# Application of the Sea-Level Affecting Marshes Model (SLAMM 5.1) to Supawna Meadows 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 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. 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 was developed in 2006 and2007 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).

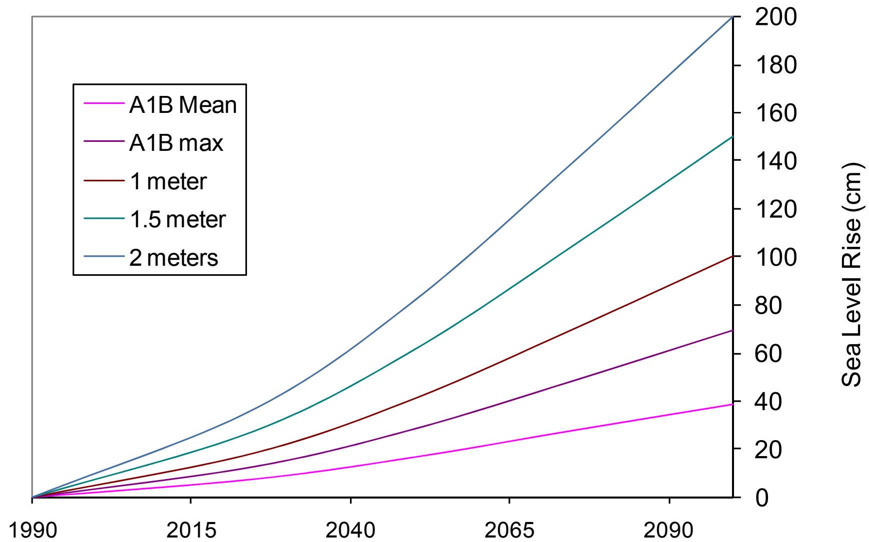
## Sea Level Rise Scenarios

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 (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. 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 a 2007 LiDAR coverage produced by the USGS and New Jersey Department of Environmental Protection (Figure 1). The LiDAR DEM was provided to us exclusively within the NWR boundaries, with contextual results based on 10 foot contour USGS topographical DEMs.

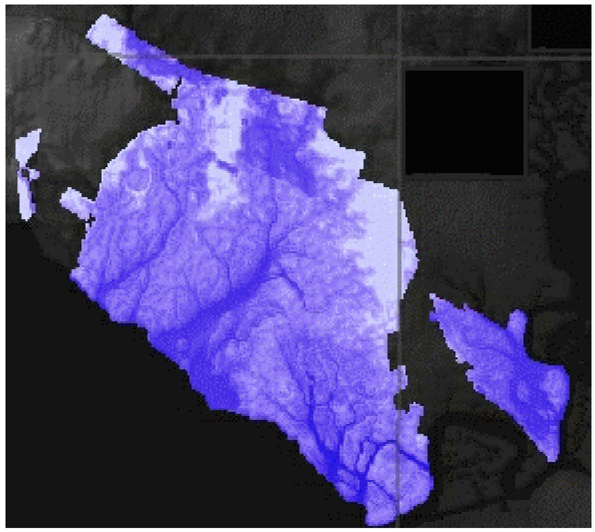


**Figure 1**: LiDAR coverage map (blue) of Supawna Meadows NWR.

The diurnal range of tide (GT) for the Supawna Meadows NWR was estimated at 1.78 m based on two NOAA gages (8551910, Reedy Point, DE; 8551762, Delaware City, DE) (). These gages were in close agreement measuring ranges of 1.779 meters and 1.786 meters.

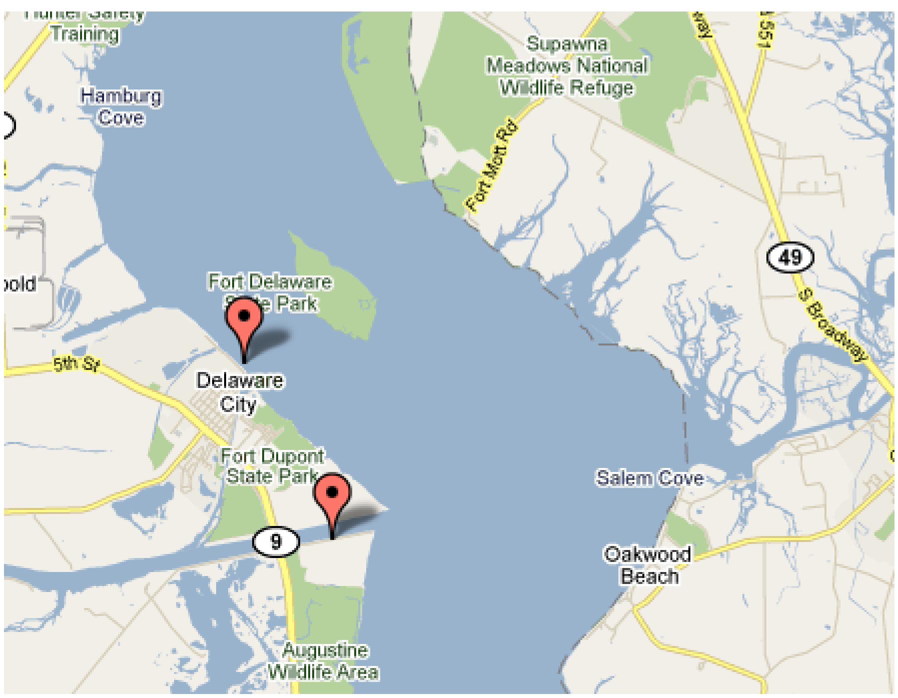



**Figure 2**: NOAA Gage Relevant to the Study Area.

The historic trend for sea level rise was estimated 3.46 mm/year using the nearest NOAA gage (Reedy Point, Delaware, 8551910). The estimated rate of sea level rise for this refuge is roughly 1.7 mm/year greater than the global average for the last 100 years (approximately 1.7 mm/year). This difference in relative sea level rise is maintained throughout all model projections.

The National Wetlands Inventory for Supawna Meadows is based on photo dates of 1999. Comparing this polygon coverage to current satellite photos, there appears to be a slight but pervasive shift throughout the NWI coverage of around 30 meters due to either horizontal uncertainty or shoreline change (Figure 3).


**Figure 3:** NWI layer over current satellite imagery.

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

| | |
|---|---|
| Irreg. Flooded Marsh | 46.4% |
| Dry Land | 22.2% |
| Estuarine Open Water | 15.5% |
| Tidal Swamp | 10.7% |
| Tidal Fresh Marsh | 1.5% |
| Inland Open Water | 1.2% |

There are several diked or impounded wetlands in the Supawna Meadows NWR according to the National Wetlands Inventory classifications.

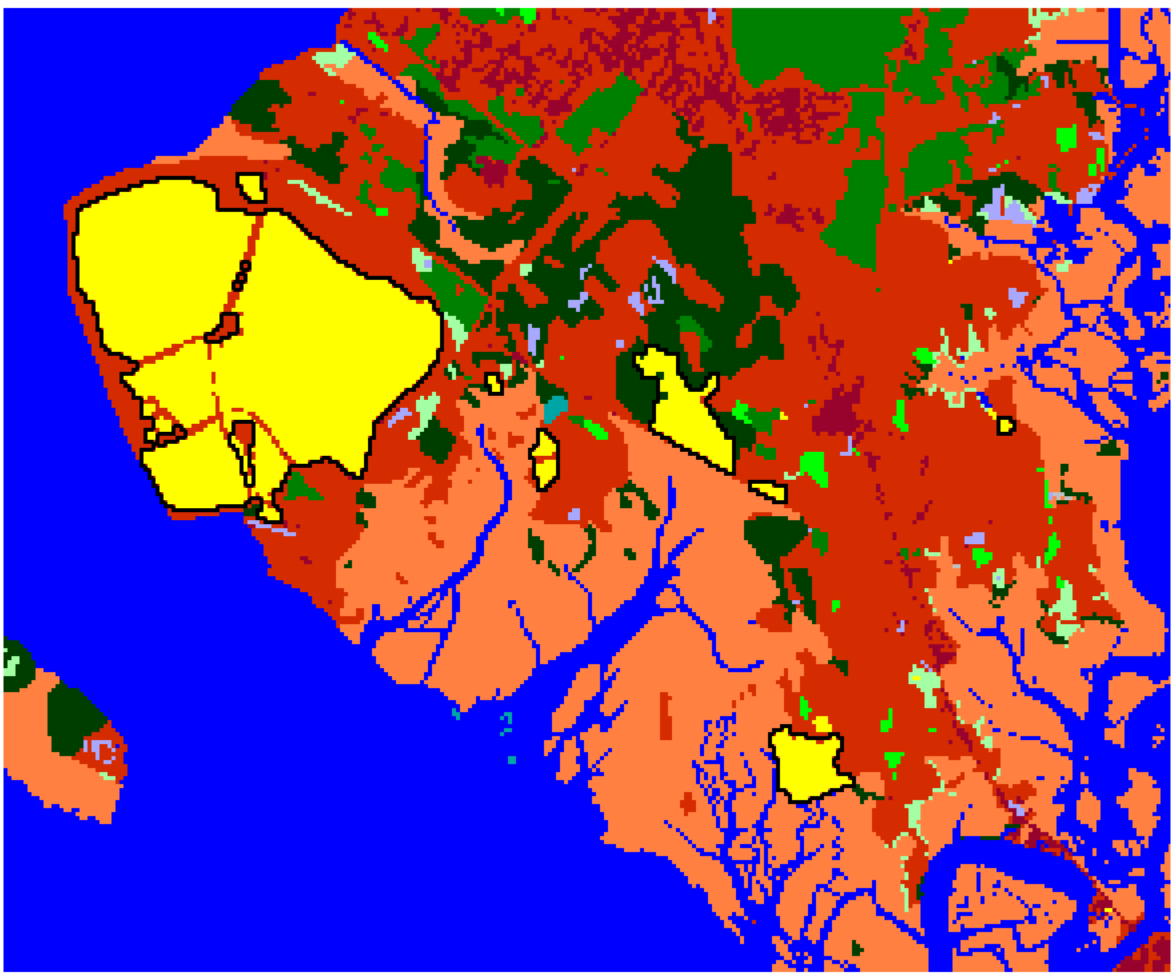


**Figure 4:** Diked areas in yellow, bordered by black.

No site-specific marsh accretion data were located for this refuge. The marsh accretion values used were based on a rough average of three different calculations:

- The marsh accretion study located nearest to this study area (Port Mahon DE, Kraft, 1992) measured accretion rates as 4.05 mm/year;
- Based on a large analysis of accretion studies within the mid-Atlantic region (Reed 2008), the average Delaware salt marsh accretion value was calculated at 3.88 mm/yr (n=9);
- Based on data in this same paper (Reed 2008), the average Delaware *estuary* accretion value was calculated at 4.28 mm/yr (n=15)

As these three different estimates are quite similar, accretion rates in regularly flooded marshes were set to 4 mm/year, irregularly flooded marshes to 4 mm/year and tidal fresh were also set to 4 mm/year.

The MTL to NAVD88 correction was derived using the NOAA VDATUM modeling product. The correction was estimated at -0.036 meters which closely matches data available at a nearby NOAA gage (8551910, Reedy Point).

Modeled U.S. Fish and Wildlife Service refuge boundaries for New Jersey 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.

Heidi Hanlon of Supawna Meadows National Wildlife Refuge located the LiDAR DEM that was utilized in simulation modeling.

Marsh erosion rates for this refuge were set to 2 horizontal meters per year based on long-term measurements of coastal erosion rates in Delaware as presented in Kraft 1992.

Based on site-specific LiDAR elevation data (and also LiDAR elevation data from other sites) the allowed elevation ranges for tidal swamp and tidal fresh marsh were altered slightly. The SLAMM 5 conceptual model has traditionally assumed that these categories are all located above the salt boundary due to their "fresh" designation. Recent experience with the model in several sites with LiDAR data indicates that the presence of fresh water allows these categories to extend well below mean high higher water. Based on the LiDAR at this location, the minimum elevation for tidal swamp was set to 0.32 and the minimum elevation for tidal fresh marsh was set to 0.42 half-tide units. (One half-tide unit is half of the diurnal range of tide or ½ GT.)

## SUMMARY OF SLAMM INPUT PARAMETERS FOR SUPAWNA NWR

| Parameter | Global | SubSite 1 | SubSite 2 | SubSite 3 |
|---|---|---|---|---|
| Description | NJ | Supawna Meadows | Supawna North | Supawna West |
| NWI Photo Date (YYYY) | 1995 | 1999 | 1999 | 1999 |
| DEM Date (YYYY) | 1989 | 2008 | 2008 | 2008 |
| Direction Offshore [n,s,e,w] | East | South | North | West |
| Historic Trend (mm/yr) | 3 | 3.46 | 3.46 | 3.46 |
| MTL-NAVD88 (m) | 0 | -0.036 | -0.036 | -0.036 |
| GT Great Diurnal Tide Range (m) | 1.65 | 1.78 | 1.78 | 1.78 |
| Salt Elev. (m above MTL) | 1.45 | 1.84 | 1.84 | 1.84 |
| Marsh Erosion (horz. M /yr) | 2 | 2 | 2 | 2 |
| Swamp Erosion (horz. M /yr) | 2 | 2 | 2 | 2 |
| T.Flat Erosion (horz. M /yr) | 2 | 2 | 2 | 2 |
| Reg. Flood Marsh Accr (mm/yr) | 4 | 4 | 4 | 4 |
| Irreg. Flood Marsh Accr (mm/yr) | 4 | 4 | 4 | 4 |
| Tidal Fresh Marsh Accr (mm/yr) | 4 | 4 | 4 | 4 |
| Beach Sed. Rate (mm/yr) | 0.5 | 0.5 | 0.5 | 0.5 |
| Freq. Overwash (years) | 25 | 25 | 25 | 25 |
| Use Elev Pre-processor [True,False] | TRUE | FALSE | FALSE | FALSE |

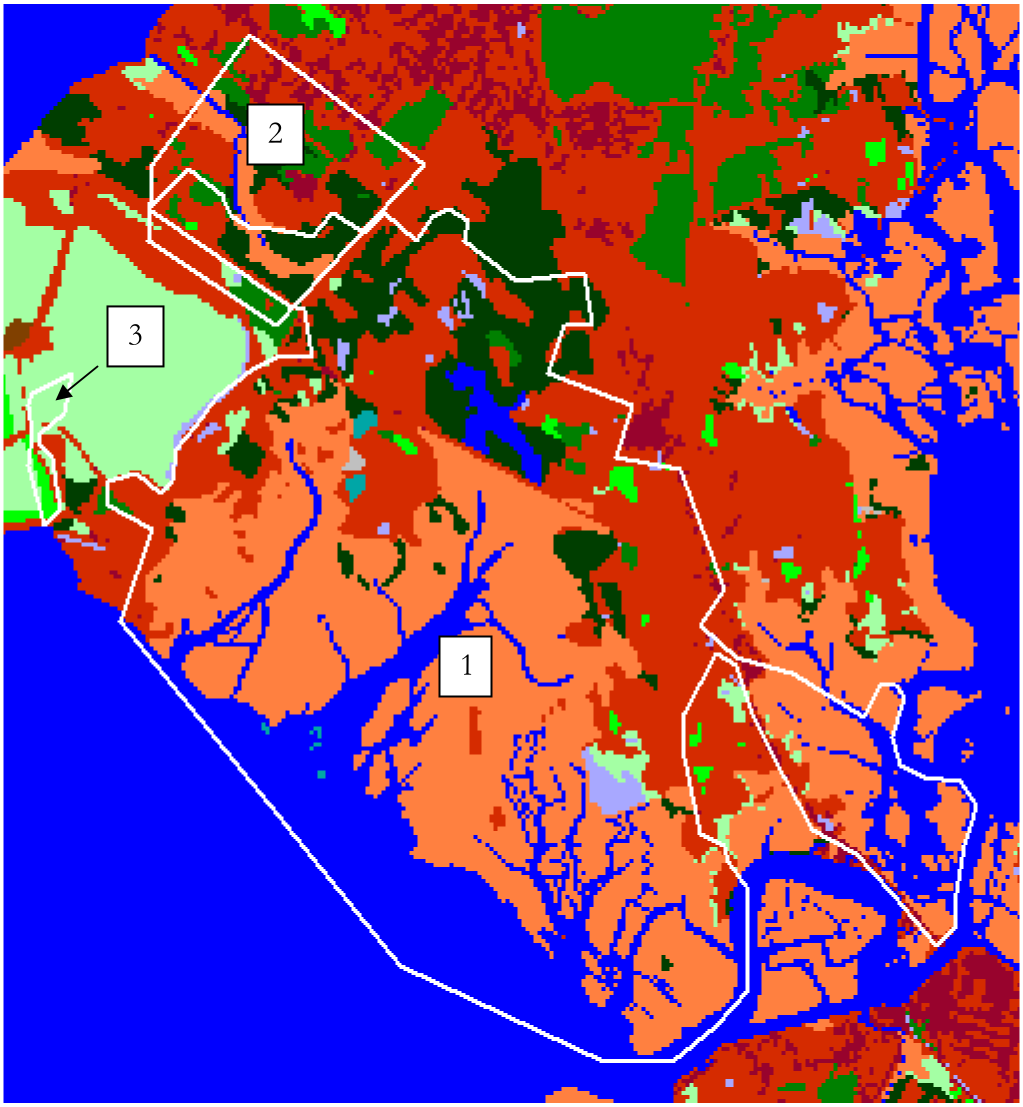



**Figure 5:** Input sub-sites correspond with above table.

# Results

The predicted effects of global sea level rise on Supawna Meadows NWR are fairly severe. For example, roughly half of the refuge's dry land is predicted to be lost even in the lowest SLR scenario examined. The refuge is predicted to lose between 49% and 88% of its dry land across all scenarios.

The model results also show a predicted loss of between 18% and 93% of irregularly flooded marsh, which currently makes up roughly half of the refuge. Tidal swamps, about 10% of the refuge, are predicted to be lost at a rate of 19% to 82% across all SLR scenarios. Maps presented below illustrate the spatial extent of these predictions.

| SLR by 2100 (m) | 0.39 | 0.69 | 1 | 1.5 | 2 |
|---|---|---|---|---|---|
| Irreg. Flooded Marsh | 18% | 28% | 48% | 89% | 93% |
| Dry Land | 49% | 59% | 69% | 80% | 88% |
| Tidal Swamp | 19% | 25% | 38% | 65% | 82% |

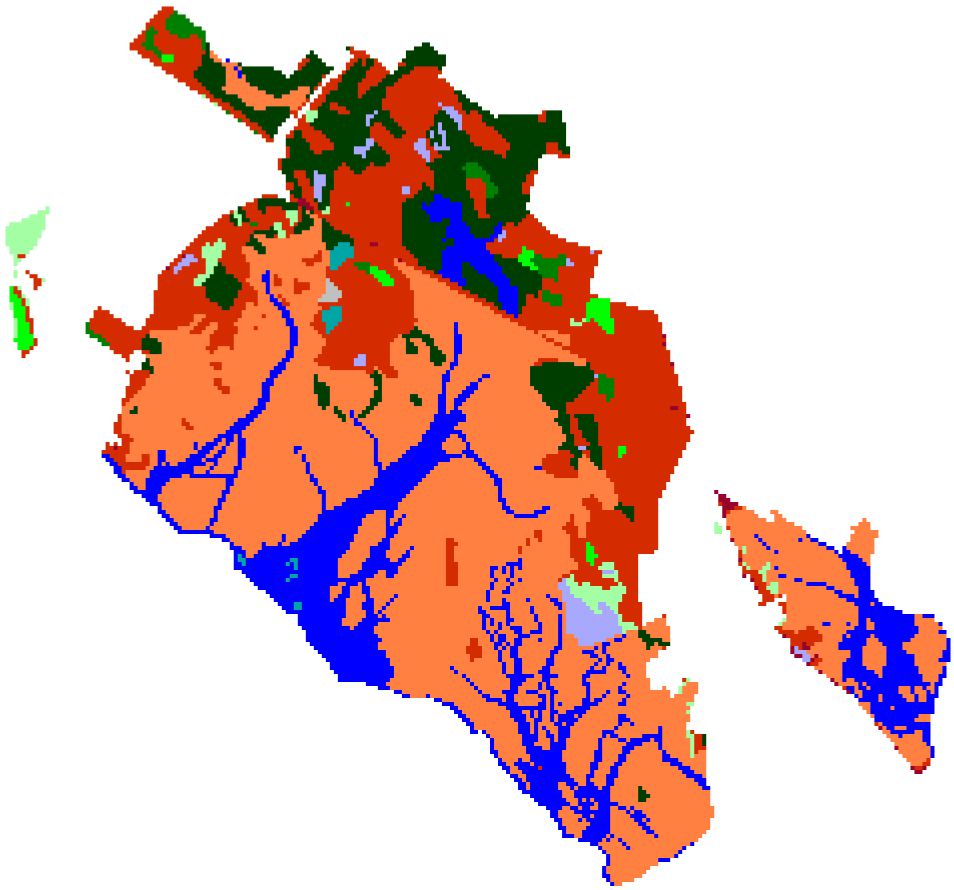
**Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise**

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

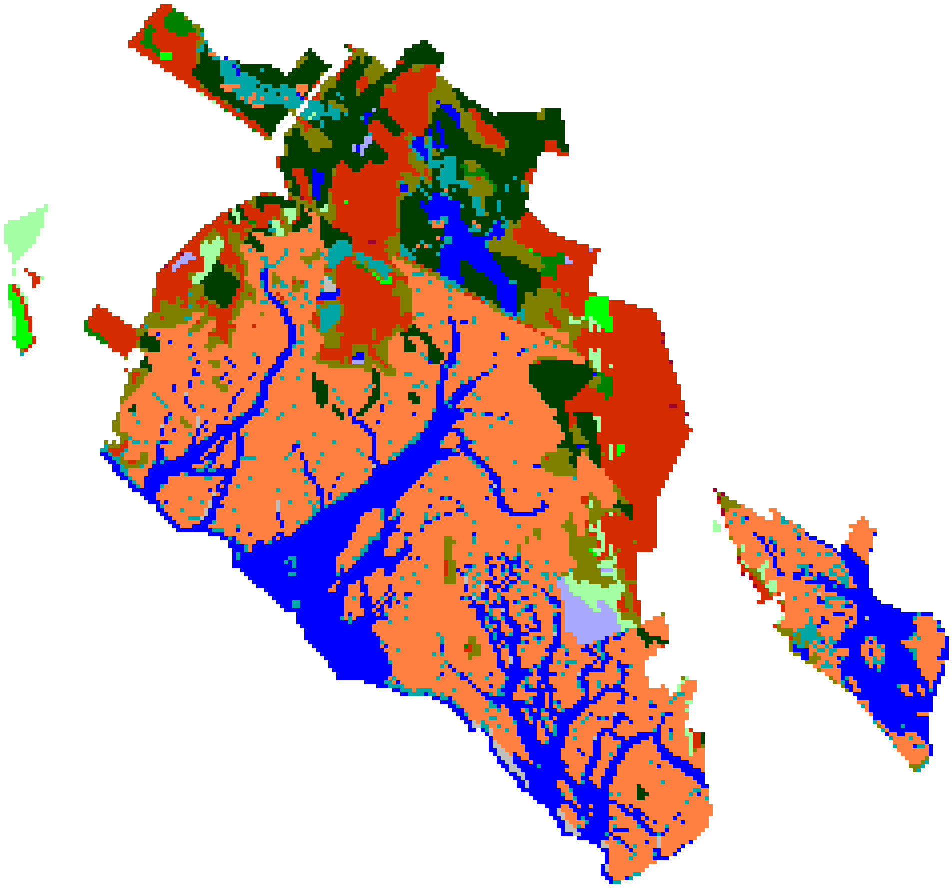
Supawna Meadows NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

