

Application of the Sea-Level Affecting Marshes Model (SLAMM 5.1) to Nansemond 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. Rising sea levels 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 5 refuges. This analysis is designed to assist in the production of comprehensive conservation plans (CCPs) for each refuge along with other long-term management plans.

Model Summary

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

Successive versions of the model have been used to estimate the impacts of sea level rise on the coasts of the U.S. (Titus et al., 1991; Lee, J.K., R.A. Park, and P.W. Mause. 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 was 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, Irregularly Flooded marsh, and tidal fresh marsh can migrate based on changes in salinity, using a simple though geographically-realistic salt wedge model. This optional model was not used in this model application.

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

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

Sea Level Rise Scenarios

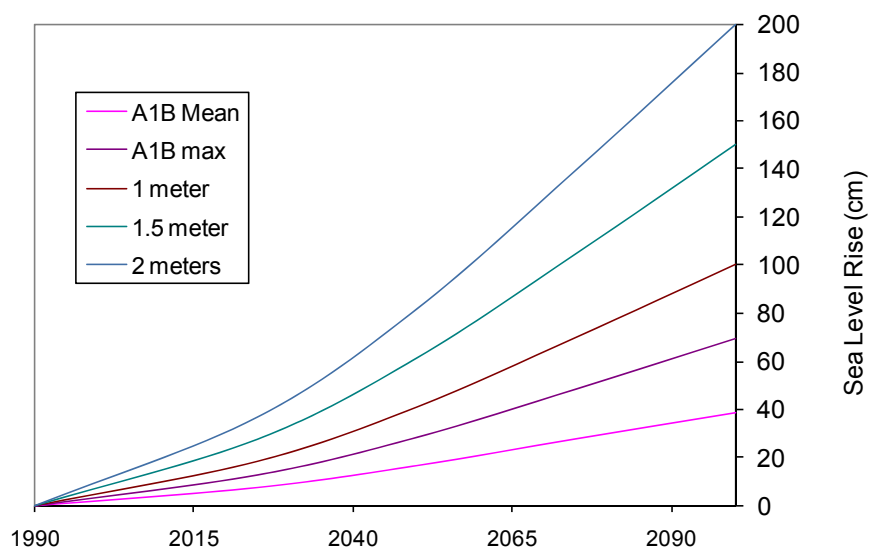
SLAMM 5 was run using scenario A1B from the Special Report on Emissions Scenarios (SRES) – mean and maximum estimates. The A1 scenario assumes that the future world includes very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. In particular, the A1B scenario assumes that energy sources will be balanced across all sources. Under the A1B scenario, the IPCC WGI Fourth Assessment Report (IPCC, 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. This work was recently updated and the ranges were increased to 75 to 190 cm (Vermeer and Rahmstorf, 2009). 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

The digital elevation map (DEM) used in this model simulation was derived from the National Elevation Dataset (NED). NED metadata indicate that these data were derived from USGS maps dated 1963, with 10 foot contour intervals and 5 foot supplemental contours (Figure 1). No high vertical resolution elevation data (e.g. LiDAR data) were publicly available for this refuge simulation.

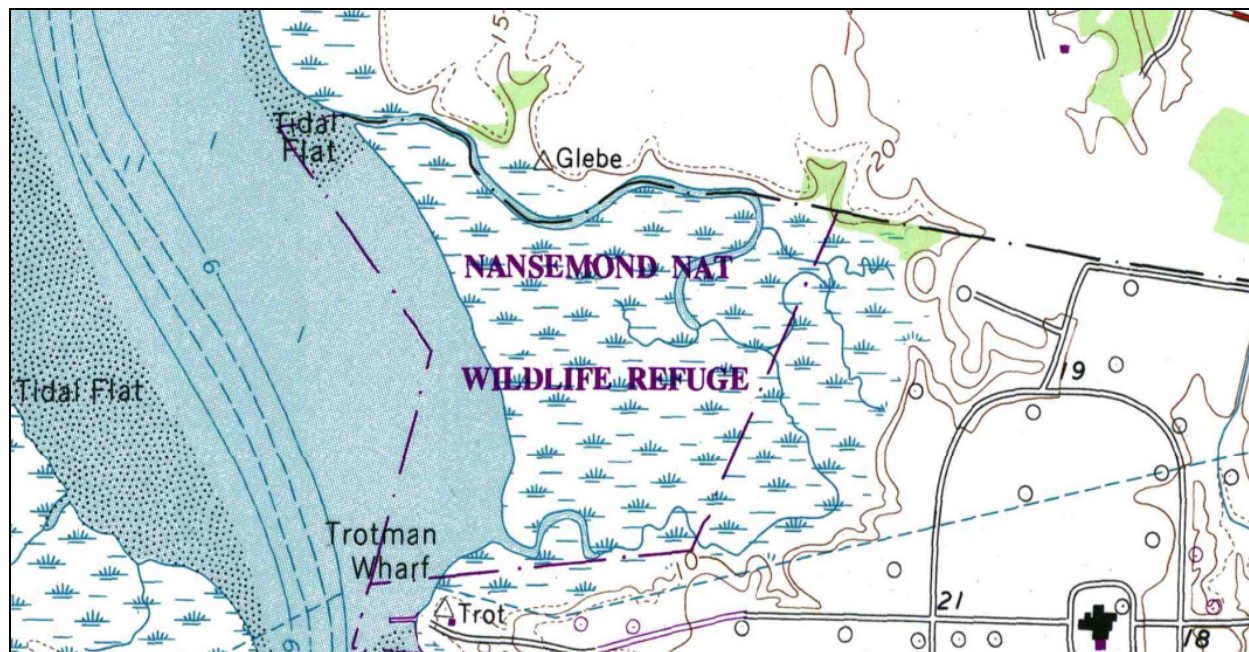


Figure 1: USGS topographical map of Nansemond NWR.

The National Wetlands Inventory for Nansemond is based on photo dates of 1990. A comparison of the NWI layer with current Google Earth satellite imagery reveals shoreline changes ranging between 20 to 40 meters (Figure 2).

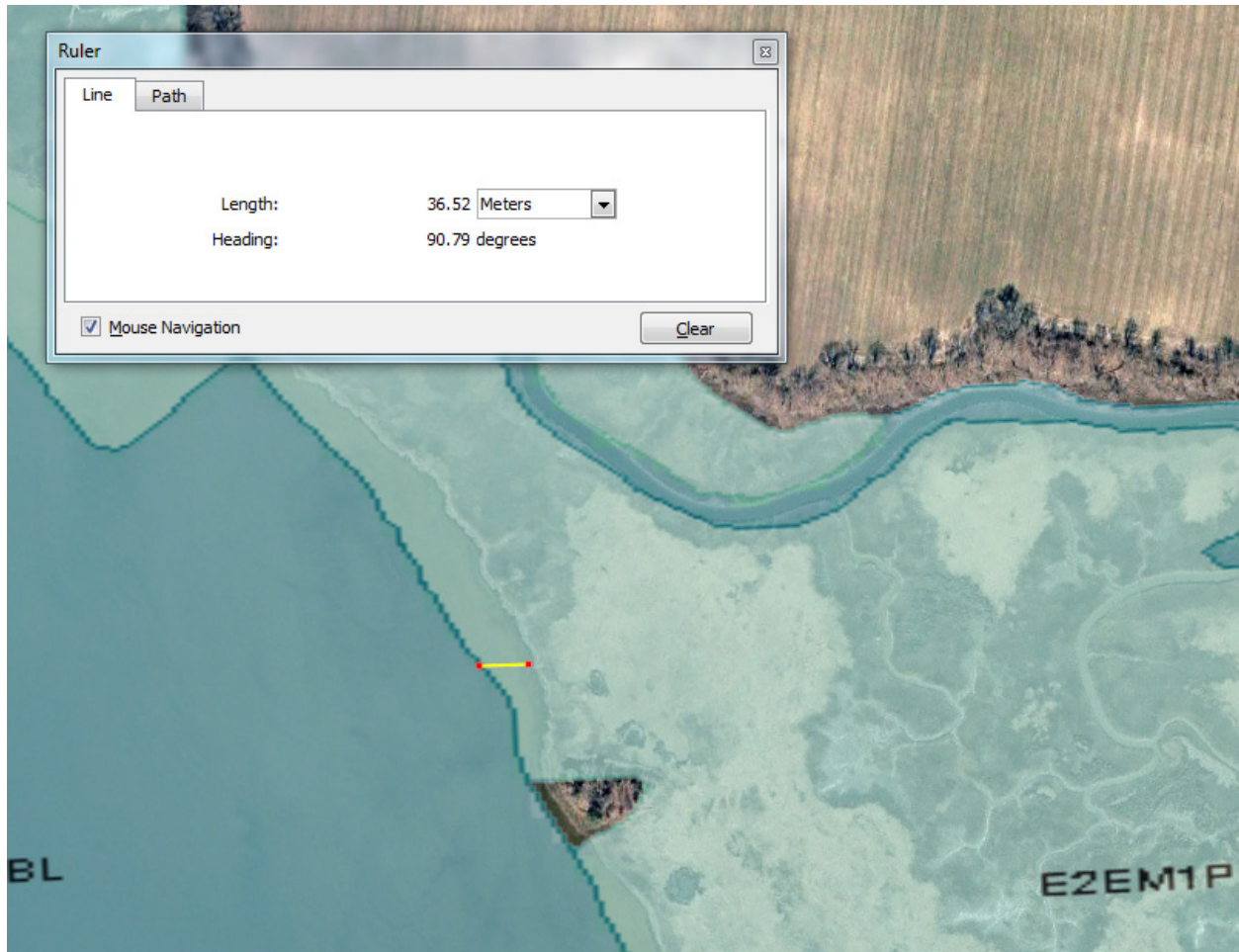


Figure 2: NWI layer over satellite imagery.

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

Irregularly Flooded Marsh	50.3%
Dry Land	38.9%
Estuarine Open Water	8.8%
Estuarine Beach	1.6%

According to the National Wetlands Inventory there are no diked or impounded regions within this refuge.

The historic trend for sea level rise was estimated 4.1 mm/year using the mean of the two nearest NOAA gages (8638660, Portsmouth, VA; 8638610, Sewells Point, VA). This estimated rate is more than twice the global average for the last 100 years (approximately 1.7 mm/year).

The tidal range for Nansemond NWR of 1.04 meters was determined using the nearest NOAA gage (8638610, Sewells Point, VA, Figure 4) and the tide table for Hollidays Point Bridge. The mean tide level (MN) estimated for Hollidays Point Bridge (0.91 meters) was converted to great diurnal tide (GT) for use in the SLAMM model using the Sewells Point ratio of GT/MN (1.13).

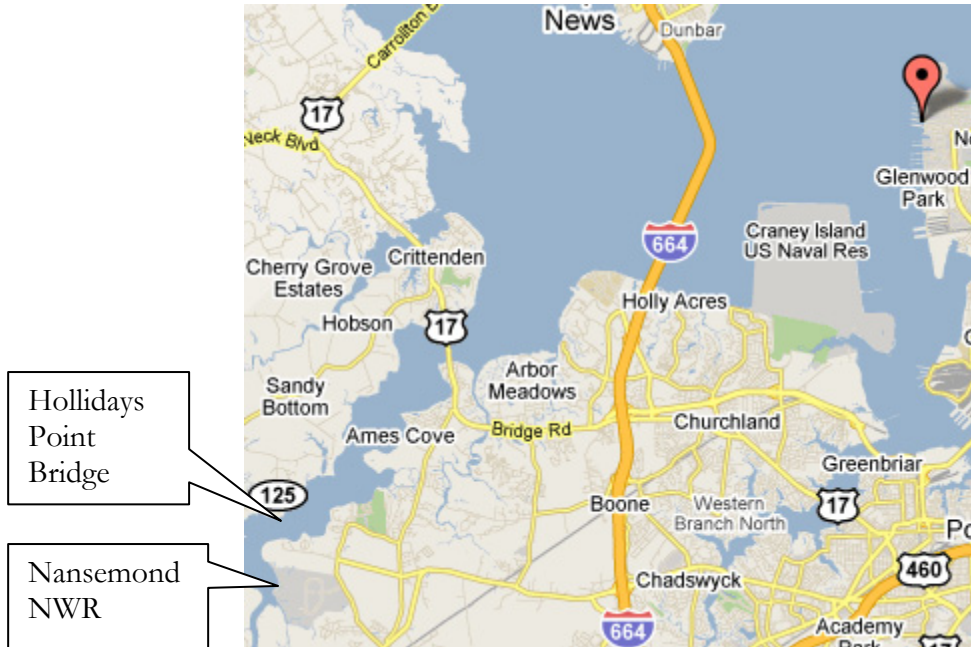


Figure 3: NOAA Gage Relevant to the Study Area.

No site-specific marsh accretion data were located for this refuge. The marsh accretion values used were based on two different estimates:

- Based on a large analysis of accretion studies within mid-Atlantic region (Reed et al. 2008), the average Virginia marsh accretion value was calculated as 4.02 mm/yr (n=5);
- From this same study, the average salt marsh accretion rates in Chesapeake Bay was 4.04 mm/year (n=12, Reed et al. 2008);

Marsh erosion rates were set to 0.37 meters/year based on a Virginia shoreline erosion study (Hardaway 1980). Tidal flat erosion rates were set to 1.5 meters/year based on an examination of NWI maps against current shoreline locations.

The MTL to NAVD88 correction was derived using the NOAA VDATUM product. The correction was determined to be -0.042 meters.

Modeled U.S. Fish and Wildlife Service refuge boundaries for Virginia 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 will track partial conversion of cells based on elevation and slope.

SUMMARY OF SLAMM INPUT PARAMETERS FOR NANSEMOND NWR

Parameter	Global	SubSite 2
Description	VA	Nansemond
NWI Photo Date (YYYY)	1989	1990
DEM Date (YYYY)	1975	1963
Direction Offshore [n,s,e,w]	East	West
Historic Trend (mm/yr)	3.9	4.1
MTL-NAVD88 (m)	-0.06	-0.0418
GT Great Diurnal Tide Range (m)	0.9	1.04
Salt Elev. (m above MTL)	0.6	0.6916
Marsh Erosion (horz. m /yr)	1.5	0.37
Swamp Erosion (horz. m /yr)	1.5	0.37
T.Flat Erosion (horz. m /yr)	3	1.5
Reg. Flood Marsh Accr (mm/yr)	4	4
Irreg. Flood Marsh Accr (mm/yr)	4	4
Tidal Fresh Marsh Accr (mm/yr)	1	5
Beach Sed. Rate (mm/yr)	0.5	0.5
Freq. Overwash (years)	25	25
Use Elev Pre-processor [True,False]	TRUE	TRUE

Results

Due to its relatively small tidal range and relatively high historical rate of sea level rise, Nansemond NWR is predicted to show significant effects from future sea level rise. SLAMM model results suggest that between 57% and 100% of Nansemond's irregularly flooded marsh – accounting for half of the refuge – will be lost across all scenarios. Less refuge dry land is predicted to be lost, with only 14% to 37% converting across all scenarios.

