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

Prepared For: Dr. Brian Czech, Conservation Biologist

U. S. Fish and Wildlife Service
National Wildlife Refuge System
Division of Natural Resources and Conservation Planning
Conservation Biology Program
4401 N. Fairfax Drive - MS 670
Arlington, VA 22203

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Jonathan S. Clough & Evan C. Larson, Warren Pinnacle Consulting, Inc.
PO Box 253, Warren VT, 05674
(802)-496-3476

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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).

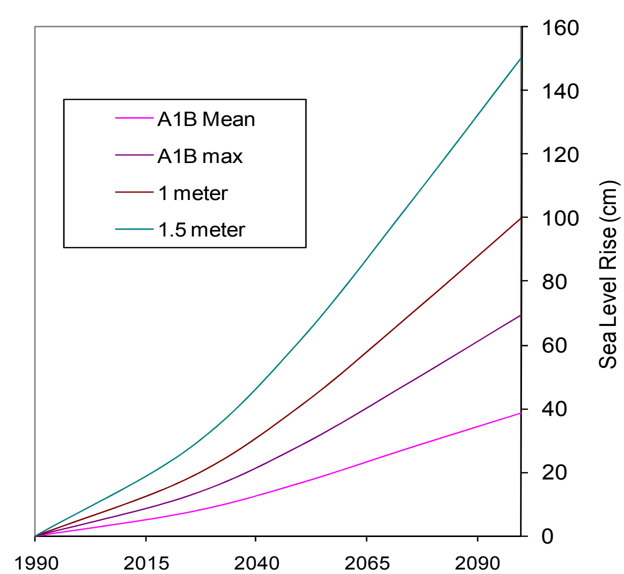
Sea Level Rise Scenarios

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

A set of coastal LIDAR data was found for Seatuck NWR study area, but not covering the refuge itself. The elevation data used for the refuge are based on National Elevation Data (NED).

NED metadata indicates that this digital elevation map (DEM) was derived from a 1955 survey with 5 foot contour intervals (Figure 2).

The National Wetlands Inventory for Seatuck is based on a photo date of 2004. Converting the NWI survey into 30 meter cells indicates that the approximately two hundred acre refuge (approved acquisition boundary including water) is composed of the categories as shown below:

Dry Land	42.5%
Brackish Marsh	24.2%
Estuarine Open Water	19.5%
Tidal Flat	4.3%
Swamp	3.7%
Trans. Salt Marsh	3.6%
Dev. Dry Land	1.9%

There are several diked or impounded wetlands in the region of the Seatuck NWR according to the National Wetlands Inventory, but none within the boundary of the refuge itself.

Figure 2: Seatuck Refuge topographic map.

The historic trend for sea level rise was estimated at 3.34 mm/year, derived from the average of the Lido Beach NWR and Amagansett NWR historic sea level rise values. The rate of sea level rise for this refuge may be considered slightly higher than the global average for the last 100 years (approximately 1.5-2.0 mm/year).

The tidal range for the Seatuck NWR is estimated at 0.376 meters (Figure 3) using tidal data from the closest gages (8515102, Bayshore, Long Island, NY).

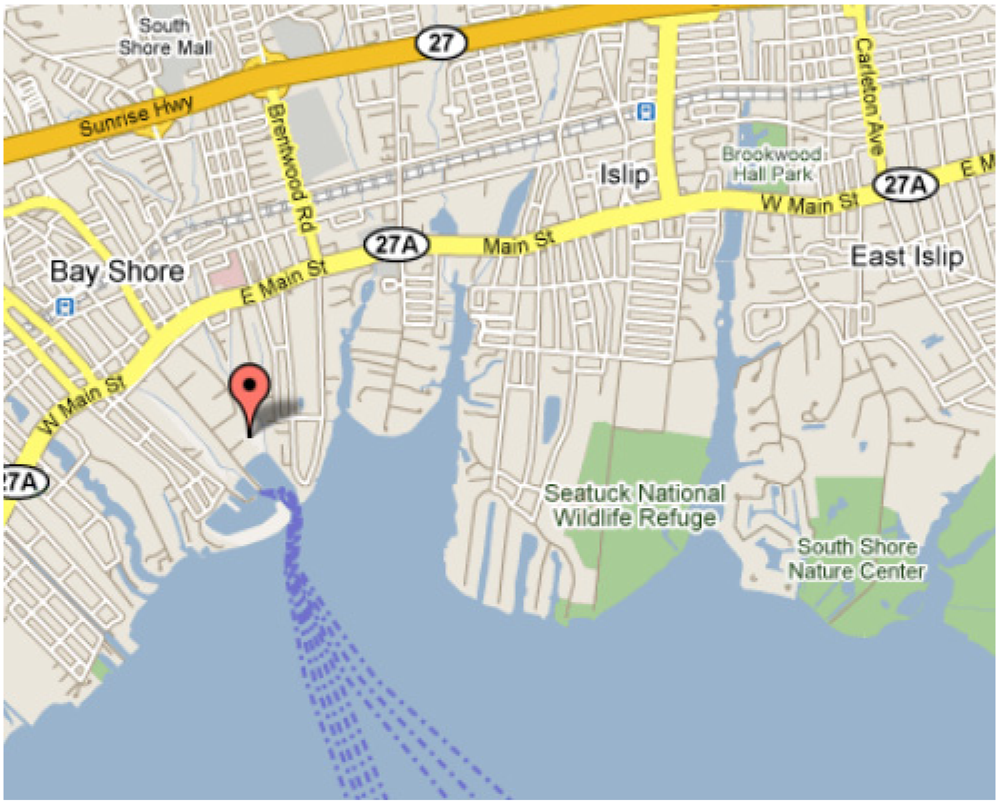


Figure 3: NOAA Gage Relevant to the Study Area (in rectangle).

Accretion rates in salt and Irregularly Flooded marshes were set to 2.9 mm/year. This represents the mean of historical saltmarsh accretion values from a study performed in nearby Wertheim NWR (McLetchie, 2006; R.A. Orson, 1998).

The MTL to NAVD correction was derived using the NOAA VDATUM product. Multiple geographic points were input into VDATUM to produce several corrections in the study area. These values ranged from 0.001532 to 0.001534 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. Review of the Long Island Comprehensive Conservation Plan (CCP) confirmed the range of these boundaries.

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. As no LiDAR data were available for this refuge, wetland elevations were estimated as a function of the local tidal range using the SLAMM elevation pre-processor.

SUMMARY OF SLAMM INPUT PARAMETERS FOR SEATUCK NWR

Description	,	Seatuck
DEM Source Date (yyyy)	,	1955
NWI_photo_date (yyyy)	,	2004
Direction_OffShore (N|S|E|W)	,	S
Historic_trend (mm/yr)	,	3.34
NAVD88_correction (MTL-NAVD88 in meters)	,	0.001533
Water Depth (m below MLW- N/A)	,	2
TideRangeOcean (meters: MHHW-MLLW)	,	0.376
TideRangeInland (meters)	,	0.376
Mean High Water Spring (m above MTL)	,	0.25004
MHSW Inland (m above MTL)	,	0.25004
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	,	2.9
Brackish March vert. accretion (mm/yr) Final	,	2.9
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

Seatuck NWR is predicted to be susceptible to the effects of sea level rise across almost all scenarios. The refuge is predicted to lose all of its irregularly flooded (brackish) marsh by 2100 under all scenarios. (Under lower SLR scenarios this marsh is retained, but converted to regularly-flooded saltmarsh.) The majority of the refuge's swamp land is predicted to be lost in any scenario other than the most conservative run. Dry land loss rates range from 5% to 59% under the range of scenarios run.

SLR by 2100 (m)	0.39	0.69	1	1.5
Dry Land	5%	17%	37%	59%
Brackish Marsh	100%	100%	100%	100%
Tidal Flat	95%	-30%	94%	70%
Swamp	4%	57%	99%	100%
Trans. Salt Marsh	94%	7%	20%	83%
Dev. Dry Land	44%	48%	50%	62%

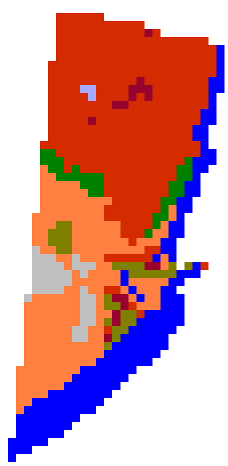
Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

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

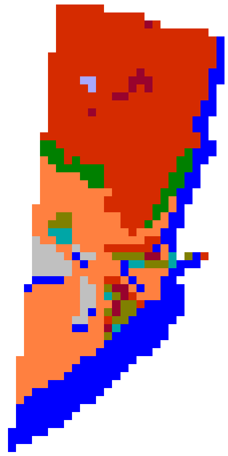
Seatuck NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

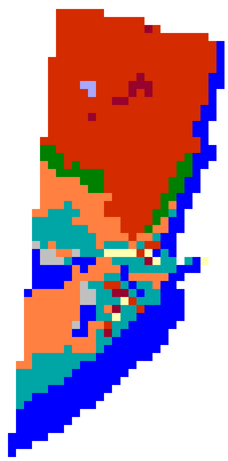
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	89.8	89.3	87.9	87.1	85.5
Brackish Marsh	51.2	51.2	31.7	2.4	0.0
Estuarine Open Water	41.1	43.3	47.6	50.2	52.2
Tidal Flat	9.1	7.0	2.7	0.0	0.5
Swamp	7.8	7.8	7.8	7.7	7.5
Trans. Salt Marsh	7.6	4.6	0.0	0.1	0.4
Dev. Dry Land	4.0	3.7	3.0	2.5	2.2
Inland Open Water	0.7	0.7	0.7	0.7	0.7
Saltmarsh	0.0	3.0	27.0	56.3	56.9
Estuarine Beach	0.0	0.9	2.9	4.3	5.4
Total (incl. water)	**211.3**	**211.3**	**211.3**	**211.3**	**211.3**



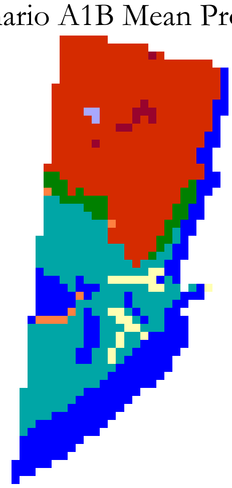
Seatuck NWR, Initial Condition



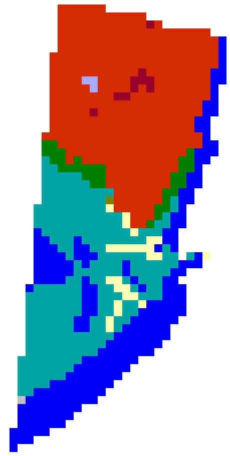
Seatuck NWR, 2025, Scenario A1B Mean Protect Developed Dry Land



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



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

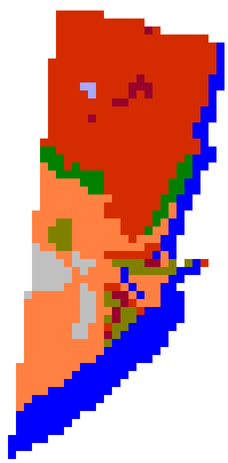


Seatuck NWR, 2100, Scenario A1B Mean Protect Developed Dry Land

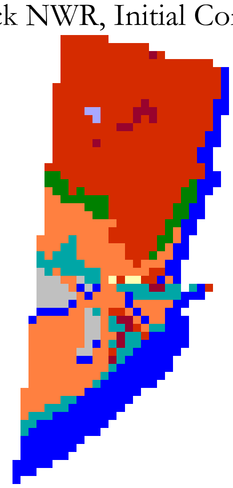
Seatuck NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

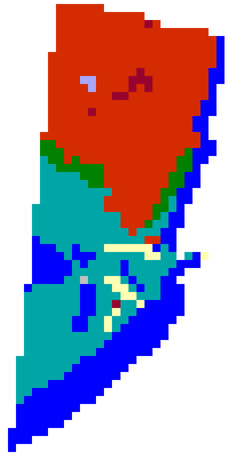
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	89.8	88.8	87.5	85.2	74.5
Brackish Marsh	51.2	44.7	0.4	0.0	0.0
Estuarine Open Water	41.1	43.9	49.9	56.3	101.1
Tidal Flat	9.1	6.3	0.4	37.4	11.9
Swamp	7.8	7.8	7.8	7.4	3.3
Trans. Salt Marsh	7.6	0.8	0.0	0.6	7.0
Dev. Dry Land	4.0	3.5	2.7	2.2	2.1
Inland Open Water	0.7	0.7	0.7	0.7	0.7
Saltmarsh	0.0	13.2	58.3	16.5	0.6
Estuarine Beach	0.0	1.5	3.7	5.0	10.0
Total (incl. water)	**211.3**	**211.3**	**211.3**	**211.3**	**211.3**



