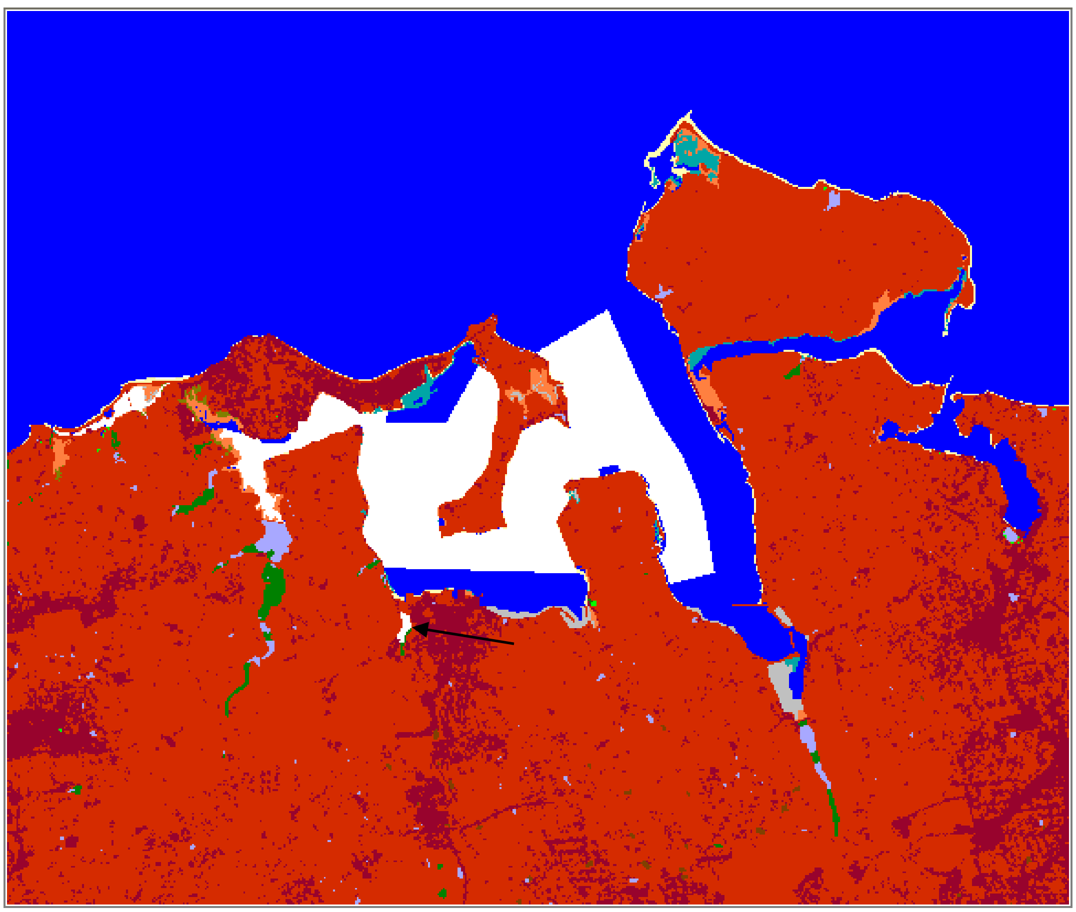


Figure 3: Oyster Bay Refuge in White. Diked region at arrow.

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

The tidal range for the Oyster Bay NWR is estimated at 2.42 meters (Figure 4) using tidal data from the closest gages (8516299, Bayville Bridge, Oyster Bay, NY; 8516061, Cold Spring Harbor, NY).

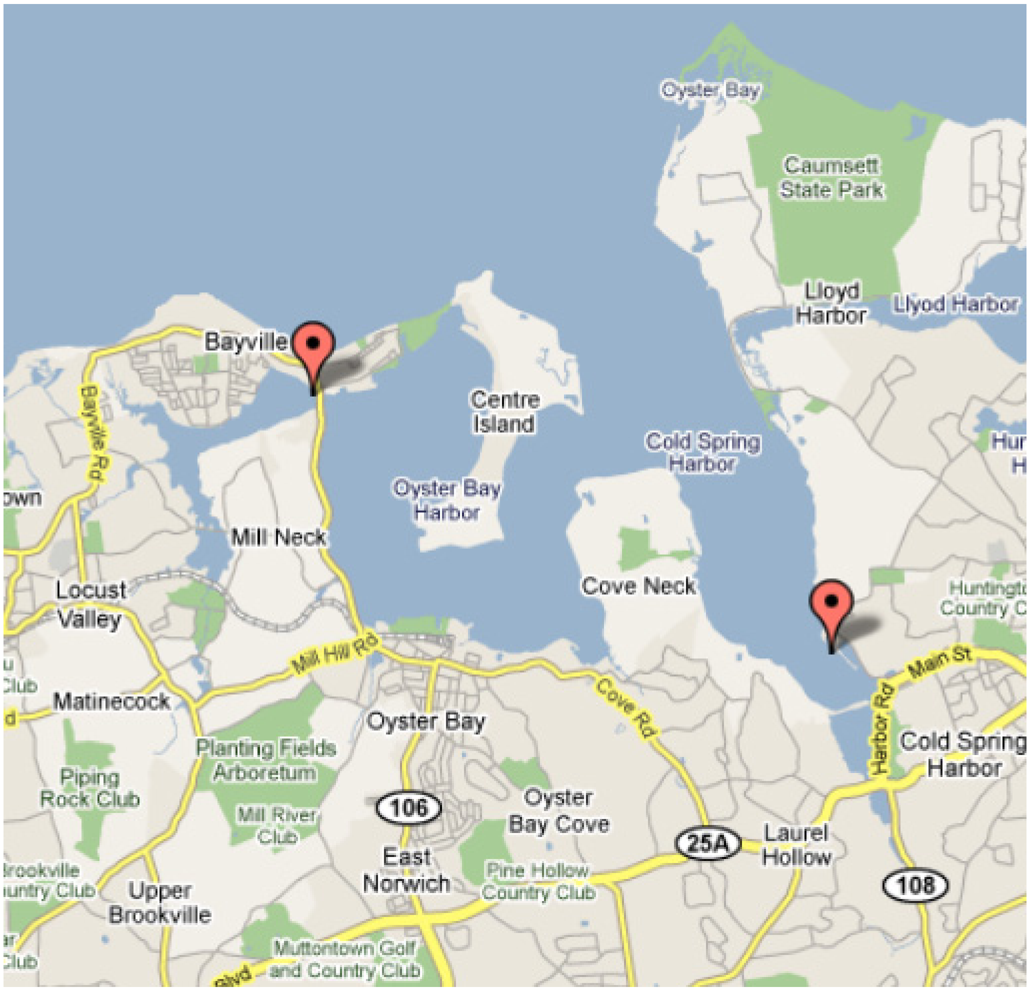


Figure 4: NOAA Gages Relevant to the Study Area (in rectangle).

Accretion rates in salt 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 20 kilometers east along the coast of Long Island Sound -- where accretion rates for regularly flooded saltmarsh 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 -0.0743 and -0.0747 meters. The resulting correction value is an average of these values.

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.

SUMMARY OF SLAMM INPUT PARAMETERS FOR OYSTER BAY NWR

Description	,	Oyster Bay
DEM Source Date (yyyy)	,	1943
NWI_photo_date (yyyy)	,	2004
Direction_OffShore (N|S|E|W)	,	N
Historic_trend (mm/yr)	,	2.44
NAVD88_correction (MTL-NAVD88 in meters)	,	-0.070975
Water Depth (m below MLW- N/A)	,	2
TideRangeOcean (meters: MHHW-MLLW)	,	2.42
TideRangeInland (meters)	,	2.42
Mean High Water Spring (m above MTL)	,	1.6093
MHSW Inland (m above MTL)	,	1.6093
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
Brackish 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 are different across land cover classes. In any scenario above 0.39 meter sea level rise the refuge is expected to lose between 34% and 100% of its irregularly flooded (brackish) marsh. This marsh is predicted to convert to "regularly flooded" saltmarsh which increases in quantity under all scenarios.

SLR by 2100 (m)	0.39	0.69	1	1.5
Irregularly Flooded Marsh	1%	34%	73%	100%
Saltmarsh	-7%	-76%	-151%	-176%
Estuarine Beach	27%	41%	55%	78%
Tidal Flat	48%	53%	62%	75%
Dry Land	60%	63%	63%	64%
Swamp	0%	0%	1%	3%

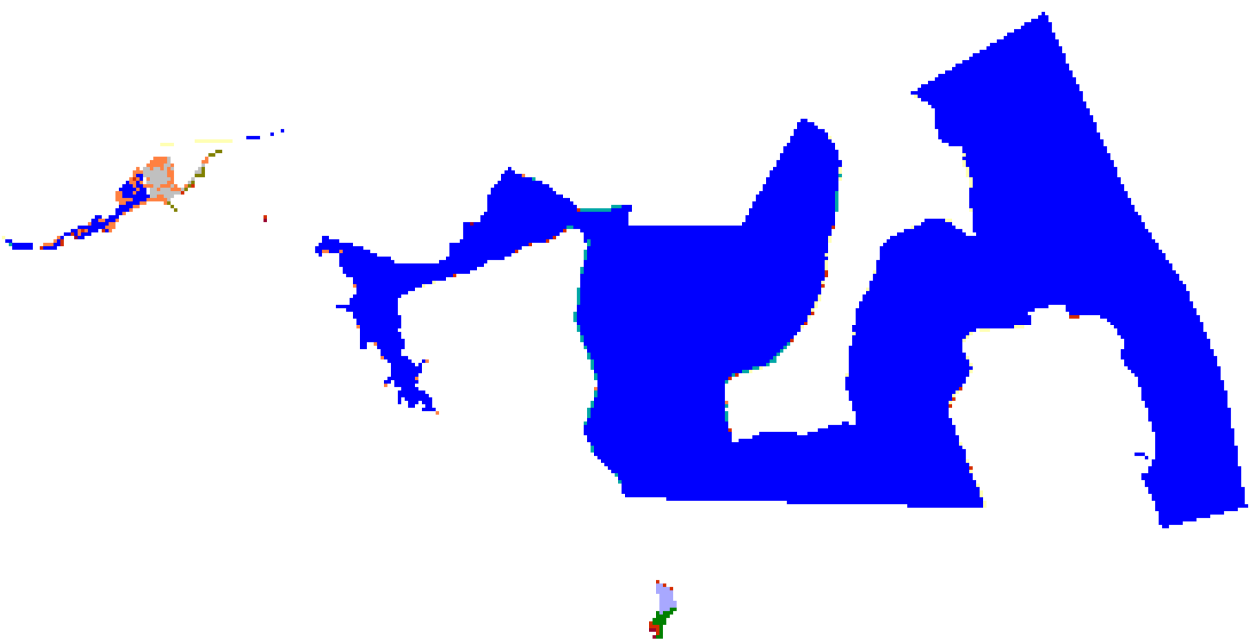
Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

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

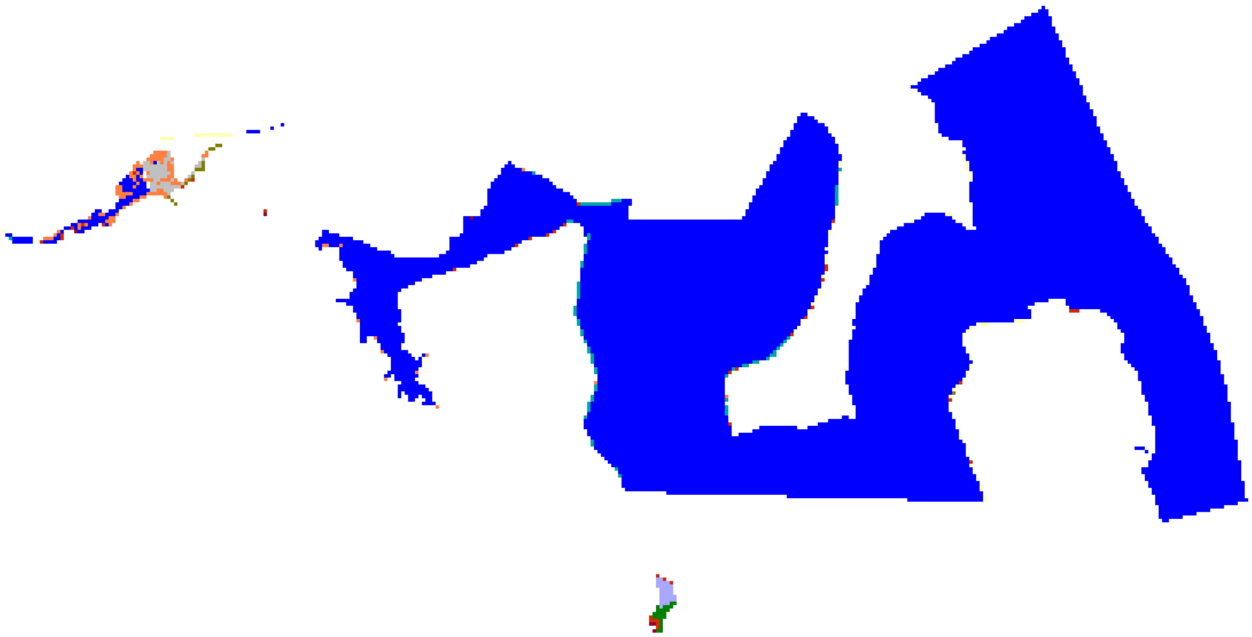
Oyster Bay NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

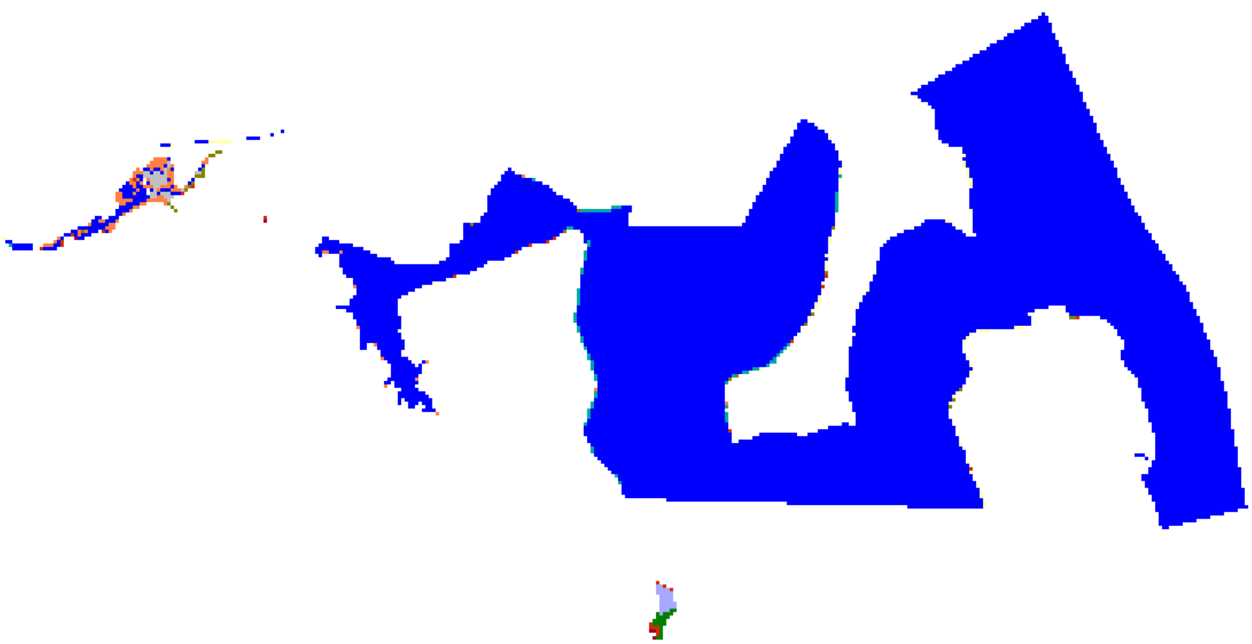
	Initial	2025	2050	2075	2100
Estuarine Open Water	3305.0	3308.1	3312.1	3314.9	3317.3
Irregularly Flooded Marsh	24.9	24.9	24.9	24.9	24.7
Saltmarsh	17.8	17.8	18.1	18.6	19.0
Estuarine Beach	17.6	16.6	15.1	13.9	12.8
Tidal Flat	14.7	12.6	10.0	8.5	7.6
Undeveloped Dry Land	9.6	8.2	6.2	4.5	3.8
Inland Open Water	7.3	7.3	7.3	7.3	7.3
Swamp	5.1	5.1	5.1	5.1	5.1
Trans. Salt Marsh	3.3	4.7	6.6	7.8	8.0
Dev. Dry Land	1.3	1.3	1.2	1.0	1.0
Total (incl. water)	**3406.6**	**3406.6**	**3406.6**	**3406.6**	**3406.6**