SLR by 2100 (m)	0.39	0.69	1	1.5	2
Irregularly Flooded Marsh	57%	100%	100%	100%	100%
Dry Land	14%	15%	18%	25%	37%
Estuarine Beach	18%	38%	99%	100%	100%
Tidal Swamp	13%	24%	33%	54%	71%

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:



Nansemond NWR

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

Results in Acres

	Initial	2025	2050	2075	2100
Irregularly Flooded Marsh	211.9	187.0	180.1	132.3	91.0
Dry Land	163.9	152.6	143.7	142.4	141.2
Estuarine Open Water	37.1	37.1	37.1	37.5	38.4
Estuarine Beach	6.9	6.9	6.9	6.5	5.7
Tidal Swamp	1.6	1.6	1.6	1.6	1.4
Regularly Flooded Marsh	0.0	25.0	31.8	79.7	121.5
Swamp	0.0	11.1	19.7	19.8	19.5
Trans. Salt Marsh	0.0	0.2	0.5	1.7	2.9
Total (incl. water)	421.4	421.4	421.4	421.4	421.4



Nansemond NWR, Initial Condition



Nansemond NWR, 2025, Scenario A1B Mean



Nansemond NWR, 2050, Scenario A1B Mean



Nansemond NWR, 2075, Scenario A1B Mean



Nansemond NWR, 2100, Scenario A1B Mean

Nansemond NWR

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

Results in Acres

	Initial	2025	2050	2075	2100
Irregularly Flooded Marsh	211.9	152.4	104.3	29.8	0.4
Dry Land	163.9	152.5	144.3	142.1	139.2
Estuarine Open Water	37.1	37.1	37.4	54.1	74.4
Estuarine Beach	6.9	6.9	6.7	5.4	4.2
Tidal Swamp	1.6	1.6	1.6	1.3	1.2
Regularly Flooded Marsh	0.0	59.5	107.7	139.7	72.9
Swamp	0.0	11.1	18.5	18.2	17.9
Trans. Salt Marsh	0.0	0.3	1.1	2.9	3.4
Tidal Flat	0.0	0.0	0.0	27.9	107.8
Total (incl. water)	421.4	421.4	421.4	421.4	421.4



Nansemond NWR, Initial Condition



Nansemond NWR, 2025, Scenario A1B Maximum



Nansemond NWR, 2050, Scenario A1B Maximum



Nansemond NWR, 2075, Scenario A1B Maximum



Nansemond NWR, 2100, Scenario A1B Maximum

Nansemond NWR

1 Meter Eustatic SLR by 2100

Results in Acres

	Initial	2025	2050	2075	2100
Irregularly Flooded Marsh	211.9	115.7	44.1	0.4	0.3
Dry Land	163.9	152.4	143.8	139.8	133.8
Estuarine Open Water	37.1	37.1	49.5	67.0	132.8
Estuarine Beach	6.9	6.9	6.1	4.6	0.0
Tidal Swamp	1.6	1.6	1.4	1.2	1.0
Regularly Flooded Marsh	0.0	96.2	146.8	51.2	6.1
Swamp	0.0	11.1	17.7	18.0	19.6
Tidal Flat	0.0	0.0	9.8	135.6	123.3
Trans. Salt Marsh	0.0	0.4	2.2	3.7	4.6
Total (incl. water)	421.4	421.4	421.4	421.4	421.4



Nansemond NWR, Initial Condition



Nansemond NWR, 2025, 1 meter



Nansemond NWR, 2050, 1 meter



Nansemond NWR, 2075, 1 meter



Nansemond NWR, 2100, 1 meter

Nansemond NWR

1.5 Meters Eustatic SLR by 2100

Results in Acres

	Initial	2025	2050	2075	2100
Irregularly Flooded Marsh	211.9	68.4	0.3	0.3	0.3
Dry Land	163.9	152.1	141.2	133.2	123.6
Estuarine Open Water	37.1	37.2	58.5	179.5	258.5
Estuarine Beach	6.9	6.8	5.1	0.0	0.0
Tidal Swamp	1.6	1.6	1.3	1.0	0.7
Tidal Flat	0.0	0.0	122.7	76.9	1.6
Regularly Flooded Marsh	0.0	143.6	70.4	4.1	6.4
Swamp	0.0	11.1	18.2	20.3	19.9
Trans. Salt Marsh	0.0	0.7	3.7	6.1	10.4
Total (incl. water)	421.4	421.4	421.4	421.4	421.4



Nansemond NWR, Initial Condition



Nansemond NWR, 2025, 1.5 meter



Nansemond NWR, 2050, 1.5 meter



Nansemond NWR, 2075, 1.5 meter



Nansemond NWR, 2100, 1.5 meter

Nansemond NWR

2 Meters Eustatic SLR by 2100

Results in Acres

	Initial	2025	2050	2075	2100
Irregularly Flooded Marsh	211.9	27.7	0.4	0.3	0.4
Dry Land	163.9	152.0	137.2	127.1	102.5
Estuarine Open Water	37.1	49.0	68.1	236.5	260.3
Estuarine Beach	6.9	6.5	4.0	0.0	0.0
Tidal Swamp	1.6	1.6	1.1	0.8	0.4
Tidal Flat	0.0	9.7	156.2	20.8	2.5
Regularly Flooded Marsh	0.0	163.2	29.2	5.8	9.7
Swamp	0.0	10.4	19.8	20.7	19.3
Trans. Salt Marsh	0.0	1.3	5.4	9.4	26.3
Total (incl. water)	421.4	421.4	421.4	421.4	421.4



Nansemond NWR, Initial Condition



Nansemond NWR, 2025, 2 meters



Nansemond NWR, 2050, 2 meters



Nansemond NWR, 2075, 2 meters



Nansemond NWR, 2100, 2 meters

Discussion

Irregularly flooded (brackish) marshes at Nansemond NWR are predicted to be vulnerable to increasing rates of sea level rise (SLR). Under the lowest scenario run, over half of irregularly flooded marsh is predicted to convert to regularly flooded salt marsh. Under scenarios of 0.69 meters and greater (eustatic SLR by 2100) all brackish marsh is predicted to be lost—converted to salt marsh, tidal flats or open water.

The dry land behind the marshes fares better with a maximum of one third lost under feasible SLR scenarios. However, these results are quite uncertain as the best available elevation data for this site date from 1963 and are based on 10 foot contour intervals. Interpolation between these contours and estimates of land elevations below the lowest contour are quite uncertain.

Measured historical sea level rise near this site has been higher than global trends. This difference has been maintained in model projections, resulting in a higher predicted local SLR than will be experienced globally.

Due to low-quality elevation data, the SLAMM pre-processor was utilized to estimate elevation ranges for irregularly flooded marshes. This pre-processor estimates wetland elevations as a function of tide ranges and known relationships between marsh-type and tide ranges. LiDAR data for the site would reduce model uncertainty considerably.

Site-specific accretion data would also reduce model uncertainty. It is also unclear whether a higher frequency of inundation will allow refuge marshes to capture additional sediment and thus vertically accrete at a higher rate. Such a feedback would provide some additional resilience to SLR. However this feedback mechanism is unlikely to provide perfect protection from SLR, especially given the relatively low tide range at this site.

Some soil saturation is predicted at this site as well, in the conversion of dry land to swamp in the northern part of the refuge. Soil saturation is predicted when the increase in salt water elevations puts pressure on the fresh water table and expansion of fresh-water wetlands is predicted.

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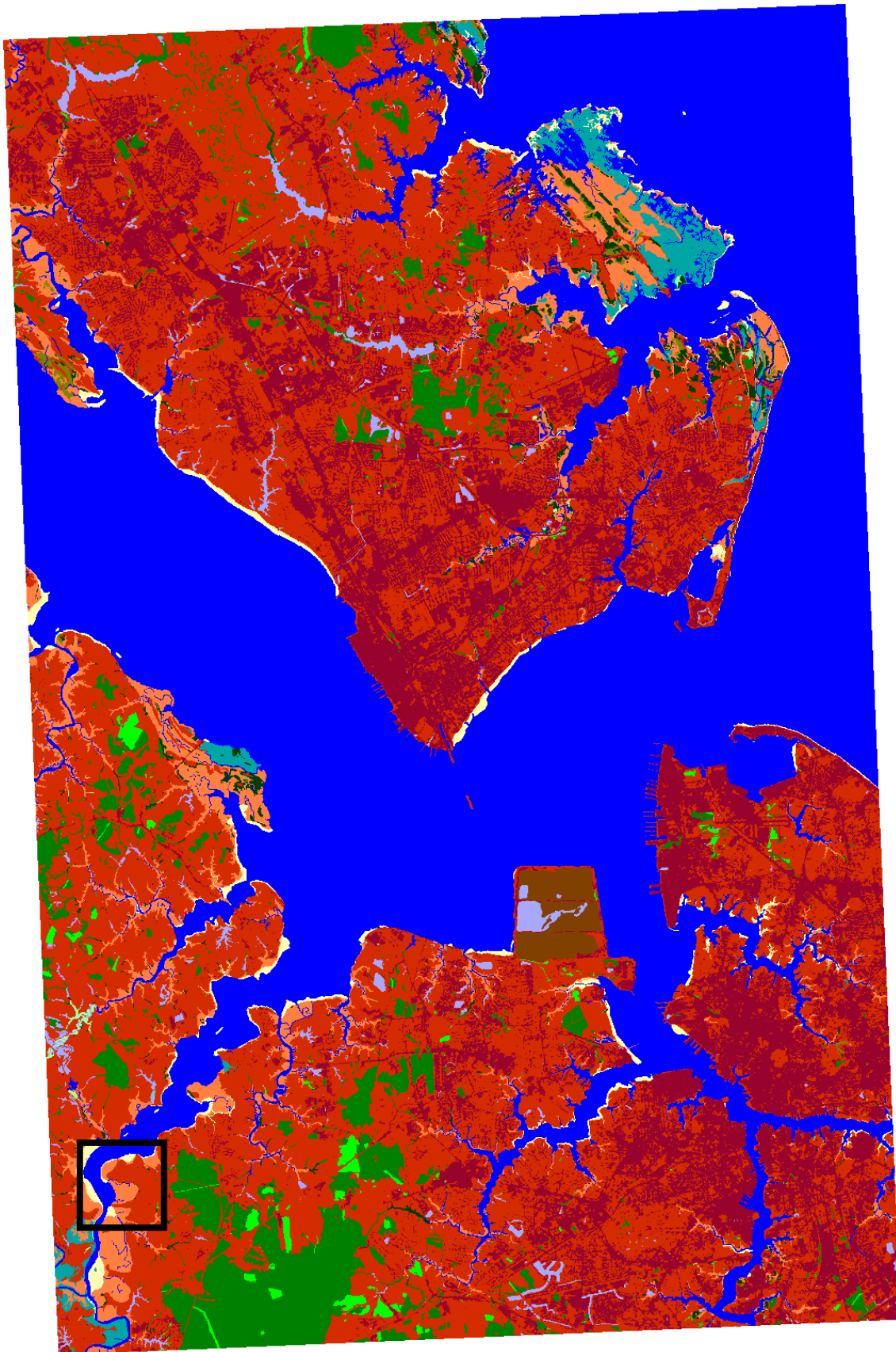
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Appendix A: Contextual Results

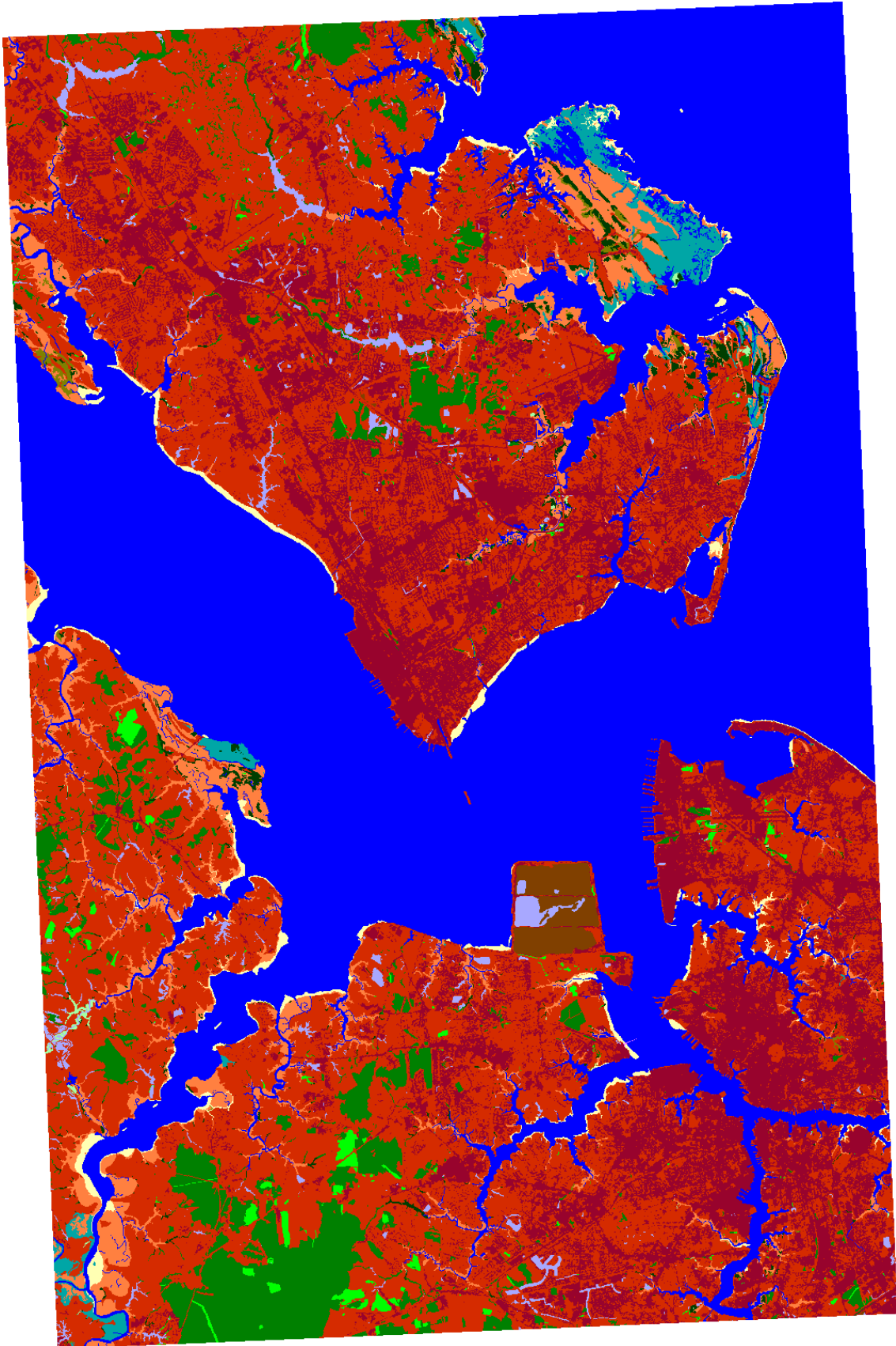
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