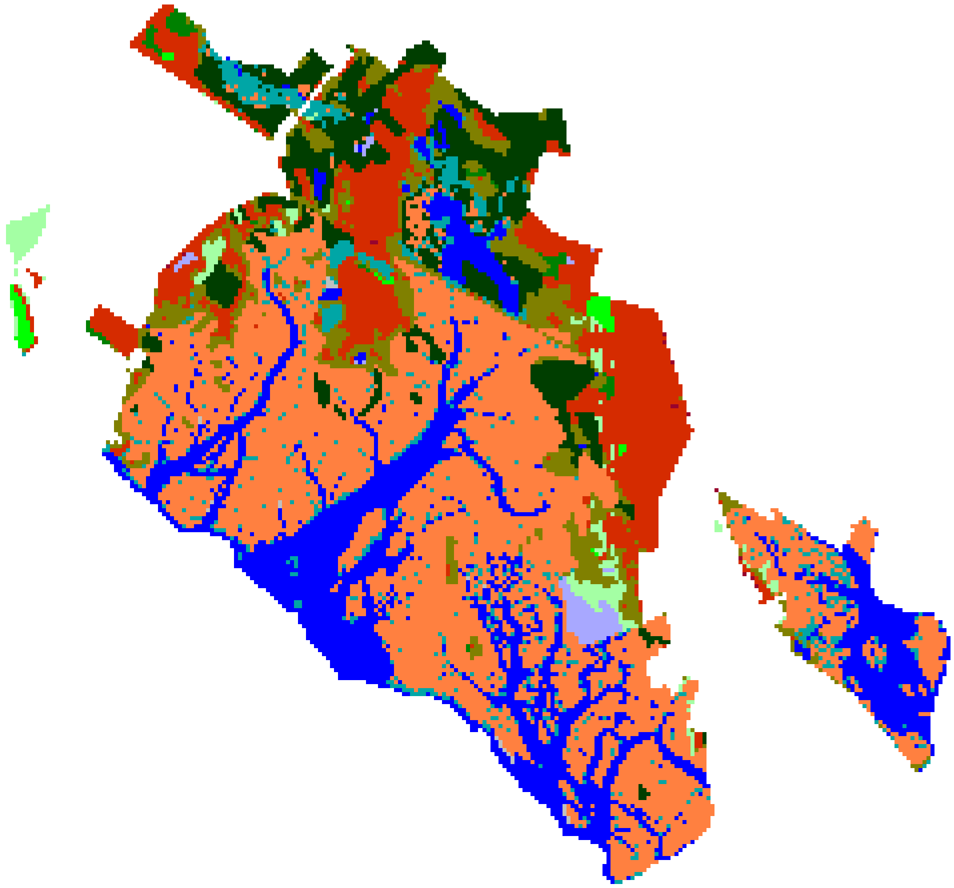
| | Initial | 2025 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|
| Irreg. Flooded Marsh | 2104.7 | 1805.6 | 1804.7 | 1764.4 | 1718.6 |
| Dry Land | 1004.3 | 665.6 | 614.1 | 563.7 | 517.1 |
| Estuarine Open Water | 704.1 | 858.1 | 895.5 | 926.1 | 951.0 |
| Tidal Swamp | 486.2 | 451.0 | 425.7 | 405.5 | 393.8 |
| Tidal Fresh Marsh | 68.7 | 80.4 | 81.3 | 81.9 | 82.2 |
| Inland Open Water | 56.0 | 36.3 | 36.0 | 35.4 | 35.4 |
| Swamp | 41.8 | 30.2 | 27.5 | 24.3 | 21.3 |
| Inland Fresh Marsh | 32.2 | 24.4 | 23.9 | 23.5 | 23.1 |
| Saltmarsh | 15.3 | 234.7 | 241.8 | 277.2 | 311.0 |
| Dev. Dry Land | 13.3 | 4.4 | 3.7 | 3.0 | 3.0 |
| Tidal Flat | 4.4 | 22.3 | 6.5 | 6.6 | 11.2 |
| Trans. Salt Marsh | 0.0 | 318.4 | 370.5 | 419.7 | 463.7 |
| **Total (incl. water)** | **4531.3** | **4531.3** | **4531.3** | **4531.3** | **4531.3** |



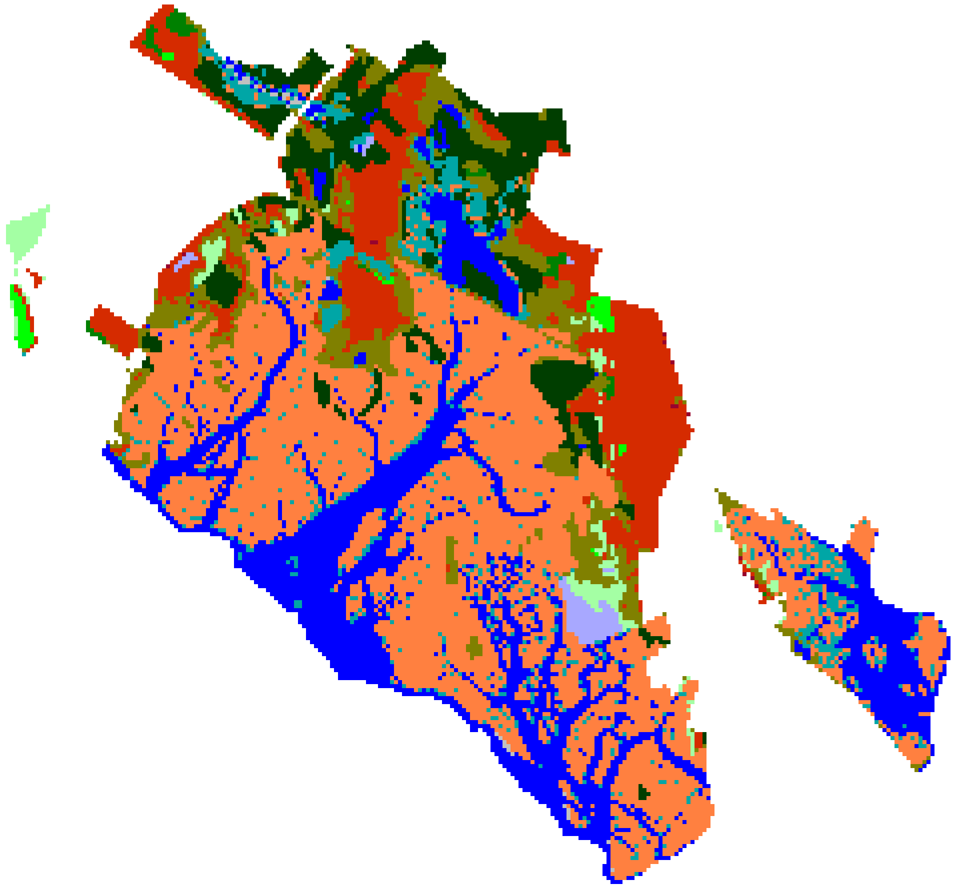
Supawna Meadows NWR, Initial Condition



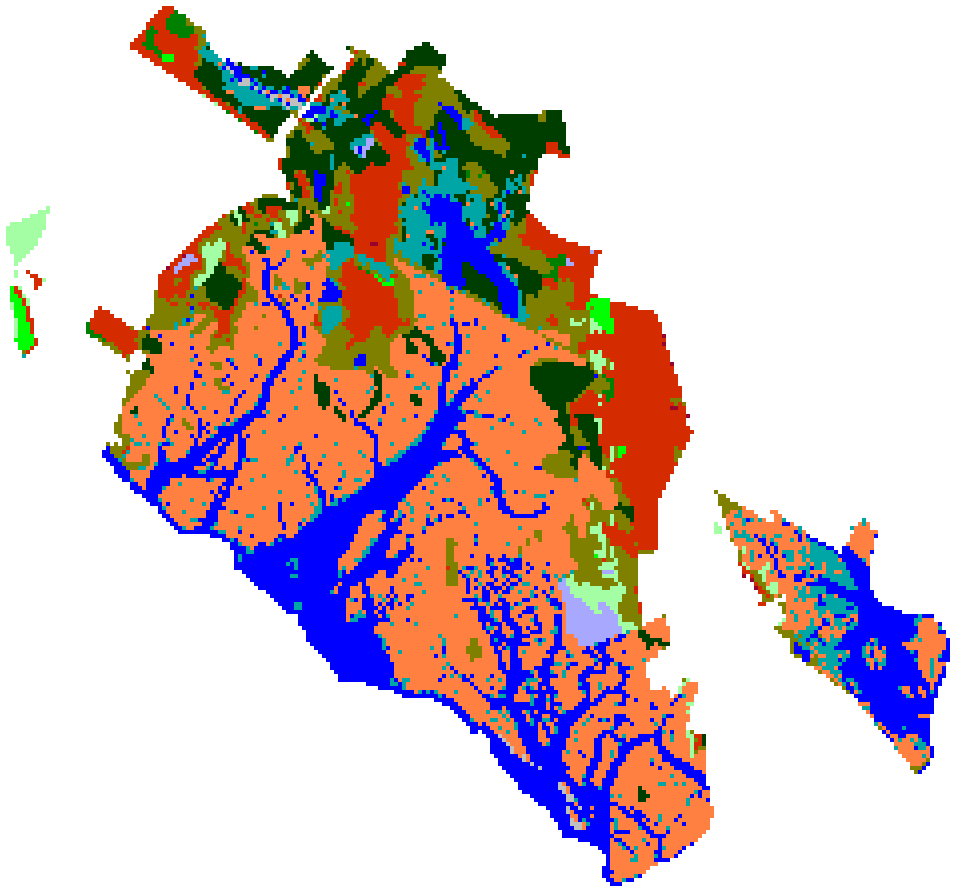
Supawna Meadows NWR, 2025, Scenario A1B Mean



Supawna Meadows NWR, 2050, Scenario A1B Mean



Supawna Meadows NWR, 2075, Scenario A1B Mean

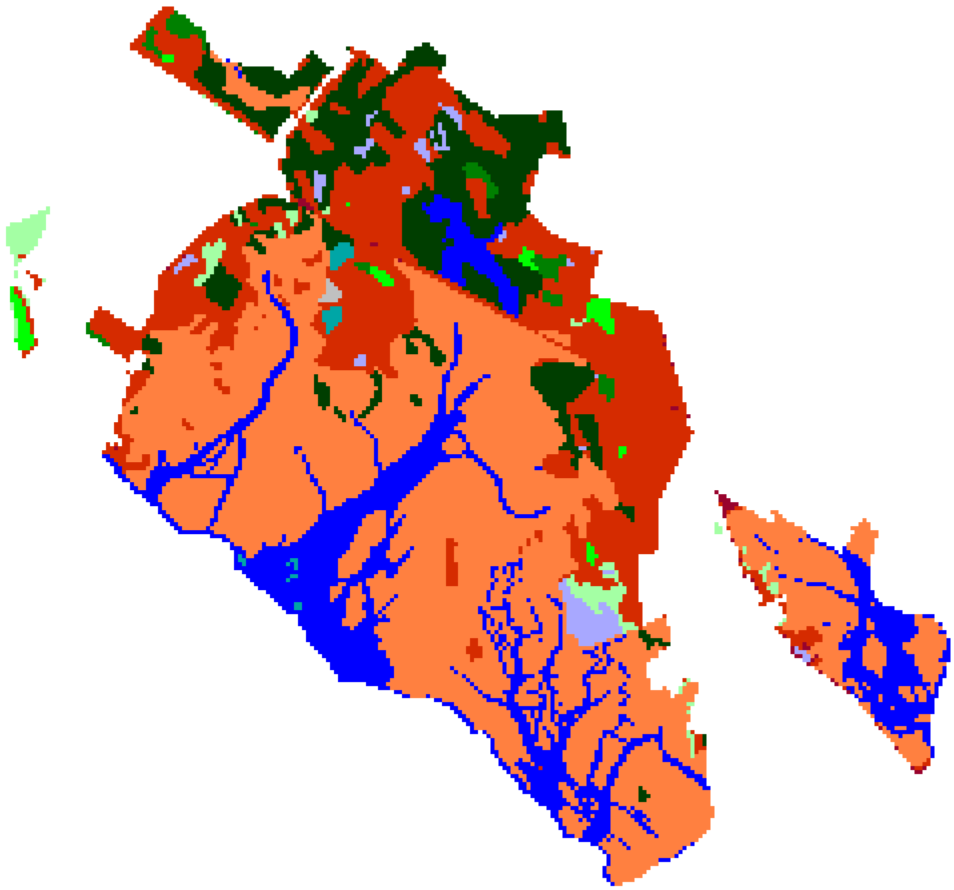


Supawna Meadows NWR, 2100, Scenario A1B Mean

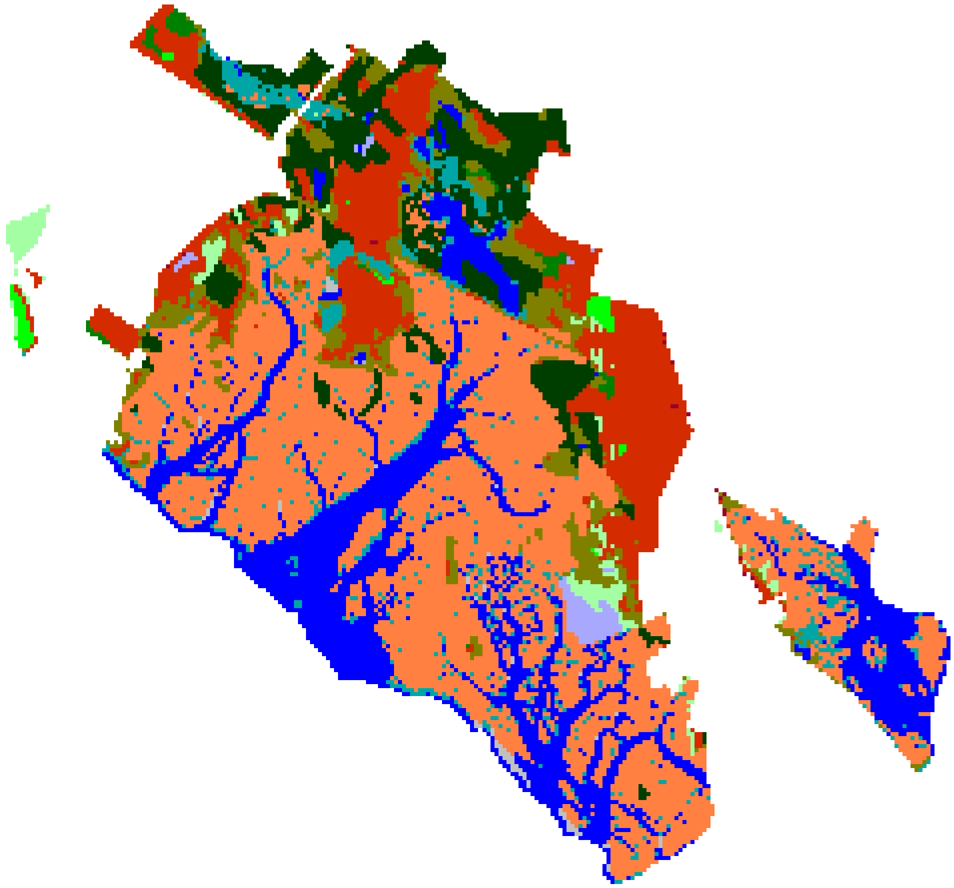
Supawna Meadows NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

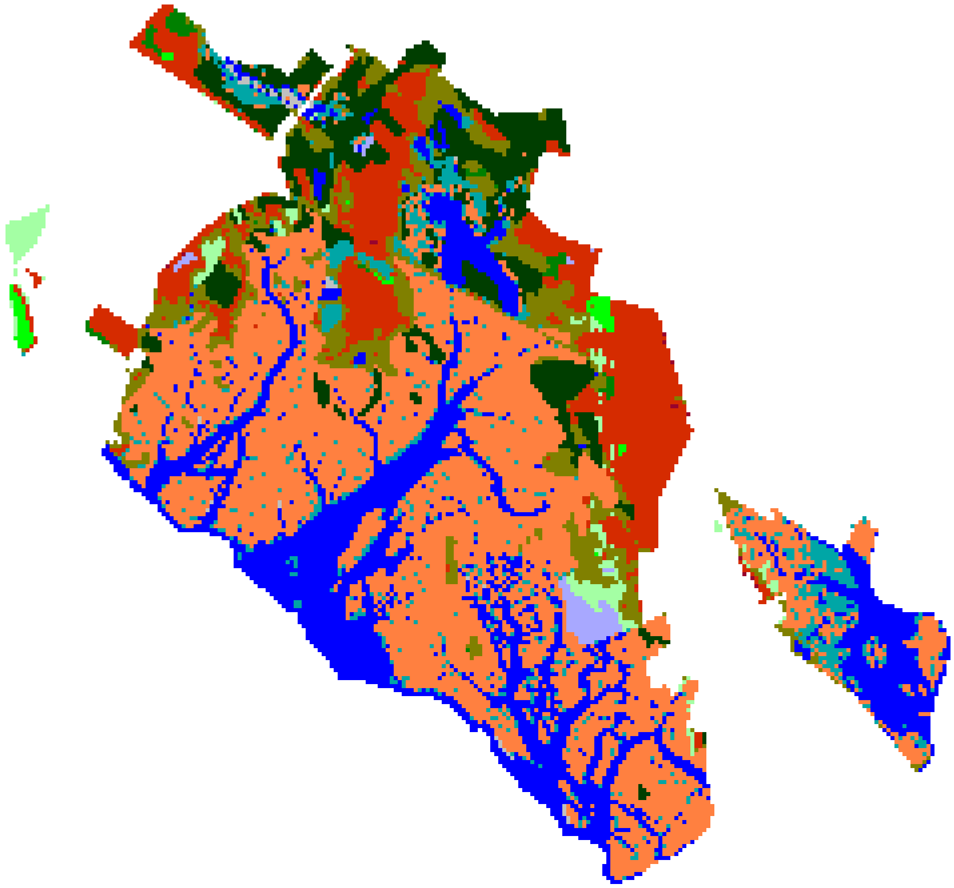
| | Initial | 2025 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|
| Irreg. Flooded Marsh | 2104.7 | 1796.6 | 1748.3 | 1634.3 | 1505.3 |
| Dry Land | 1004.3 | 652.3 | 579.8 | 503.7 | 406.8 |
| Estuarine Open Water | 704.1 | 869.7 | 940.7 | 1009.8 | 1102.4 |
| Tidal Swamp | 486.2 | 441.3 | 408.4 | 387.8 | 365.7 |
| Tidal Fresh Marsh | 68.7 | 79.1 | 80.4 | 80.8 | 81.0 |
| Inland Open Water | 56.0 | 36.0 | 35.4 | 35.4 | 33.1 |
| Swamp | 41.8 | 29.2 | 25.2 | 20.1 | 13.8 |
| Inland Fresh Marsh | 32.2 | 24.1 | 23.3 | 21.9 | 20.2 |
| Saltmarsh | 15.3 | 243.9 | 274.9 | 357.5 | 442.3 |
| Dev. Dry Land | 13.3 | 4.2 | 3.1 | 2.9 | 2.7 |
| Tidal Flat | 4.4 | 23.0 | 12.9 | 18.1 | 37.0 |
| Trans. Salt Marsh | 0.0 | 331.9 | 399.0 | 459.0 | 520.9 |
| **Total (incl. water)** | **4531.3** | **4531.3** | **4531.3** | **4531.3** | **4531.3** |



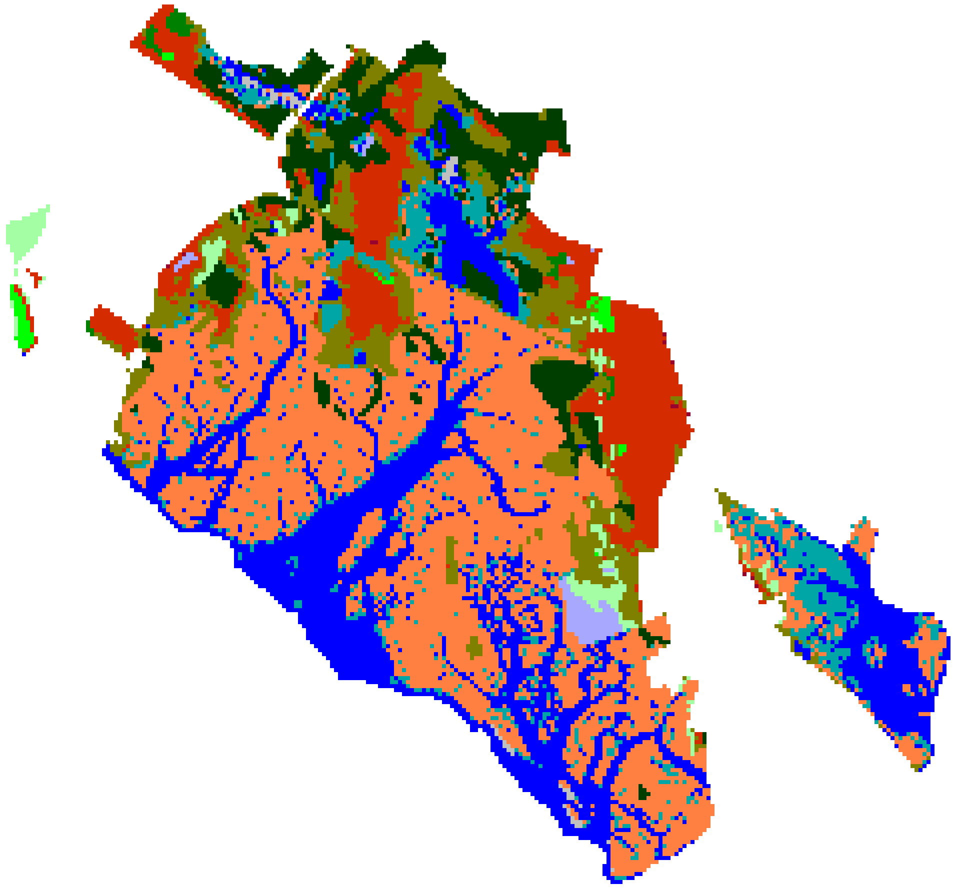
Supawna Meadows NWR, Initial Condition



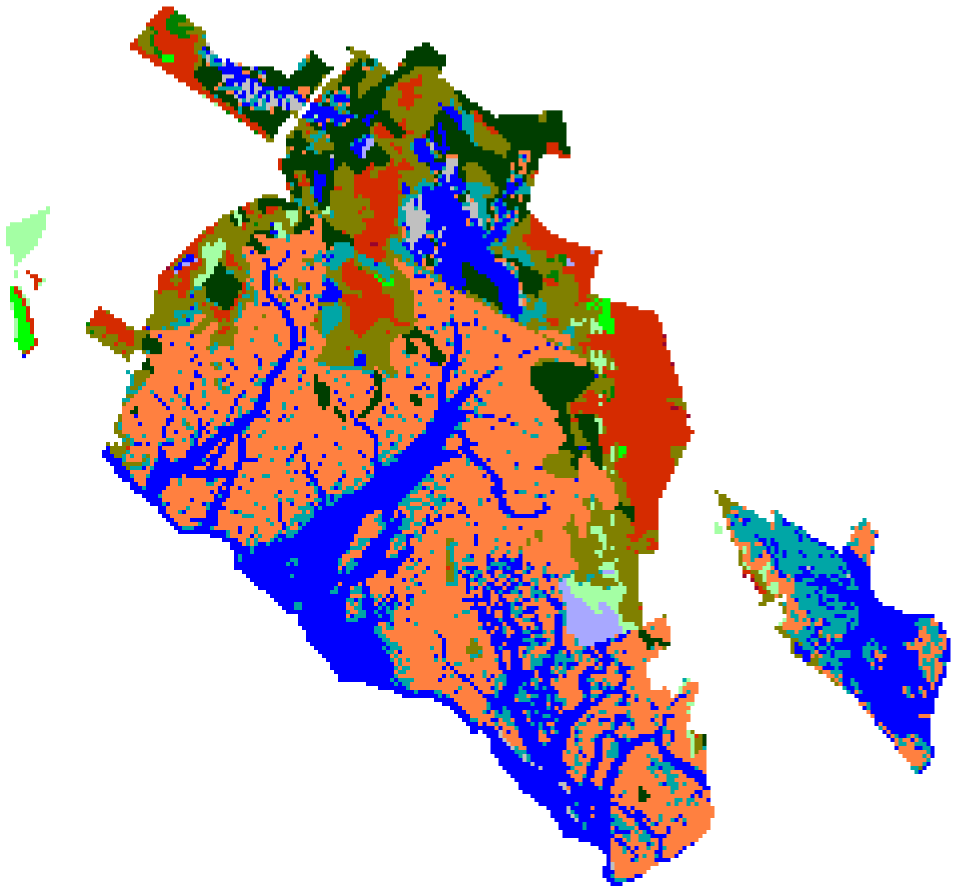
Supawna Meadows NWR, 2025, Scenario A1B Maximum



