Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Bayou Sauvage NWR

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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 Region 4 refuges. This analysis is designed to assist in the production of comprehensive conservation plans (CCPs) for each refuge along with other long-term management plans.

This application of SLAMM to Bayou Sauvage NWR was guided by a project previously conducted to analyze the effects of SLR on southeastern Louisiana (Glick et al. 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 (SLAMM 6) 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).

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 (m) 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. Accretion feedbacks were applied in this simulation.
- 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 USFWS simulations to test the SLAMM conceptual model at each site. 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. In USFWS simulations, the use of values outside of SLAMM defaults is rarely utilized. If such a change is made, the change and the reason for it are fully documented within the model application reports.
- 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 *Discussion* section of this report.

Sea Level Rise Scenarios

Some SLAMM 6 predictions are obtained using SLR estimates from the Special Report on Emissions Scenarios (SRES) published by the Intergovernmental Panel on Climate Change (IPCC). All IPCC scenarios describe futures that are generally more affluent than today and span a wide range of future levels of economic activity, with gross world product rising to 10 times today's values by 2100 in the lowest, to 26-fold in the highest scenarios (IPCC 2007). Among the IPCC families of scenarios, two approaches were used, one that made harmonized assumptions about global population, economic growth, and final energy use, and those with an alternative approach to quantification. This is important to keep in mind as not all of the IPCC scenarios share common assumptions regarding the driving forces of climate change.

In this model application, the A1B scenario mean and maximum predictions are applied. Important assumptions were made in this scenario: reduction in the dispersion of income levels across economies (i.e. economic convergence), capacity building, increased cultural and social interactions among nations, and a substantial reduction in regional differences in per capita income, primarily from the economic growth of nations with increasing income (Nakicenovic et al. 2000). In addition, 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. Given today's global economic and political climate, as well as environmental and ecological constraints, these may not be feasible assumptions for the future.

In particular, the A1B scenario assumes that energy sources will be balanced across all sources, with an increase in use of renewable energy sources coupled with a reduced reliance on fossil fuels (Nakicenovic et al. 2000). Given this A1B scenario, the IPCC WGI Fourth Assessment Report (IPCC 2007) suggests a likely range of 0.21 m to 0.48 m of SLR by 2090-2099 "excluding future rapid dynamical changes in ice flow." The IPCC-produced A1B-mean scenario that was run as a part of this project falls near the middle of this estimated range, predicting 0.39 m of global SLR by 2100. A1B-maximum predicts 0.69 m of global SLR by 2100. However, other scientists using the same set of economic growth scenarios have produced much higher estimates of SLR as discussed below.

Recent literature (Chen et al. 2006; Monaghan et al. 2006) indicates that eustatic sea level rise is progressing more rapidly than was previously assumed. This underestimation may be due to the dynamic changes in ice flow omitted within the IPCC report's calculations, and a consequence of overestimating the possibilities for future reductions in greenhouse gas emissions while concurrently striving for economic growth.

A recent paper in the journal *Science* (Rahmstorf 2007) suggests that, taking into account possible model error, a feasible range of 50 to 140 cm by 2100. 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 m 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 SLRs 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.

The variability of SLR predictions presented in the scientific literature illustrates the significant amount of uncertainty in estimating future SLR. Much of the uncertainty may be due to the unknown future of the drivers climate change, such as fossil fuel consumption and the scale of human enterprise. In order to account for these uncertainties, and to better reflect these uncertainties as well as recently published peer-reviewed measurements and projections of SLR as noted above, SLAMM was run not only assuming A1B-mean and A1B-maximum SLR scenarios, but also for 1 m, 1.5 m, and 2 m of eustatic SLR by the year 2100 as shown in Figure 1.

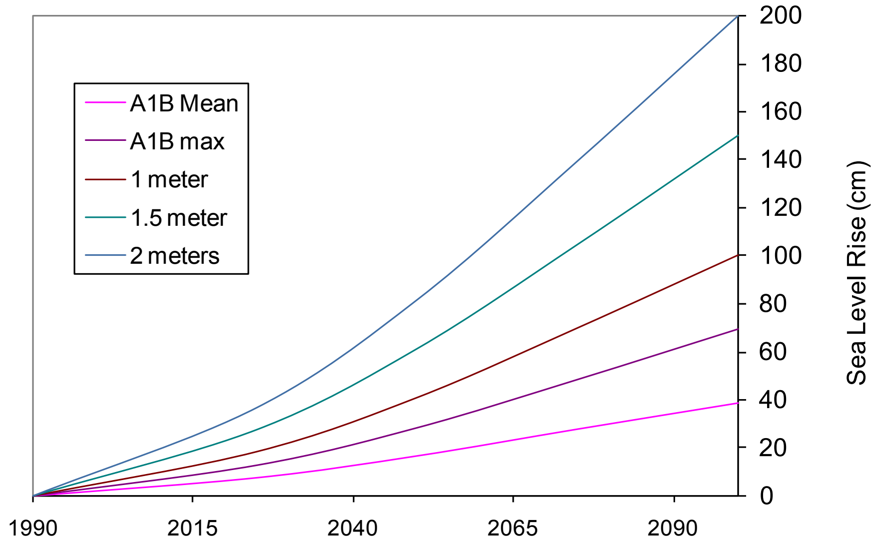


Figure 1. Summary of SLR scenarios utilized.

Data Sources and Methods

Elevation Data. Portions of the refuge are covered by LiDAR data collected in 2009 by the US Army Corps of Engineers, 2008 USGS/NPS/NASA Experimental Advanced Airborne Research LiDAR and 2006 NED LiDAR. However, as LiDAR data was not available for the southern tip of the refuge; a 1998 contour-based NED data was used, as shown in Figure 2. In areas lacking LiDAR data the elevation pre-processor module of SLAMM was used to assign elevations for wetlands as a function of the local tide range.