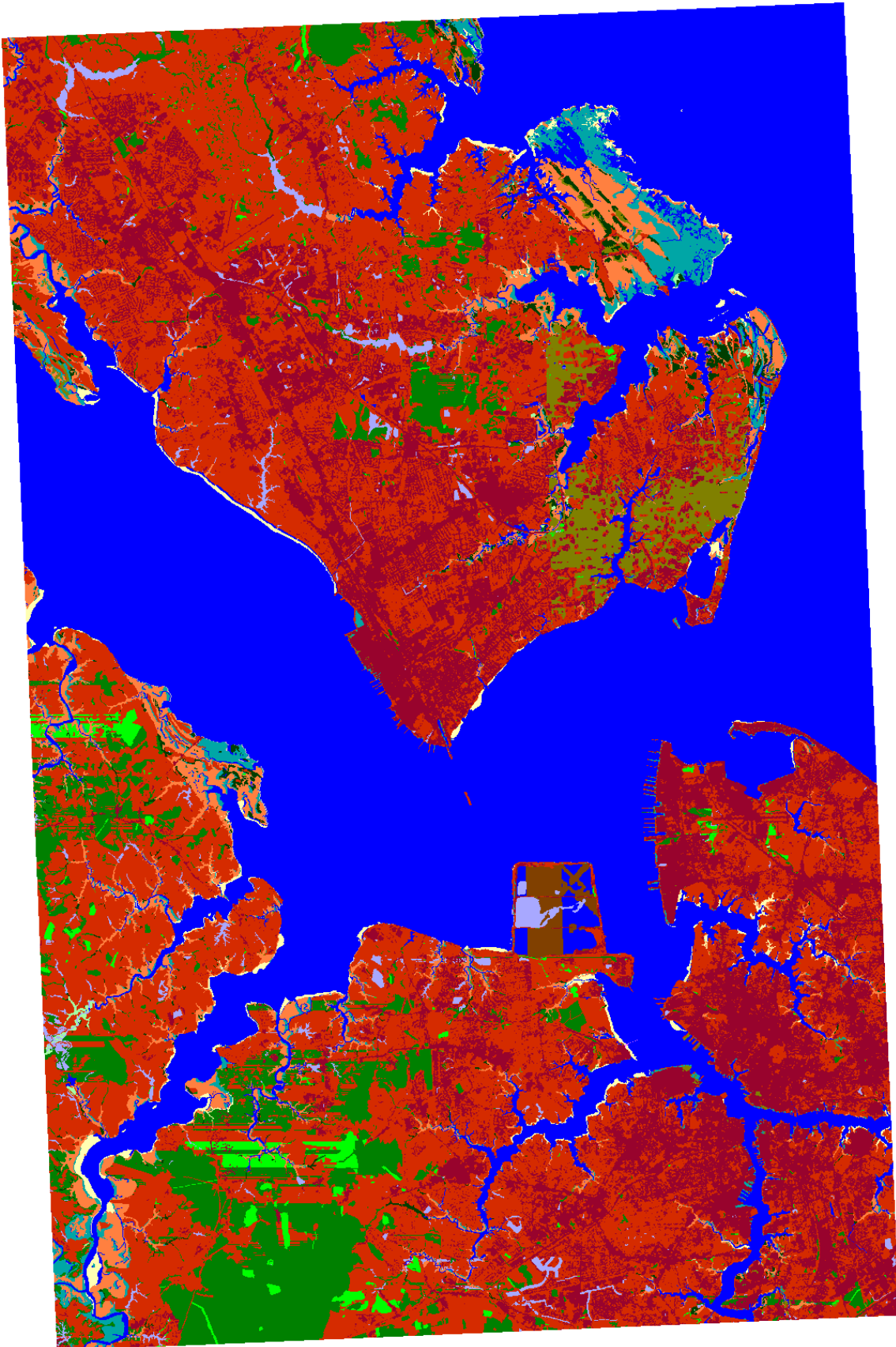
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



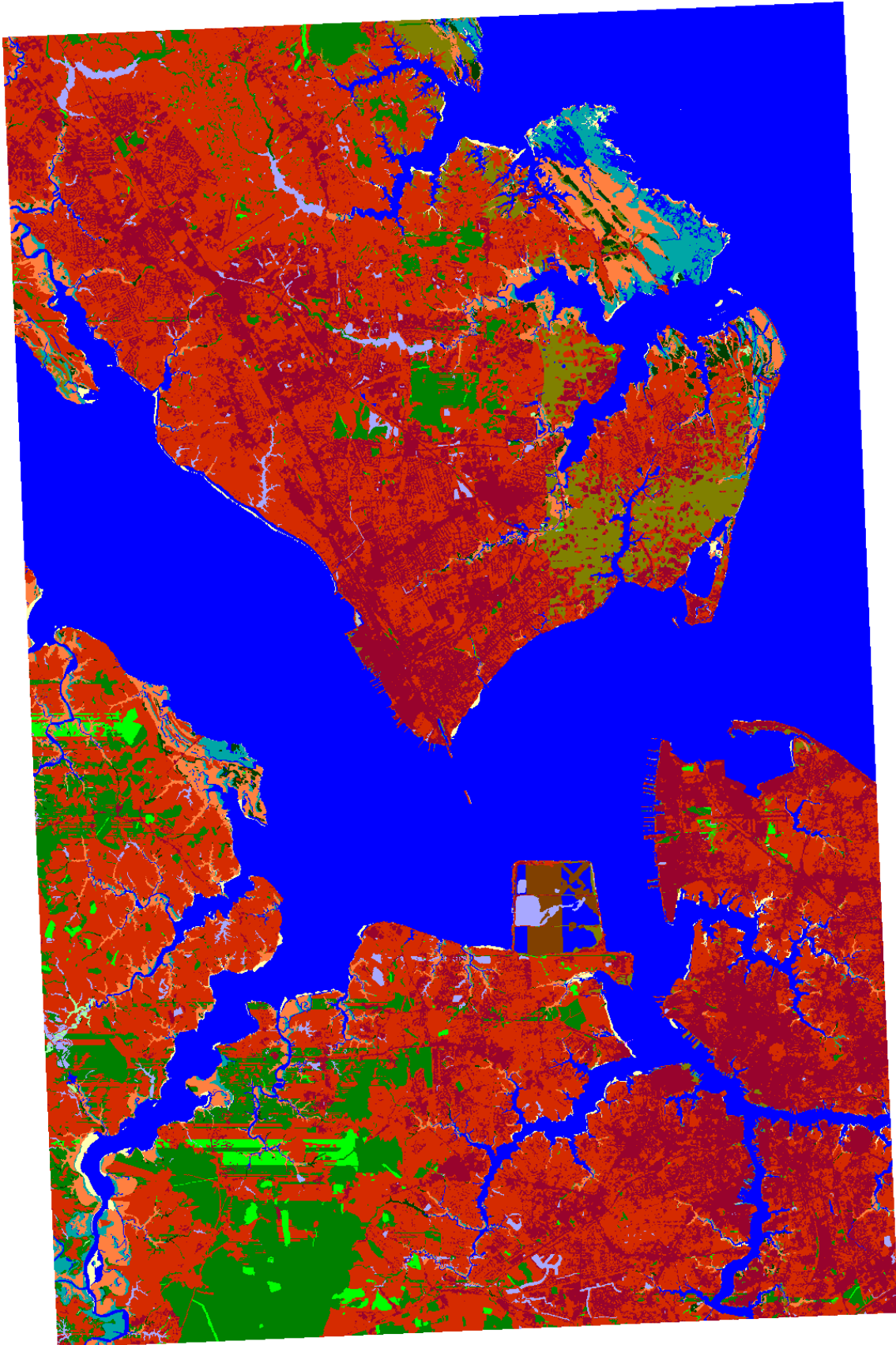
Location of Nansemond National Wildlife Refuge (in rectangle) within simulation context