Supawna Meadows NWR, 2050, Scenario A1B Maximum



Supawna Meadows NWR, 2075, Scenario A1B Maximum

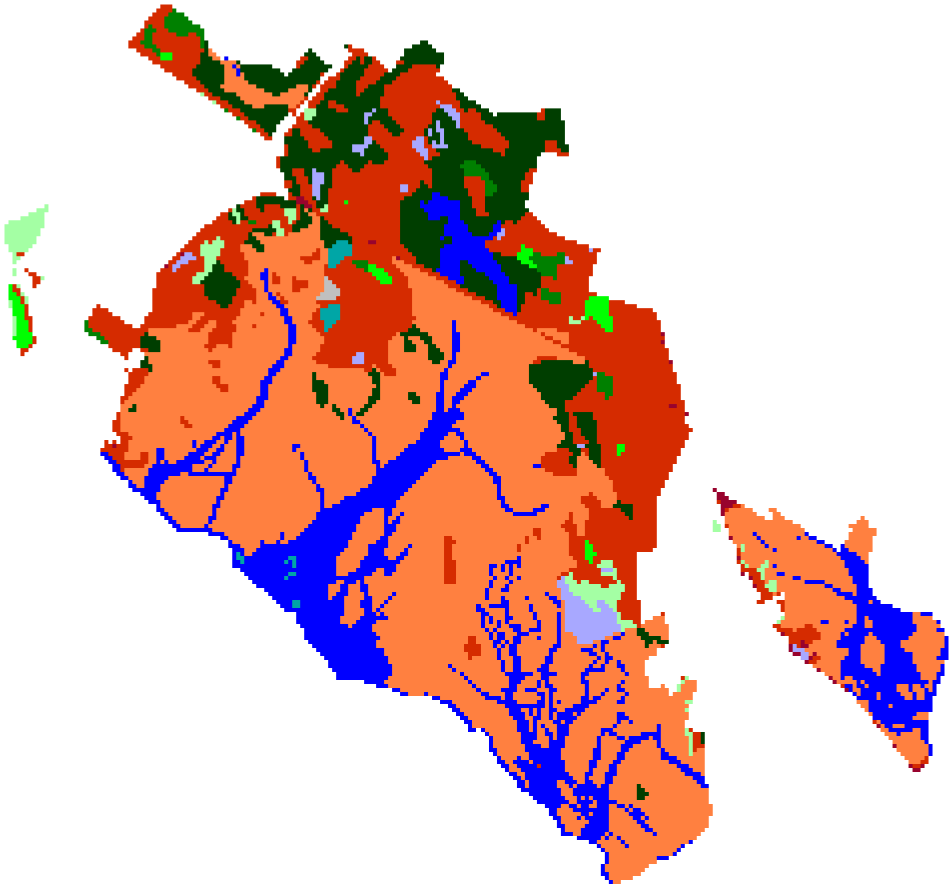


Supawna Meadows NWR, 2100, Scenario A1B Maximum

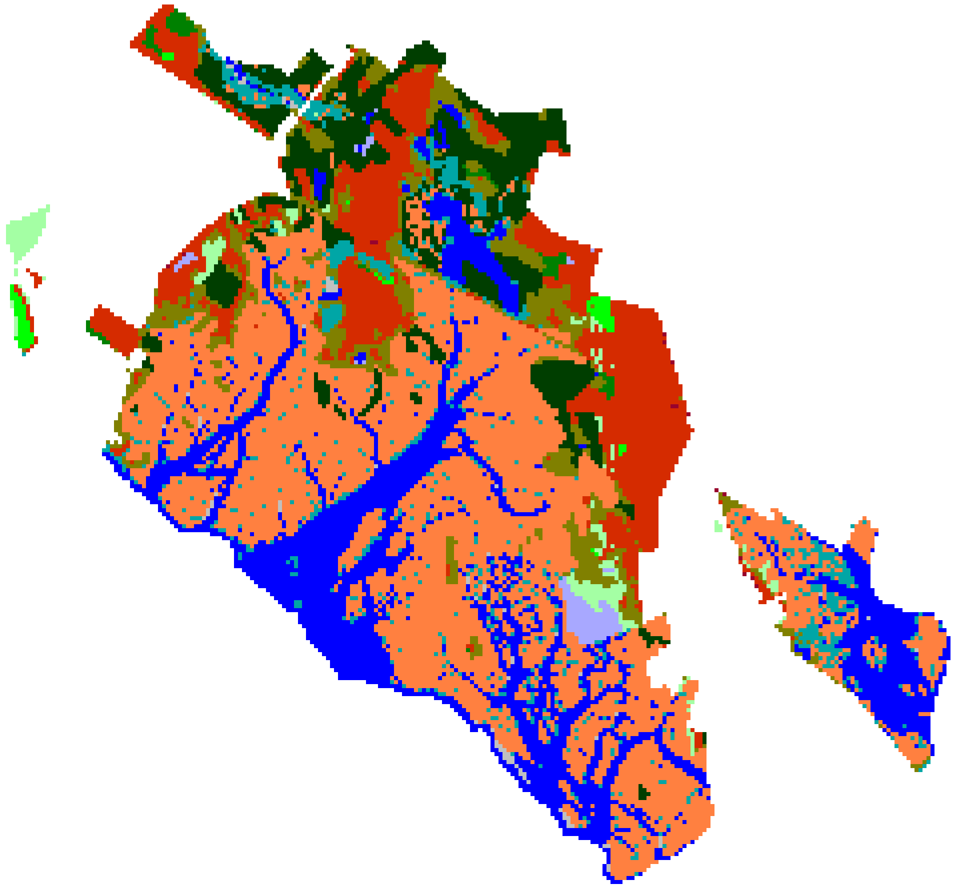
Supawna Meadows NWR
1 Meter Eustatic SLR by 2100

Results in Acres

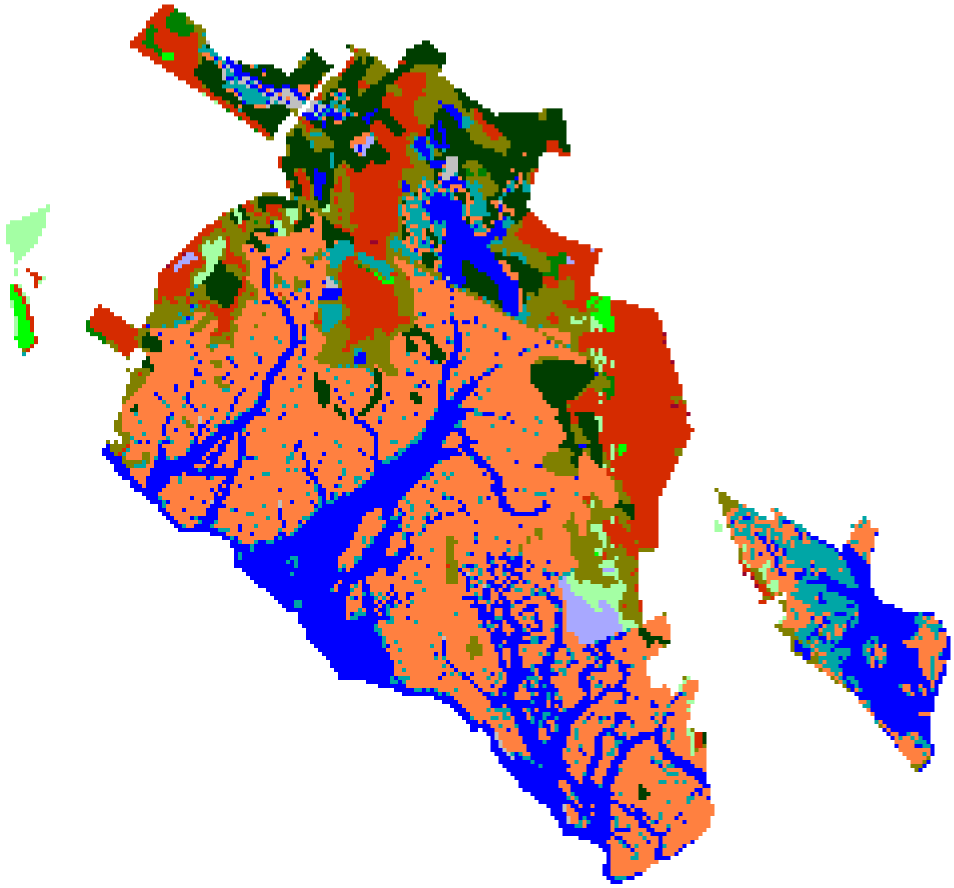
| | Initial | 2025 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|
| Irreg. Flooded Marsh | 2104.7 | 1781.3 | 1677.1 | 1466.1 | 1098.3 |
| Dry Land | 1004.3 | 635.8 | 546.1 | 428.8 | 313.8 |
| Estuarine Open Water | 704.1 | 884.0 | 984.8 | 1106.1 | 1289.2 |
| Tidal Swamp | 486.2 | 431.0 | 396.8 | 368.8 | 302.1 |
| Tidal Fresh Marsh | 68.7 | 78.7 | 80.1 | 80.2 | 79.0 |
| Inland Open Water | 56.0 | 36.0 | 35.4 | 33.6 | 30.7 |
| Swamp | 41.8 | 28.1 | 22.8 | 14.8 | 7.9 |
| Inland Fresh Marsh | 32.2 | 23.8 | 22.1 | 19.8 | 16.7 |
| Saltmarsh | 15.3 | 256.5 | 323.6 | 493.5 | 821.2 |
| Dev. Dry Land | 13.3 | 3.9 | 3.0 | 2.8 | 1.8 |
| Tidal Flat | 4.4 | 25.4 | 19.2 | 34.6 | 65.1 |
| Trans. Salt Marsh | 0.0 | 346.7 | 420.4 | 482.3 | 505.5 |
| **Total (incl. water)** | **4531.3** | **4531.3** | **4531.3** | **4531.3** | **4531.3** |



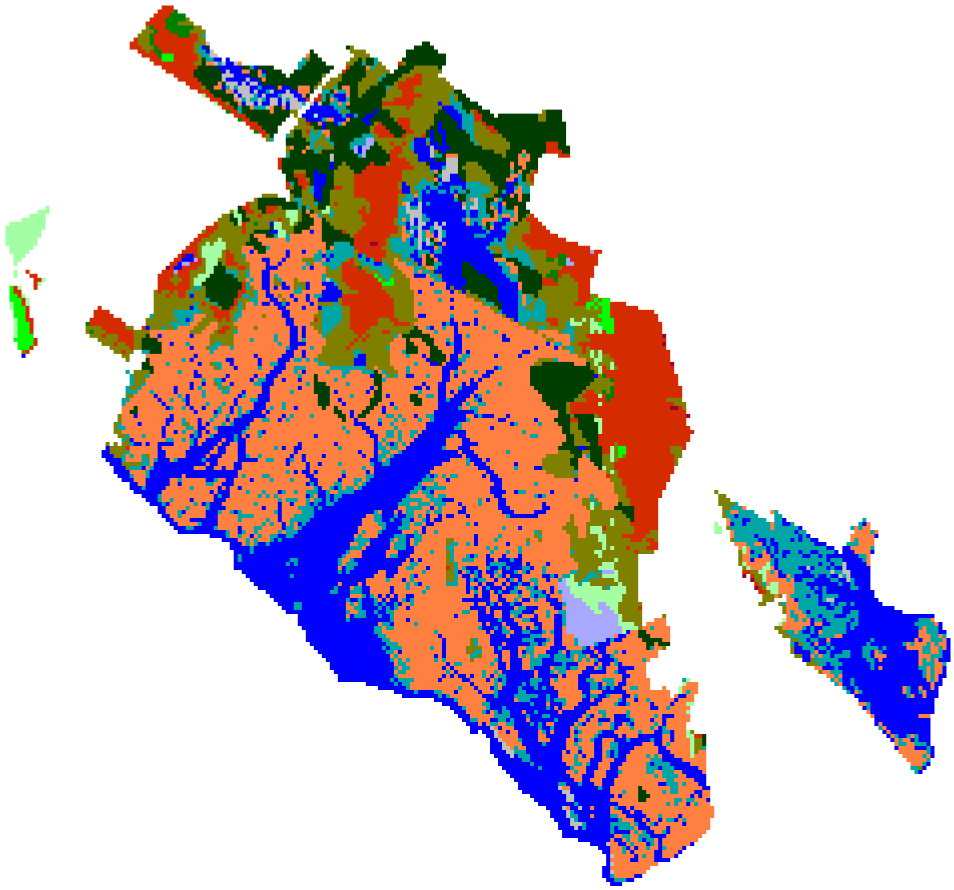
Supawna Meadows NWR, Initial Condition



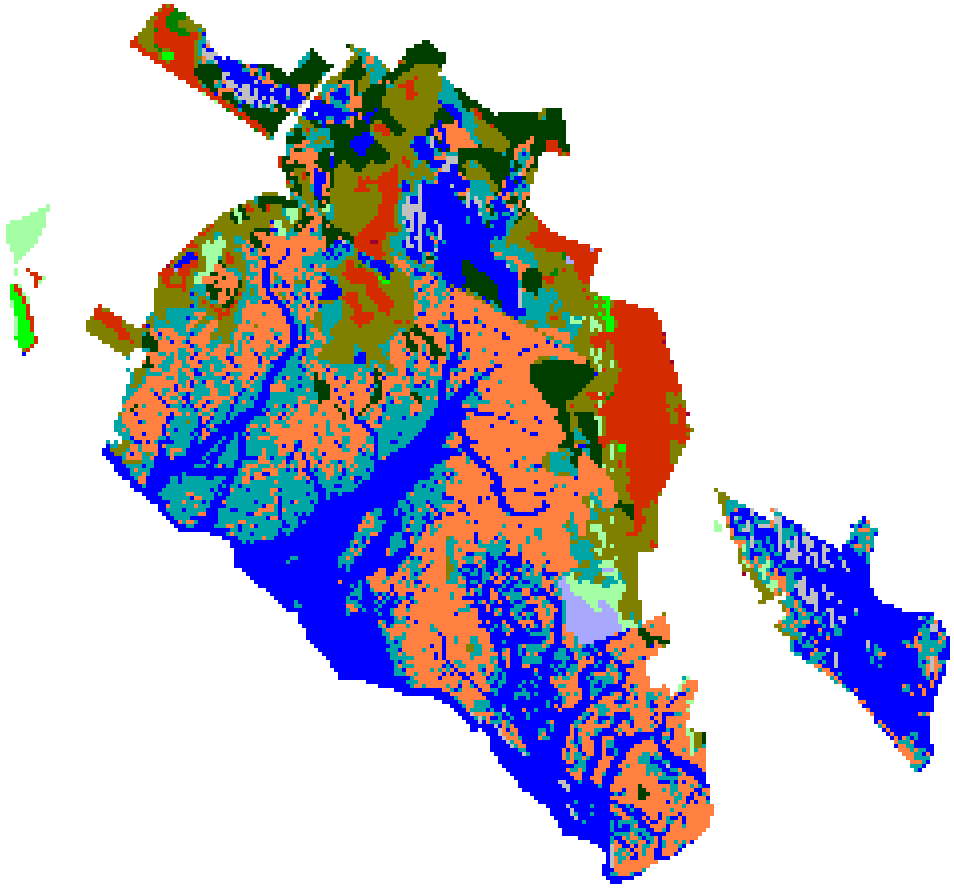
Supawna Meadows NWR, 2025, 1 meter



Supawna Meadows NWR, 2050, 1 meter



Supawna Meadows NWR, 2075, 1 meter

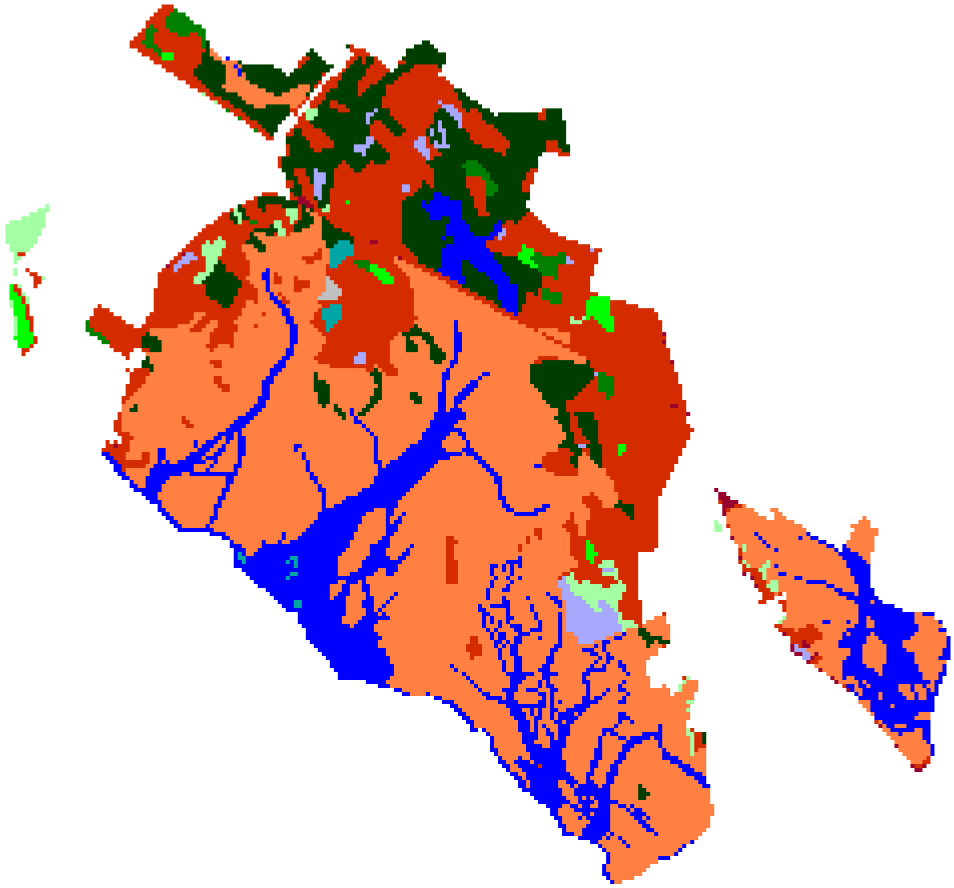


Supawna Meadows NWR, 2100, 1 meter

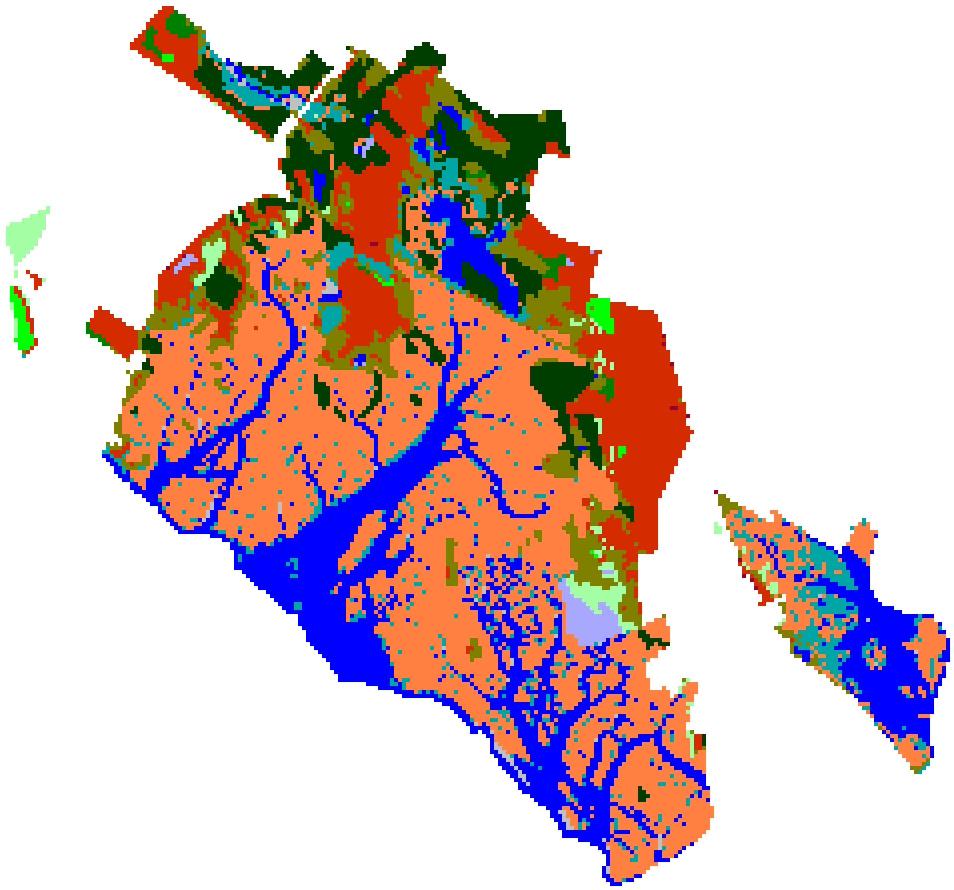
Supawna Meadows NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

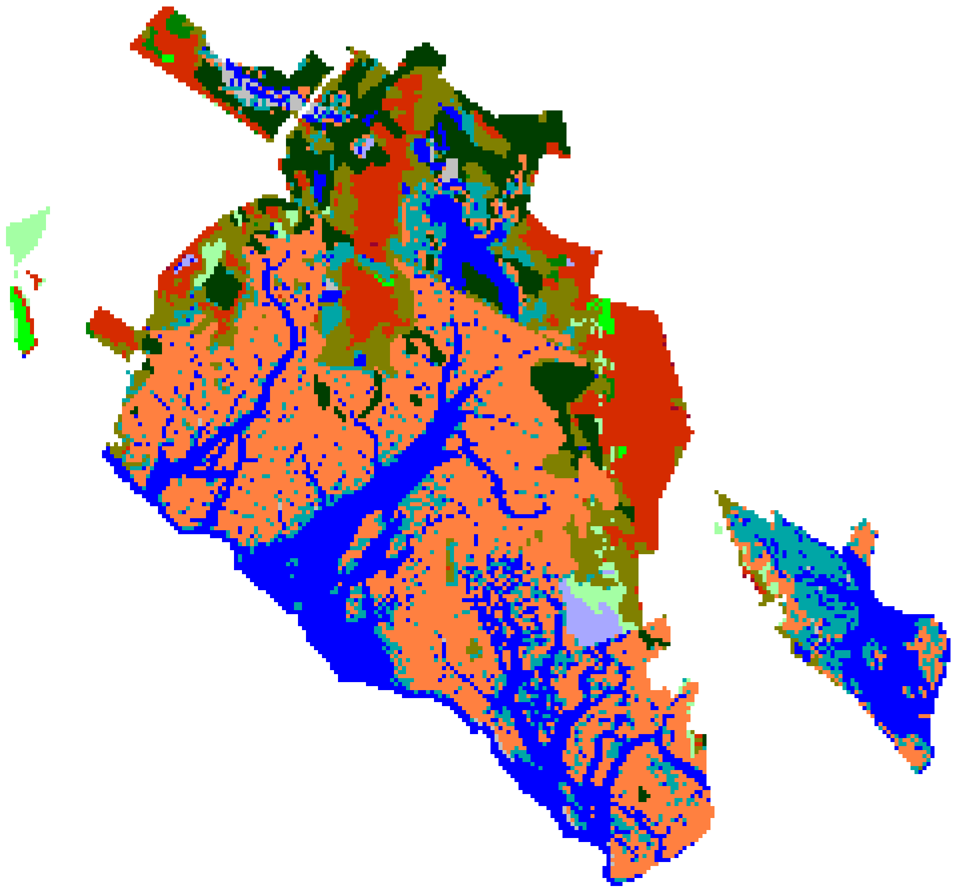
| | Initial | 2025 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|
| Irreg. Flooded Marsh | 2104.7 | 1750.8 | 1531.0 | 925.4 | 236.1 |
| Dry Land | 1004.3 | 612.4 | 487.5 | 319.5 | 198.4 |
| Estuarine Open Water | 704.1 | 904.3 | 1050.9 | 1296.2 | 1777.2 |
| Tidal Swamp | 486.2 | 418.5 | 381.2 | 300.4 | 169.9 |
| Tidal Fresh Marsh | 68.7 | 76.8 | 77.2 | 73.5 | 63.8 |
| Inland Open Water | 56.0 | 36.0 | 34.7 | 32.7 | 30.5 |
| Swamp | 41.8 | 26.6 | 18.5 | 8.1 | 3.8 |
| Inland Fresh Marsh | 32.2 | 23.3 | 20.4 | 15.6 | 10.5 |
| Saltmarsh | 15.3 | 283.1 | 457.5 | 989.0 | 1347.7 |
| Dev. Dry Land | 13.3 | 3.6 | 2.9 | 1.8 | 1.6 |
| Tidal Flat | 4.4 | 29.1 | 28.6 | 96.4 | 299.1 |
| Trans. Salt Marsh | 0.0 | 366.8 | 440.8 | 472.5 | 392.9 |
| **Total (incl. water)** | **4531.3** | **4531.3** | **4531.3** | **4531.3** | **4531.3** |