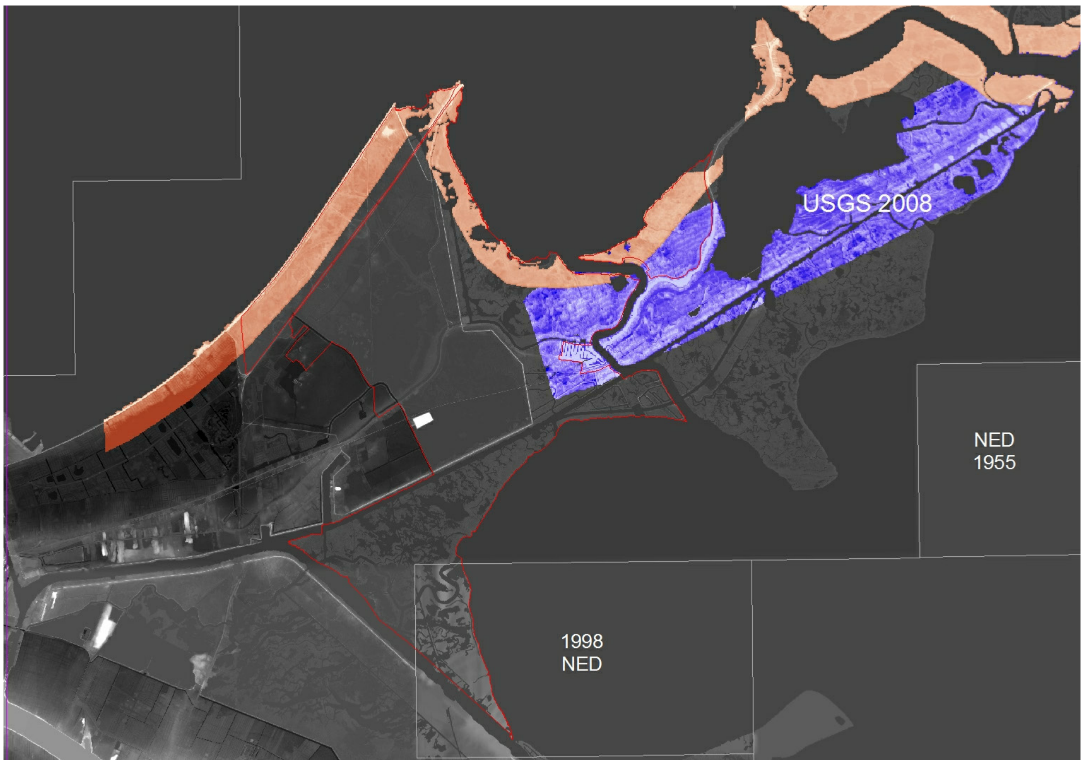


Figure 2. Location of LiDAR and NED-derived elevation data. USACE 2009 coastal LiDAR in orange, approved acquisition boundaries shown in red.

Wetland layer. Figure 3 shows the most recent available wetlands layer obtained from a National Wetlands Inventory (NWI) photo dated 2009. Converting the NWI survey into 10 m x 10 m cells indicated that the approximately 33,500 acre Bayou Sauvage NWR (approved acquisition boundary including water) is composed of the categories presented in Table 1.

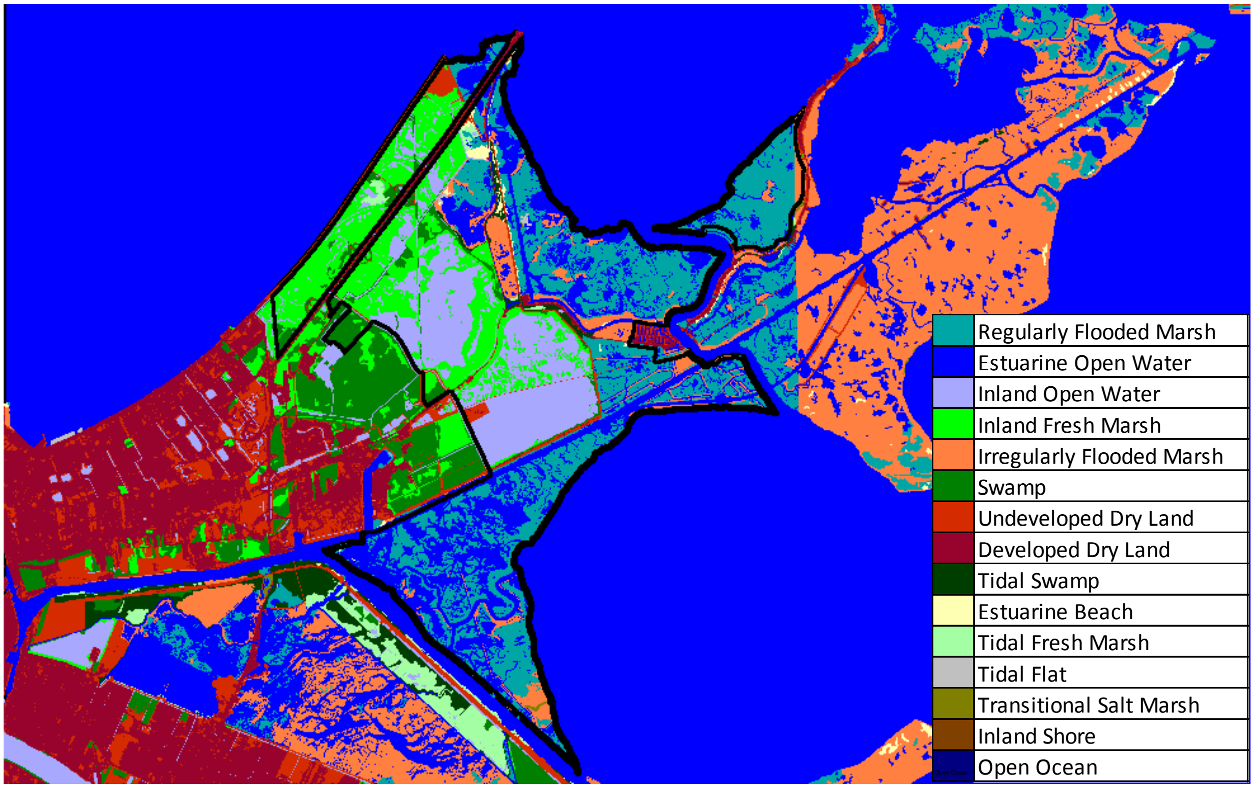


Figure 3. 2009 NWI coverage of the study area. Refuge boundaries are indicated in black.

Table 1. Wetland categories and distribution in Bayou Sauvage NWR.

	Land cover type	Area (acres)	Percentage (%)
	Regularly-flooded Marsh	9796	29
	Estuarine Open Water	8013	24
	Inland Open Water	5445	16
	Inland Fresh Marsh	5308	16
	Irregularly-flooded Marsh	1899	6
	Swamp	1318	4
	Undeveloped Dry Land	884	3
	Developed Dry Land	243	1
	Tidal Swamp	221	1
	Estuarine Beach	195	1
	Tidal Fresh Marsh	149	< 1
	Tidal Flat	36	< 1
	Transitional Salt Marsh	27	< 1
	Inland Shore	1	< 1
	Total (incl. water)	**33535**	**100**

Dikes and Impoundments. According to the National Wetland Inventory and the US Army Corps of Engineers, much of the refuge is protected by dikes and levees. The protected areas are shown in yellow in Figure 4. The model assumes lands protected by dikes are not subject to inundation until they reach 2 m below mean tide level.