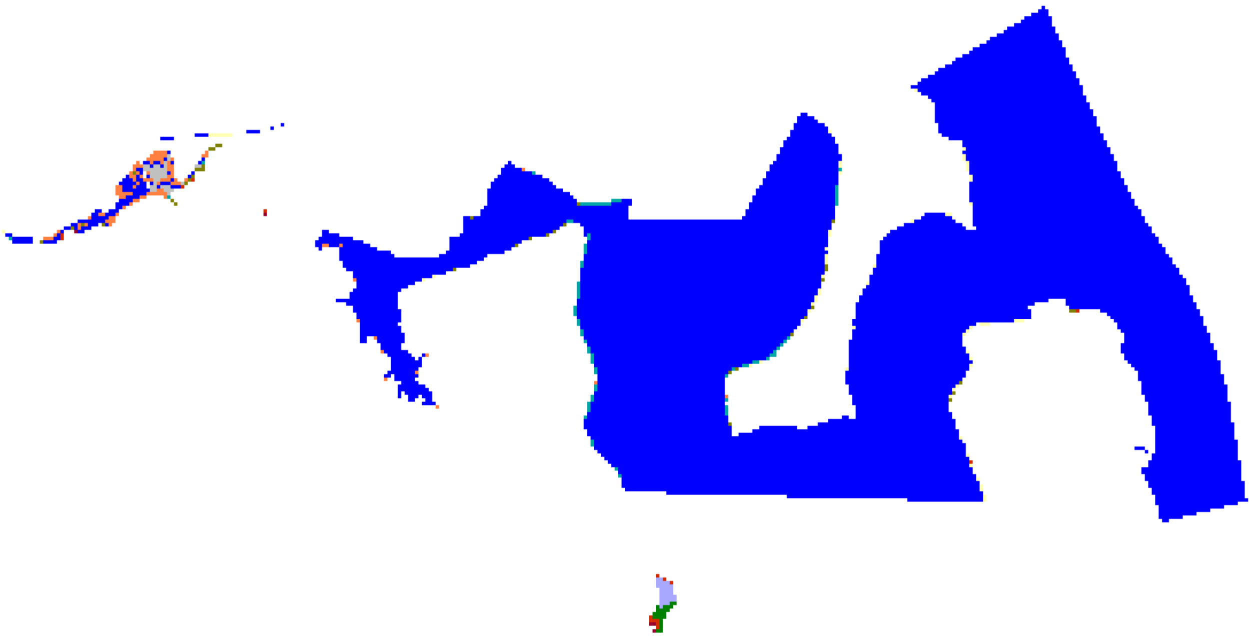
Oyster Bay NWR, Initial Condition



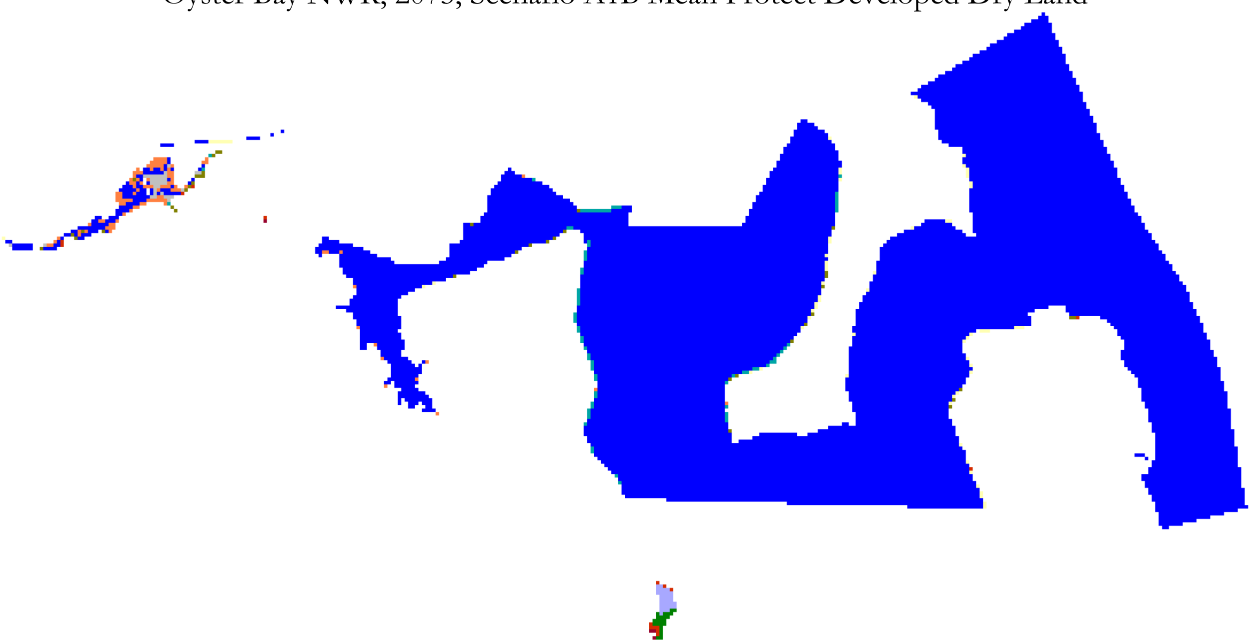
Oyster Bay NWR, 2025, Scenario A1B Mean Protect Developed Dry Land



Oyster Bay NWR, 2050, Scenario A1B Mean Protect Developed Dry Land



Oyster Bay NWR, 2075, Scenario A1B Mean Protect Developed Dry Land

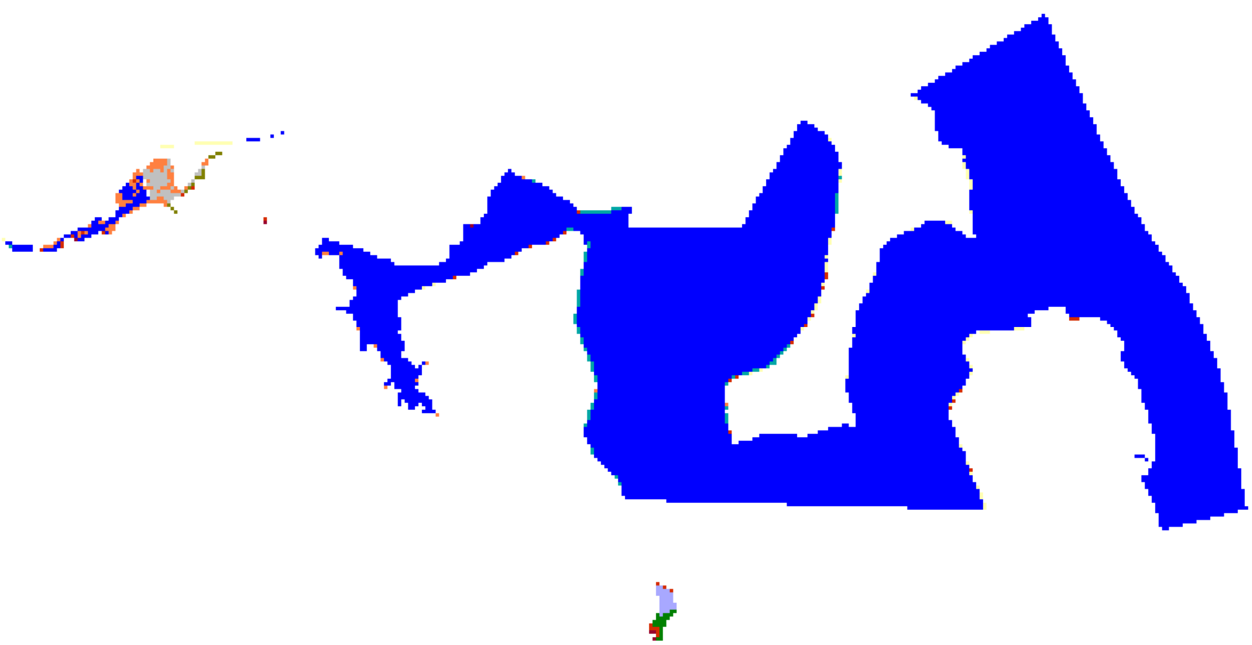


Oyster Bay NWR, 2100, Scenario A1B Mean Protect Developed Dry Land

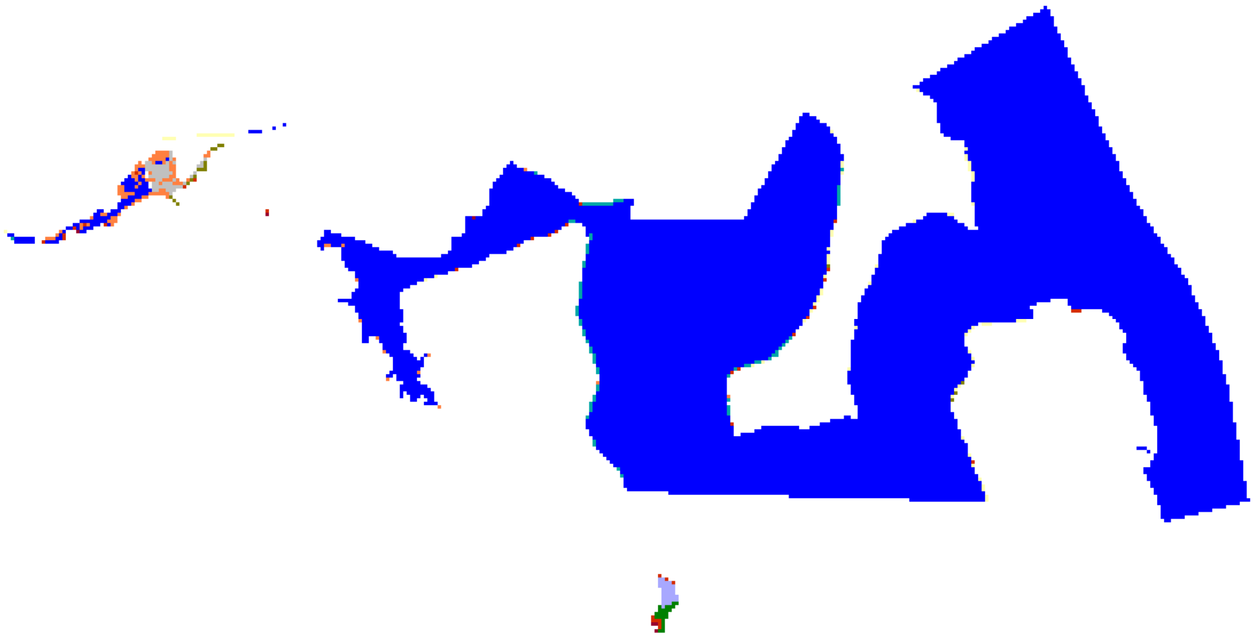
Oyster Bay NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

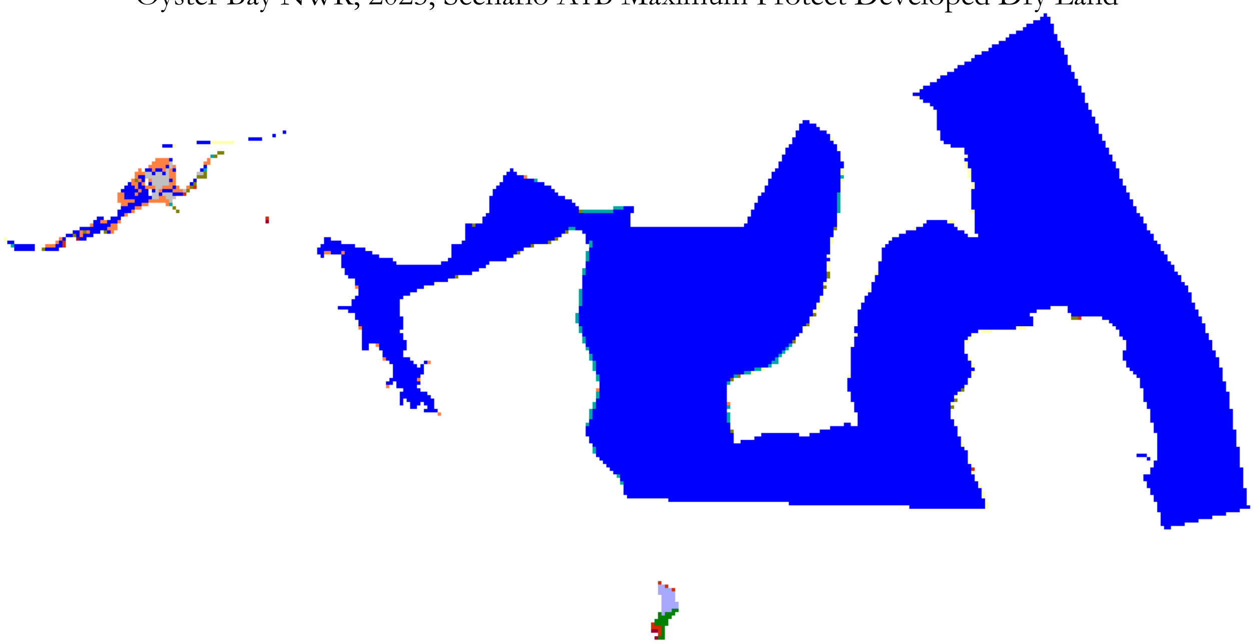
	Initial	2025	2050	2075	2100
Estuarine Open Water	3305.0	3308.5	3313.2	3316.8	3320.3
Irregularly Flooded Marsh	24.9	24.9	24.9	22.1	16.5
Saltmarsh	17.8	18.1	19.0	23.3	31.4
Estuarine Beach	17.6	16.3	14.3	12.4	10.4
Tidal Flat	14.7	12.4	9.8	8.1	6.9
Undeveloped Dry Land	9.6	7.6	4.7	3.6	3.5
Inland Open Water	7.3	7.3	7.3	7.3	7.3
Swamp	5.1	5.1	5.1	5.1	5.1
Trans. Salt Marsh	3.3	5.1	7.2	7.0	4.2
Dev. Dry Land	1.3	1.2	1.1	1.0	0.9
Total (incl. water)	**3406.6**	**3406.6**	**3406.6**	**3406.6**	**3406.6**



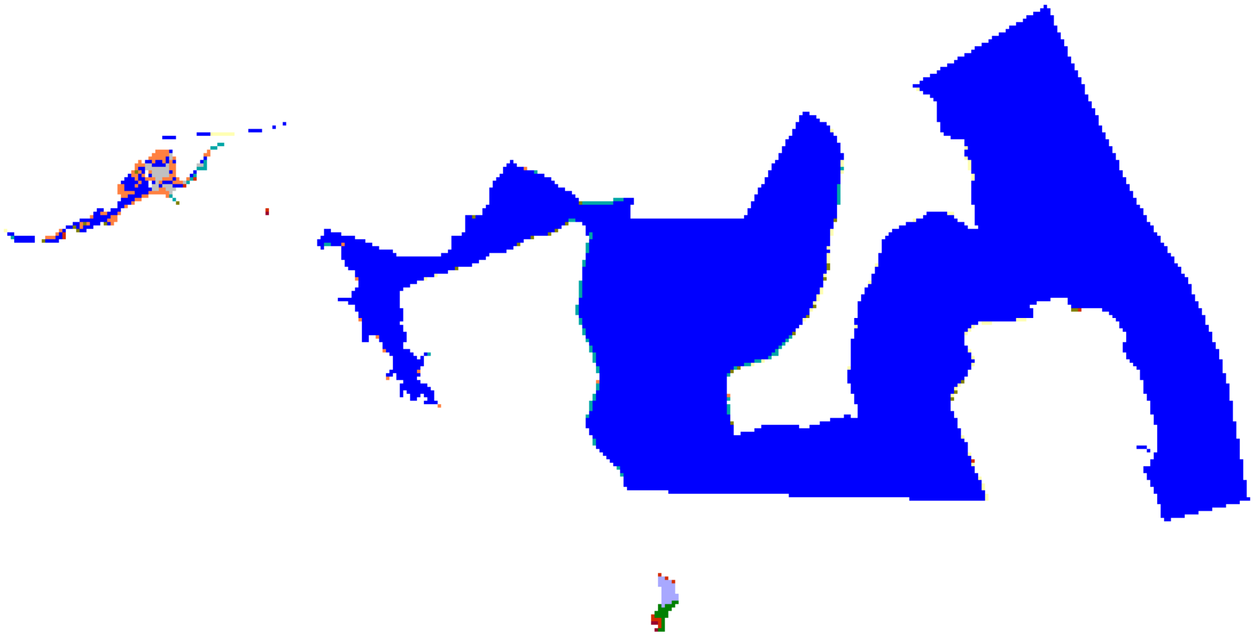
Oyster Bay NWR, Initial Condition



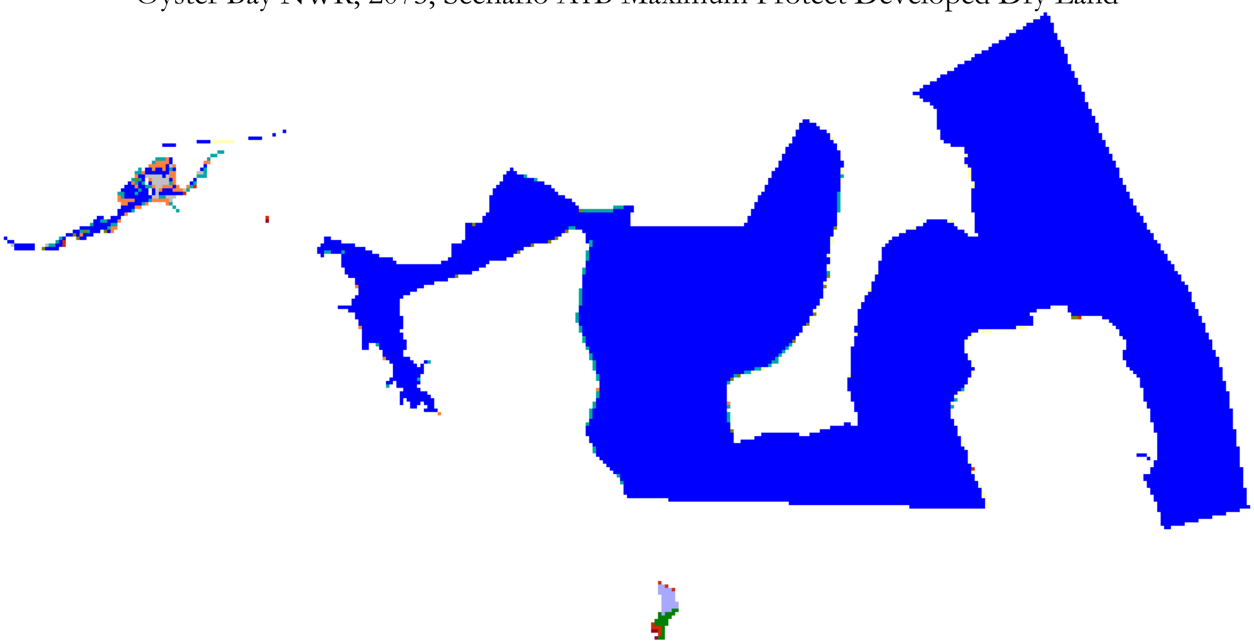
Oyster Bay NWR, 2025, Scenario A1B Maximum Protect Developed Dry Land