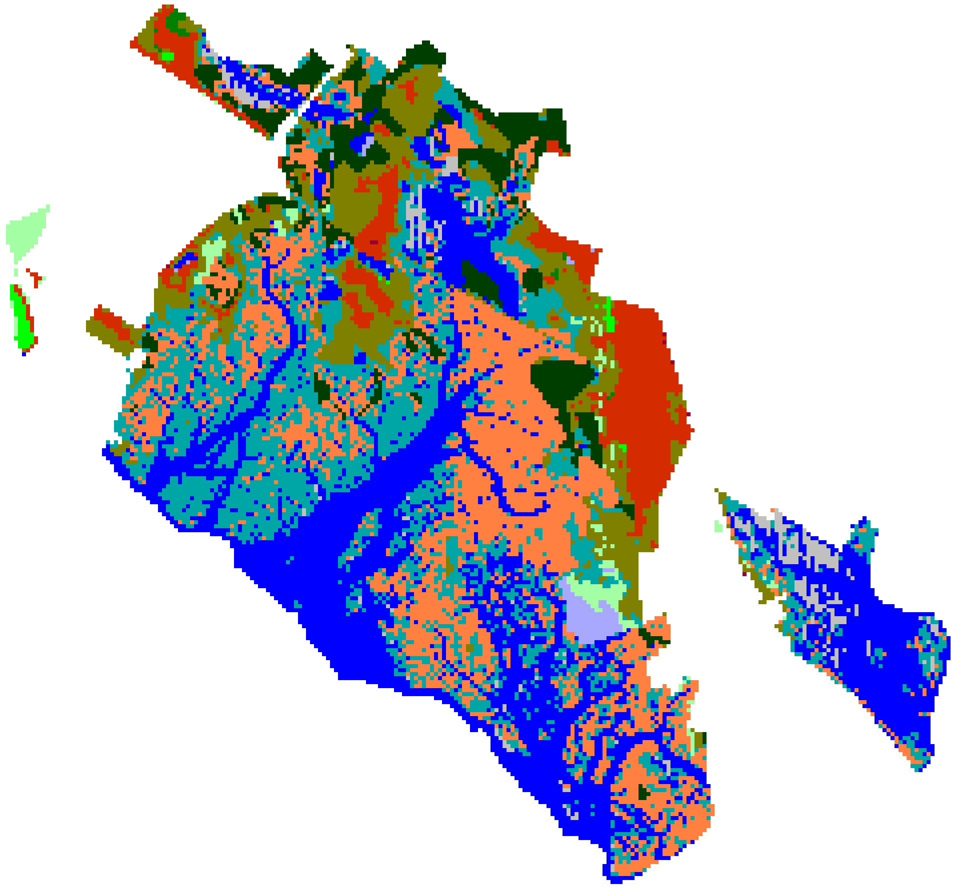
Supawna Meadows NWR, Initial Condition



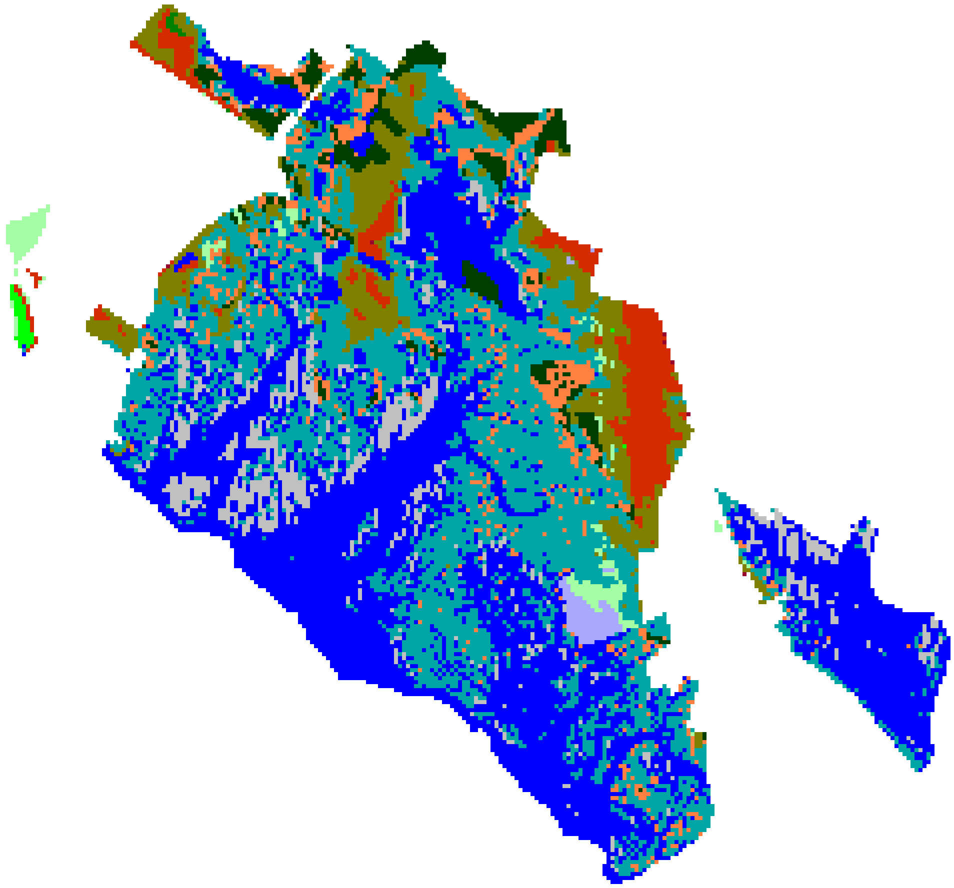
Supawna Meadows NWR, 2025, 1.5 meter



Supawna Meadows NWR, 2050, 1.5 meter



Supawna Meadows NWR, 2075, 1.5 meter

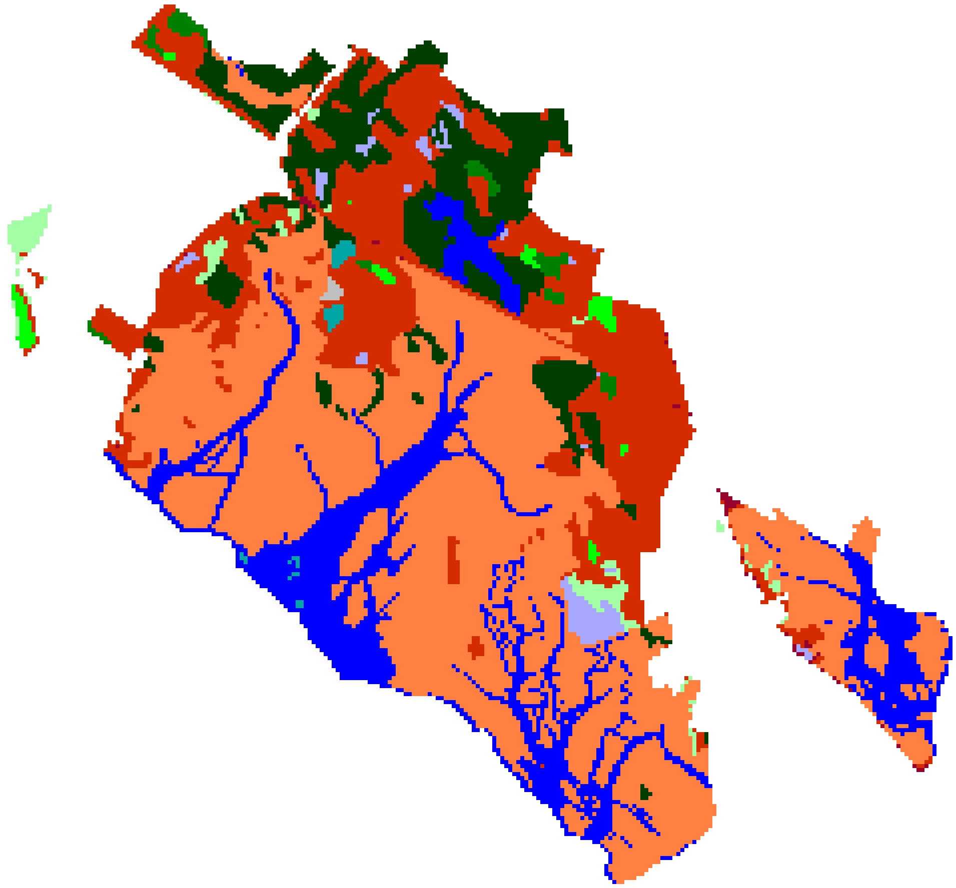


Supawna Meadows NWR, 2100, 1.5 meter

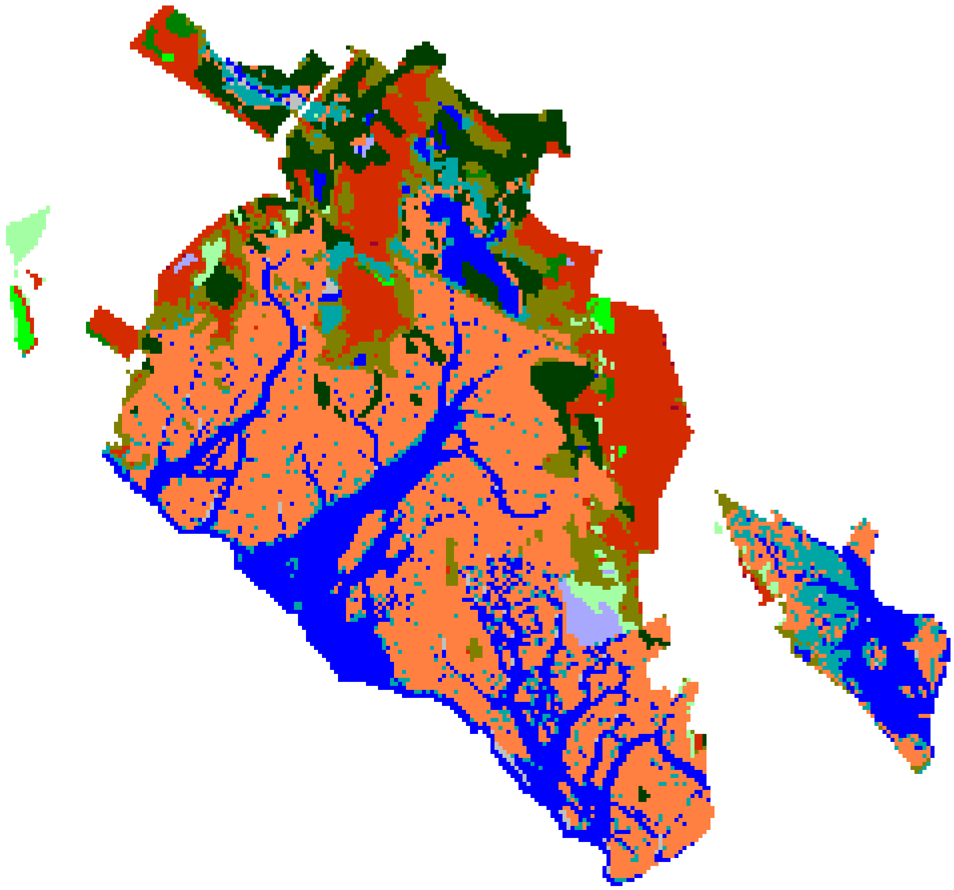
Supawna Meadows NWR
2 Meters Eustatic SLR by 2100

Results in Acres

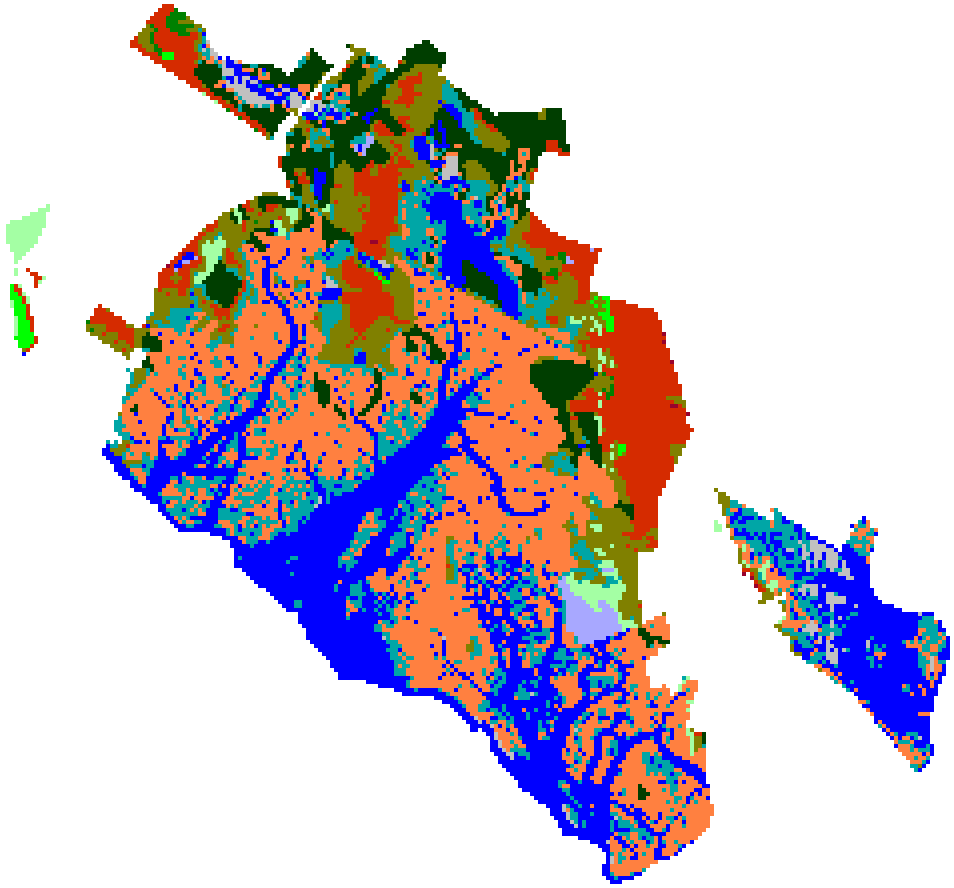
| | Initial | 2025 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|
| Irreg. Flooded Marsh | 2104.7 | 1717.0 | 1304.7 | 318.7 | 140.1 |
| Dry Land | 1004.3 | 588.6 | 417.0 | 236.2 | 117.1 |
| Estuarine Open Water | 704.1 | 924.1 | 1134.9 | 1544.3 | 2250.6 |
| Tidal Swamp | 486.2 | 407.6 | 361.9 | 209.1 | 86.3 |
| Tidal Fresh Marsh | 68.7 | 76.1 | 76.2 | 64.6 | 55.0 |
| Inland Open Water | 56.0 | 35.6 | 33.6 | 30.5 | 30.2 |
| Swamp | 41.8 | 25.2 | 14.0 | 4.6 | 1.2 |
| Inland Fresh Marsh | 32.2 | 22.5 | 18.1 | 10.9 | 9.6 |
| Saltmarsh | 15.3 | 315.1 | 665.2 | 1525.9 | 761.3 |
| Dev. Dry Land | 13.3 | 3.2 | 2.8 | 1.7 | 0.8 |
| Tidal Flat | 4.4 | 32.6 | 59.9 | 189.8 | 829.7 |
| Trans. Salt Marsh | 0.0 | 383.8 | 442.9 | 395.1 | 249.3 |
| **Total (incl. water)** | **4531.3** | **4531.3** | **4531.3** | **4531.3** | **4531.3** |



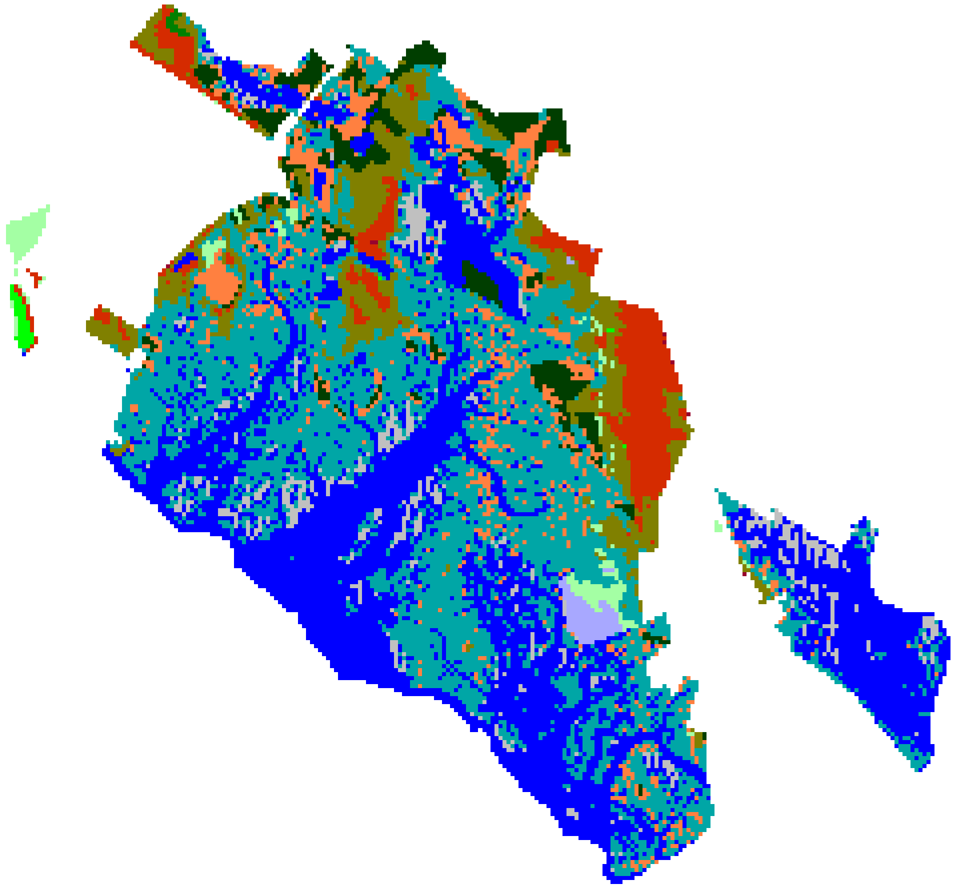
Supawna Meadows NWR, Initial Condition



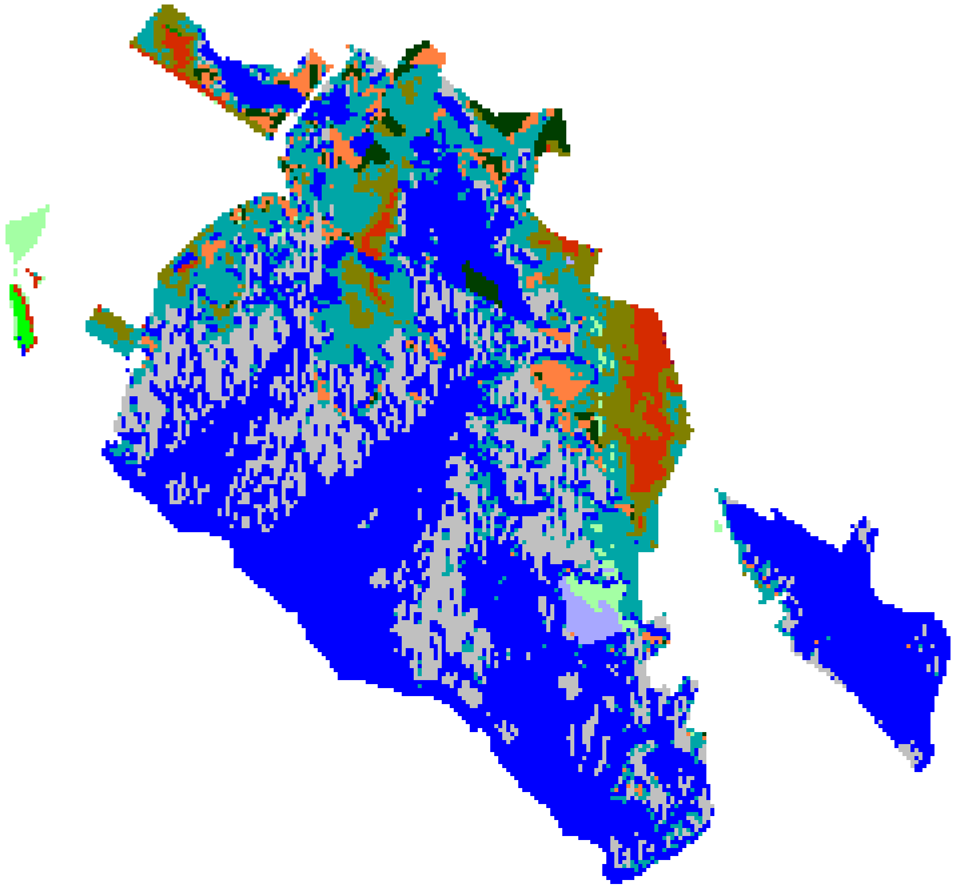
Supawna Meadows NWR, 2025, 2 meters



Supawna Meadows NWR, 2050, 2 meters



Supawna Meadows NWR, 2075, 2 meters



Supawna Meadows NWR, 2100, 2 meters

# Discussion

Supawna Meadows NWR is predicted to show effects of SLR under even the most conservative SLR scenarios utilized. However, as shown in the chart below, loss rates become increasingly severe as predicted SLR increases.

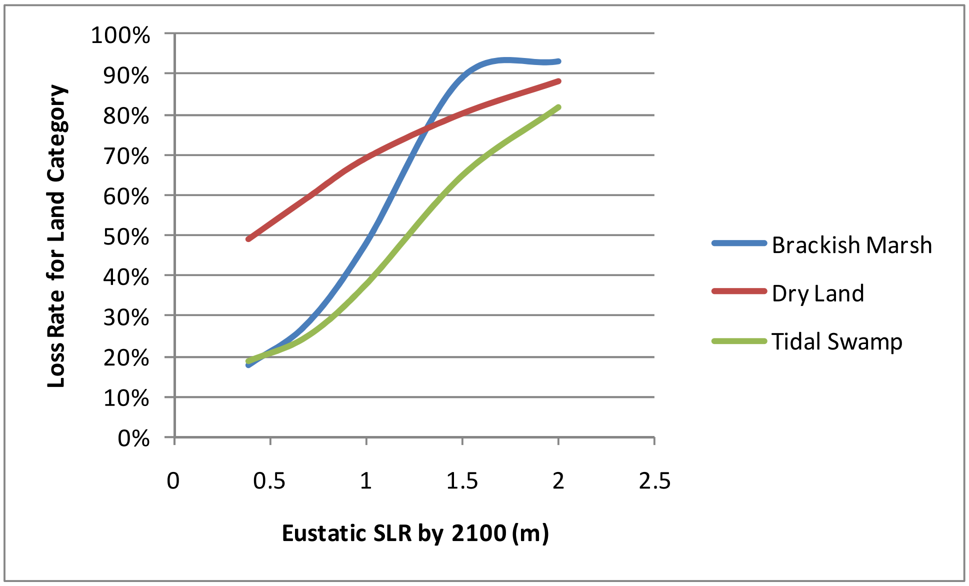



**Figure 6 Loss rates of Primary NWR land-cover categories as a function of SLR**

When marsh accretion rates are unable to keep up with predicted local SLR, Irregularly Flooded marsh is predicted to first convert to regularly flooded marsh (saltmarsh). If this regularly flooded marsh falls to too low of an elevation to maintain itself, it is then predicted to convert to tidal flats and eventually to open water. Dry land, when it falls to an elevation range that suggests regular inundation, is predicted to convert to "transitional marsh." Although significant irregularly flooded marsh conversion is predicted in eustatic scenarios of under 1 meter, total refuge marsh acreage (including salt marsh, and transitional marsh), is predicted to increase due primarily to the conversion of dry lands. However, under the highest SLR scenario utilized, 50% of total marsh acreage is predicted to be lost.

As shown above, there are some shifts visible between the latest National Wetland Inventory data and current satellite photos. This likely means that some of the change predicted under lower scenarios is a result of change that has already occurred, or horizontal data uncertainty.

This site was entirely covered with high-vertical-resolution LiDAR data which reduces model uncertainty considerably. However, how refuge marshes will respond to SLR and their potential to vertically accrete at a higher rate is uncertain. These model results assume that historically measured accretion rates will continue for the next 100 years. Additionally, no site-specific accretion data were available, further exacerbating the uncertainty caused by the accretion assumptions within the model.

