Application of the Sea-Level Affecting Marshes Model (SLAMM 5.1) to Presquile 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 is the latest version of the SLAMM Model, developed in 2006/2007 and based on SLAMM 4.0. SLAMM 5.0 provides the following refinements:

- The capability to simulate fixed levels of sea-level rise by 2100 in case IPCC estimates of sea-level rise prove to be too conservative;
- Additional model categories such as "Inland Shore," "Irregularly Flooded (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

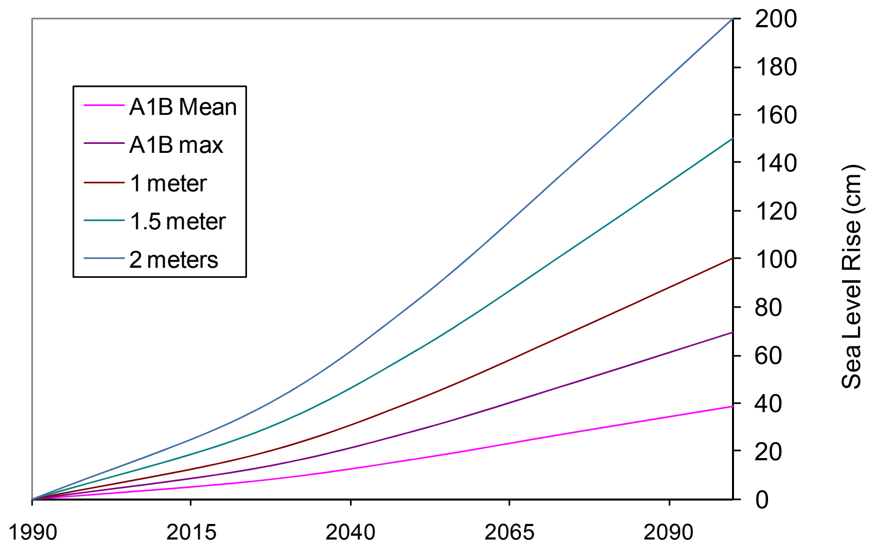
SLAMM 5 was run using scenario A1B from the Special Report on Emissions Scenarios (SRES) – mean and maximum estimates. The A1 scenario assumes that the future world includes very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of 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. 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

High vertical-resolution LiDAR elevation data were not located for this site. Therefore, elevation data used for model simulations were based on the USGS National Elevation Dataset. NED metadata indicate that these maps were derived from 1968 surveys with a resulting contour interval of ten feet (Figure 1). Cell elevations are interpolated between contour intervals.

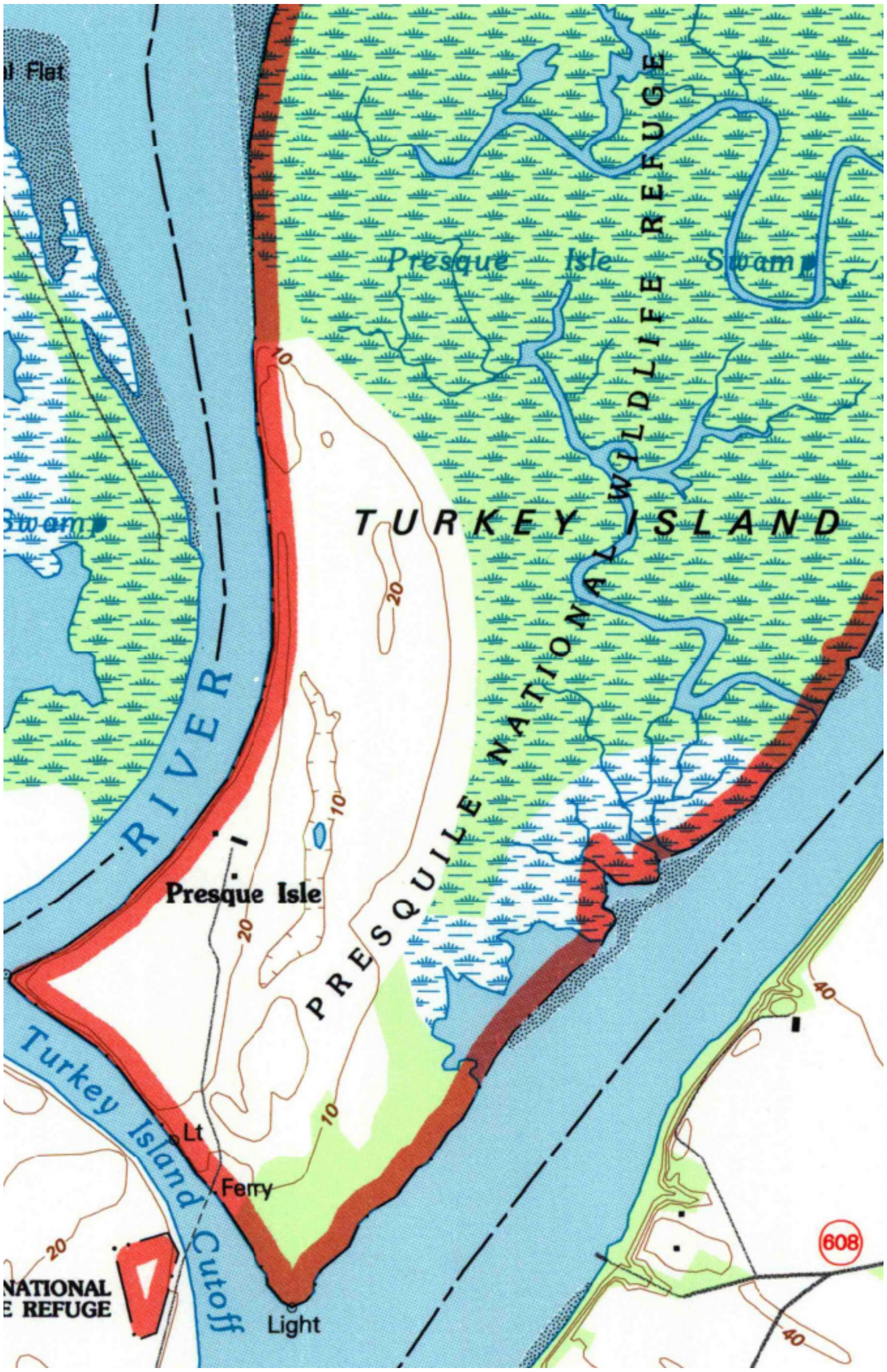


Figure 1: USGS map of Presquile NWR.

The National Wetlands Inventory for Presquile NWR is based on a photo date of 1994. Converting this NWI survey into 30 meter cells indicates that the approximately thirteen hundred acre refuge (approved acquisition boundary including water) is composed of the categories as shown below:

Tidal Swamp	56.8%
Dry Land	22.2%
Riverine Tidal	10.9%
Tidal Fresh Marsh	9.7%

There are no diked wetlands in the Presquile NWR according to the National Wetlands Inventory.

The historic trend for sea level rise was estimated at 4.44 mm/year using long term tide data from a NOAA gage (8638610, Sewells Point, VA). The estimated rate of sea level rise for this refuge is nearly 3 mm/year greater than the global average for the last 100 years (approximately 1.7 mm/year). This differential in sea level rise is also applied to future sea level projections.

Eustatic projections of future sea level rise were further increased by 0.5 mm/year as a result of a study performed by Dr. Victoria Coles of University of Maryland (Figure 2). This study suggests that sea level rise in Chesapeake Bay will increase faster than eustatic trends due to regional heating, freshwater effects, or mass adjustments. Based on this analysis 0.5 mm/year were added to eustatic sea level rise trends. (This adjustment was performed by adding 0.5 mm/year to the historic SLR trend parameter.)

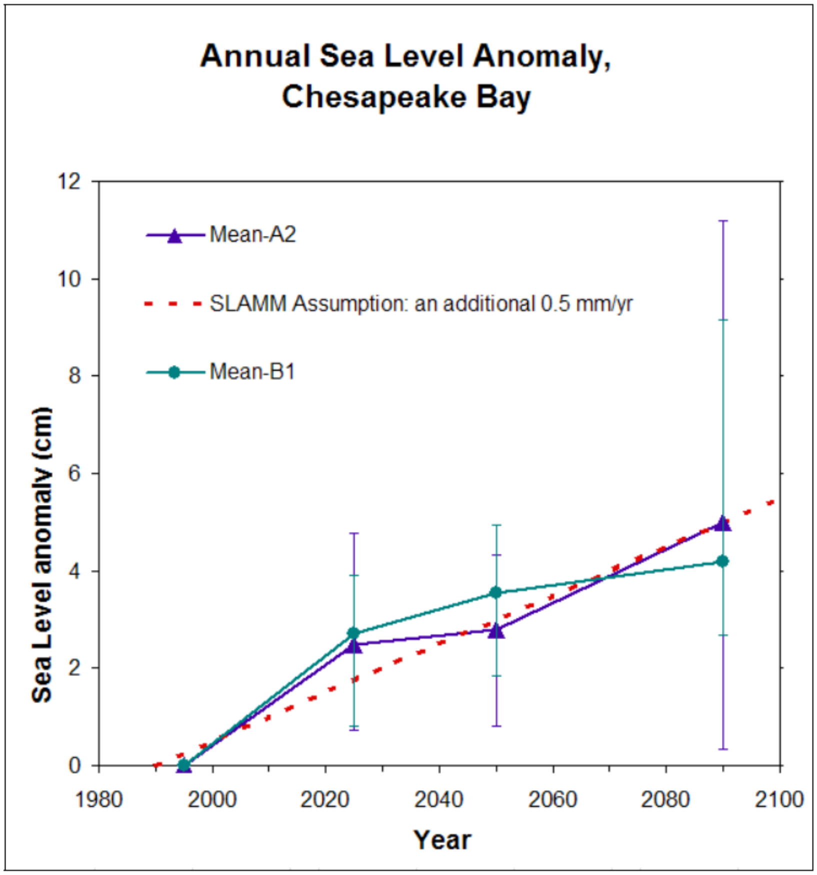


Figure 2: Adjustment of Eustatic SLR in SLAMM illustrated as red line. Source of model results, Dr. Victoria Coles Research Web Page, 11/15/2009, **http://hpl.umces.edu/vcoles/cbayclim-sl.htm**.

The tide range for Presquile NWR was determined to be 0.848 meters using a NOAA gage (8638481, City Point, Hopewell, VA) (Figure 3).

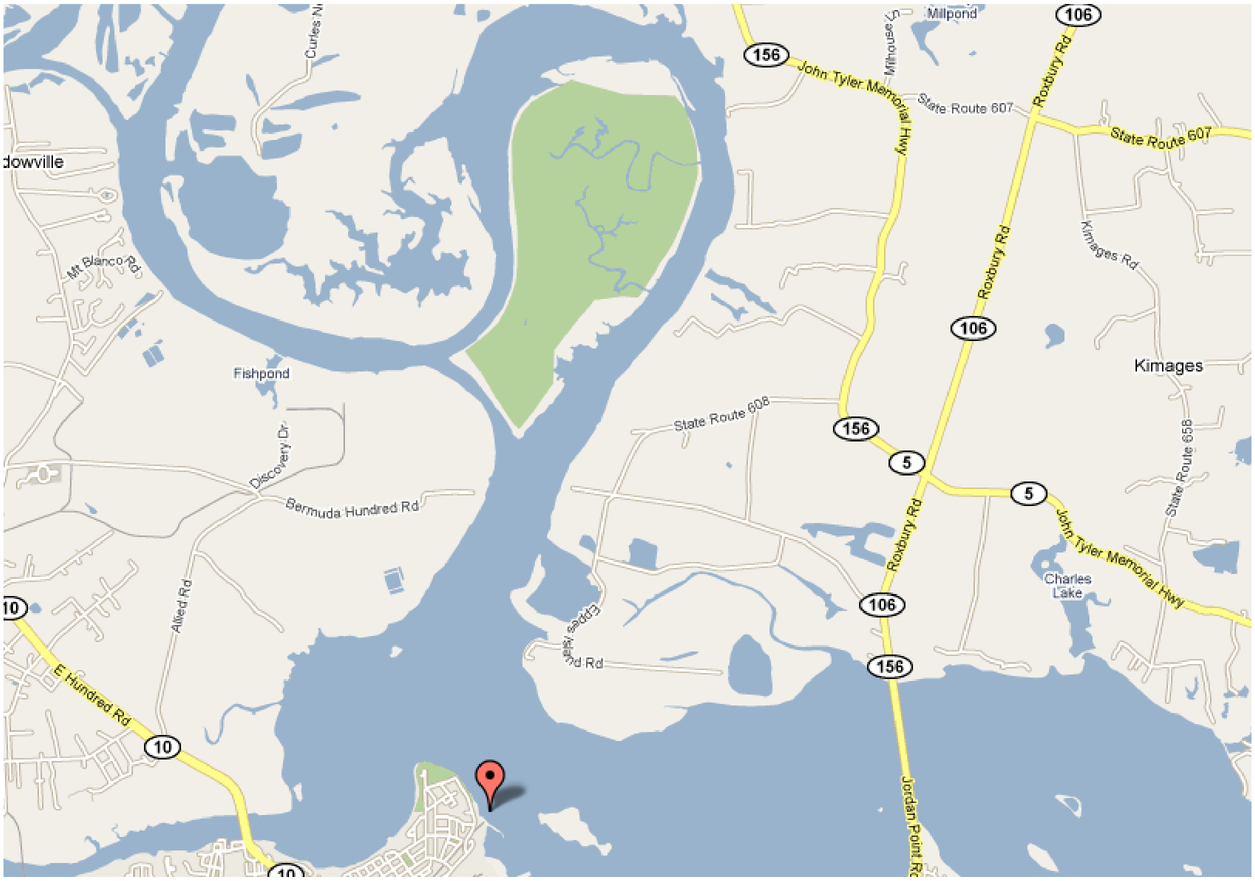


Figure 3: NOAA Gage Relevant to the Study Area.

No site-specific marsh accretion data were located for this refuge. Accretion rates in regularly flooded marshes were set to 6 mm/year (n=2), irregularly flooded marshes to 4.8 mm/year (n=5) and tidal fresh to 7.2 mm/year (n=5) using the means of numerous studies of marsh accretion within Maryland (Reed et al., 2008).

The MTL to NAVD correction was derived using the NOAA VDATUM modeling product. The correction varies by sub-site, and was determined to range from -0.001 meters to -0.0005 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, SLAMM will track partial conversion of cells based on elevation and slope.

The refuge manager of the Eastern Virginia Rivers NWR Complex, Joseph F. McCauley, indicated that no LiDAR elevation data, local accretion or erosion studies exist for this refuge.

SUMMARY OF SLAMM INPUT PARAMETERS FOR PRESQUILE NWR

Parameter	Global	Sub-site 1	Sub-site 2	Sub-site 3
Description	Chessy South	Presquile1	Presquile2	Presquile3
NWI Photo Date (YYYY)	1994	1994	1994	1994
DEM Date (YYYY)	1968	1968	1982	1968
Direction Offshore [n,s,e,w]	East	North	East	West
Historic Trend (mm/yr)	4.44	4.44	4.44	4.44
MTL-NAVD88 (m)	-0.0005	-0.002	-0.0005	-0.001
GT Great Diurnal Tide Range (m)	0.848	0.848	0.848	0.848
Salt Elev. (m above MTL)	0.564	0.564	0.564	0.564
Marsh Erosion (horz. m /yr)	1.8	1.8	1.8	1.8
Swamp Erosion (horz. m /yr)	1	1	1	1
T.Flat Erosion (horz. m /yr)	6	6	6	6
Reg. Flood Marsh Accr (mm/yr)	6	6	6	6
Irreg. Flood Marsh Accr (mm/yr)	4.8	4.8	4.8	4.8
Tidal Fresh Marsh Accr (mm/yr)	7.2	7.2	7.2	7.2
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	TRUE	TRUE	TRUE

Results

The vulnerability of Presquile NWR to the sea level rise is quite sensitive to the SLR scenario utilized. Tidal swamp, which comprises more than half of the refuge, is predicted to lose between 15% and 76% across the range of scenarios examined. Dry land, which makes up nearly one quarter of the refuge, is predicted to lose between 6% and 38% across all scenarios.

