Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Pine Island NWR

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This report was derived from a study performed by The Florida Nature Conservancy.

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Introduction

Tidal marshes are among the most susceptible ecosystems to climate change, especially accelerated sea-level rise (SLR). The Intergovernmental 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 is 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 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 many coastal 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. This report was derived from a study performed by The Florida Nature Conservancy (2011).

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 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 et al. 1992; Park et al. 1993; Galbraith et al. 2002; National Wildlife Federation & Florida Wildlife Federation 2006; Glick et al. 2007; Craft et al. 2009). The first phase of this work was completed using SLAMM 5, while the second phase simulations were run with SLAMM 6.

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 specified interval for large 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 and can be specified to respond to feedbacks such as frequency of flooding.

SLAMM Version 6.0 was developed in 2008/2009 and is based on SLAMM 5. SLAMM 6.0 provides backwards compatibility to SLAMM 5, that is, SLAMM 5 results can be replicated in SLAMM 6. However, SLAMM 6 also provides several optional capabilities.

- Accretion Feedback Component: Feedbacks based on wetland elevation, distance to channel, and salinity may be specified. This feedback will be used in USFWS simulations, but only where adequate data exist for parameterization.
- Salinity Model: Multiple time-variable freshwater flows may be specified. Salinity is estimated and mapped at MLLW, MHHW, and MTL. Habitat switching may be specified as a function of salinity. This optional sub-model is not utilized in USFWS simulations.
- Integrated Elevation Analysis: SLAMM will summarize site-specific categorized elevation ranges for wetlands as derived from LiDAR data or other high-resolution data sets. This functionality is used in the current simulations to test the SLAMM conceptual model. The causes of any discrepancies are then tracked down and reported on within the model application report.
- Flexible Elevation Ranges for land categories: If site-specific data indicate that wetland elevation ranges are outside of SLAMM defaults, a different range may be specified within the interface. If such a change is made, the change and the reason for it are fully documented.
- Many other graphic user interface and memory management improvements are also part of the new version including an updated *Technical Documentation*, and context sensitive help files.

For a thorough accounting of SLAMM model processes and the underlying assumptions and equations, please see the SLAMM 6.0 *Technical Documentation* (Clough et al. 2010). 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 (Council for Regulatory Environmental Modeling 2008). Site-specific factors that increase or decrease model uncertainty may be covered in the Results and Discussion section of this report.

Sea Level Rise Scenarios

Forecast simulations used scenario A1B from the Special Report on Emissions Scenarios (SRES) – mean and maximum estimates. The A1 family of scenarios assumes that the future world includes 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 0.39 meters of global sea level rise by 2100. A1B-maximum predicts 0.69 meters of global SLR 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 of 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." (Clark 2009) 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…" Grinsted also states that there is a "low probability" that SLR will match the lower IPCC estimates.

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 2).

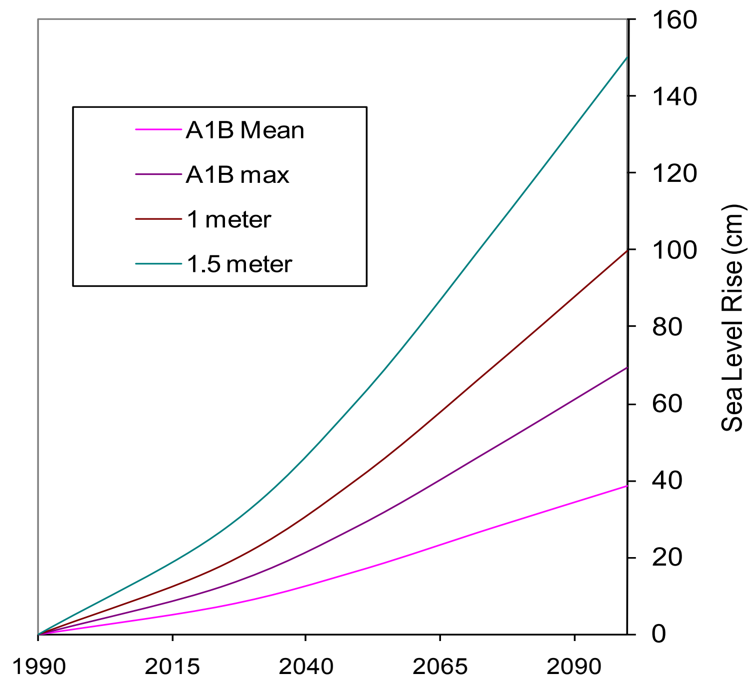

Figure 1. Summary of SLR Scenarios

Methods and Data Sources

Two sets of elevation data from the NOAA Coastal Services Center for the Charlotte Harbor study area were used for this study:

- 2005 Southwest Florida Water Management District, Peace River South District LiDAR
- 2004-2008 Florida Division of Emergency Management: Southwest Florida LiDAR

Both were downloaded as 15 m digital elevation maps (DEM) using Average Bin method in State Plane coordinates. Datasets were mosaicked, resampled and clipped to the study area. Areas lacking elevation data in the estuary or the ocean were set to zero.

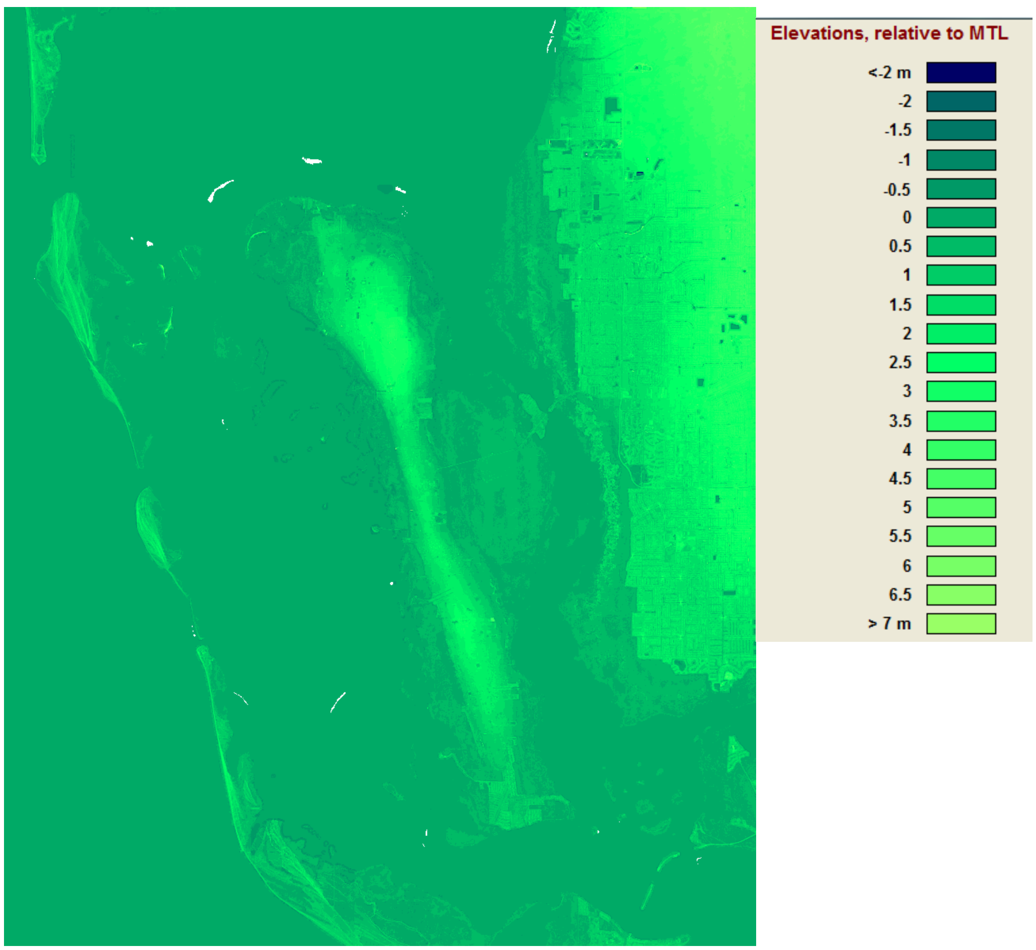

Figure 2. Elevation data for area of Pine Island NWR

The Florida Natural Areas Inventory Cooperative Land Cover (CLC) 1.1 was used as the basis for vegetation. Land Cover codes were crosswalked to SLAMM categories. The National Wetlands Inventory data was also crosswalked to SLAMM categories. Areas identified by the NWI as tidal flats replaced CLC vegetation if they were overlaid areas identified by the CLC as water. An area identified by the NWI as tidal swamp replaced a small area in the Peace River. Photo dates for subsites were taken from the CLC as either 2004 or 2008. The land cover map used is shown in Figure 3.

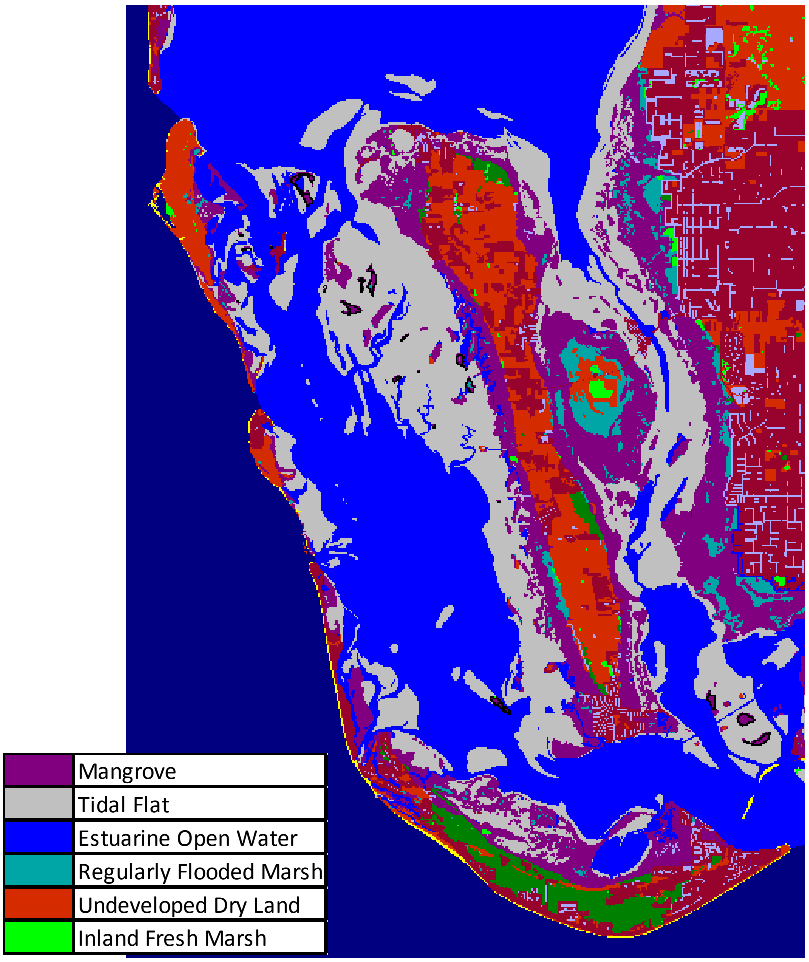

Figure 3. Wetland layer used for Pine Island NWR. Refuge boundary in black

Converting the CLC survey into 30 meter cells indicated that the approximately 635 acre study area is composed of the categories shown in Table 1.

Table 1. Land cover categories and their abundance in the Pine Island NWR study area according to the 2009 NWI layer.

Land cover type		Area (acres)	Percentage (%)
	Mangrove	537	85
	Tidal Flat	49	8
	Estuarine Open Water	27	4
	Regularly Flooded Marsh	16	3
	Undeveloped Dry Land	3	0
	Inland Fresh Marsh	2	0
	Total (incl. water)	**634**	**100**

According to the National Wetland Inventory, there are no impounded and /or diked areas in the refuge.

The historic trend for sea level rise was taken as 2.4 mm/yr from the NOAA gauge at Fort Myers (# 8725520).

The study area surrounding the refuge was divided into two subsites based on tide range values, as shown in Figure 4. The majority of the refuge is located in subsite 1, with only a small portion potentially falling in subsite 2. Tidal parameters were obtained the local NOAA gauges shown in Table 2.

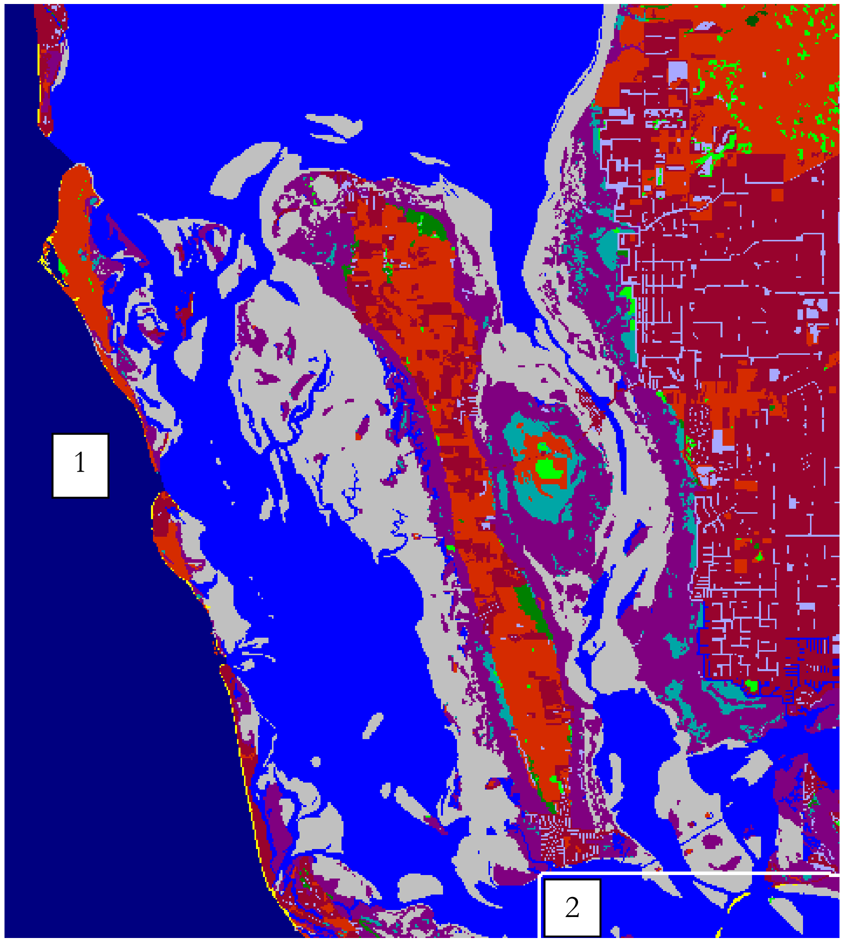

Figure 4. Input parameter subsites used

Table 2. NOAA gauges used for GT

NOAA Gauge Name	NOAA Station ID	GT (m)	Subsite where applied
Matanzas Pass Estero Island	8725366	0.794	2
Estero Island Estero Bay	8725351	0.769	2
Hurricane Bay San Carlos Island	8725368	0.794	2
Tarpon Bay	8725362	0.693	2
Punta Rassa	8725391	0.689	2
Ostego Bay	8725331	0.758	2
Estero River Estero Bay	8725346	0.747	2
Coconut Point Estero Bay	8725319	0.755	2
Port Boca Grande Charlotte Hbr	8725577	0.475	1
Bokellia	8725541	0.526	1
Englewood Lemon Bay	8725747	0.534	1
Pine Island	8725528	0.517	1
North Captiva Island	8725488	0.606	1
Manasota	8725809	0.512	1
Nokomis Venice Inlet	8725899	0.534	1

The "salt elevation" parameter within SLAMM designates the boundary between coastal wetlands and dry lands or fresh water wetlands. An estimate of this elevation may be derived by examining historical tide gauge data to determine how frequently different elevations are flooded with ocean water. Within SLAMM modeling simulations this elevation is usually defined as the elevation over which flooding is predicted less than once in every 30 days. Dry lands and fresh-water wetlands are assumed to be located above that elevation. In this study the salt elevation was calculated from multi-year data from Fort Myers (NOAA station ID 8725520) and Naples (NOAA station ID 8725110), resulting in a salt elevation that was predicted to be 0.92 times the great diurnal tide range applied to the subsite.