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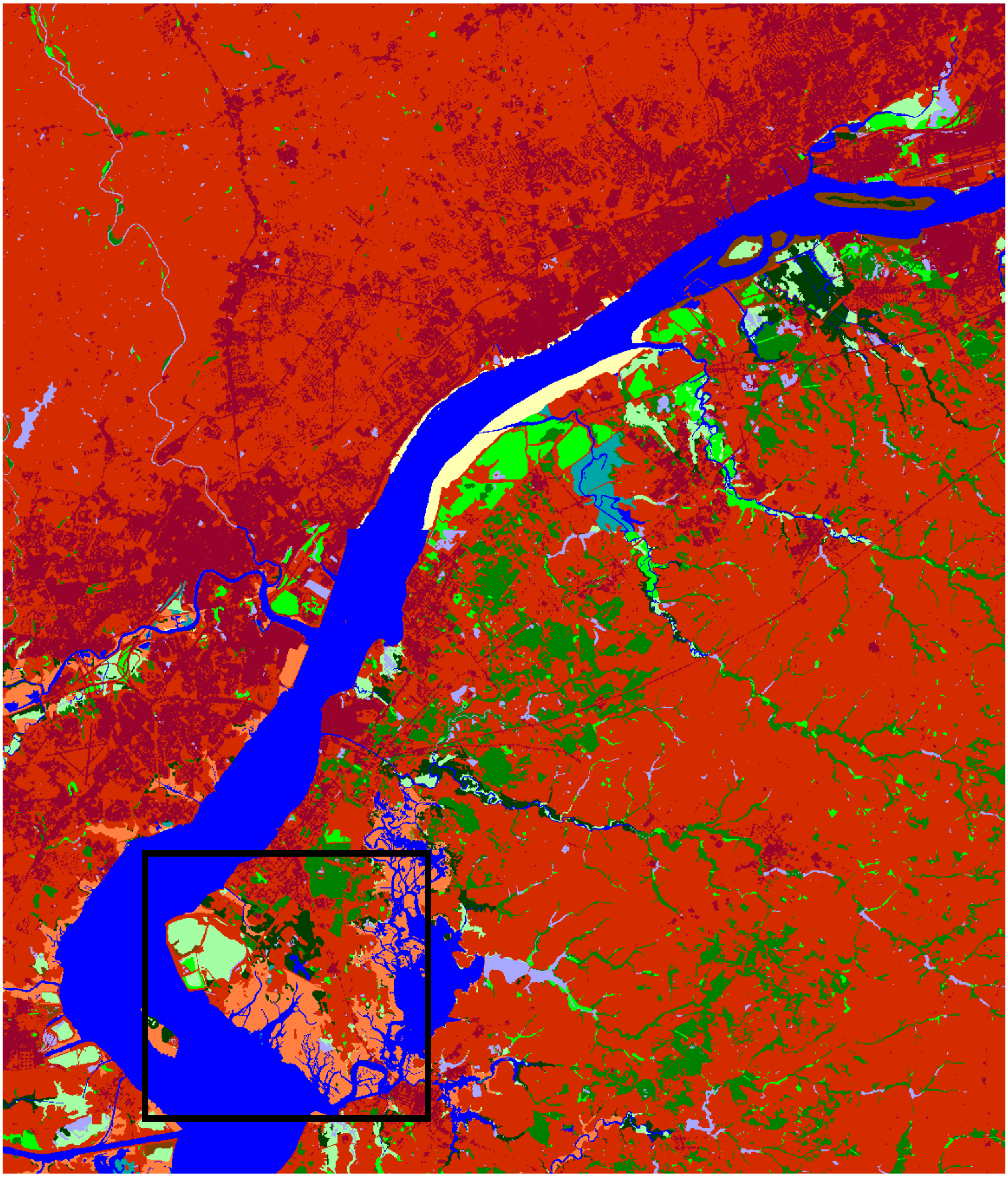
# Appendix A: Contextual Results

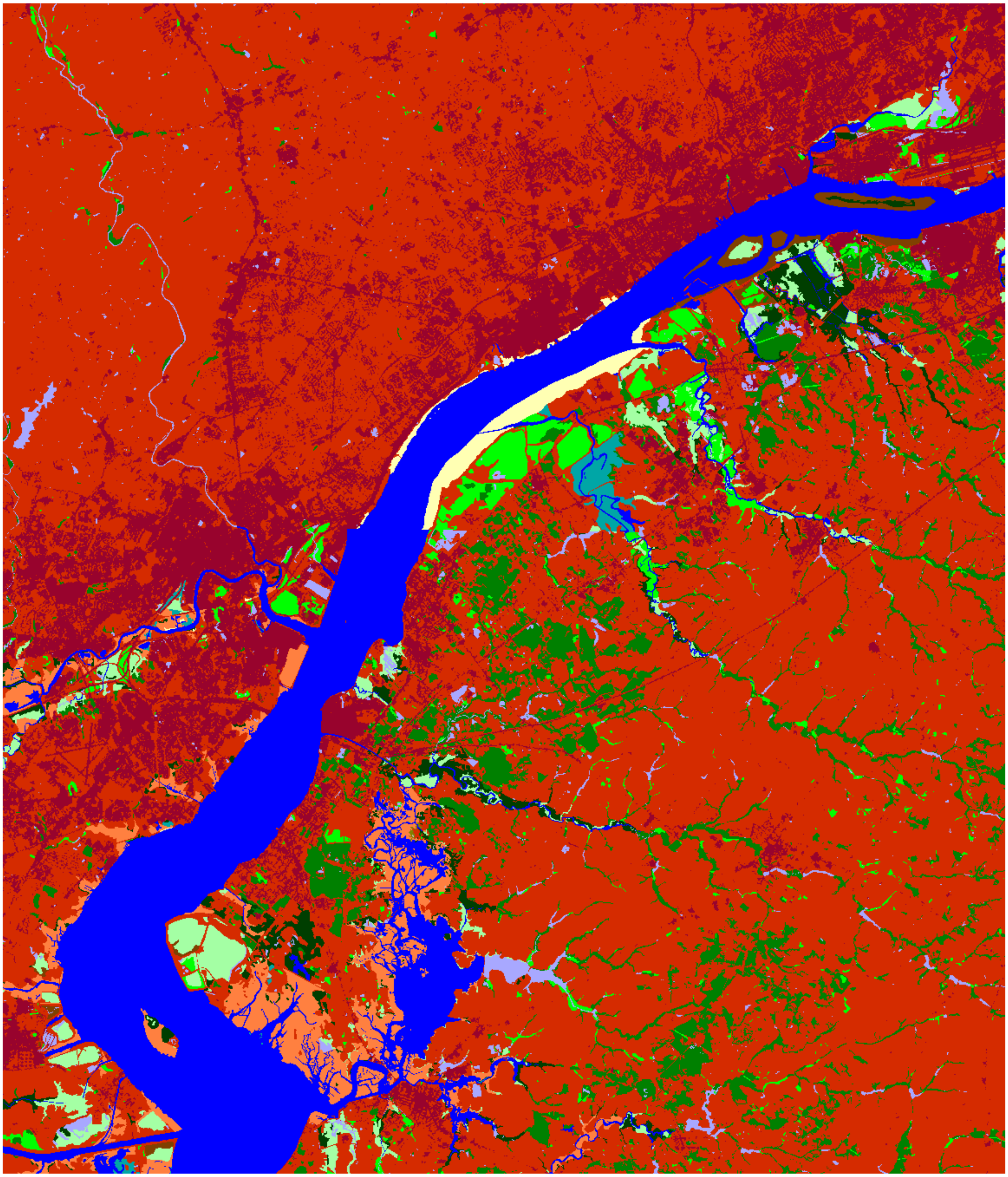
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

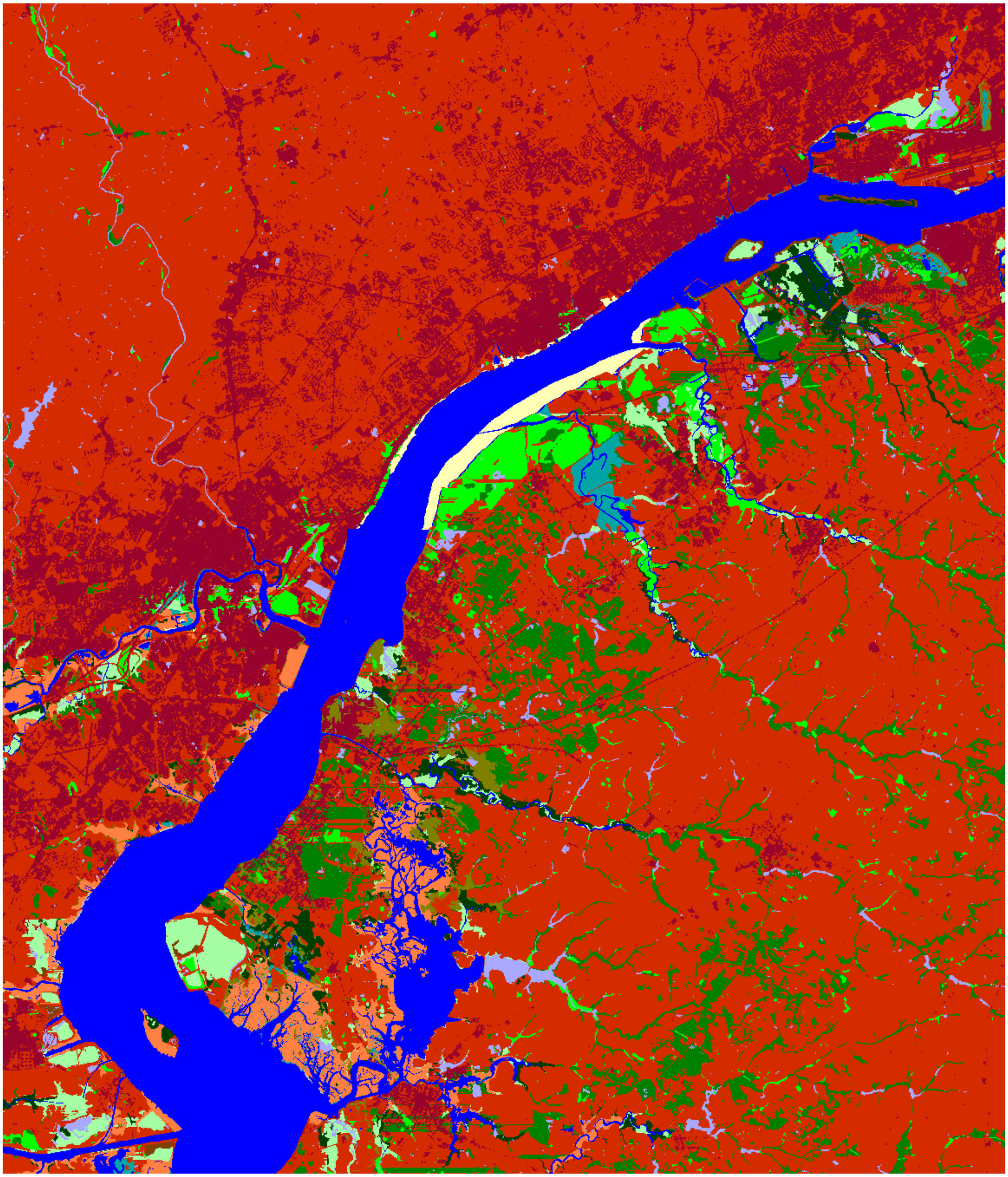
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



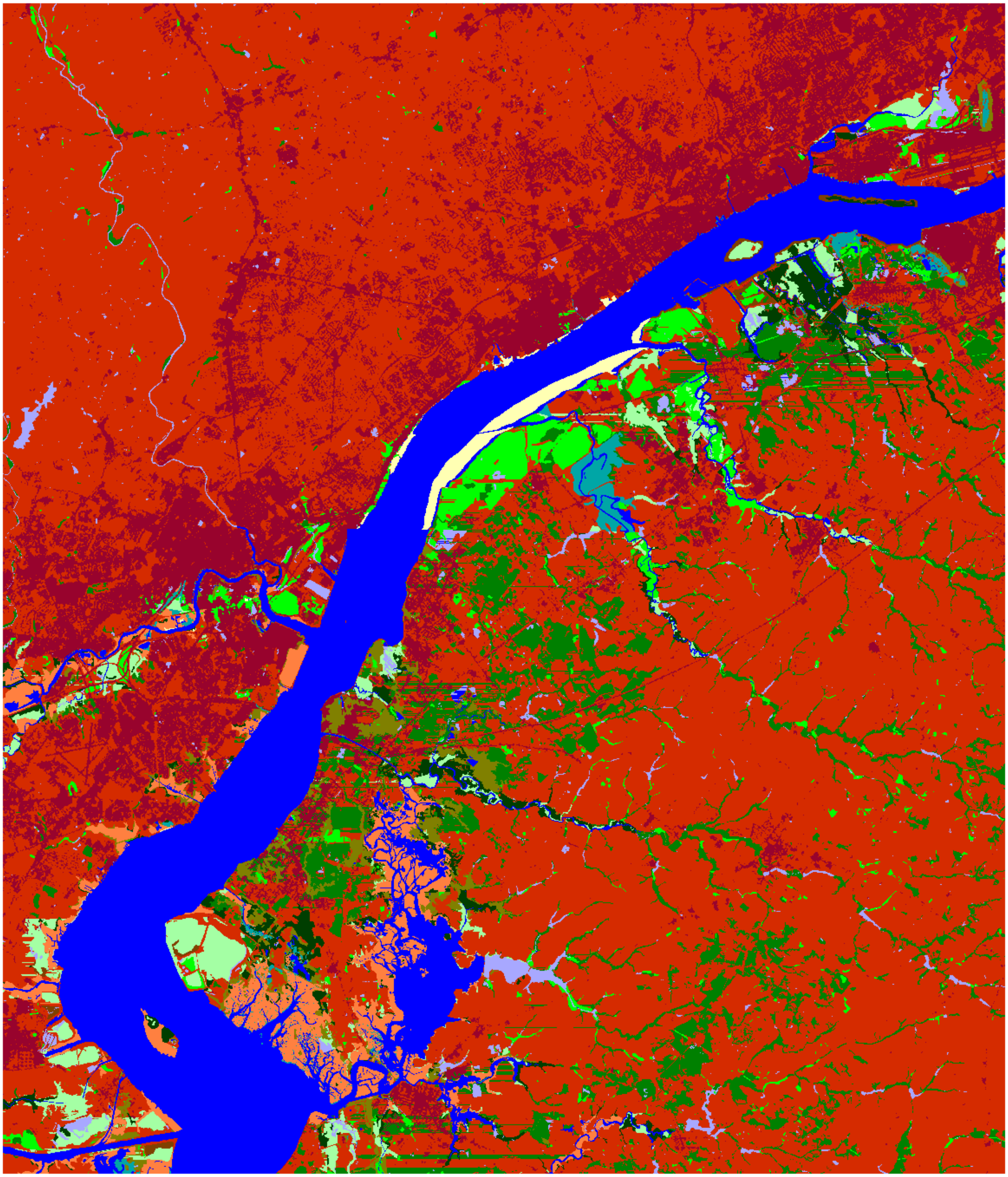
Location of Supawna Meadows National Wildlife Refuge (in rectangle) within simulation context



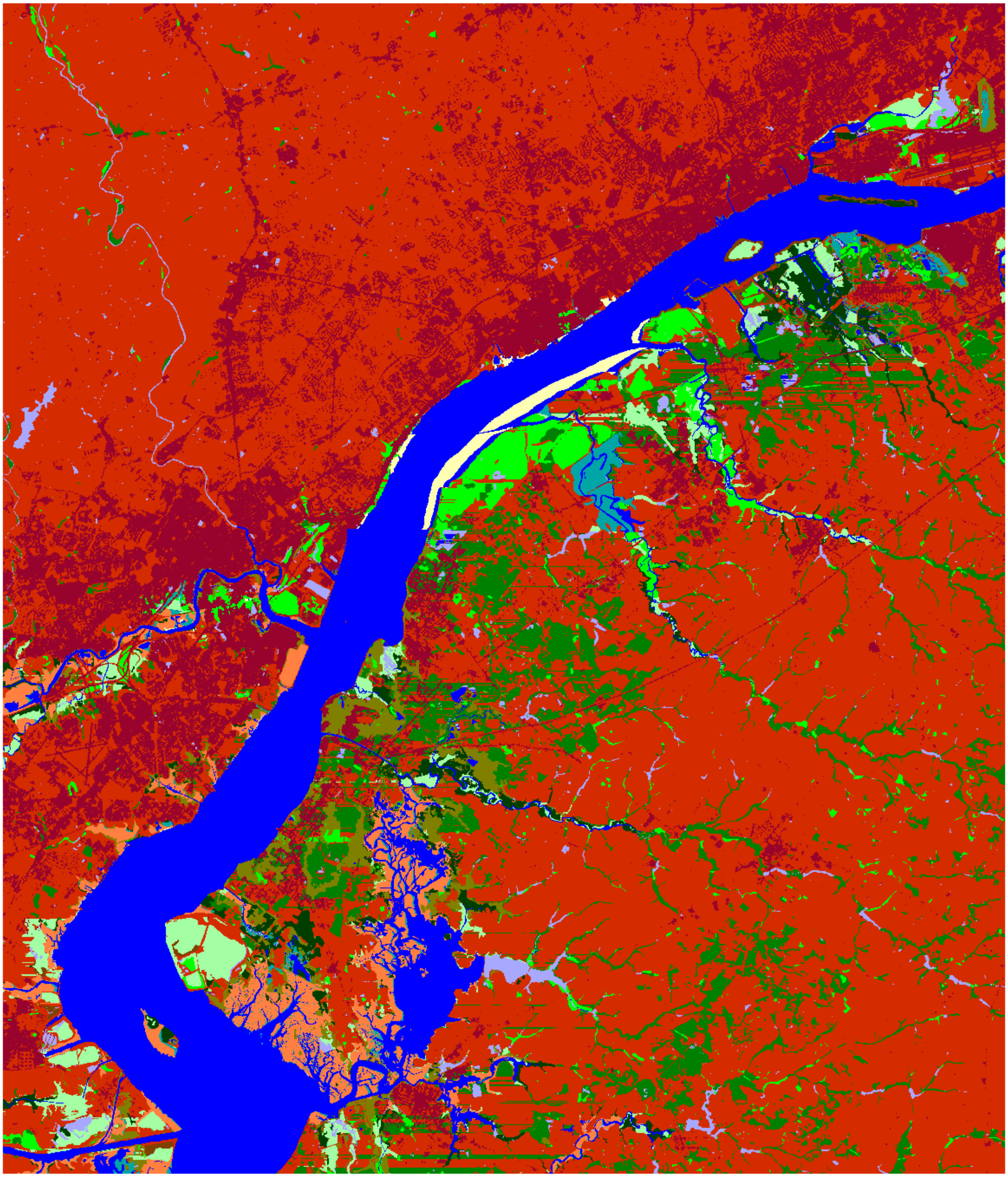
Supawna Meadows NWR, Initial Condition



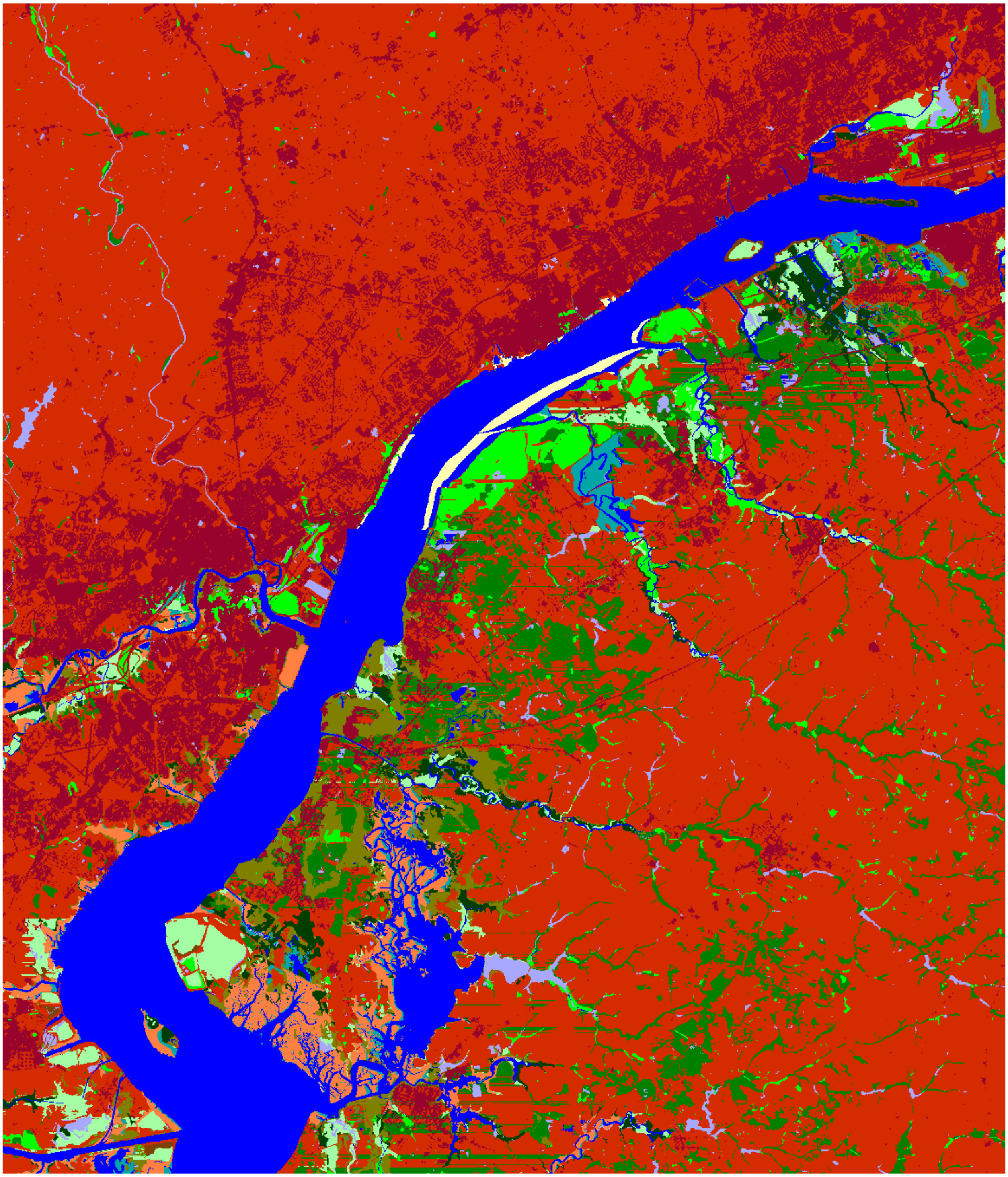
Supawna Meadows NWR, 2025, Scenario A1B Mean