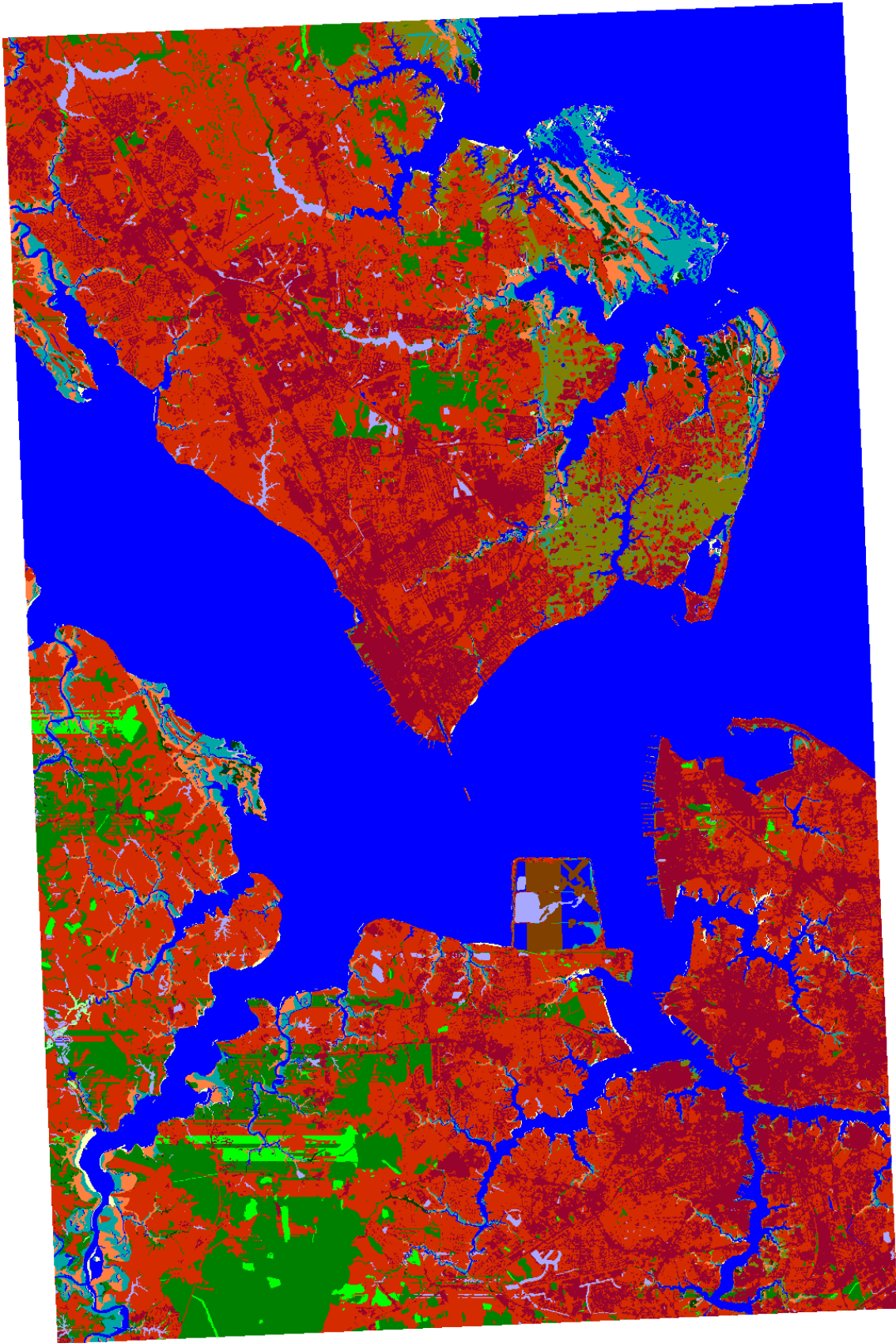
Nansemond NWR, Initial Condition



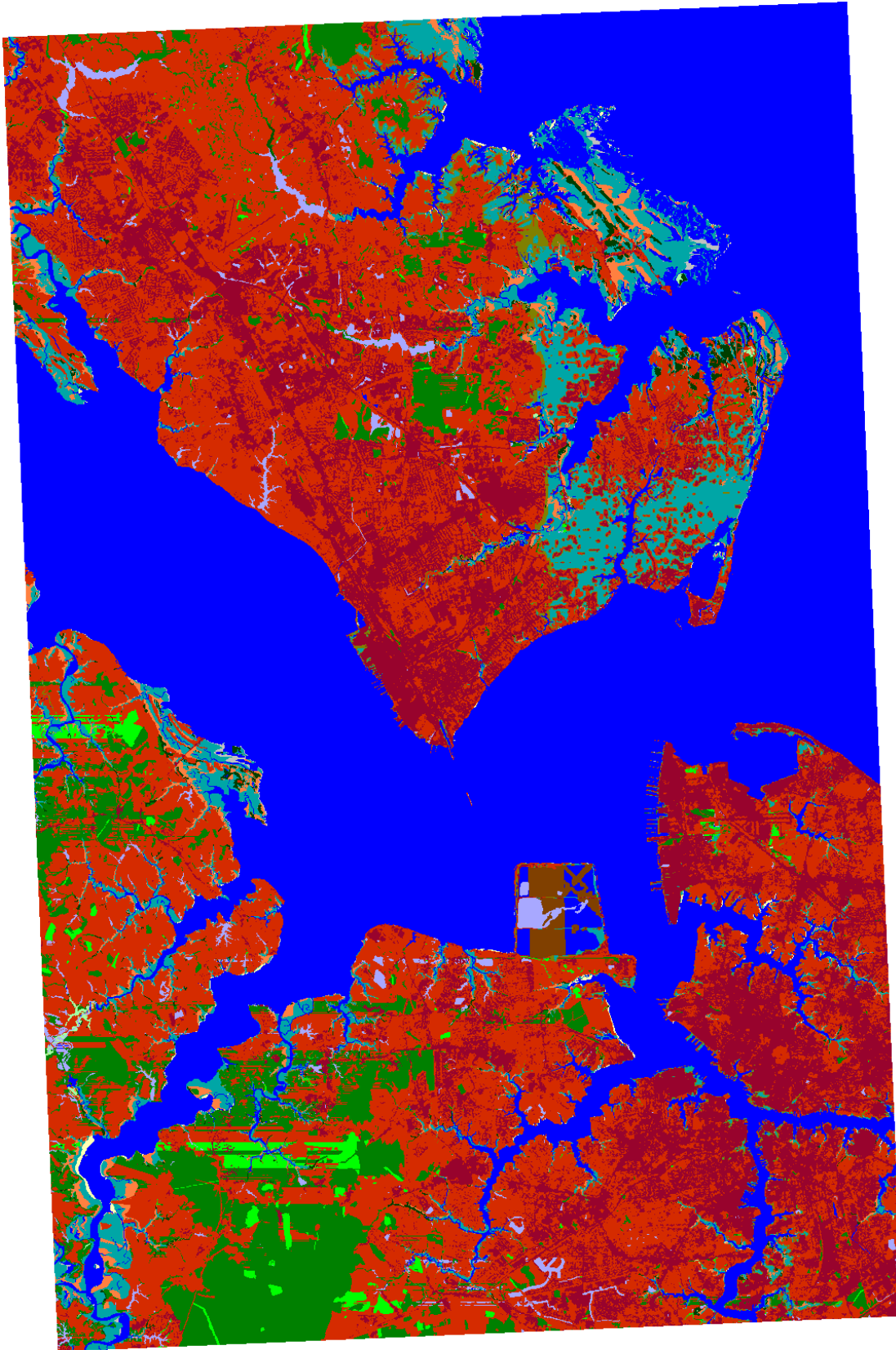
Nansemond NWR, 2025, Scenario A1B Mean



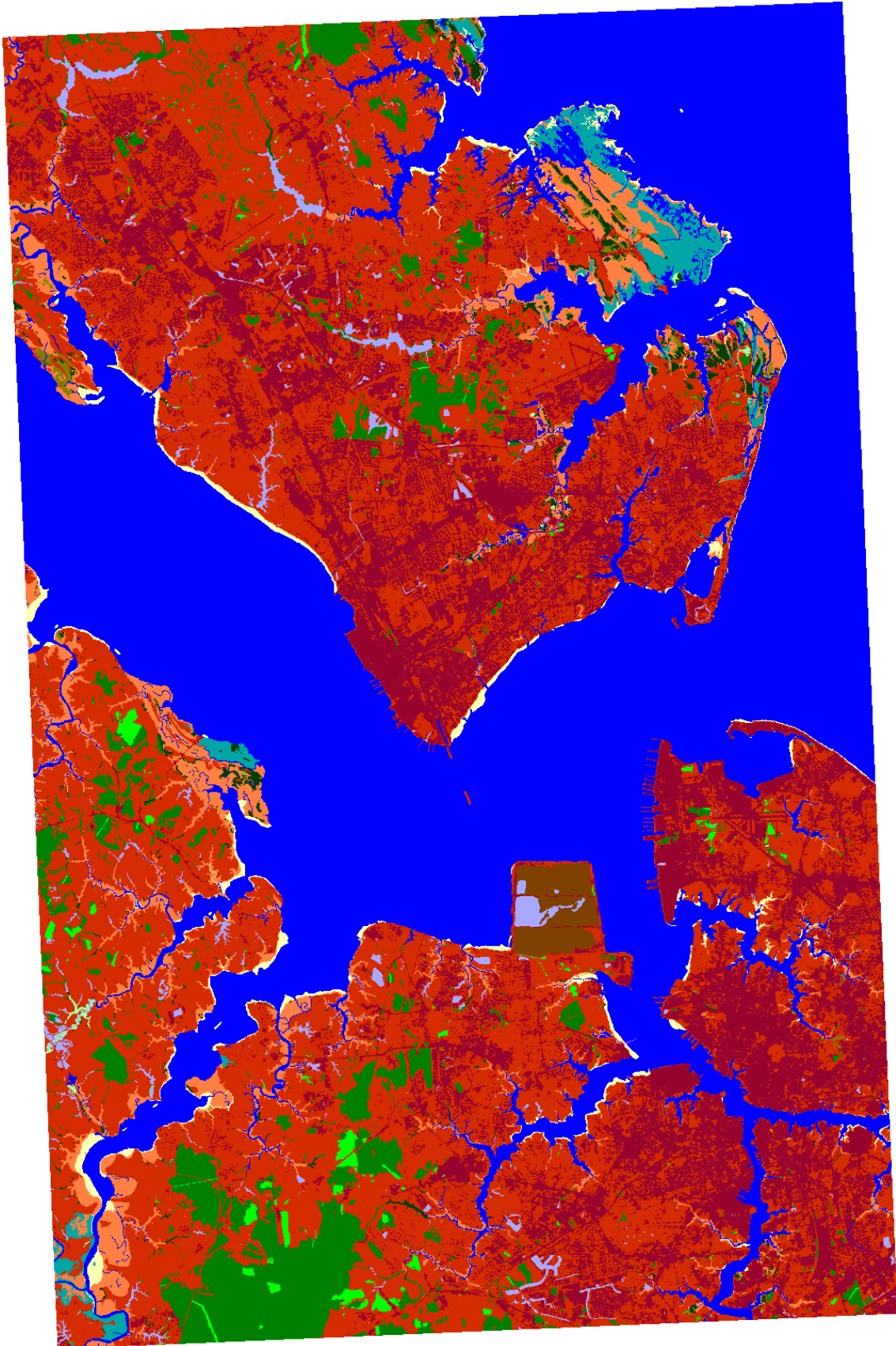
Nansemond NWR, 2050, Scenario A1B Mean



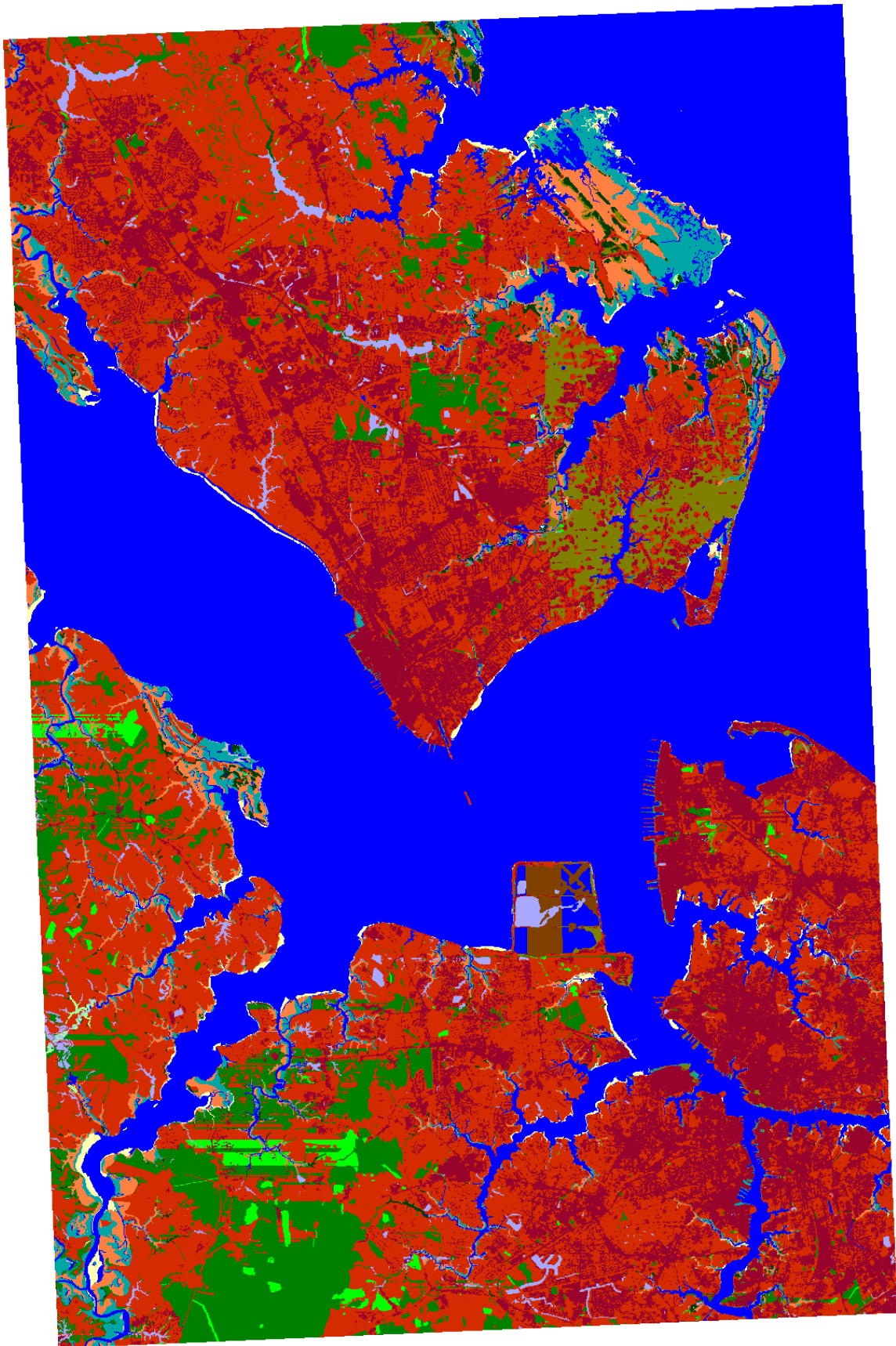
Nansemond NWR, 2075, Scenario A1B Mean



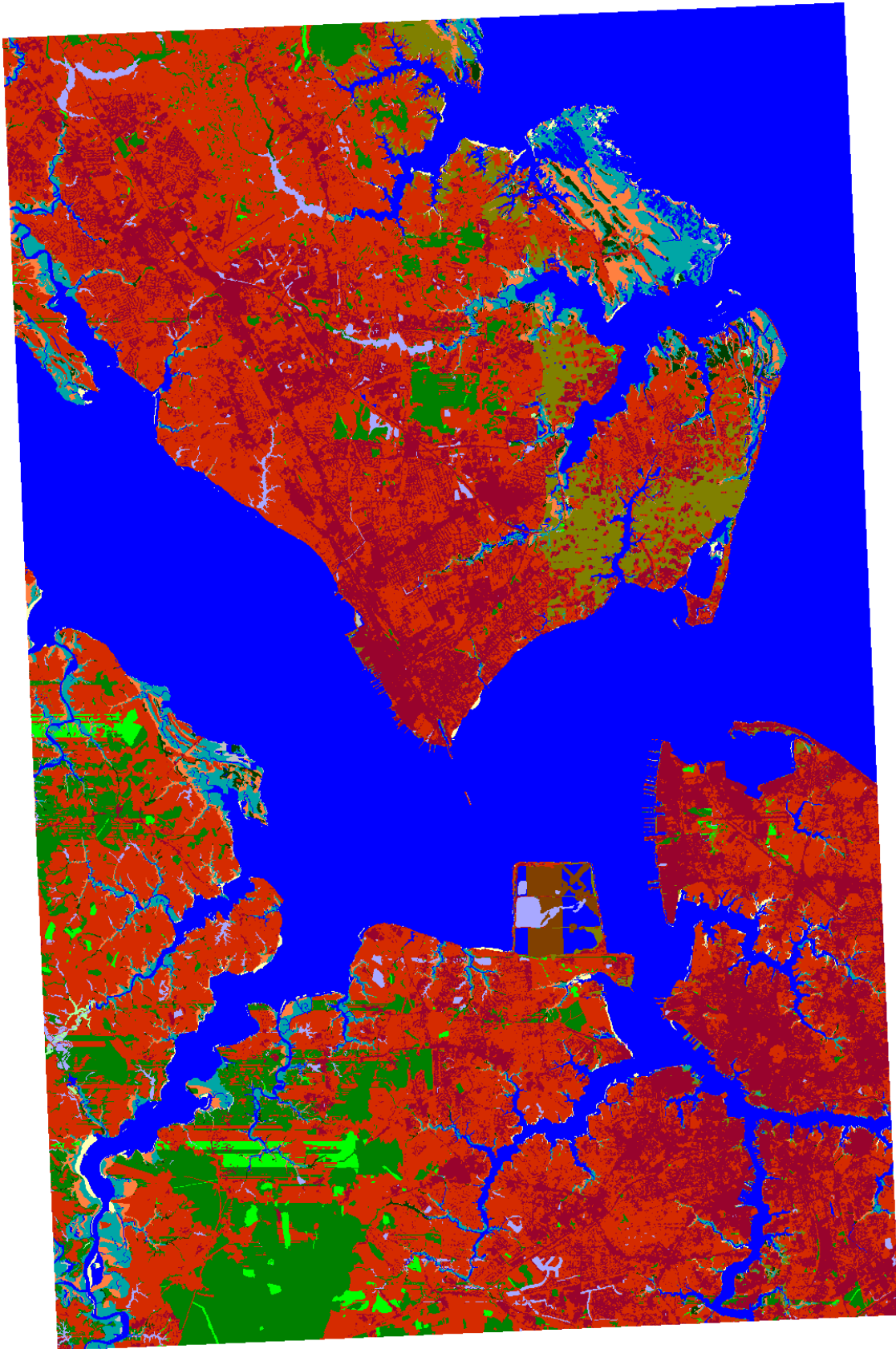
Nansemond NWR, 2100, Scenario A1B Mean