No erosion, accretion or sedimentation values specific to this study area were found that would be suitable for use, therefore SLAMM default values were used.

The MTL to NAVD88 correction was averaged across subsites from NOAA gauge values and are shown in Table 3, which presents a summary of the input parameters used for this SLAMM application.

Table 3. Summary of SLAMM input parameters for Pine Island NWR site

Parameter	SubSite1	SubSite 2
Description	Charlotte Harbor	Estero
NWI Photo Date (YYYY)	2004	2004
DEM Date (YYYY)	2007	2007
Direction Offshore [n,s,e,w]	West	West
Historic Trend (mm/yr)	2.4	2.4
MTL-NAVD88 (m)	-0.178	-0.185
GT Great Diurnal Tide Range (m)	0.529	0.75
Salt Elev. (m above MTL)	0.434	0.615
Marsh Erosion (horz. m /yr)	2	2
Swamp Erosion (horz. m /yr)	1	1
T.Flat Erosion (horz. m /yr)	0.2	0.2
Reg.-Flood Marsh Accr (mm/yr)	2.25	2.25
Irreg.-Flood Marsh Accr (mm/yr)	3.75	3.75
Tidal-Fresh Marsh Accr (mm/yr)	4	4
Inland-Fresh Marsh Accr (mm/yr)	4	4
Mangrove Accr (mm/yr)	7	7
Tidal Swamp Accr (mm/yr)	1.1	1.1
Swamp Accretion (mm/yr)	0.3	0.3
Beach Sed. Rate (mm/yr)	0.3	0.3
Freq. Overwash (years)	25	25

Results

SLAMM simulations predict Pine Island NWR is likely to be impacted by SLR, particularly at SLR scenarios of 0.69 m by 2100 and higher. Table 4 presents the losses of wetland categories by 2100 under each SLR scenario examined, suggesting near complete inundation of the refuge under the 2 m SLR scenario.

Pine Island NWR is primarily composed of mangrove (85% of the land area of the refuge). The small amount of marsh in the refuge is predicted to be completely lost at all SLR scenarios of 1 m and above. However, because mangrove is assigned a relatively high accretion rate (7 mm/yr), the majority of the refuge appears resilient until the rate of SLR exceeds the accretion rate. At scenarios above 1.5 m by 2100, though, more than 90% of refuge mangroves are predicted to be lost.

Regularly flooded marsh, dry land, and freshwater marsh, which make up a small portion of the refuge. These habitats are predicted to be severely reduced under the A1B max scenario (0.69 m by 2100) and lost completely at SLR scenarios of 1m and higher.

Table 4. Predicted Loss of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

Land cover category	**Land cover change by 2100 for different SLR scenarios (%)**				
	0.39 m	**0.69 m**	**1 m**	**1.5 m**	**2 m**
Mangrove	0	1	9	92	98
Tidal Flat	24	49	82	96	96
Regularly Flooded Marsh	6	98	100	100	100
Undeveloped Dry Land	76	96	100	100	100
Inland Fresh Marsh	0	76	99	100	100

Pine Island NWR
IPCC Scenario A1B-Mean, 0.39 m SLR eustatic by 2100

Results in Acres

		Initial	2025	2050	2075	2100
	Mangrove	537	534	534	535	535
	Tidal Flat	49	48	46	42	37
	Estuarine Open Water	27	32	34	38	44
	Regularly Flooded Marsh	16	16	16	16	15
	Undeveloped Dry Land	3	2	1	1	1
	Inland Fresh Marsh	2	2	2	2	2
	Total (incl. water)	**634**	**634**	**634**	**634**	**634**

Pine Island NWR, Initial Condition

Pine Island NWR, 2025, Scenario A1B Mean

Pine Island NWR, 2050, Scenario A1B Mean

Pine Island NWR, 2075, Scenario A1B Mean

Pine Island NWR, 2100, Scenario A1B Mean

Pine Island NWR
IPCC Scenario A1B-Max, 0.69 m SLR eustatic by 2100

Results in Acres

		Initial	2025	2050	2075	2100
	Mangrove	537	534	535	536	533
	Tidal Flat	49	47	44	44	25
	Estuarine Open Water	27	33	36	48	75
	Regularly Flooded Marsh	16	16	16	5	0
	Undeveloped Dry Land	3	2	1	0	0
	Inland Fresh Marsh	2	2	2	2	0
	Total (incl. water)	**634**	**634**	**634**	**634**	**634**

Pine Island NWR, Initial Condition

Pine Island NWR, 2025, Scenario A1B Max

Pine Island NWR, 2050, Scenario A1B Max

Pine Island NWR, 2075, Scenario A1B Max

Pine Island NWR, 2100, Scenario A1B Max

Pine Island NWR
1 m eustatic SLR by 2100

Results in Acres

		Initial	2025	2050	2075	2100
	Mangrove	537	534	532	525	488
	Tidal Flat	49	47	43	27	9
	Estuarine Open Water	27	34	45	81	138
	Regularly Flooded Marsh	16	16	11	0	0
	Undeveloped Dry Land	3	2	1	0	0
	Inland Fresh Marsh	2	2	2	0	0
	Total (incl. water)	**634**	**634**	**634**	**634**	**634**

Pine Island NWR, Initial Condition

Pine Island NWR, 2025, Scenario 1 Meter

Pine Island NWR, 2050, Scenario 1 Meter

Pine Island NWR, 2075, Scenario 1 Meter

Pine Island NWR, 2100, Scenario 1 Meter

Pine Island NWR
1.5 m eustatic SLR by
2100

Results in Acres

		Initial	2025	2050	2075	2100
	Mangrove	537	532	521	270	45
	Tidal Flat	49	46	44	5	2
	Estuarine Open Water	27	37	68	359	587
	Regularly Flooded Marsh	16	16	1	0	0
	Undeveloped Dry Land	3	1	0	0	0
	Inland Fresh Marsh	2	2	0	0	0
	Total (incl. water)	**634**	**634**	**634**	**634**	**634**

Pine Island NWR, Initial Condition

Pine Island NWR, 2025, Scenario 1.5 Meters

Pine Island NWR, 2050, Scenario 1.5 Meters

Pine Island NWR, 2075, Scenario 1.5 Meters

Pine Island NWR, 2100, Scenario 1.5 Meters

Pine Island NWR
2 m eustatic SLR by 2100

Results in Acres

		Initial	2025	2050	2075	2100
	Mangrove	537	529	428	44	10
	Tidal Flat	49	45	30	1	2
	Estuarine Open Water	27	41	176	589	621
	Regularly Flooded Marsh	16	16	0	0	0
	Undeveloped Dry Land	3	1	0	0	0
	Inland Fresh Marsh	2	2	0	0	0
	Total (incl. water)	**634**	**634**	**634**	**634**	**634**

Pine Island NWR, Initial Condition

Pine Island NWR, 2025, Scenario 2 Meters

Pine Island NWR, 2050, Scenario 2 Meters

Pine Island NWR, 2075, Scenario 2 Meters

Pine Island NWR, 2100, Scenario 2 Meters

Conclusions

Model results for Pine Island NWR indicate that it is vulnerable to sea level rise. Under each SLR scenario examined, marshes are predicted to sustain considerable losses while mangroves are predicted to "keep up" with SLR until the rate of sea level rise reaches 1.5 m by 2100. Overall, the entire refuge is predicted to be nearly completely inundated at SLR scenarios of 1.5 m and above.

One of the main requirements for producing reliable results using SLAMM is the use of high-quality elevation data. This analysis was run using LiDAR data, which reduces uncertainty in the model results to a degree. However, at this site an important source of model uncertainty is from the accretion rates. There were no local accretion data available in the literature; therefore SLAMM default values were applied. Specific measurements of accretion rates within the refuge could provide better predictions of marsh losses in the future.

This report was derived from an analysis of Charlotte Harbor produced by The Florida Nature Conservancy. Spatial results for this study are presented in Appendix A.

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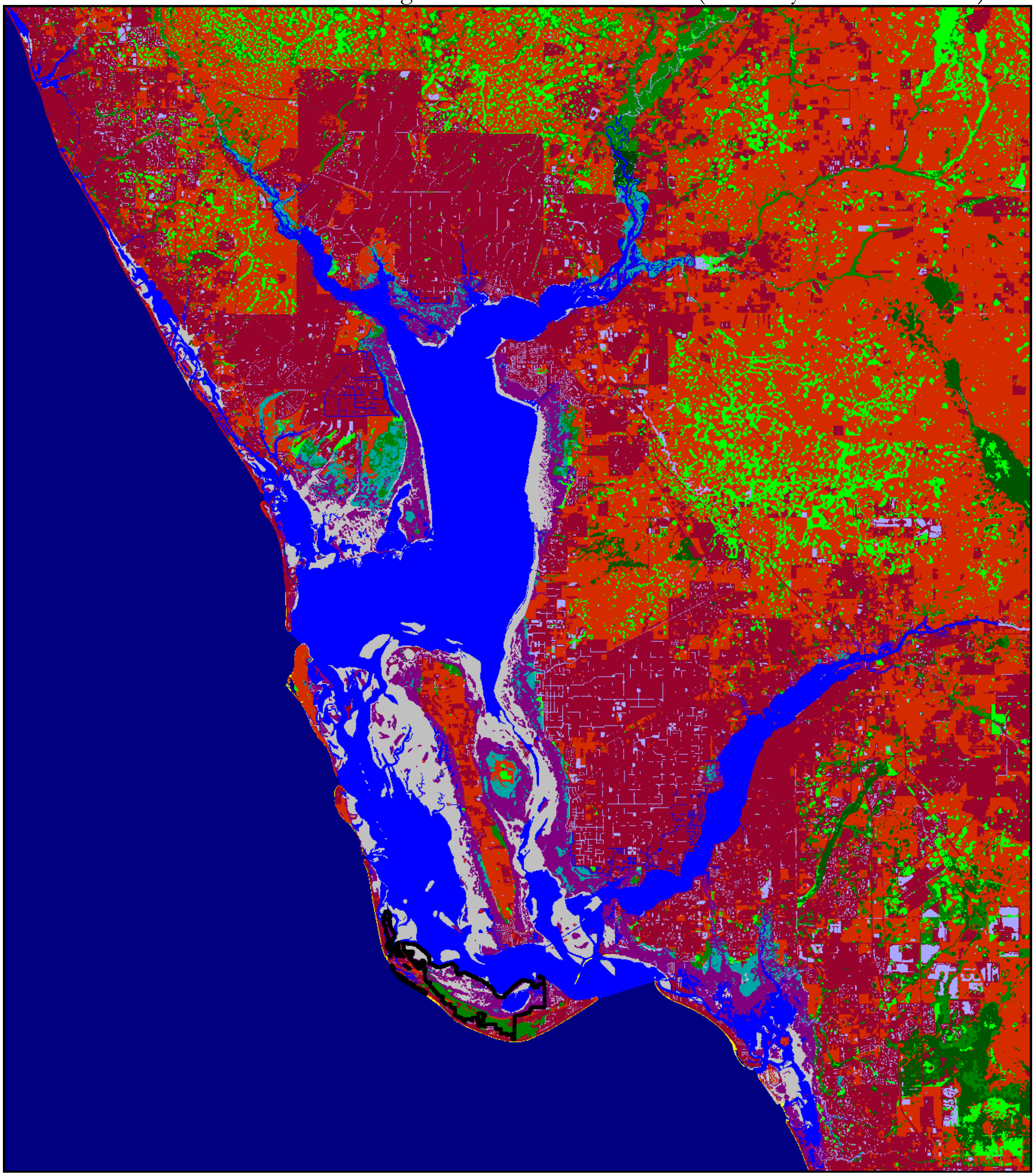
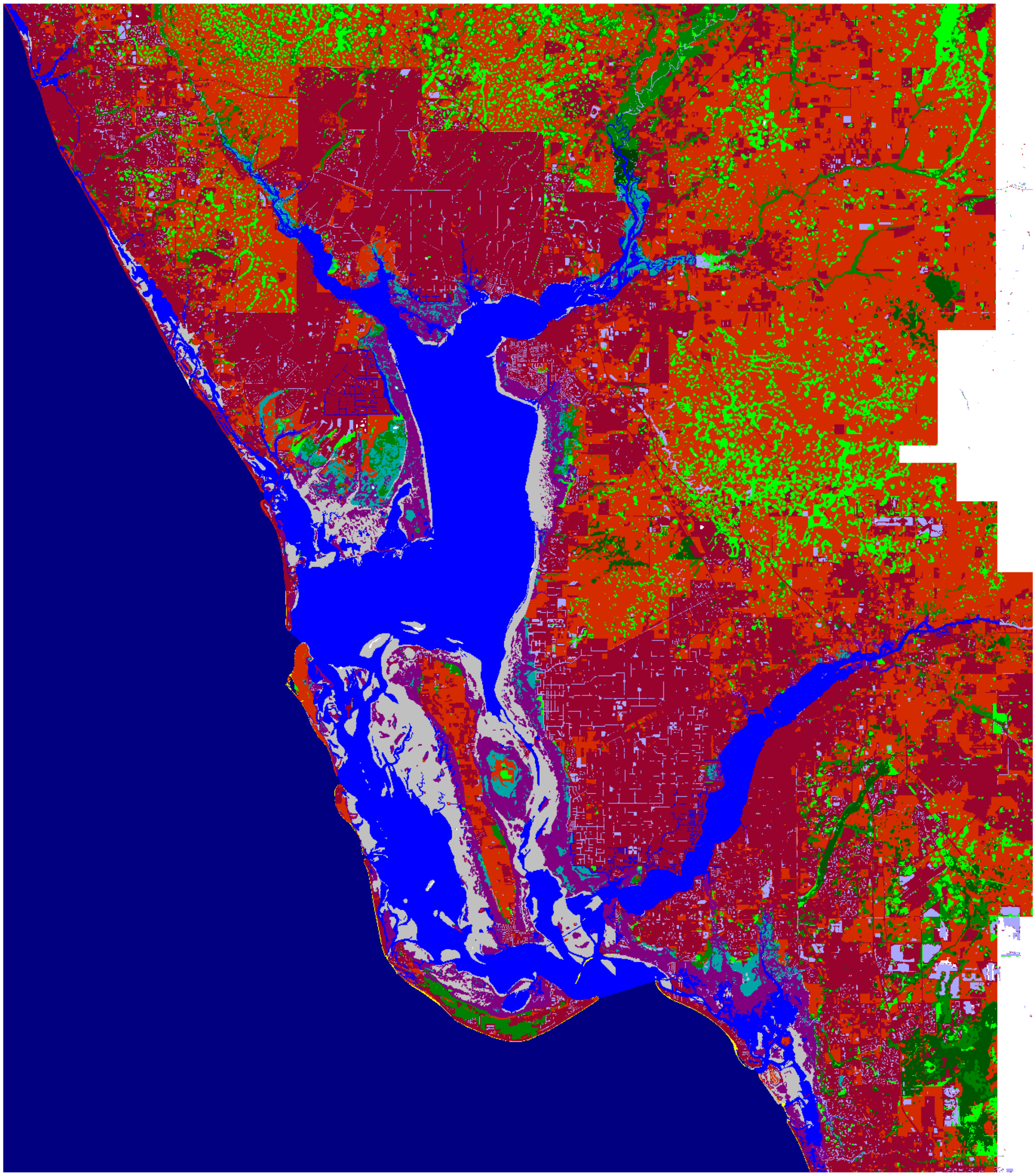
Appendix A: Contextual Results