Supawna Meadows NWR, 2050, Scenario A1B Mean



Supawna Meadows NWR, 2075, Scenario A1B Mean



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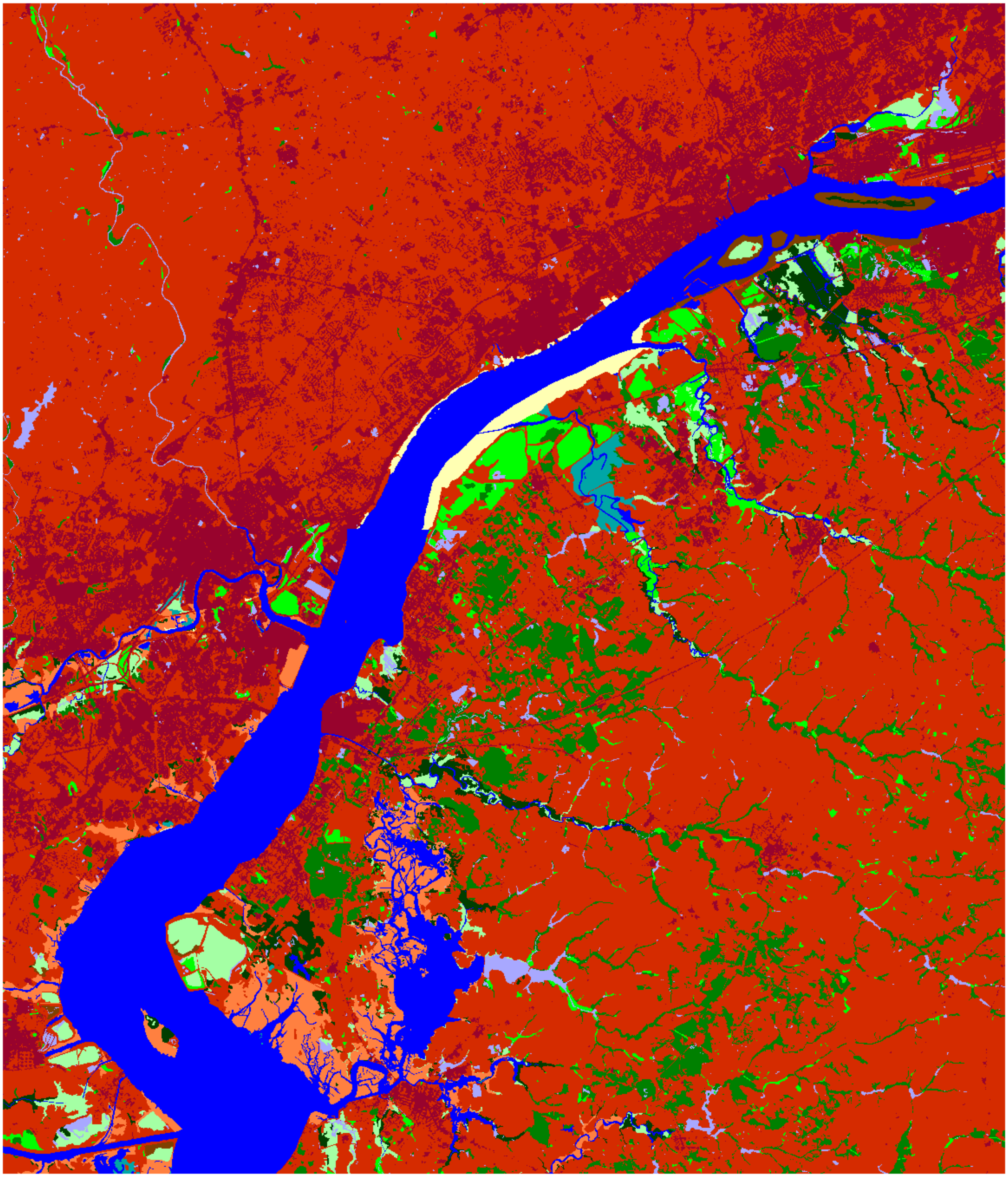

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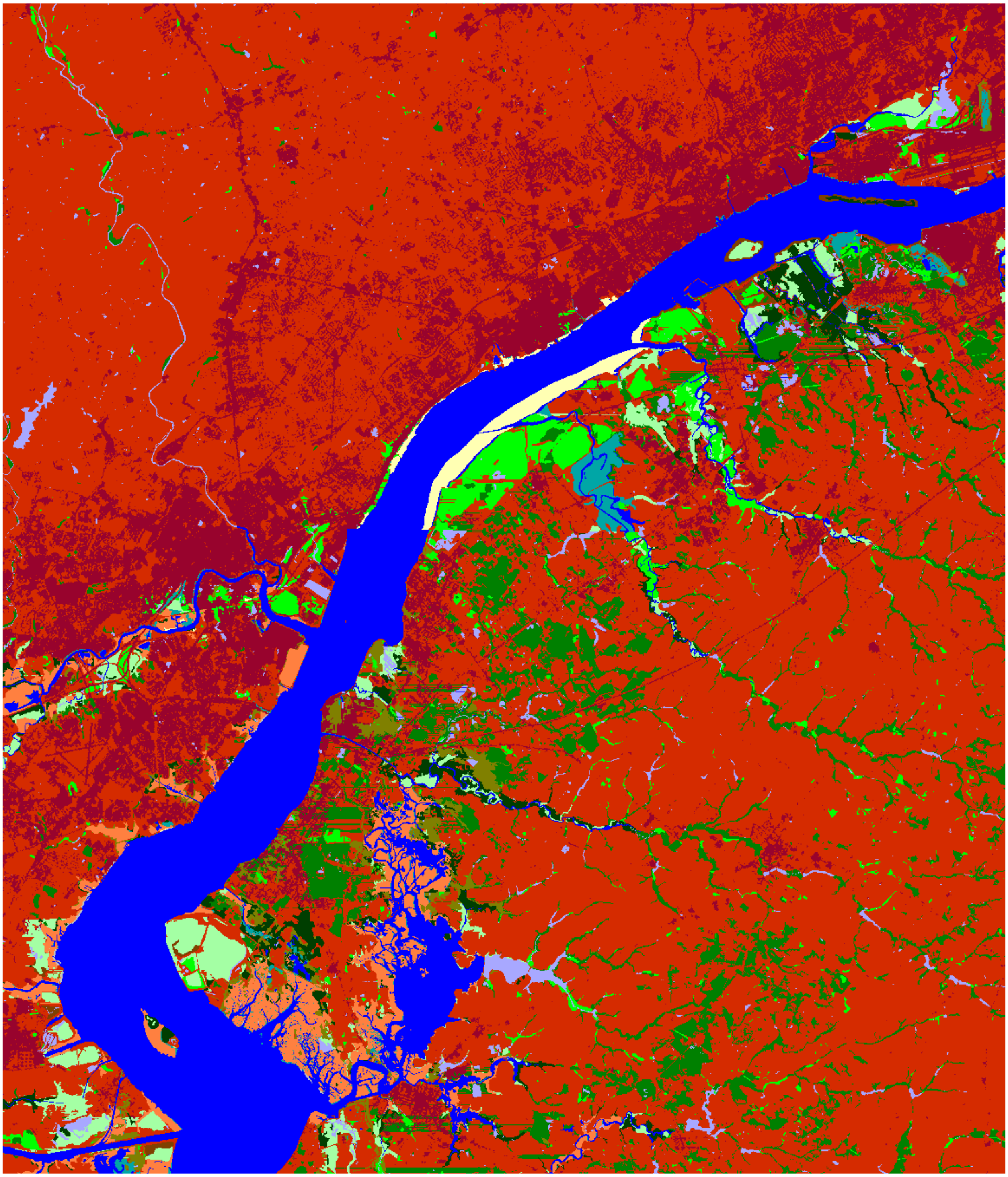
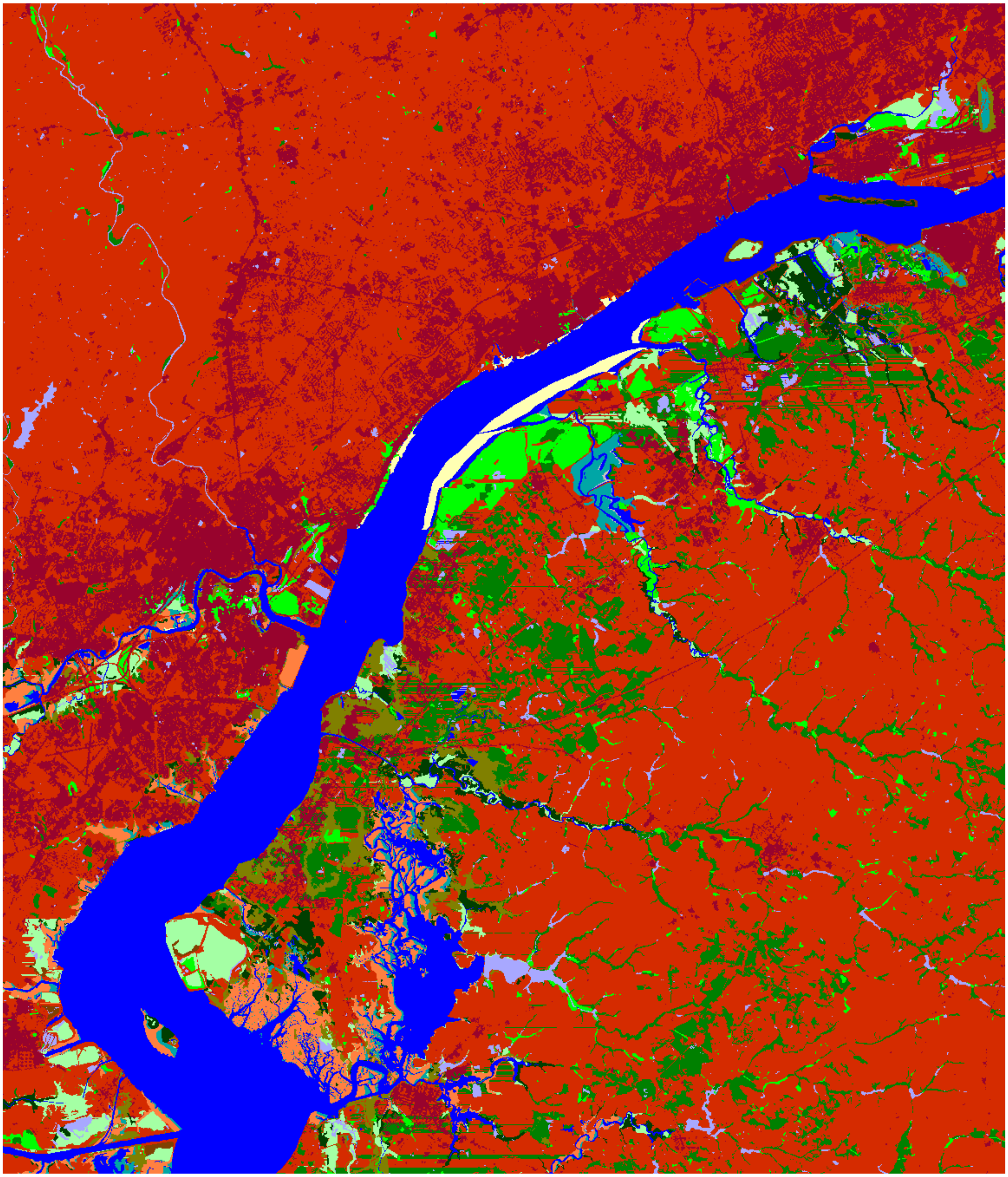


Supawna Meadows NWR, 2025, Scenario A1B Maximum



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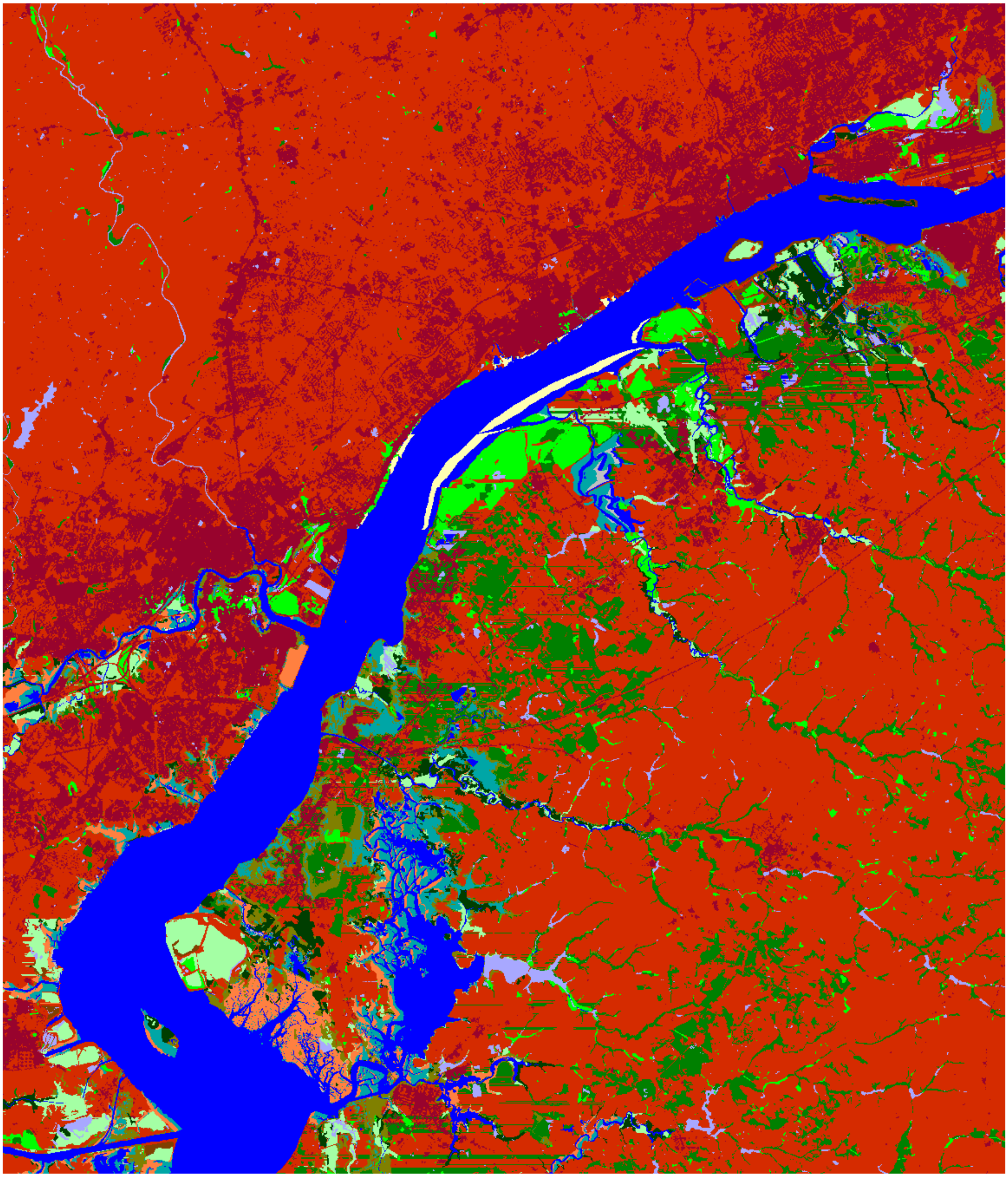

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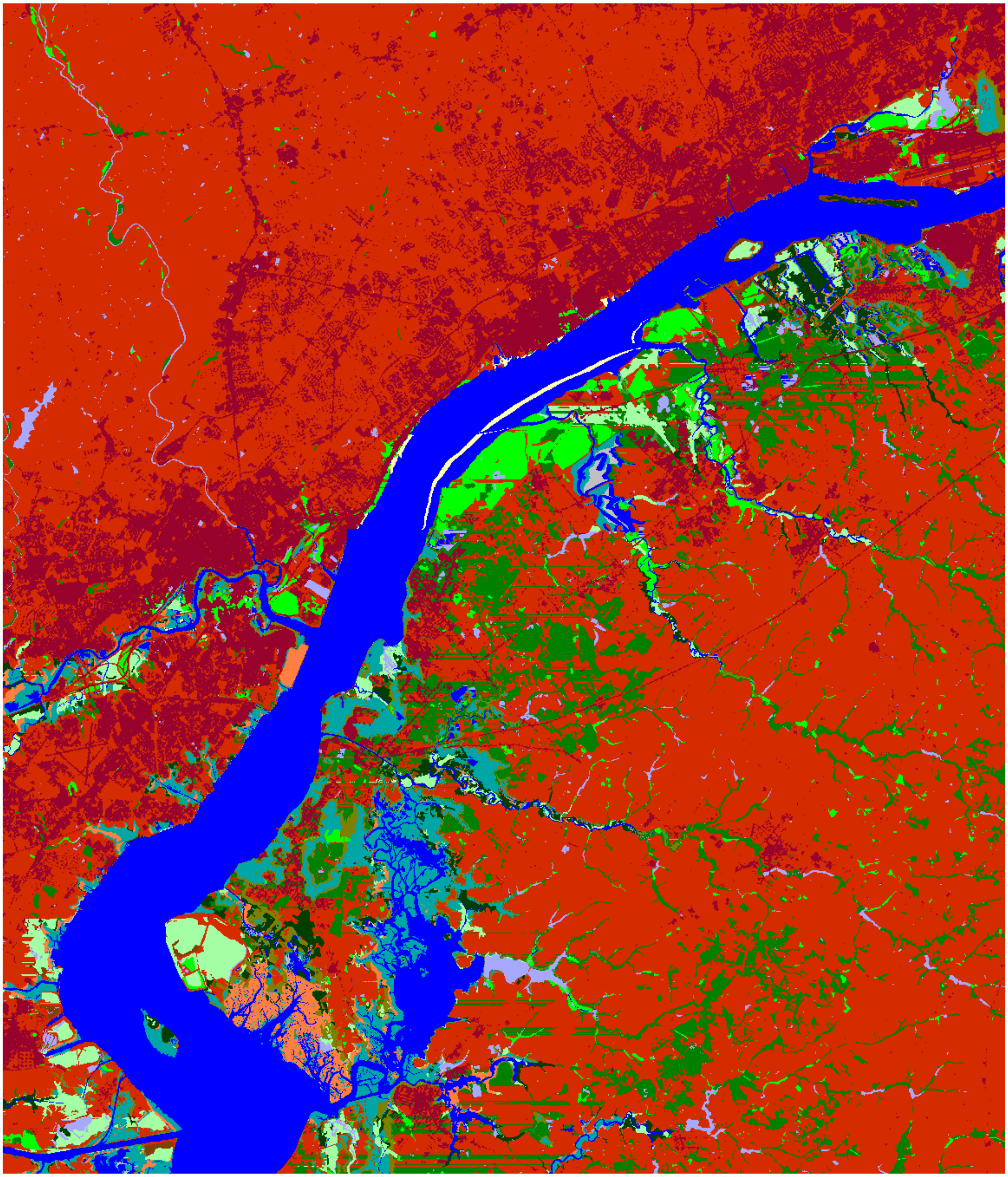

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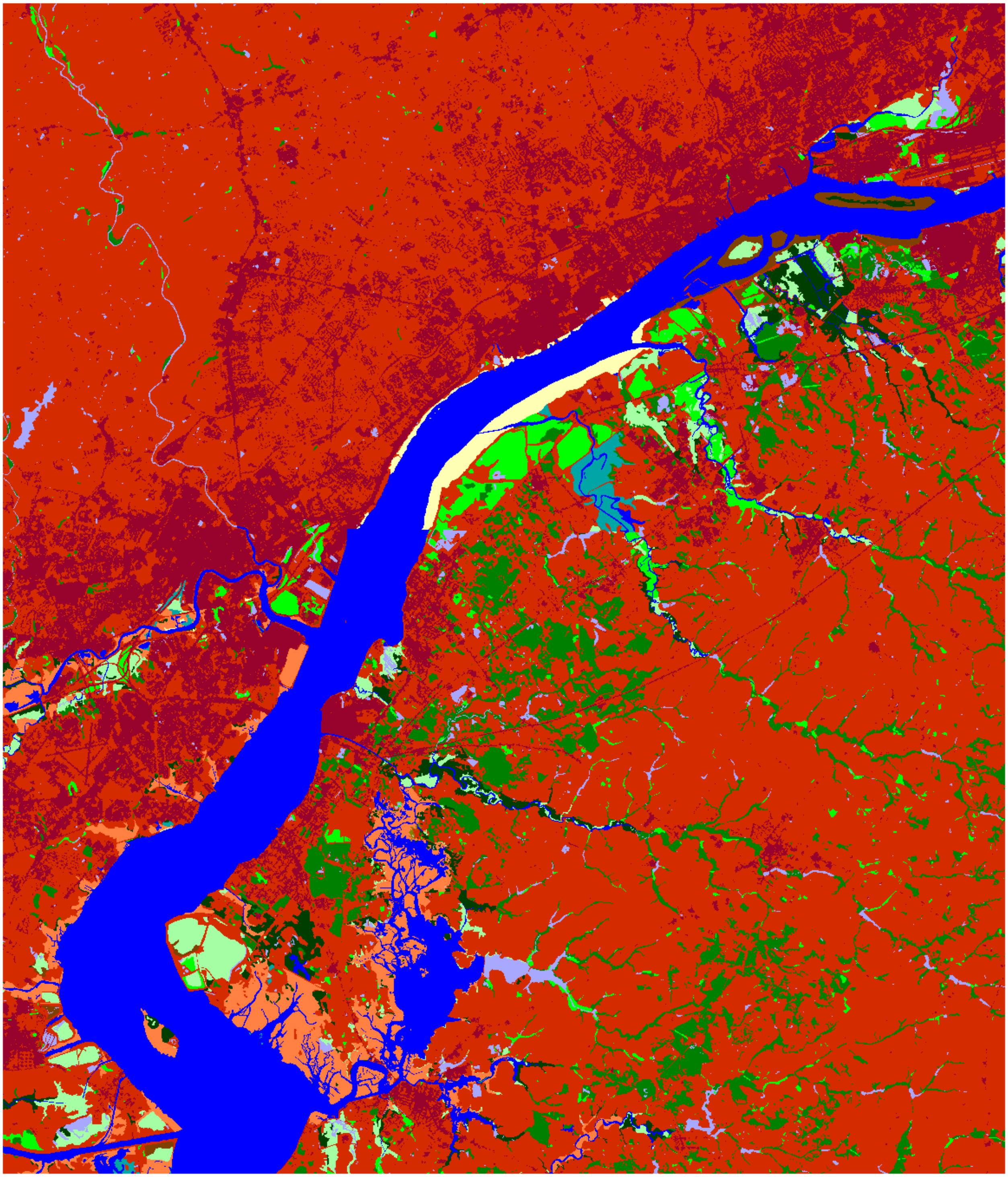