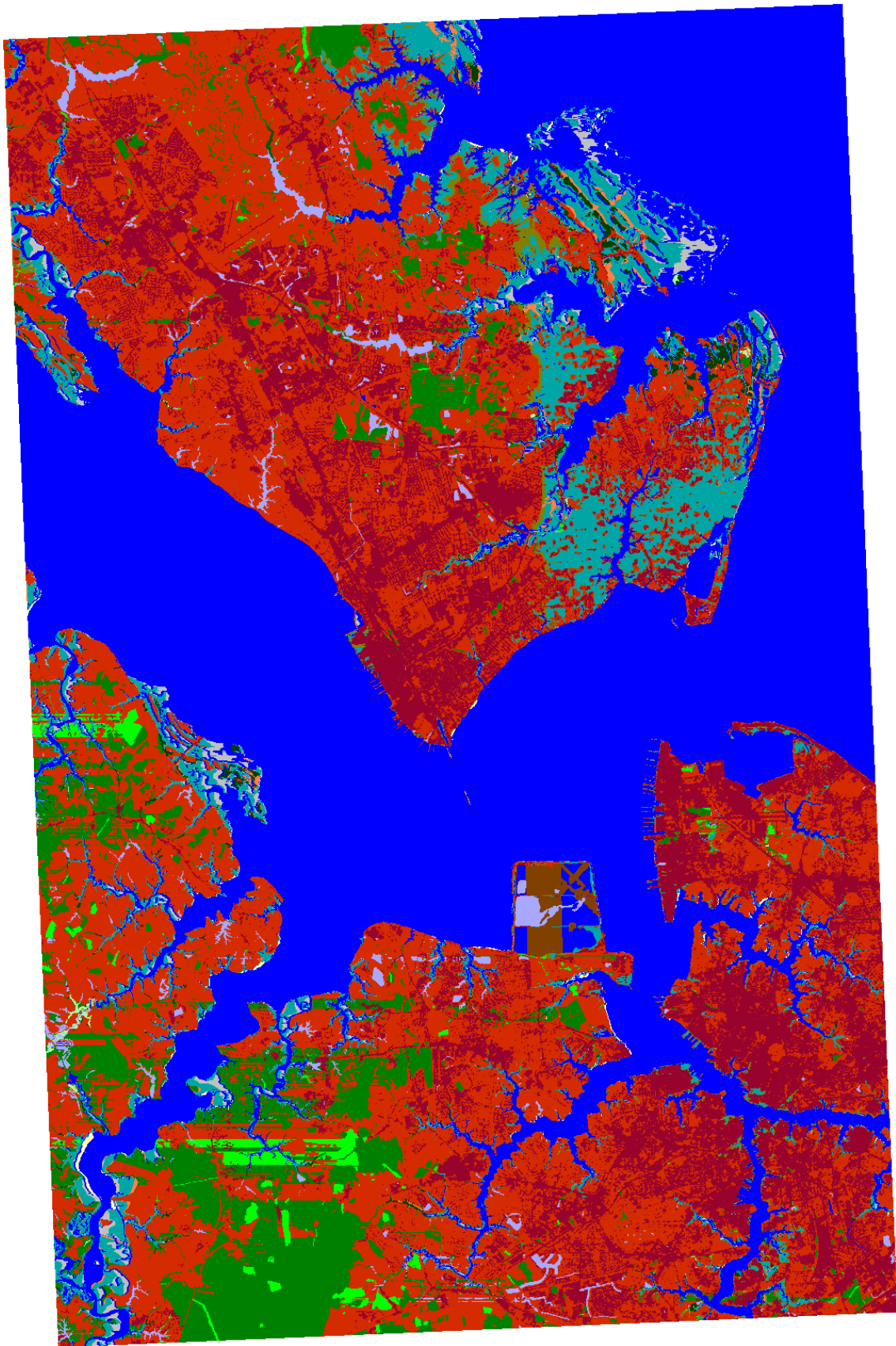
Nansemond NWR, Initial Condition



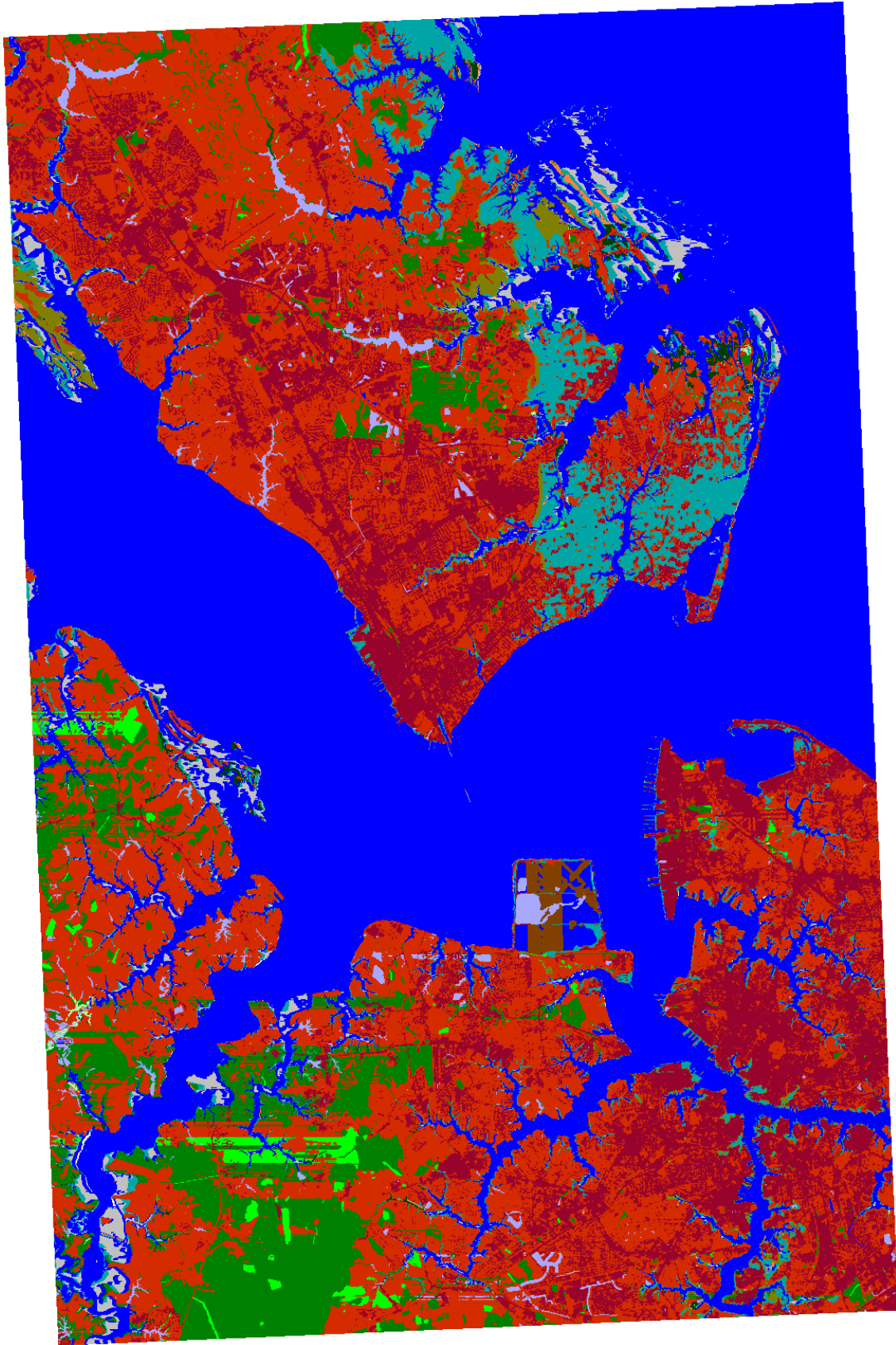
Nansemond NWR, 2025, Scenario A1B Maximum



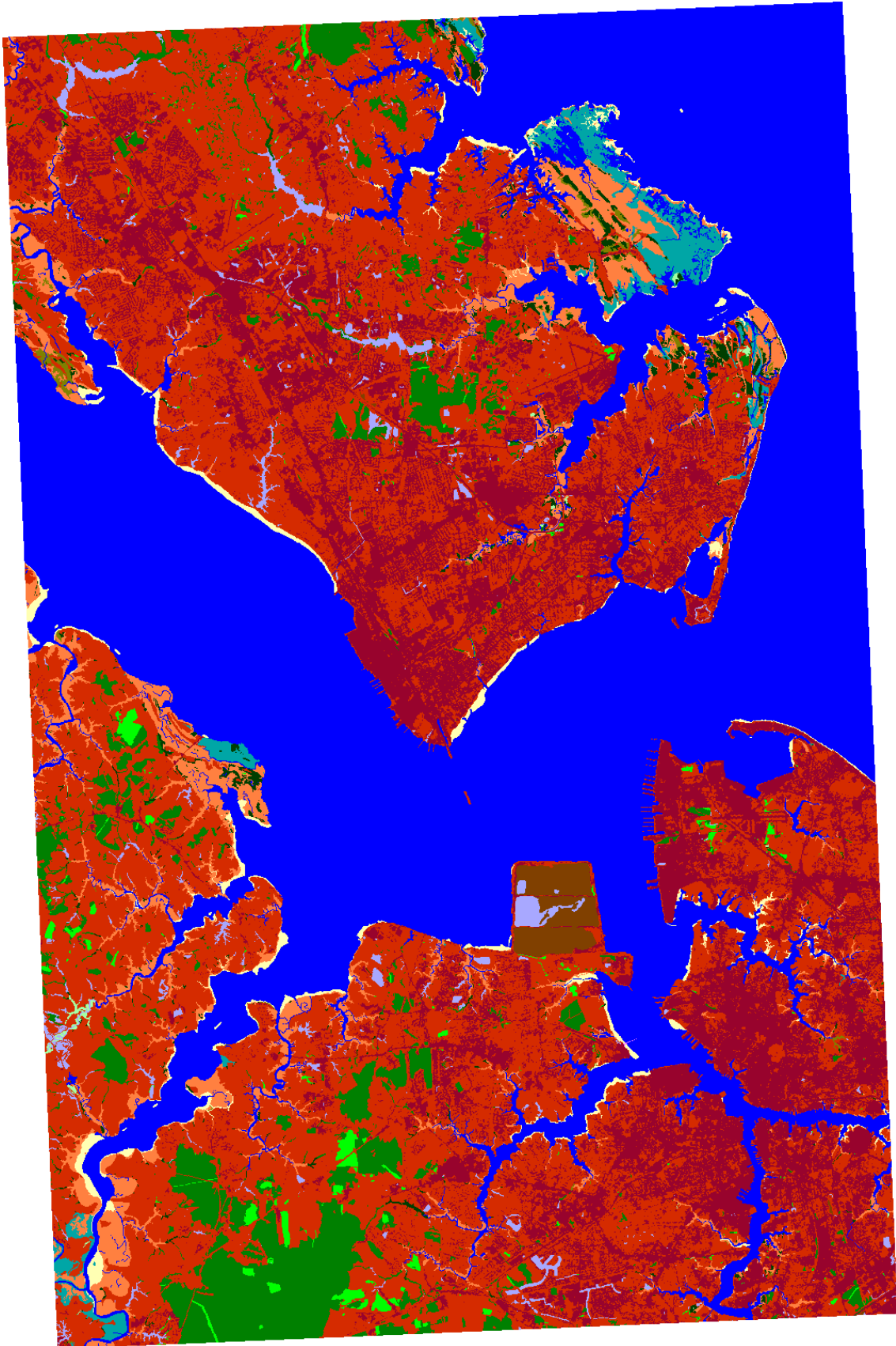
Nansemond NWR, 2050, Scenario A1B Maximum



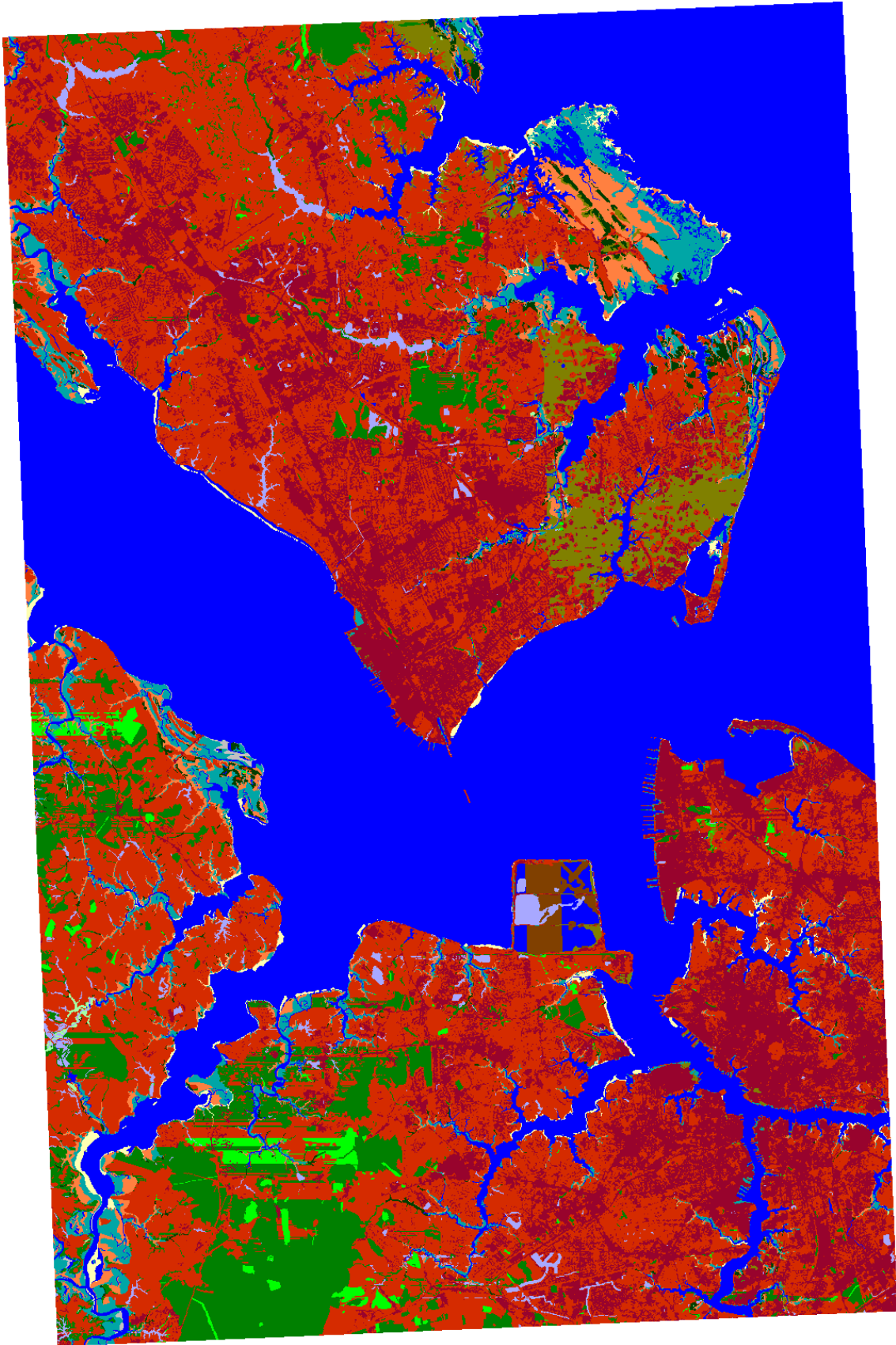
Nansemond NWR, 2075, Scenario A1B Maximum



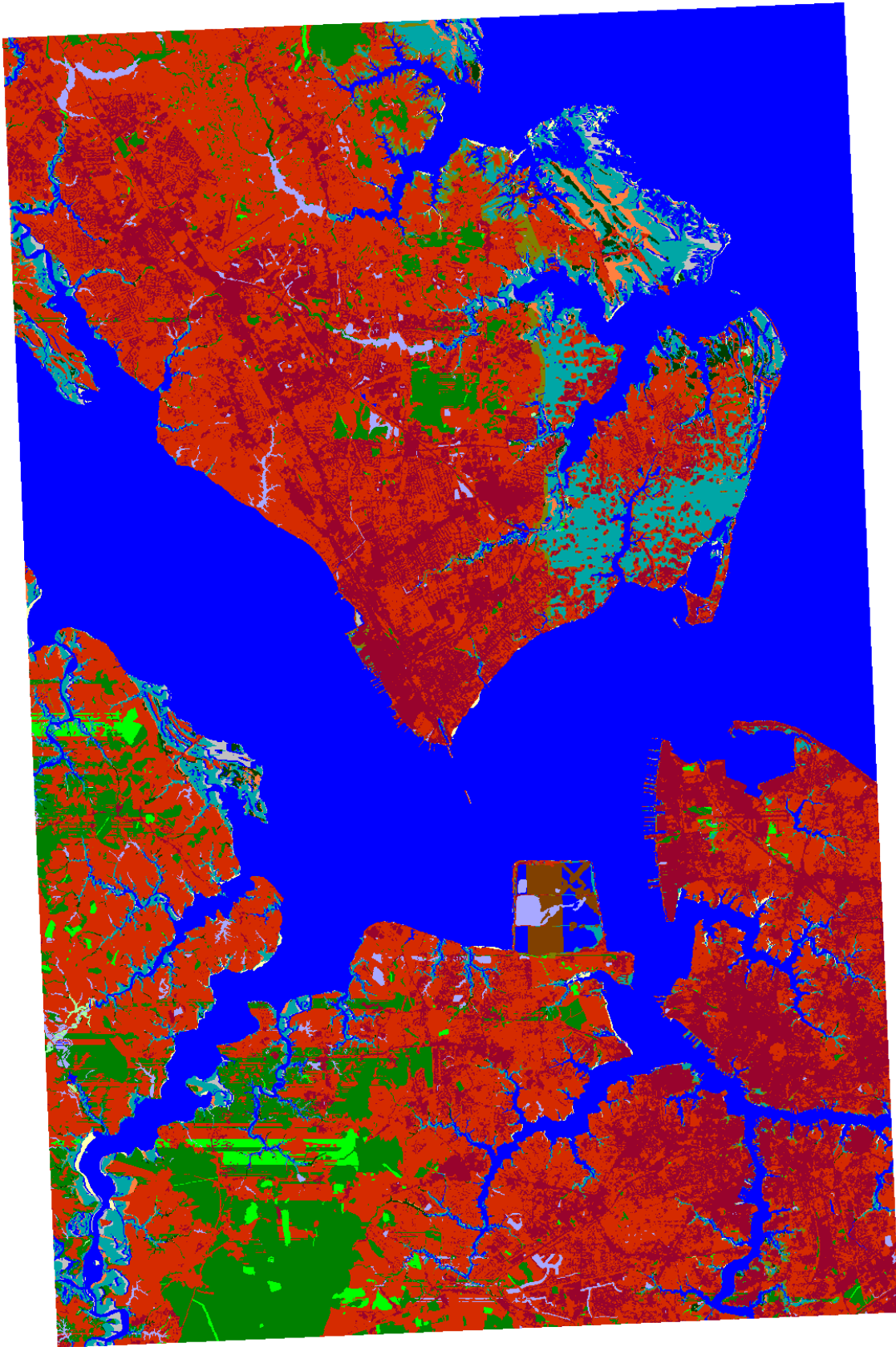
Nansemond NWR, 2100, Scenario A1B Maximum