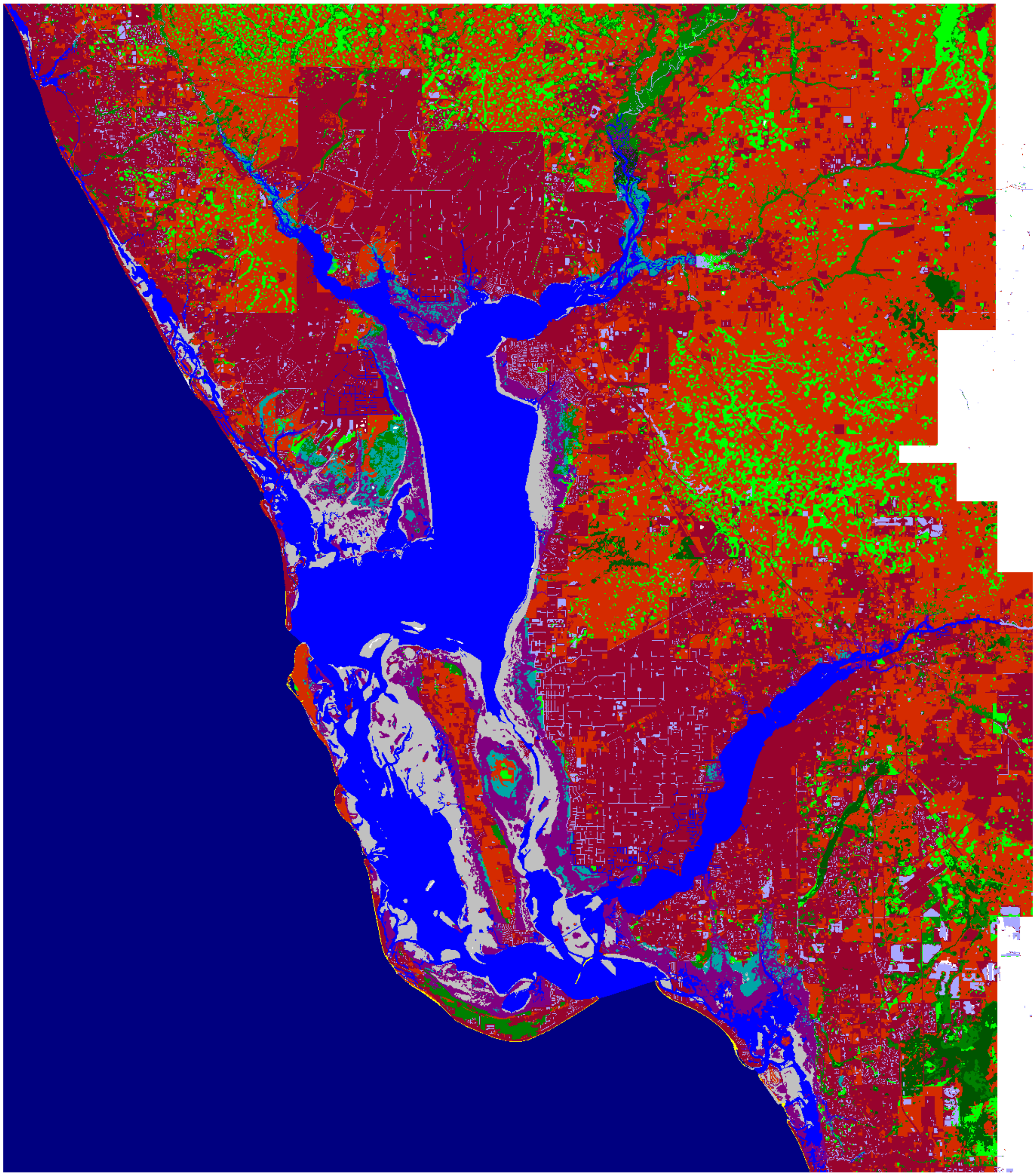
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

Pine Island National Wildlife Refuge within simulation context (boundary outlined in black)

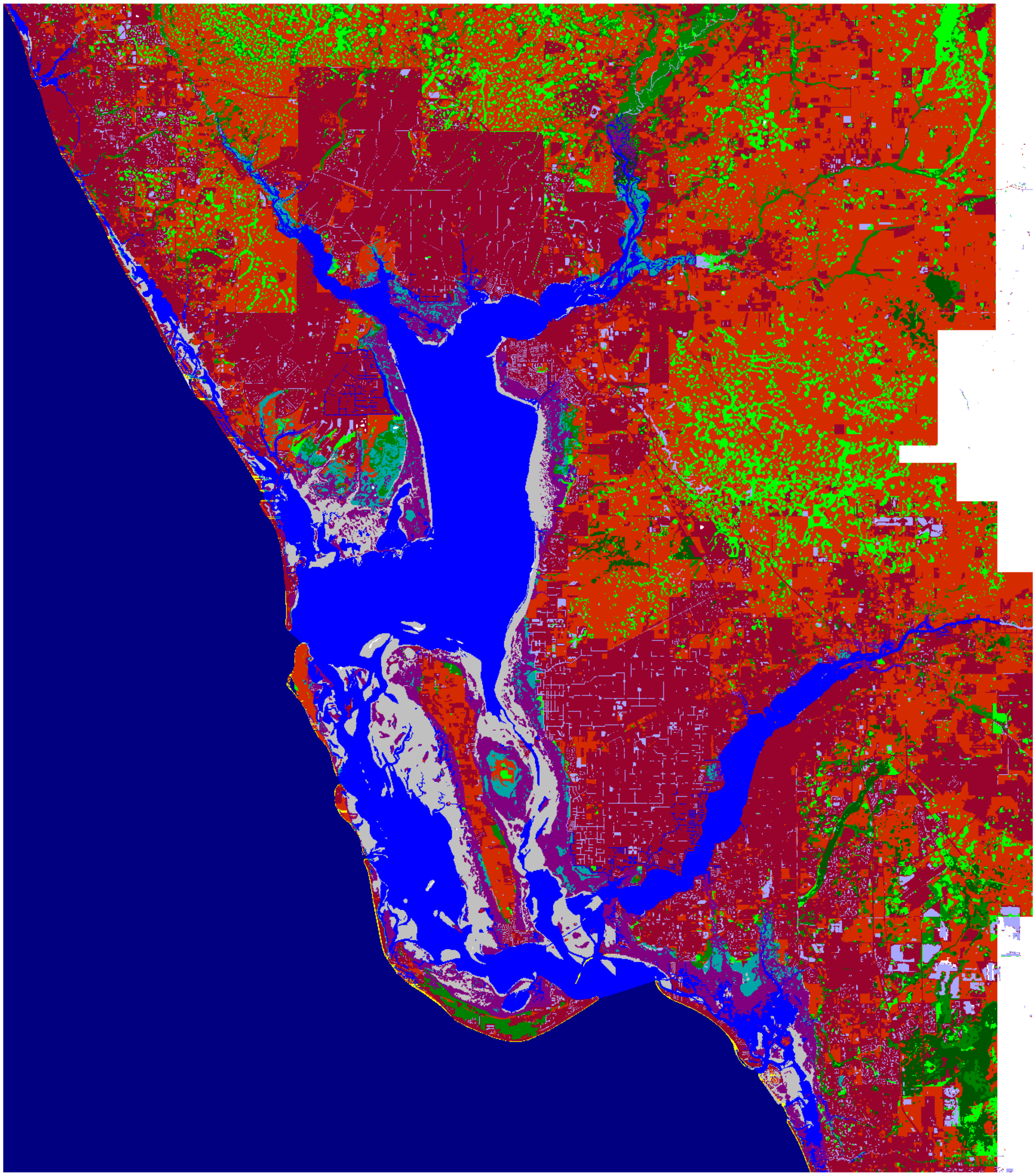




Pine Island Context, Initial Condition



Pine Island Context, 2025, Scenario A1B Mean



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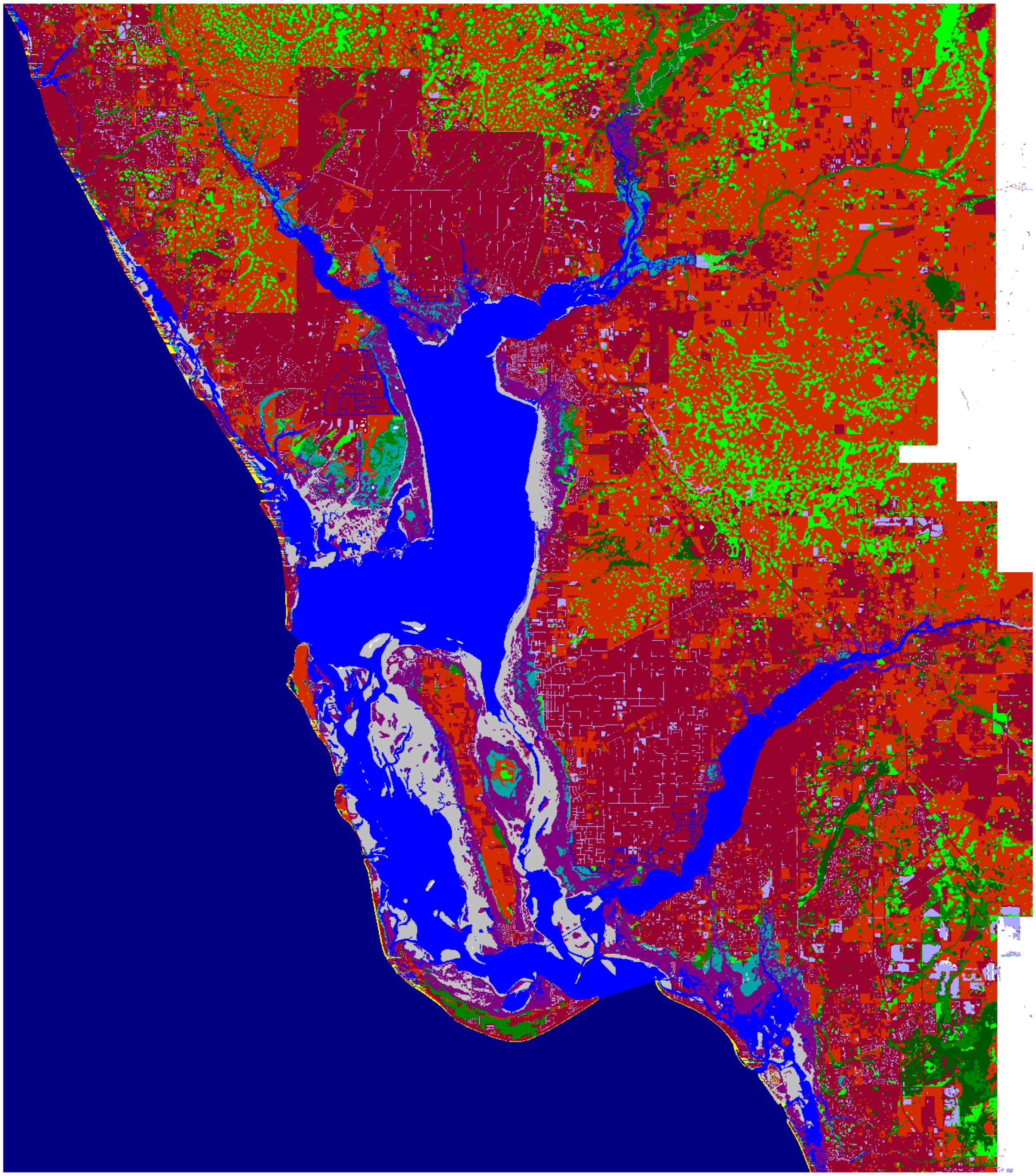
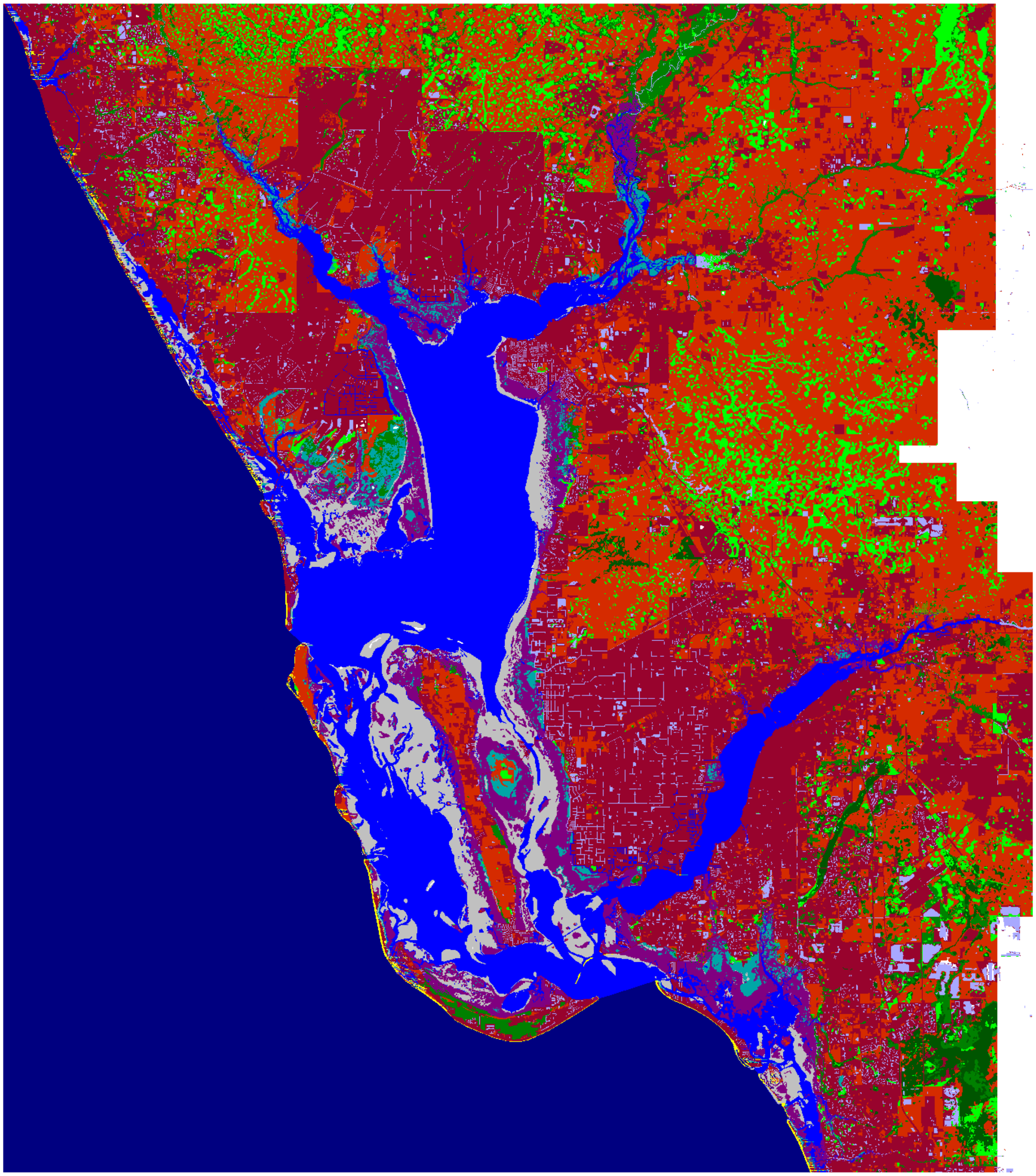
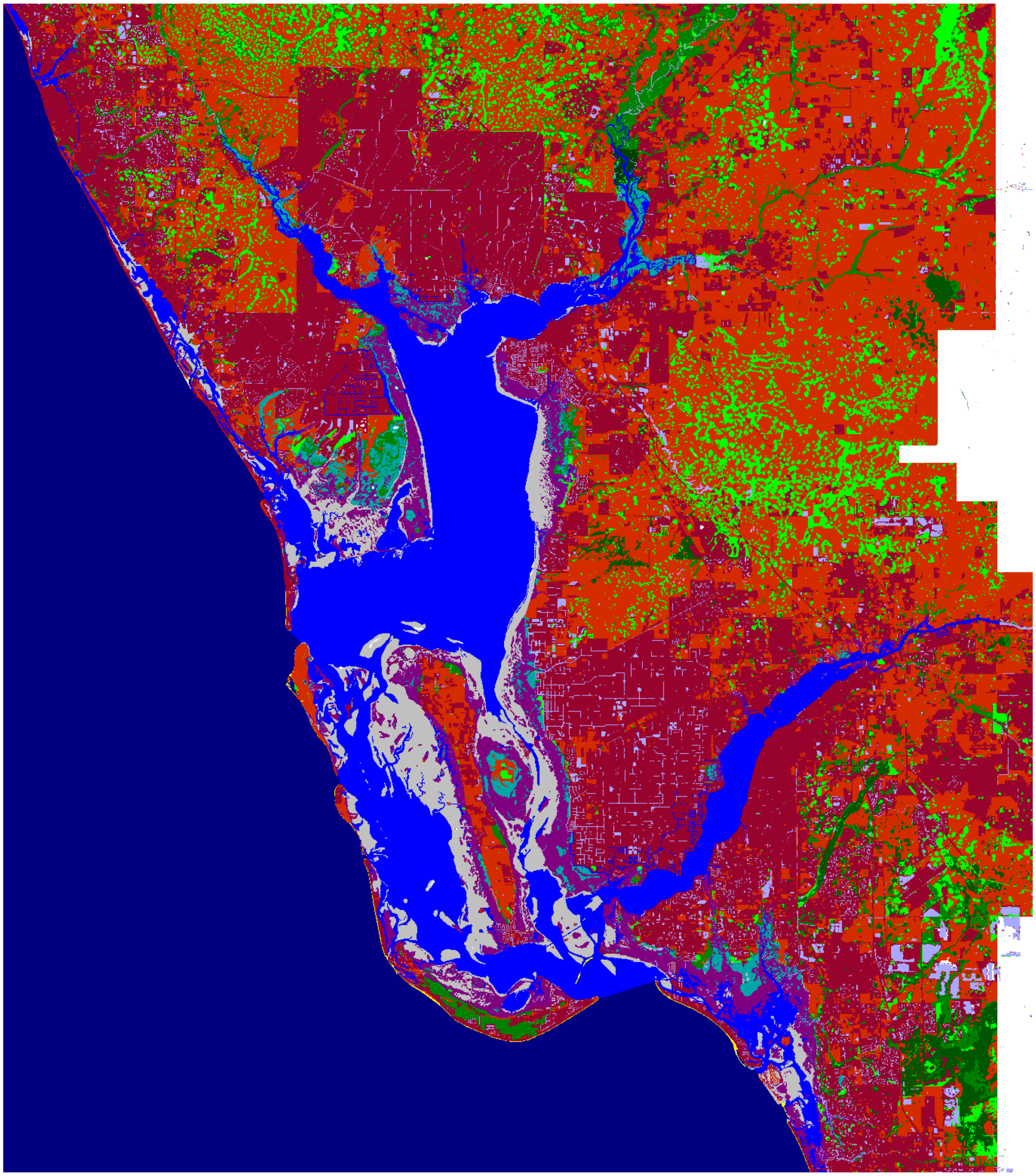