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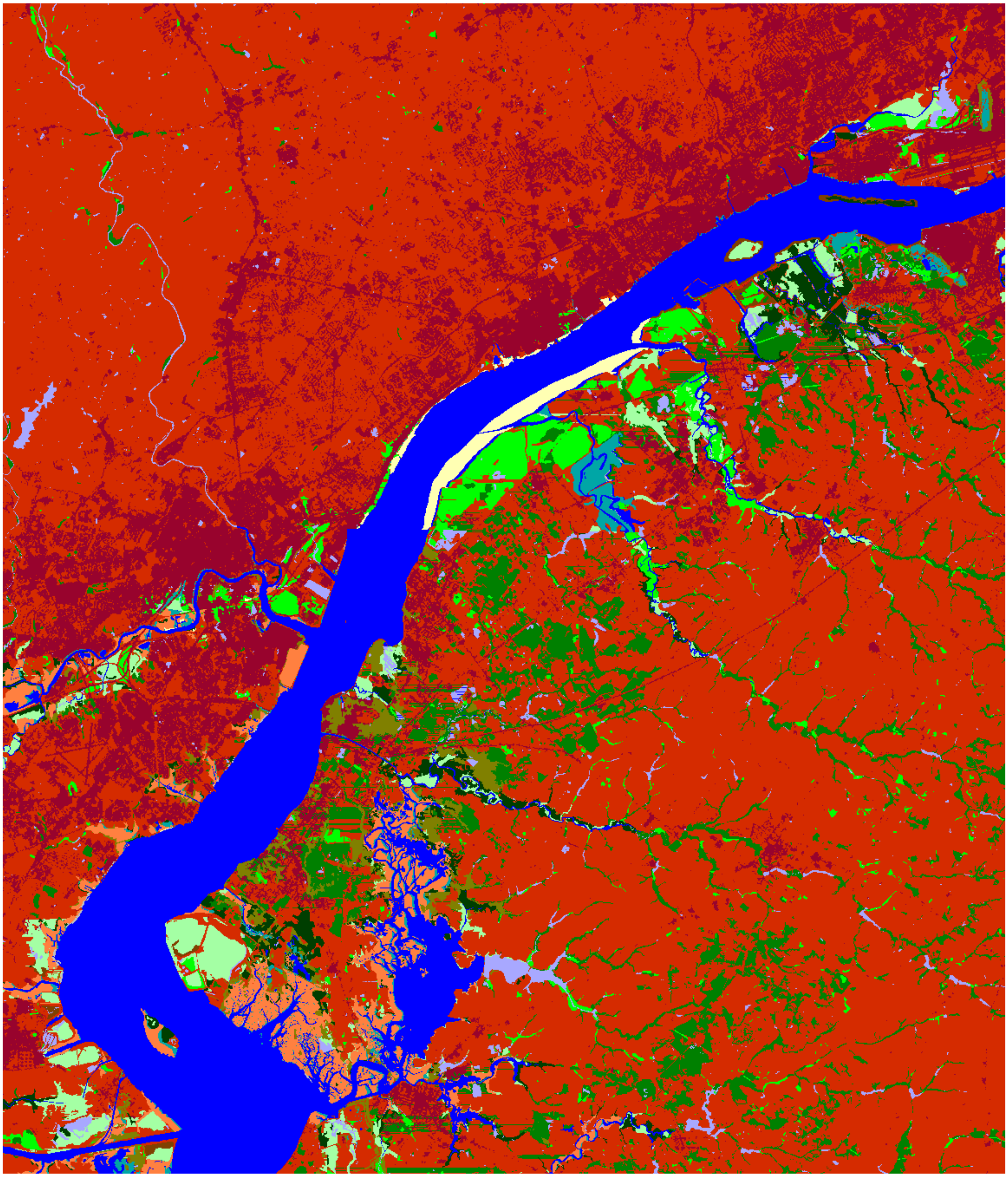
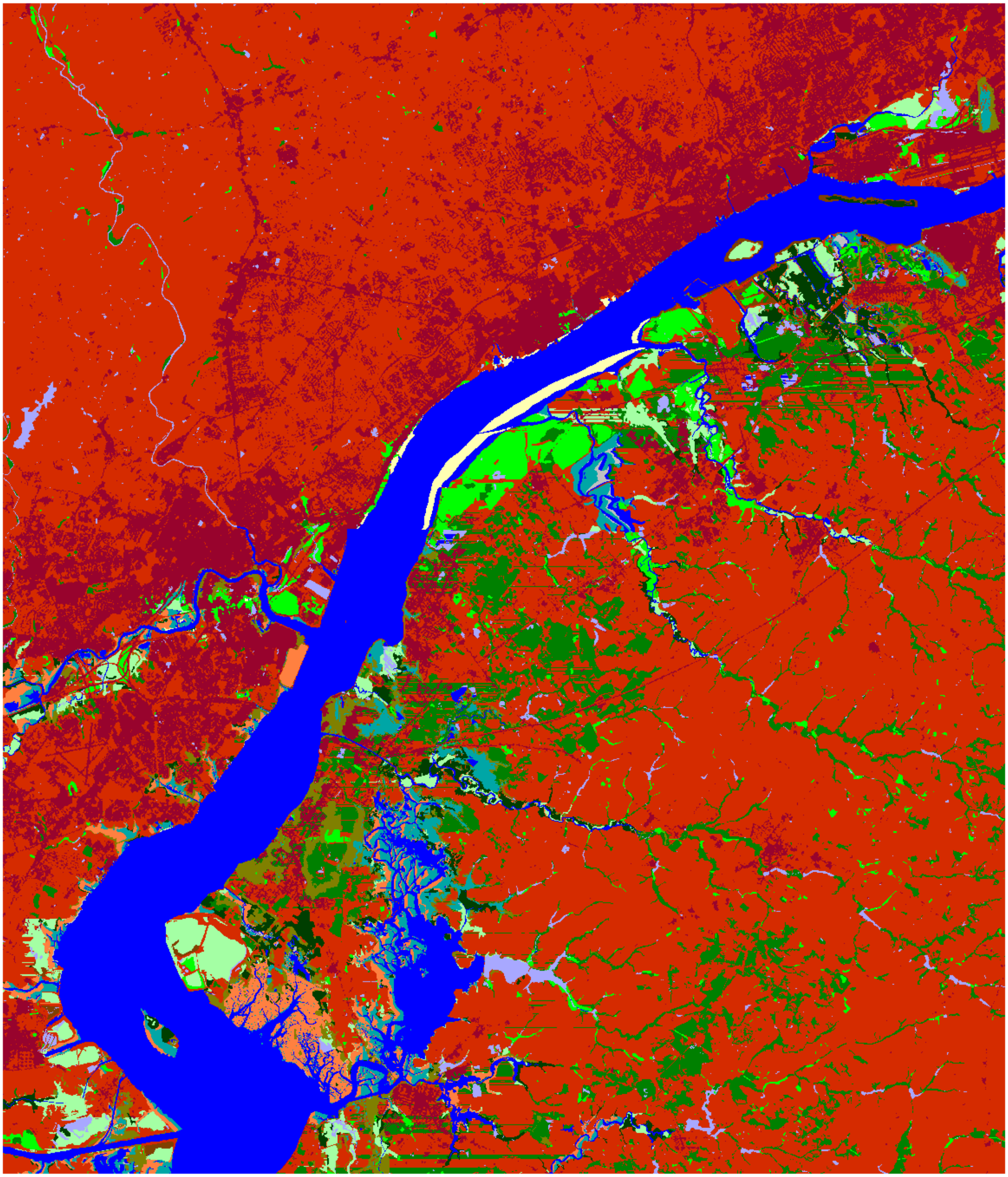


Supawna Meadows NWR, 2025, 1 meter



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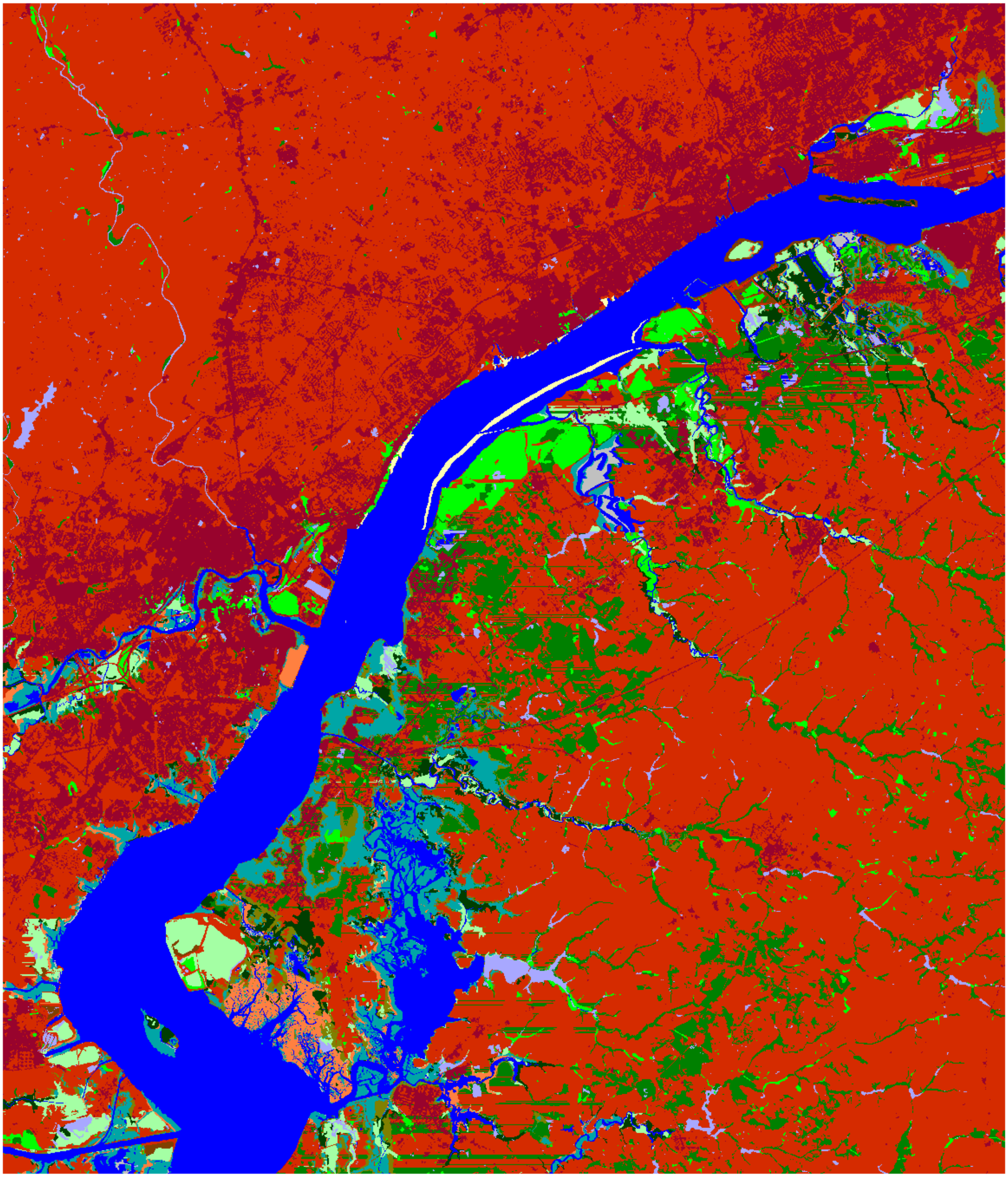

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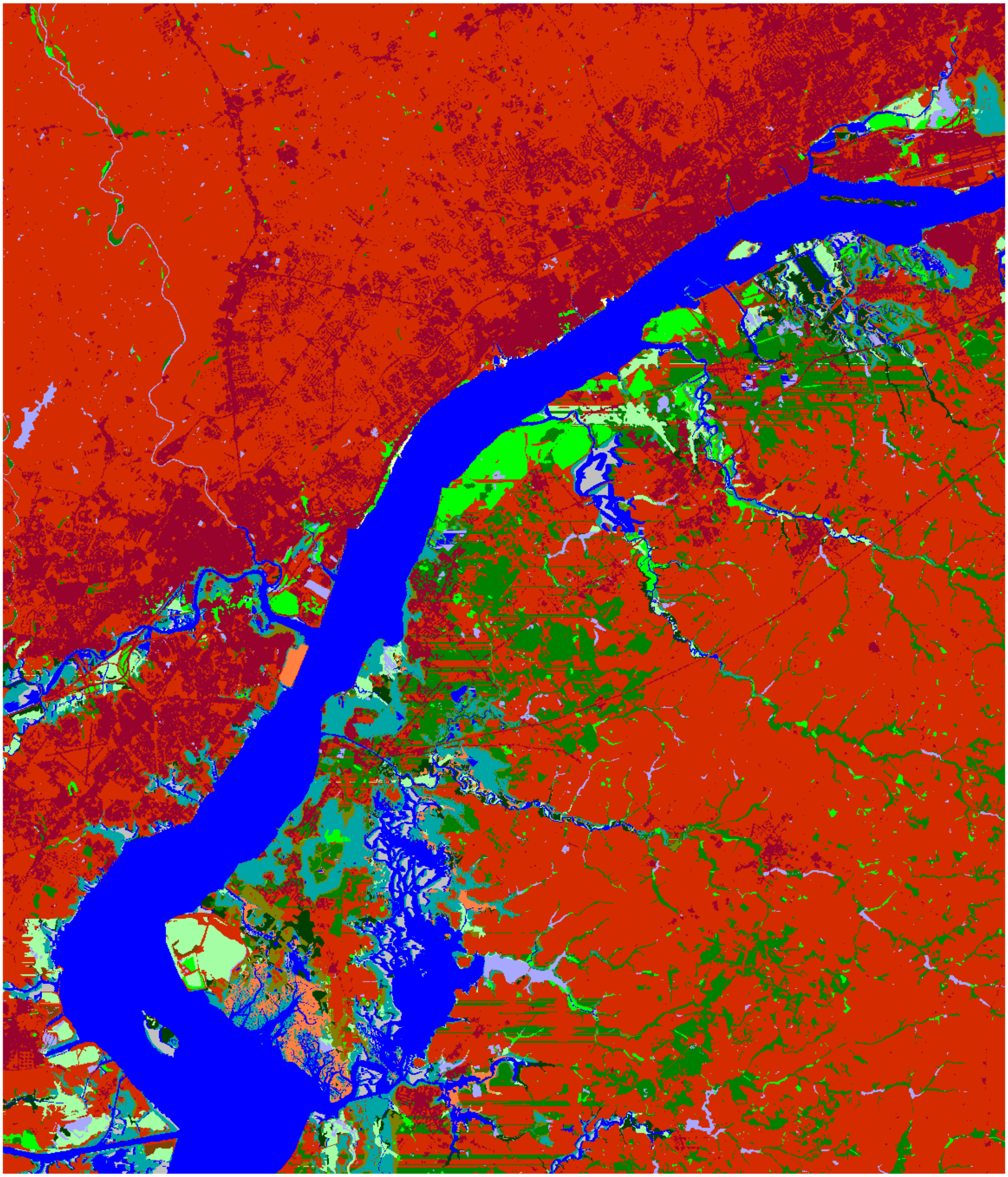

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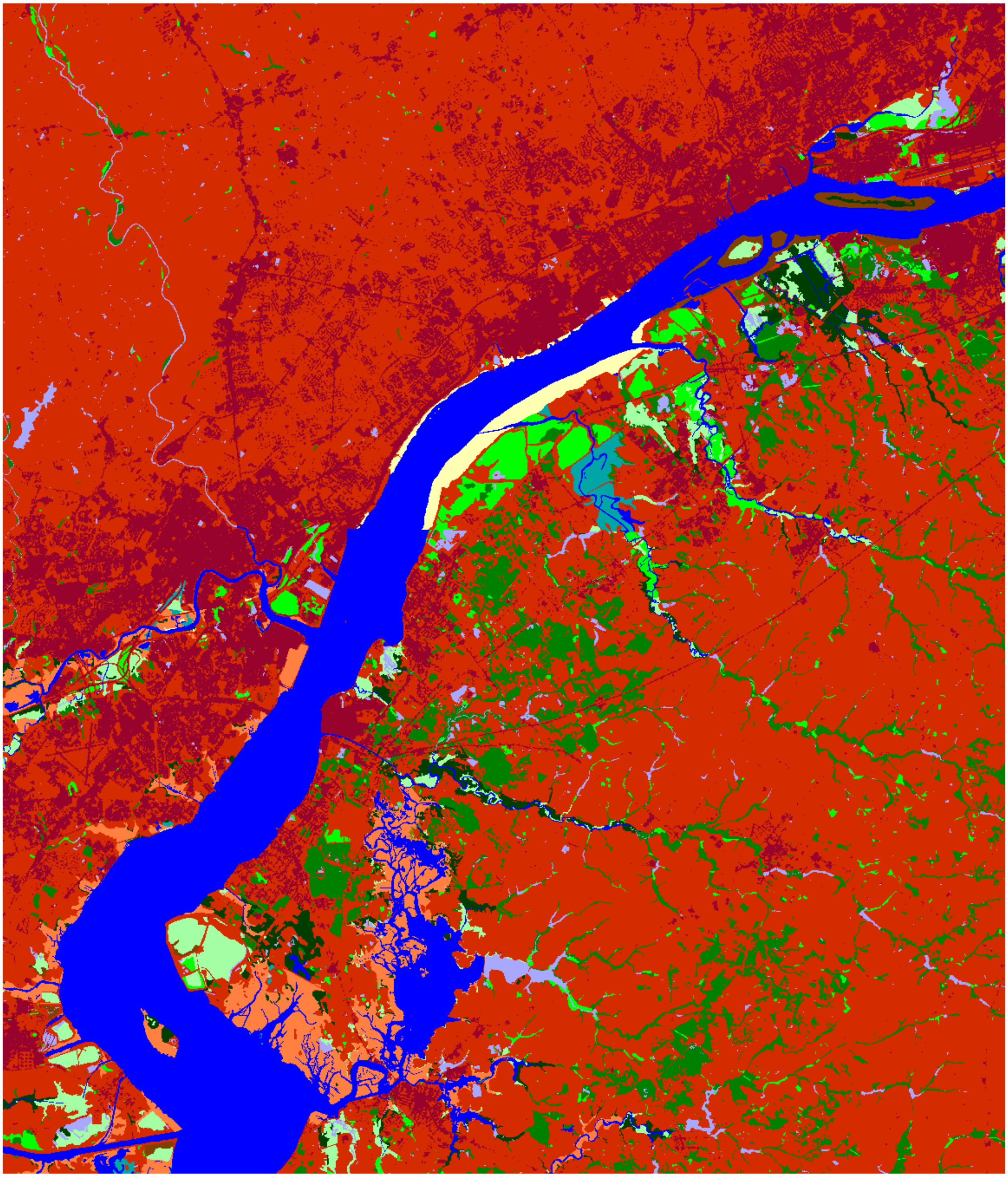

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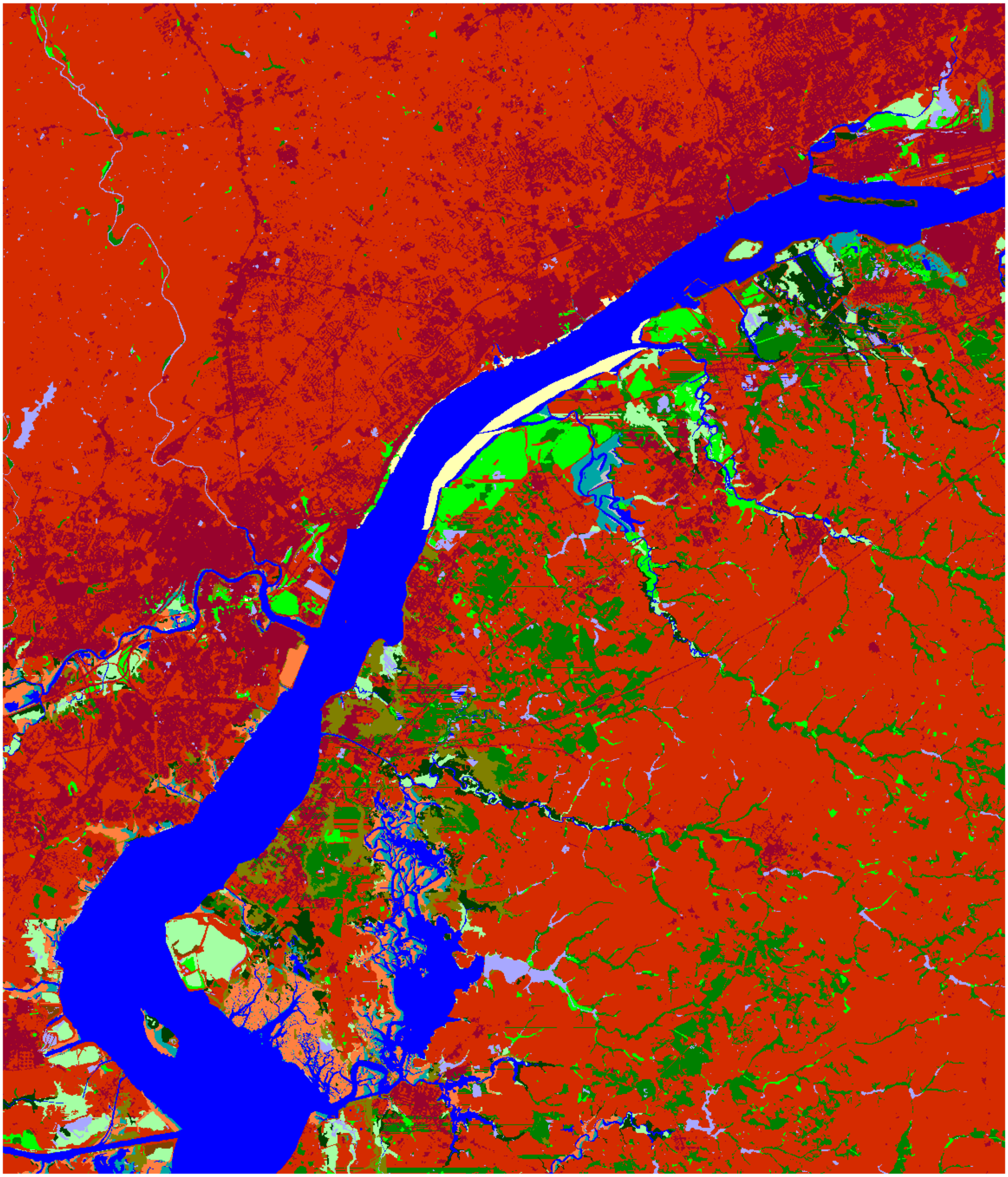
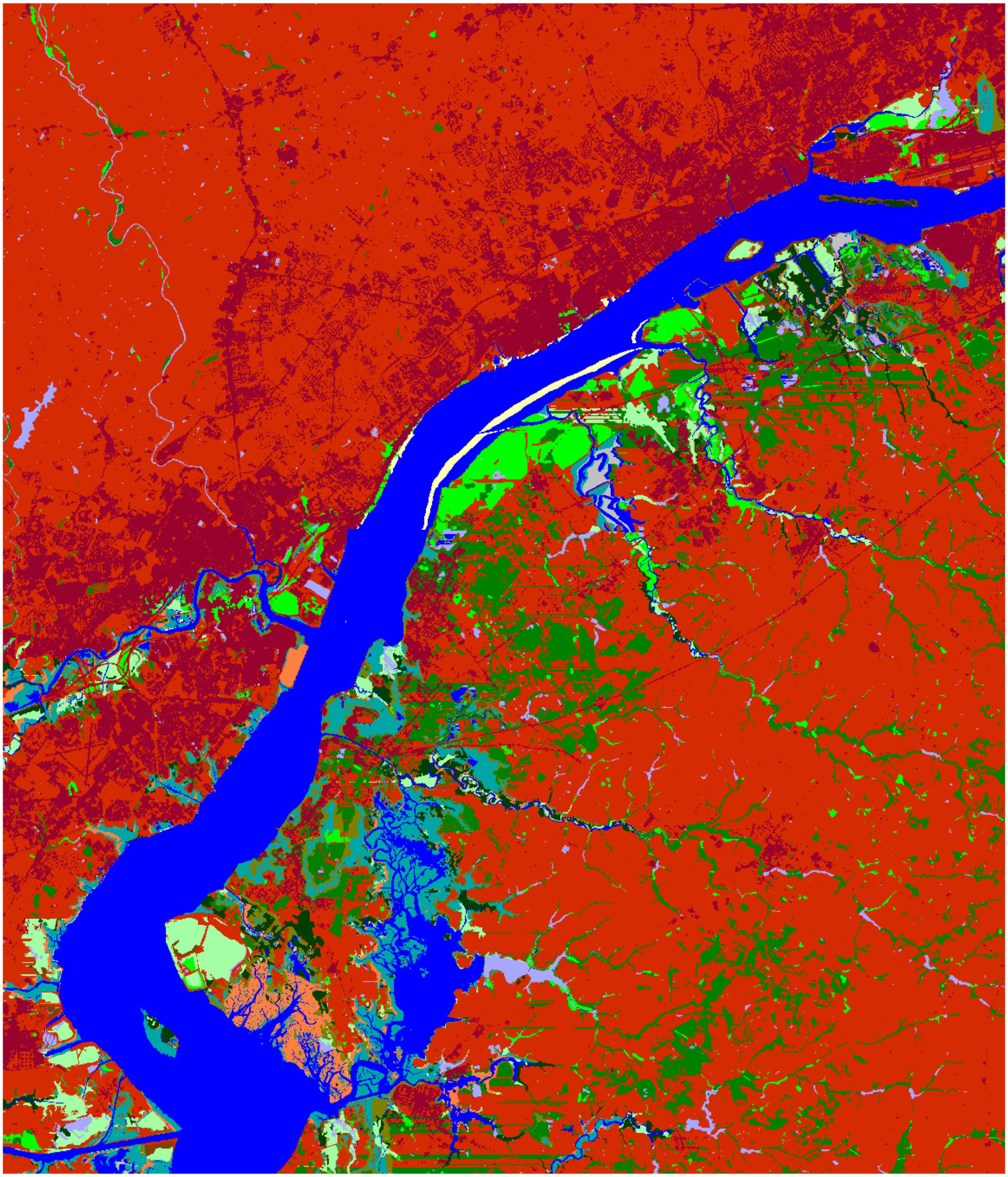


Supawna Meadows NWR, 2025, 1.5 meter



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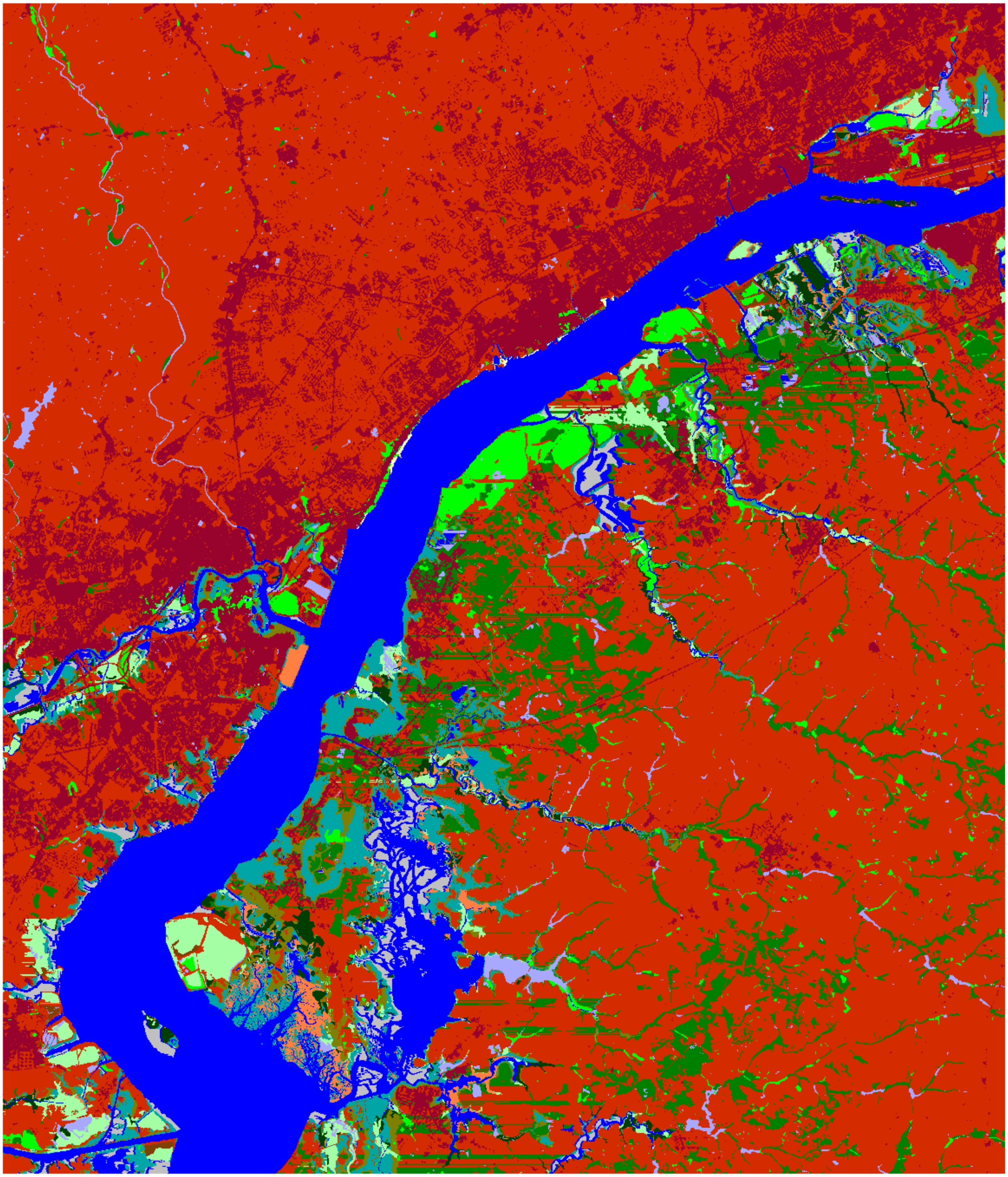