Oyster Bay NWR, 2050, Scenario A1B Maximum Protect Developed Dry Land



Oyster Bay NWR, 2075, Scenario A1B Maximum Protect Developed Dry Land

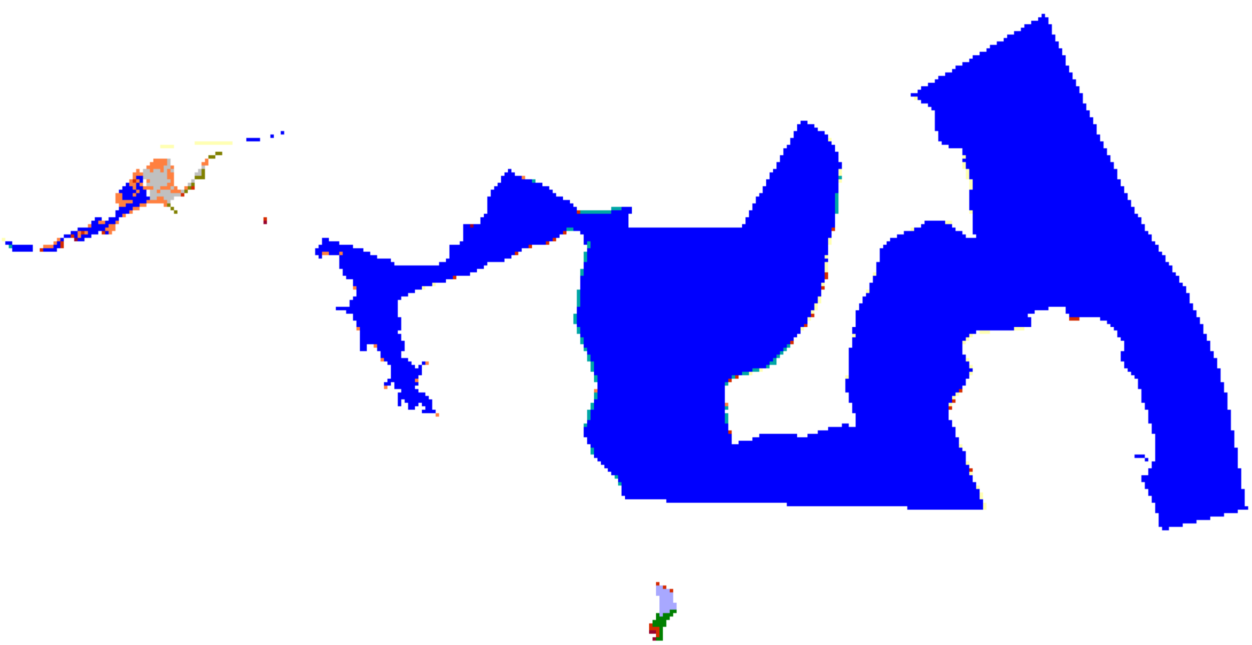


Oyster Bay NWR, 2100, Scenario A1B Maximum Protect Developed Dry Land

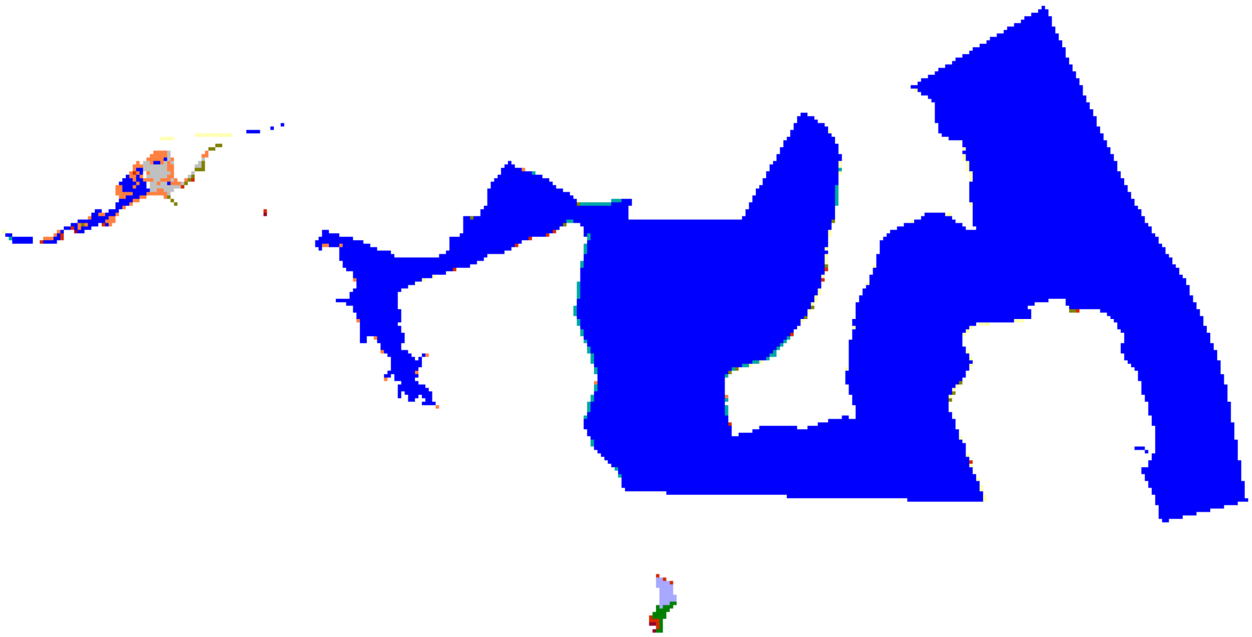
Oyster Bay NWR
1 Meter Eustatic SLR by 2100

Results in Acres

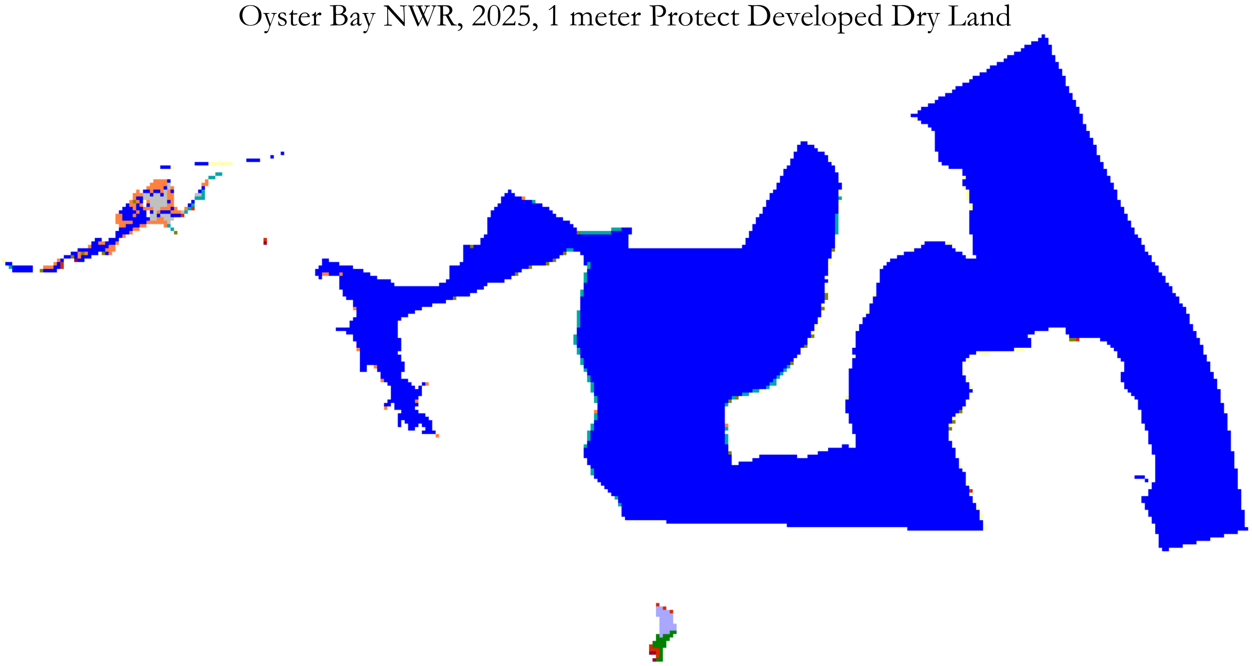
	Initial	2025	2050	2075	2100
Estuarine Open Water	3305.0	3308.9	3314.4	3319.2	3324.1
Irregularly Flooded Marsh	24.9	24.9	23.4	15.3	6.7
Saltmarsh	17.8	18.3	21.6	33.8	44.7
Estuarine Beach	17.6	16.0	13.4	10.8	8.0
Tidal Flat	14.7	12.3	9.4	7.3	5.6
Undeveloped Dry Land	9.6	7.0	4.2	3.5	3.5
Inland Open Water	7.3	7.3	7.3	7.3	7.3
Swamp	5.1	5.1	5.1	5.1	5.1
Trans. Salt Marsh	3.3	5.4	6.7	3.4	0.7
Dev. Dry Land	1.3	1.2	1.0	0.9	0.9
Total (incl. water)	**3406.6**	**3406.6**	**3406.6**	**3406.6**	**3406.6**



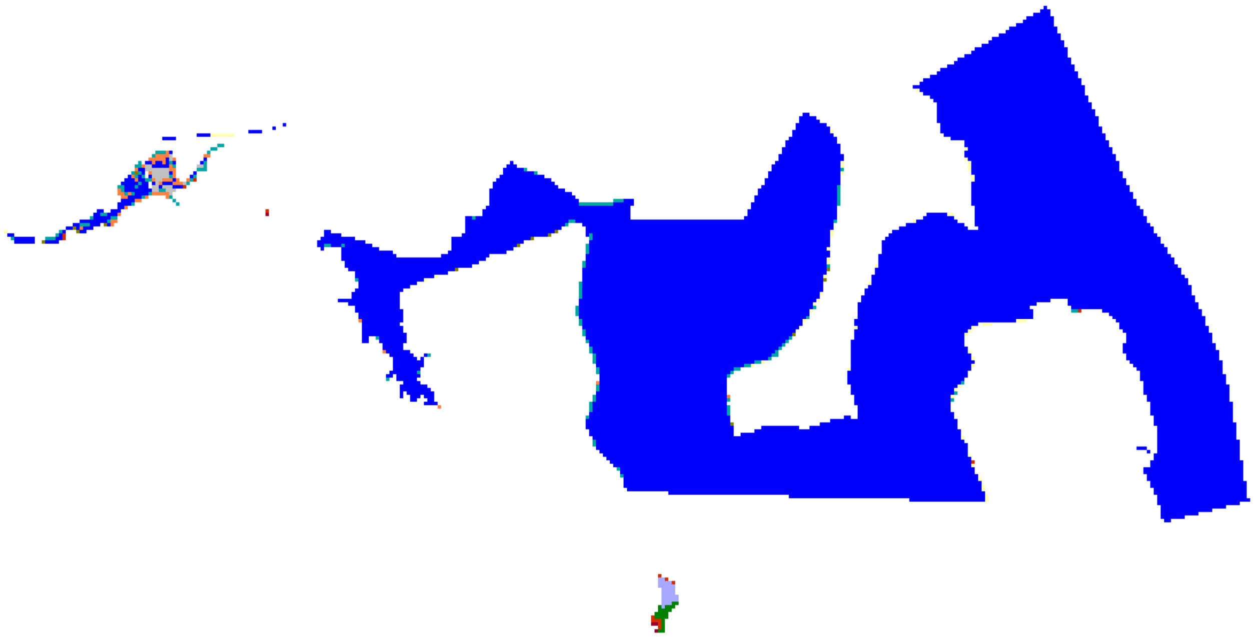
Oyster Bay NWR, Initial Condition



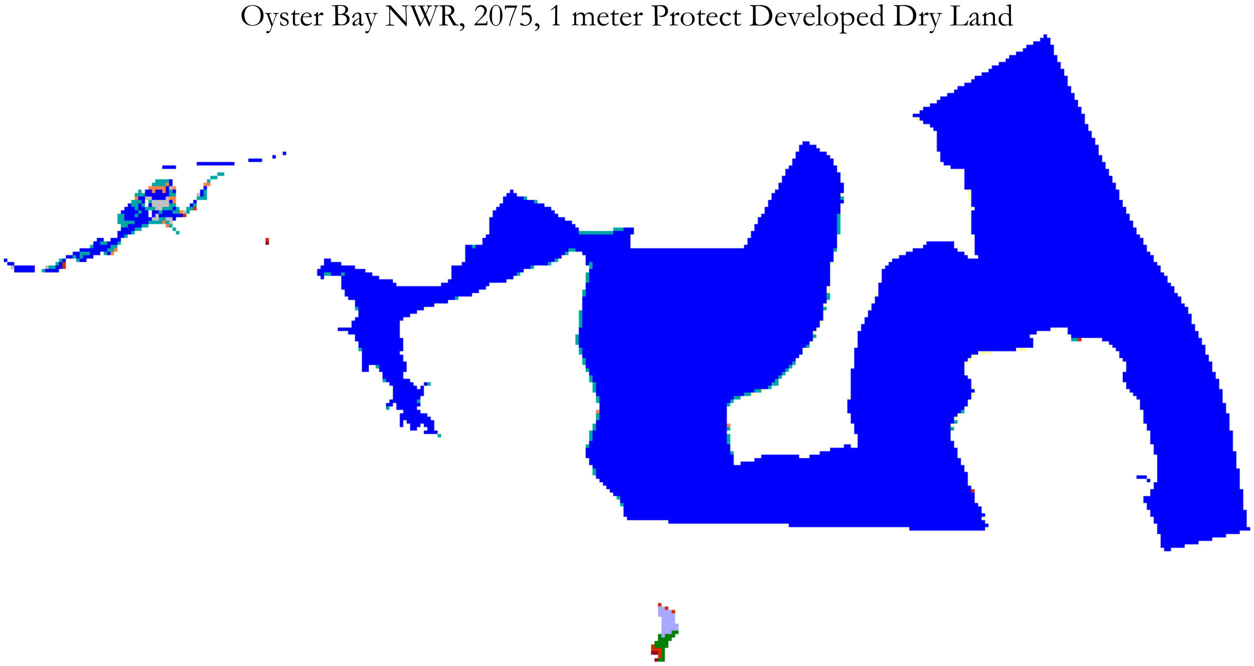
Oyster Bay NWR, 2025, 1 meter Protect Developed Dry Land



Oyster Bay NWR, 2050, 1 meter Protect Developed Dry Land



Oyster Bay NWR, 2075, 1 meter Protect Developed Dry Land

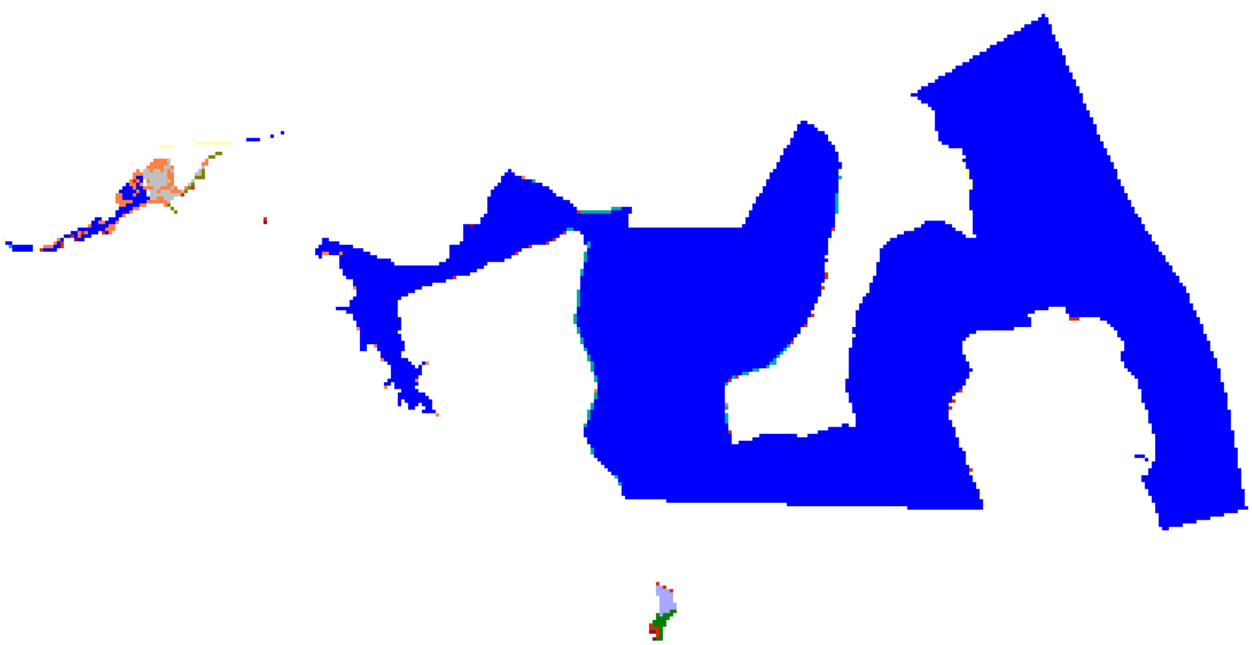


Oyster Bay NWR, 2100, 1 meter Protect Developed Dry Land

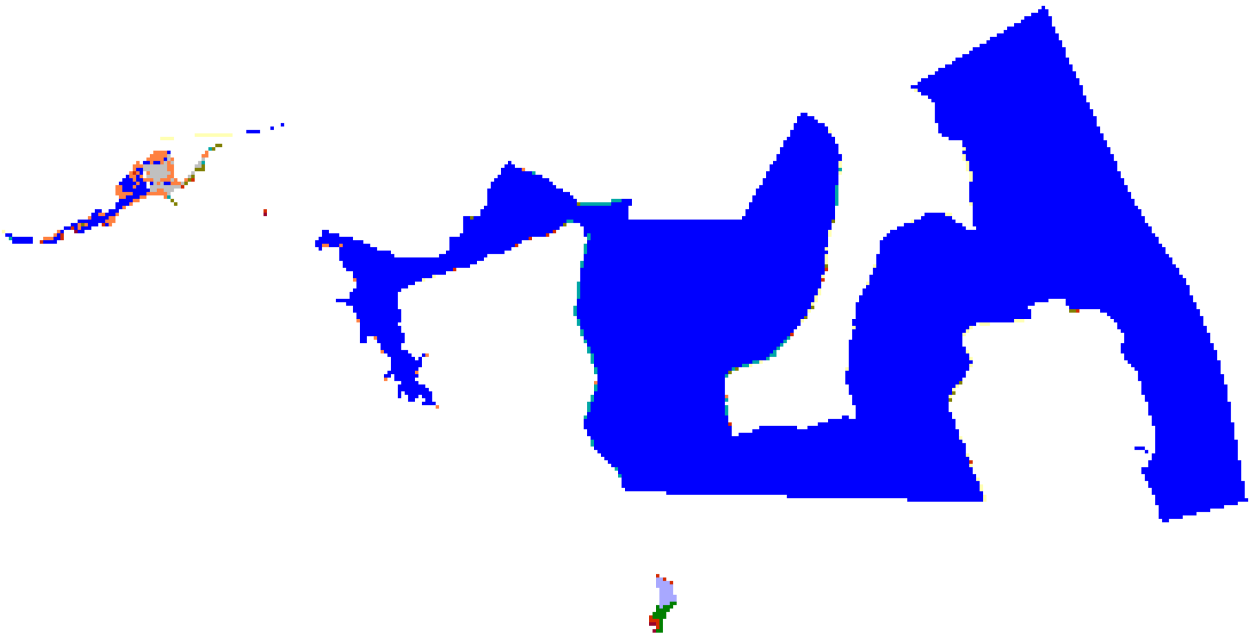
Oyster Bay NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