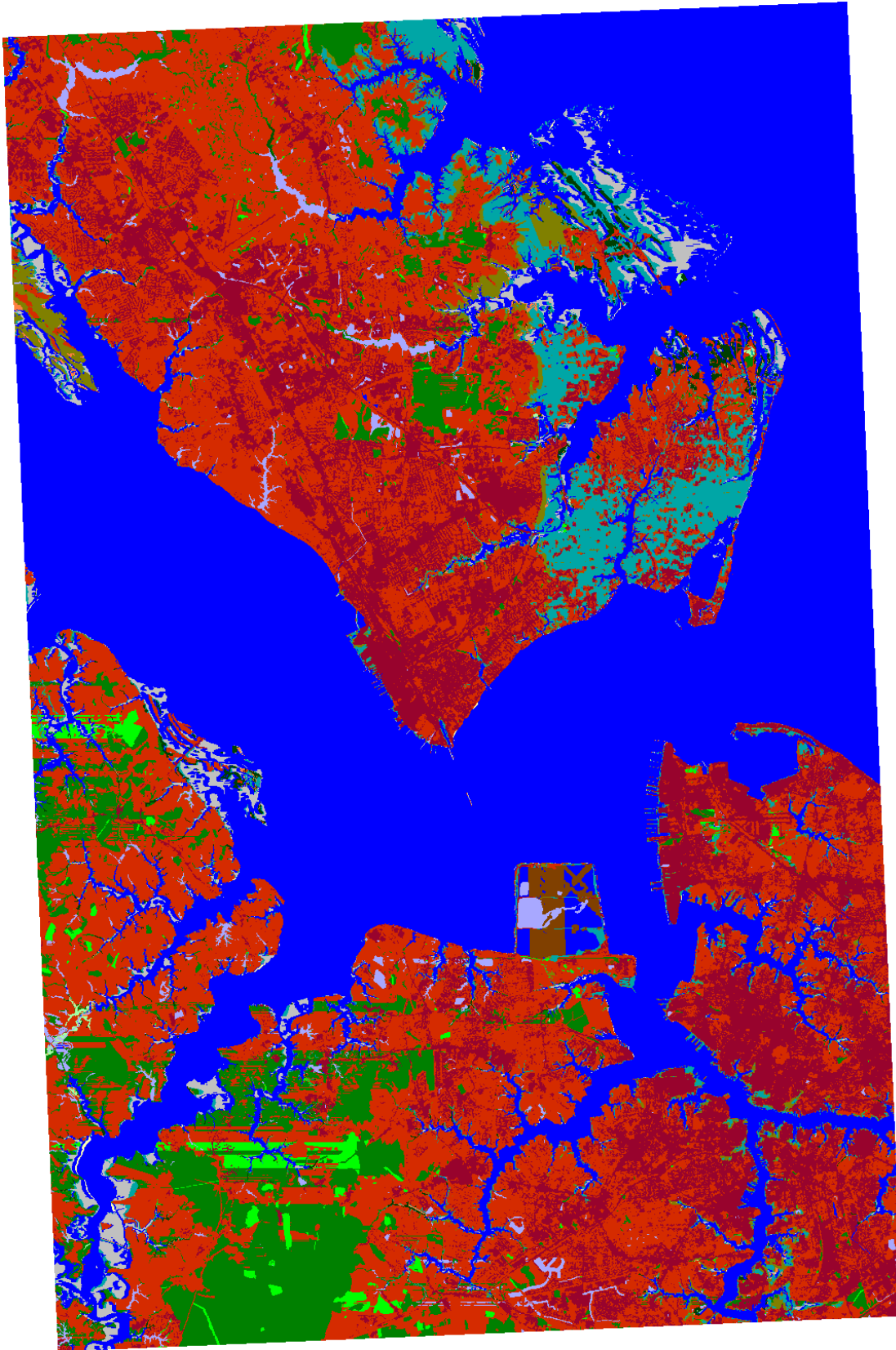
Nansemond NWR, Initial Condition



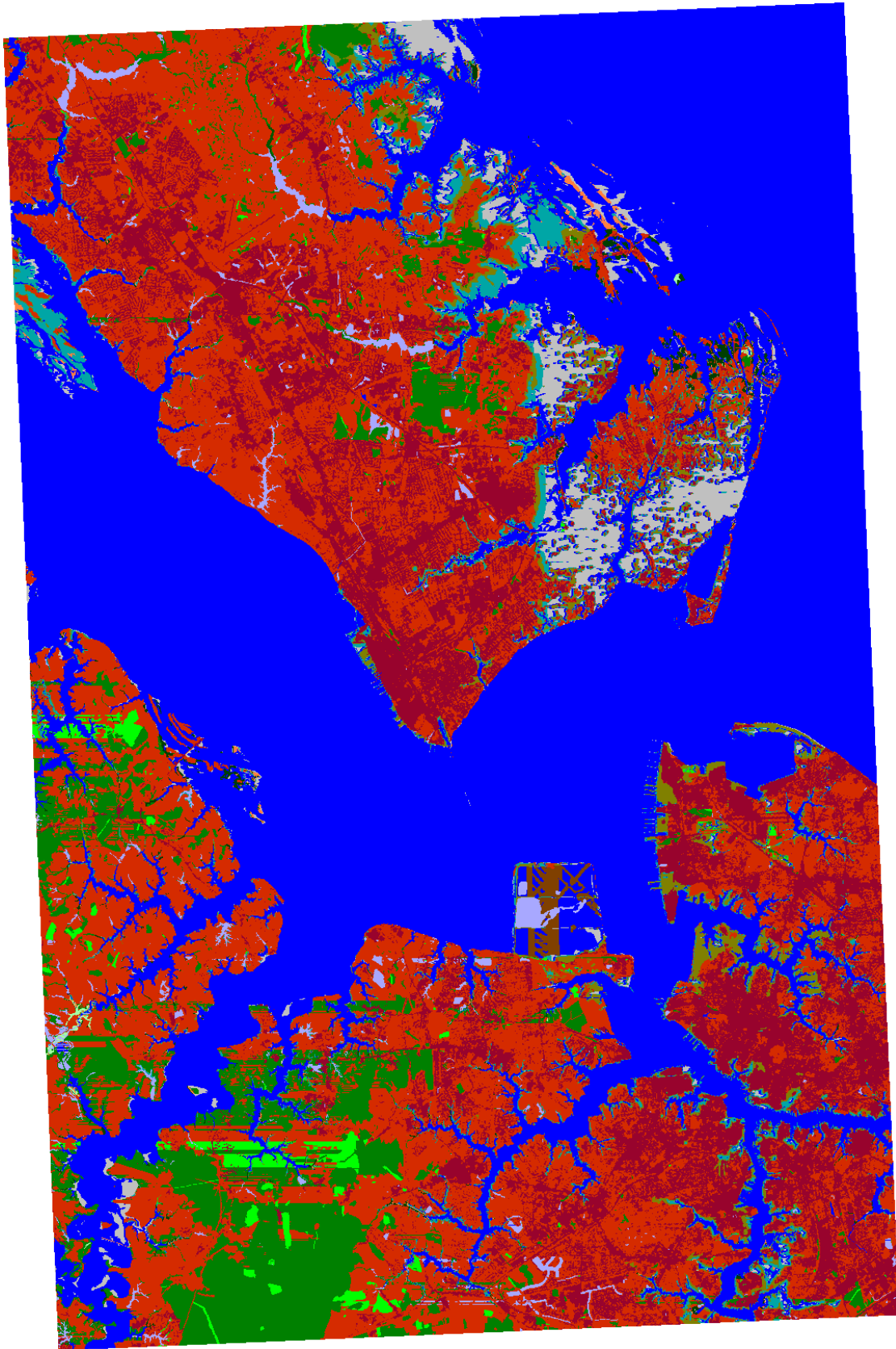
Nansemond NWR, 2025, 1 meter



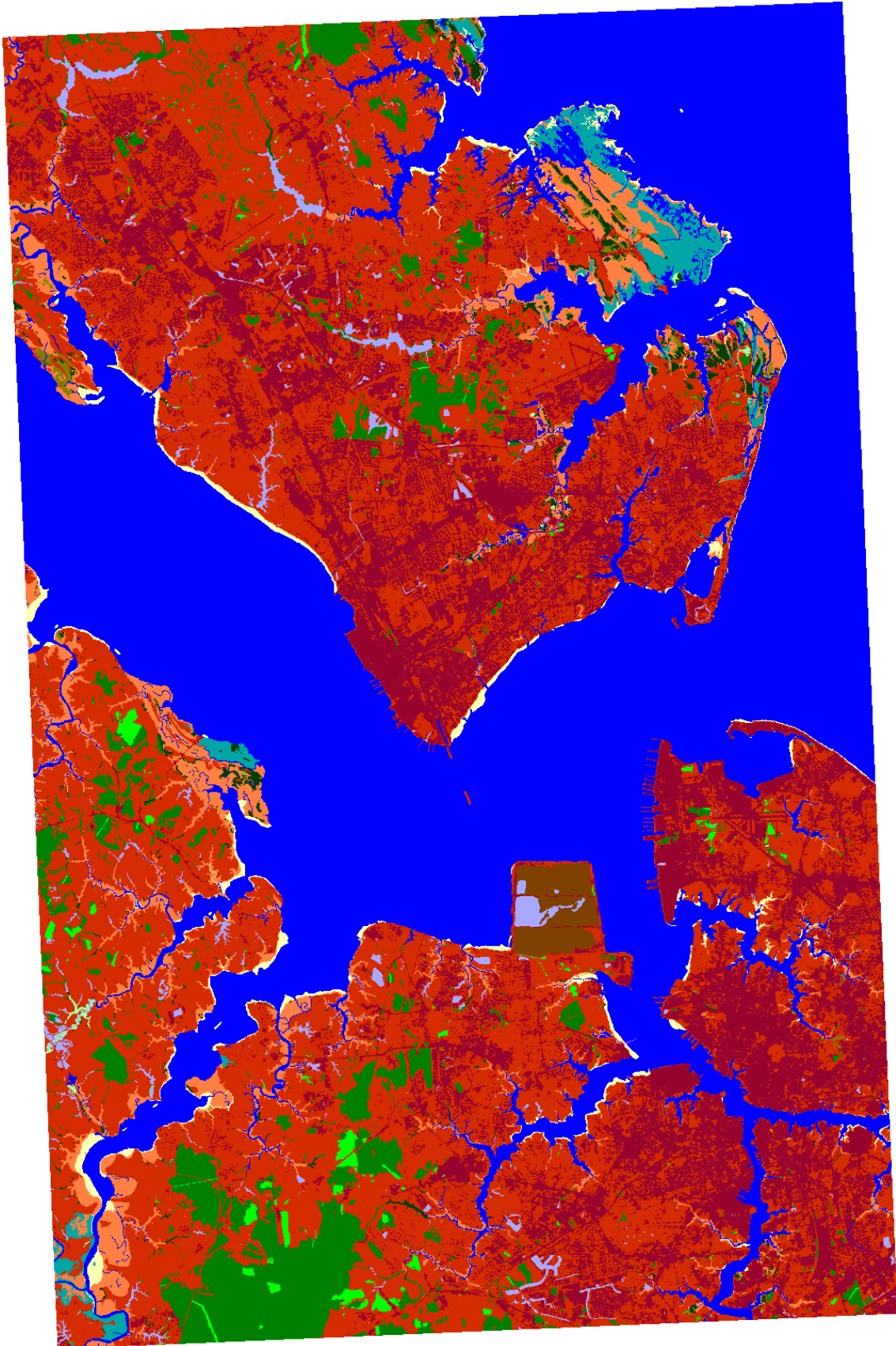
Nansemond NWR, 2050, 1 meter



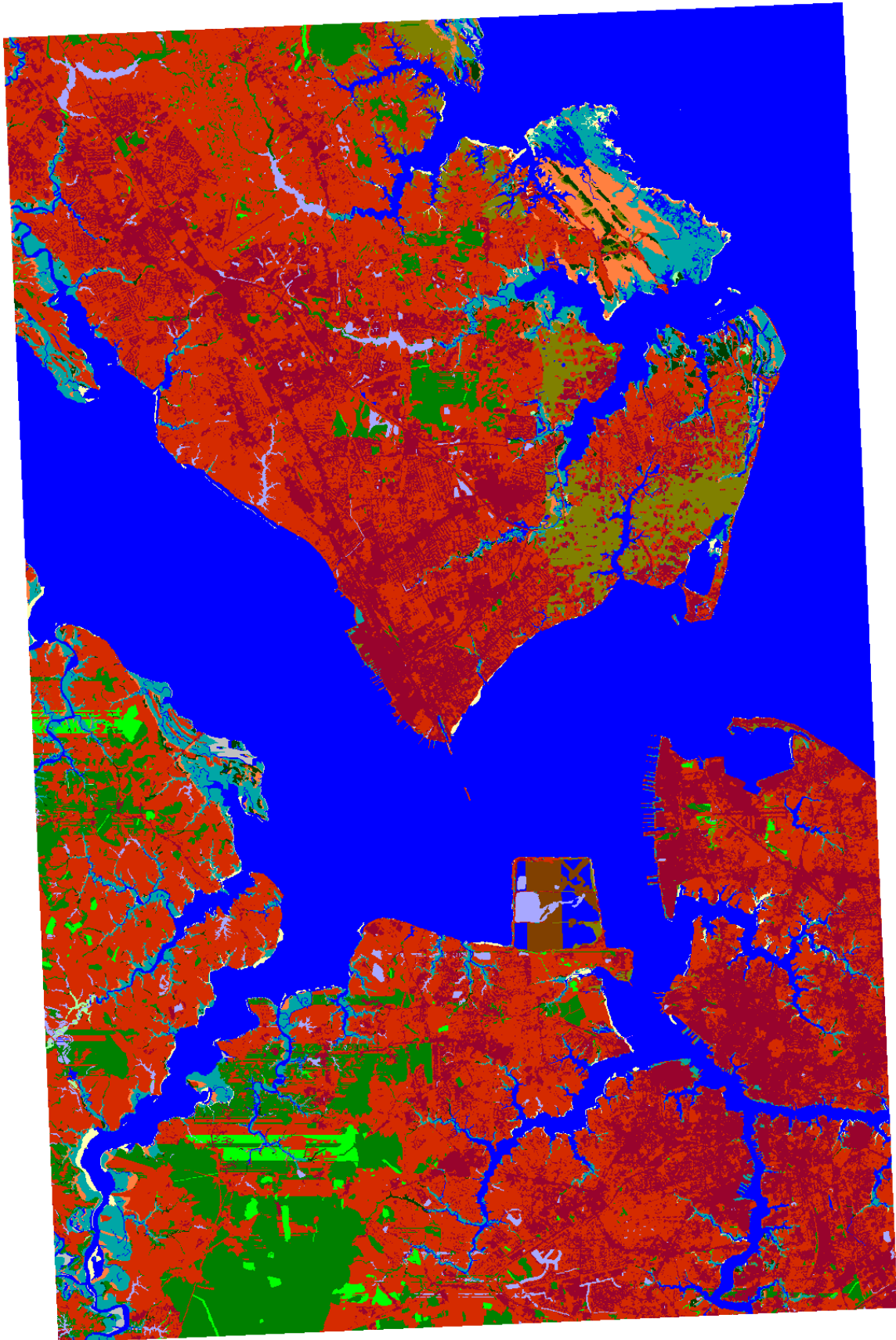
Nansemond NWR, 2075, 1 meter



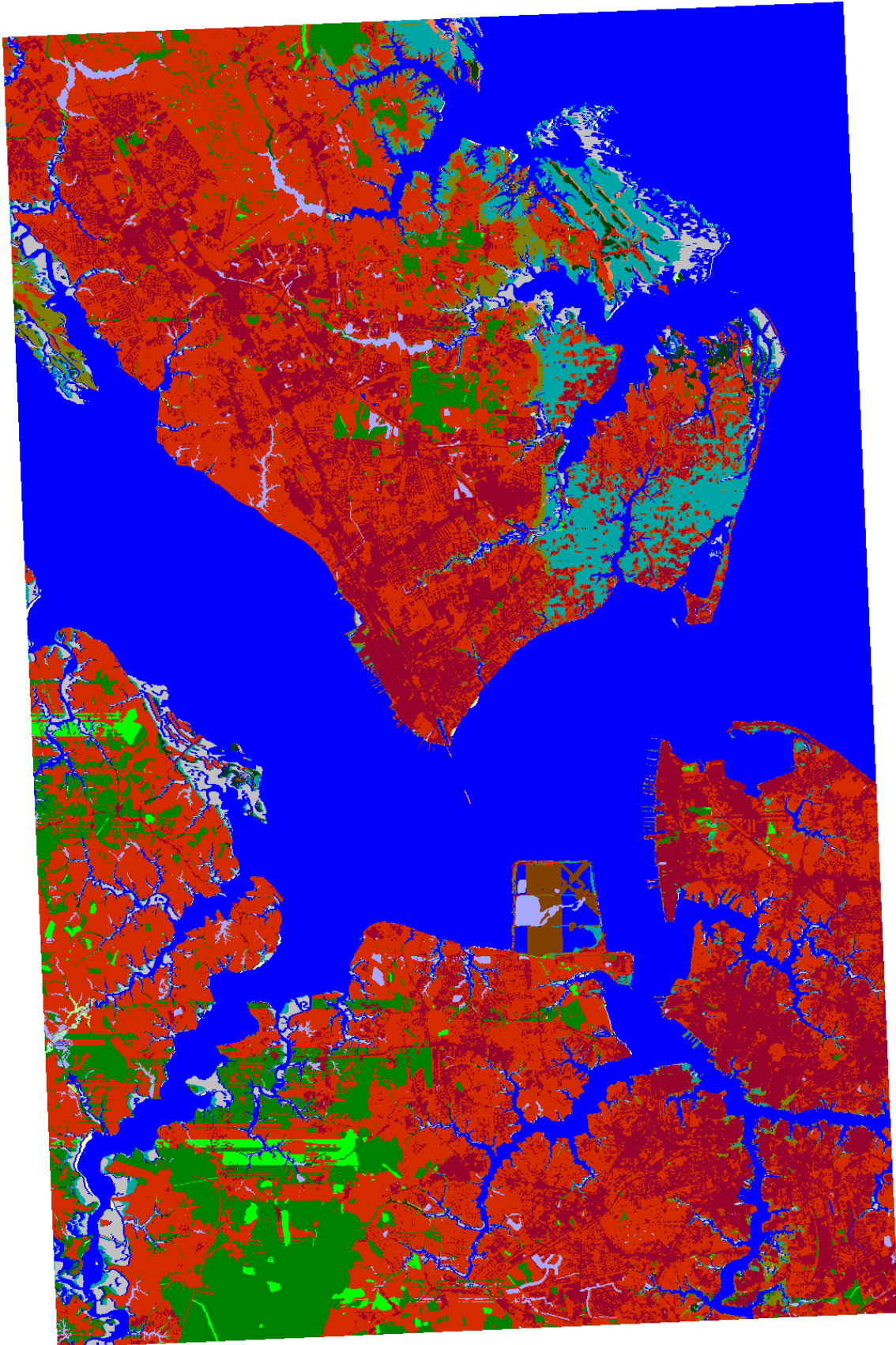