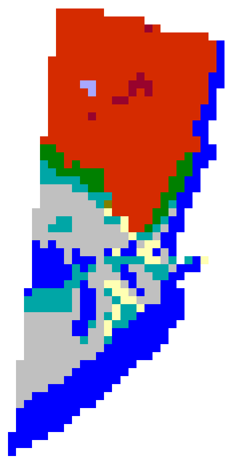
Seatuck NWR, Initial Condition



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



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



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

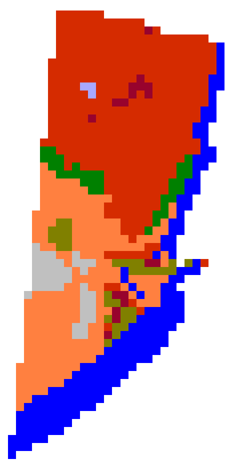
Seatuck NWR, 2100, Scenario A1B Maximum Protect Developed Dry Land

Seatuck NWR

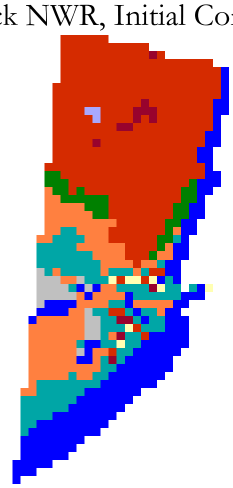
1 Meter Eustatic SLR by 2100

Results in Acres

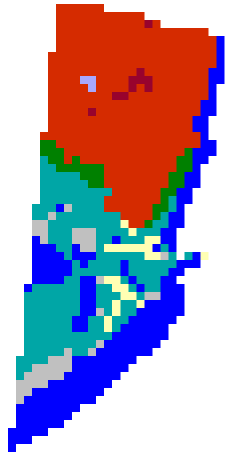
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	89.8	88.4	86.8	78.9	56.7
Brackish Marsh	51.2	31.5	0.0	0.0	0.0
Estuarine Open Water	41.1	44.9	54.0	71.0	117.5
Tidal Flat	9.1	5.4	8.3	41.5	0.6
Swamp	7.8	7.8	7.7	4.1	0.1
Trans. Salt Marsh	7.6	0.0	0.1	4.6	6.0
Dev. Dry Land	4.0	3.4	2.4	2.2	2.0
Inland Open Water	0.7	0.7	0.7	0.7	0.4
Saltmarsh	0.0	27.2	46.7	0.1	4.4
Estuarine Beach	0.0	2.0	4.7	8.1	23.5
Total (incl. water)	**211.3**	**211.3**	**211.3**	**211.3**	**211.3**



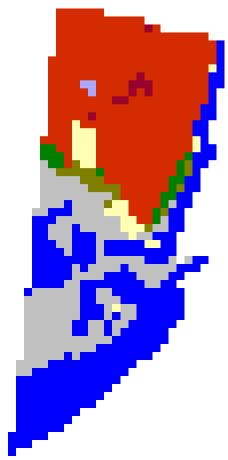
Seatuck NWR, Initial Condition



Seatuck NWR, 2025, 1 meter Protect Developed Dry Land



Seatuck NWR, 2050, 1 meter Protect Developed Dry Land



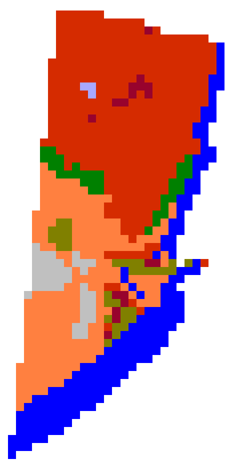
Seatuck NWR, 2075, 1 meter Protect Developed Dry Land

Seatuck NWR, 2100, 1 meter Protect Developed Dry Land

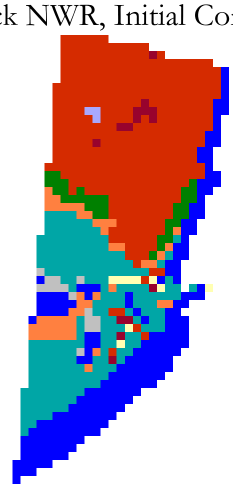
Seatuck NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

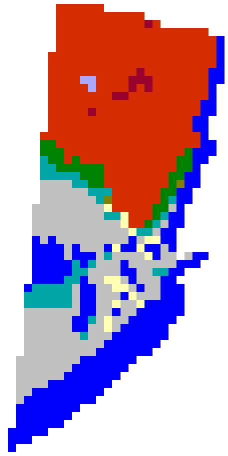
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	89.8	88.0	84.8	58.8	36.6
Brackish Marsh	51.2	10.8	0.0	0.0	0.0
Estuarine Open Water	41.1	47.2	56.8	108.3	136.1
Tidal Flat	9.1	3.1	43.2	7.4	2.7
Swamp	7.8	7.8	7.1	0.1	0.0
Trans. Salt Marsh	7.6	0.0	0.9	14.1	1.3
Dev. Dry Land	4.0	3.1	2.2	2.0	1.5
Inland Open Water	0.7	0.7	0.7	0.4	0.0
Saltmarsh	0.0	47.9	10.8	0.9	11.8
Estuarine Beach	0.0	2.7	4.7	19.1	21.2
Total (incl. water)	**211.3**	**211.3**	**211.3**	**211.3**	**211.3**



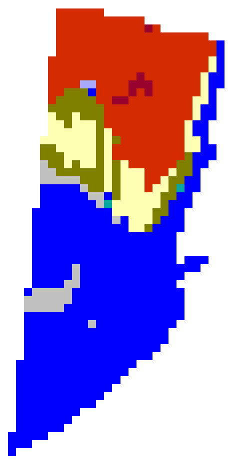
Seatuck NWR, Initial Condition



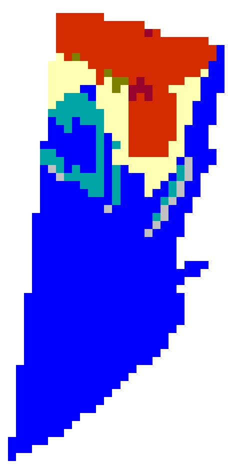
Seatuck NWR, 2025, 1.5 meter Protect Developed Dry Land



Seatuck NWR, 2050, 1.5 meter Protect Developed Dry Land



Seatuck NWR, 2075, 1.5 meter Protect Developed Dry Land



Seatuck NWR, 2100, 1.5 meter Protect Developed Dry Land

Discussion

Model results suggest that Seatuck NWR will be altered by sea level rise. Even in the most conservative scenario (0.39 meter eustatic SLR by 2100) the refuge is expected to lose all of its irregularly flooded marsh. Under this scenario, the model predicts that the marsh will convert to regularly flooded saltmarsh. Under more aggressive scenarios, the marsh is converted to tidal flats or open water

Predicted loss rates of brackish marsh within SLAMM are functions of initial marsh elevations, estimated accretion rates, and predicted local sea level rise rates. Initial marsh elevations are quite uncertain due to the age and vertical precision of the National Elevation Dataset. Accretion rates are predicted to remain spatially and temporally constant within this simulation and are also a source of model uncertainty.

Dry land loss rates are primarily a function of initial dry land elevations. Again, a more accurate digital elevation map (DEM) will assist in reducing uncertainty for these loss-rate estimates.

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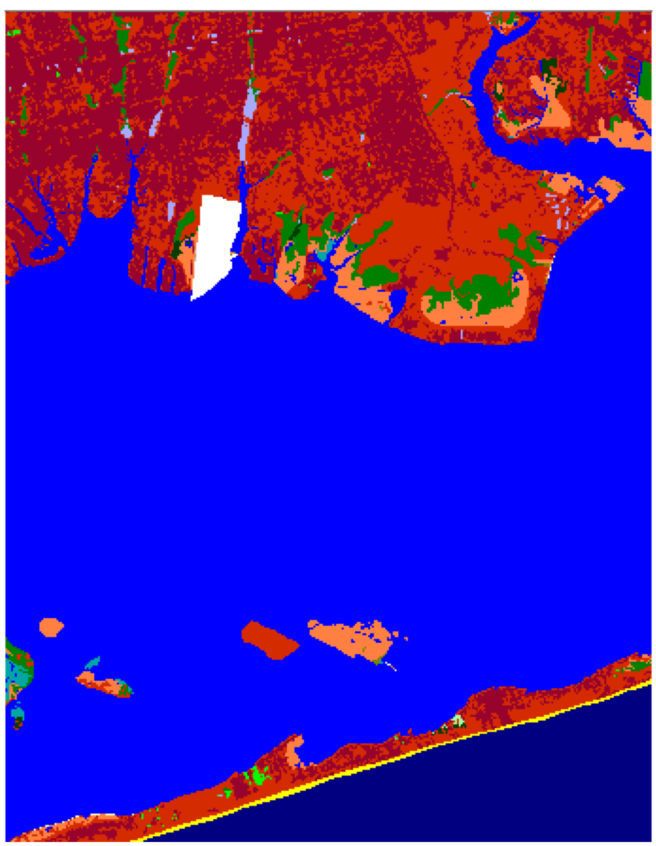
Appendix A: Contextual Results

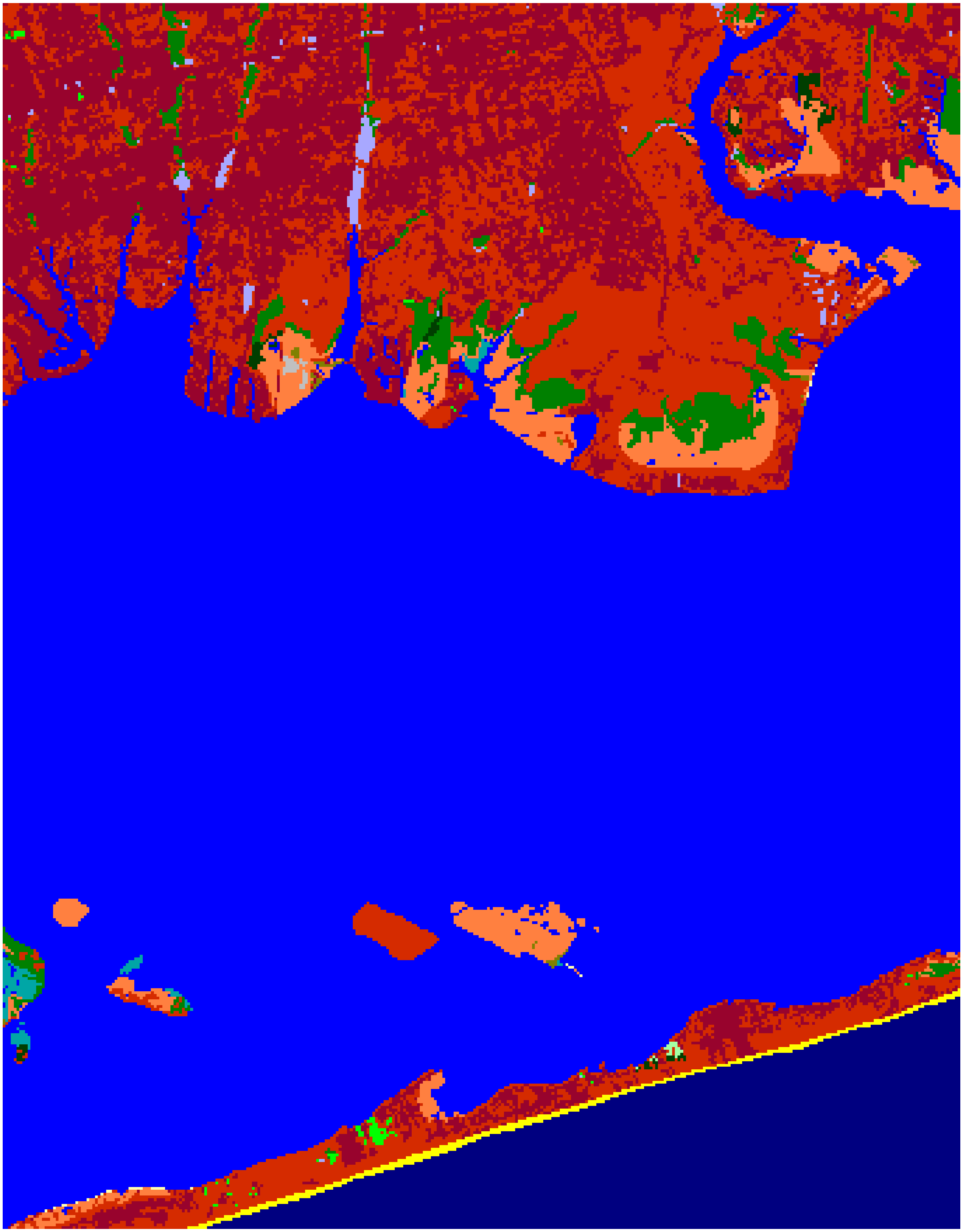
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