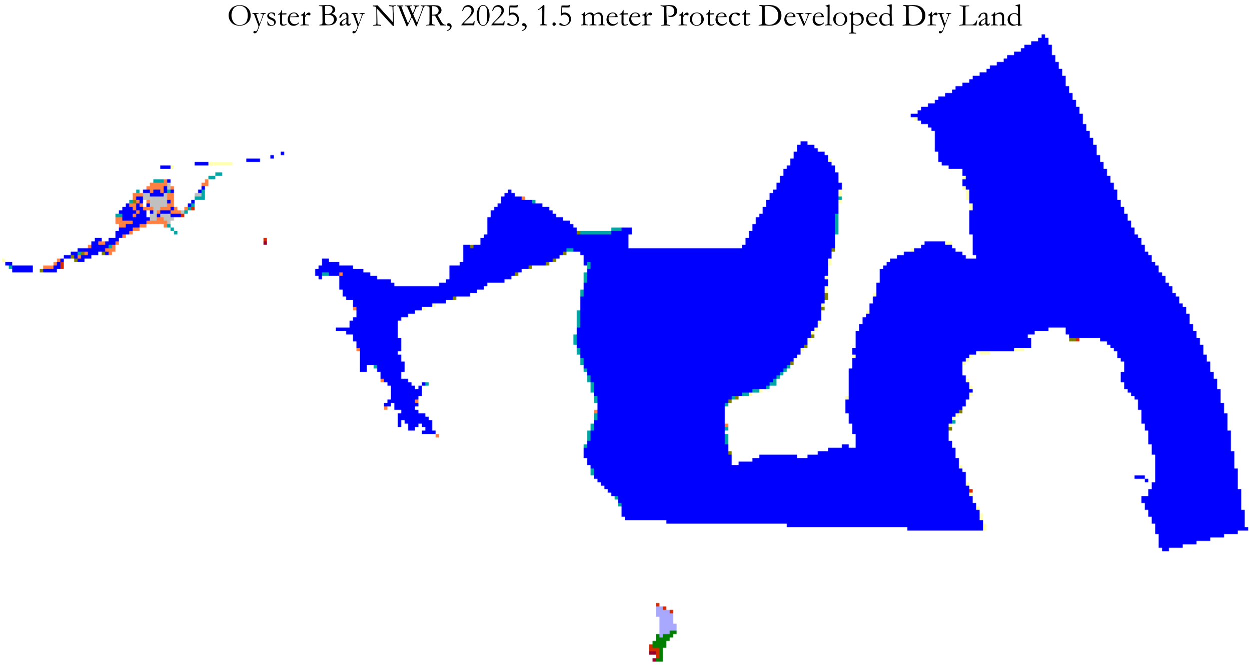
	Initial	2025	2050	2075	2100
Estuarine Open Water	3305.0	3309.6	3316.3	3322.9	3333.2
Irregularly Flooded Marsh	24.9	24.9	17.9	5.6	0.0
Saltmarsh	17.8	18.9	29.7	46.3	49.1
Estuarine Beach	17.6	15.6	12.1	8.1	3.8
Tidal Flat	14.7	12.0	8.8	6.6	3.7
Undeveloped Dry Land	9.6	6.1	3.6	3.5	3.4
Inland Open Water	7.3	7.3	7.3	7.3	7.3
Swamp	5.1	5.1	5.1	5.1	5.0
Trans. Salt Marsh	3.3	5.9	4.9	0.4	0.2
Dev. Dry Land	1.3	1.2	0.9	0.9	0.9
Total (incl. water)	**3406.6**	**3406.6**	**3406.6**	**3406.6**	**3406.6**



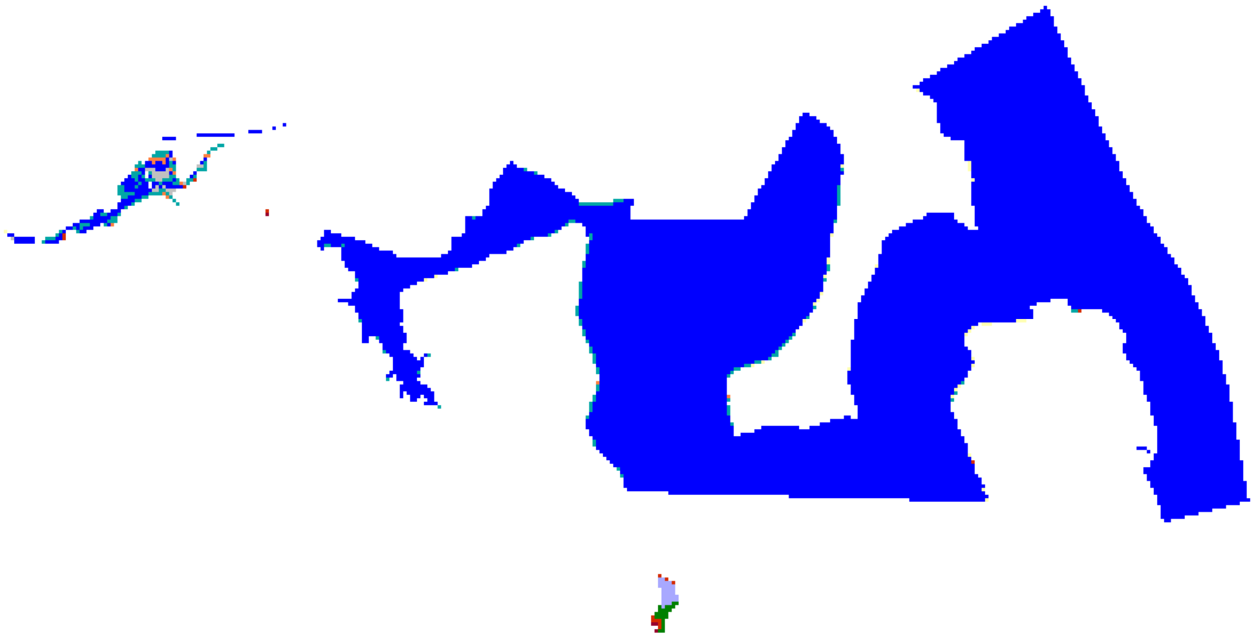
Oyster Bay NWR, Initial Condition



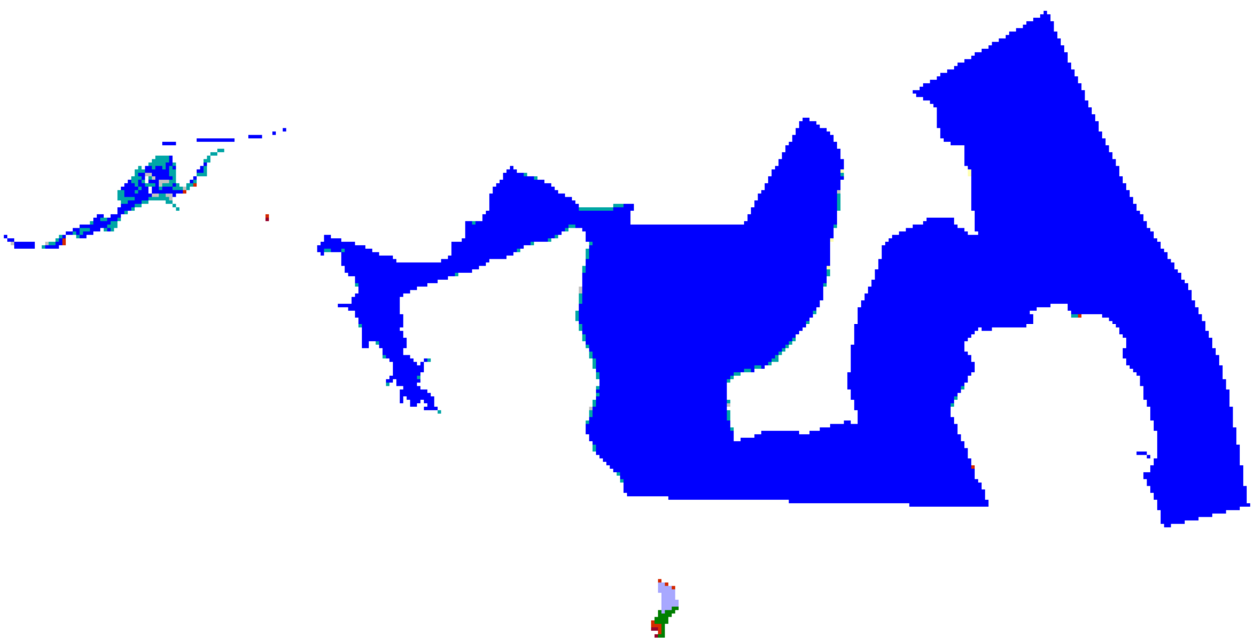
Oyster Bay NWR, 2025, 1.5 meter Protect Developed Dry Land



Oyster Bay NWR, 2050, 1.5 meter Protect Developed Dry Land



Oyster Bay NWR, 2075, 1.5 meter Protect Developed Dry Land



Oyster Bay NWR, 2100, 1.5 meter Protect Developed Dry Land

Discussion

Irregularly flooded marshes at this site are quite sensitive to the rate of sea level rise. When the rate of sea level rise exceeds measured accretion rates, losses for this category are predicted to begin in earnest. Irregularly flooded marsh is predicted to first convert to regularly flooded (saltmarsh) and ultimately tidal flats and open water. Accretion rates were not measured on-site but nearby which is a source of some uncertainty. Whether accretion rates will increase under higher rates of sea level rise is an additional source of uncertainty. Accretion rates were kept temporally constant within this simulation.

Tide ranges at this site are relatively large (2.42 meters) meaning that marshes are predicted to be more resilient to SLR than marshes located in microtidal regions.

Of the small quantity of dry land located at this site, 60% is predicted to be lost under all scenarios. However, elevations of dry lands are quite uncertain due to the low quality elevation data available for this site. The model result likely is a result of 40% of land existing above the 20 foot contour and 60% of the land existing below it.

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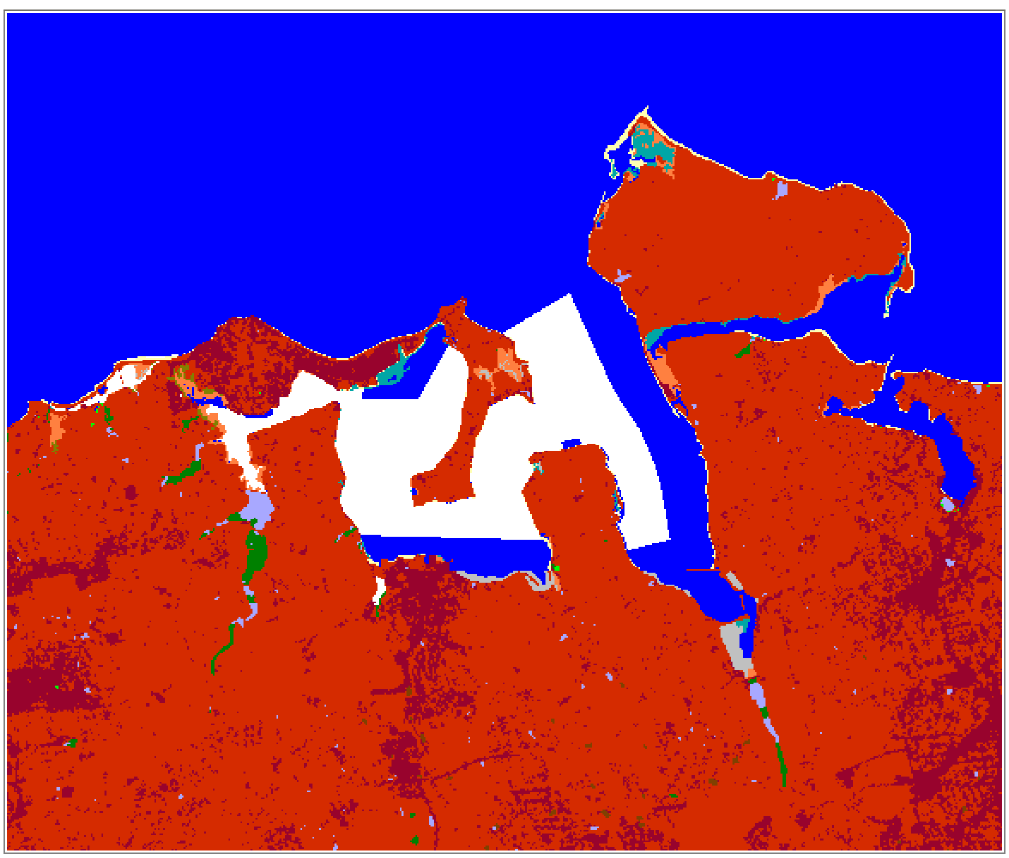
Appendix A: Contextual Results

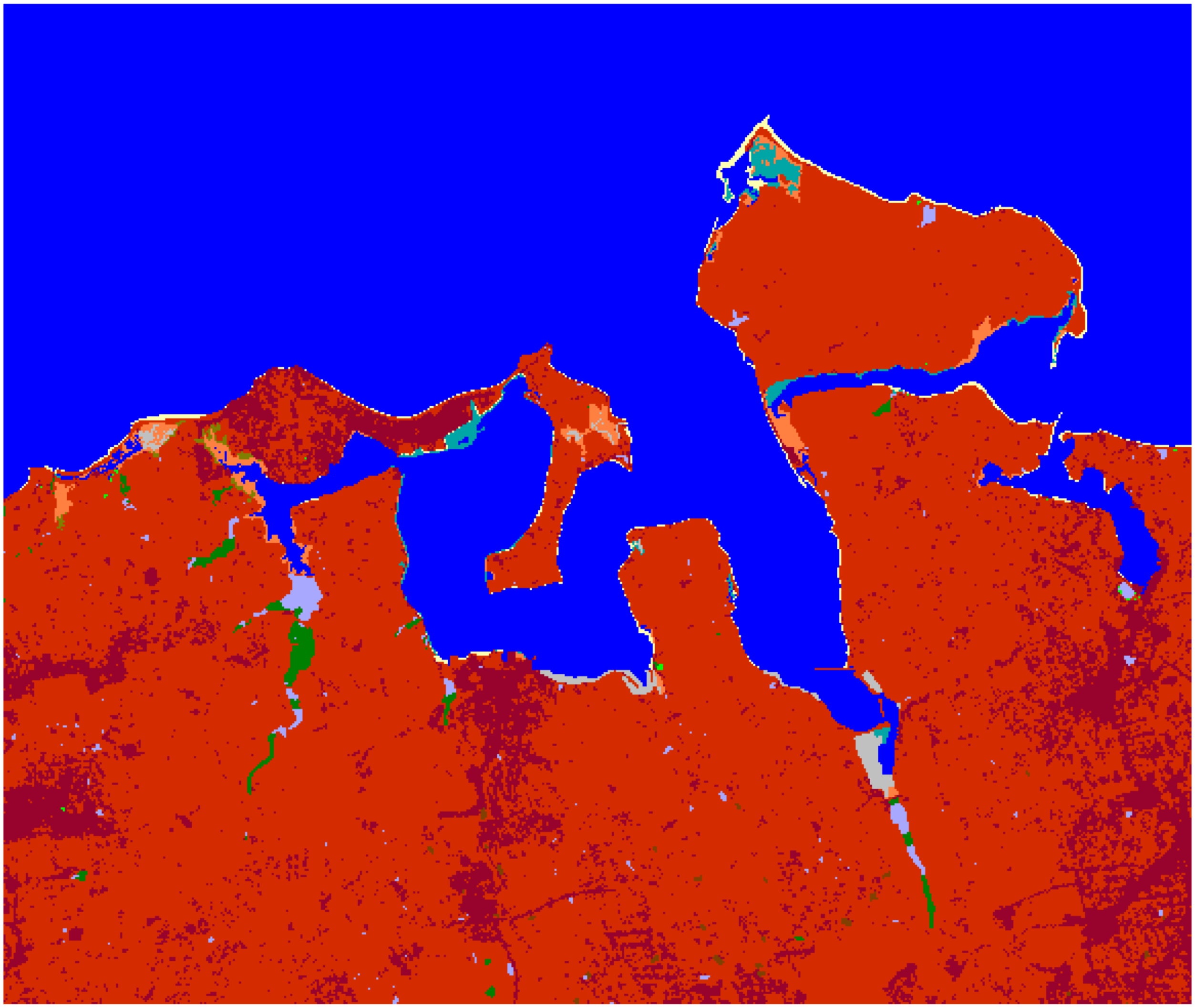
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