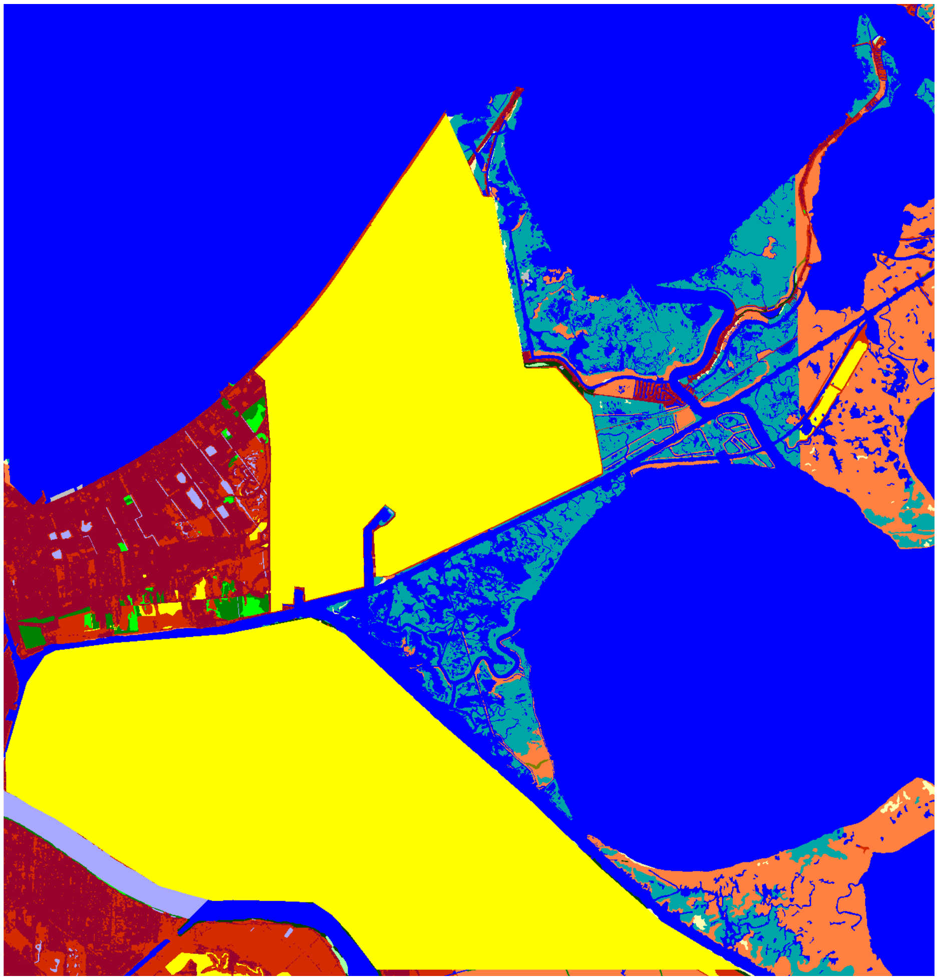
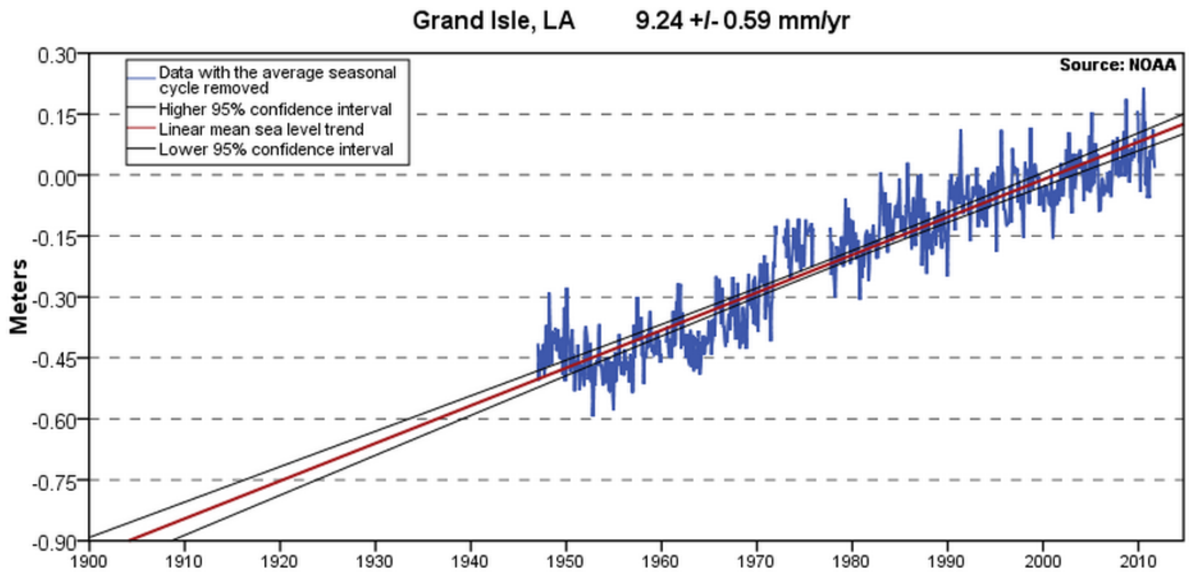


Figure 4. Location of dikes in and around Bayou Sauvage NWR (shown in yellow).

Model Timesteps. Model forecast data was output for years 2025, 2050, 2075 and 2100 with the initial condition date set to 2009 (the most recent wetland data available). SLAMM uses a built in processor to correct elevations in an attempt to account for any elevation variation due to sea level rise between the wetland photo date and the DEM date.

Historic sea level rise rates. The historic trend for relative sea level rise was estimated at 9.44 mm/yr. using the average of the rates recorded at NOAA gauge stations #8761724 and #8764311 (Grand Isle and Eugene Island, LA; shown in Figure 5). This rate is much higher than the global (eustatic) SLR for the last 100 years (approximately 1.7 mm/year), which reflects the high degree of subsidence that is known to be occurring along the Louisiana coast. The rate of subsidence based on the sea-level rise gauges is more than 7 mm/yr. This value falls within the range measured by Shinkle and Dokka in their study of land movement in southern Louisiana, which suggested a subsidence rate between 5 and 10 mm/yr. for the area east of Lake Pontchartrain (2004).



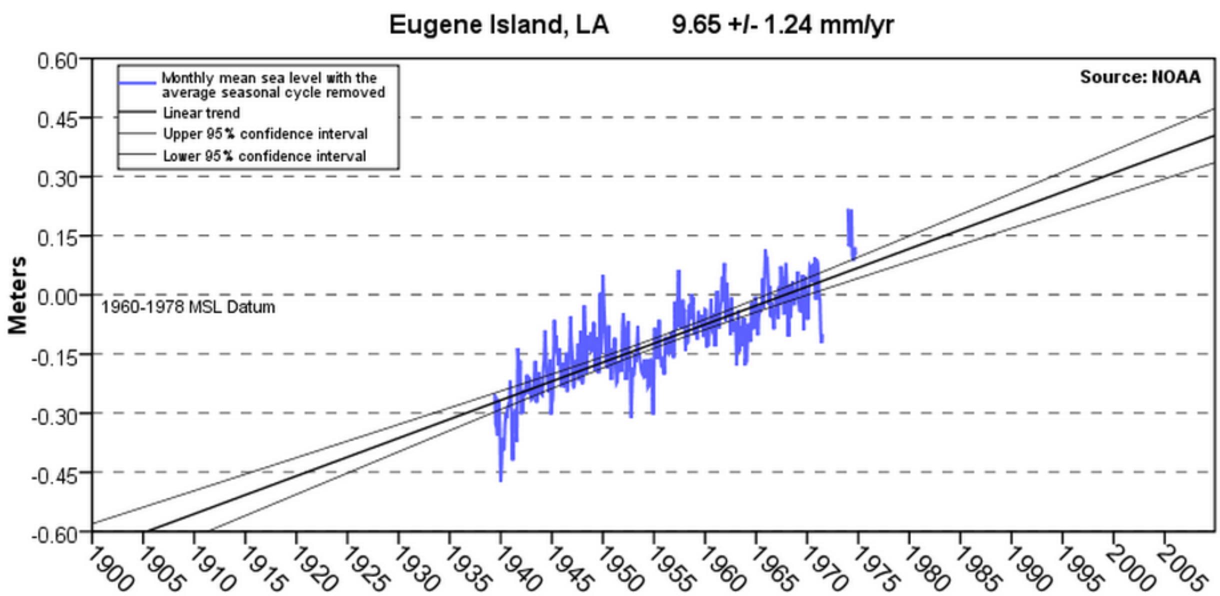


Figure 5. Historic sea level trends at the Grand Isle and Eugene Island NOAA gauge stations.