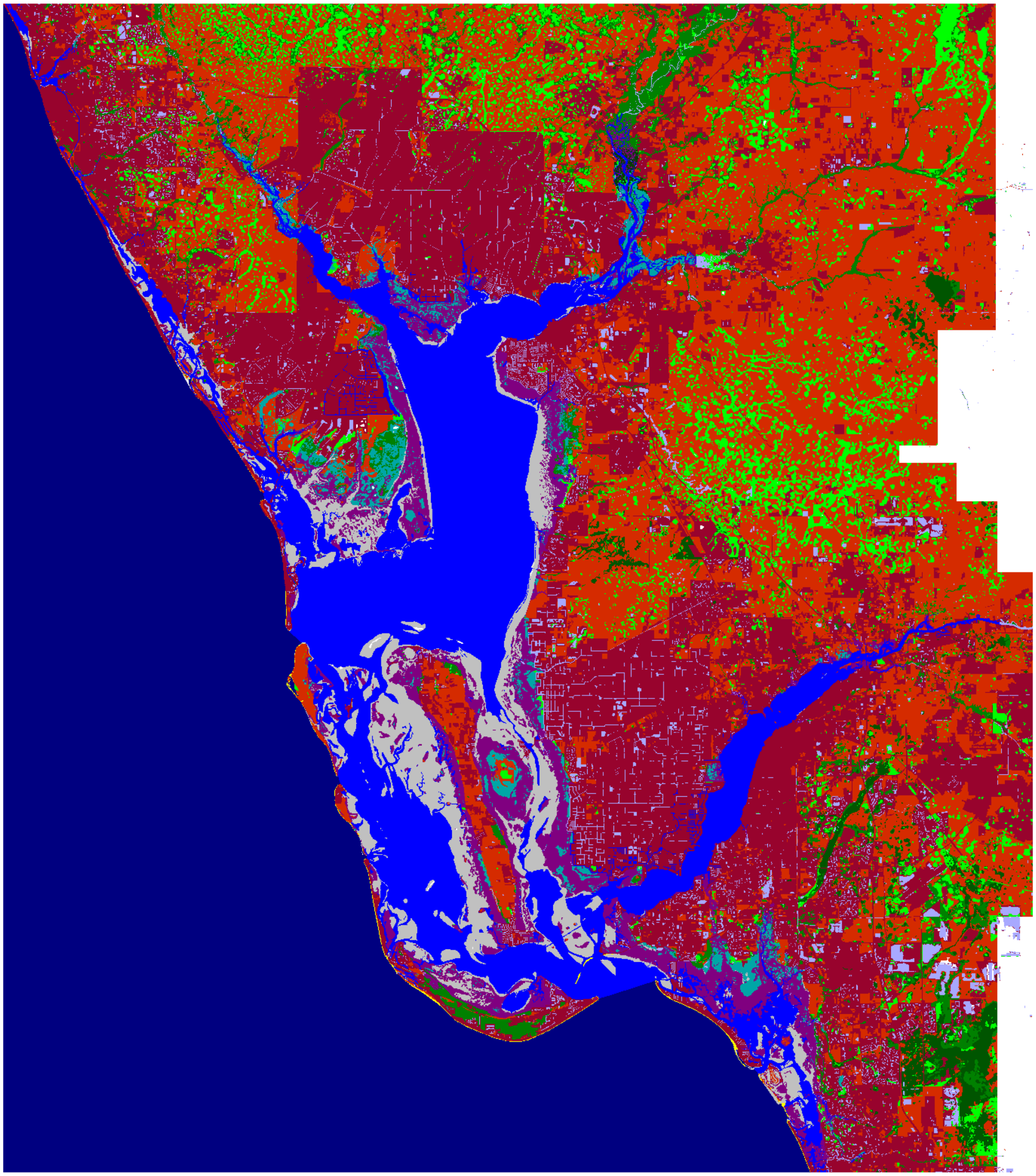
Pine Island Context, 2075, Scenario A1B Mean



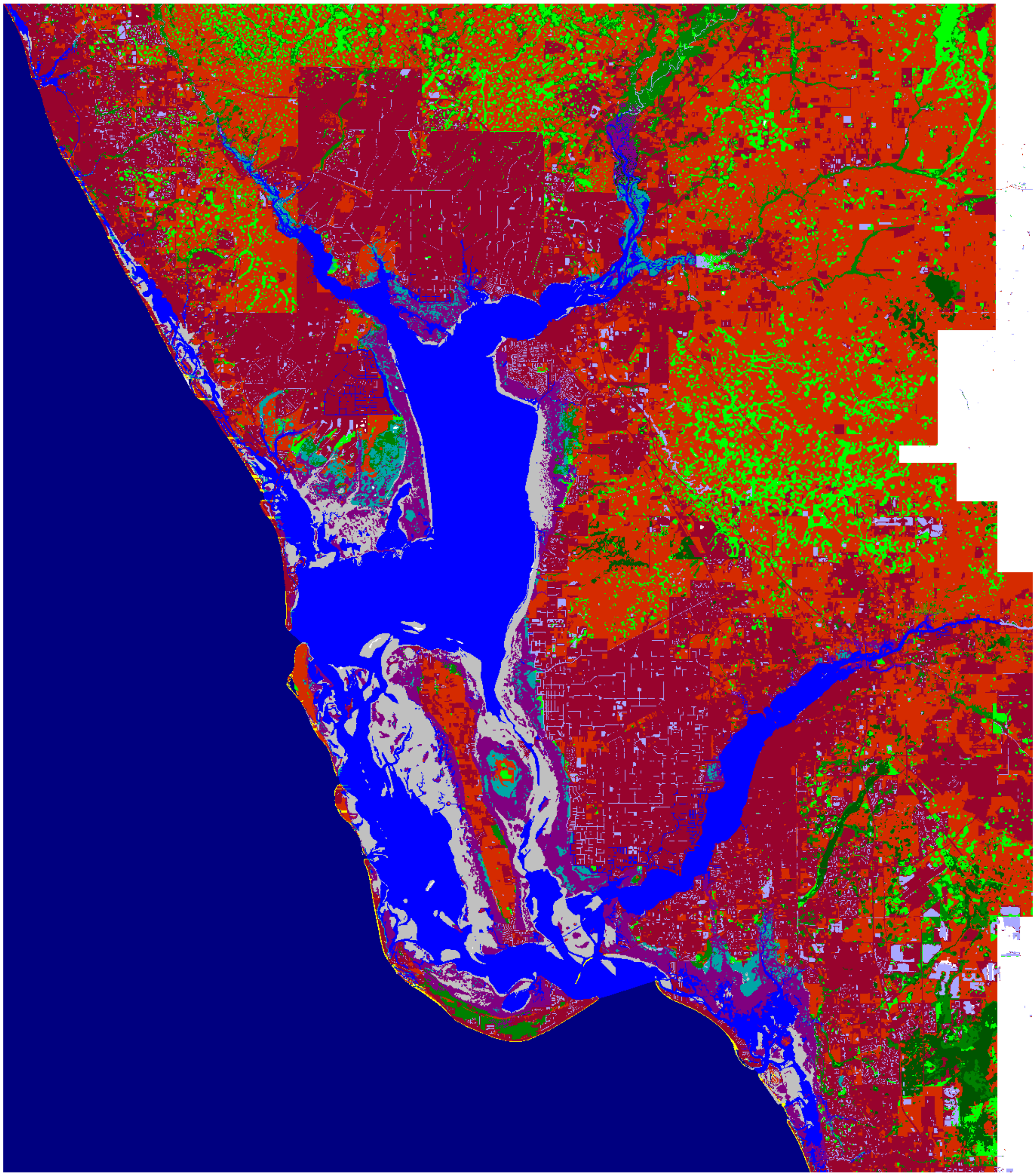
Pine Island Context, 2100, Scenario A1B Mean