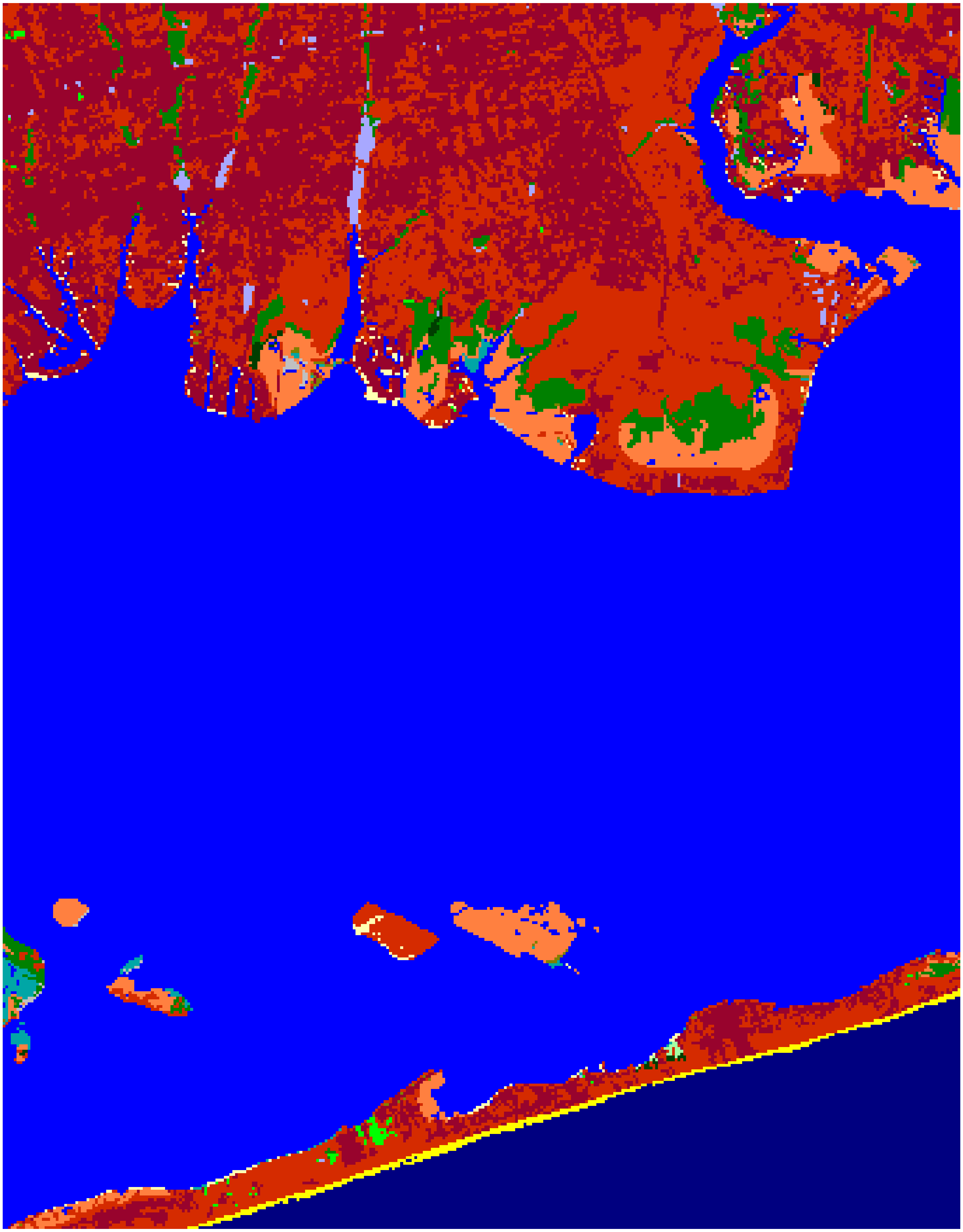
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



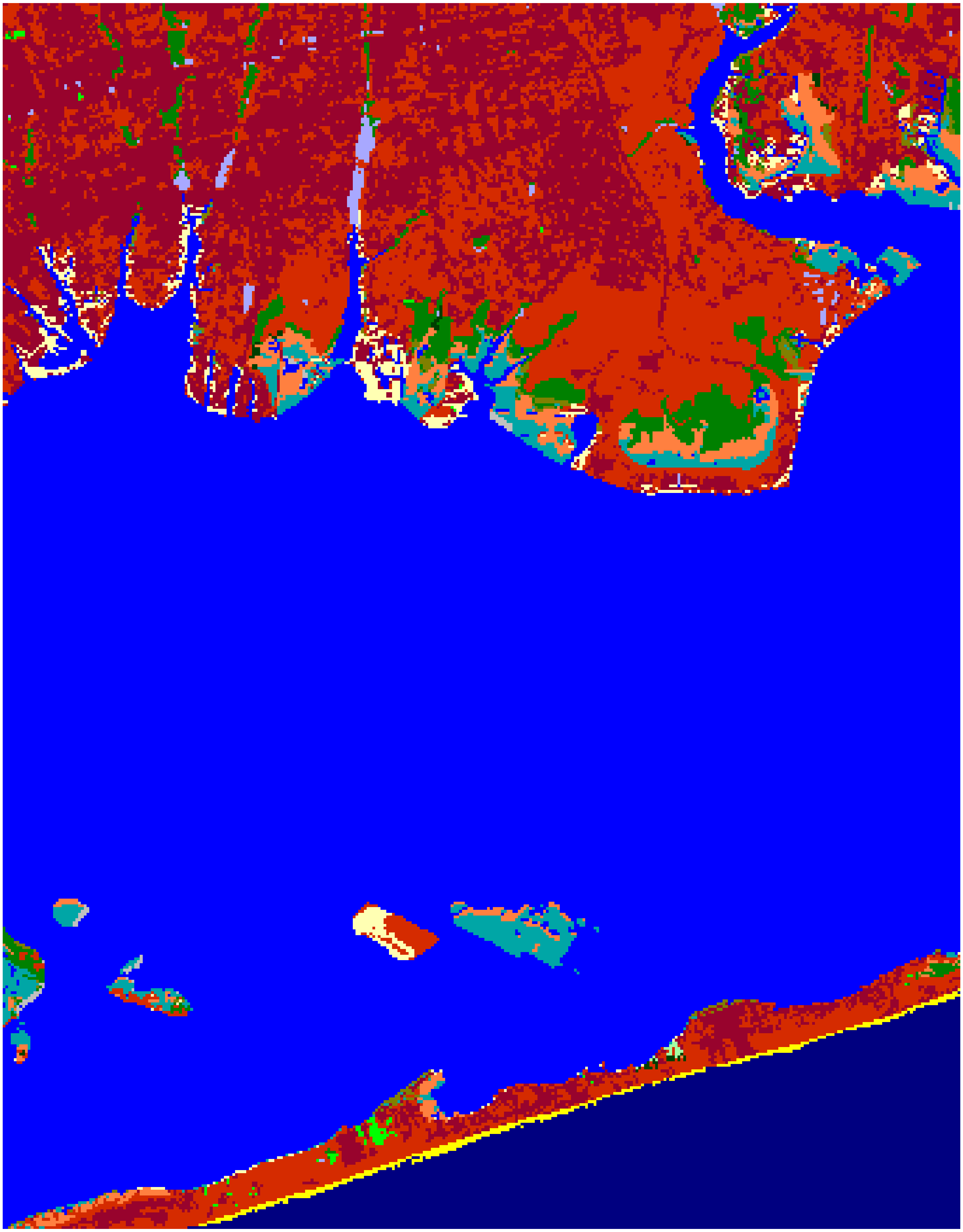
Location of Seatuck National Wildlife Refuge (white area) within simulation context