Tide Ranges. The great diurnal range (GT) measured at the NOAA gauge stations present in the area (shown in Figure 6), ranged from 0.48 m in the gulf and 0.15 m in Lake Pontchartrain. For the Bayou Sauvage refuge, several different tide values were applied based on NOAA tide data. The subsites used and parameters applied to each subsite are shown in Figure 8 and Table 2, respectively.

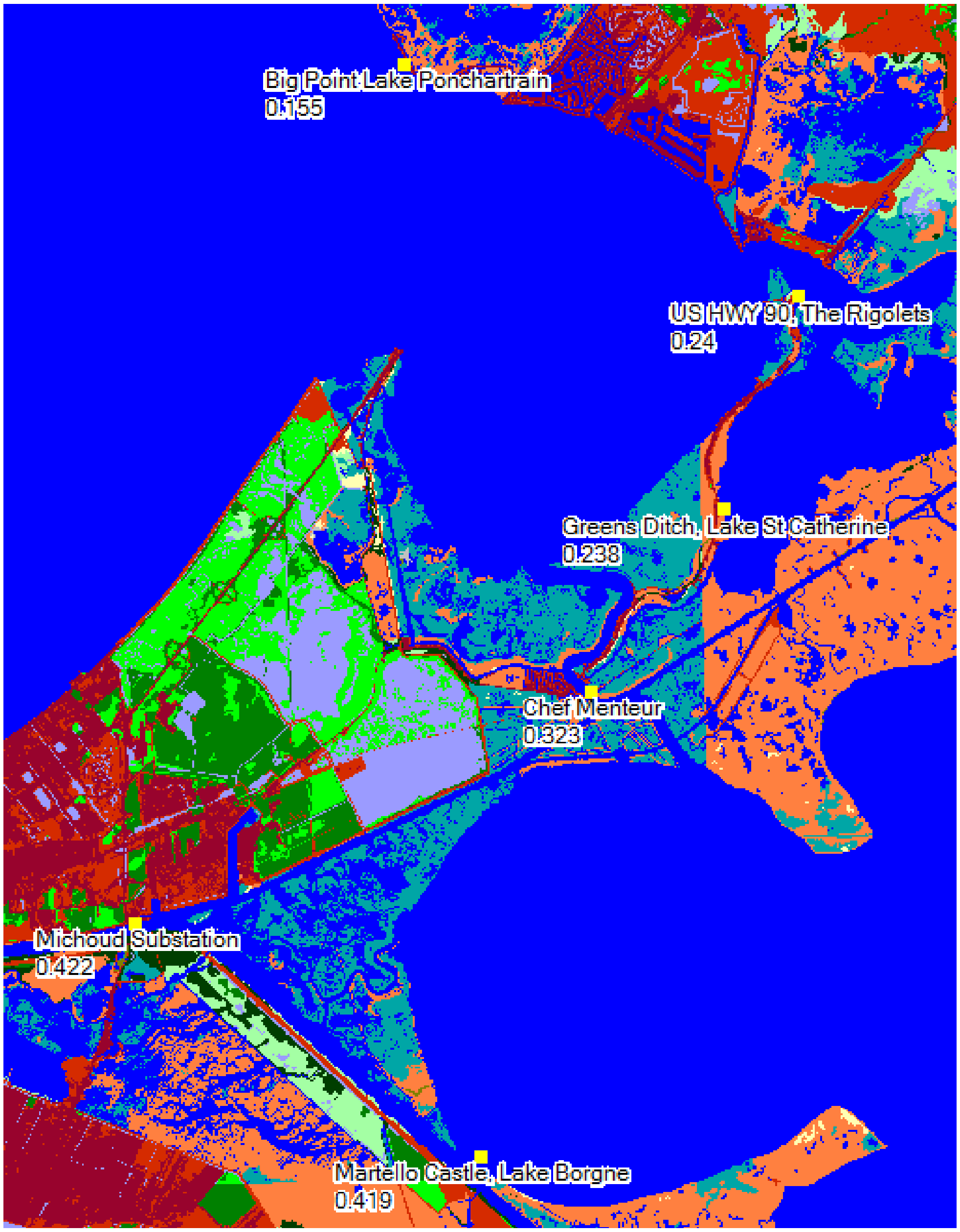


Figure 6. NOAA tide station locations used for this study (yellow icons with GT in meters).

Salt elevation. This parameter within SLAMM designates the boundary between wet lands and dry lands or saline wetlands and fresh water wetlands. For this application, salt elevation was estimated at 1.7 Half Tide Units (HTU), for the refuge (Glick et al. 2011).

Accretion rates. The accretion rates applied in a SLAMM model calibrated and applied to southern Louisiana were used in simulations of the Bayou Sauvage NWR (Glick et al. submitted). Accretion data for coastal Louisiana were collected from several studies published in peer-reviewed journals (Bryant and Chabreck 1998; Cahoon and Turner 1989; Nyman et al. 1993; Nyman et al. 1990; Nyman et al. 2006). The average marsh accretion value for coastal Louisiana SLAMM modeling project was determined to be approximately 8.2 mm/year. For comparison, the average elevation change calculated from data in the Coastwide Reference Monitoring System (CRMS) database was 8.63 mm/year. From this extensive array of SET tables placed throughout the study area, short term accretion rates were measured. However, this data set had considerable variability (ranging from -114 mm/year to 60 mm/year). Based on the observed relationship between cell elevations and accretion rates within the CRMS dataset, and also strong relationships between elevation and accretion encountered in other studies of marsh accretion (e.g. Morris et al. 2002), a negative relationship between cell elevation and the predicted accretion rate was utilized in this modeling analysis, as shown in Figure 7. Because observed accretion rates did not vary significantly as a function of marsh type and no spatial relationships regarding accretion rates were determined within the study area, the same elevation-to-accretion relationship was used throughout the majority of the study area.