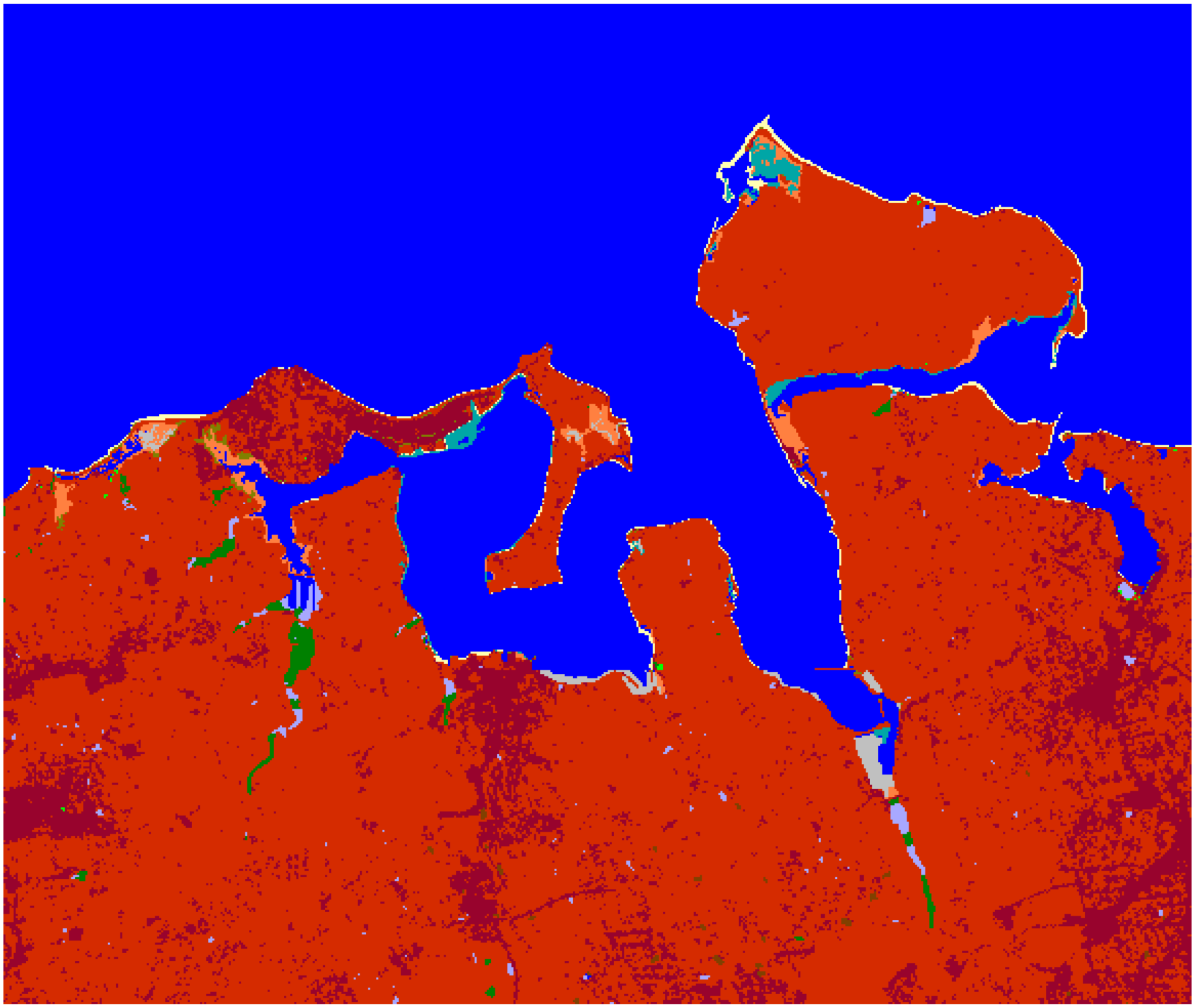
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



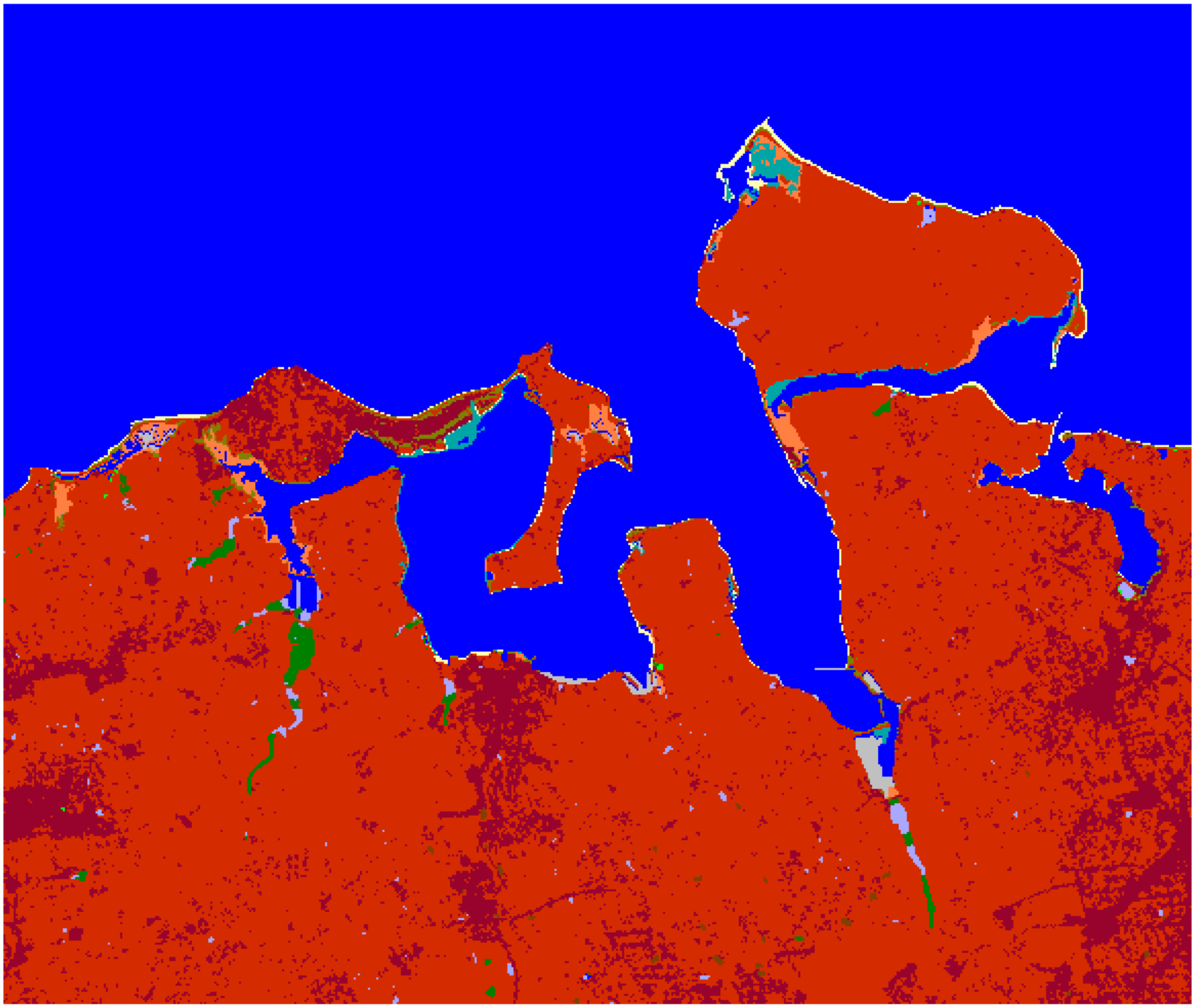
Location of Oyster Bay National Wildlife Refuge (white area in rectangle) within simulation context



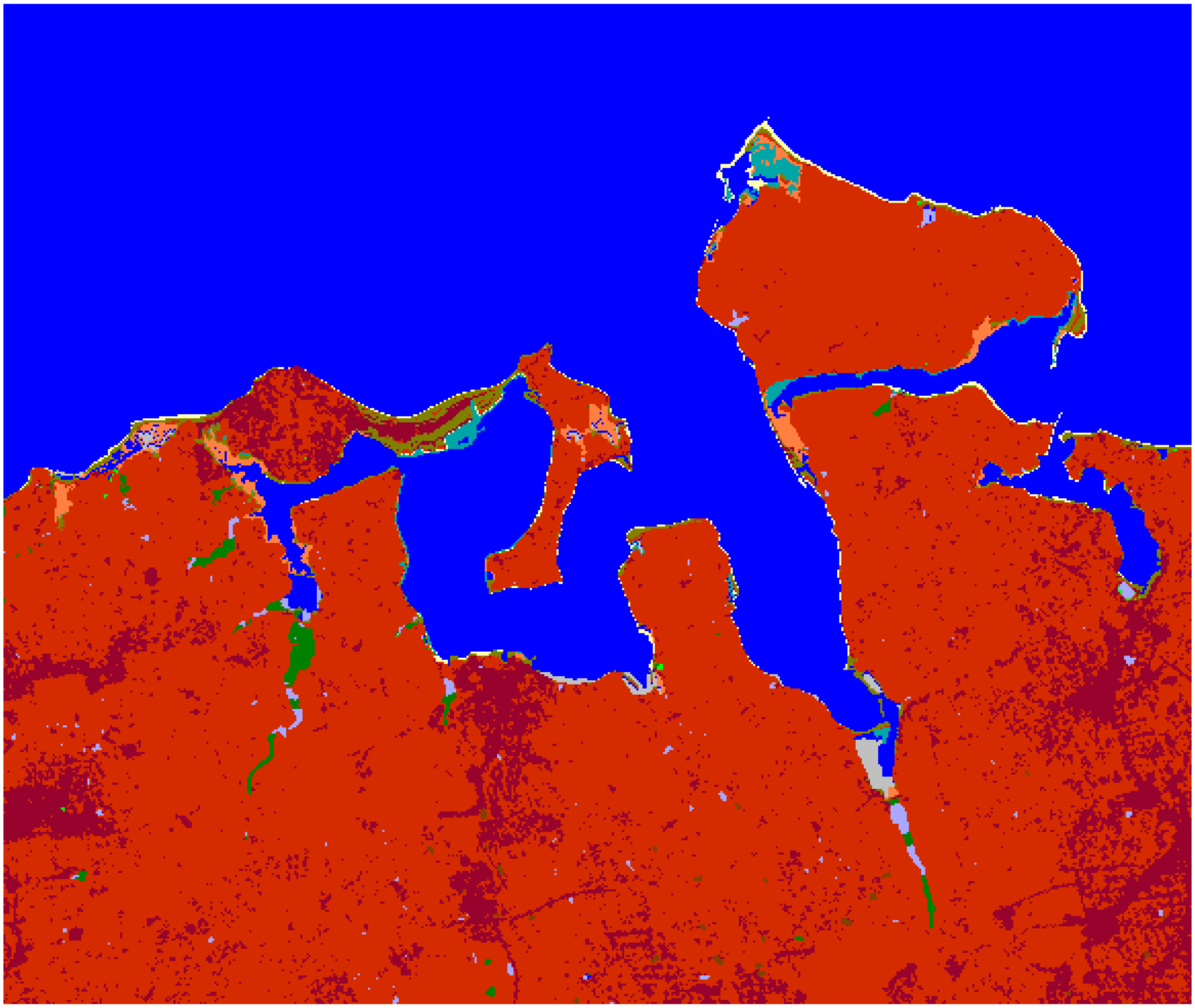
Oyster Bay NWR, Initial Condition



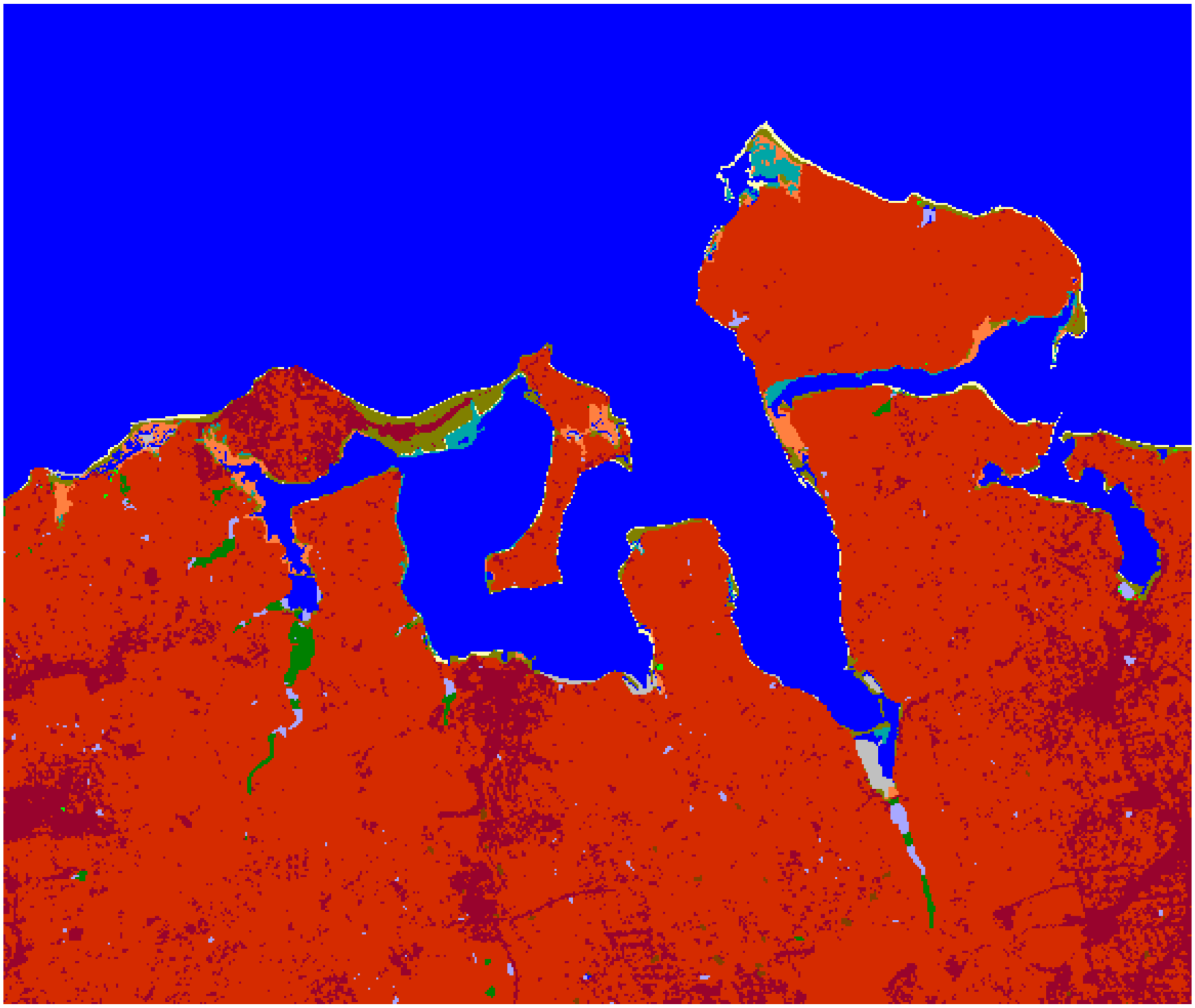
Oyster Bay NWR, 2025, Scenario A1B Mean Protect Developed Dry Land



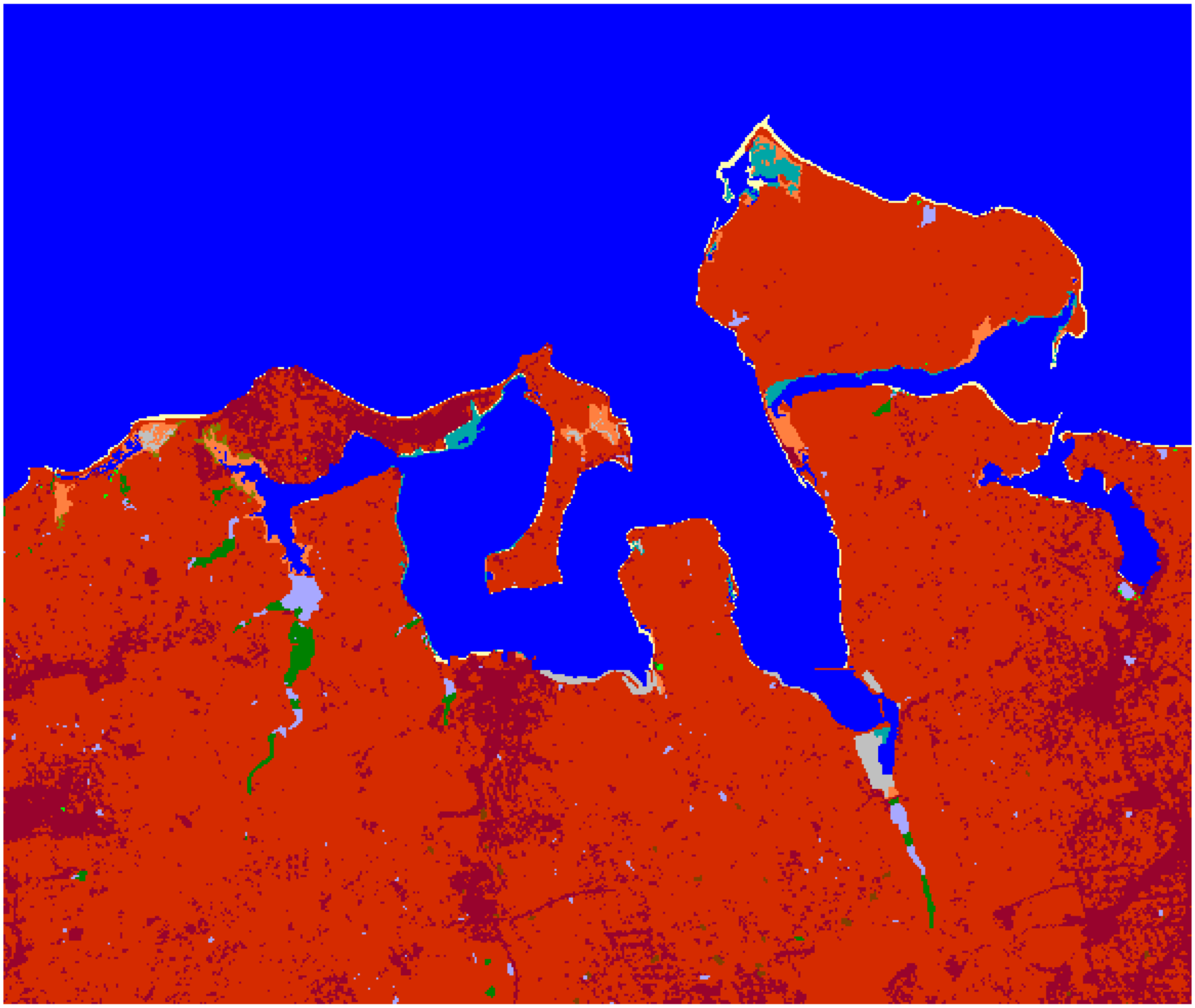
Oyster Bay NWR, 2050, Scenario A1B Mean Protect Developed Dry Land