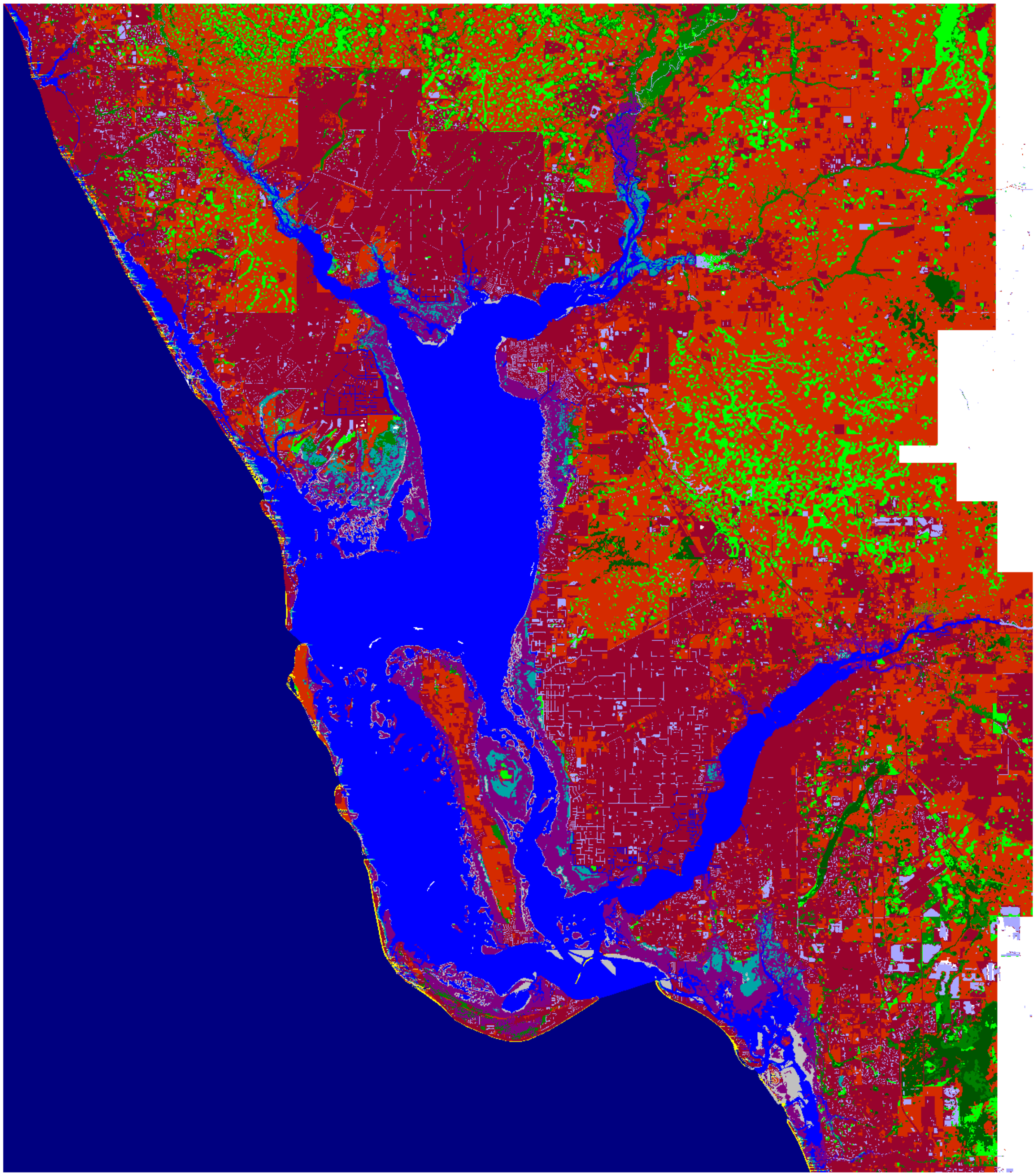
Pine Island Context, Initial Condition



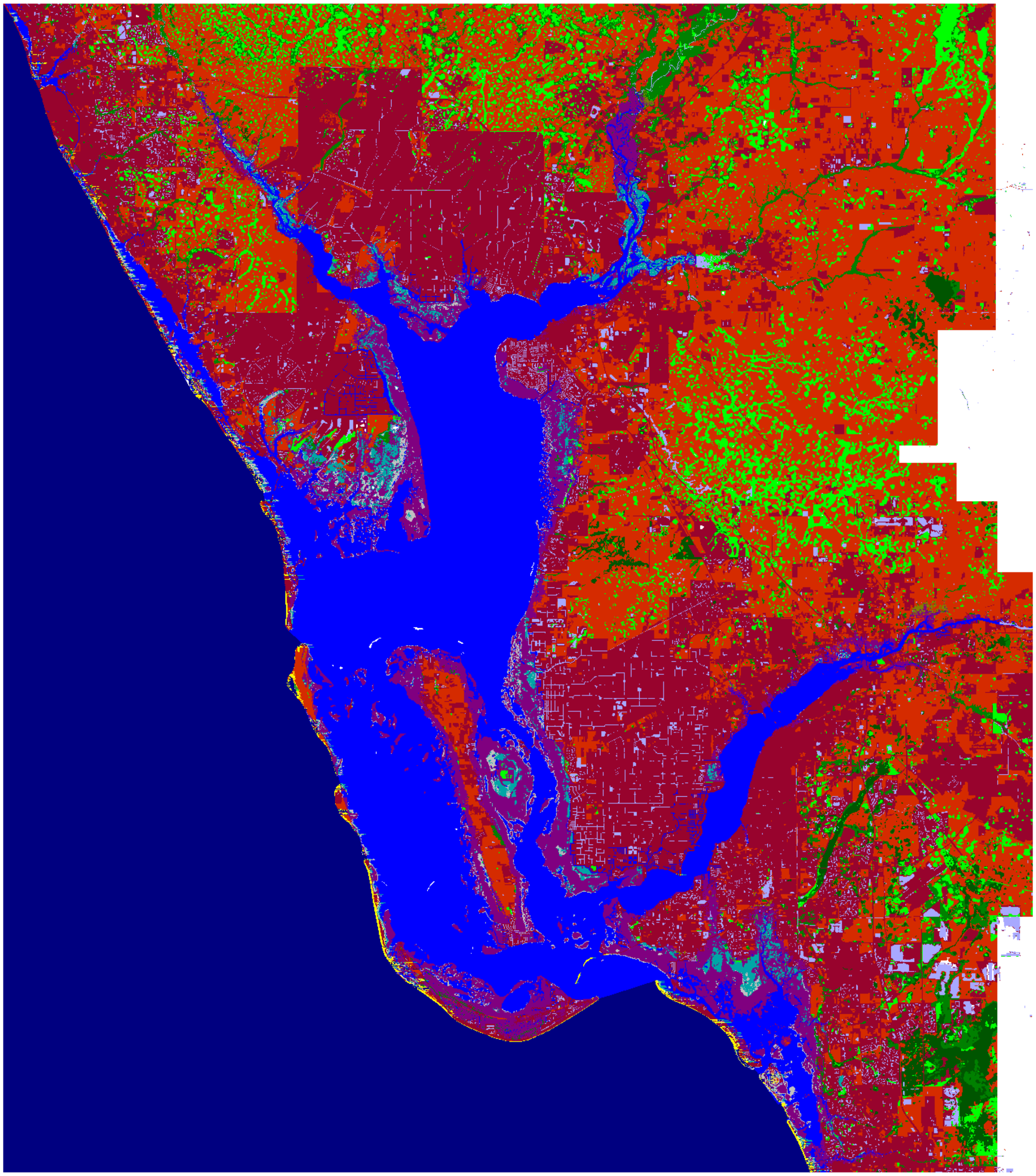
Pine Island Context, 2025, Scenario A1B Maximum



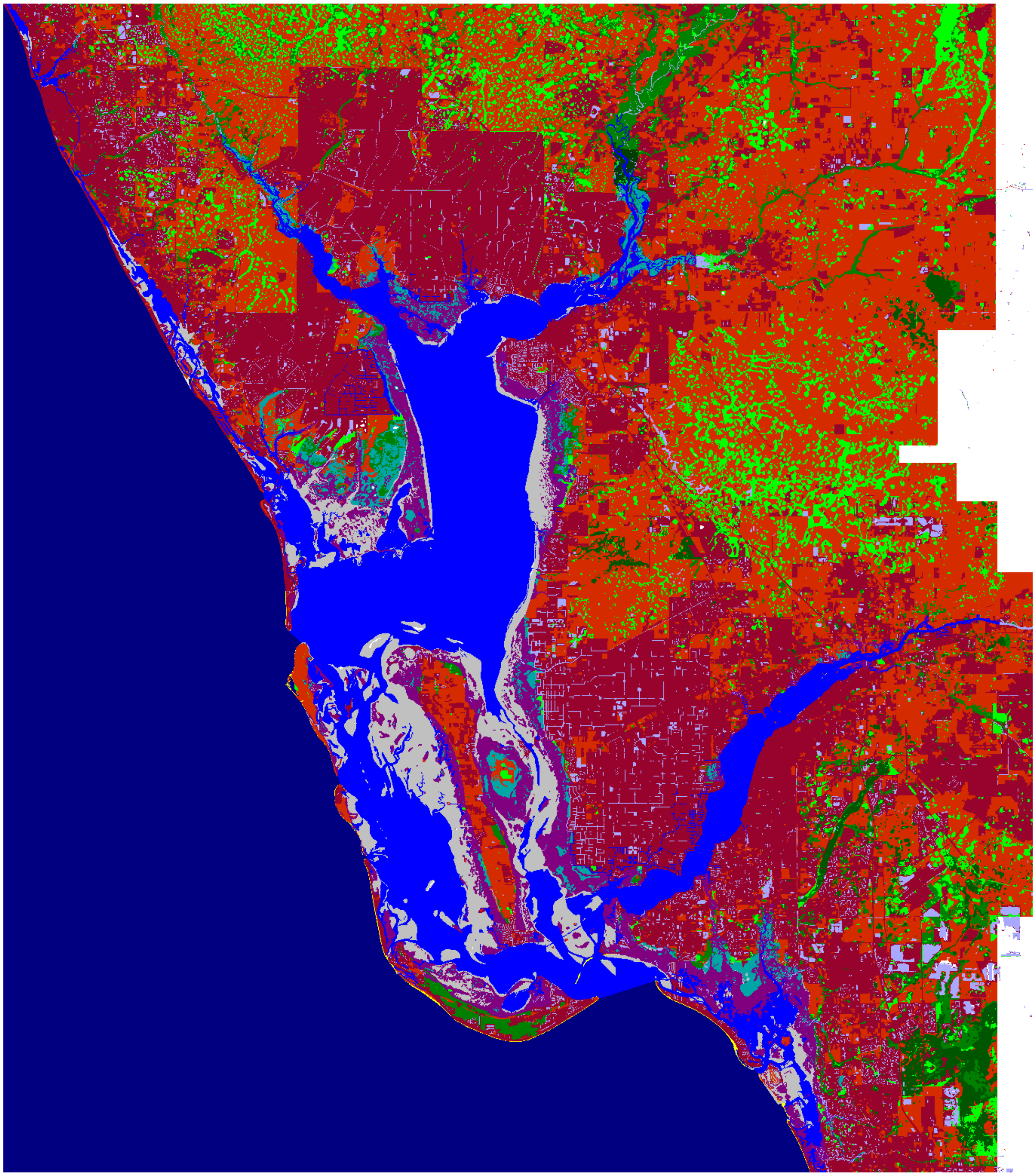
Pine Island Context, 2050, Scenario A1B Maximum



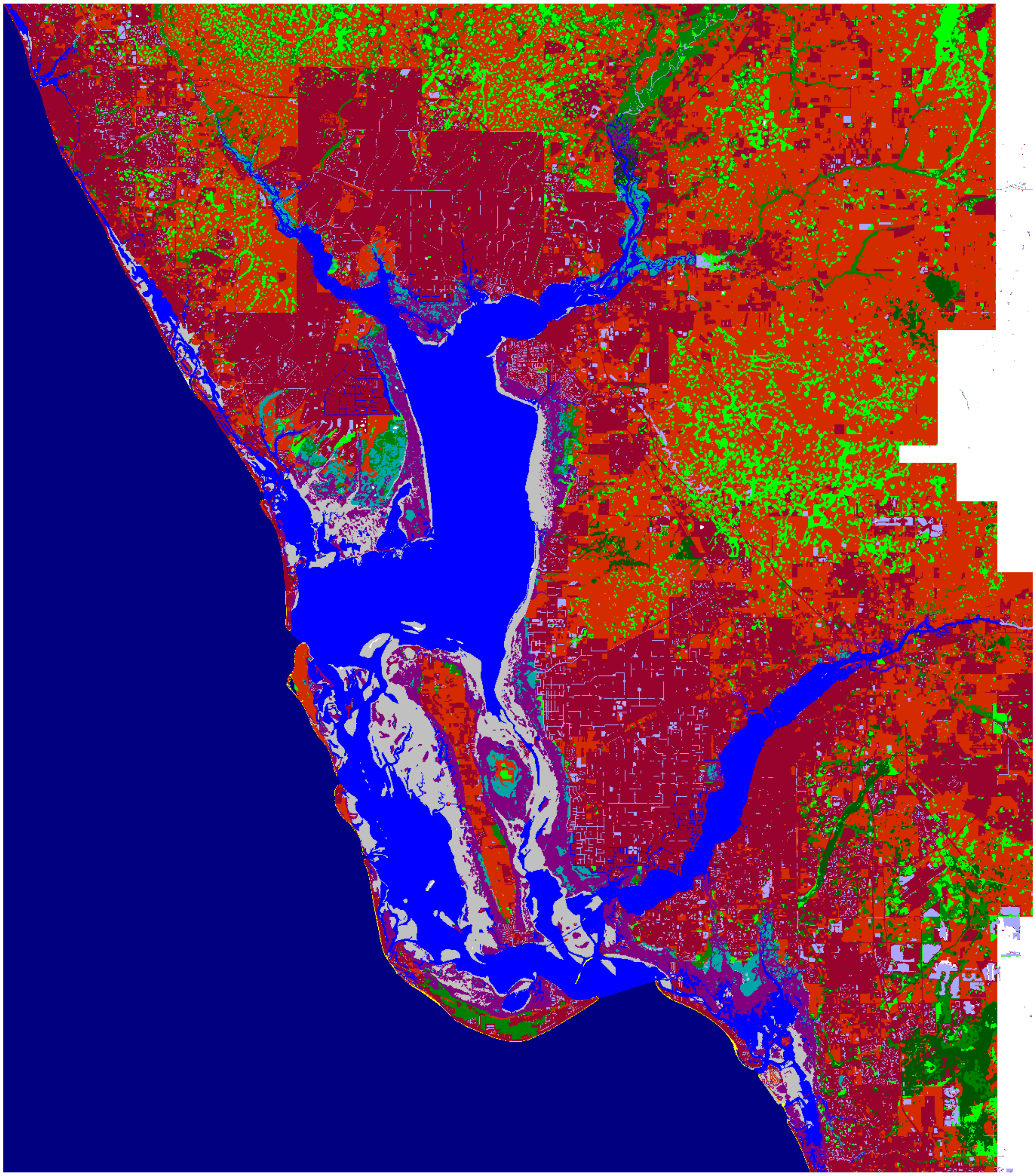
Pine Island Context, 2075, Scenario A1B Maximum



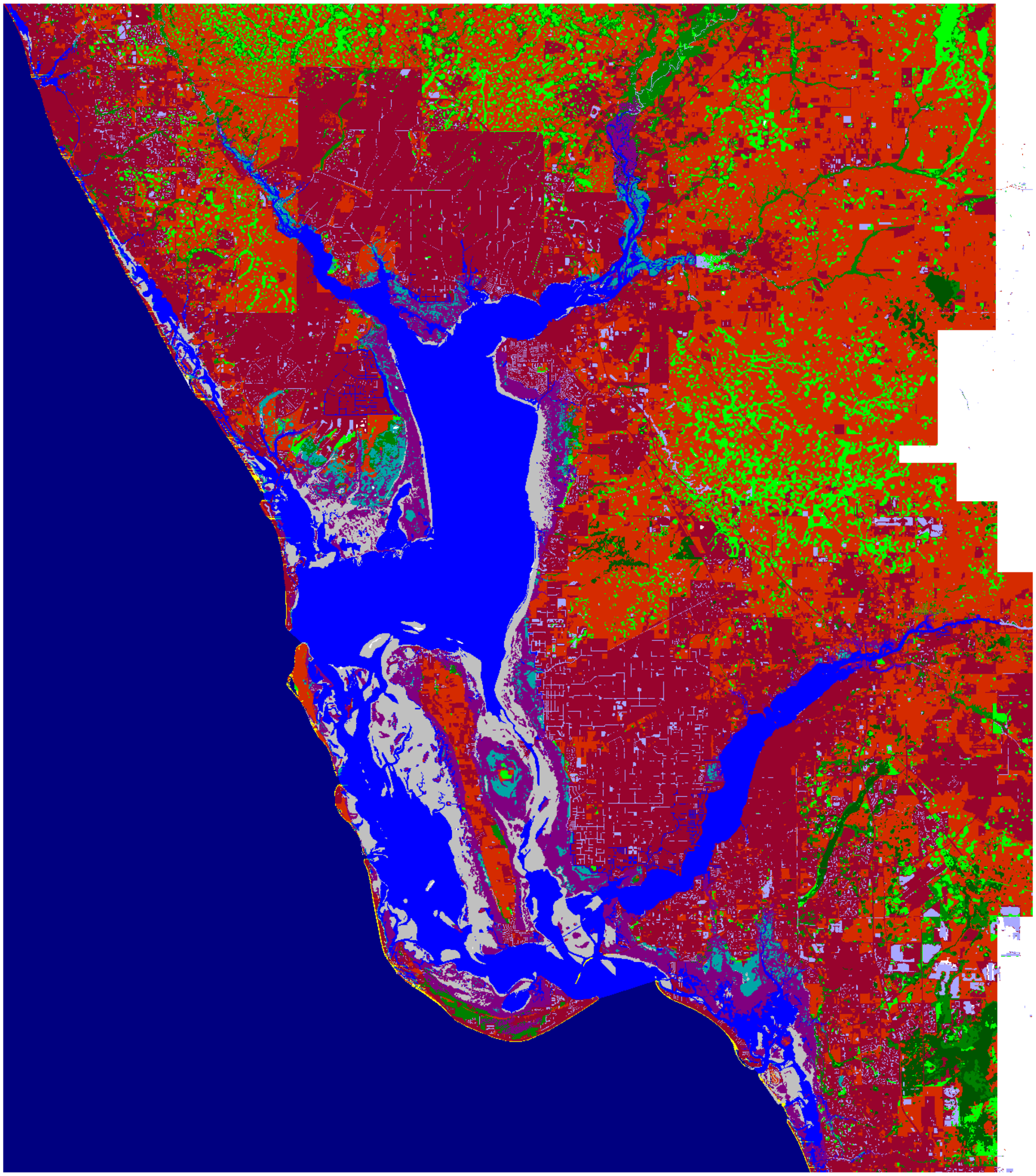
Pine Island Context, 2100, Scenario A1B Maximum