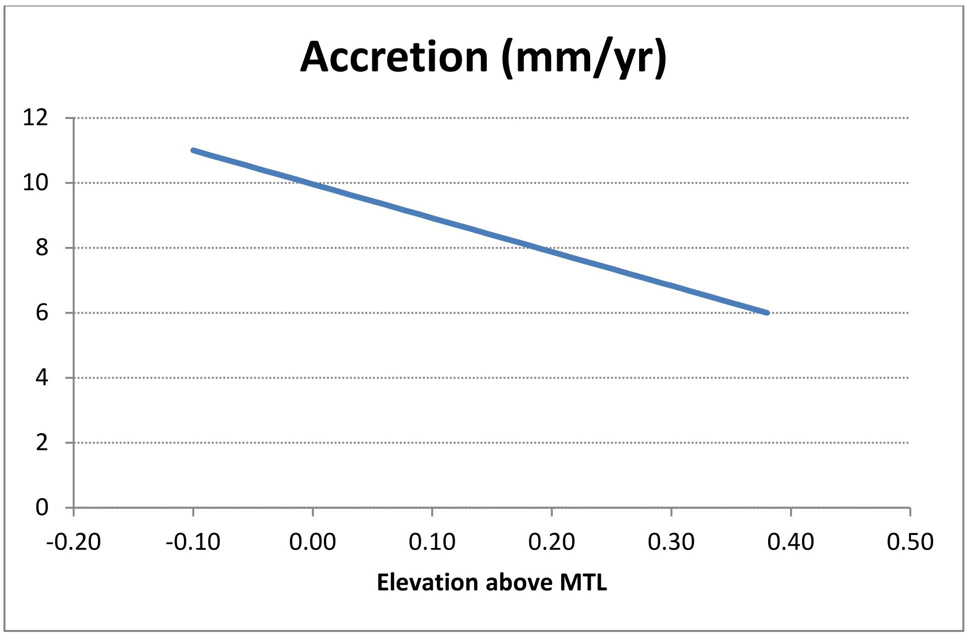


Figure 7. Relationship between predicted accretion rates and elevation used for regularly-flooded marsh.

Erosion rates. Horizontal erosion of marshes and swamps occurs only at the wetland-to-open-water interface and only when adequate open water (fetch) exists for wave setup. Due to lack of site-specific values, erosion rates were set to the SLAMM defaults. Tidal flat erosion was set to 0.2 m/yr., marshes were set to 2 m/yr., and a rate of 1 m/yr. was applied to swamps. This choice is supported by a study of the Mississippi delta by Morton and coworkers (2005) that found "most of the wetland losses around open-water bodies at the coring sites are due to subsidence. The imagery analysis and core pairs taken near the land-water interface clearly show that erosion is only a minor process converting wetlands to open water, and subsidence is largely responsible for the conversion".

Elevation correction. MTL to NAVD88 corrections determined using NOAA's VDATUM software ranged from 0.07 to 0.21 m and were applied on a subsite-by-subsite basis.

Parameter summary. The Bayou Sauvage refuge is located in the Lake Pontch., MRGO, and Lake Borgne 2 and 3 subsites. In addition, the remaining contextual area was divided into several subsites in order to represent differences in tide ranges and elevation data sources. Subsites were defined as shown in Figure 8. The parameters assigned to each subsite are presented in Table 2. Subsites where elevation data was derived from the National Elevation Dataset (NED) were subjected to the SLAMM elevation preprocessor to account for uncertainty associated with contour-based data (Clough et al. 2010). The cell size used for this analysis was 10 m by 10 m.

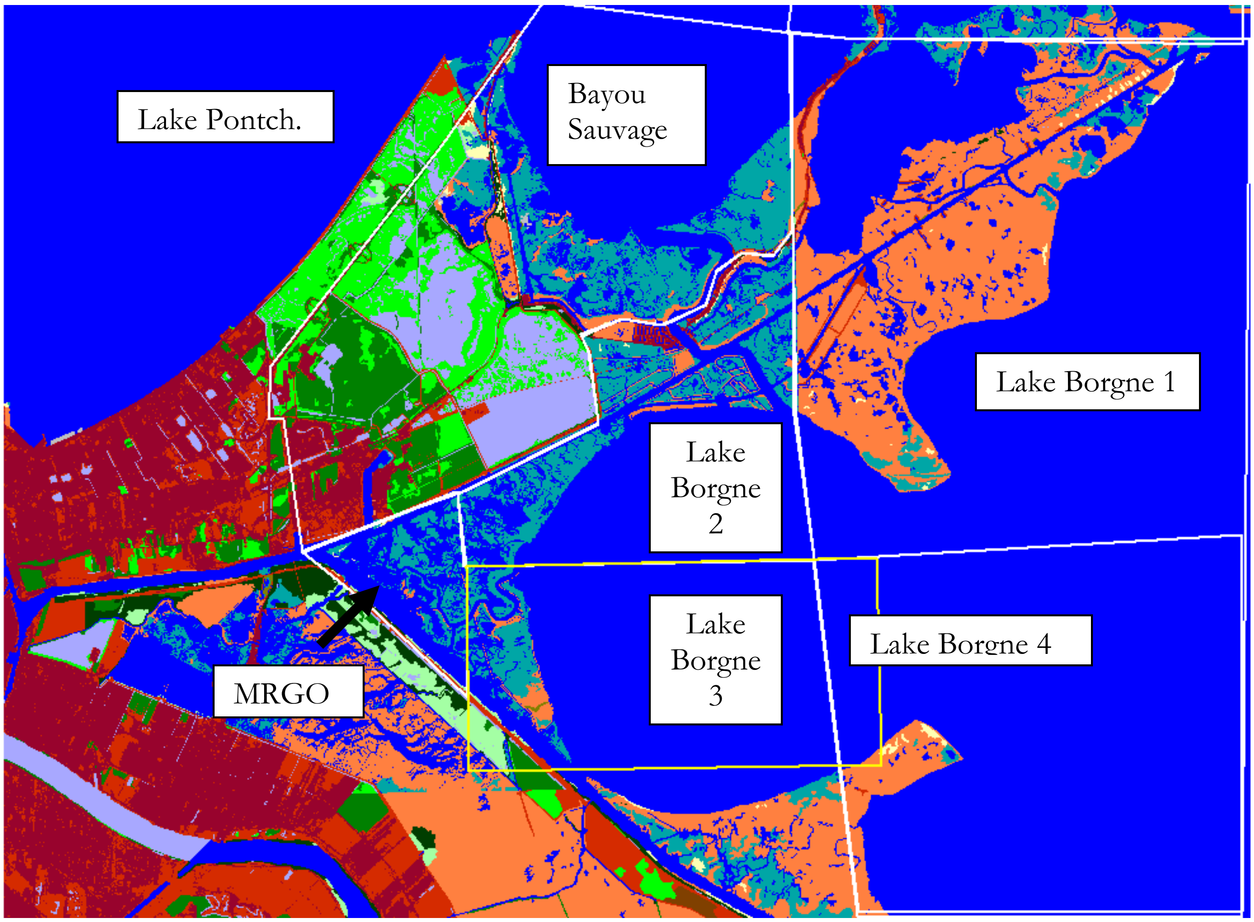


Figure 8. Subsites.

Table 2. Summary of SLAMM input parameters for Bayou Sauvage NWR.