Nansemond NWR, 2100, 1 meter



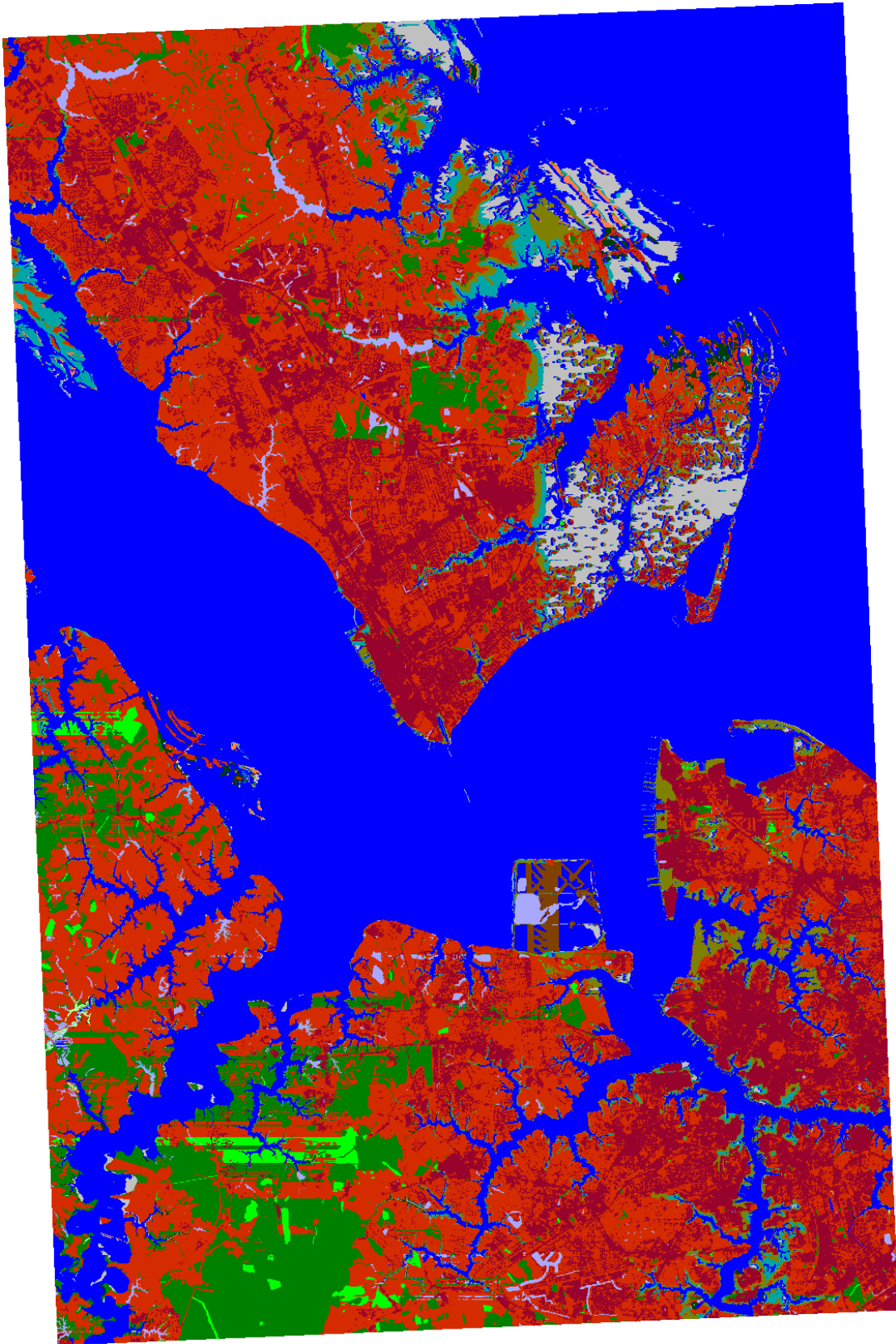
Nansemond NWR, Initial Condition



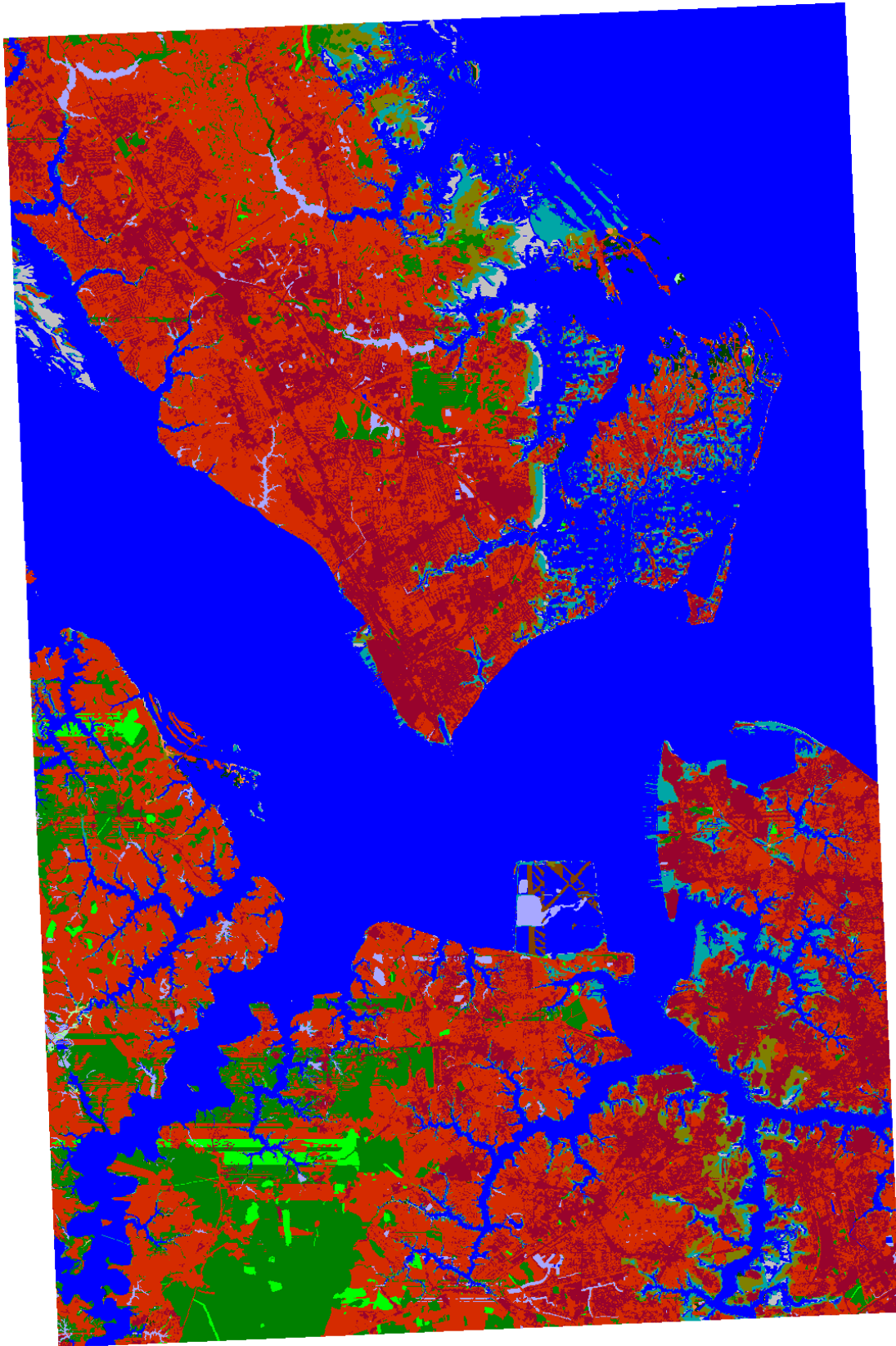
Nansemond NWR, 2025, 1.5 meter



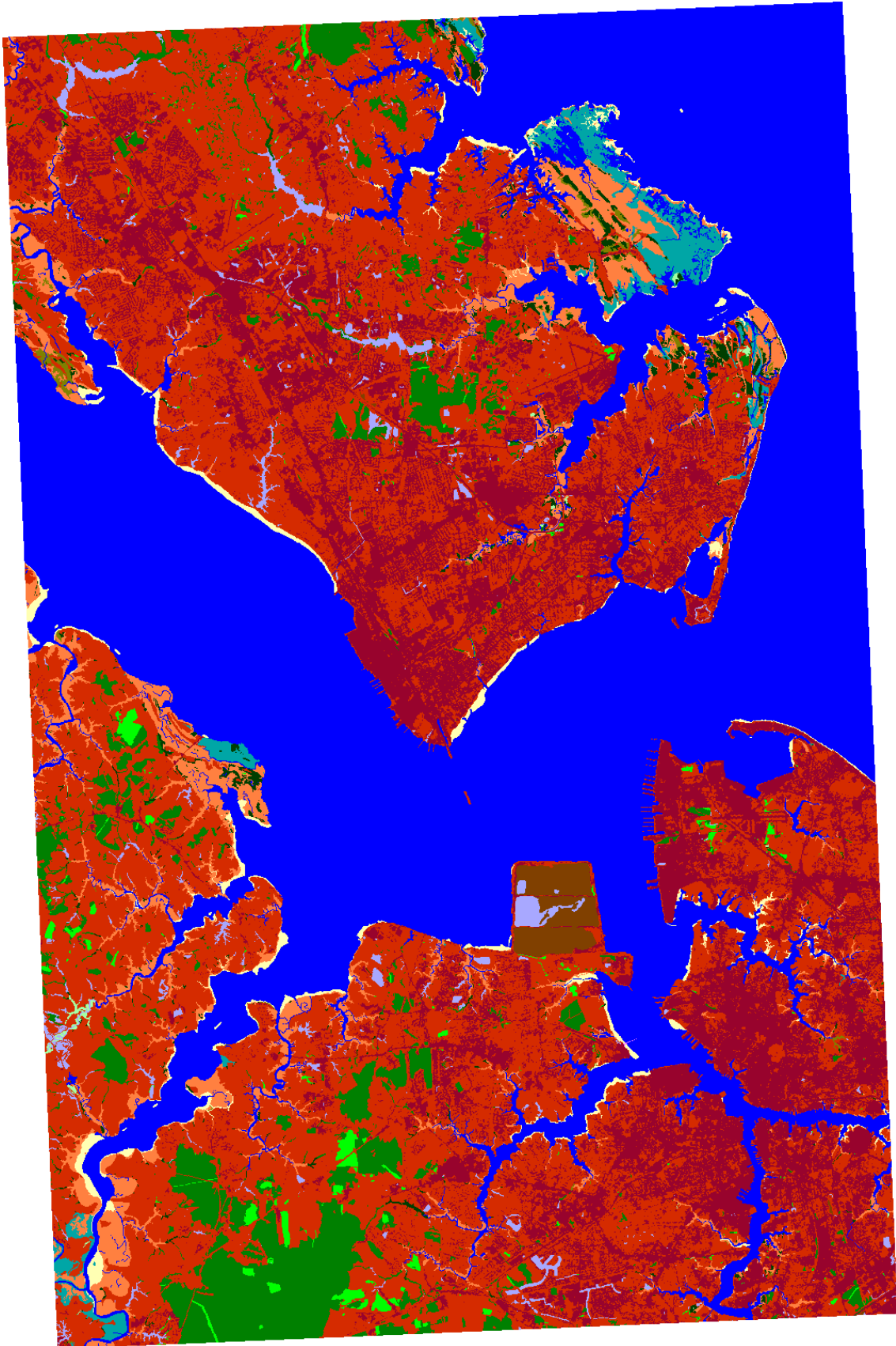
Nansemond NWR, 2050, 1.5 meter



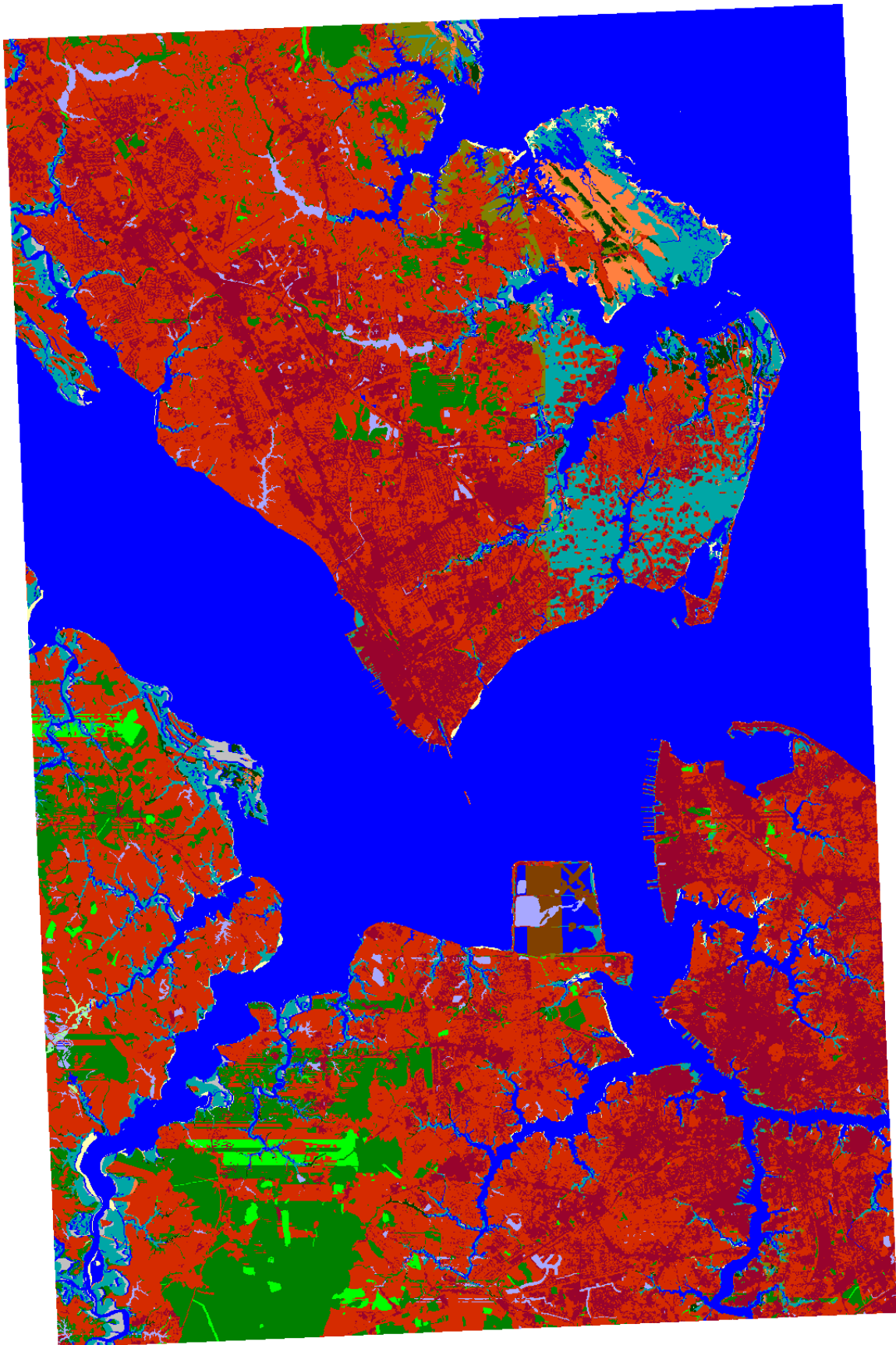
Nansemond NWR, 2075, 1.5 meter