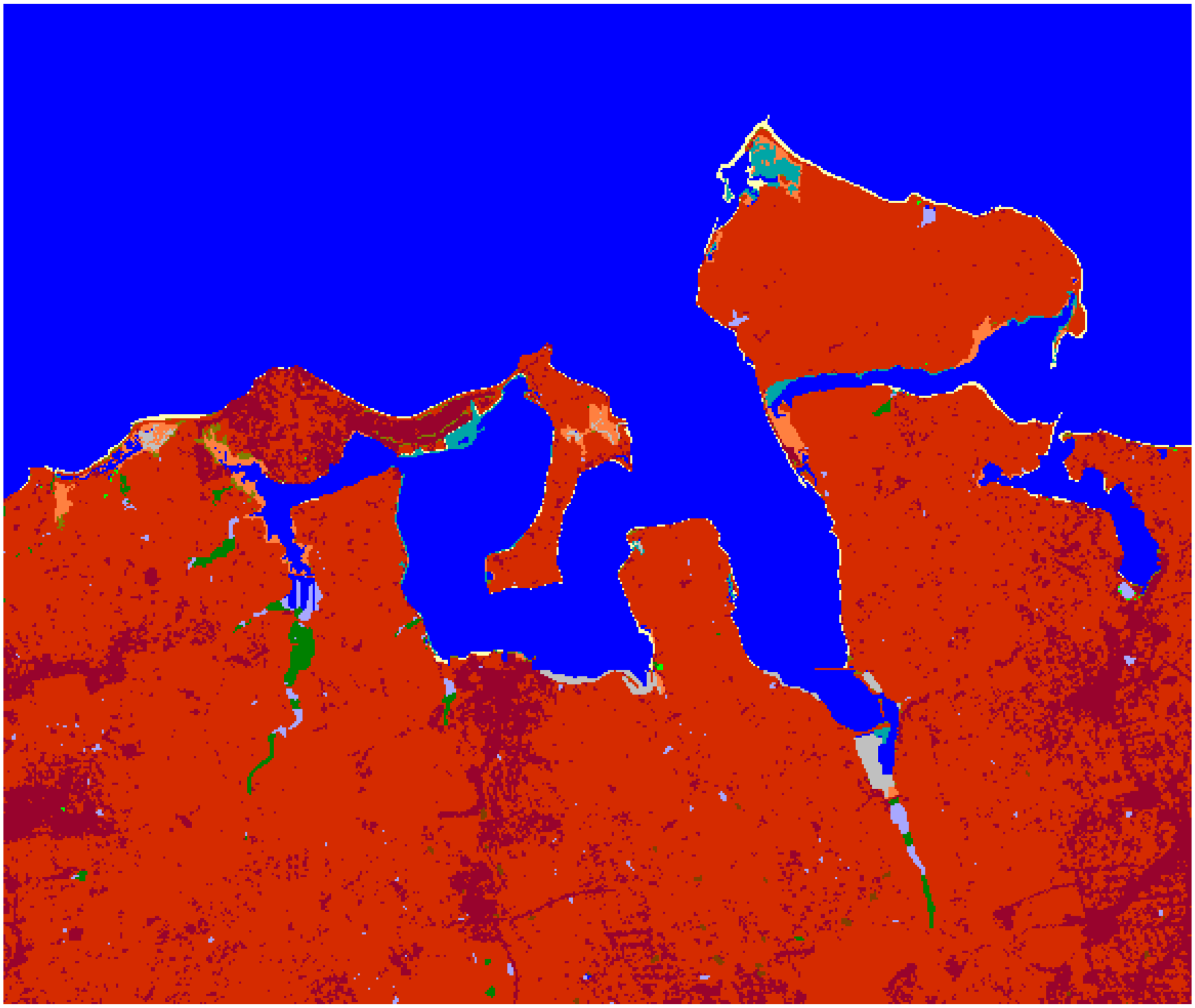
Oyster Bay NWR, 2075, Scenario A1B Mean Protect Developed Dry Land



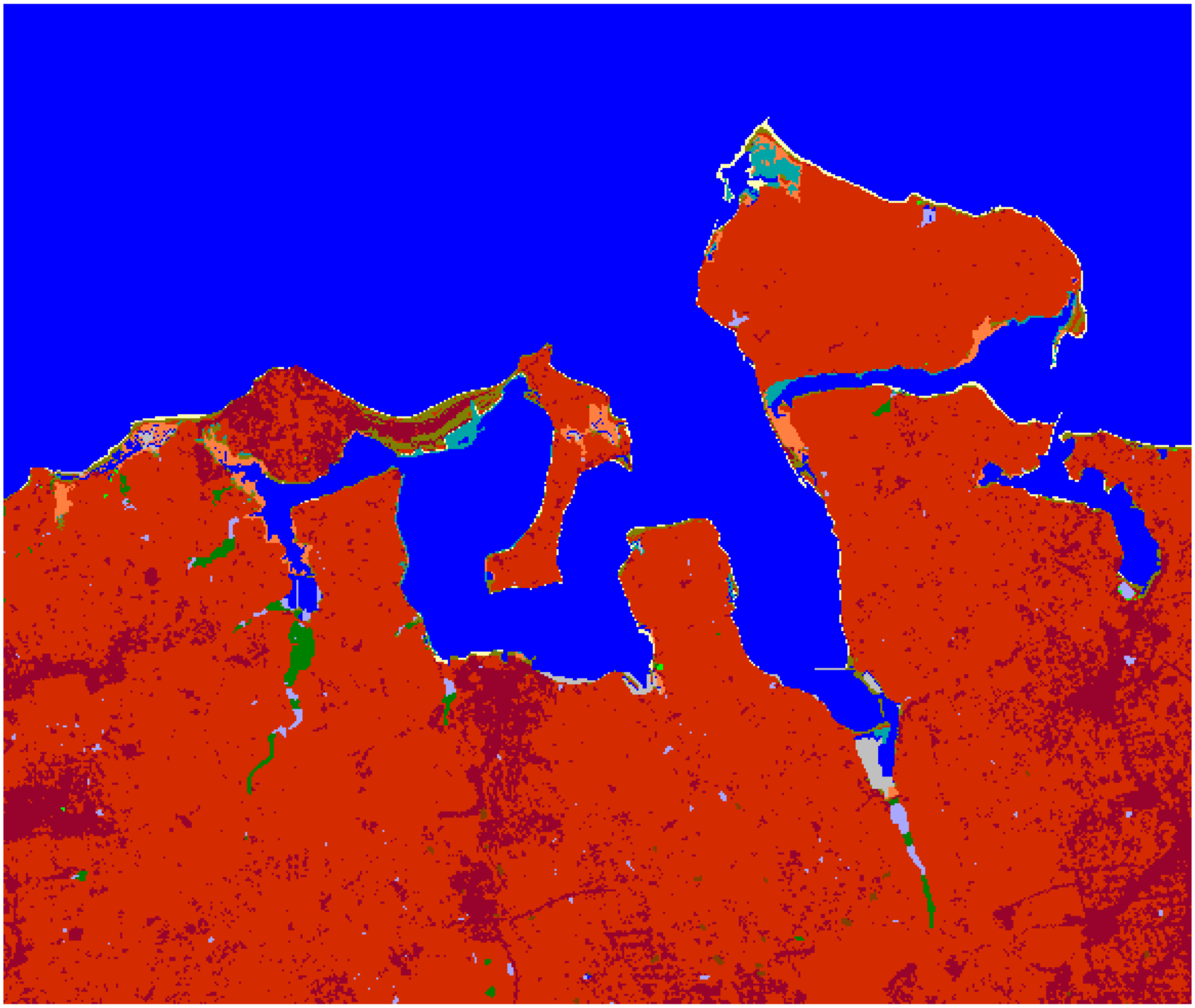
Oyster Bay NWR, 2100, Scenario A1B Mean Protect Developed Dry Land



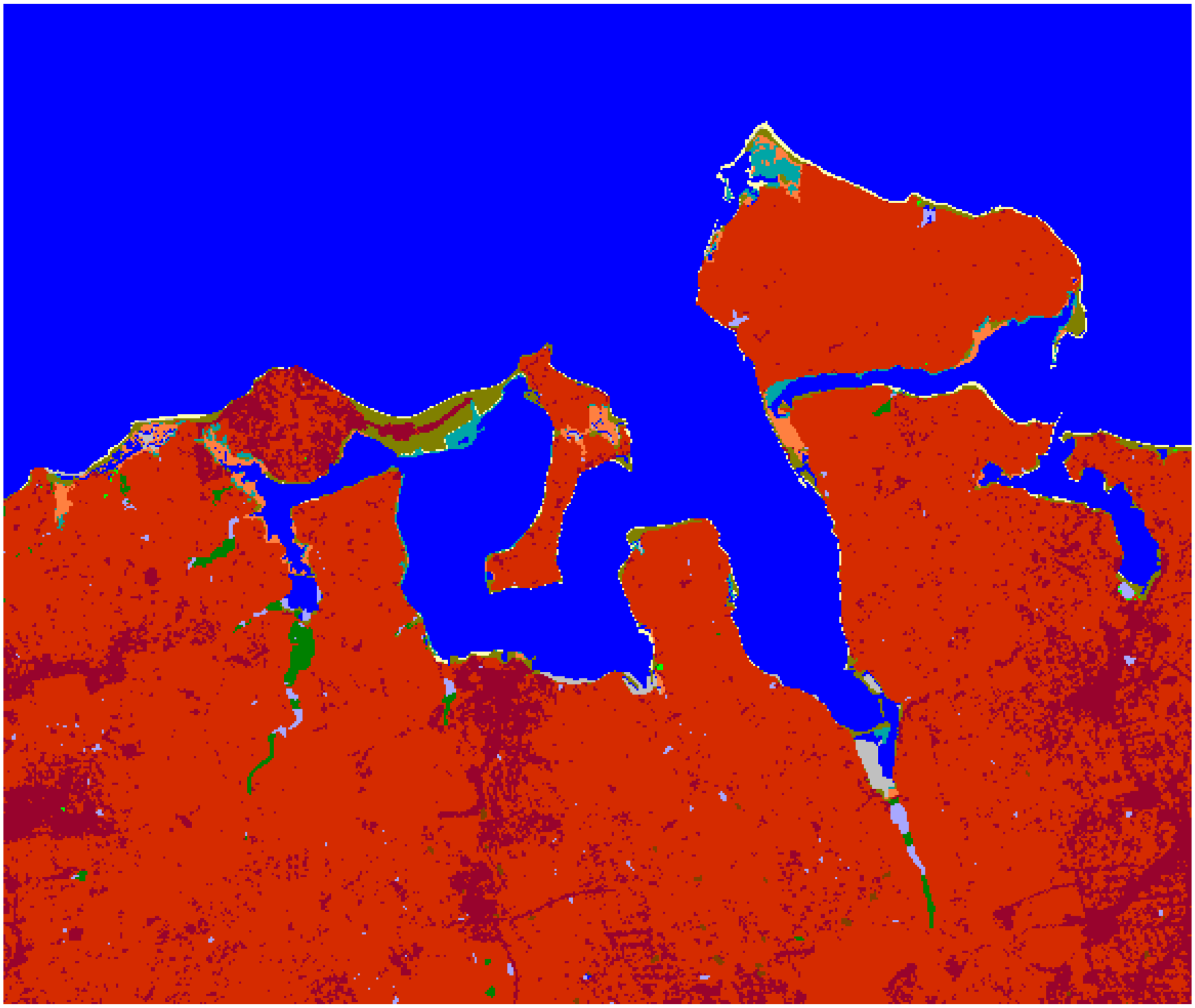
Oyster Bay NWR, Initial Condition



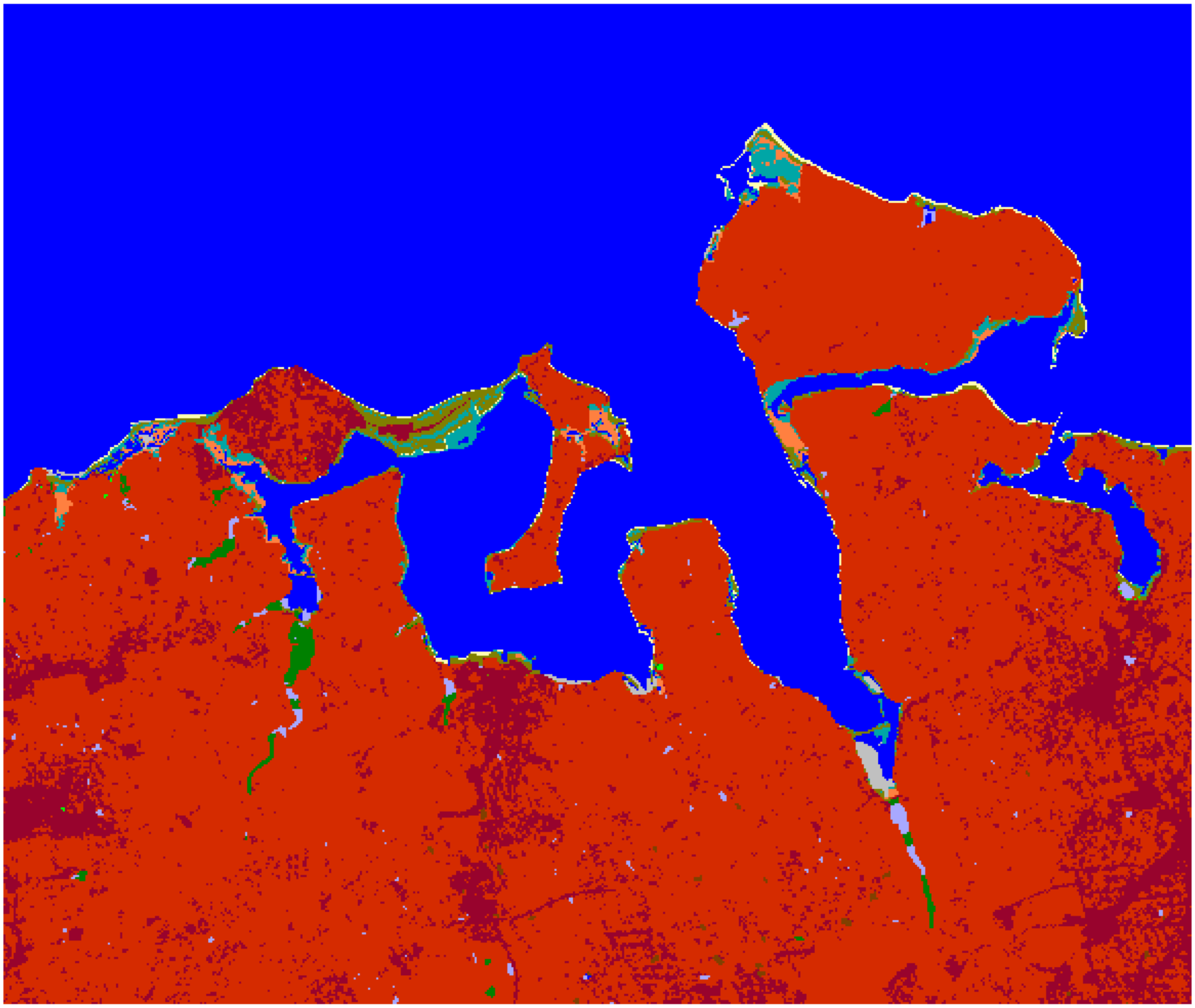
Oyster Bay NWR, 2025, Scenario A1B Maximum Protect Developed Dry Land



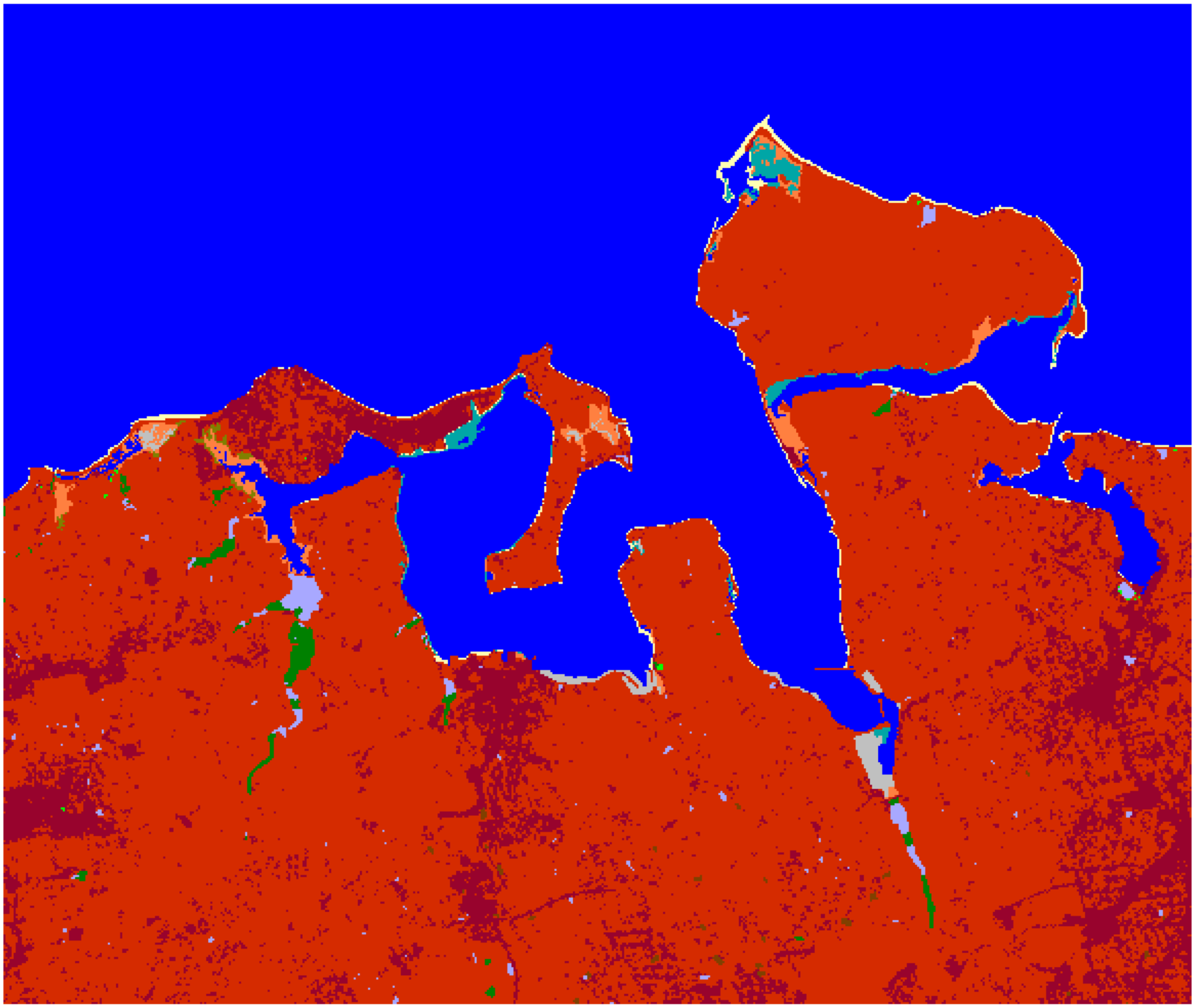
Oyster Bay NWR, 2050, Scenario A1B Maximum Protect Developed Dry Land