SLR by 2100 (m)	0.39	0.69	1	1.5	2
Tidal Swamp	15%	25%	35%	61%	76%
Dry Land	6%	8%	11%	18%	38%
Tidal Fresh Marsh	0%	11%	30%	58%	85%

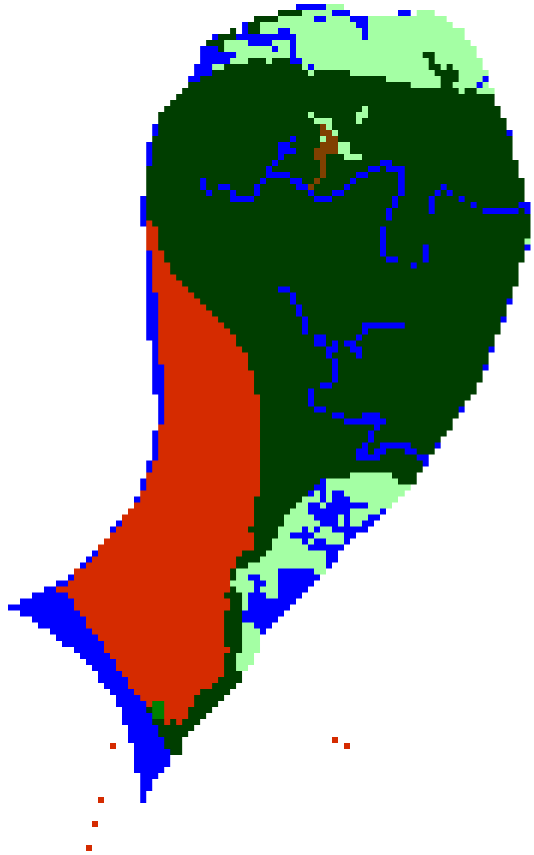
Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

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

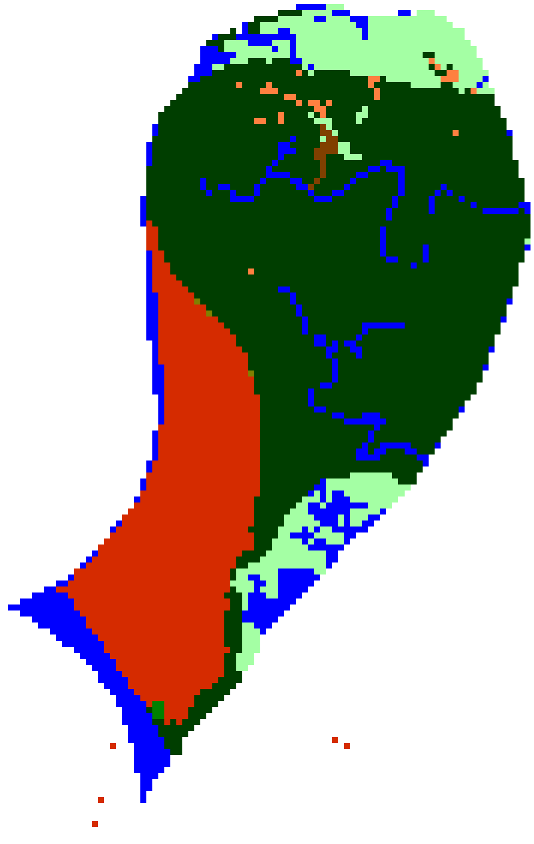
Presquile
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

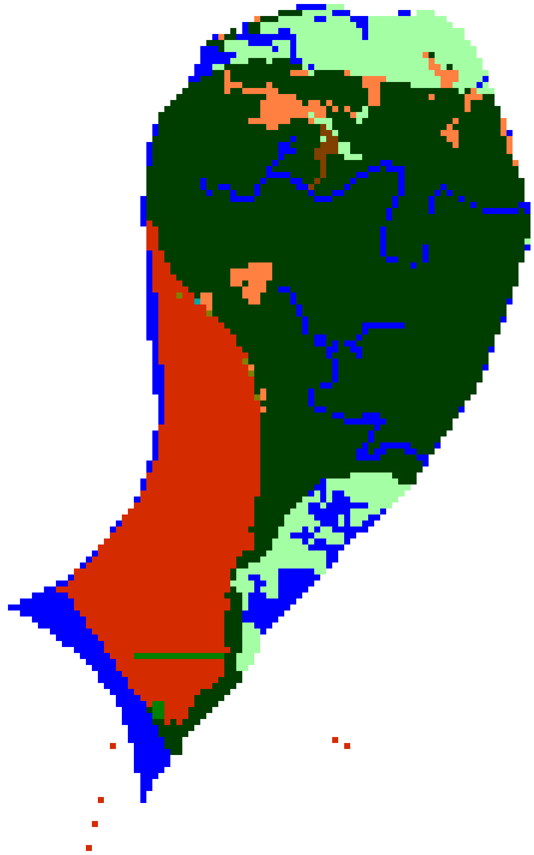
	Initial	2025	2050	2075	2100
Tidal Swamp	735.7	725.0	698.2	661.5	622.9
Undev. Dry Land	287.6	286.1	280.7	277.7	271.3
Riverine Tidal	140.8	140.3	129.4	107.6	103.4
Tidal Fresh Marsh	126.3	126.3	126.3	126.3	126.3
Inland Shore	4.2	4.2	4.2	4.2	4.2
Swamp	1.3	1.3	4.7	4.7	8.0
Irregularly Flooded Marsh	0.0	10.7	37.5	74.2	112.8
Saltmarsh	0.0	0.0	0.5	1.6	3.5
Estuarine Open Water	0.0	0.4	11.3	33.1	37.4
Trans. Salt Marsh	0.0	1.4	2.9	5.0	6.1
Total (incl. water)	**1295.9**	**1295.9**	**1295.9**	**1295.9**	**1295.9**



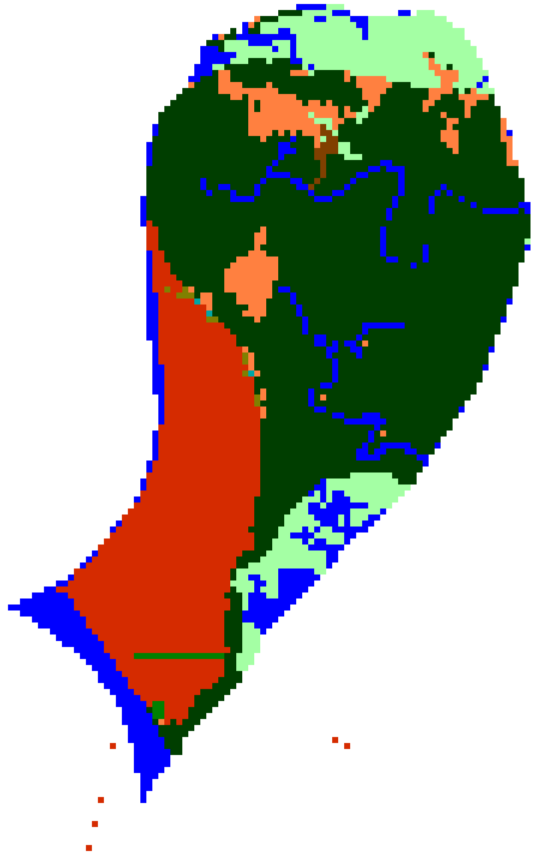
Presquile NWR, Initial Condition



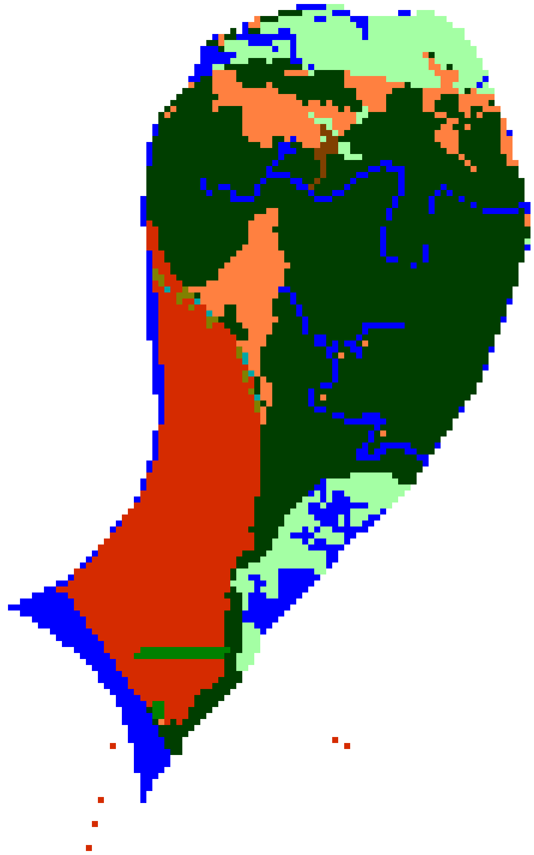
Presquile NWR, 2025, Scenario A1B Mean



Presquile NWR, 2050, Scenario A1B Mean



Presquile NWR, 2075, Scenario A1B Mean

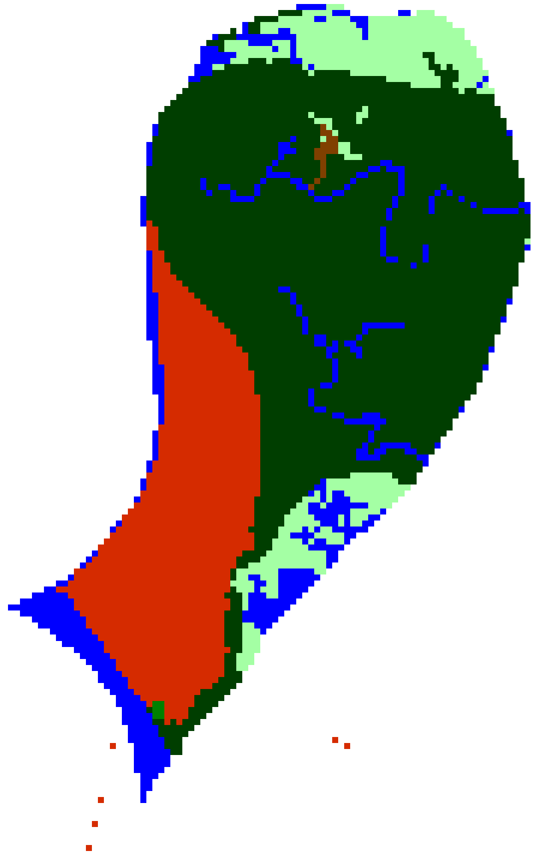


Presquile NWR, 2100, Scenario A1B Mean

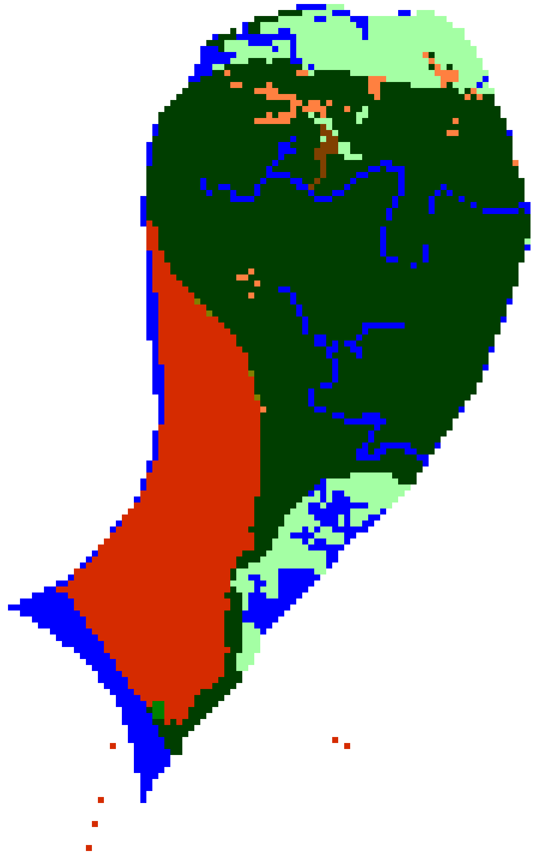
Presquile
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

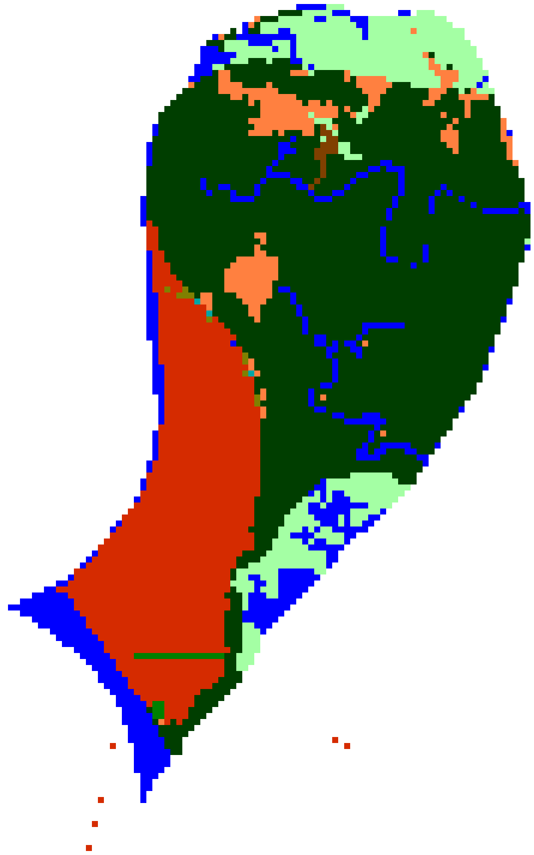
	Initial	2025	2050	2075	2100
Tidal Swamp	735.7	716.8	672.7	609.9	553.2
Undev. Dry Land	287.6	285.7	278.7	274.1	264.5
Riverine Tidal	140.8	140.3	117.1	105.1	94.0
Tidal Fresh Marsh	126.3	126.3	125.5	120.1	112.7
Inland Shore	4.2	4.2	4.2	4.2	4.2
Swamp	1.3	1.3	4.7	4.7	8.0
Irregularly Flooded Marsh	0.0	18.9	63.8	128.4	136.6
Saltmarsh	0.0	0.0	1.5	8.9	69.3
Estuarine Open Water	0.0	0.4	23.8	35.8	46.9
Trans. Salt Marsh	0.0	1.9	3.9	4.7	6.4
Total (incl. water)	**1295.9**	**1295.9**	**1295.9**	**1295.9**	**1295.9**