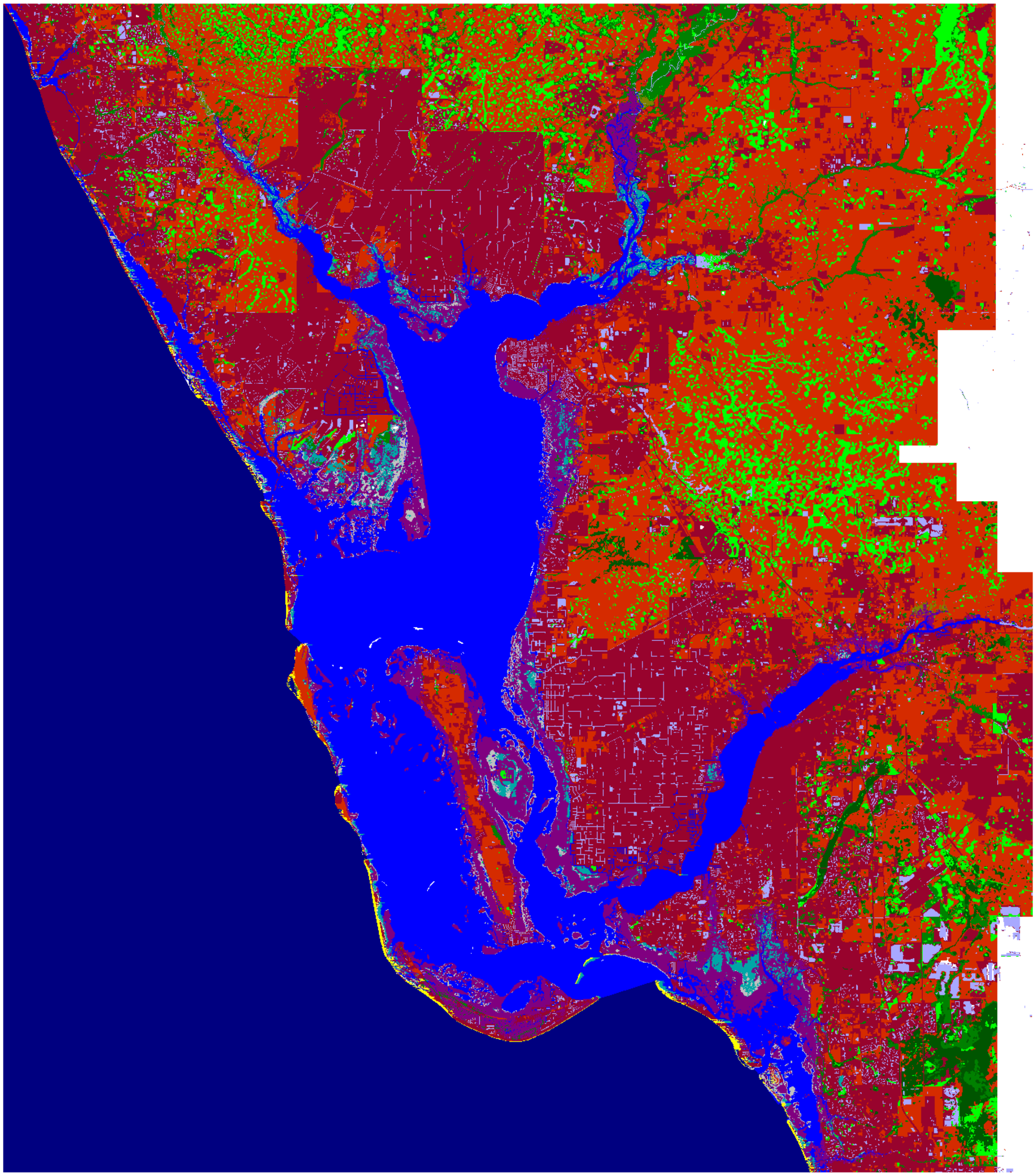
Pine Island Context, Initial Condition



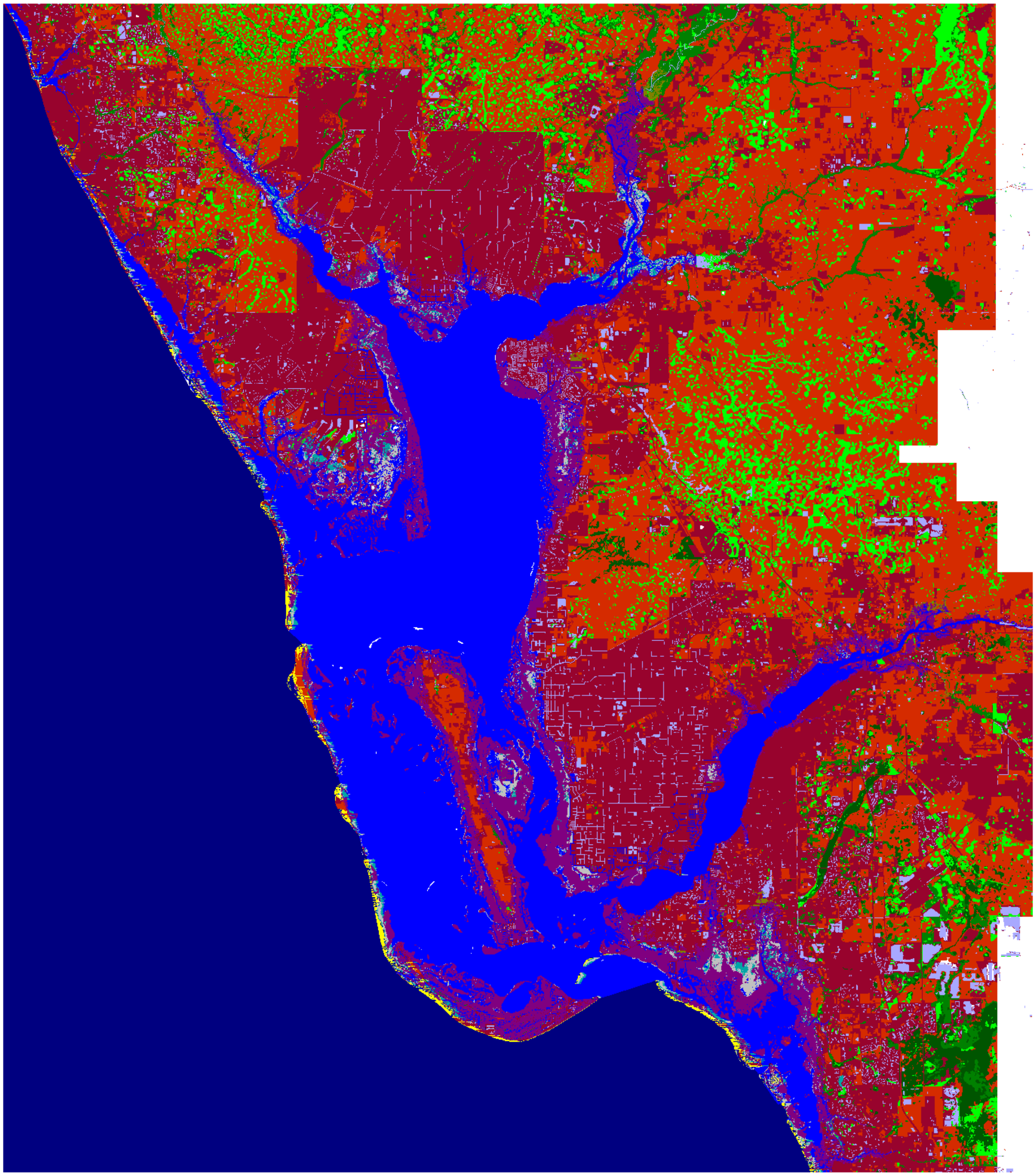
Pine Island Context, 2025, 1 m



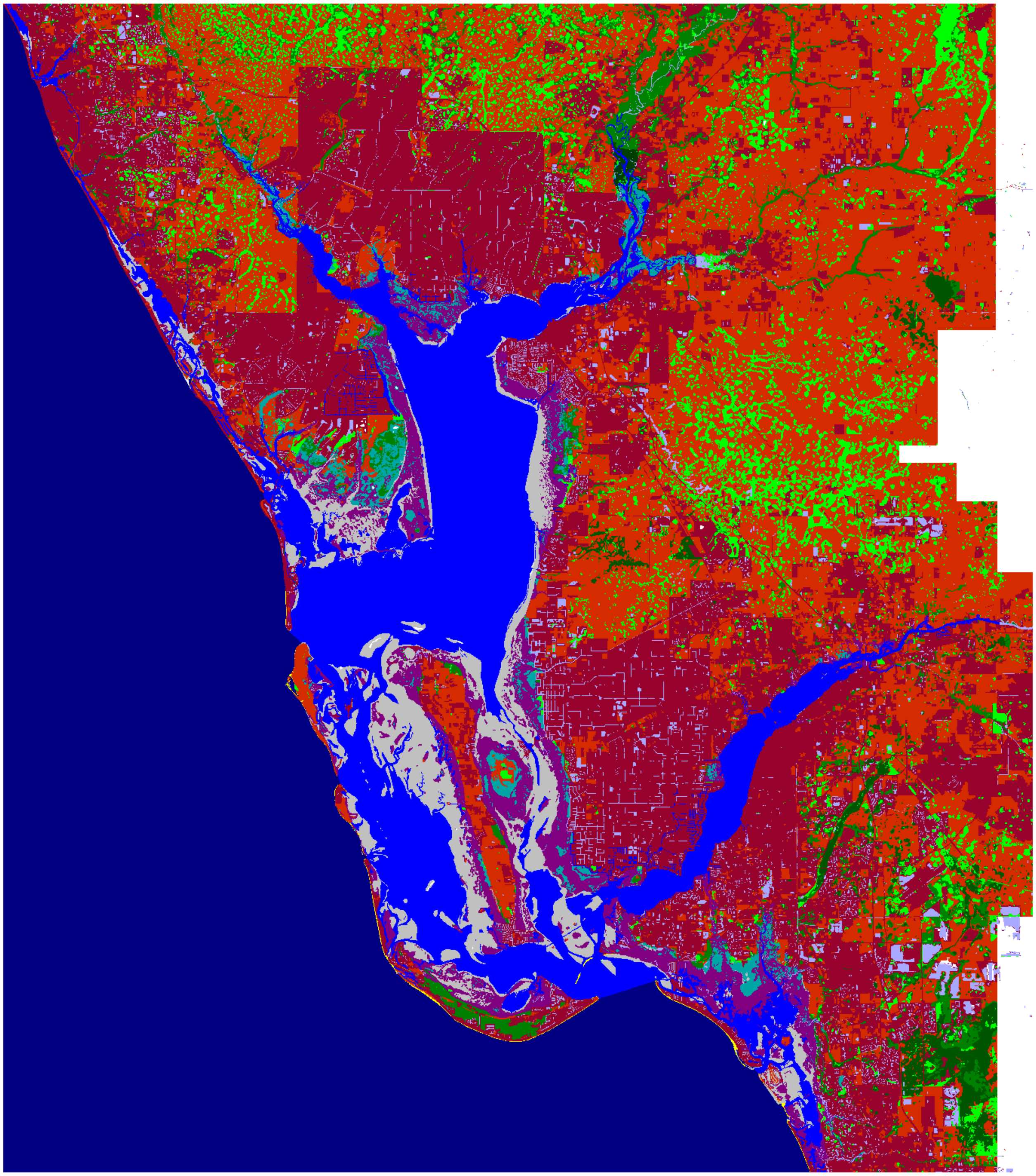
Pine Island Context, 2050, 1 m



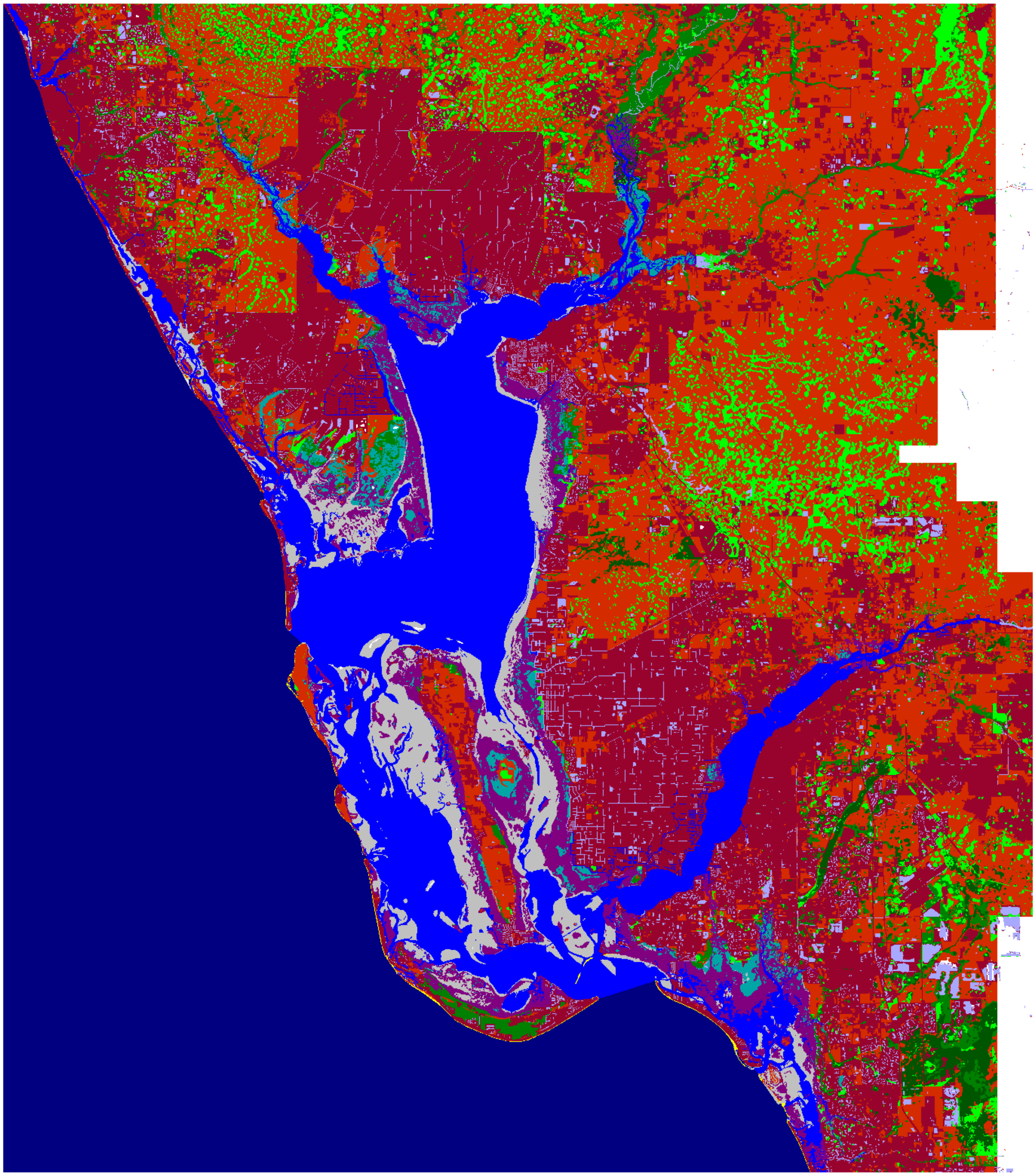
Pine Island Context, 2075, 1 m



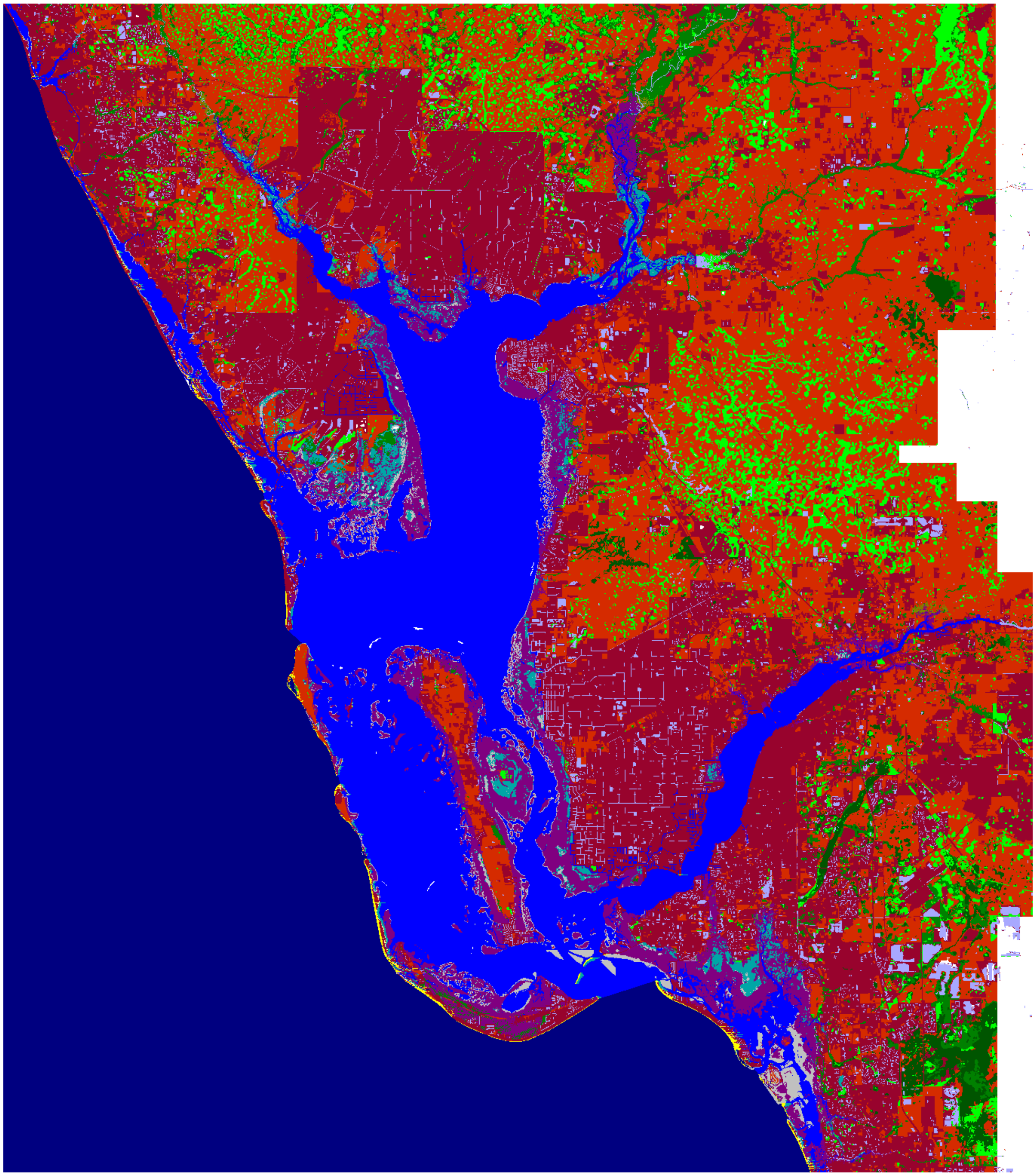