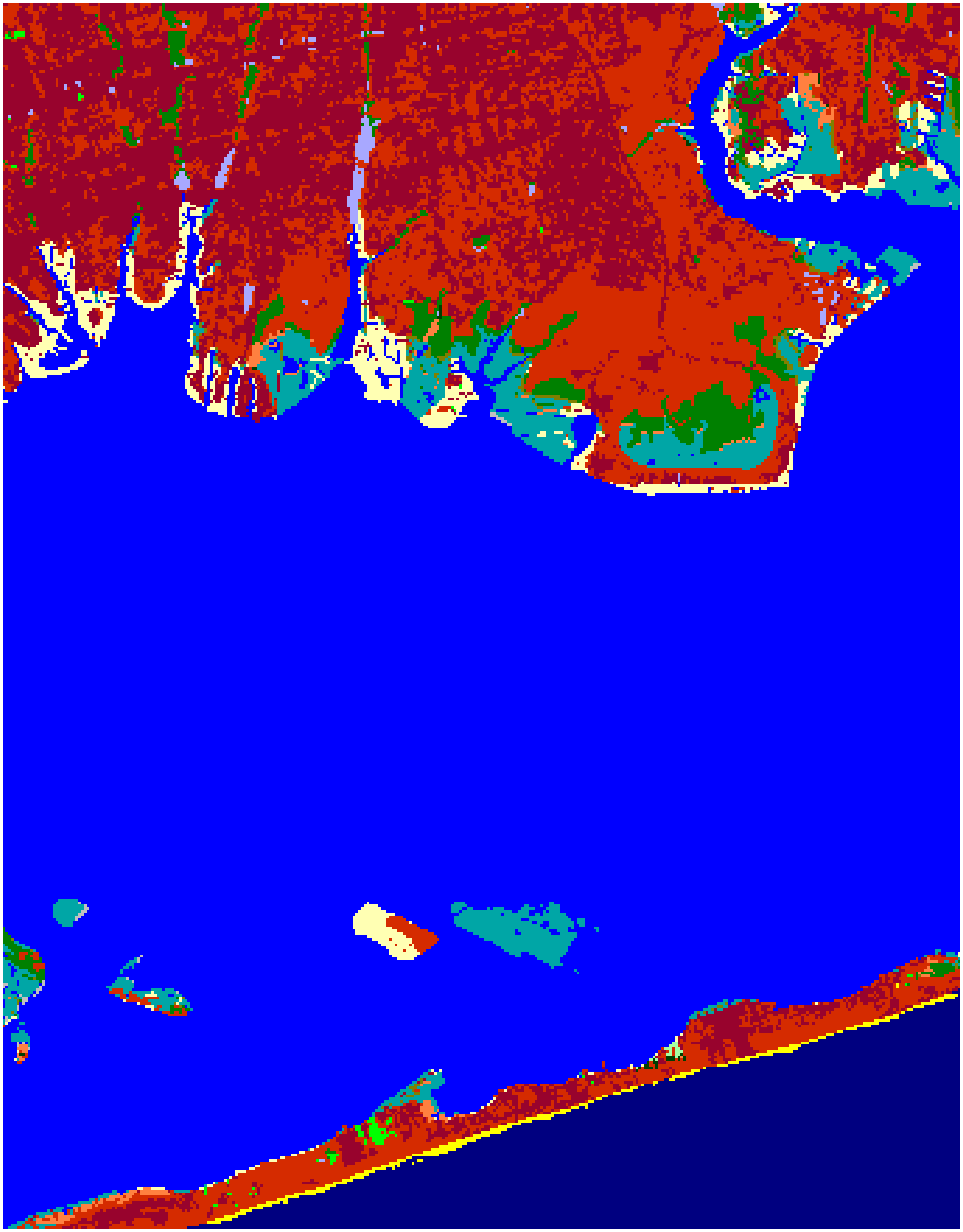


Seatuck NWR, Initial Condition

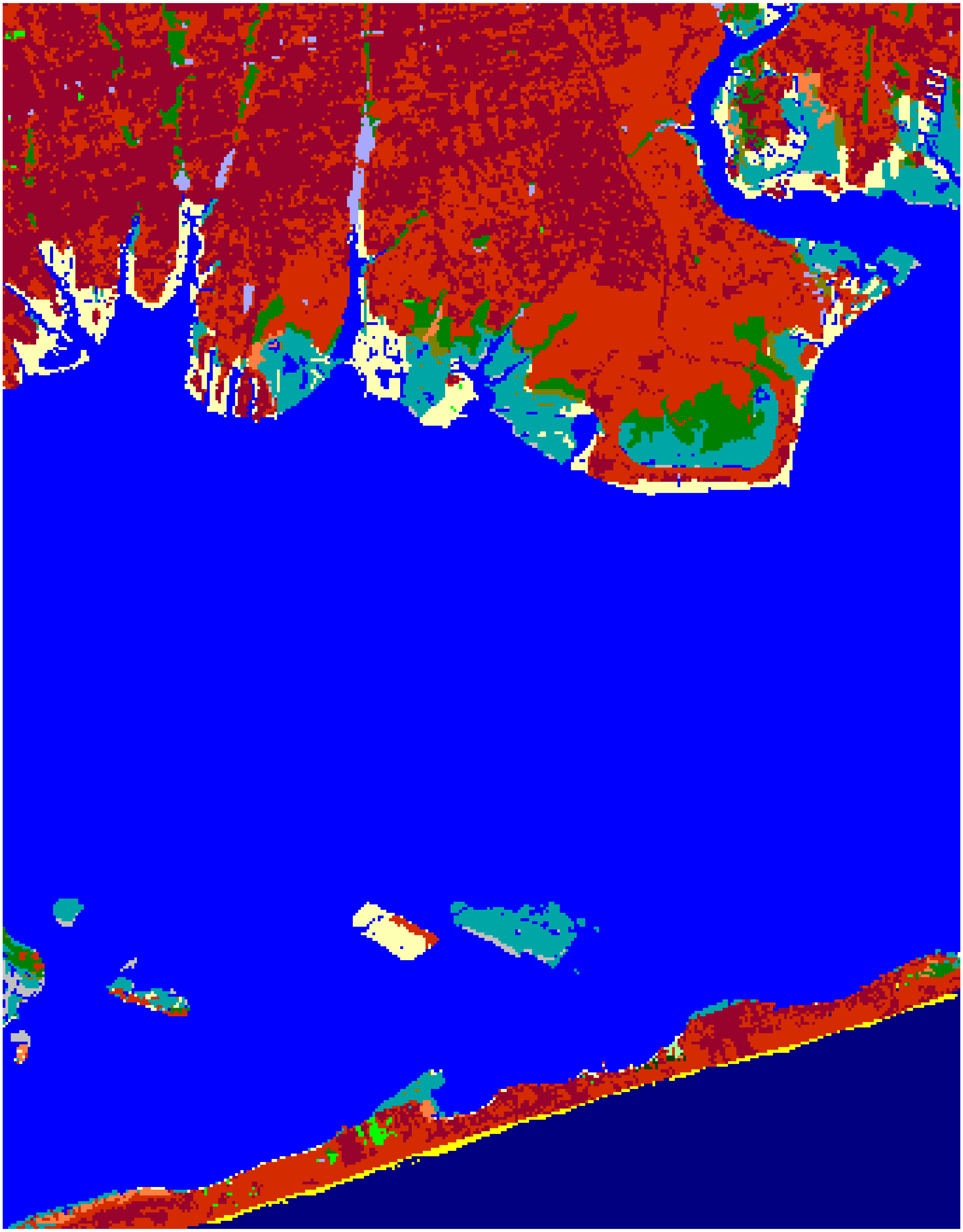


Seatuck NWR, 2025, Scenario A1B Mean Protect Developed Dry Land

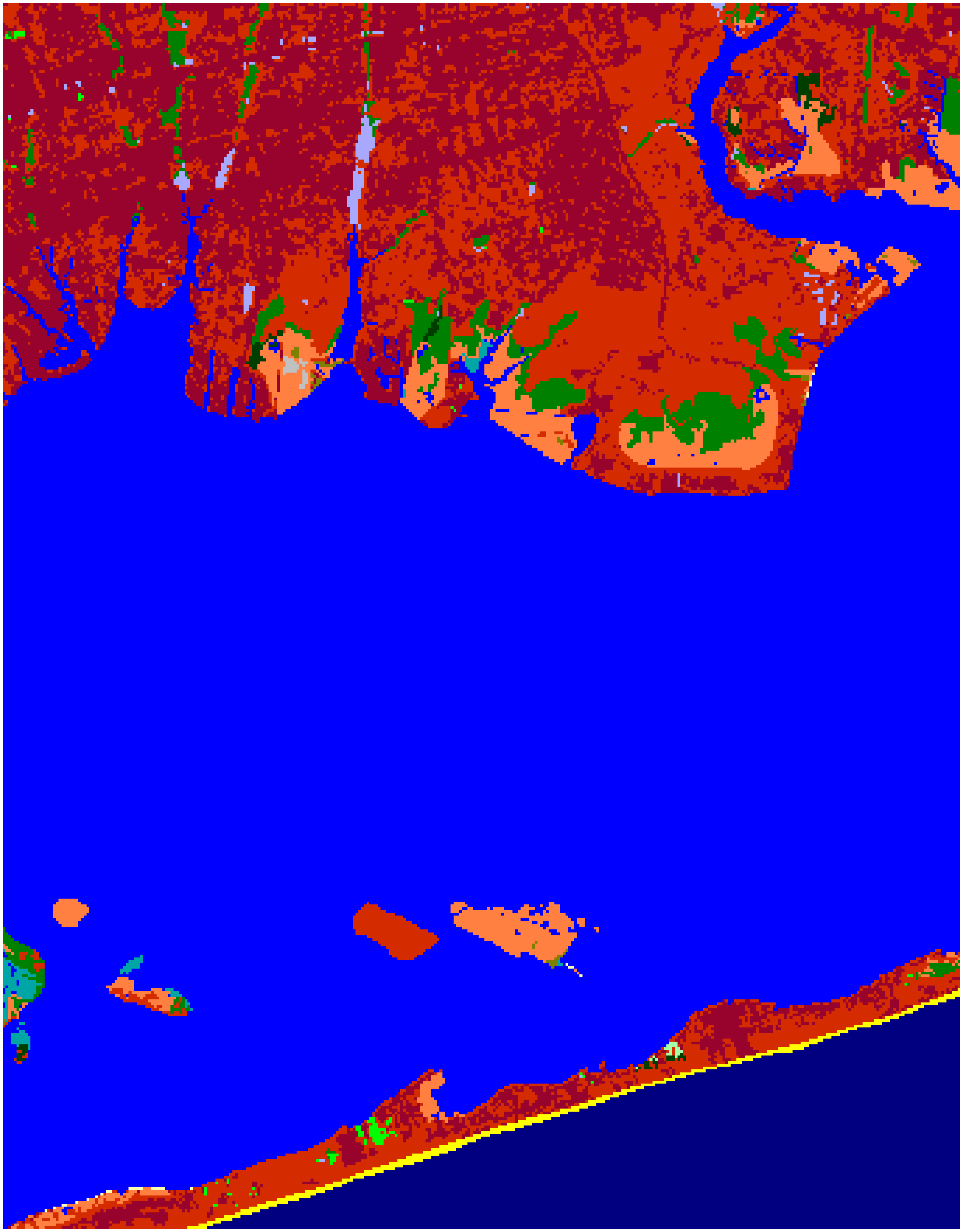

Seatuck NWR, 2050, Scenario A1B Mean Protect Developed Dry Land



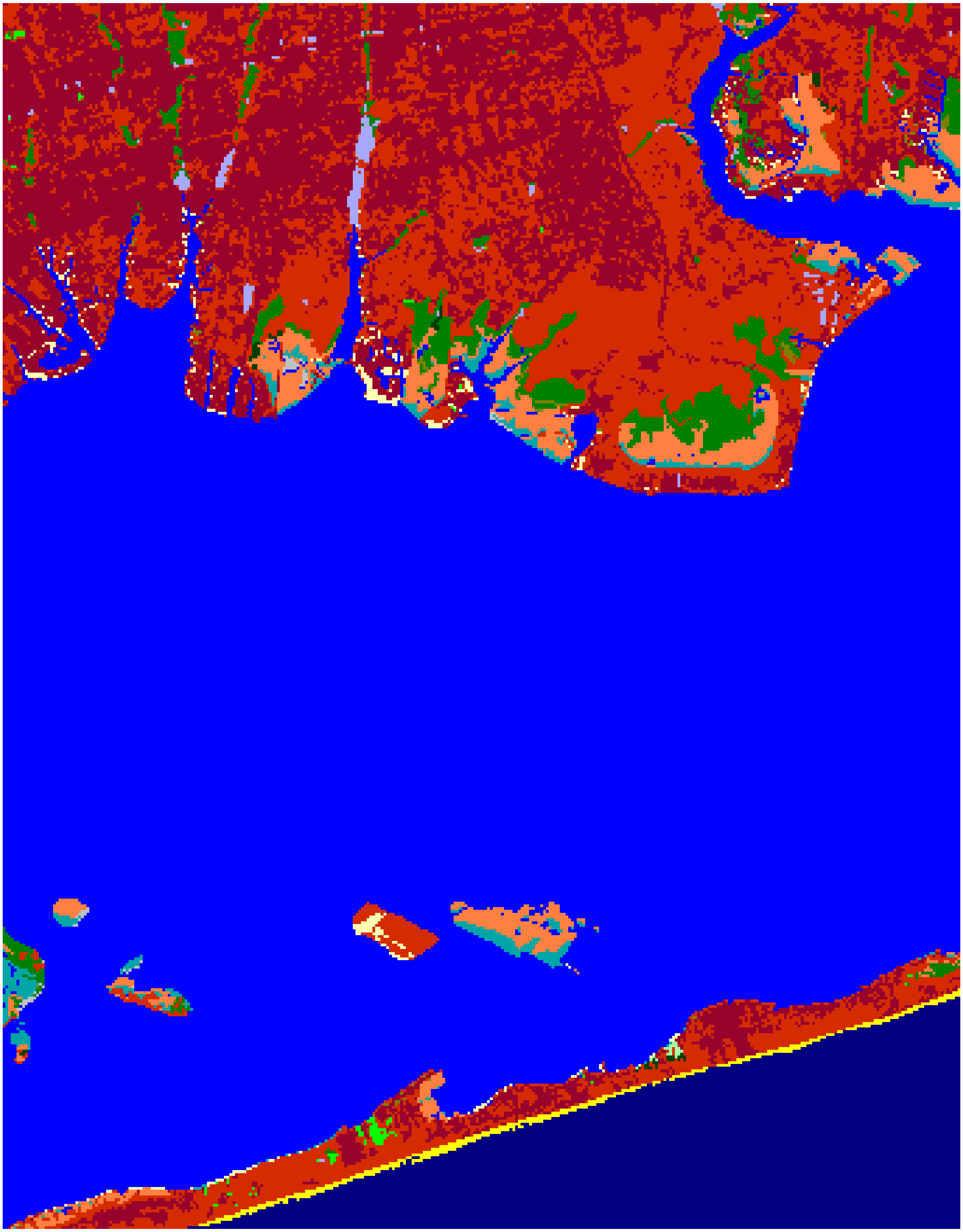
Seatuck NWR, 2075, Scenario A1B Mean Protect Developed Dry Land