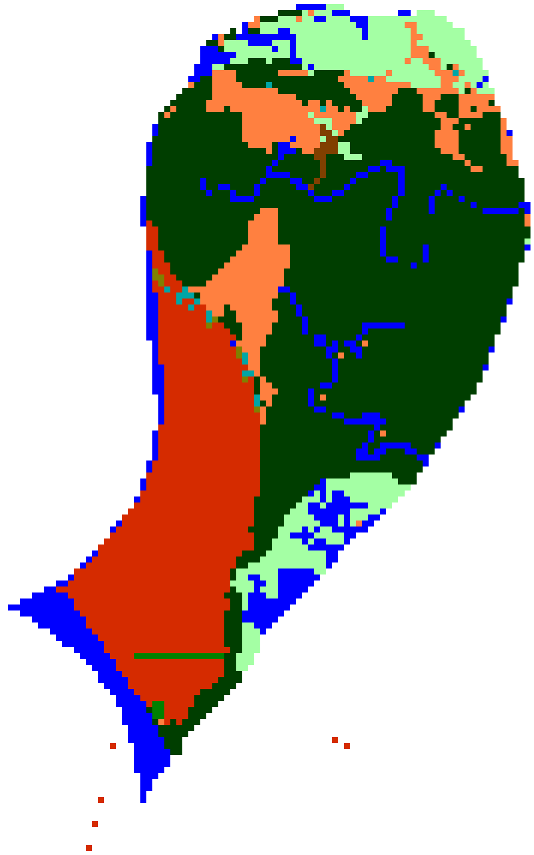
Presquile NWR, Initial Condition



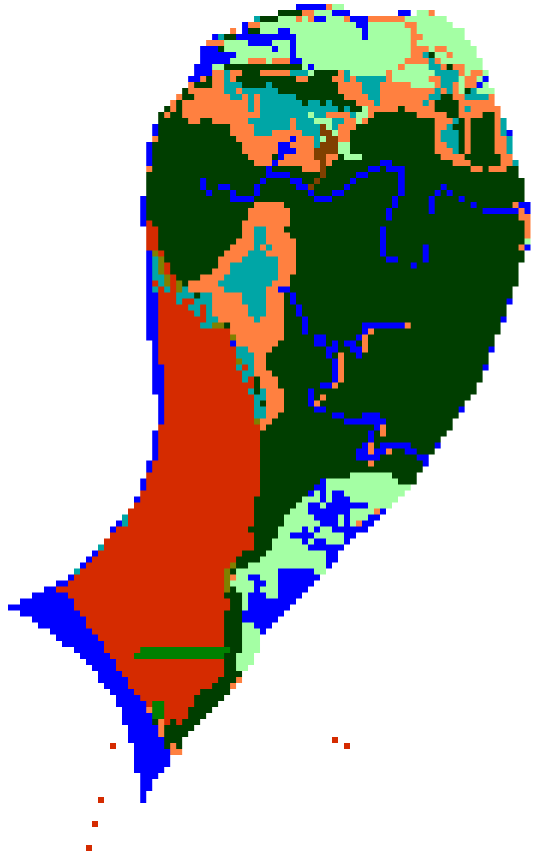
Presquile NWR, 2025, Scenario A1B Maximum



Presquile NWR, 2050, Scenario A1B Maximum



Presquile NWR, 2075, Scenario A1B Maximum

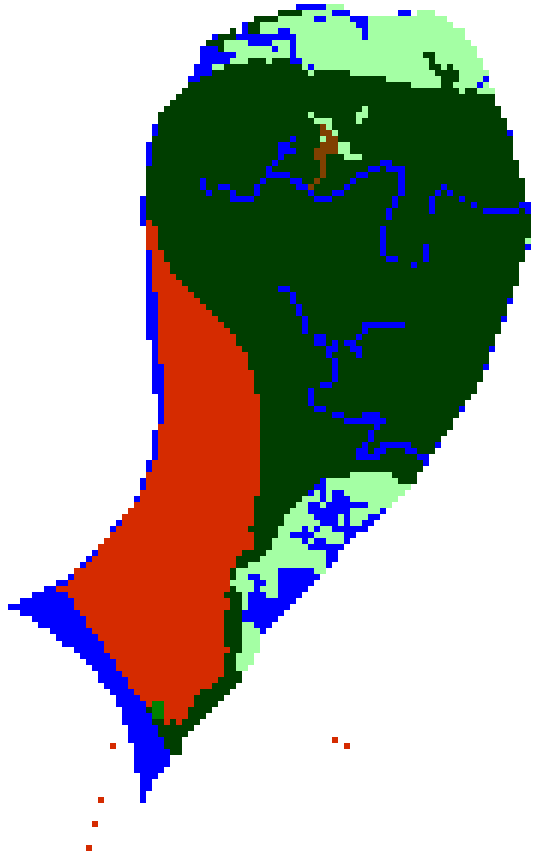


Presquile NWR, 2100, Scenario A1B Maximum

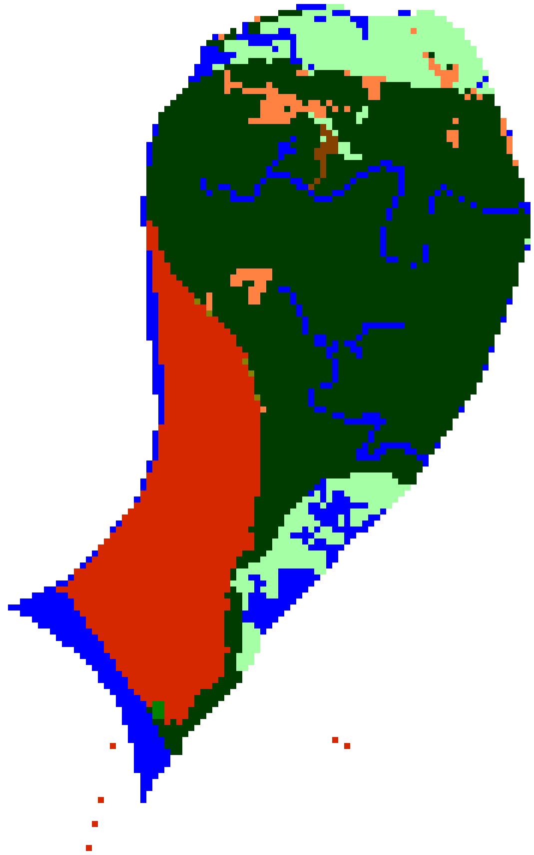
Presquile
1 Meter Eustatic SLR by 2100

Results in Acres

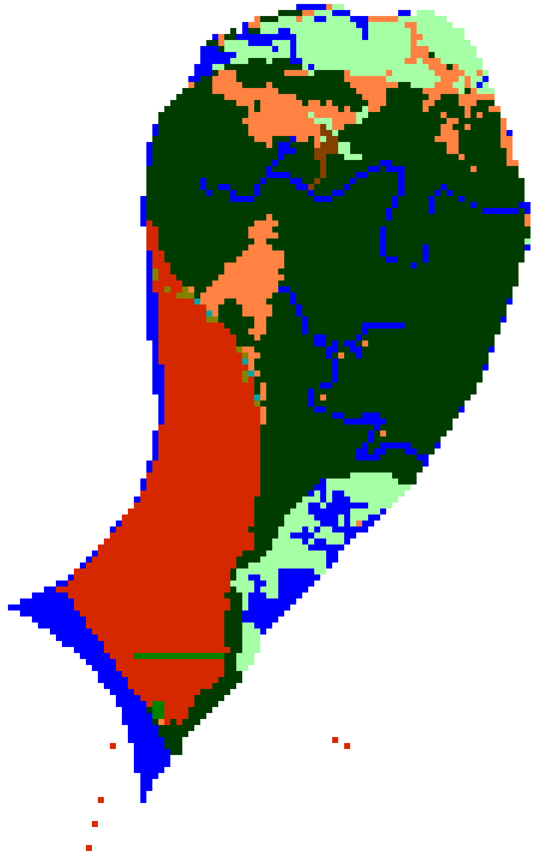
	Initial	2025	2050	2075	2100
Tidal Swamp	735.7	705.4	641.8	562.8	475.4
Undev. Dry Land	287.6	285.1	276.9	266.4	255.9
Riverine Tidal	140.8	140.3	112.3	96.1	78.9
Tidal Fresh Marsh	126.3	125.2	117.8	103.4	88.9
Inland Shore	4.2	4.2	4.2	4.2	4.2
Swamp	1.3	1.3	4.7	8.0	7.9
Irregularly Flooded Marsh	0.0	31.4	101.1	131.9	136.3
Saltmarsh	0.0	0.0	3.8	70.2	107.6
Estuarine Open Water	0.0	0.4	28.5	45.8	103.0
Trans. Salt Marsh	0.0	2.5	4.9	7.2	10.6
Total (incl. water)	**1295.9**	**1295.9**	**1295.9**	**1295.9**	**1295.9**



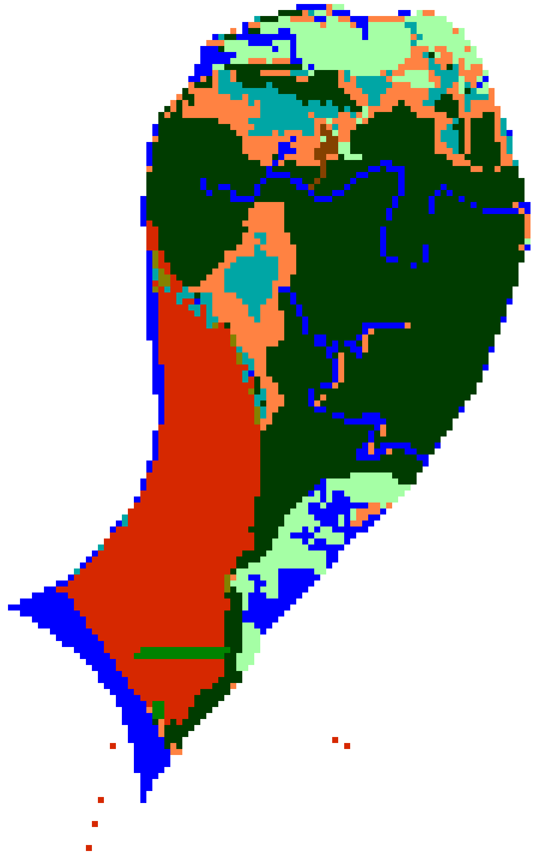
Presquile NWR, Initial Condition



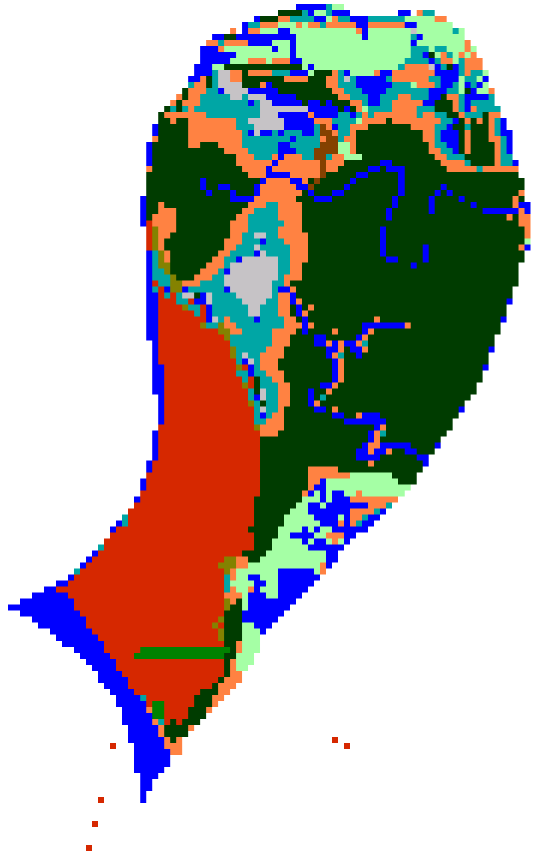
Presquile NWR, 2025, 1 meter



Presquile NWR, 2050, 1 meter



Presquile NWR, 2075, 1 meter

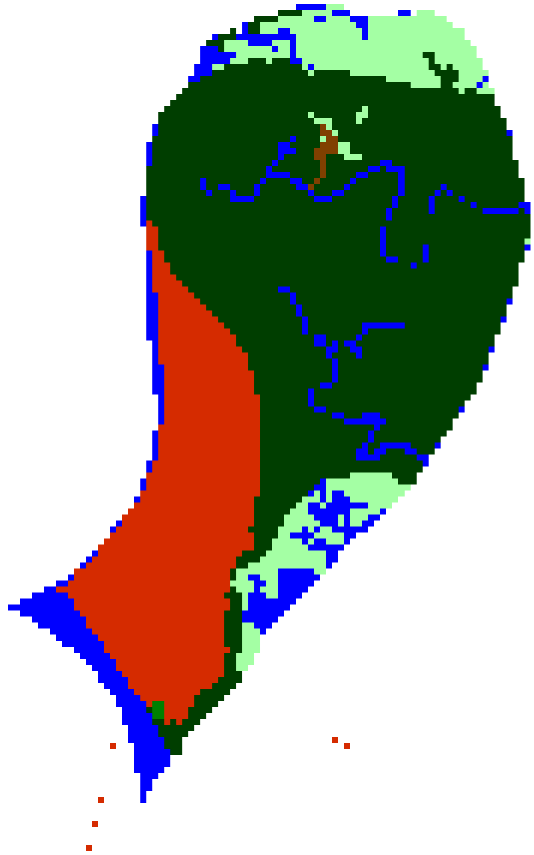


Presquile NWR, 2100, 1 meter

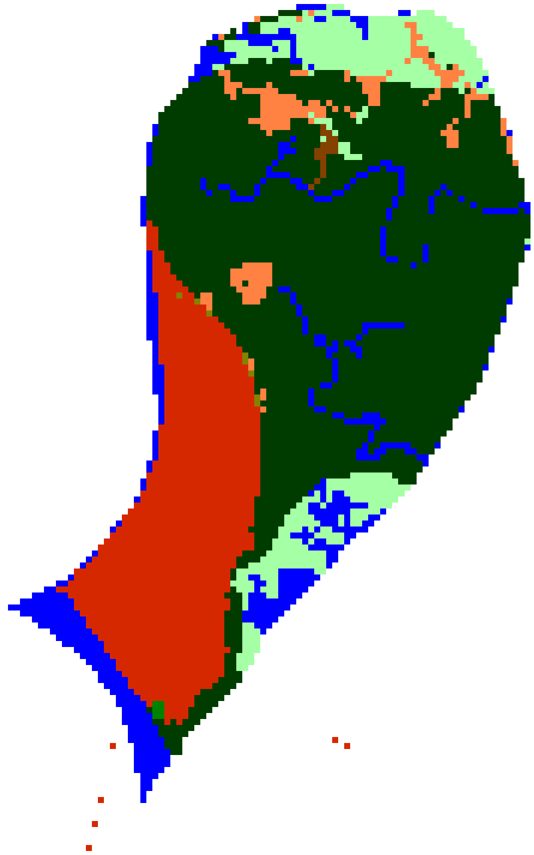
Presquile
1.5 Meters Eustatic SLR by 2100

Results in Acres

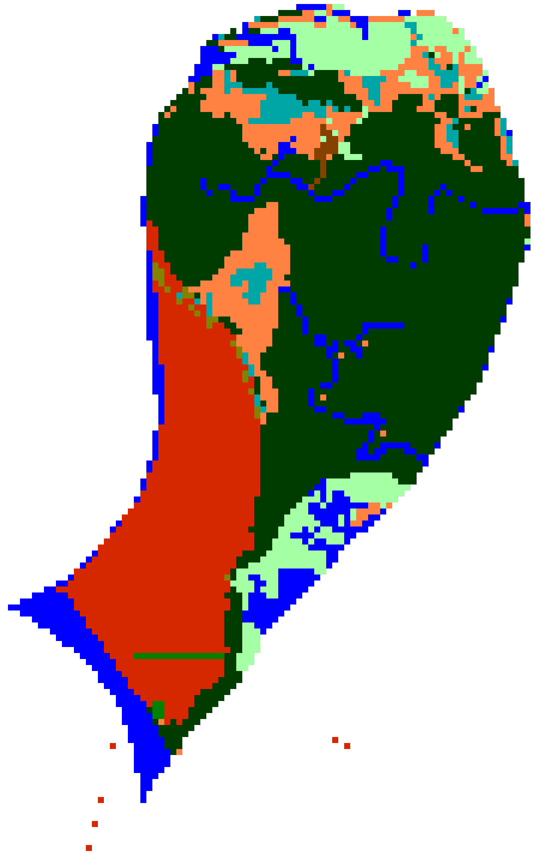
	Initial	2025	2050	2075	2100
Tidal Swamp	735.7	689.1	593.5	476.1	289.6
Undev. Dry Land	287.6	283.8	273.3	257.1	236.8
Riverine Tidal	140.8	140.3	105.4	82.1	62.5
Tidal Fresh Marsh	126.3	120.2	102.0	79.2	52.9
Inland Shore	4.2	4.2	4.2	4.2	0.9
Swamp	1.3	1.3	4.7	7.9	6.0
Irregularly Flooded Marsh	0.0	52.7	130.9	141.2	215.3
Saltmarsh	0.0	0.0	39.4	138.0	155.1
Estuarine Open Water	0.0	0.4	35.4	86.4	186.3
Trans. Salt Marsh	0.0	3.8	7.1	13.9	23.5
Total (incl. water)	**1295.9**	**1295.9**	**1295.9**	**1295.9**	**1295.9**