Parameter	Lake Pontch.	MRGO	Bayou Sauvage	Lake Borgne 1	Lake Borgne 2	Lake Borgne 3	Lake Borgne 4
NWI Photo Date (YYYY)	2009	2009	2009	1989	2009	2009	1988
DEM Date (YYYY)	2008	2008	2008	2008	2008	1998	1998
Direction Offshore [n,s,e,w]	East	East	East	East	East	East	East
Historic Trend (mm/yr.)	9.44	9.44	9.44	9.44	9.44	9.44	9.44
MTL-NAVD88 (m)	0.1	0.16	0.16	0.21	0.2	0.2	0.2
GT Great Diurnal Tide Range (m)	0.155	0.422	0.155	0.24	0.323	0.419	0.419
Salt Elev. (m above MTL)	0.13175	0.3587	0.13175	0.204	0.27455	0.35615	0.35615
Marsh Erosion (horz. m /yr.)	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Swamp Erosion (horz. m /yr.)	1	1	1	1	1	1	1
T.Flat Erosion (horz. m /yr.)	2	2	2	2	2	2	2
Reg.-Flood Marsh Accr (mm/yr.)	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Irreg.-Flood Marsh Accr (mm/yr.)	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Tidal-Fresh Marsh Accr (mm/yr.)	9.8	9.8	9.8	9.8	9.8	9.8	9.8
Inland-Fresh Marsh Accr (mm/yr.)	5.9	5.9	5.9	5.9	5.9	5.9	5.9
Mangrove Accr (mm/yr.)	7	7	7	7	7	7	7
Tidal Swamp Accr (mm/yr.)	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Swamp Accretion (mm/yr.)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Beach Sed. Rate (mm/yr.)	1	1	1	1	1	1	1
Freq. Overwash (years)	30	30	30	30	30	30	30
Use Elev Pre-processor [True,False]	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE
Reg Flood Max. Accr. (mm/year)	11	11	11	11	11	11	11
Reg Flood Min. Accr. (mm/year)	6	6	6	6	6	6	6
Reg Flood Elev c coeff. (linear)	1	1	1	1	1	1	1
Irreg Flood Max. Accr. (mm/year)	11	11	11	11	11	11	11
Irreg Flood Min. Accr. (mm/year)	6	6	6	6	6	6	6
Irreg Flood Elev c coeff. (linear)	1	1	1	1	1	1	1
Tidal Fresh Max. Accr. (mm/year)	11	11	11	11	11	11	11
Tidal Fresh Min. Accr. (mm/year)	6	6	6	6	6	6	6
Tidal Fresh Elev c coeff. (linear)	1	1	1	1	1	1	1

Results

Table 3 presents the predicted losses for each land cover type by 2100 for each of the five SLR scenarios examined. For this simulation the land-cover losses are calculated in comparison to the 2009 NWI wetland layer.

Although the majority of the refuge is protected by a levee system, SLAMM predicts the refuge to undergo serious losses of wetlands based on the SLR scenarios examined. Regularly- and irregularly flooded marsh, which predominantly occur is portions of the refuge not protected by levees, are predicted to undergo wetland losses at the lower SLR scenarios examined, with 92% of regularly-flooded marsh and 75% of irregularly-flooded marsh predicted to be lost under the A1B maximum (0.69 m by 2100) scenario. At scenarios of 1.5 m of SLR by 2100 and greater, SLAMM predicts complete loss of these wetland habitats.

Table 3. Predicted loss rates of land categories by 2100 given simulated scenarios of eustatic SLR at Bayou Sauvage NWR.
Positive values indicate losses while negative values indicate gains.

	Land cover change by 2100 for different SLR scenarios (%)				
	0.39 m	0.69 m	1 m	1.5 m	2 m
Regularly-flooded Marsh	41%	92%	96%	99%	99%
Inland Fresh Marsh	1%	2%	25%	96%	100%
Irregularly-flooded Marsh	60%	75%	81%	99%	100%
Swamp	25%	28%	38%	85%	98%
Undeveloped Dry Land	15%	19%	28%	54%	68%
Tidal Swamp	33%	35%	43%	87%	96%
Estuarine Beach	43%	43%	60%	98%	99%
Tidal Fresh Marsh	2%	10%	37%	100%	100%

Wetlands protected by the levee system are also predicted to be lost at the higher SLR scenarios studied. Inland fresh and tidal fresh marsh, tidal swamp, swamp, and estuarine beach are all projected to be lost at high percentages under the SLR scenarios of 1.5 m by 2100 and above. In comparison, (undeveloped) dry land is predicted to be relatively resilient to the effects of SLR.

The losses of wetlands are offset by gains in open water, tidal flat and transitional salt marsh. Table 4 presents the predicted gains of each of these categories by 2100 for each of the SLR scenarios examined. The majority of wetlands are predicted to be replaced by open water. Tidal flats are also predicted to become more prevalent in the refuge, with the highest predicted acreages by 2100 occurring under the A1B mean and A1B maximum scenarios (0.39 m and 0.69 m by 2100, respectively), while for higher rates of SLR tidal flat is predicted to initially expand but is then completely inundated by the rising water .

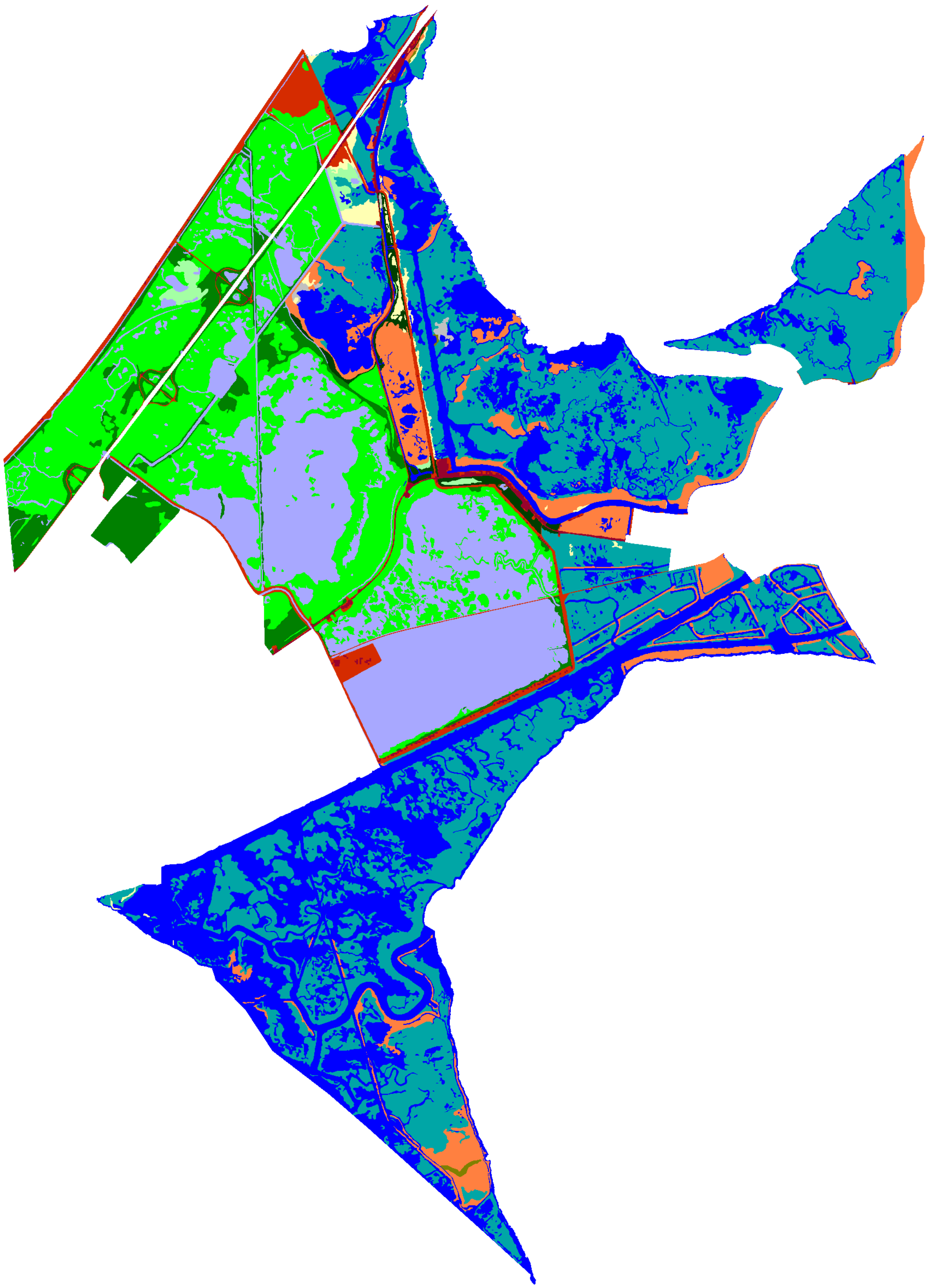
Table 4. Predicted gains of land categories by 2100 given simulated scenarios of eustatic SLR at Bayou Sauvage NWR.
Positive values indicate gains while negative values indicate losses.