Pine Island Context, 2100, 1 m



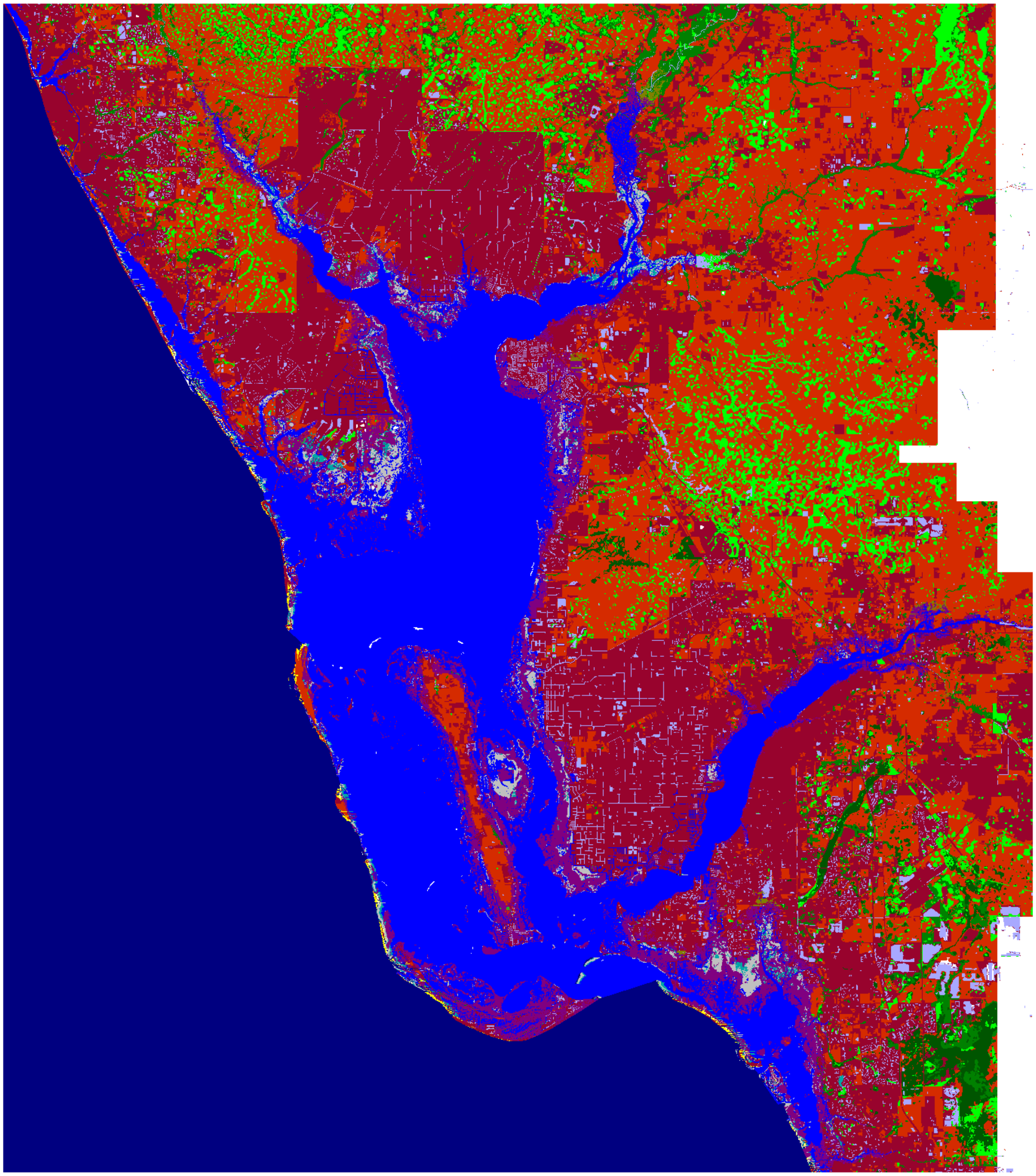
Pine Island Context, Initial Condition



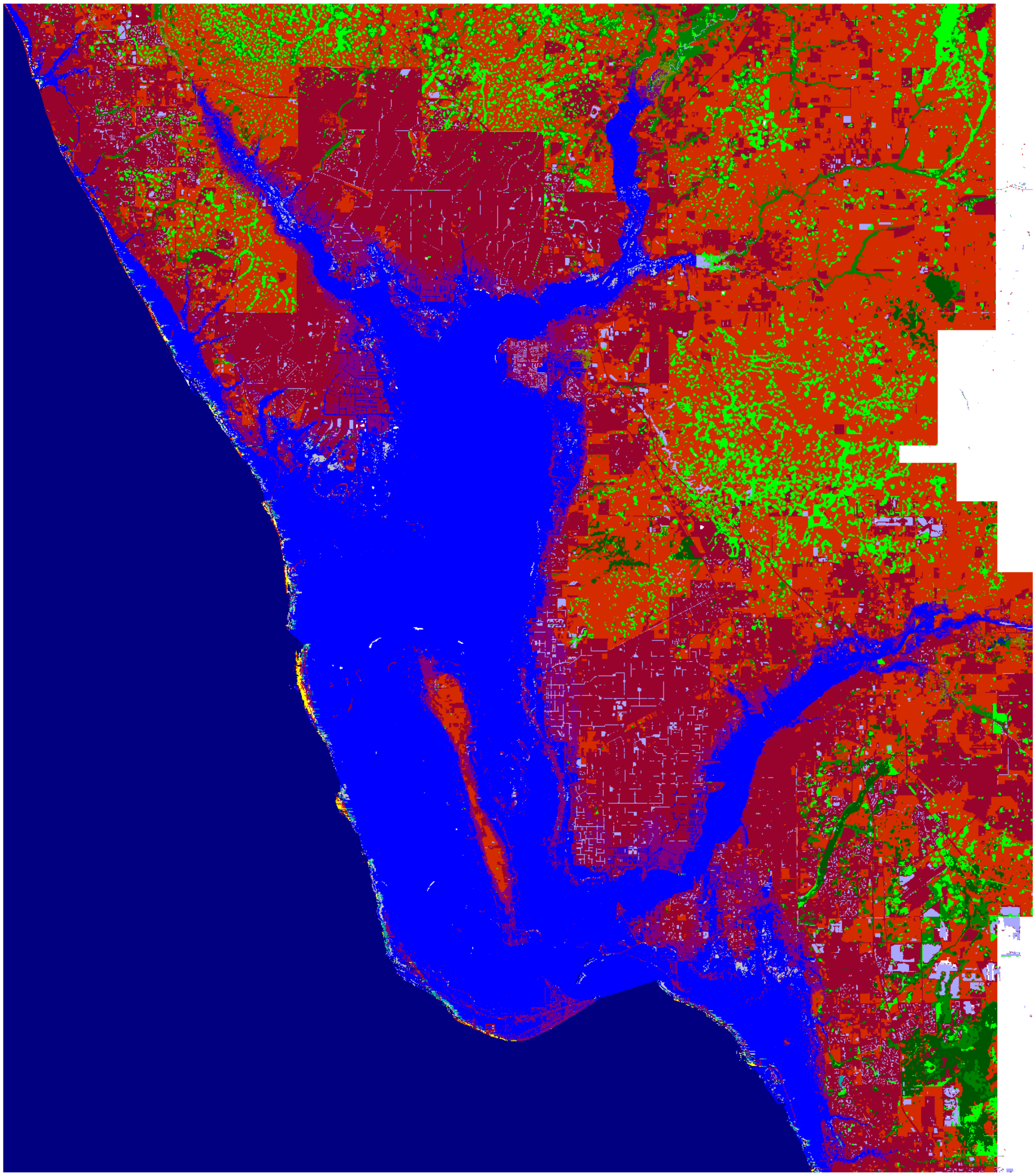
Pine Island Context, 2025, 1.5 m



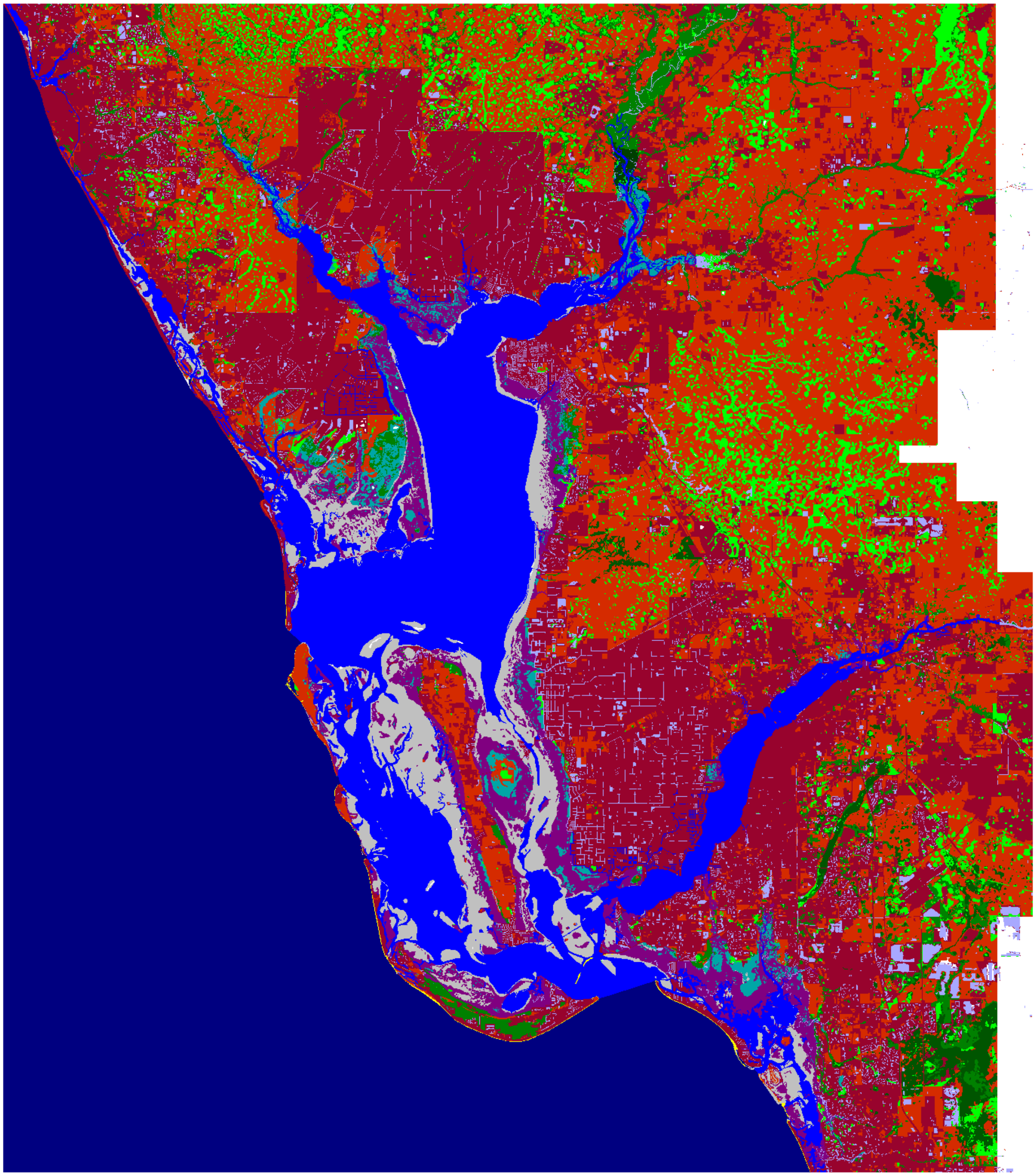
Pine Island Context, 2050, 1.5 m



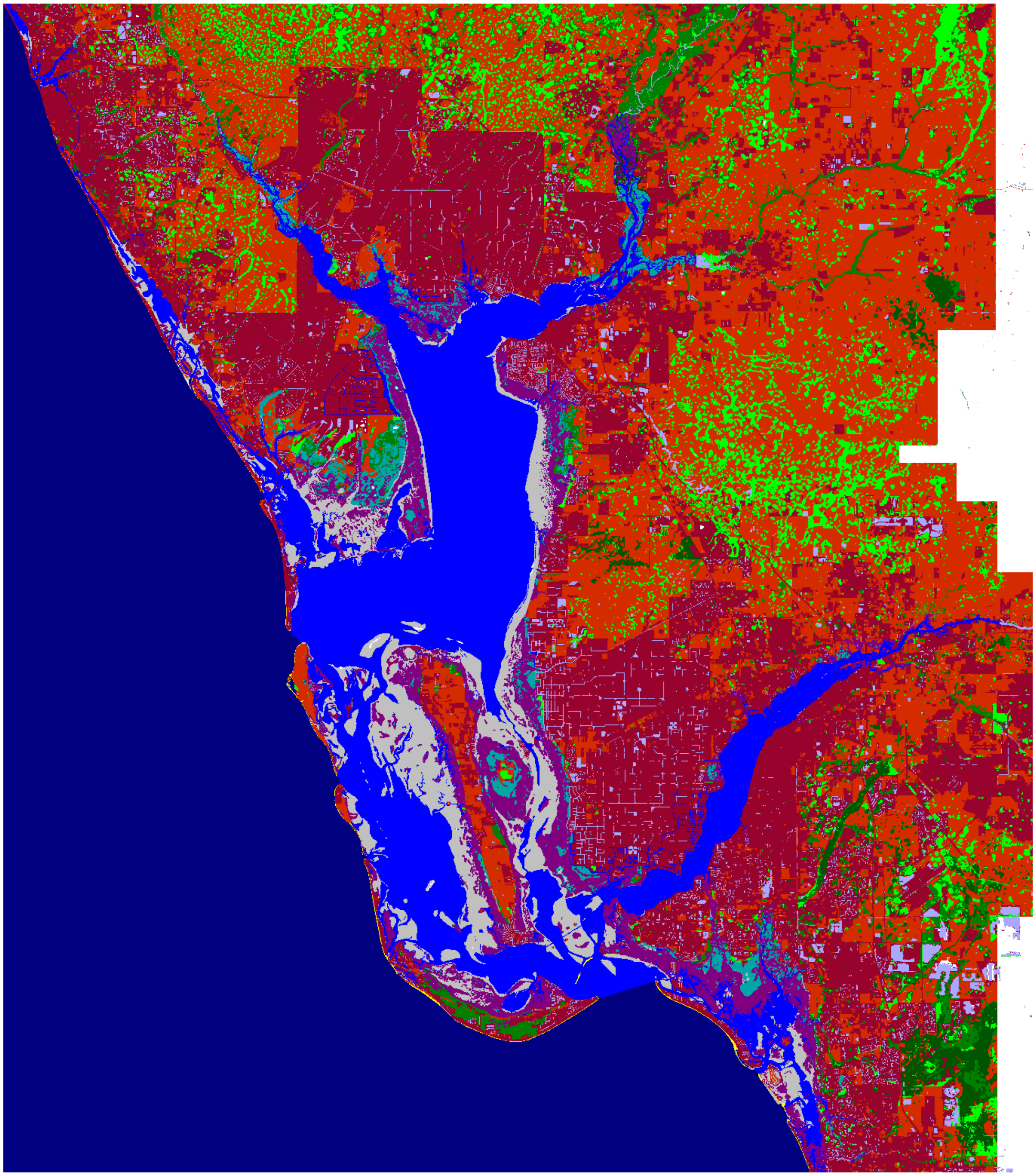
Pine Island Context, 2075, 1.5 m