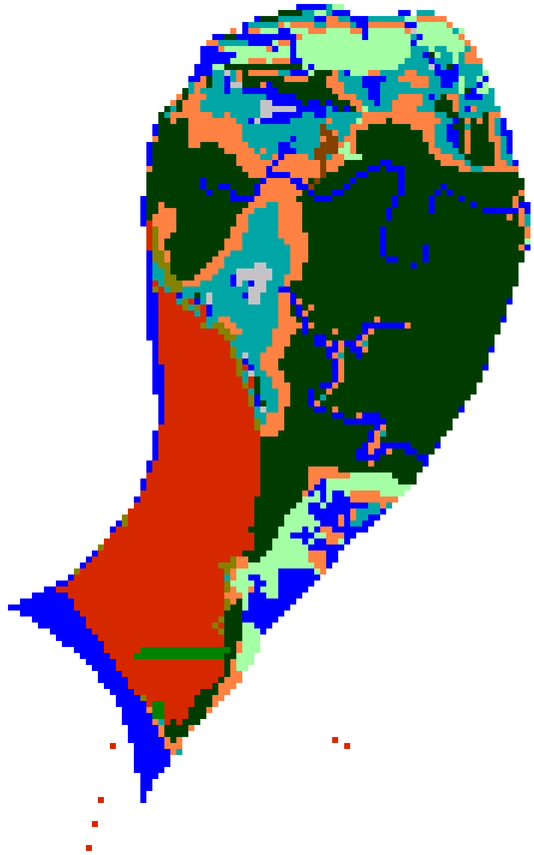
Presquile NWR, Initial Condition



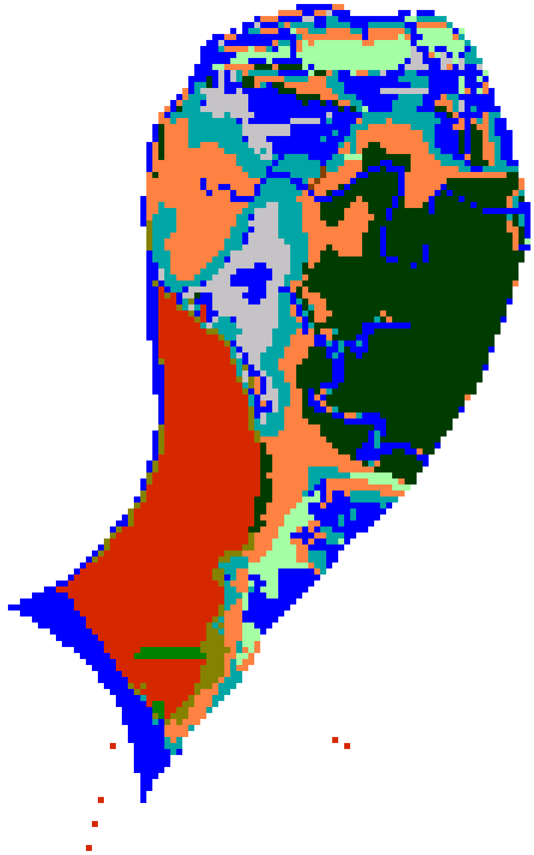
Presquile NWR, 2025, 1.5 meter



Presquile NWR, 2050, 1.5 meter



Presquile NWR, 2075, 1.5 meter

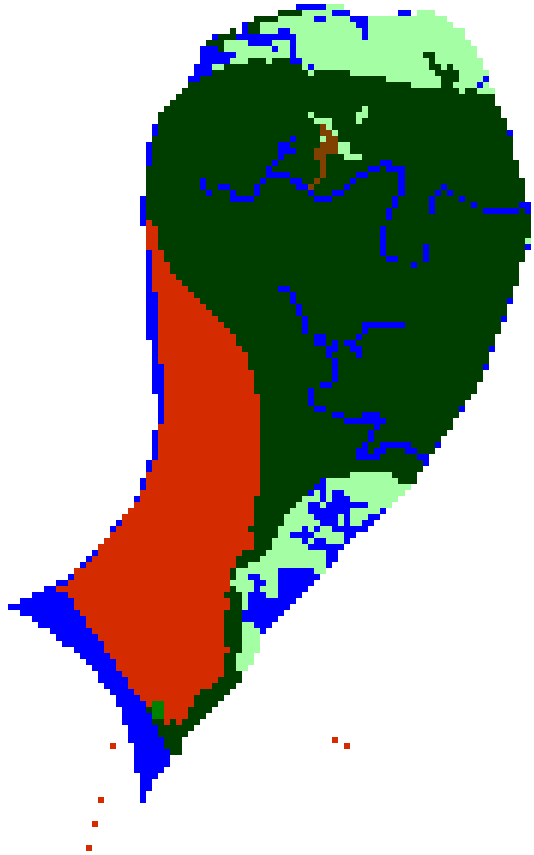


Presquile NWR, 2100, 1.5 meter

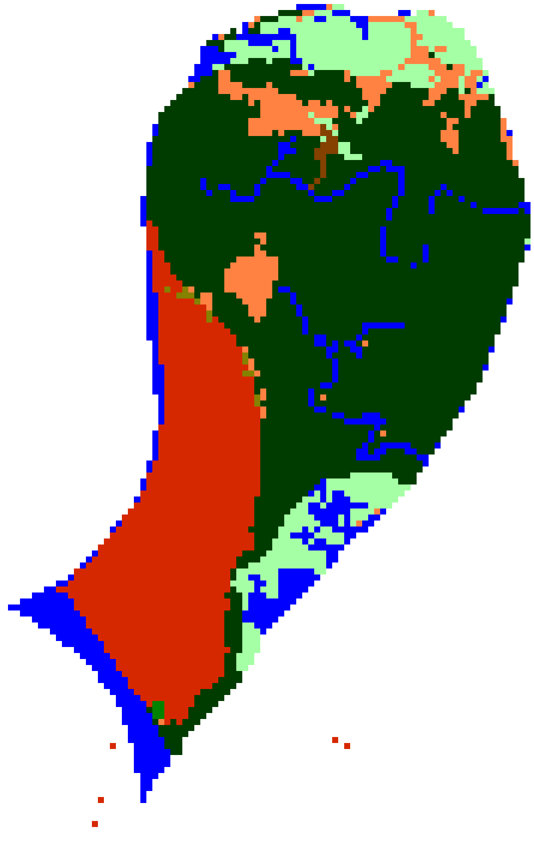
Presquile
2 Meters Eustatic SLR by 2100

Results in Acres

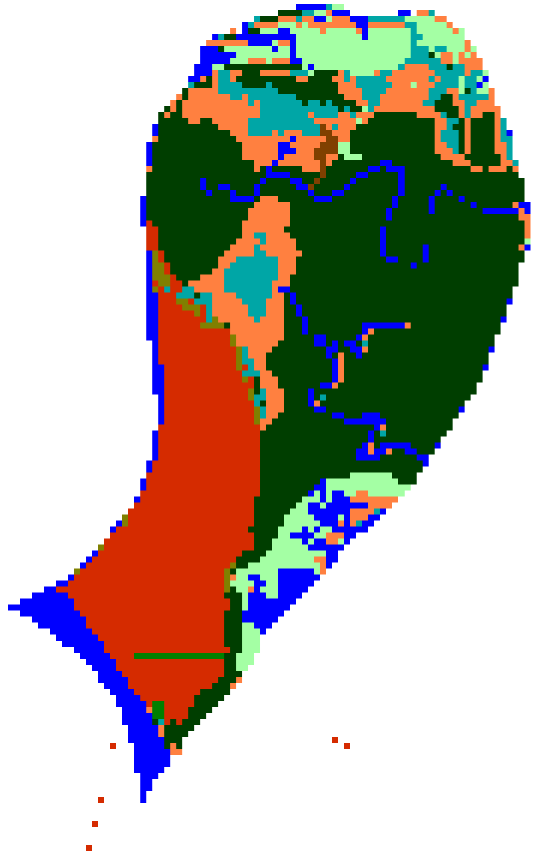
	Initial	2025	2050	2075	2100
Tidal Swamp	735.7	668.8	550.1	348.1	177.3
Undev. Dry Land	287.6	282.3	269.0	245.1	177.9
Riverine Tidal	140.8	140.3	97.0	70.9	55.4
Tidal Fresh Marsh	126.3	114.1	87.7	53.5	19.2
Inland Shore	4.2	4.2	4.2	1.8	0.3
Swamp	1.3	1.3	4.6	6.4	4.5
Irregularly Flooded Marsh	0.0	79.1	145.1	238.2	206.2
Saltmarsh	0.0	0.0	84.4	155.1	261.4
Estuarine Open Water	0.0	0.4	43.8	121.3	247.2
Trans. Salt Marsh	0.0	5.2	10.0	23.2	69.4
Total (incl. water)	**1295.9**	**1295.9**	**1295.9**	**1295.9**	**1295.9**



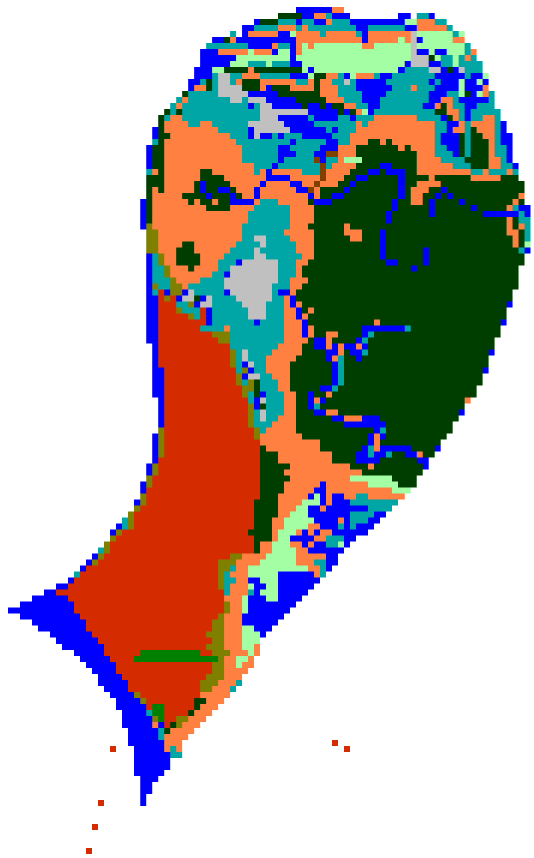
Presquile NWR, Initial Condition



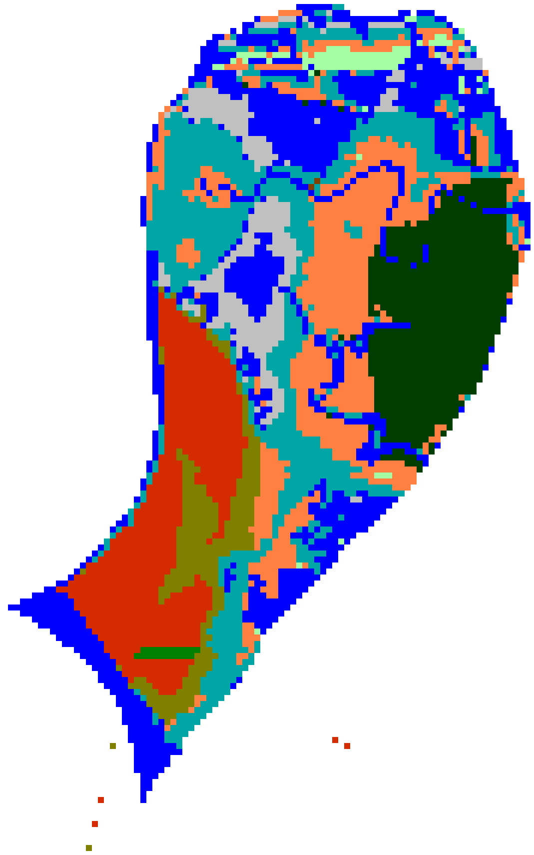
Presquile NWR, 2025, 2 meters



Presquile NWR, 2050, 2 meters



Presquile NWR, 2075, 2 meters



Presquile NWR, 2100, 2 meters

Discussion

The SLAMM analysis for Presquile NWR produces dramatically different results for wetland fate under different scenarios of sea level rise.

Tidal swamps are predicted to convert, first to irregularly flooded marsh, then to regularly flooded marsh (potentially saltmarsh depending on water salinity), then to non-vegetated tidal flats, and finally to open water. The prediction of land type is a function of each cell's elevation in relation to the projected heights of tides. Under lower scenarios of sea level rise, only a small portion of tidal swamp is predicted to convert to marsh by 2100. Under higher scenarios, much open water and tidal flats become visible.

Tidal swamp in the northwest corner of the refuge is most vulnerable because of its low initial-condition elevation. However, model results are quite uncertain on the basis of elevation data which is out of date and based on interpolations between USGS contours. Future simulations would significantly benefit from higher resolution LiDAR elevation data. Additionally no site-specific accretion data were available for this site, so vertical accretion of wetlands were set to regional averages.