	Land cover change by 2100 for different SLR scenarios (acres)					
	Initial	**0.39 m**	**0.69 m**	**1 m**	**1.5 m**	**2 m**
Estuarine Open Water	8013	4784	10000	12904	18709	19264
Tidal Flat	36	1098	1204	312	101	62
Transitional Salt Marsh	27	-3	-1	28	52	12

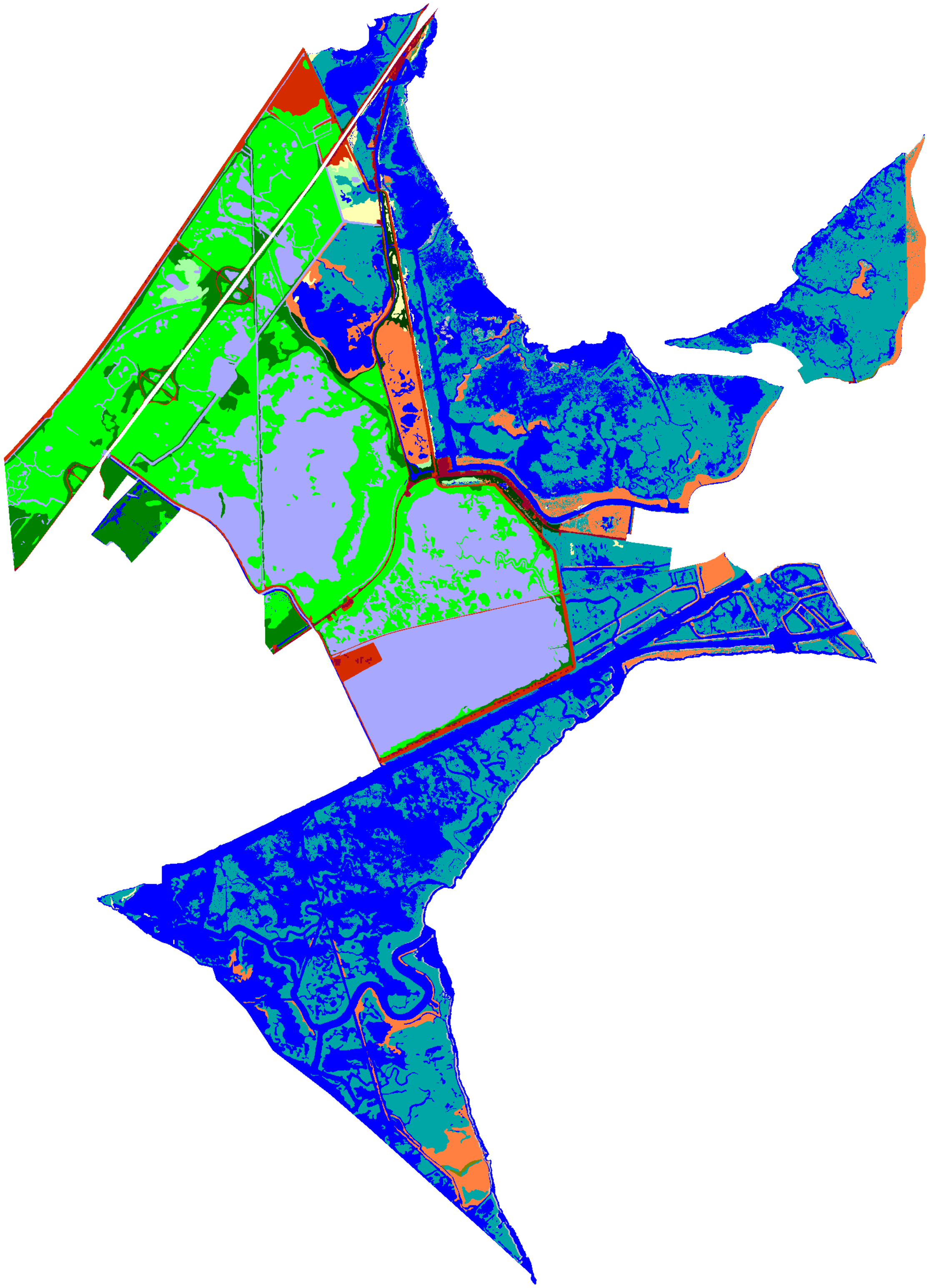
IPCC Scenario A1B-Mean, 0.39 m SLR eustatic by 2100