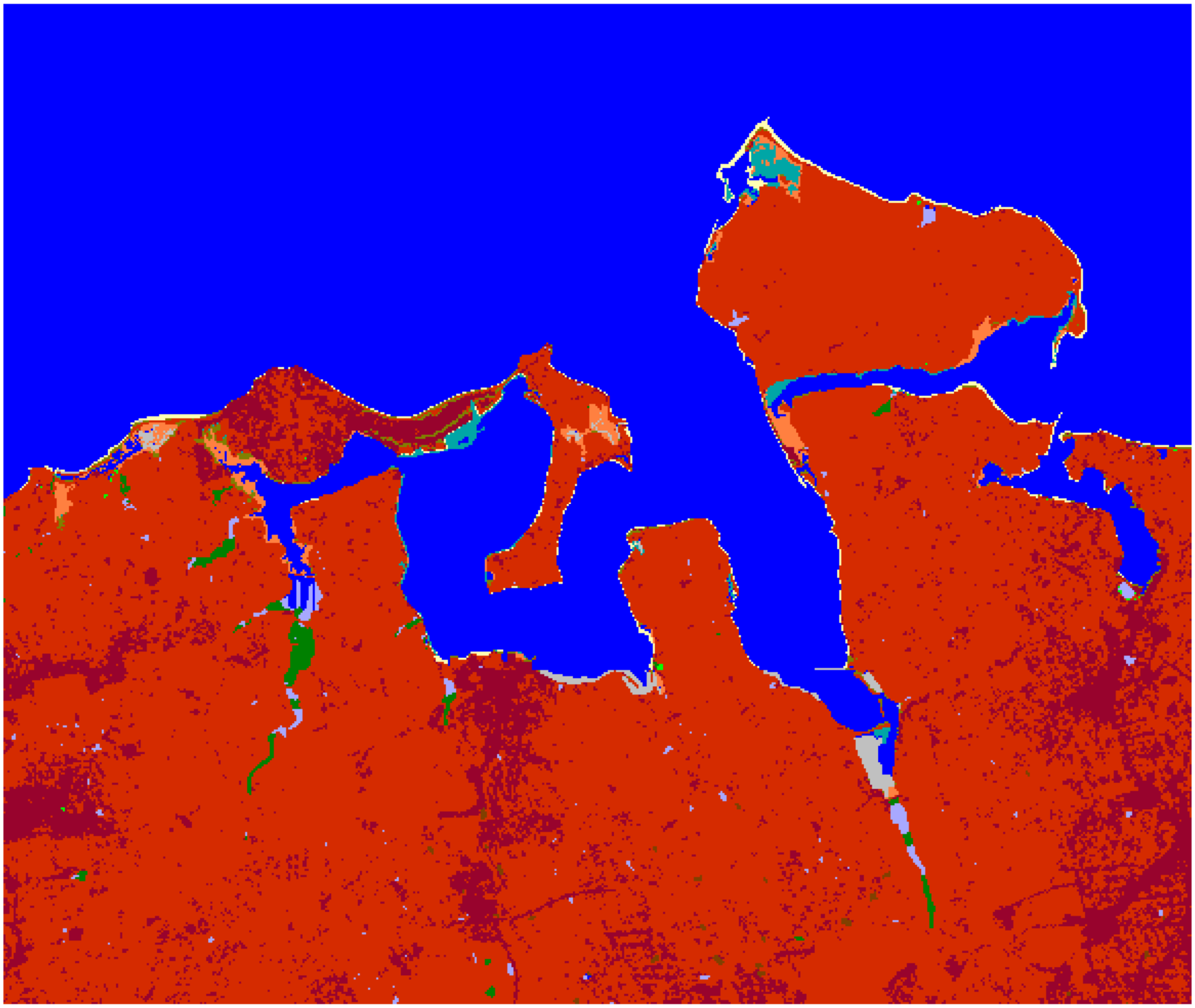
Oyster Bay NWR, 2075, Scenario A1B Maximum Protect Developed Dry Land



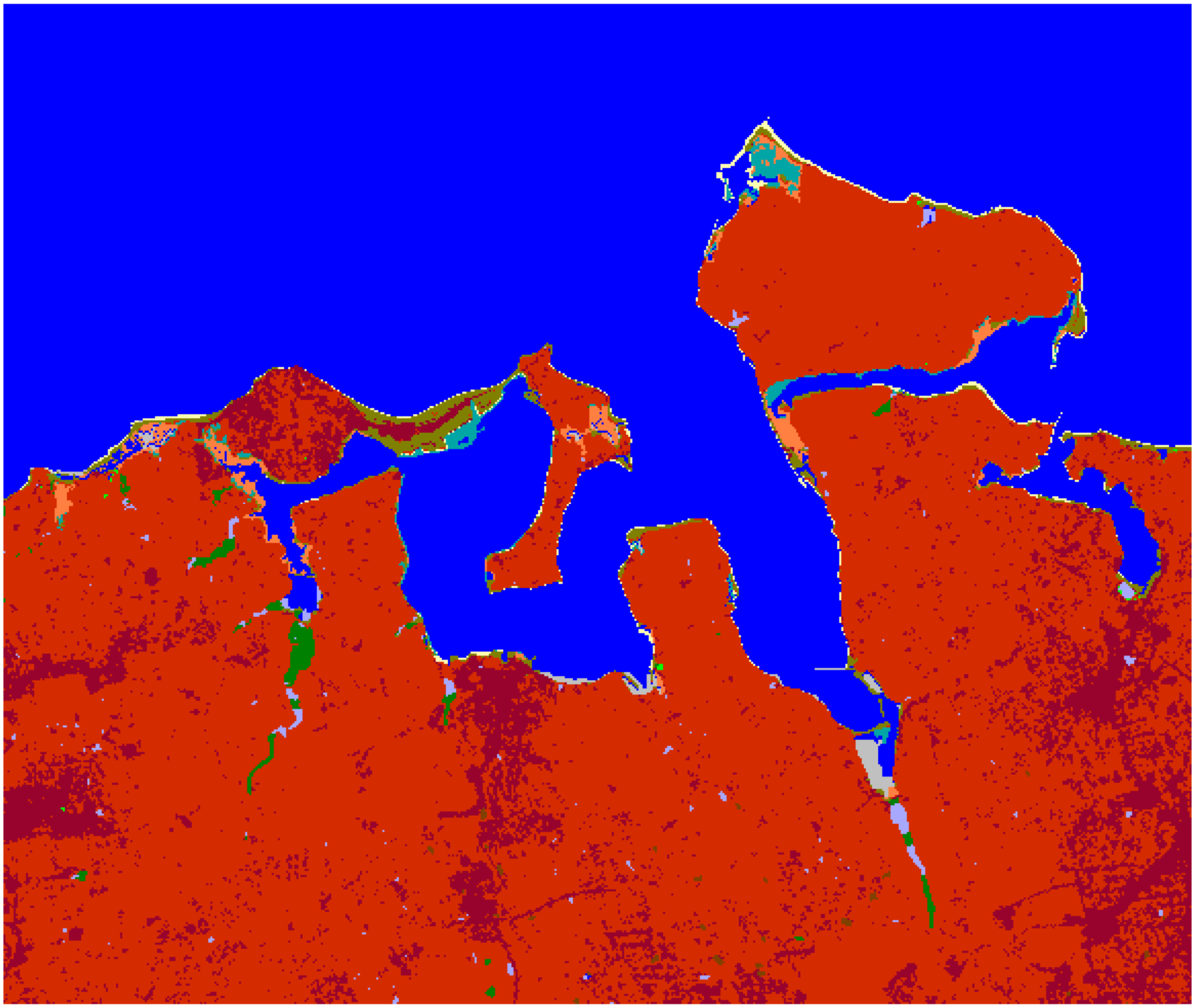
Oyster Bay NWR, 2100, Scenario A1B Maximum Protect Developed Dry Land



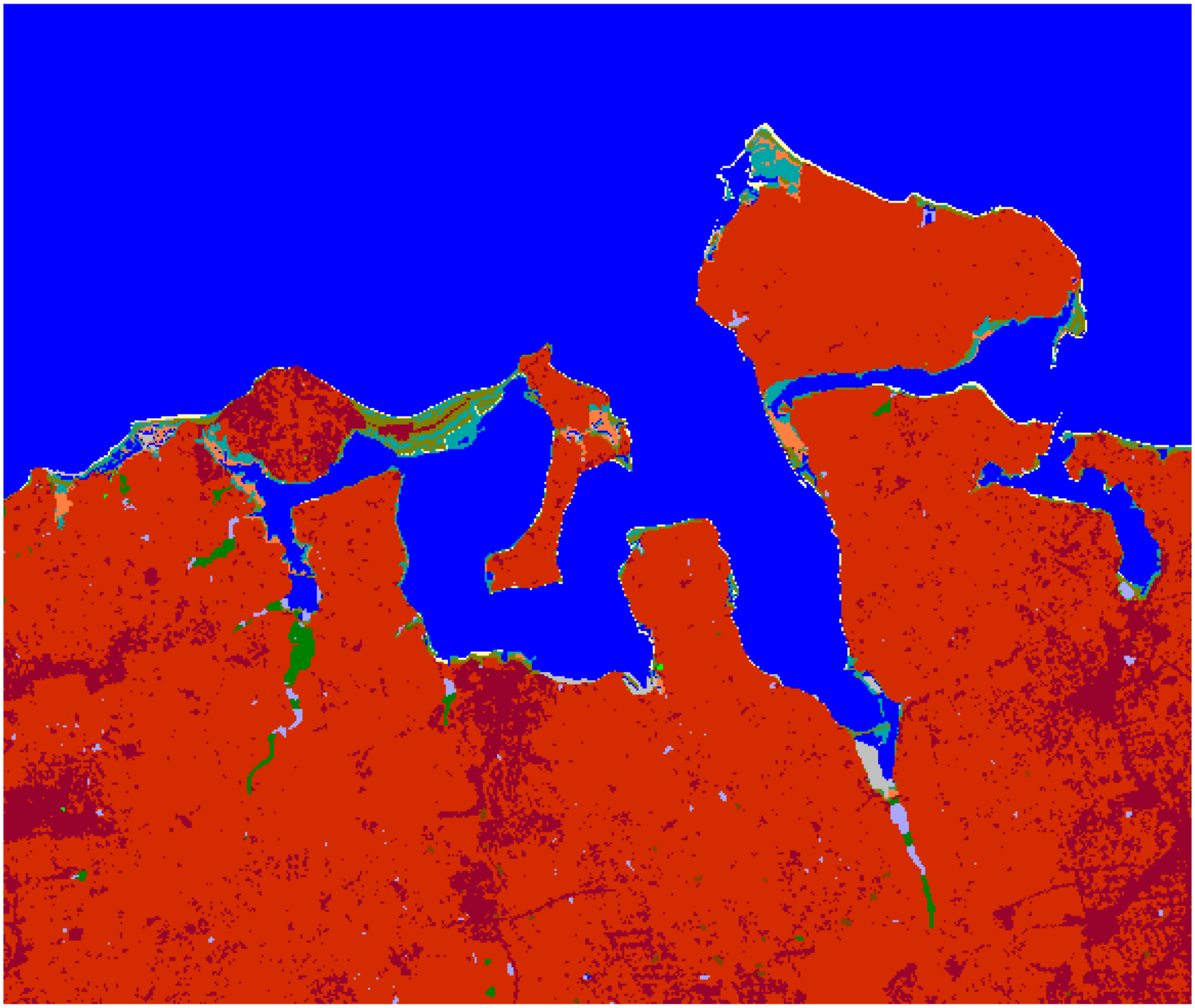
Oyster Bay NWR, Initial Condition



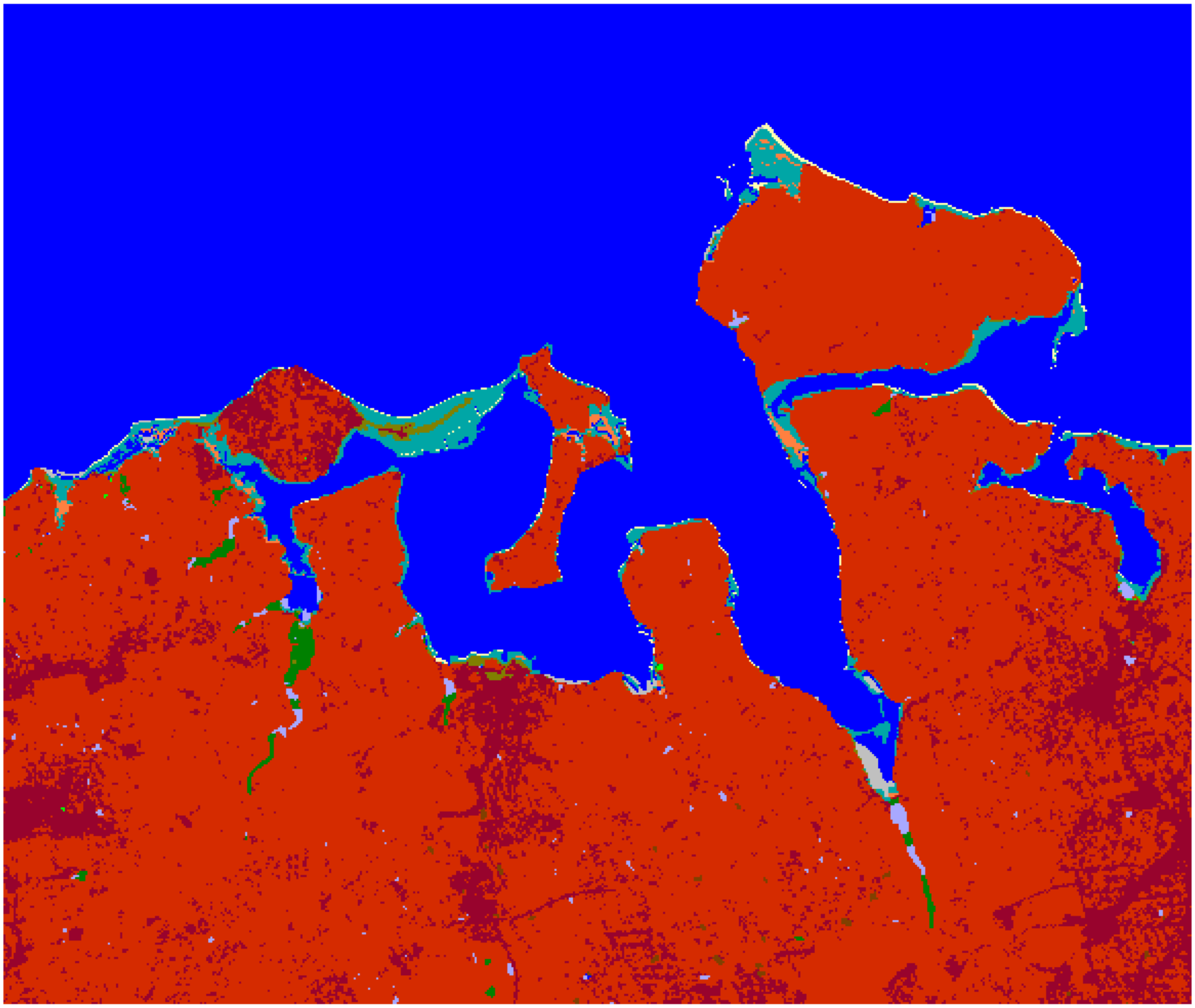
Oyster Bay NWR, 2025, 1 meter Protect Developed Dry Land