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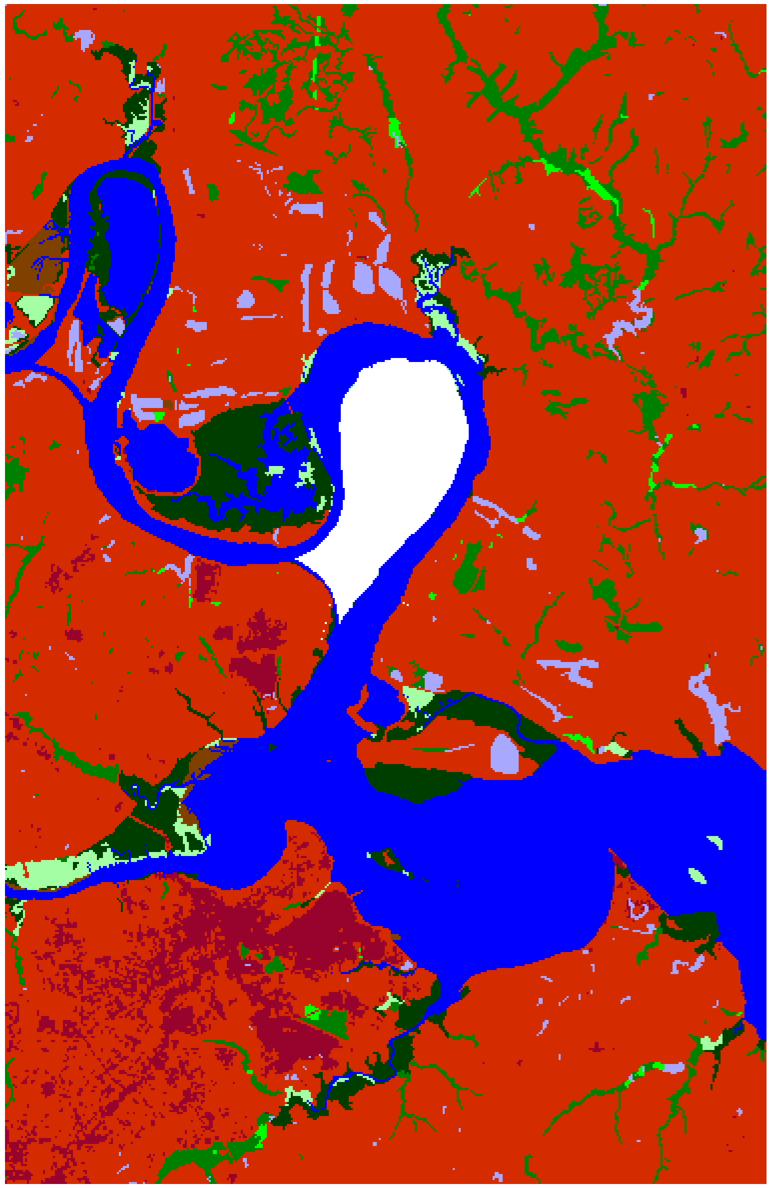
Appendix A: Contextual Results

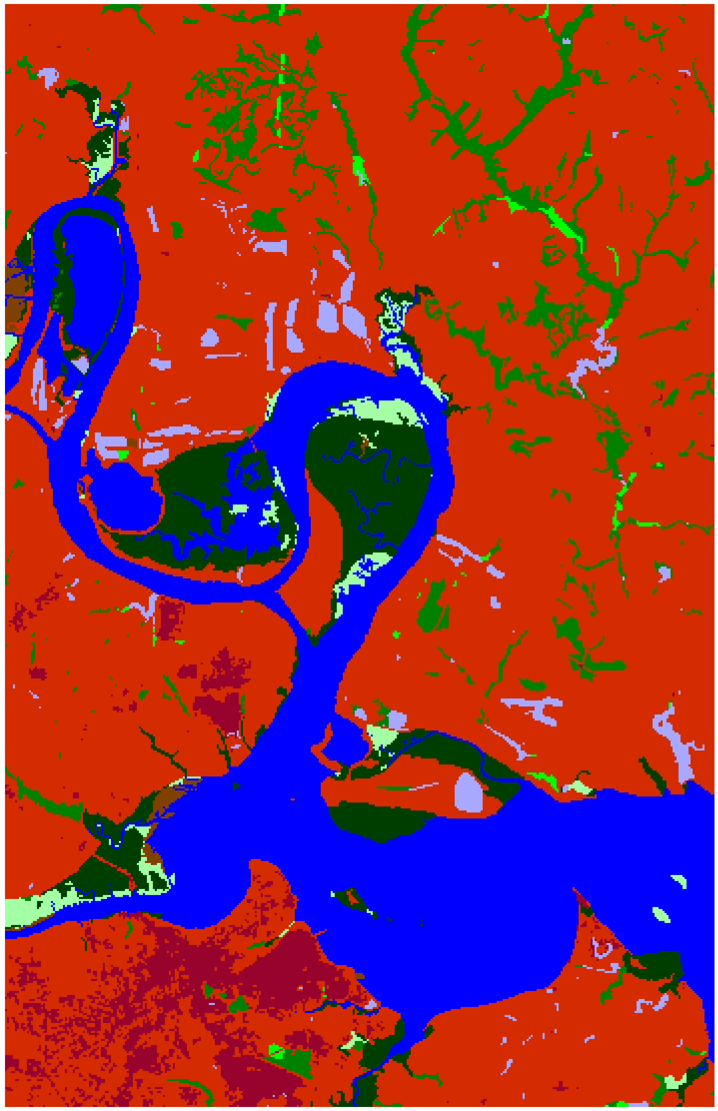
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

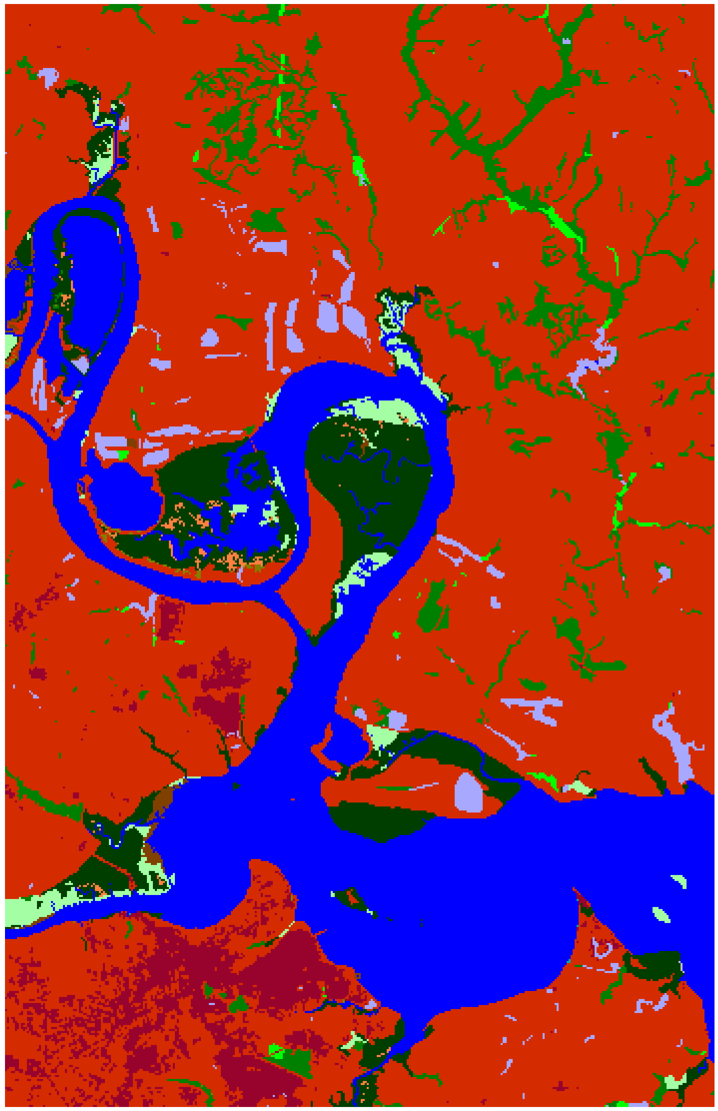
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



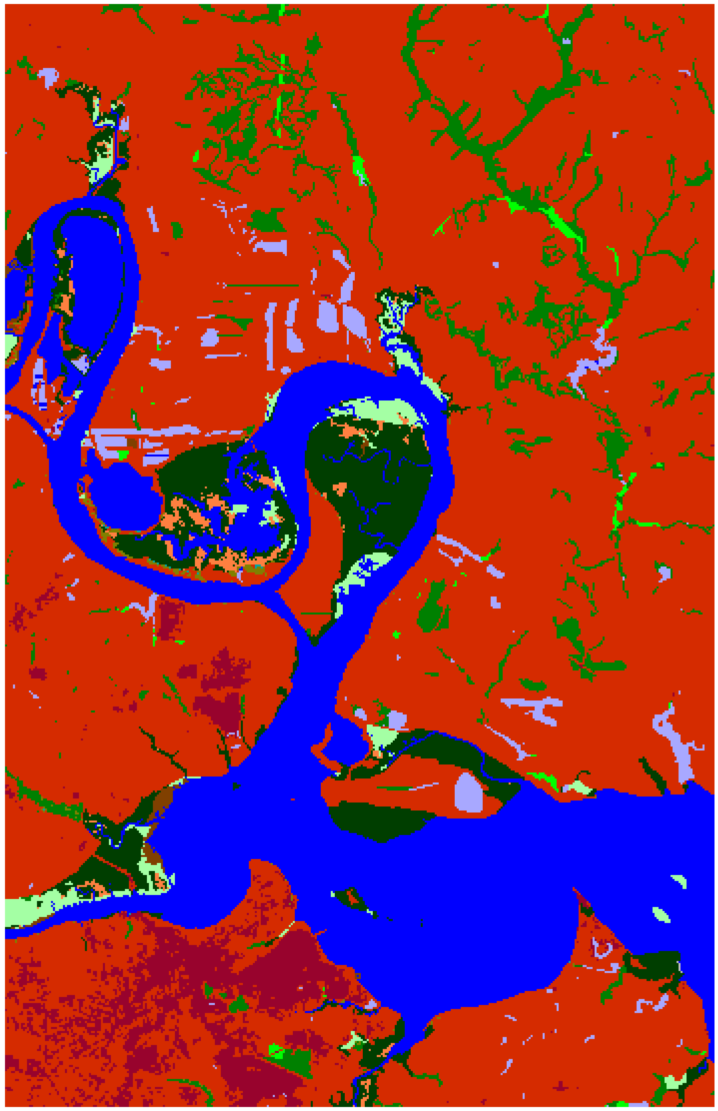
Location of Presquile National Wildlife Refuge (white area) within simulation context



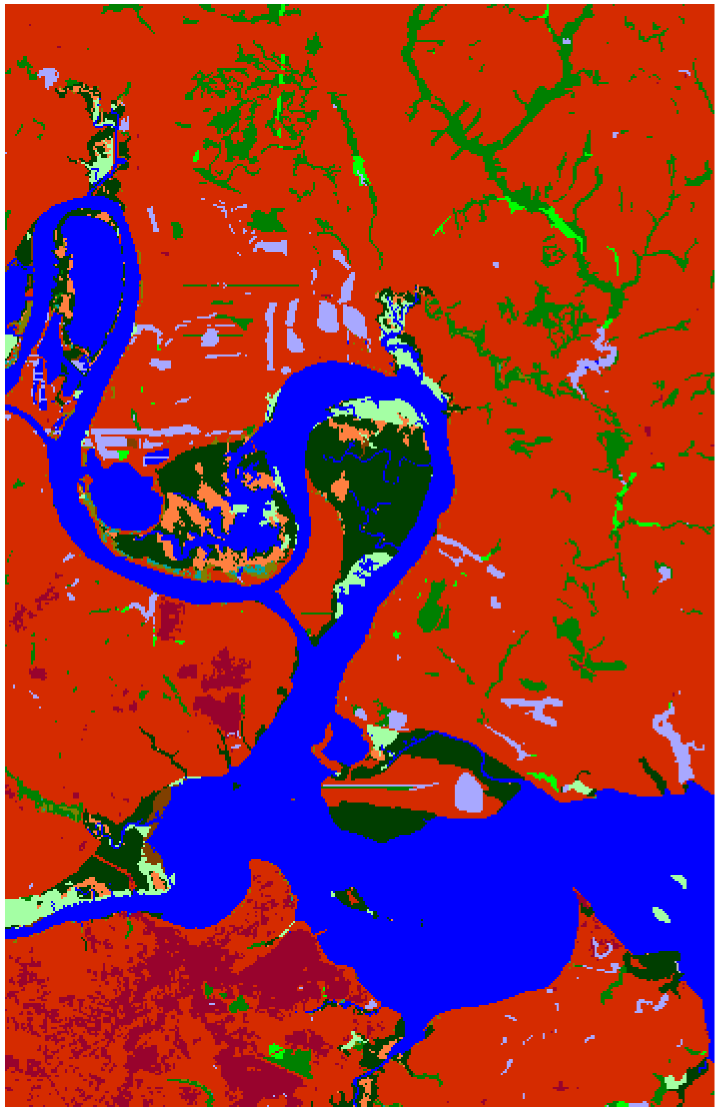
Presquile NWR, Initial Condition



Presquile NWR, 2025, Scenario A1B Mean



Presquile NWR, 2050, Scenario A1B Mean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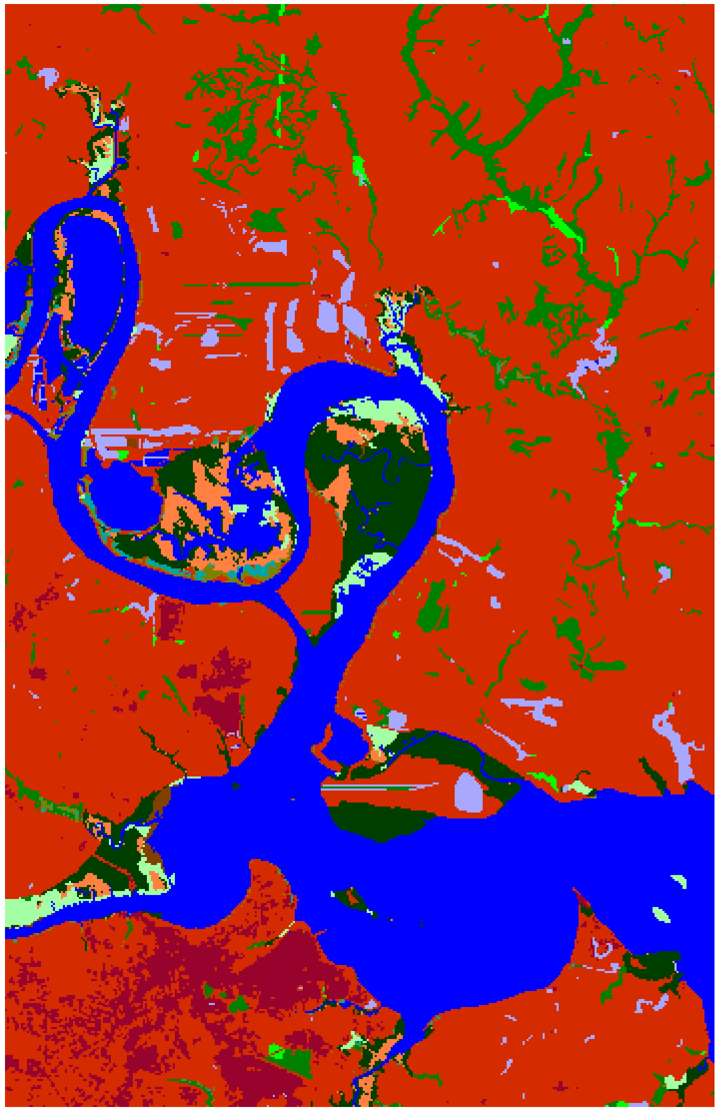
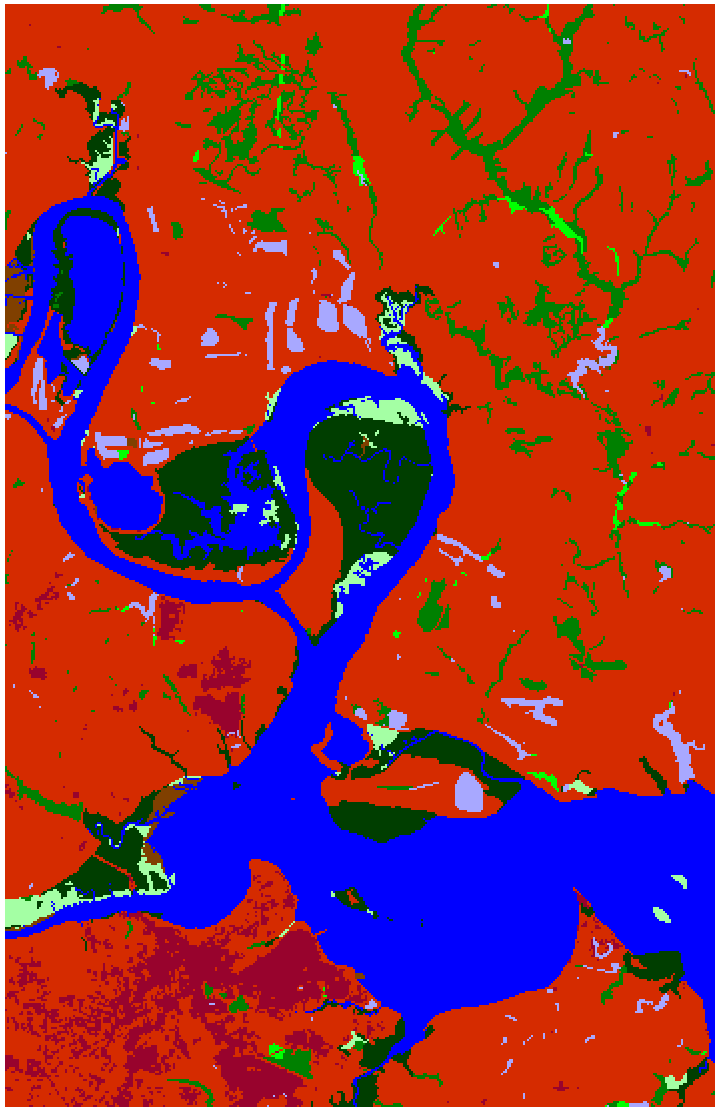
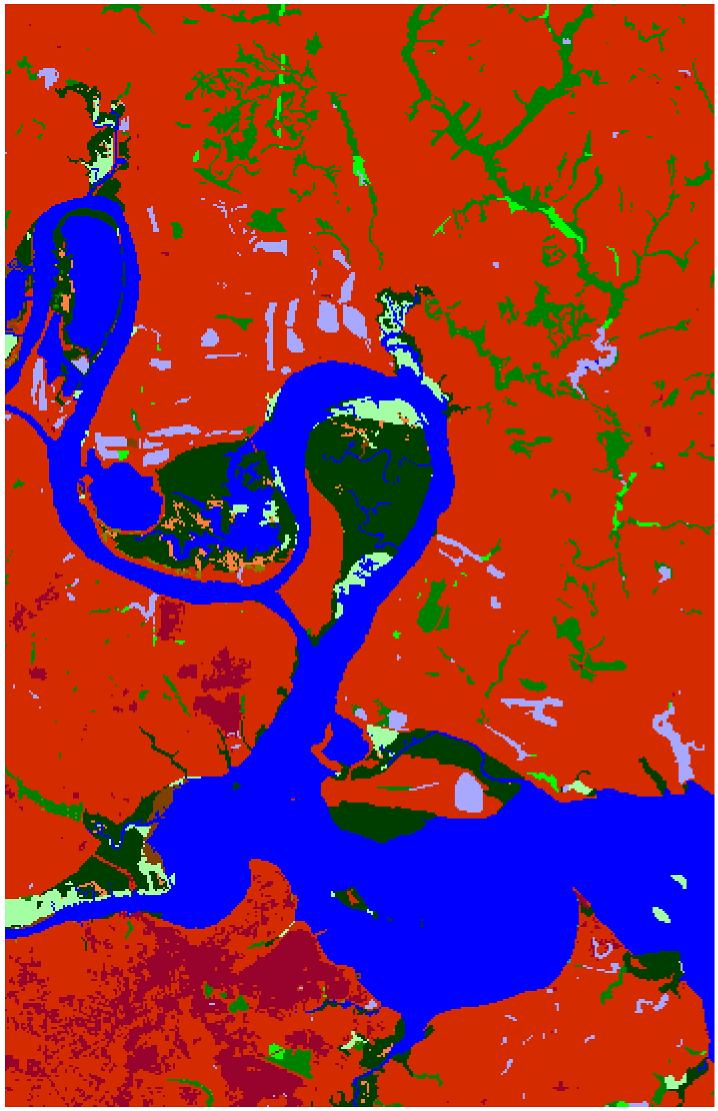