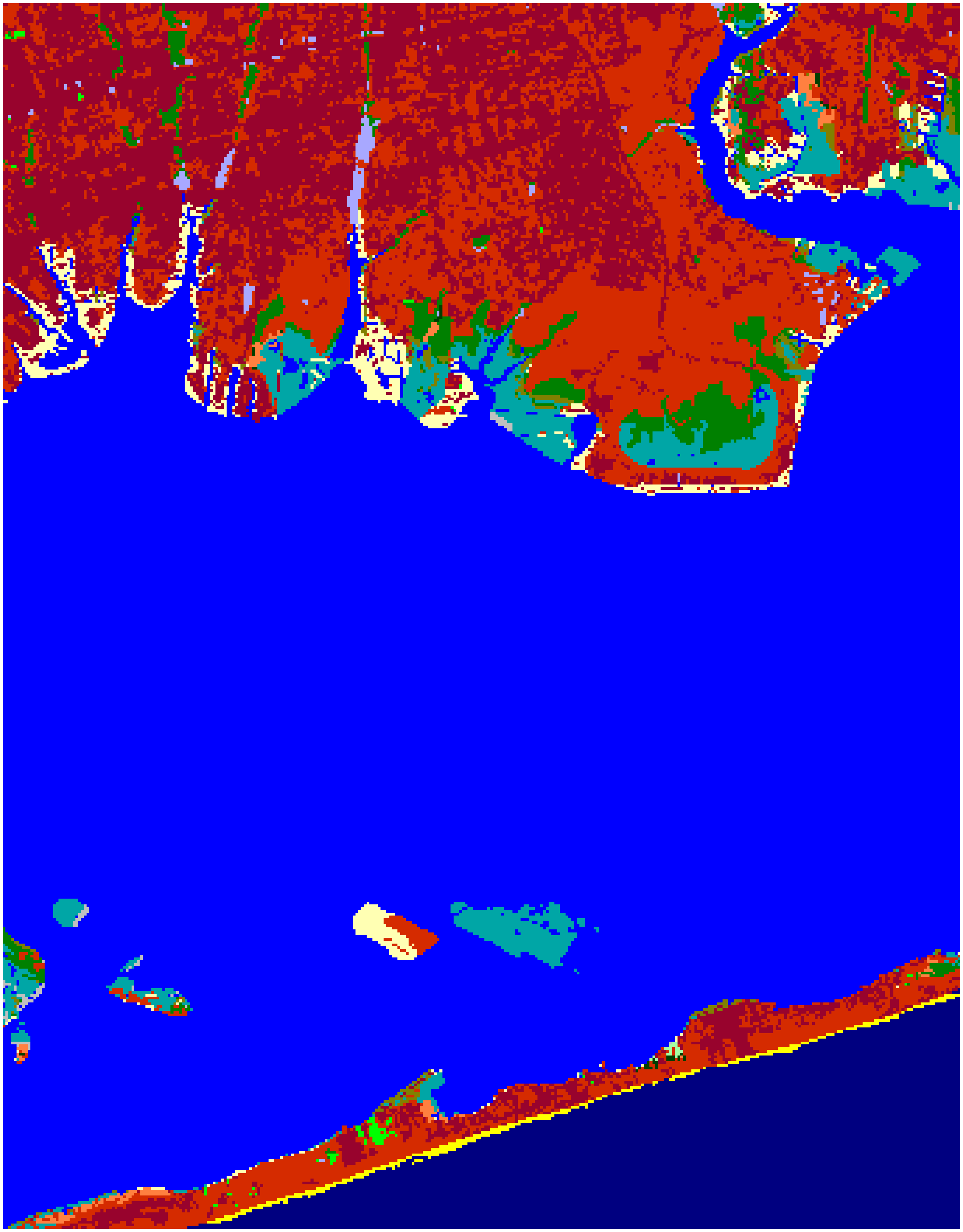
Seatuck NWR, 2100, Scenario A1B Mean Protect Developed Dry Land



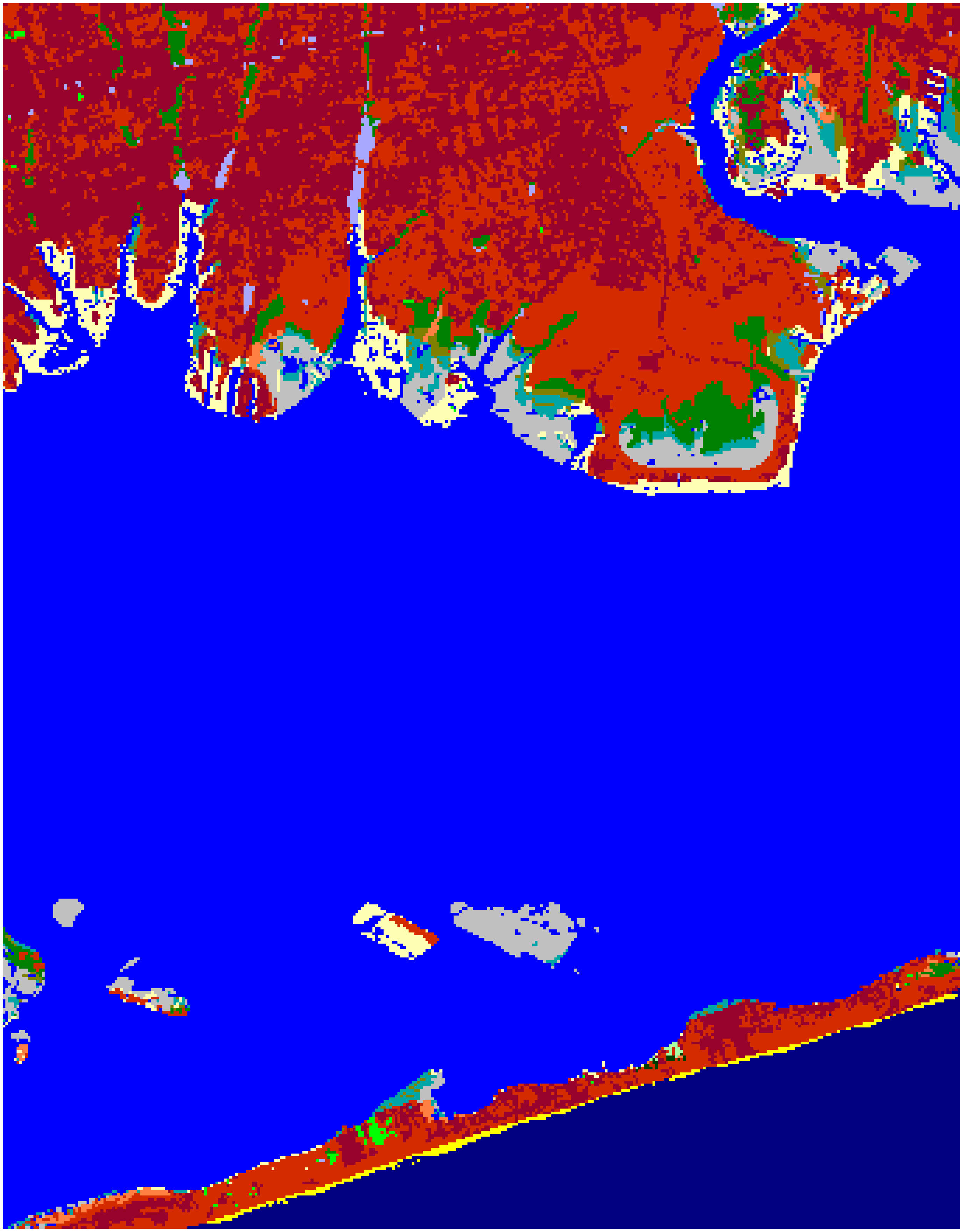
Seatuck NWR, Initial Condition



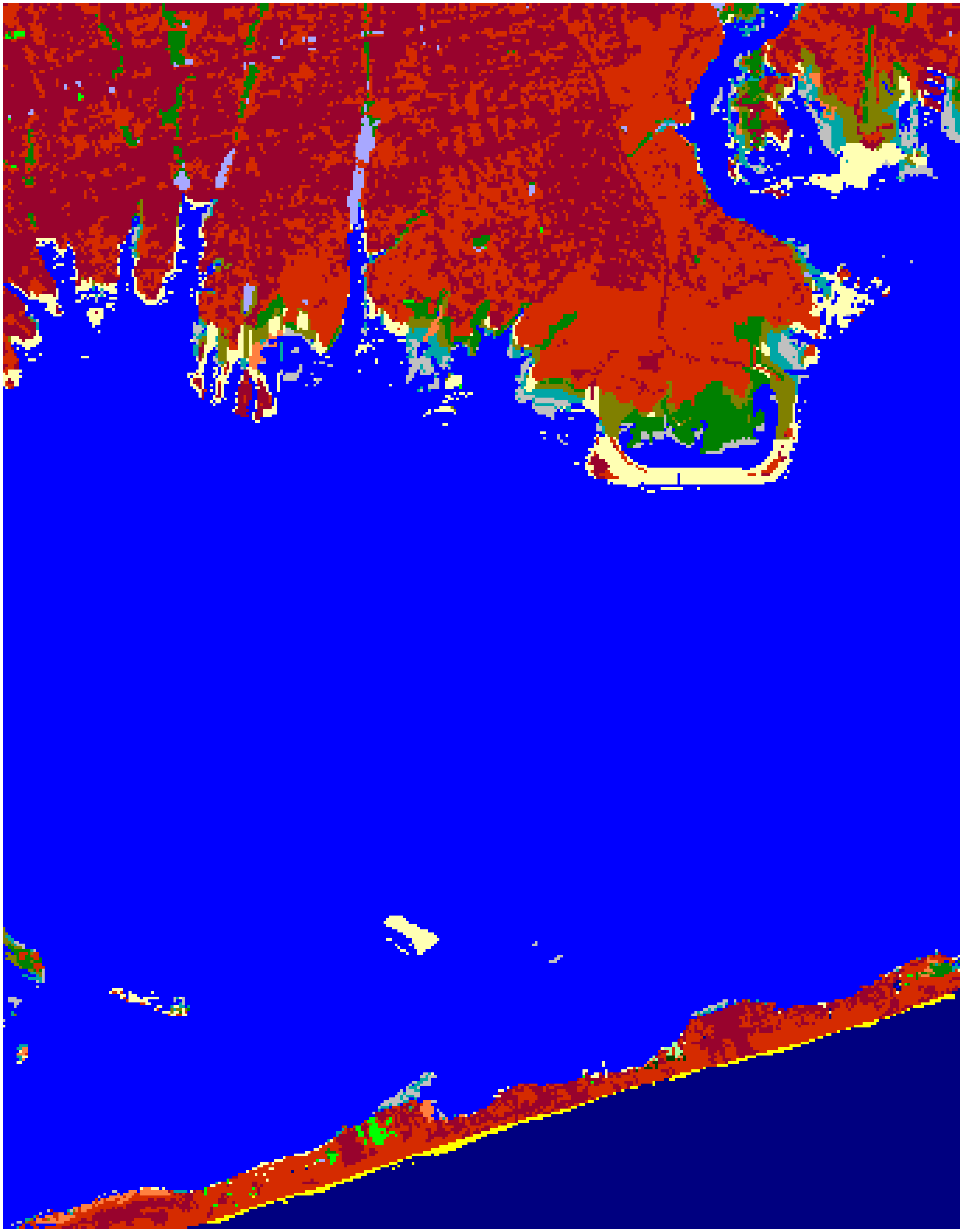
Seatuck NWR, 2025, Scenario A1B Maximum Protect Developed Dry Land