Oyster Bay NWR, 2050, 1 meter Protect Developed Dry Land



Oyster Bay NWR, 2075, 1 meter Protect Developed Dry Land



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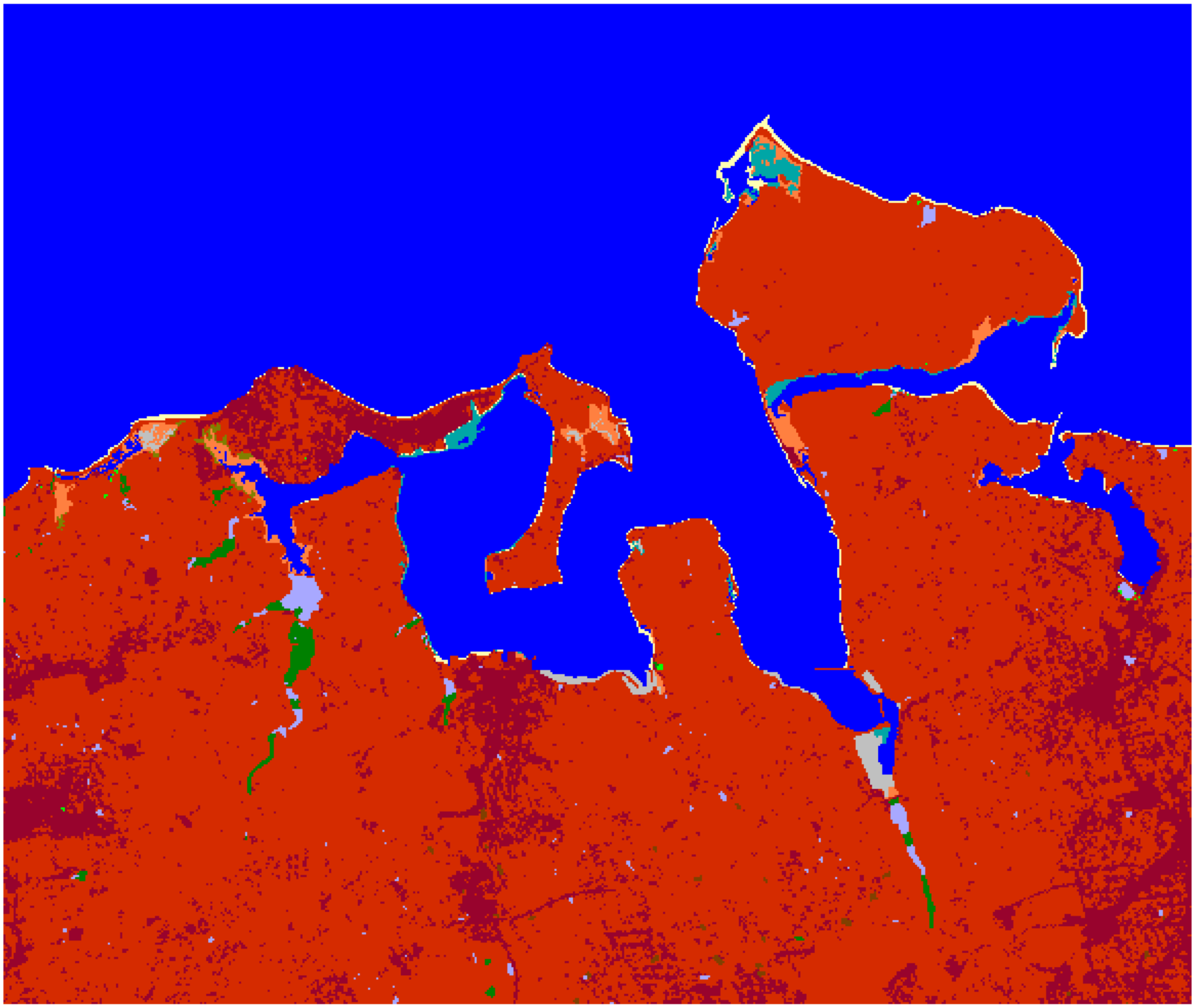
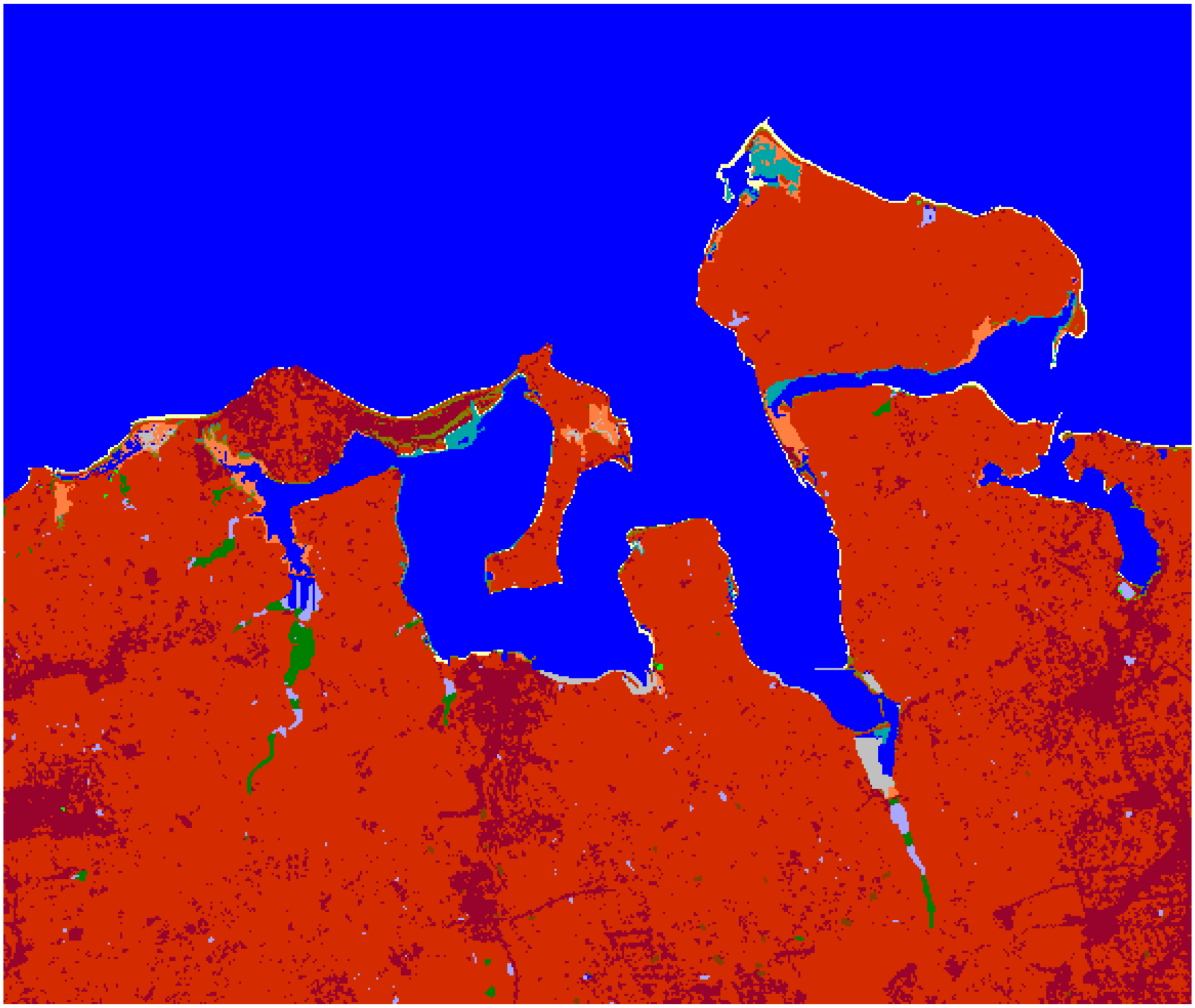
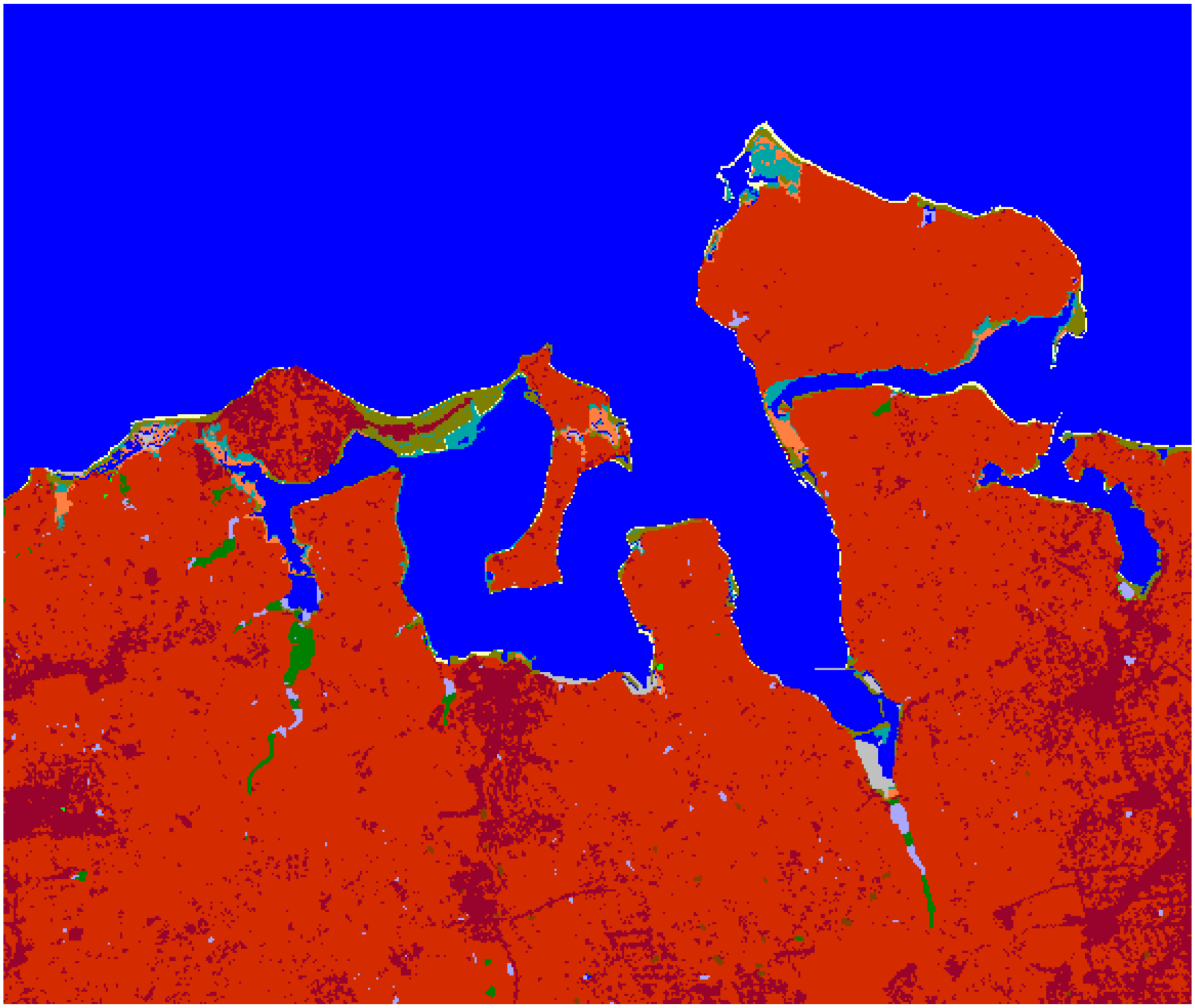


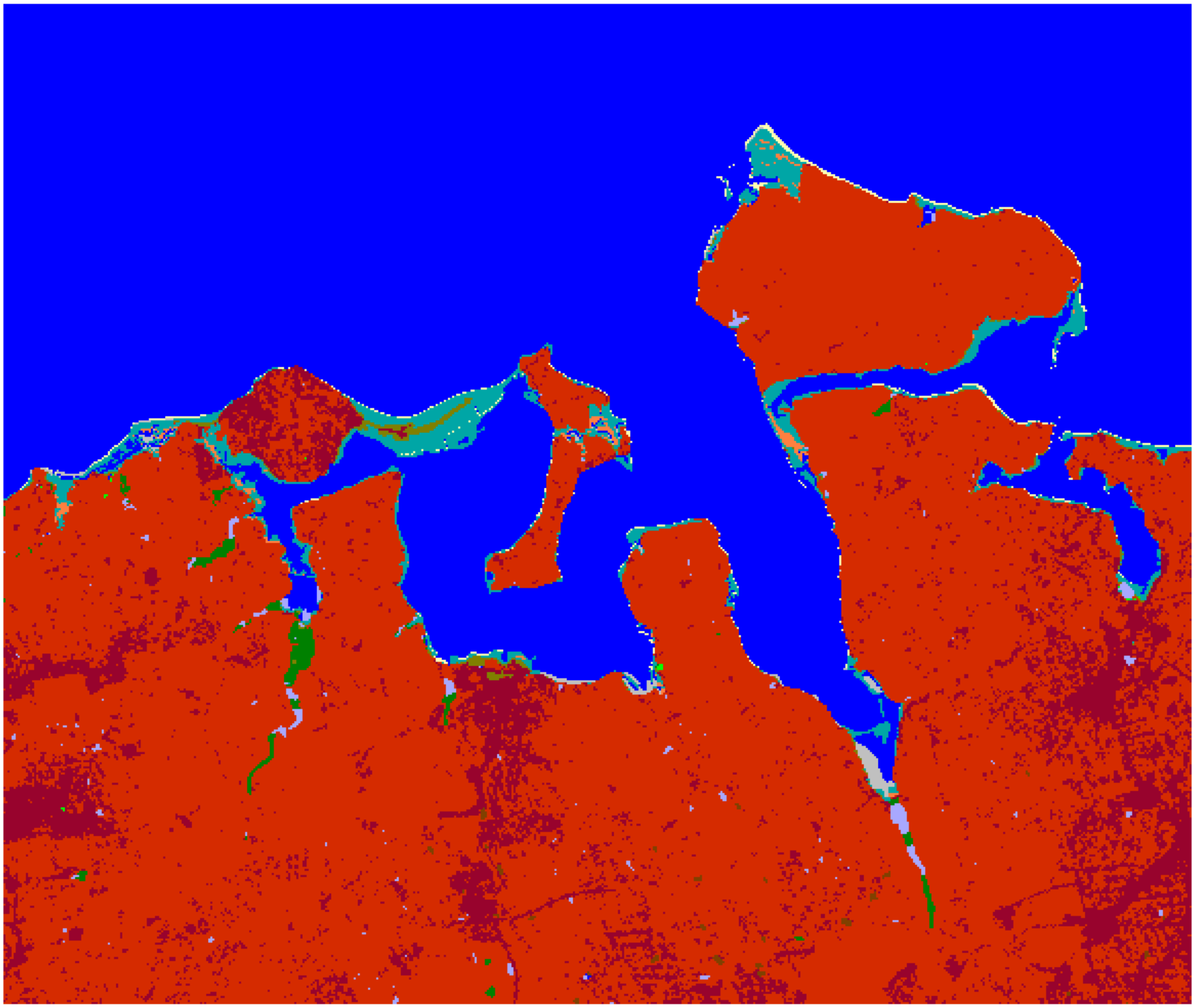
Oyster Bay NWR, Initial Condition



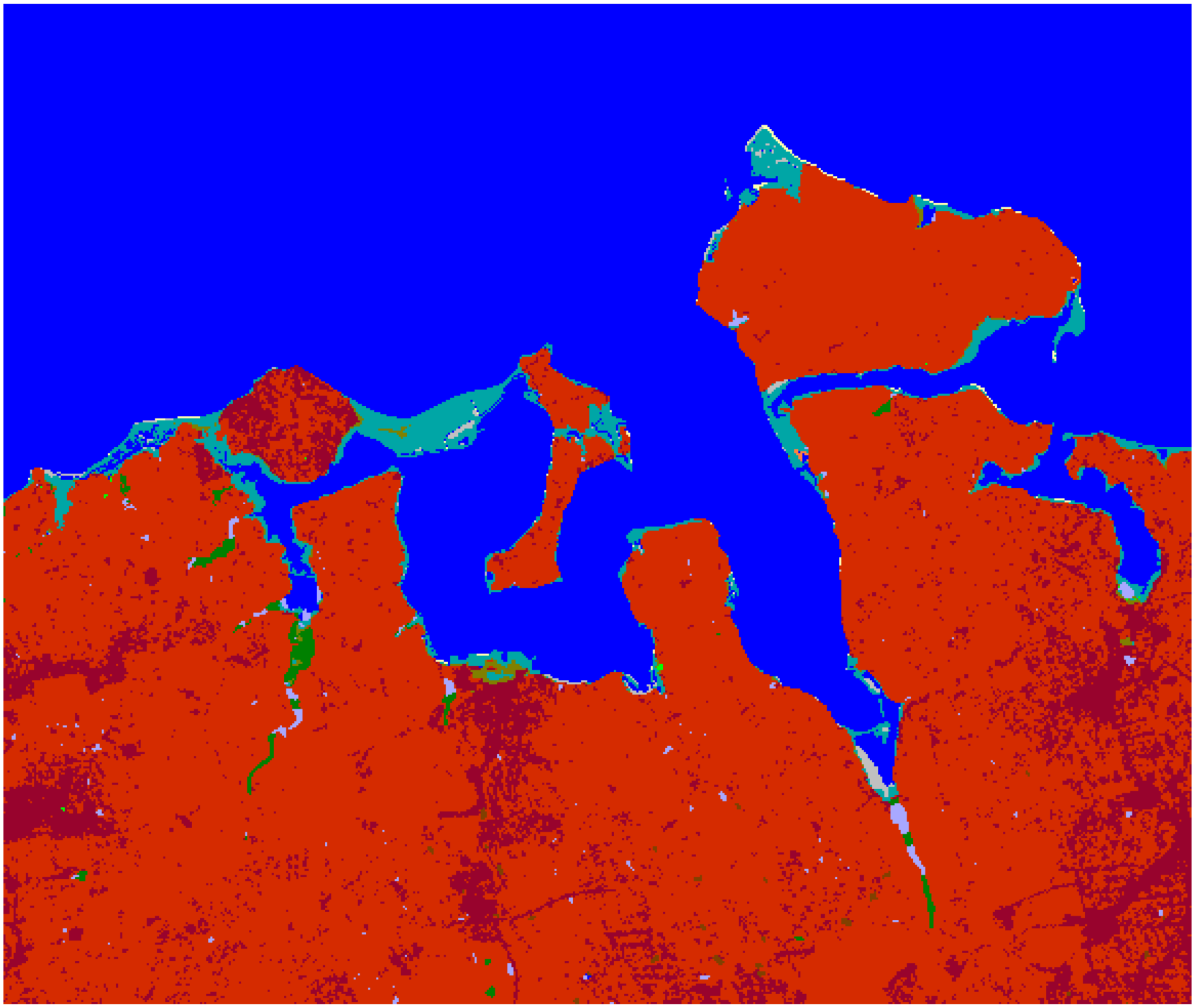
Oyster Bay NWR, 2025, 1.5 meter Protect Developed Dry Land



Oyster Bay NWR, 2050, 1.5 meter Protect Developed Dry Land



Oyster Bay NWR, 2075, 1.5 meter Protect Developed Dry Land



Oyster Bay NWR, 2100, 1.5 meter Protect Developed Dry Land