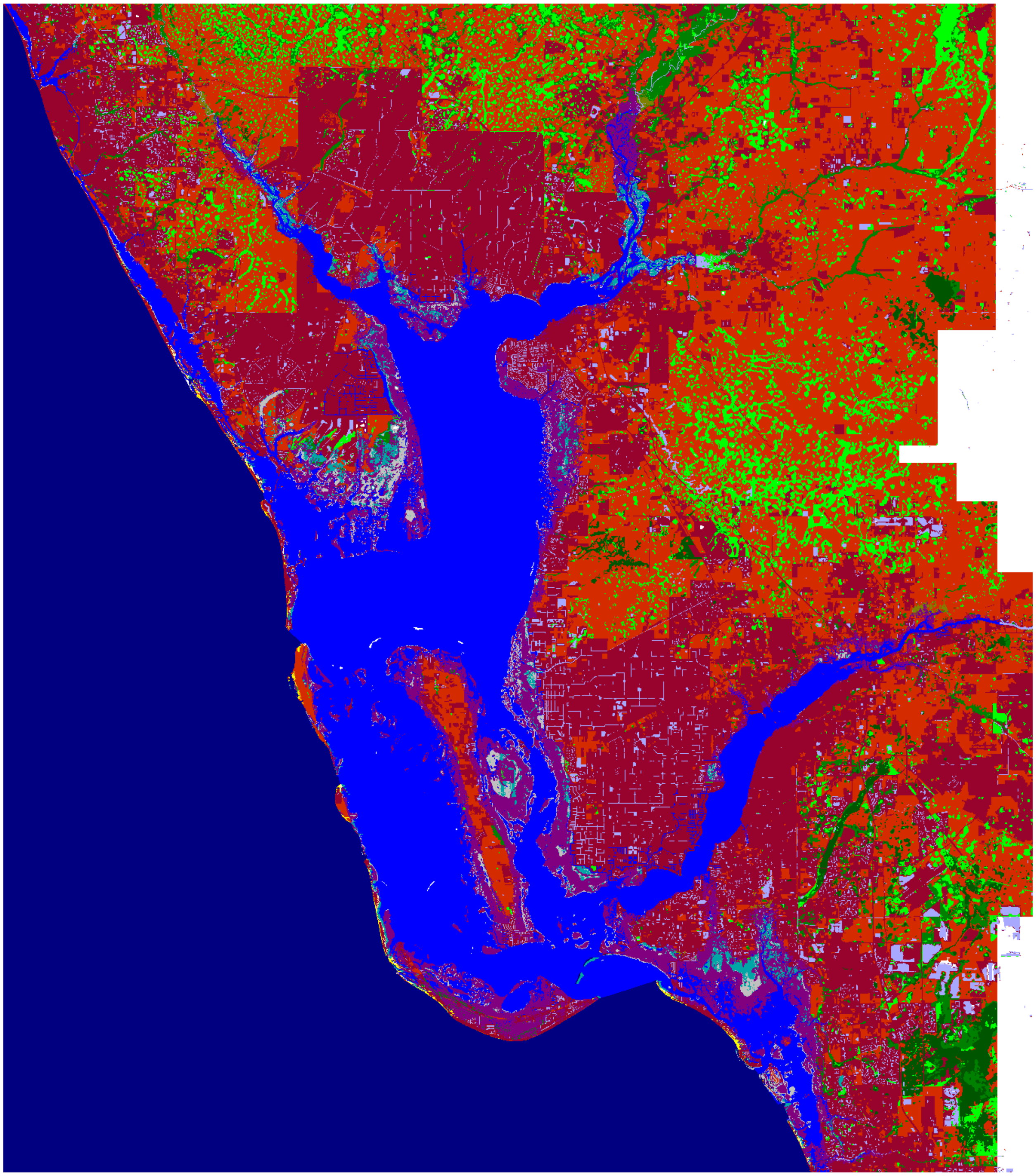
Pine Island Context, 2100, 1.5 m



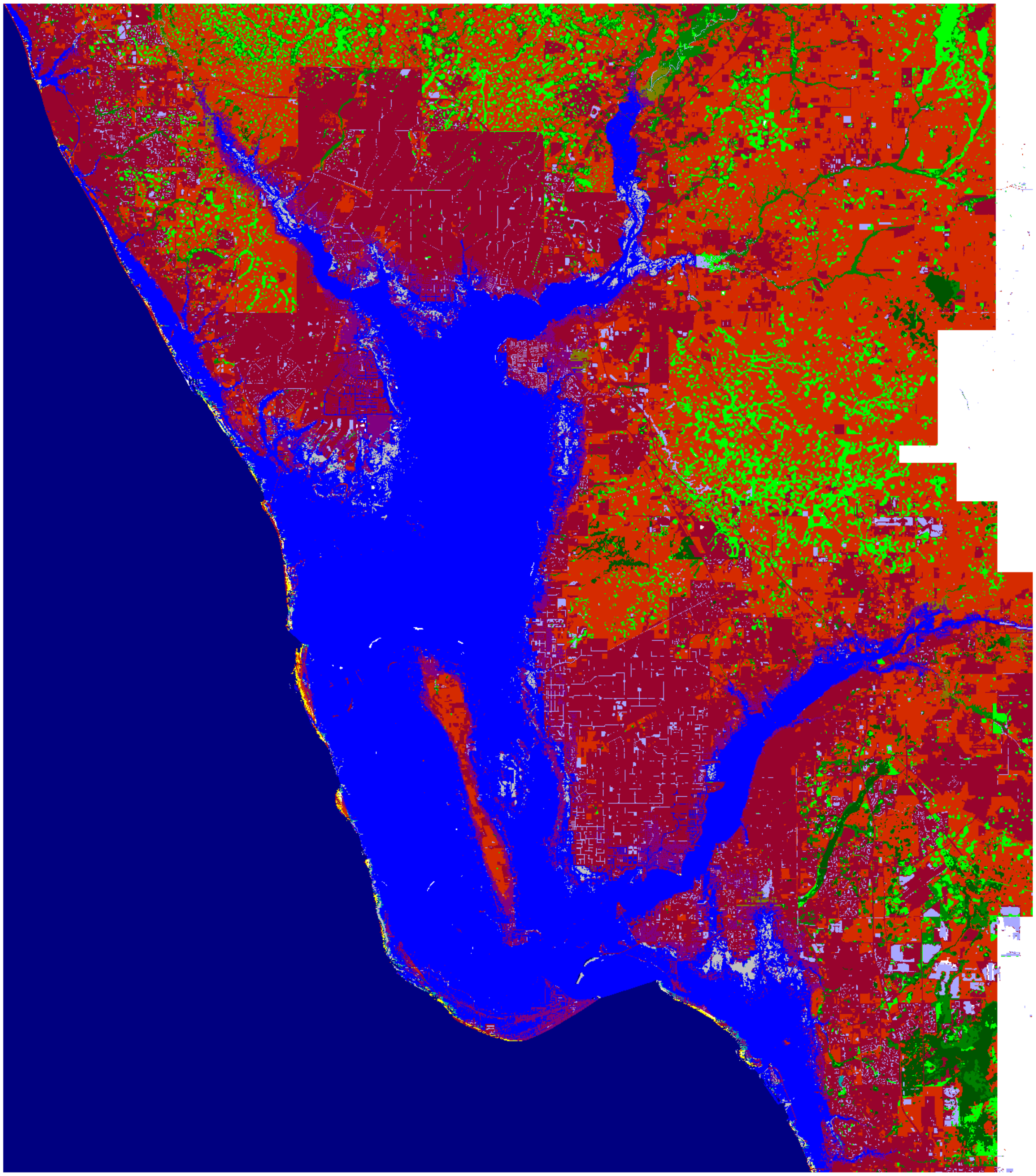
Pine Island Context, Initial Condition



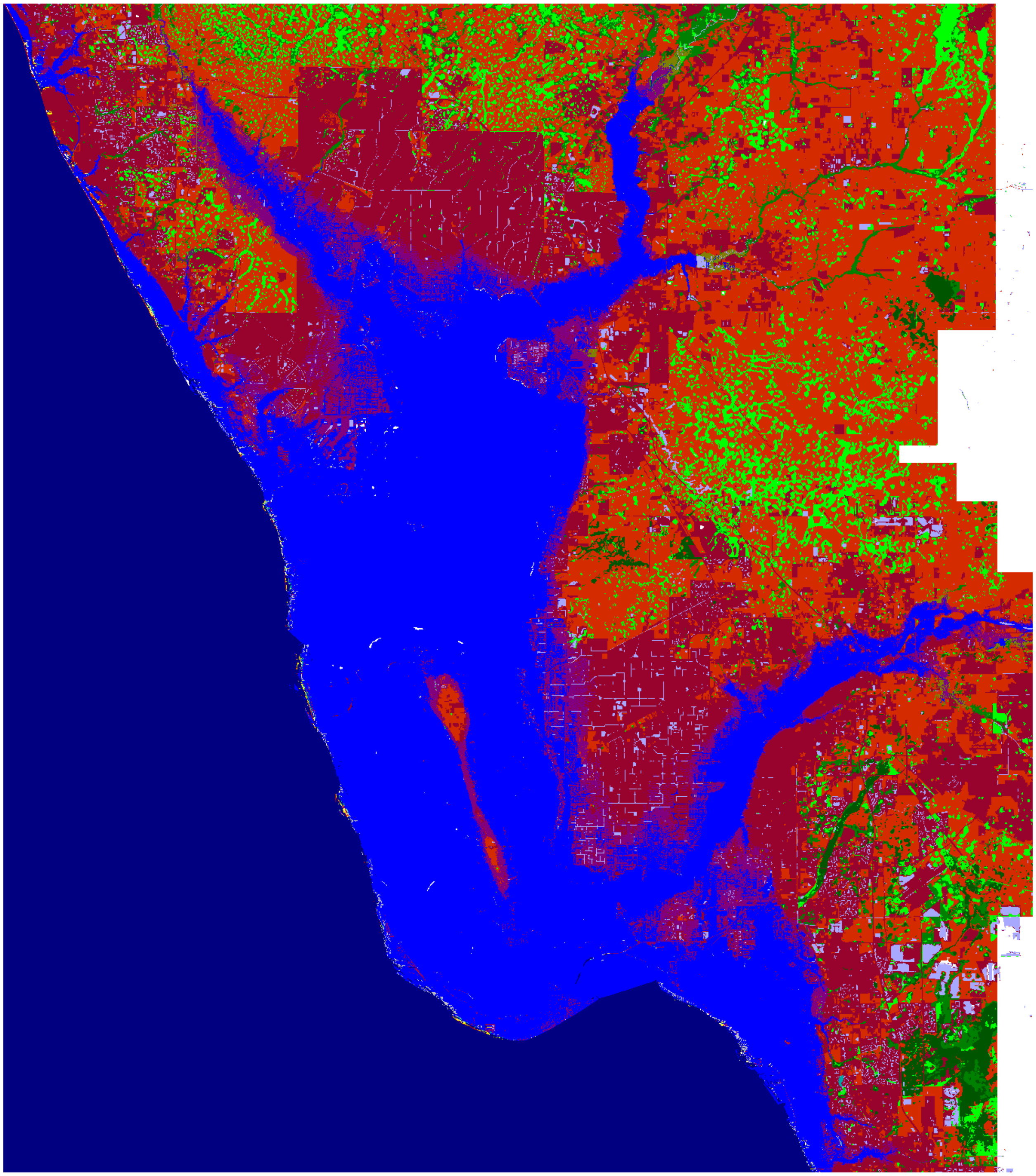
Pine Island Context, 2025, 2 m



Pine Island Context, 2050, 2 m



Pine Island Context, 2075, 2 m



Pine Island Context, 2100, 2 m