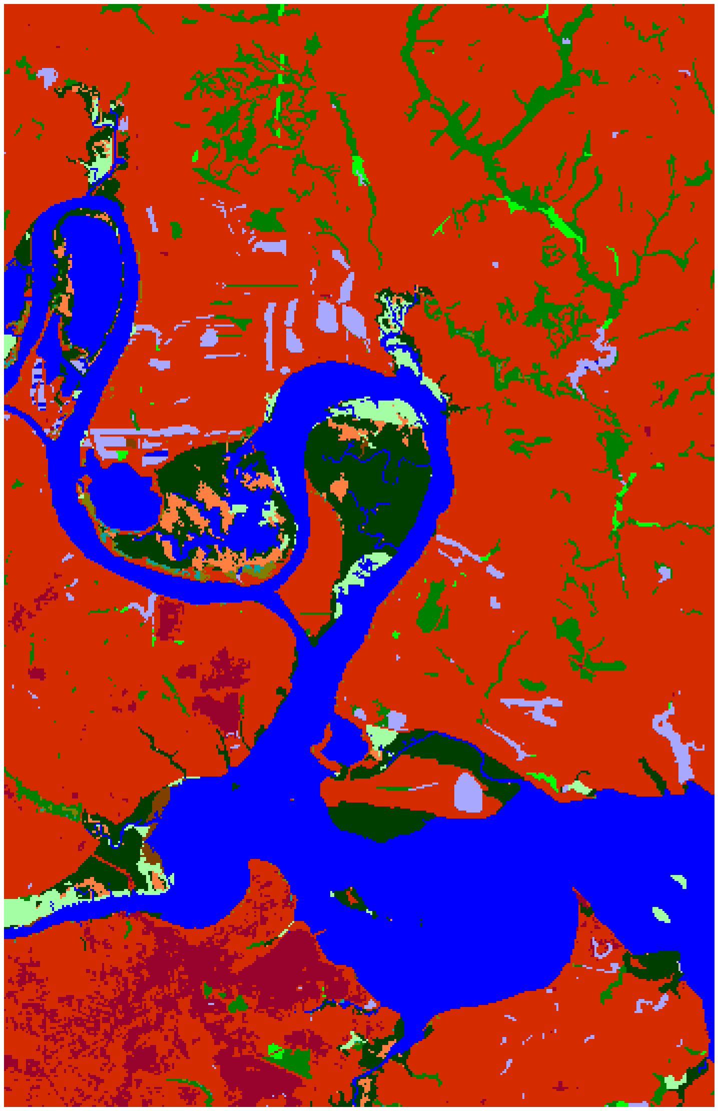
Presquile NWR, 2100, Scenario A1B Mean



Presquile NWR, Initial Condition



Presquile NWR, 2025, Scenario A1B Maximum



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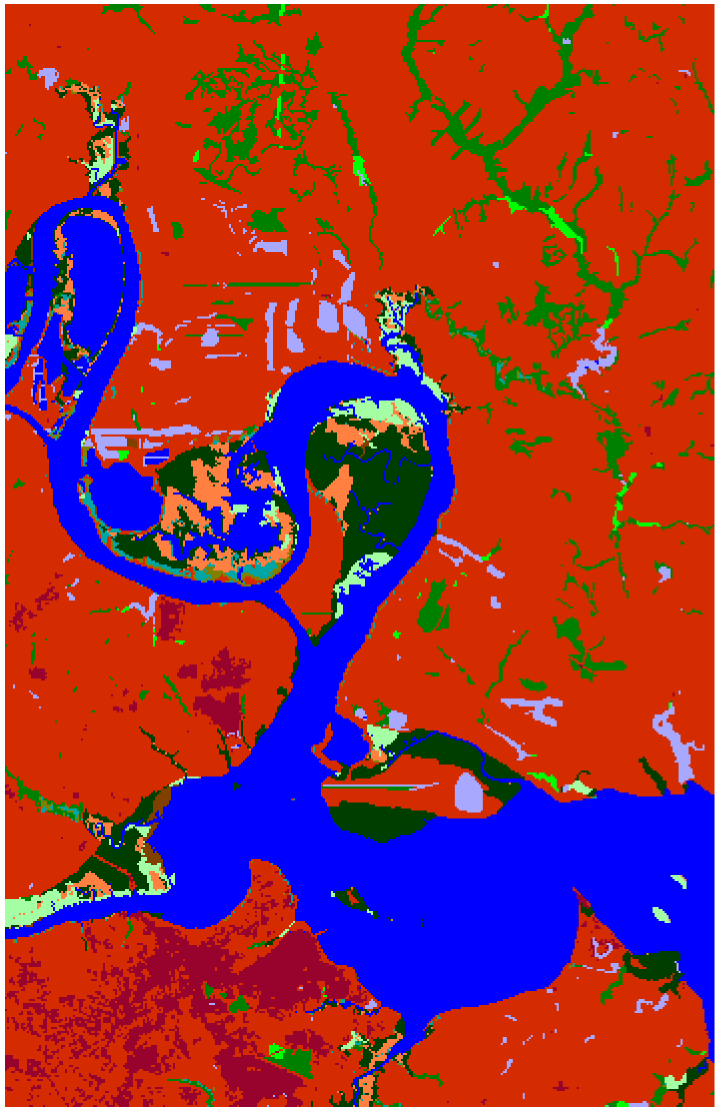

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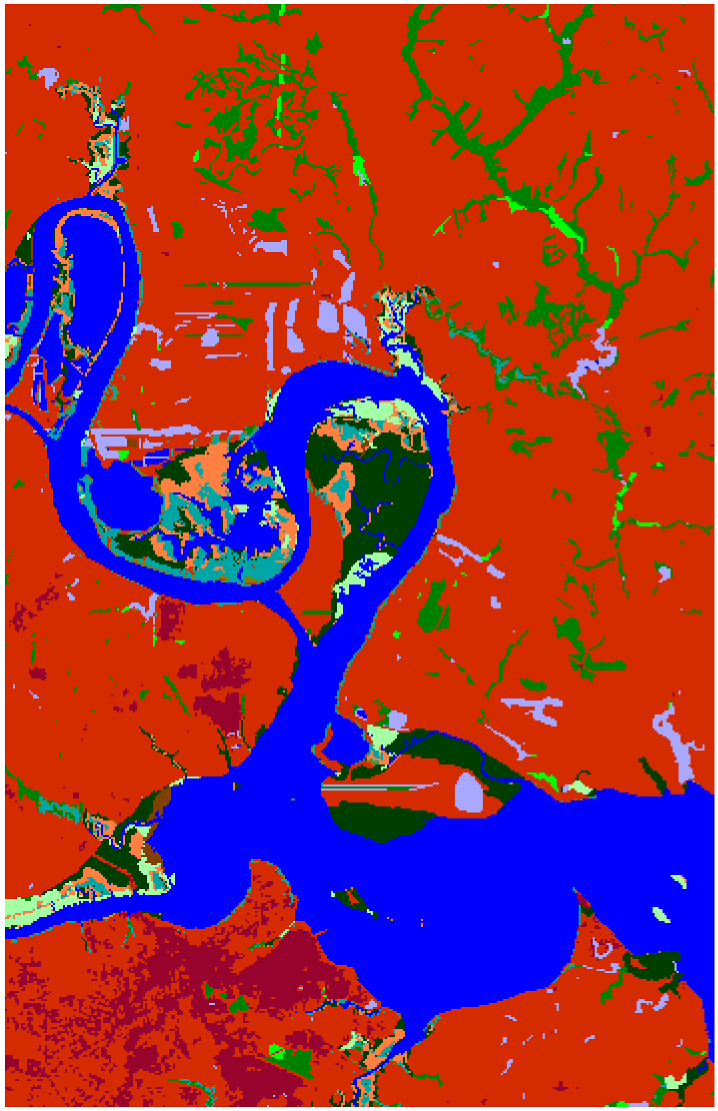
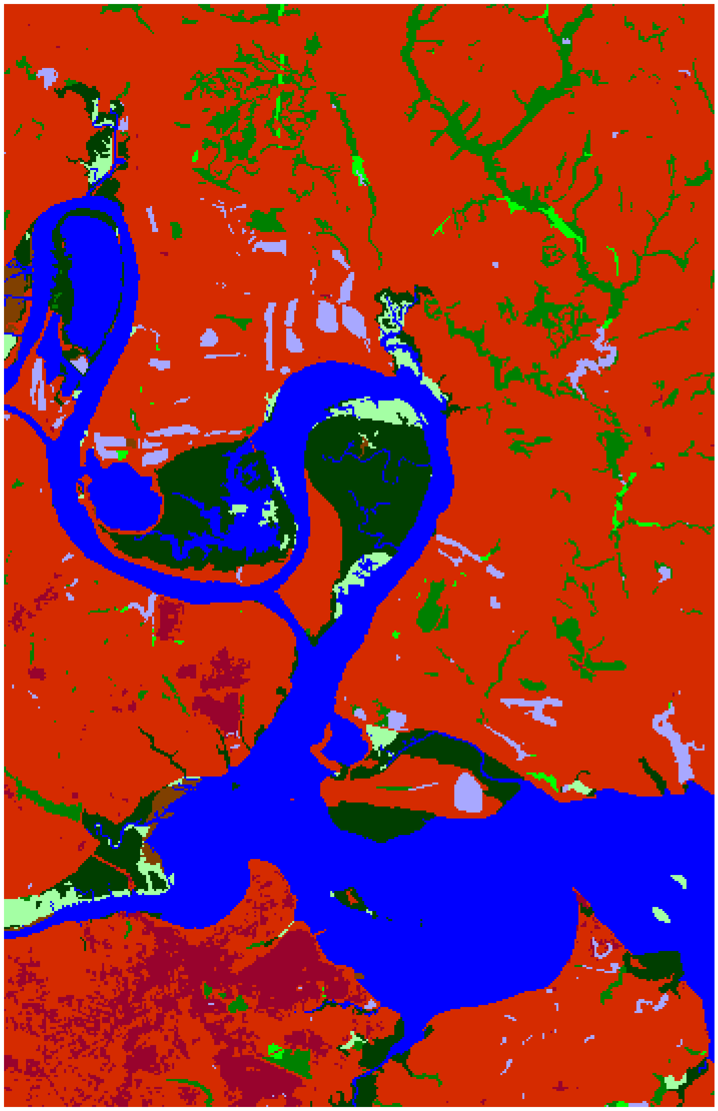