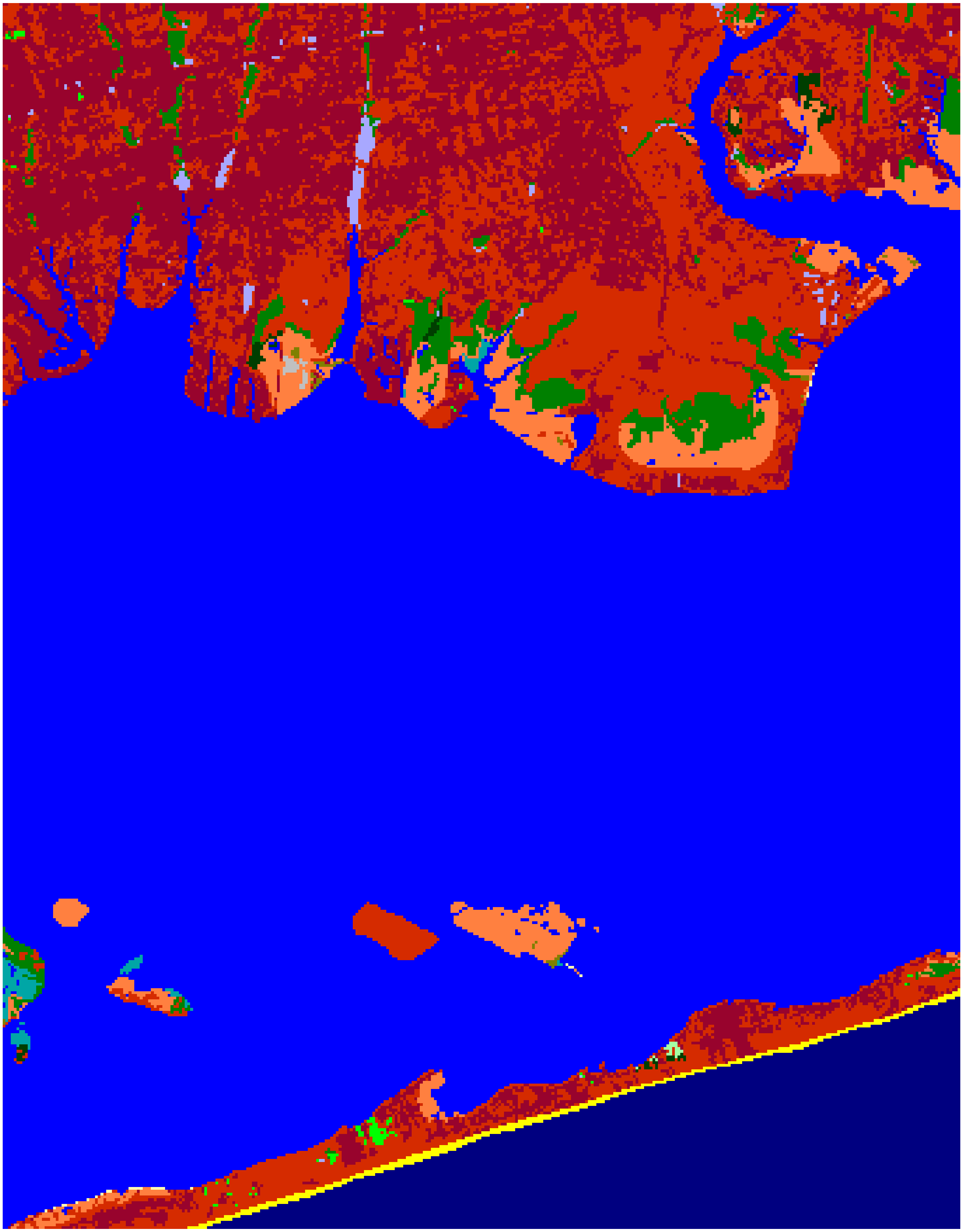
Seatuck NWR, 2050, Scenario A1B Maximum Protect Developed Dry Land



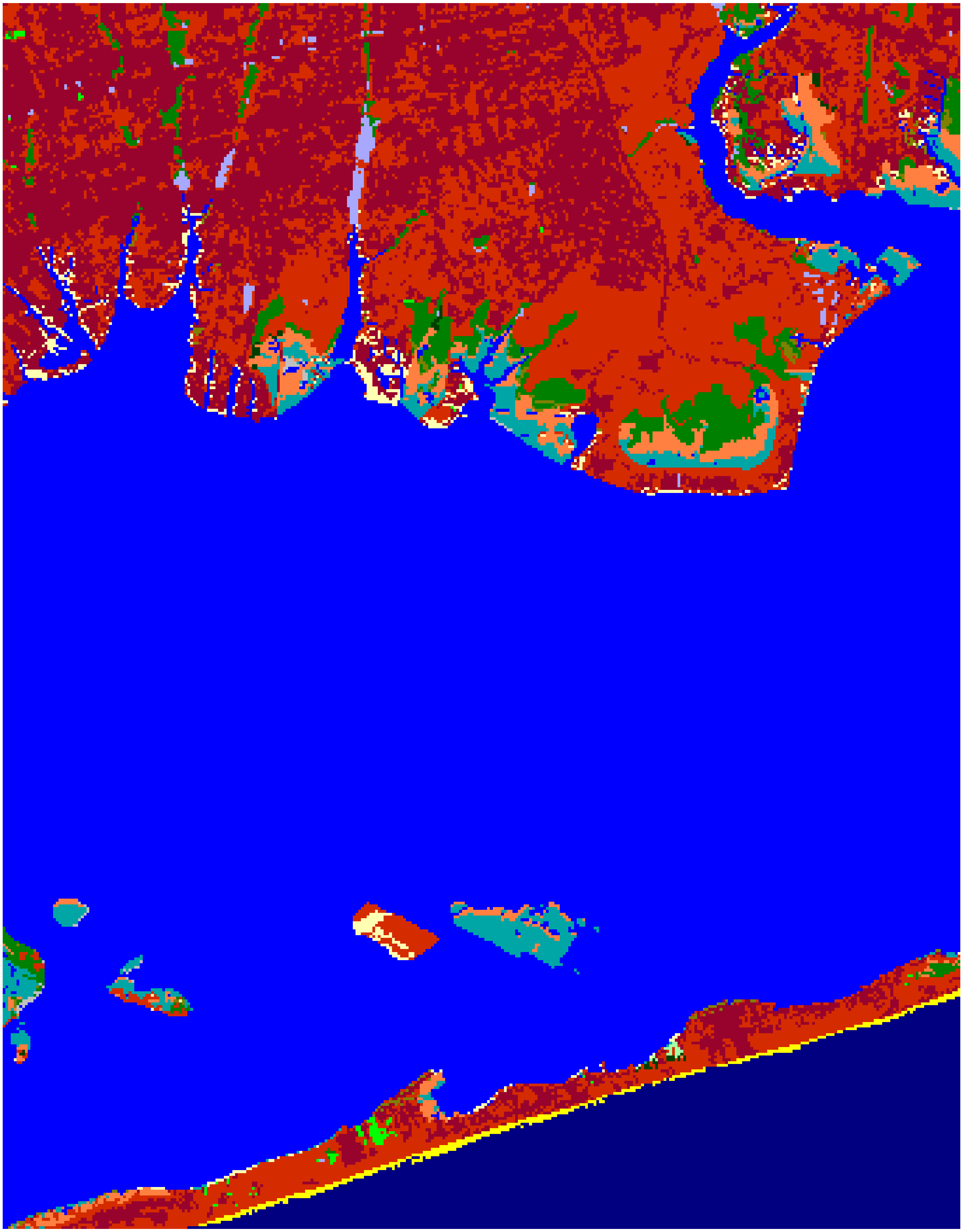
Seatuck NWR, 2075, Scenario A1B Maximum Protect Developed Dry Land



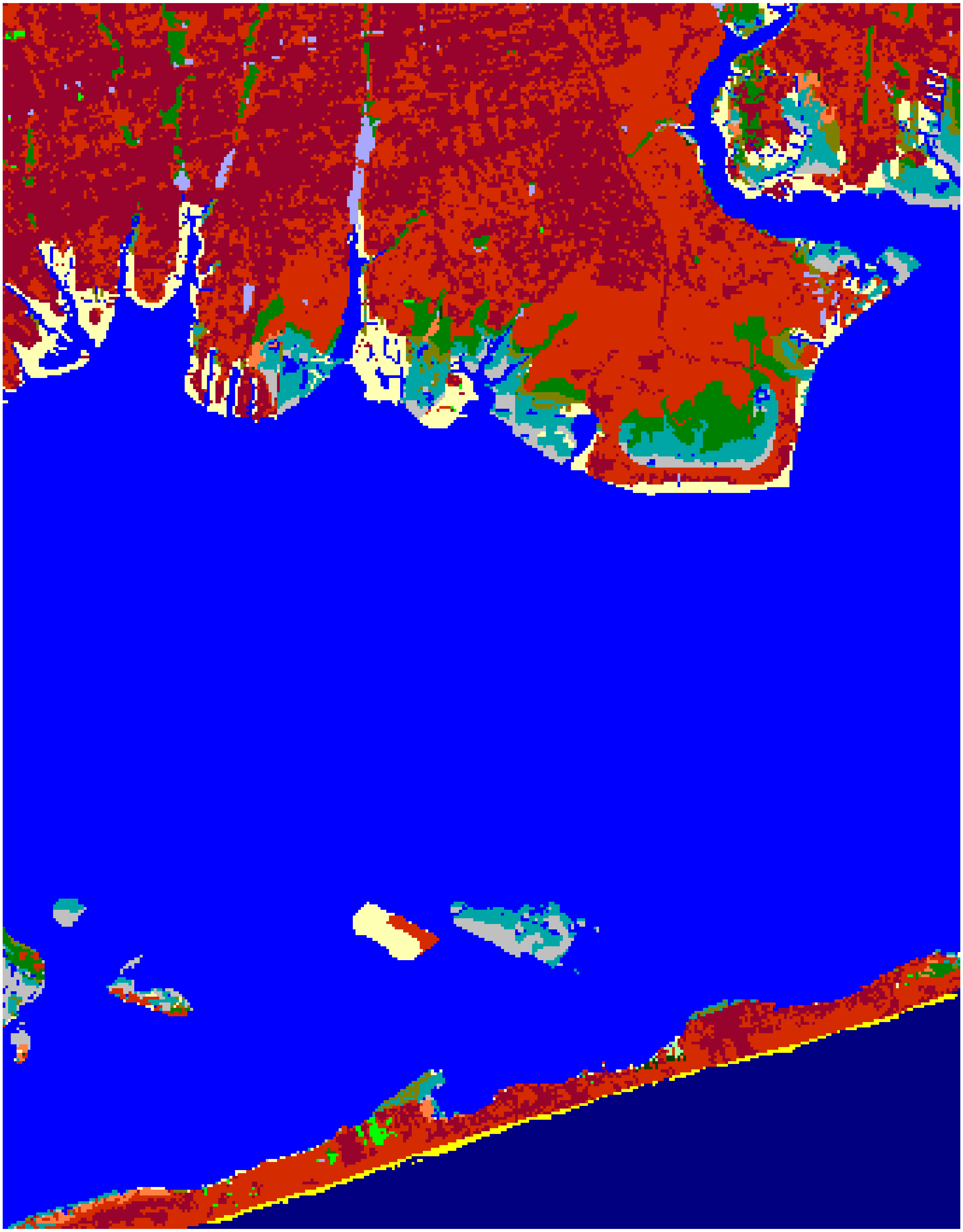
Seatuck NWR, 2100, Scenario A1B Maximum Protect Developed Dry Land