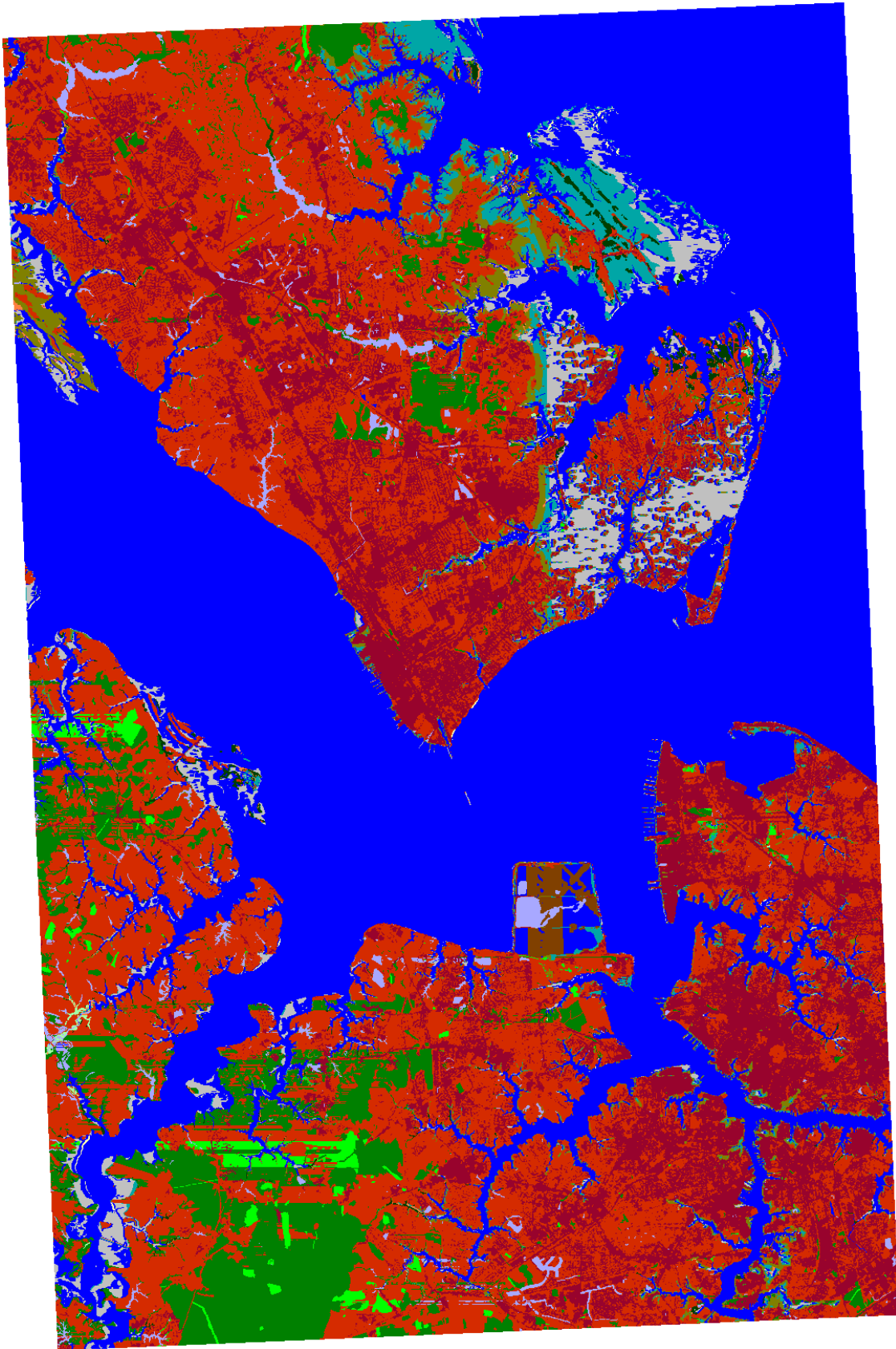
Nansemond NWR, 2100, 1.5 meter



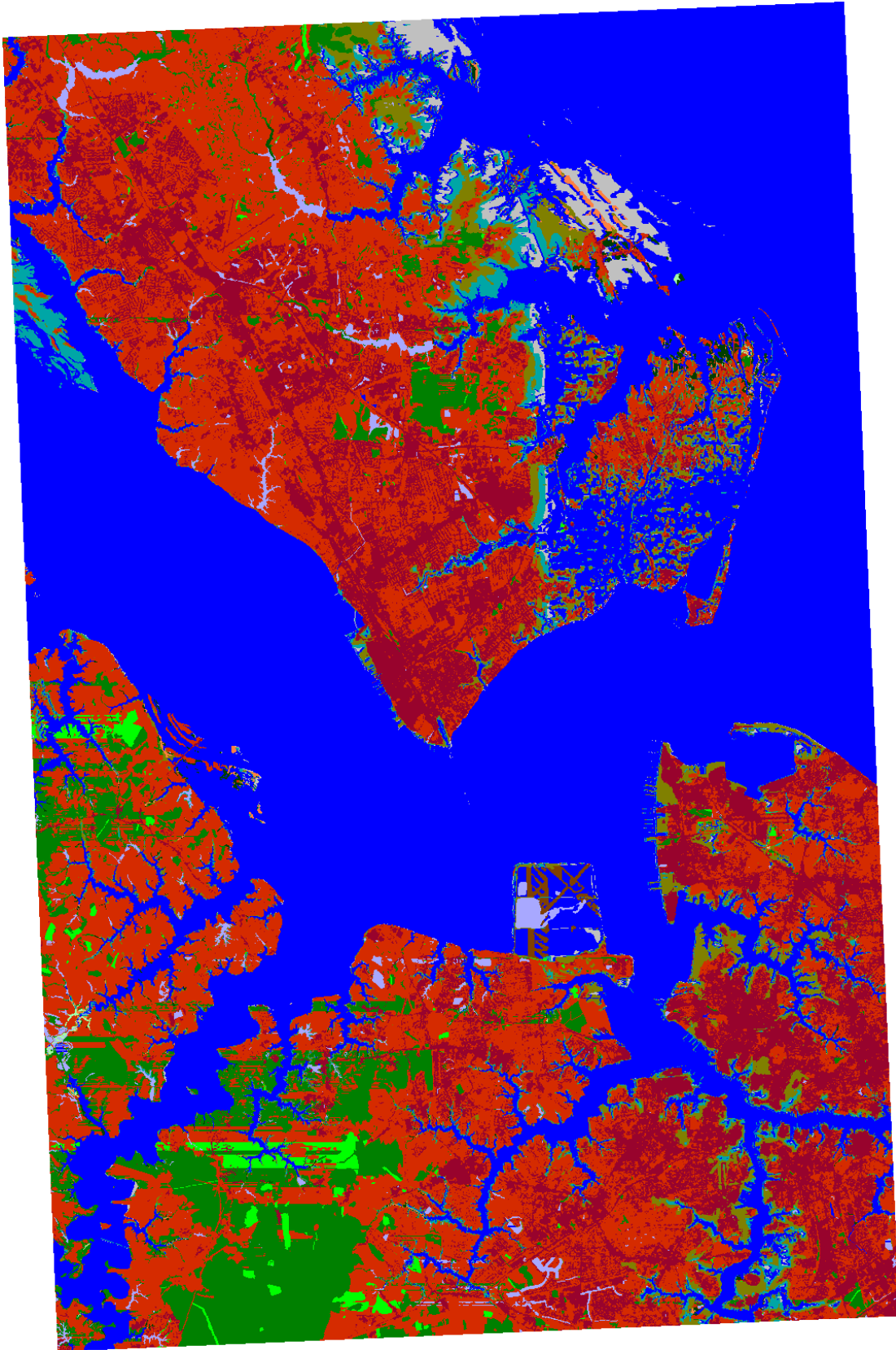
Nansemond NWR, Initial Condition



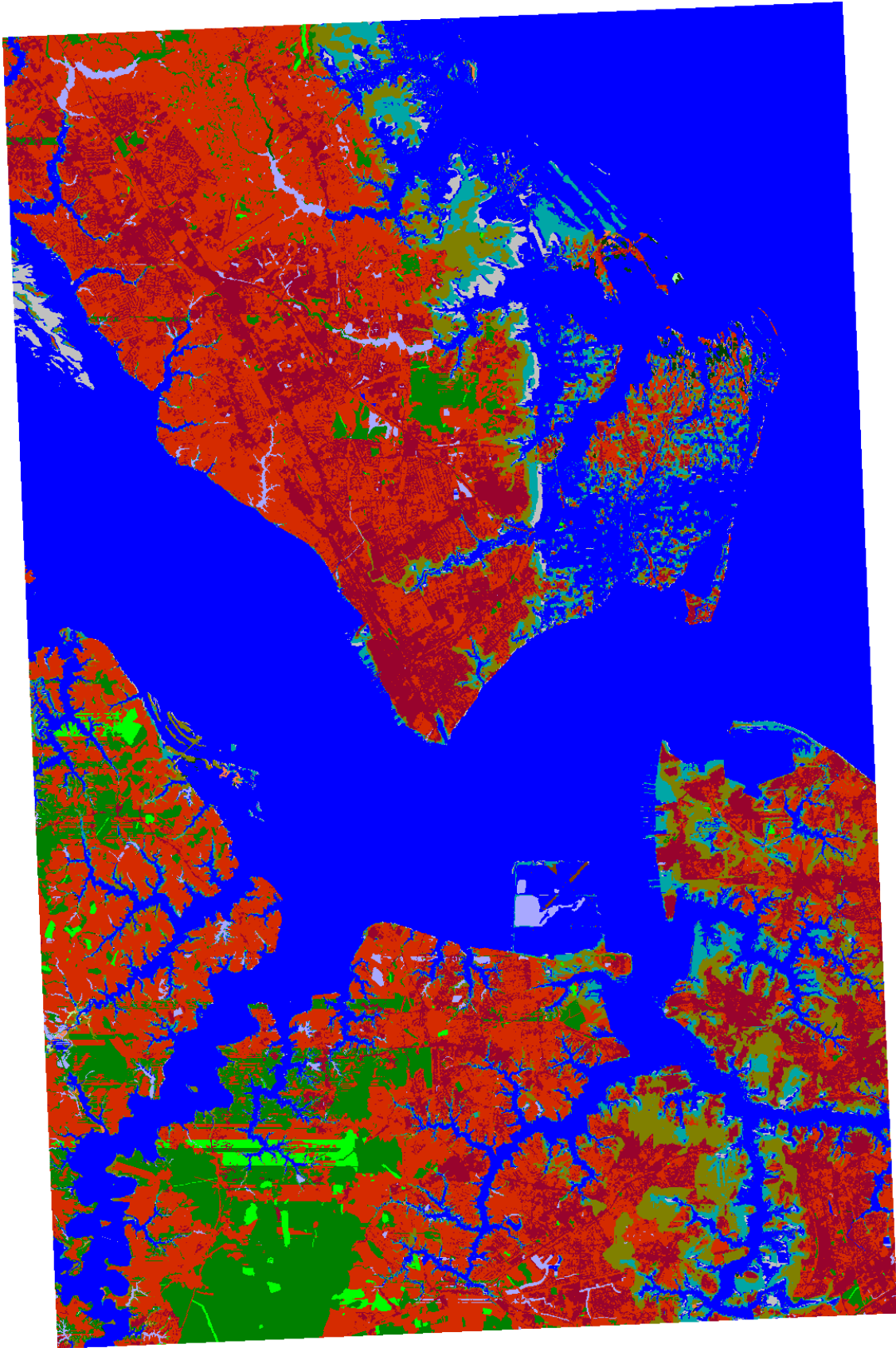
Nansemond NWR, 2025, 2 meter



Nansemond NWR, 2050, 2 meter



Nansemond NWR, 2075, 2 meter



Nansemond NWR, 2100, 2 meter