Presquile NWR, 2100, Scenario A1B Maximum



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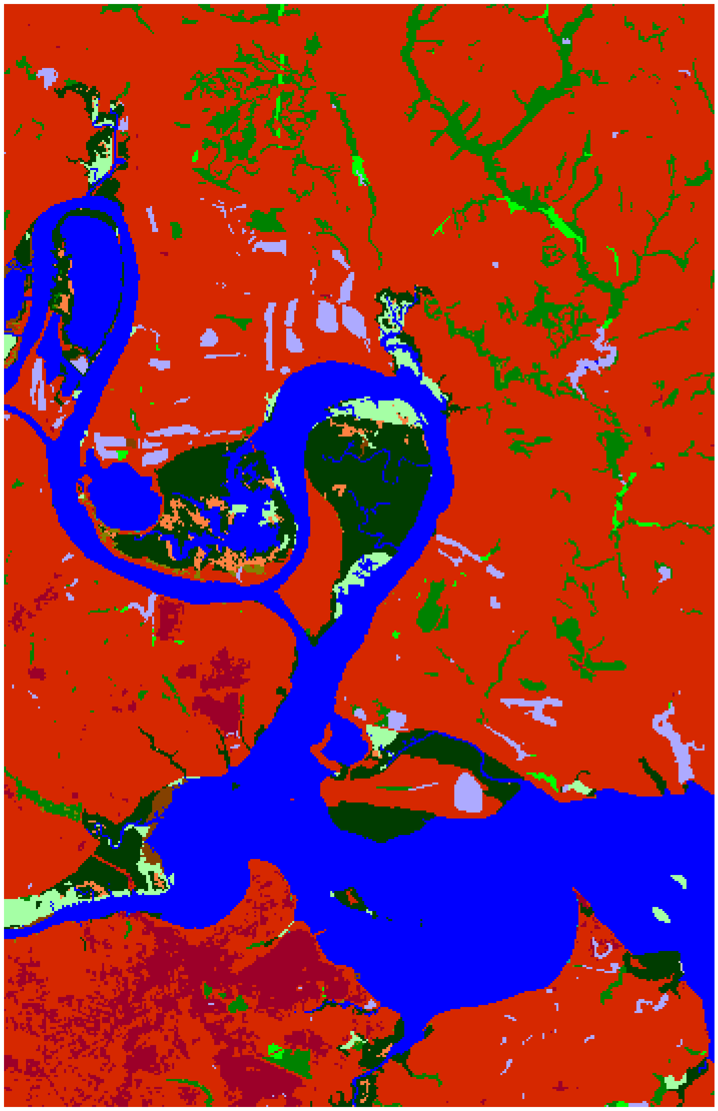
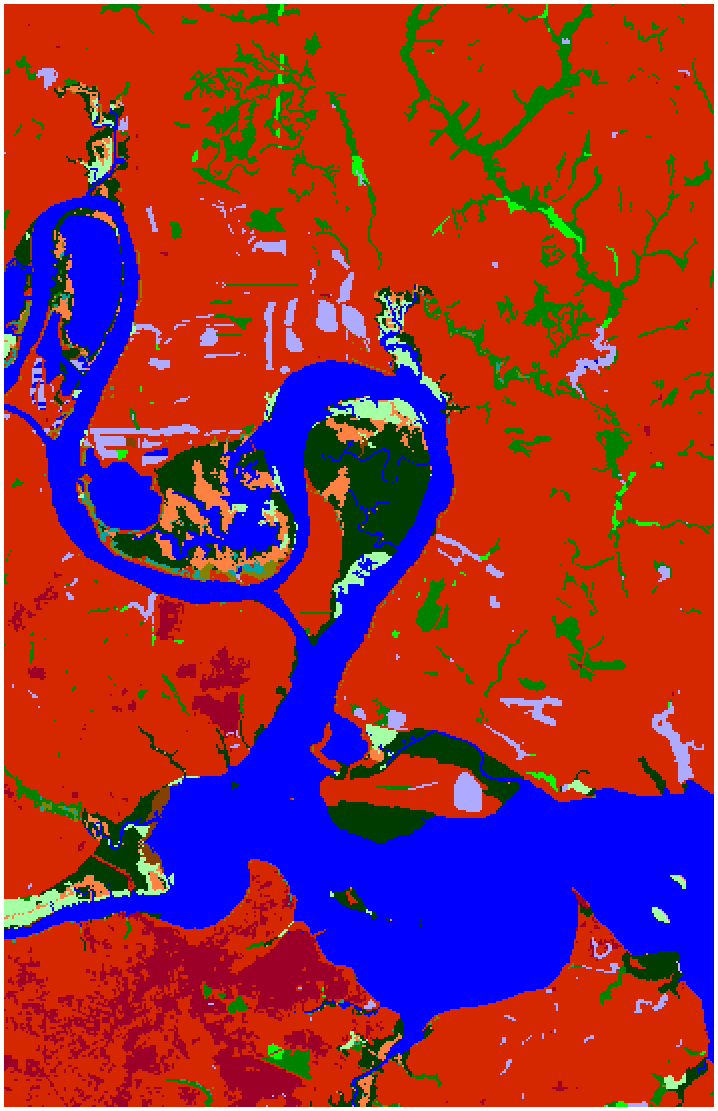
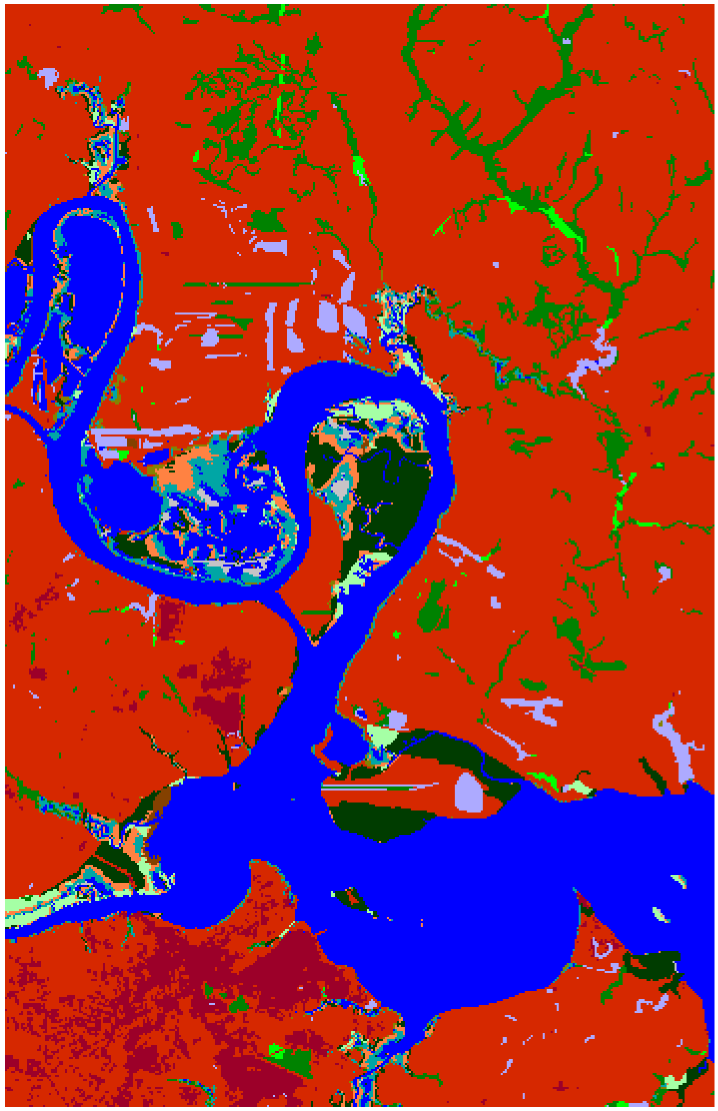


Presquile NWR, 2025, 1 meter



Presquile NWR, 2050, 1 meter

Presquile NWR, 2075, 1 meter



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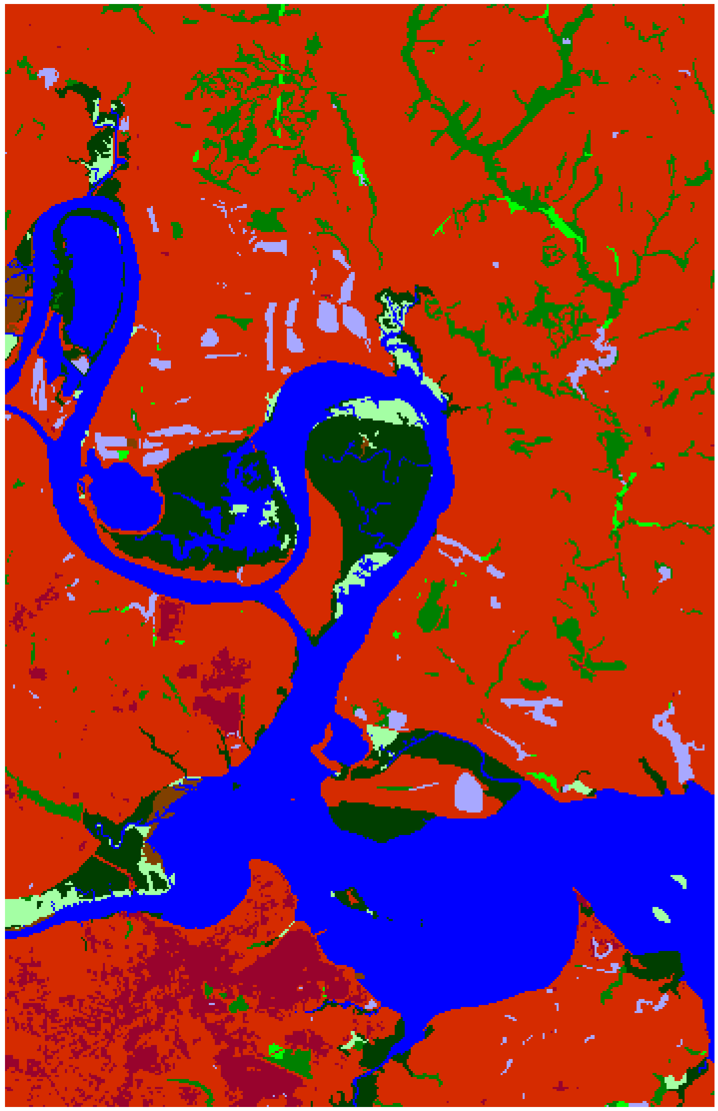

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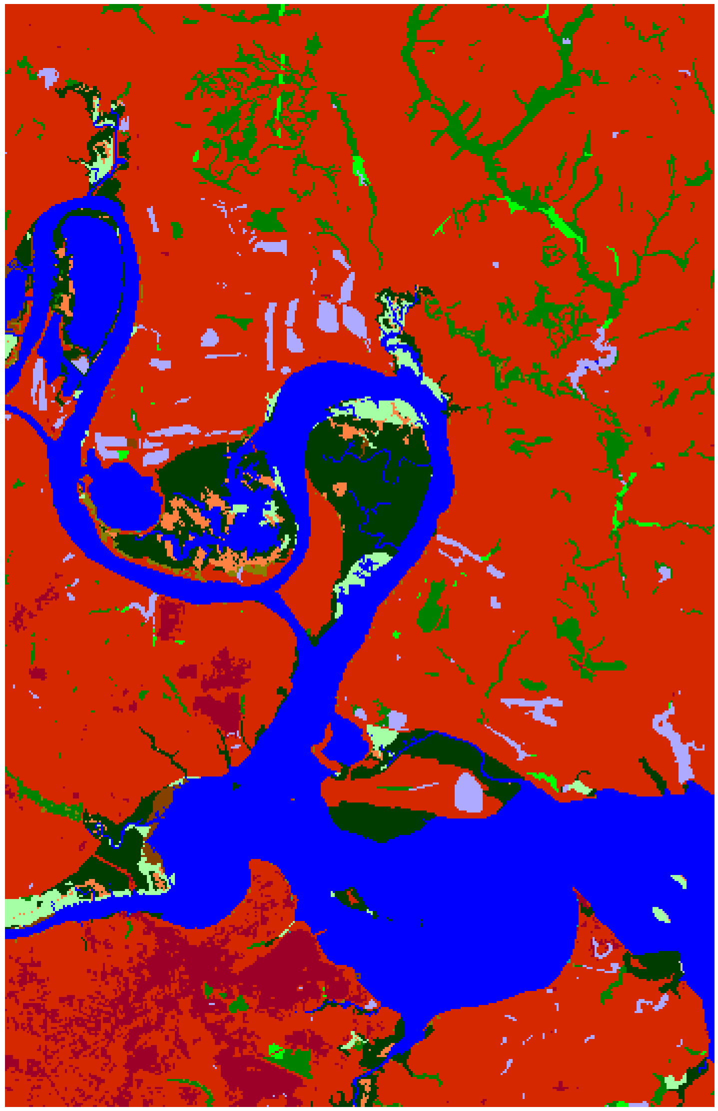
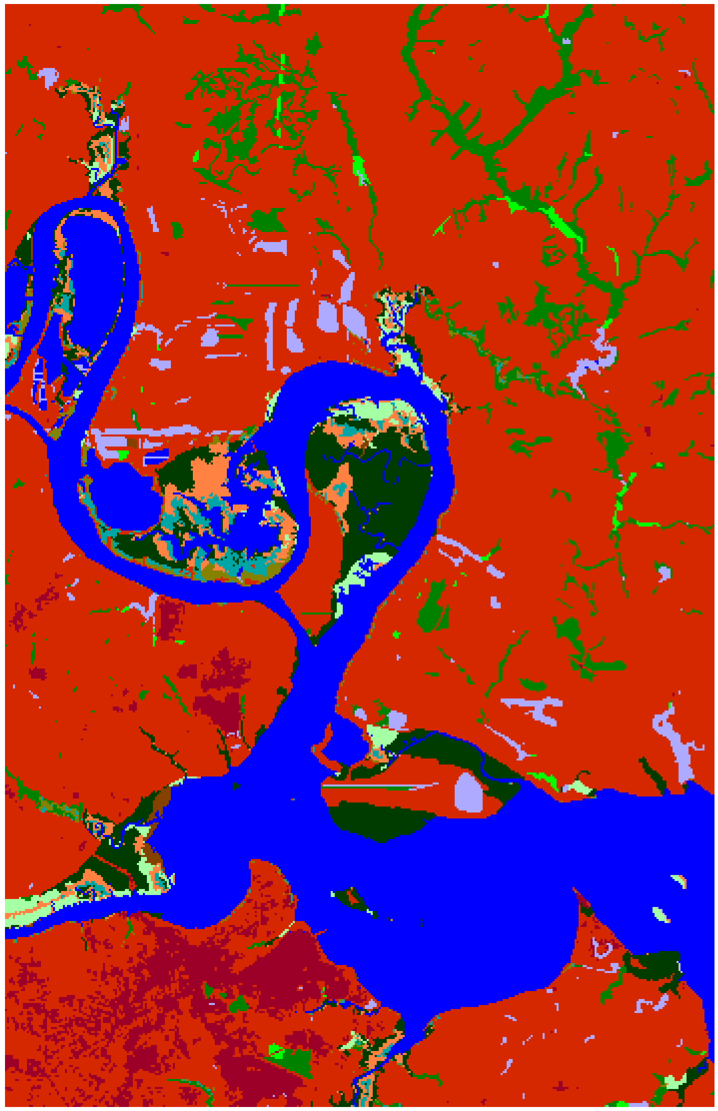


Presquile NWR, 2025, 1.5 meter



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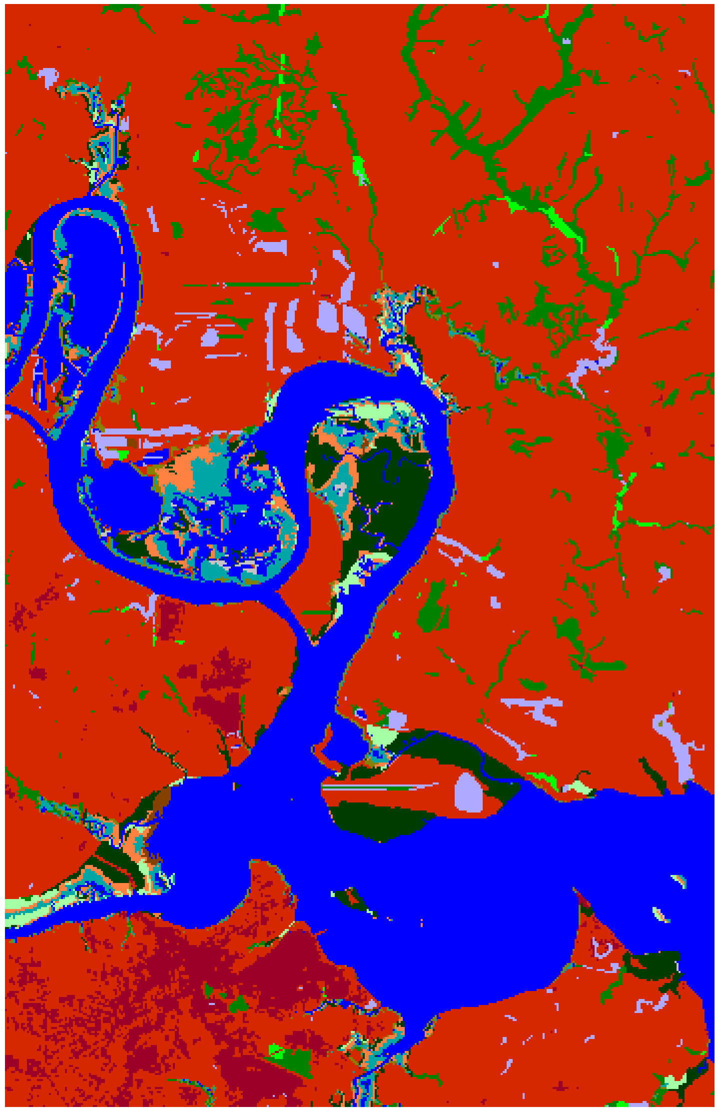