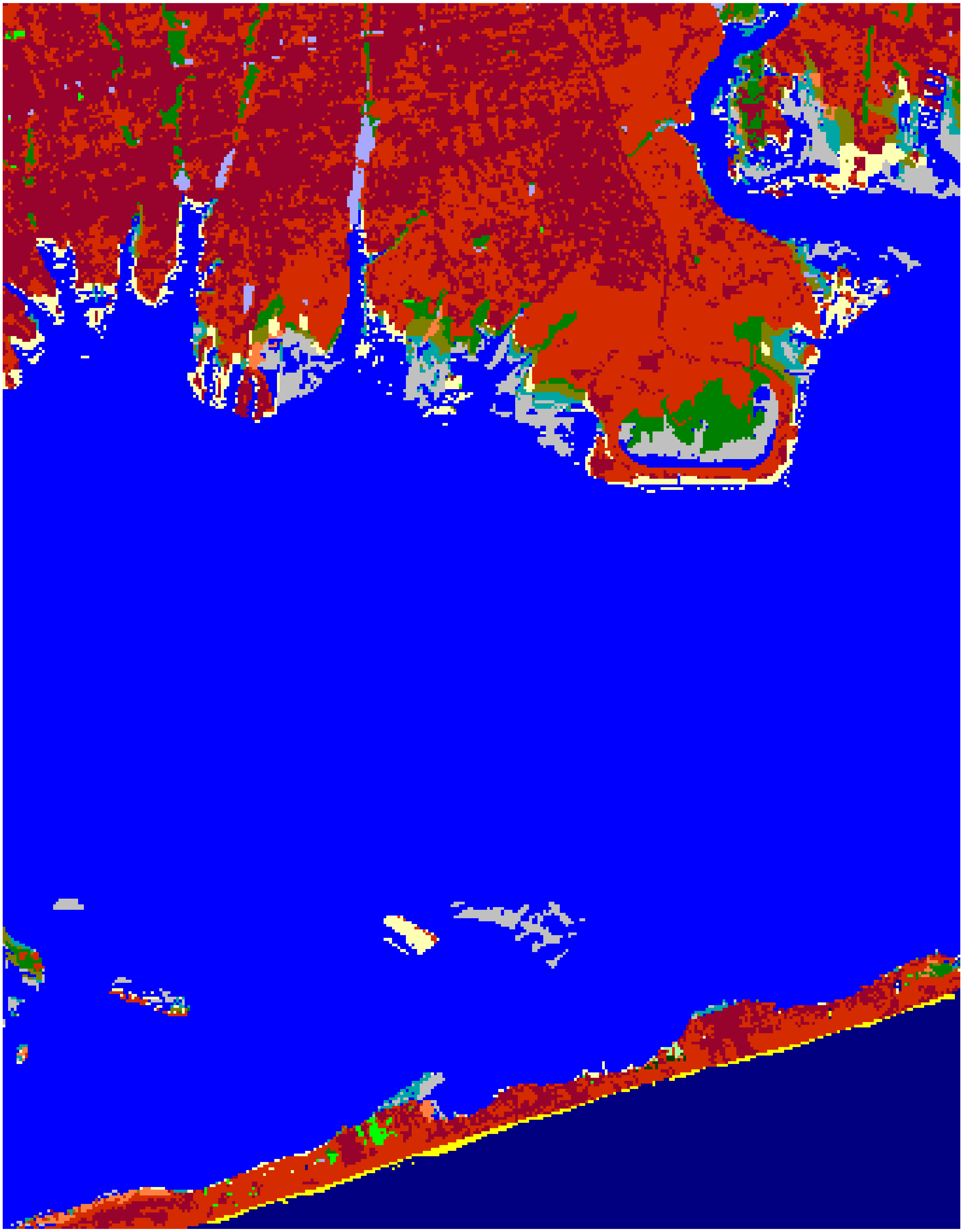
Seatuck NWR, Initial Condition



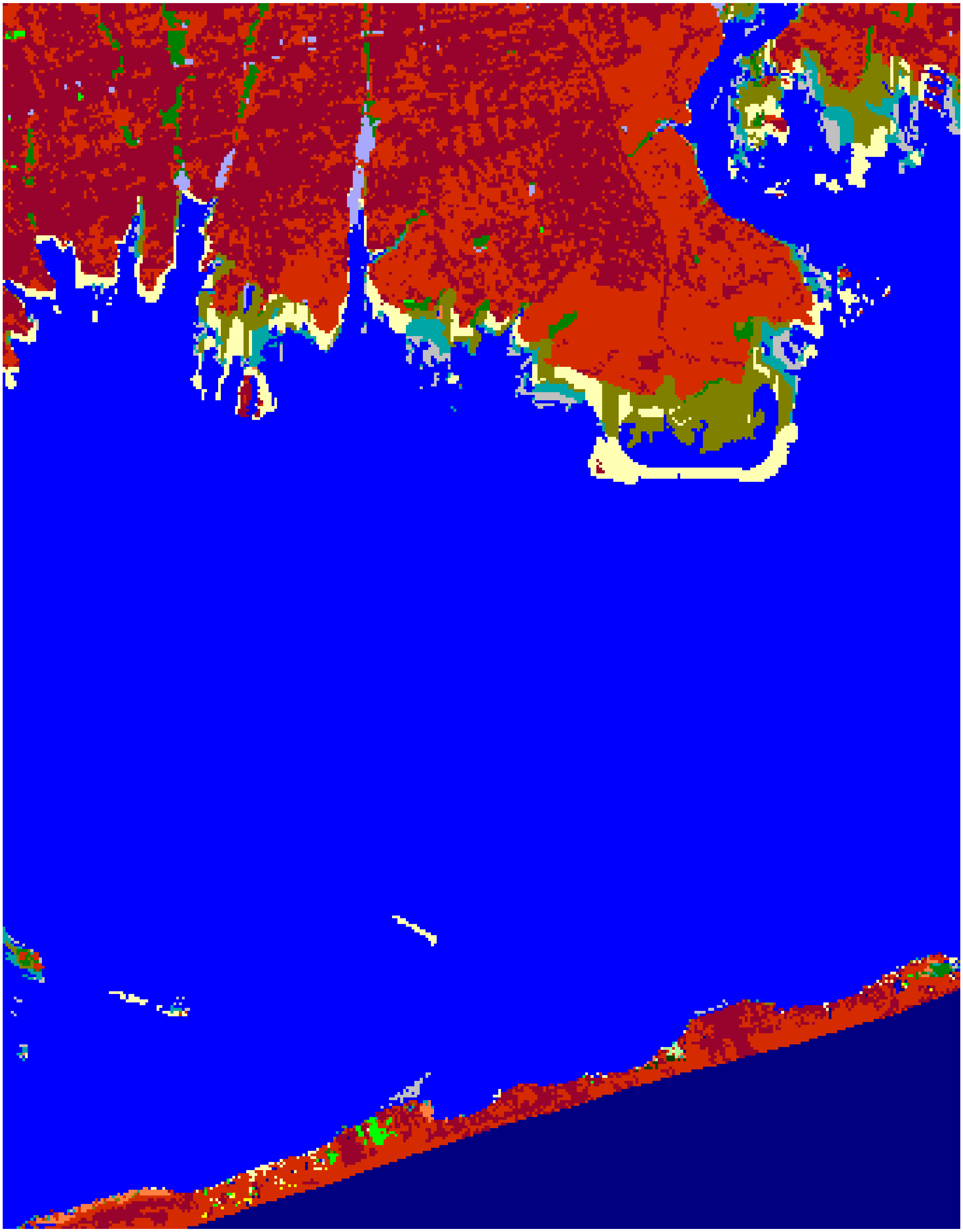
Seatuck NWR, 2025, 1 meter Protect Developed Dry Land



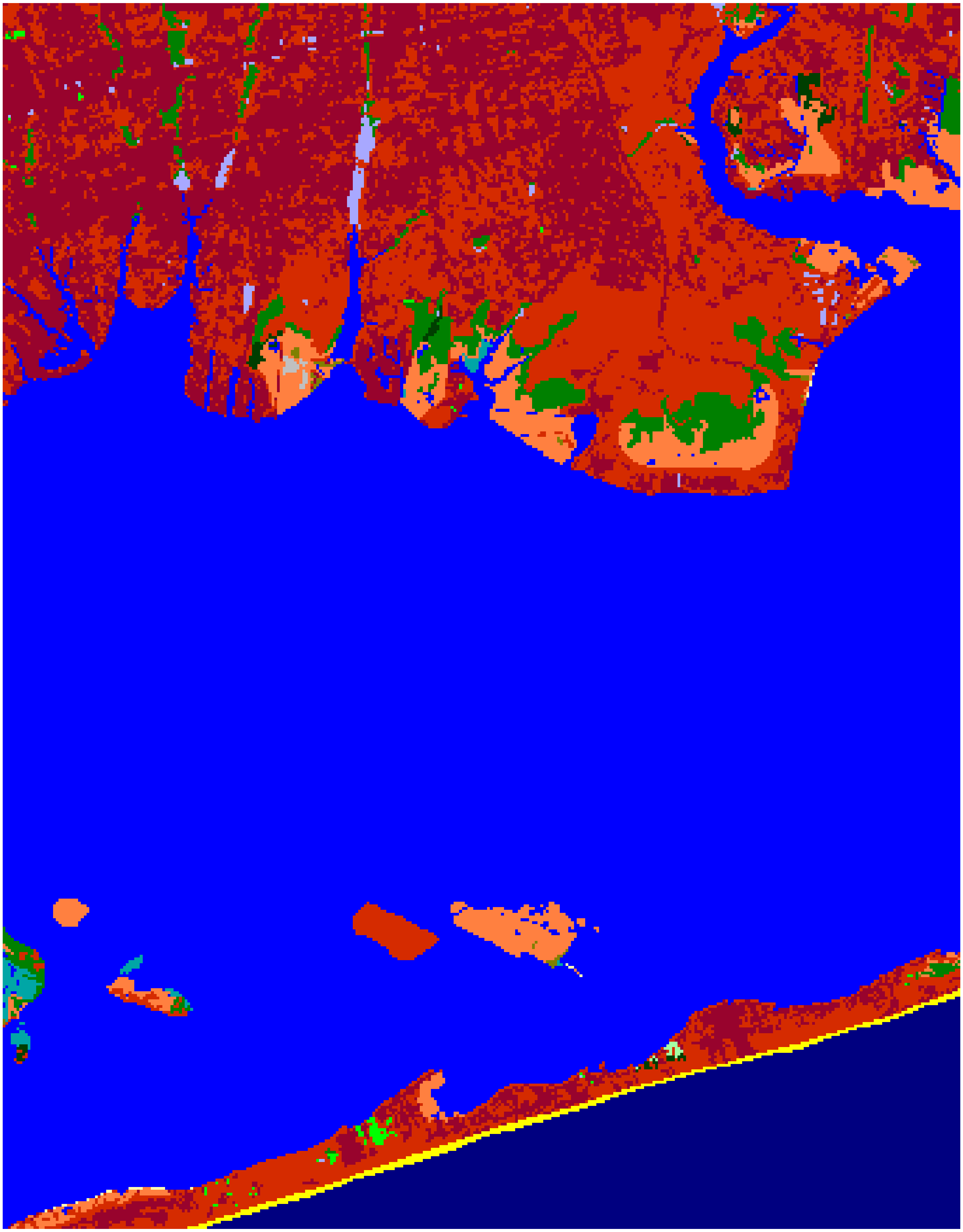
Seatuck NWR, 2050, 1 meter Protect Developed Dry Land



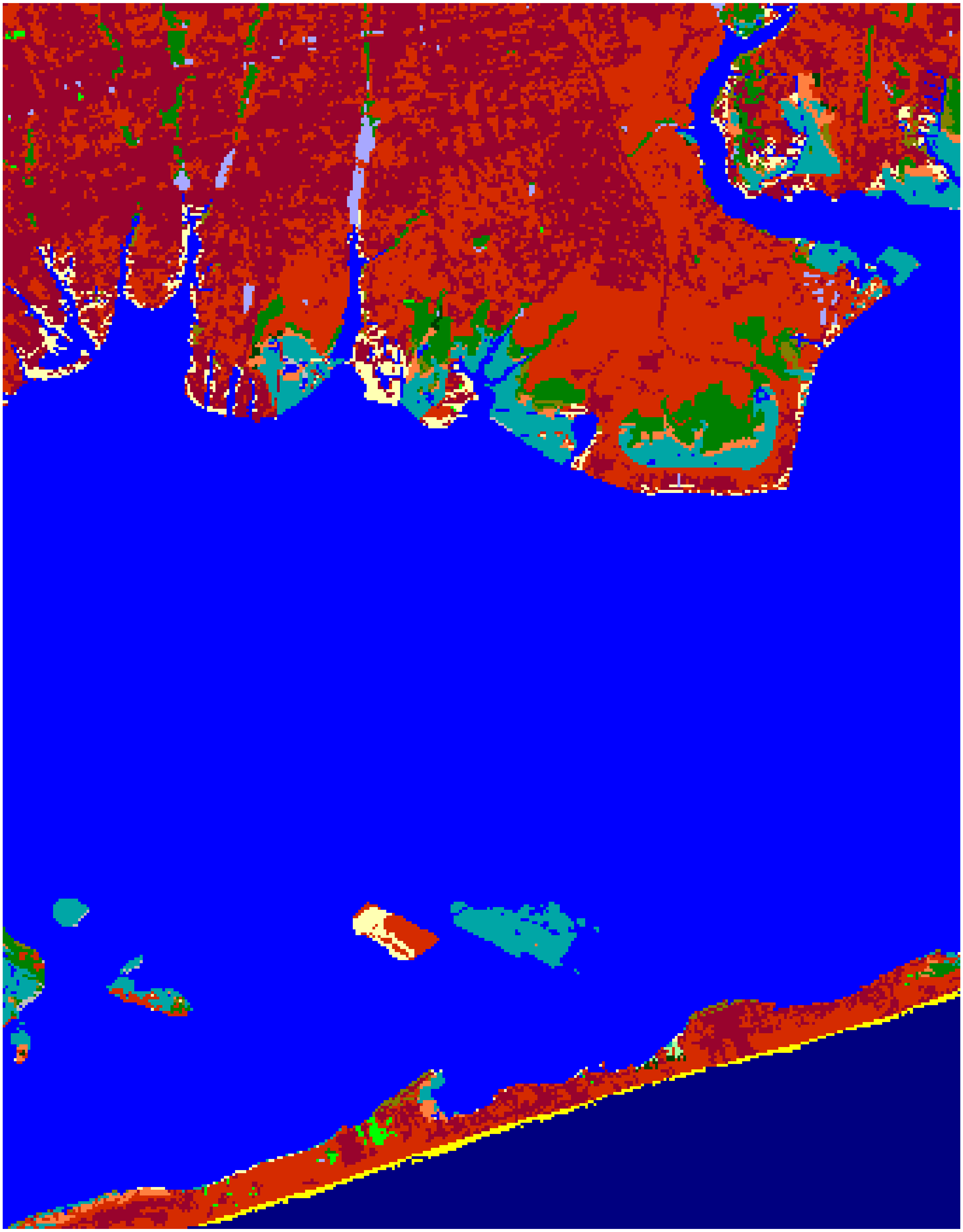
Seatuck NWR, 2075, 1 meter Protect Developed Dry Land