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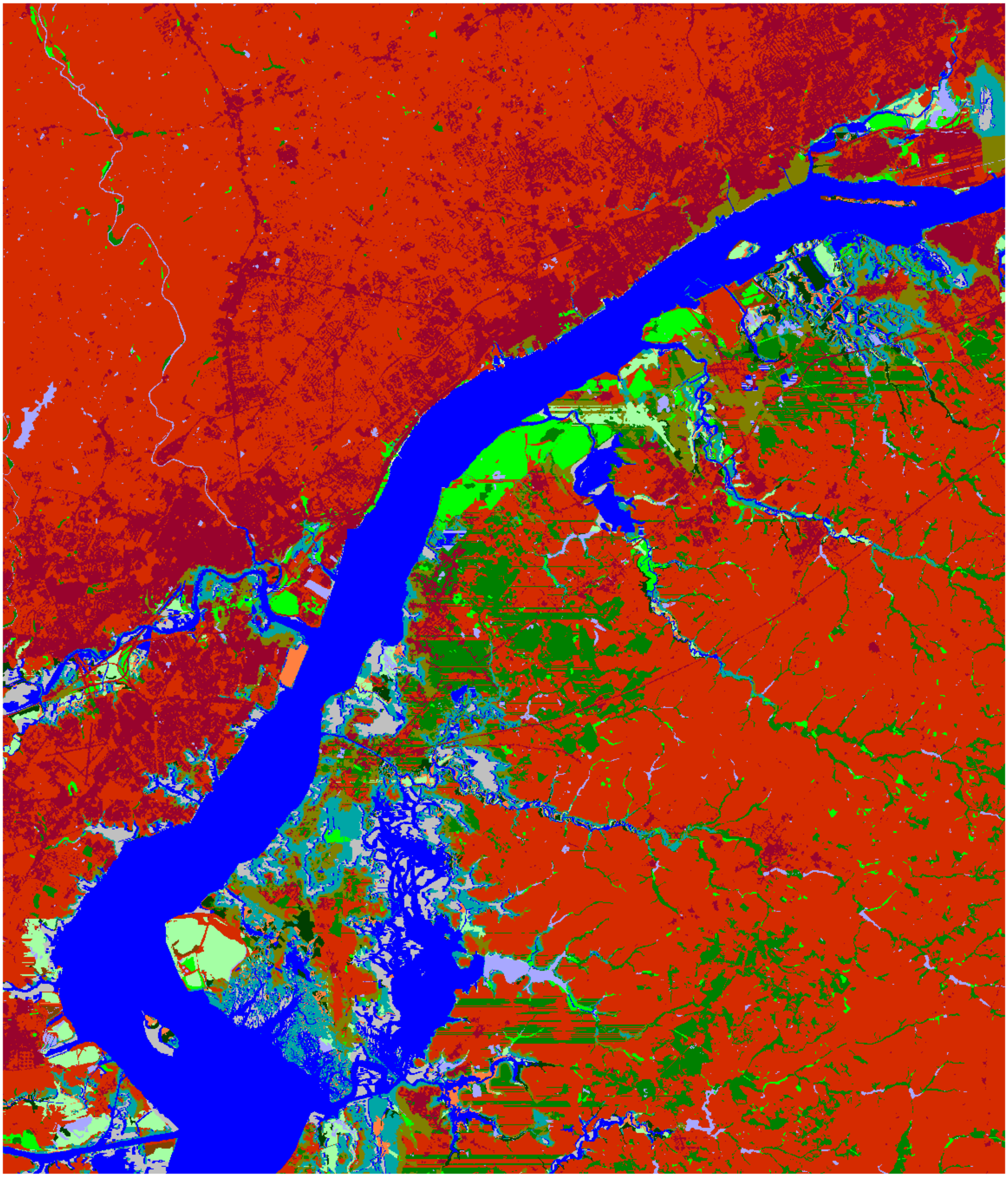

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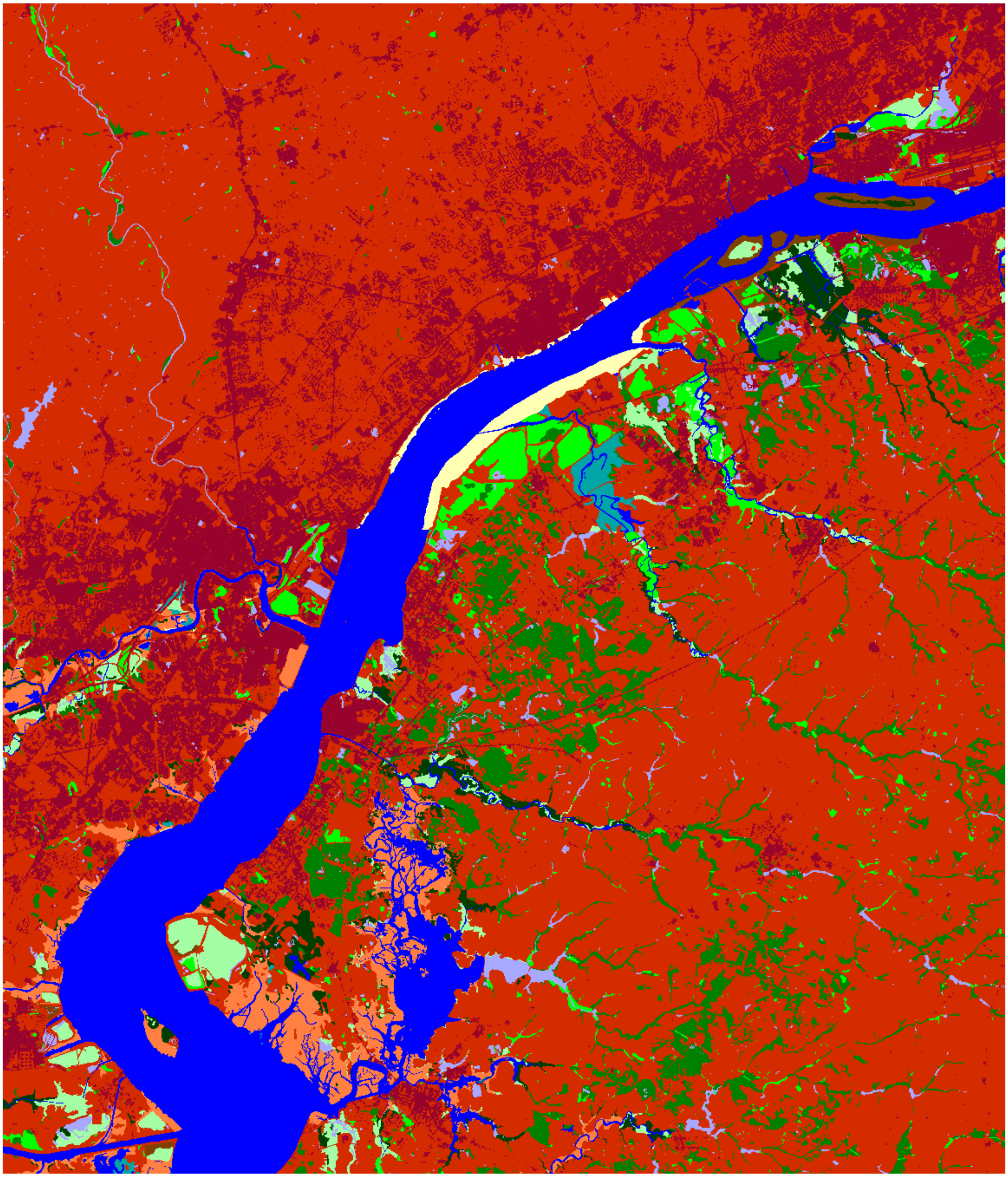

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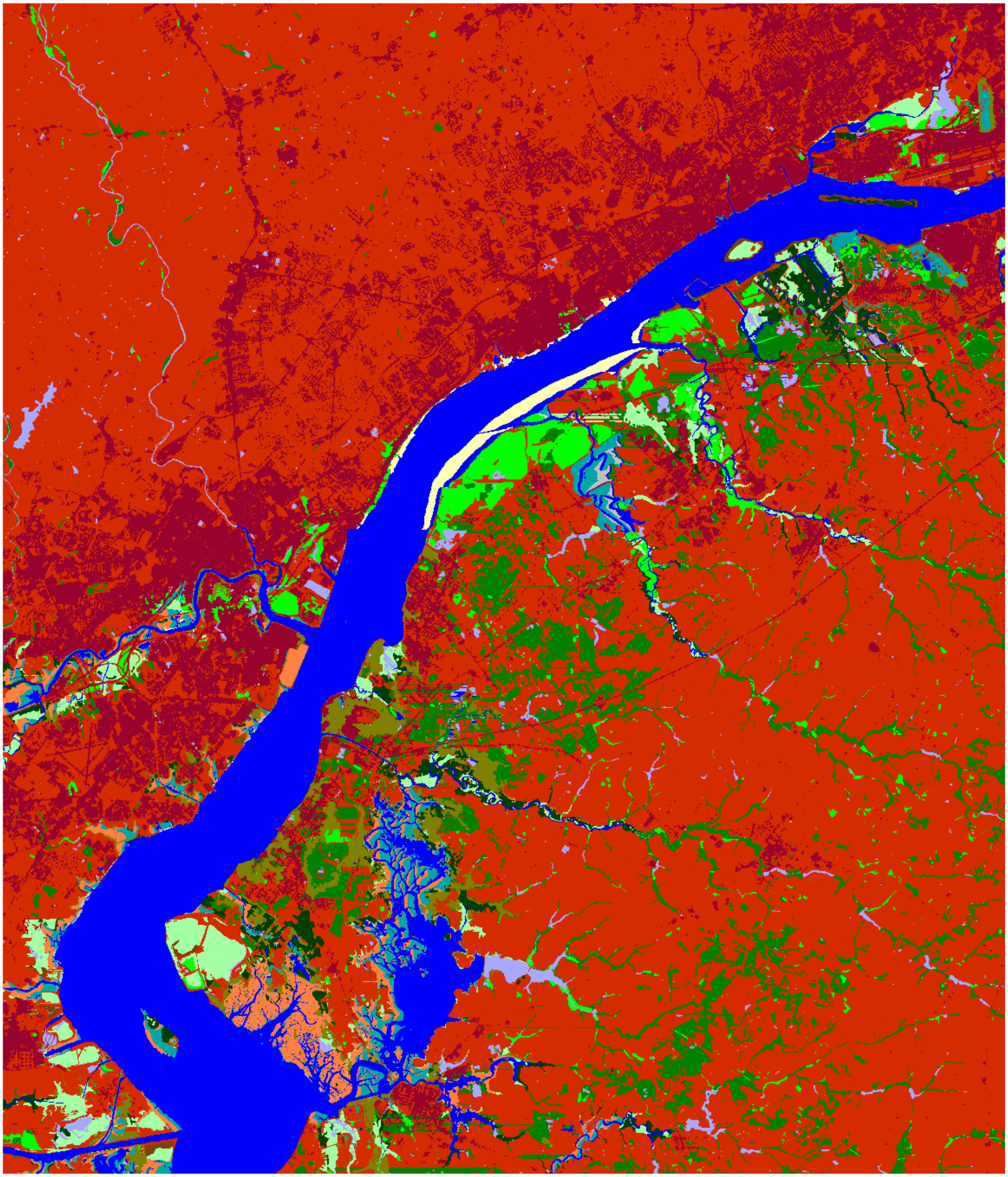
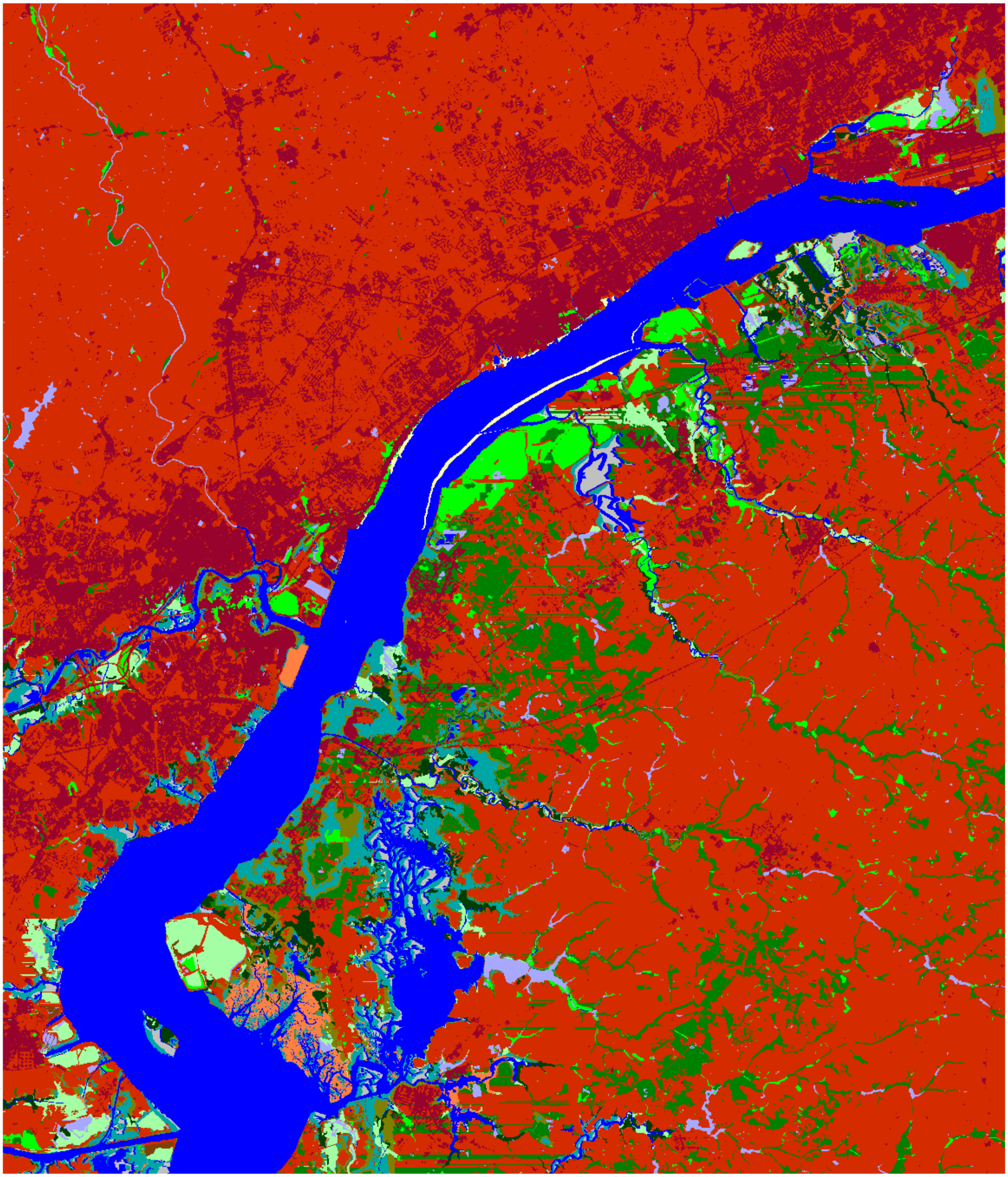


Supawna Meadows NWR, 2025, 2 meter



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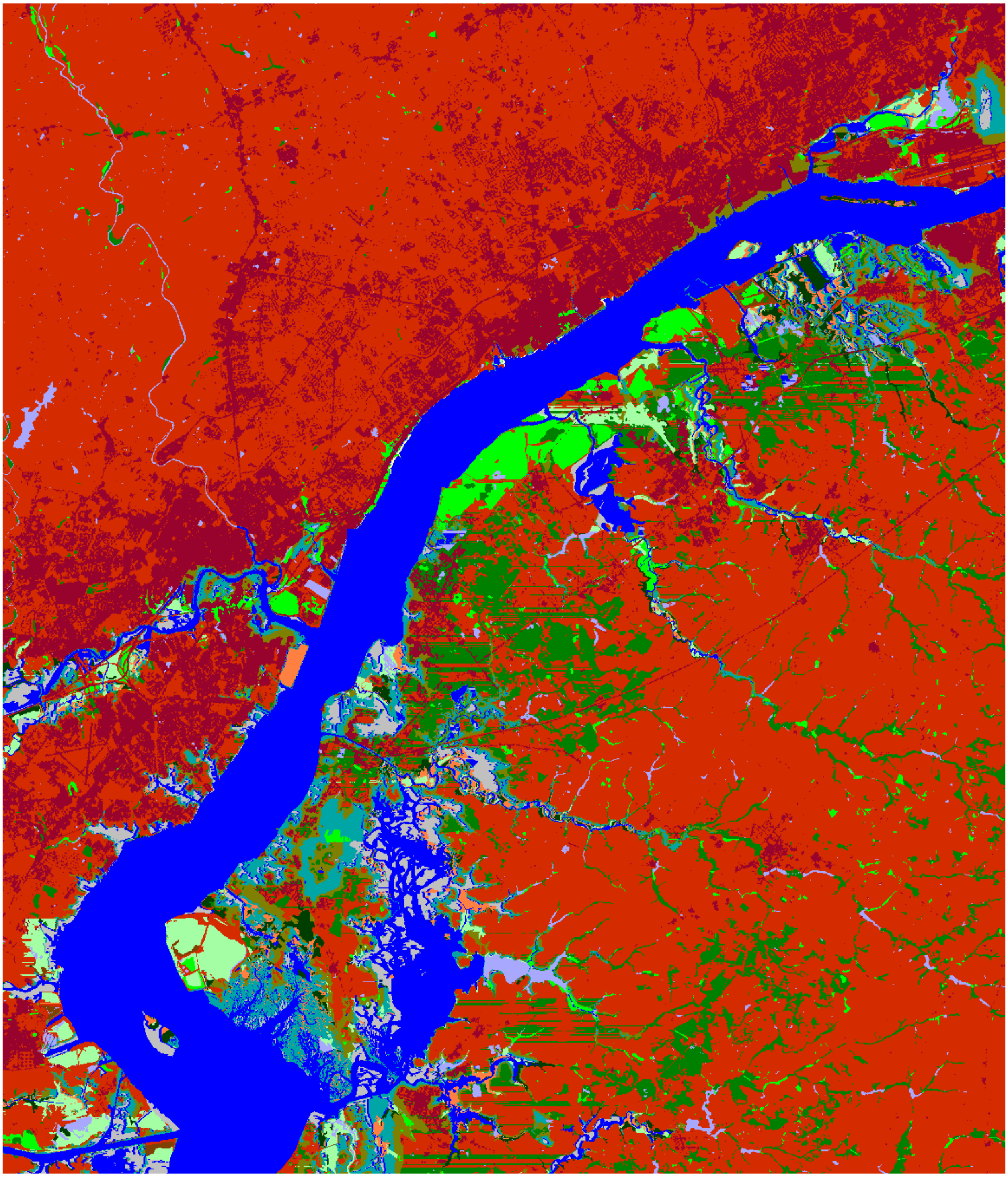

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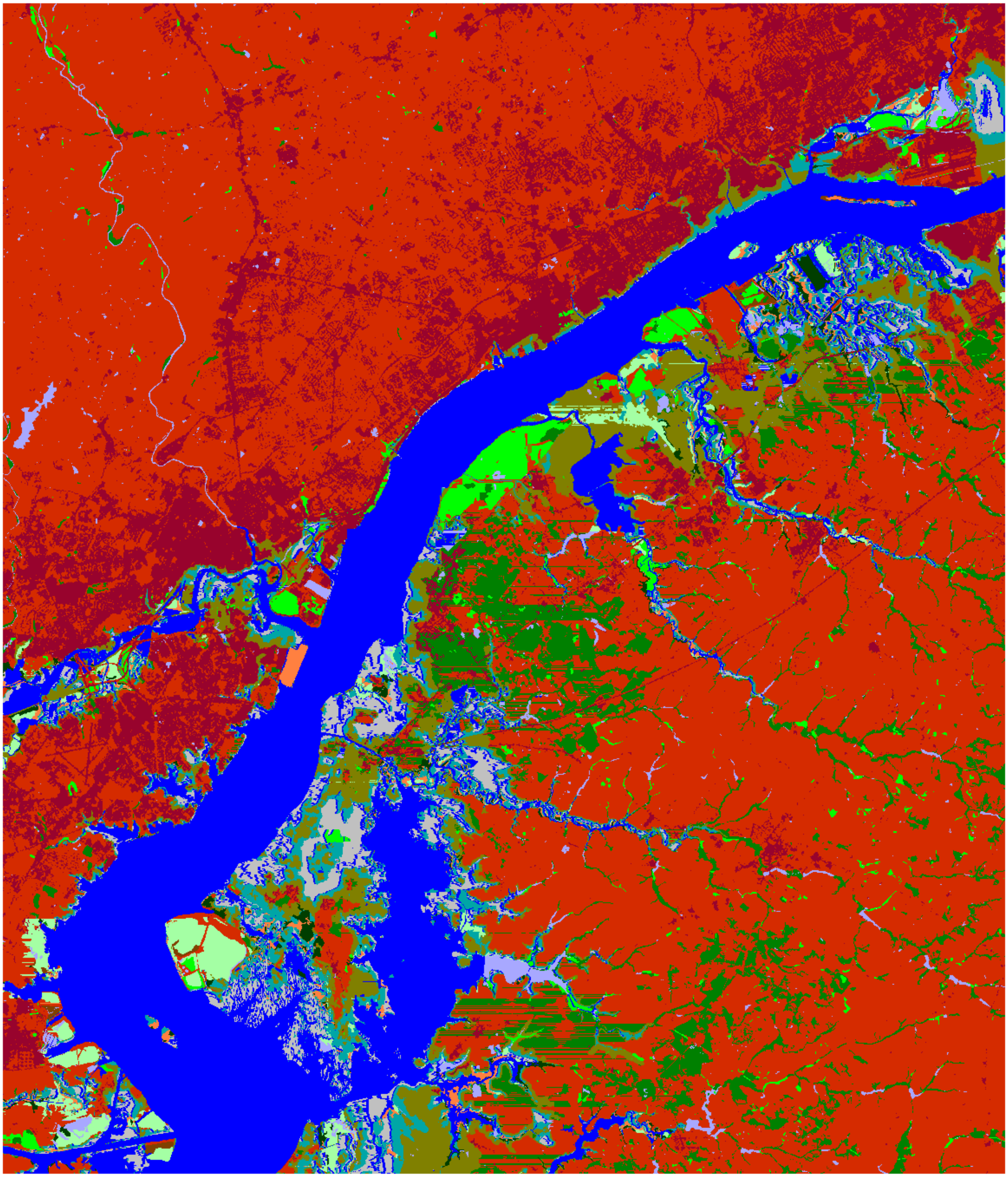

Supawna Meadows NWR, 2100, 2 meter