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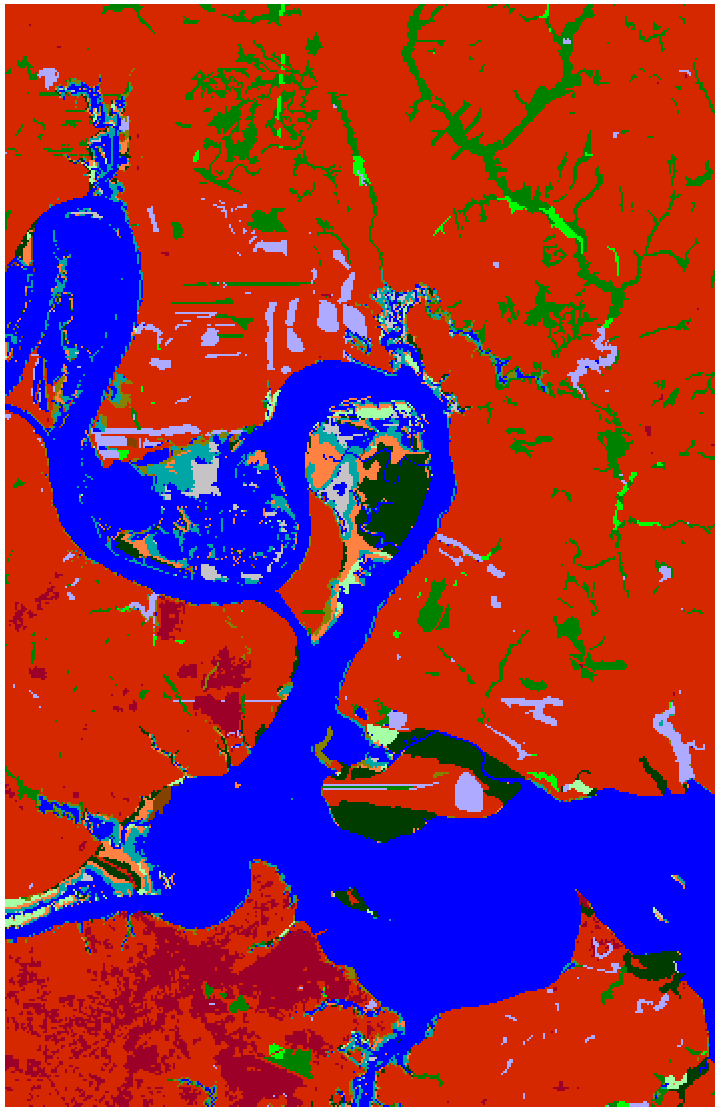

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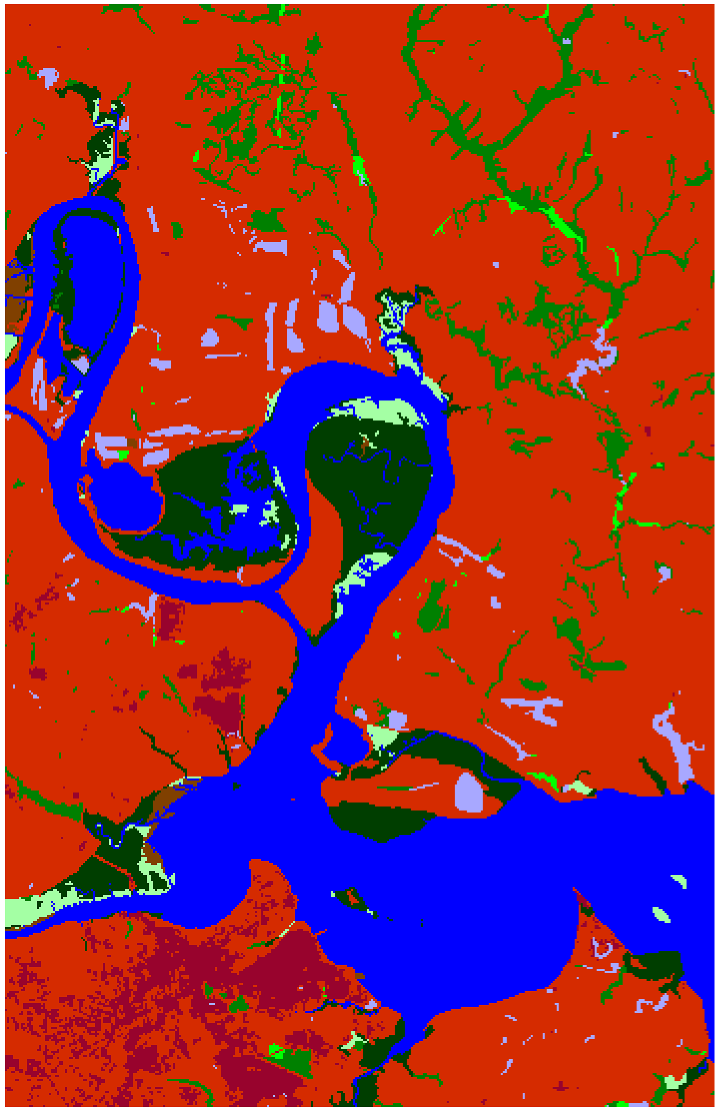
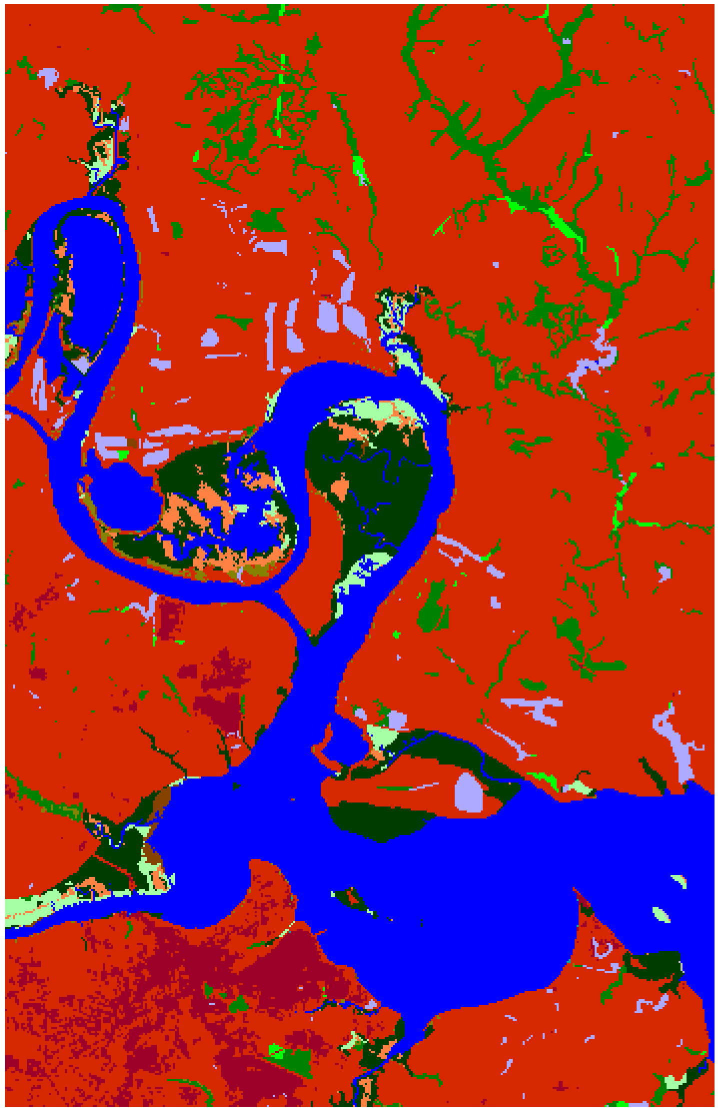


Presquile NWR, Initial Condition



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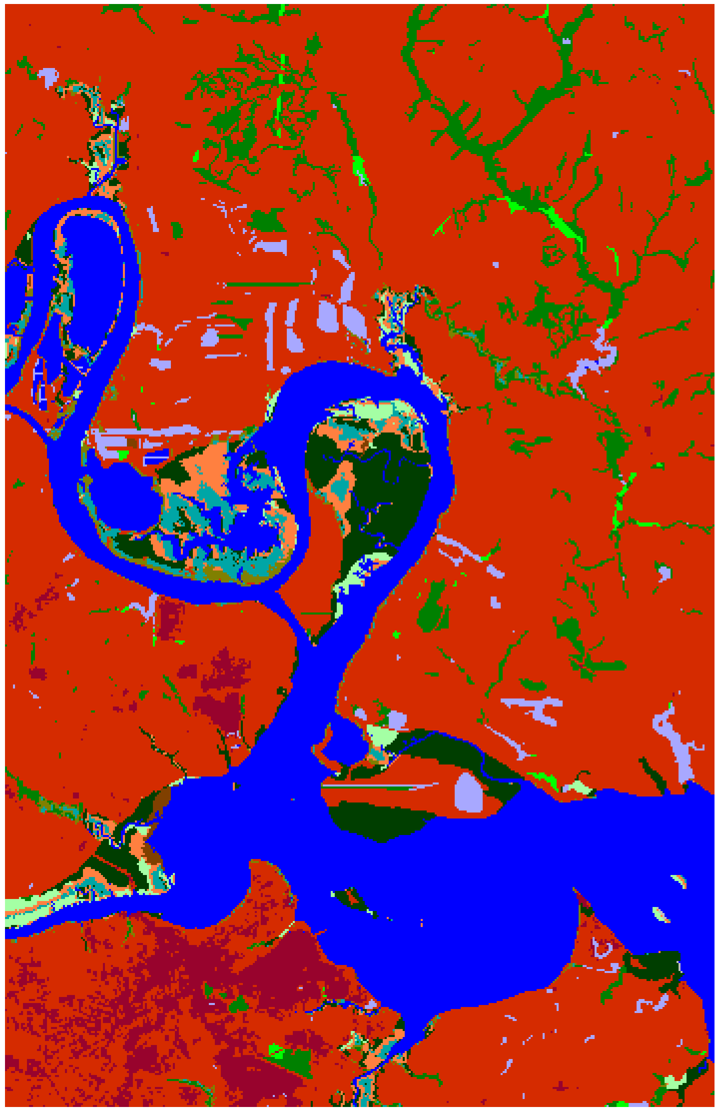

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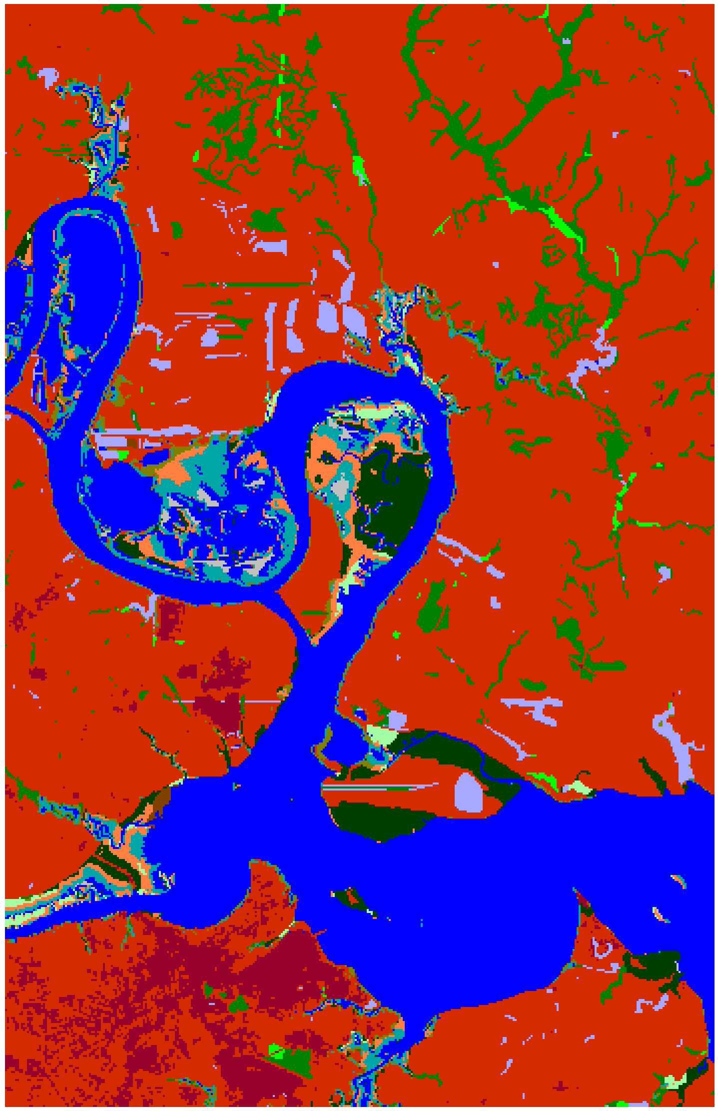

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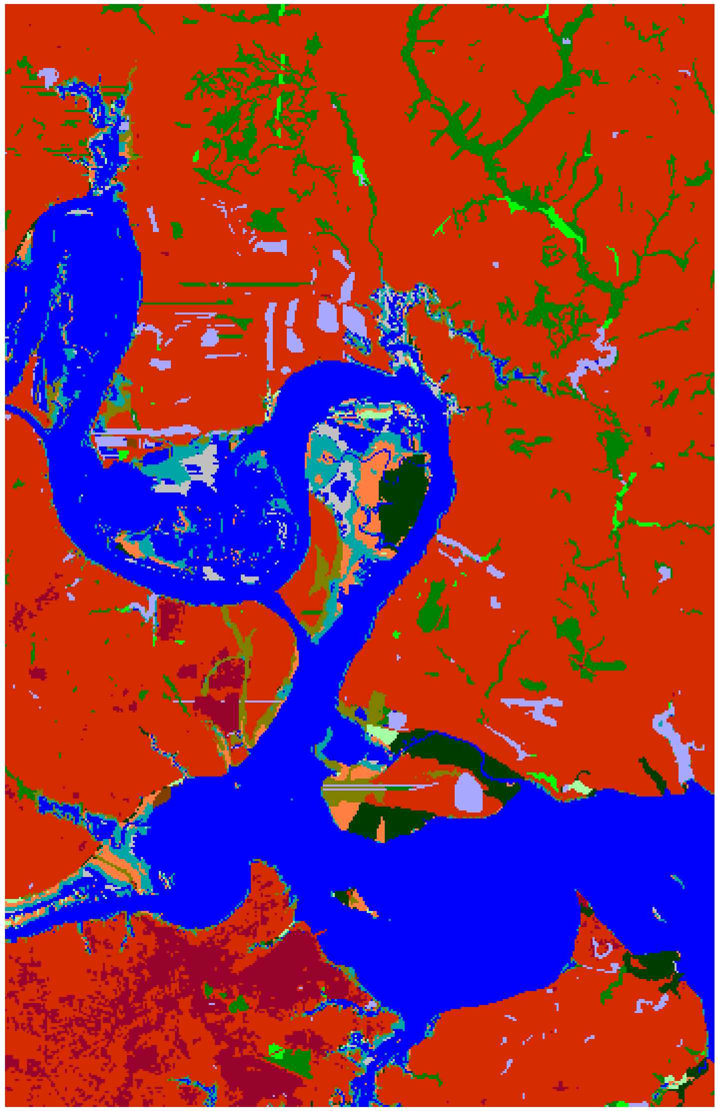

Presquile NWR, 2100, 2 meter