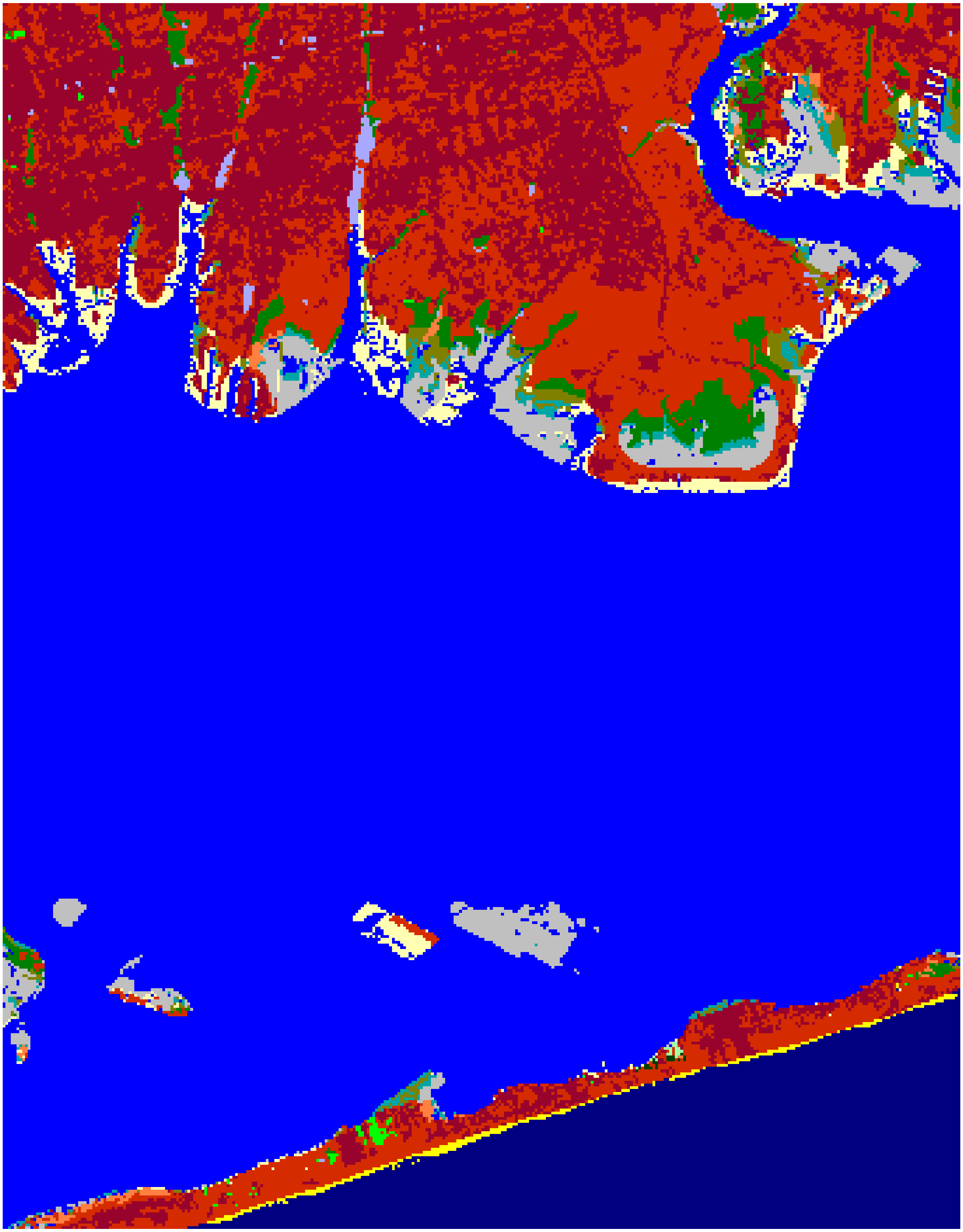
Seatuck NWR, 2100, 1 meter Protect Developed Dry Land



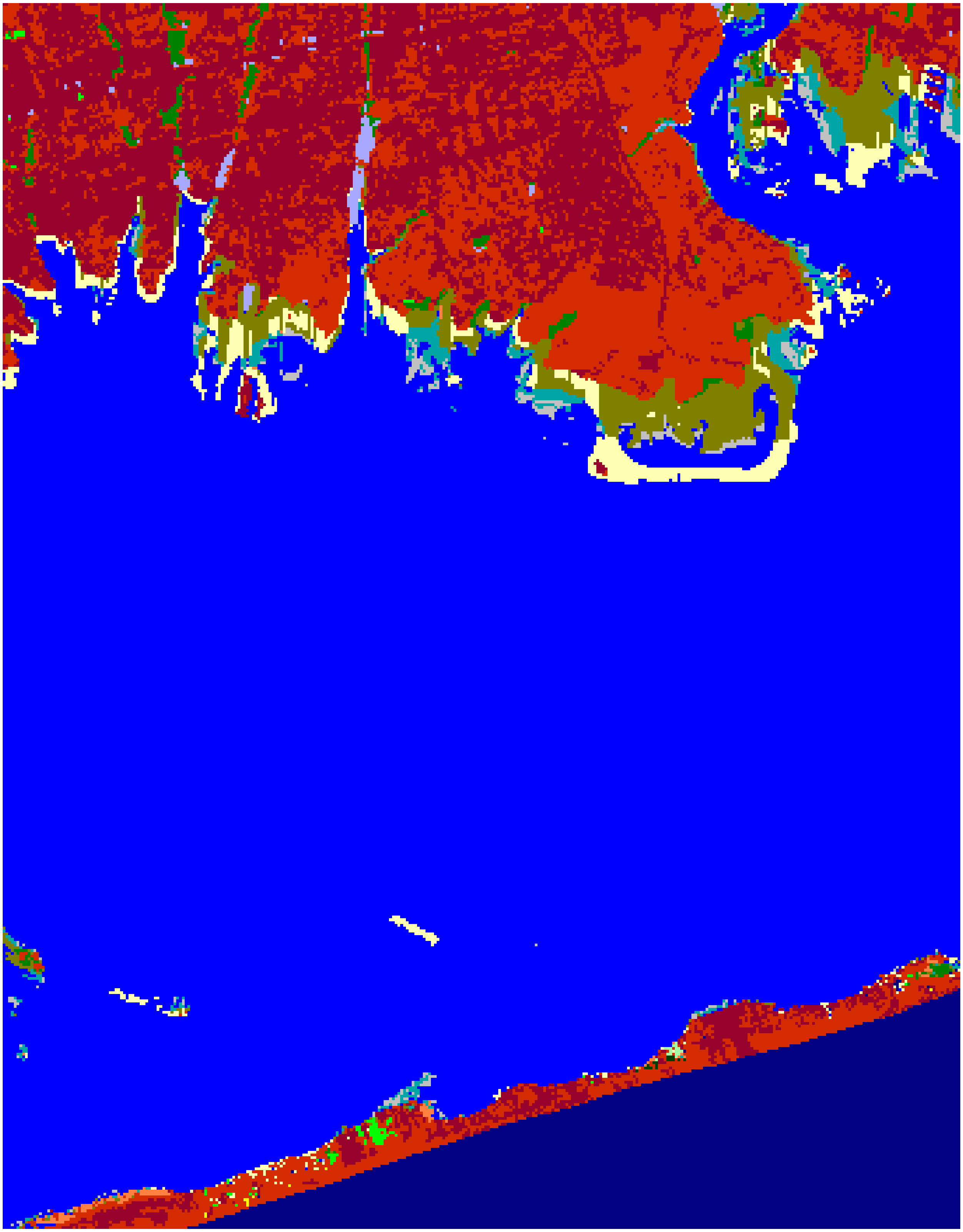
Seatuck NWR, Initial Condition



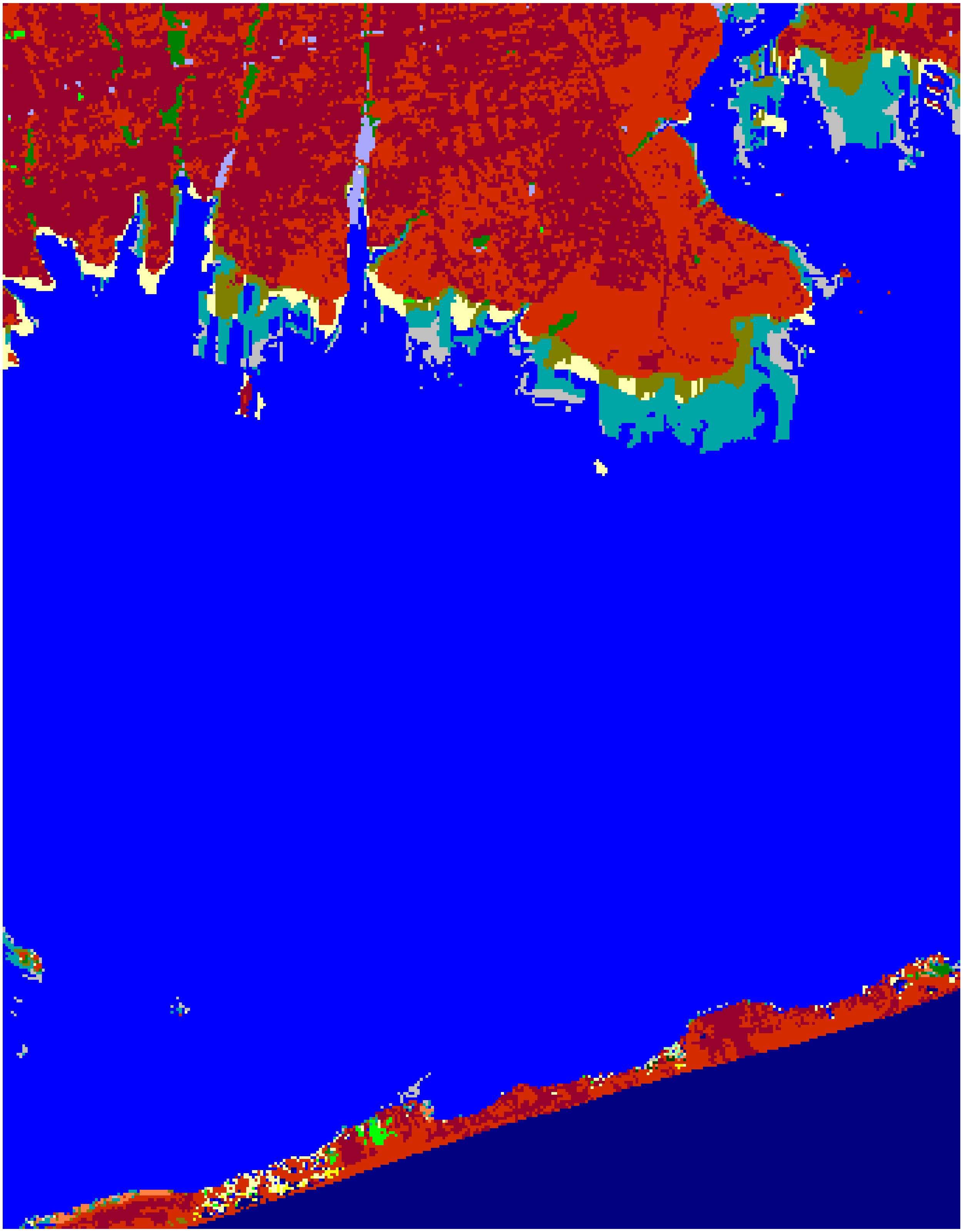
Seatuck NWR, 2025, 1.5 meter Protect Developed Dry Land



Seatuck NWR, 2050, 1.5 meter Protect Developed Dry Land



Seatuck NWR, 2075, 1.5 meter Protect Developed Dry Land



Seatuck NWR, 2100, 1.5 meter Protect Developed Dry Land