Results in Acres

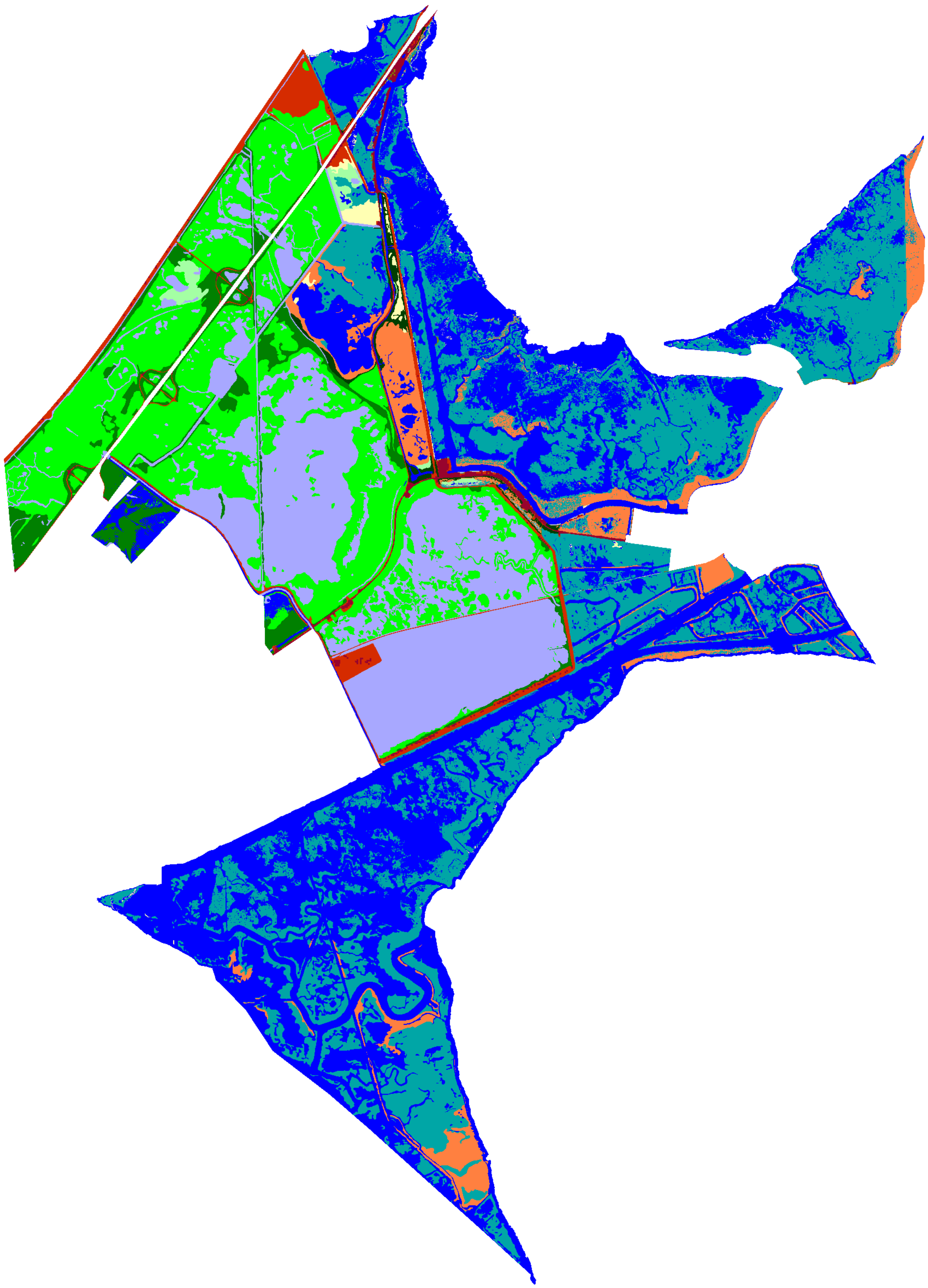
		Initial	2025	2050	2075	2100
	Regularly-flooded Marsh	9796	8343	8338	7270	5763
	Estuarine Open Water	8013	9721	10188	11145	12797
	Inland Open Water	5445	5443	5442	5442	5442
	Inland Fresh Marsh	5308	5304	5257	5235	5230
	Irregularly-flooded Marsh	1899	1584	1523	1023	768
	Swamp	1318	1273	1168	1051	982
	Undeveloped Dry Land	884	833	807	775	748
	Developed Dry Land	243	243	243	243	243
	Tidal Swamp	221	205	178	157	147
	Estuarine Beach	195	175	129	113	111
	Tidal Fresh Marsh	149	147	147	147	145
	Tidal Flat	36	237	89	904	1134
	Transitional Salt Marsh	27	25	25	29	24
	Inland Shore	1	1	0	0	0
	Total (incl. water)	**33535**	**33535**	**33535**	**33535**	**33535**



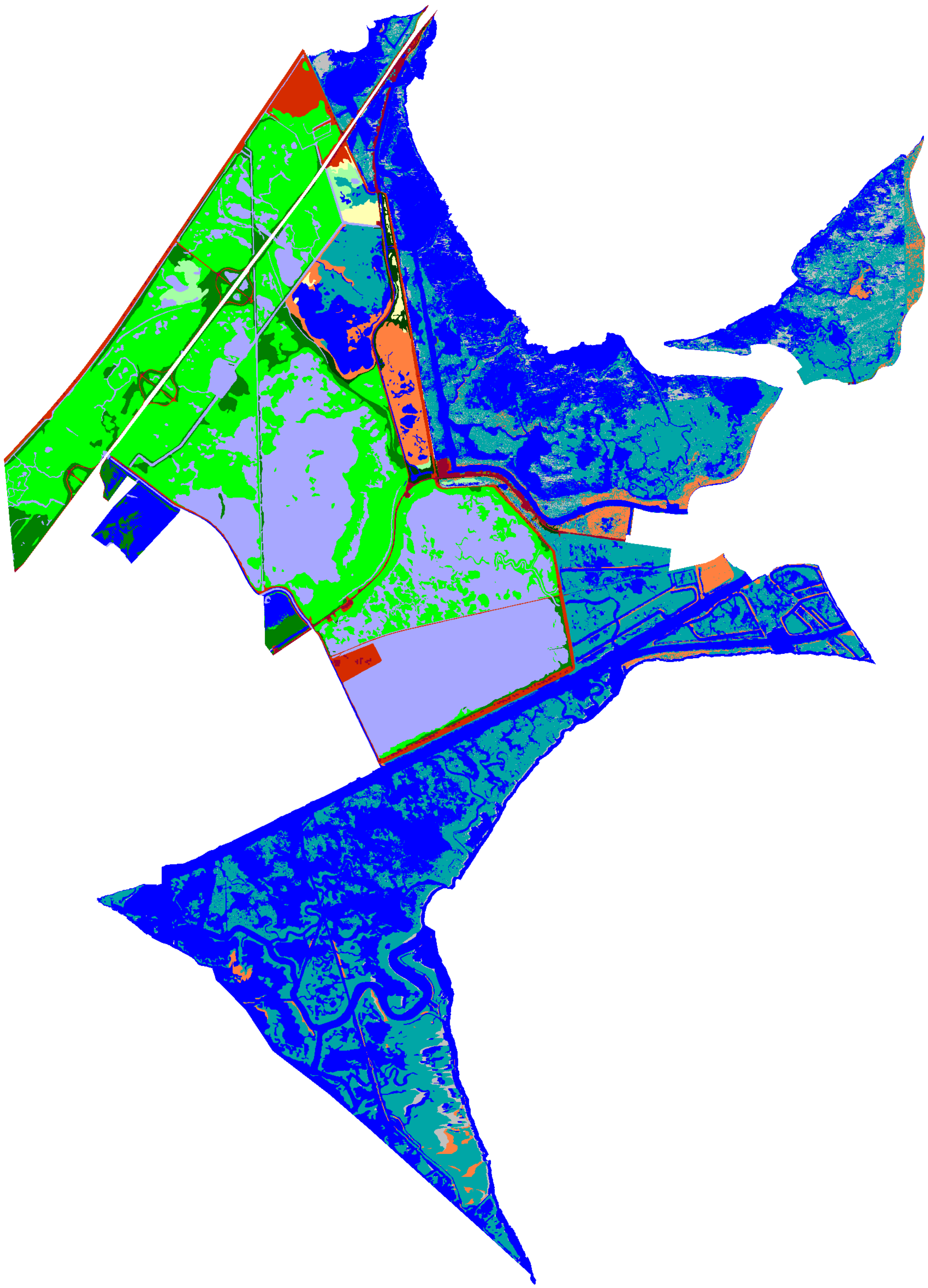
Bayou Sauvage NWR, Initial Condition



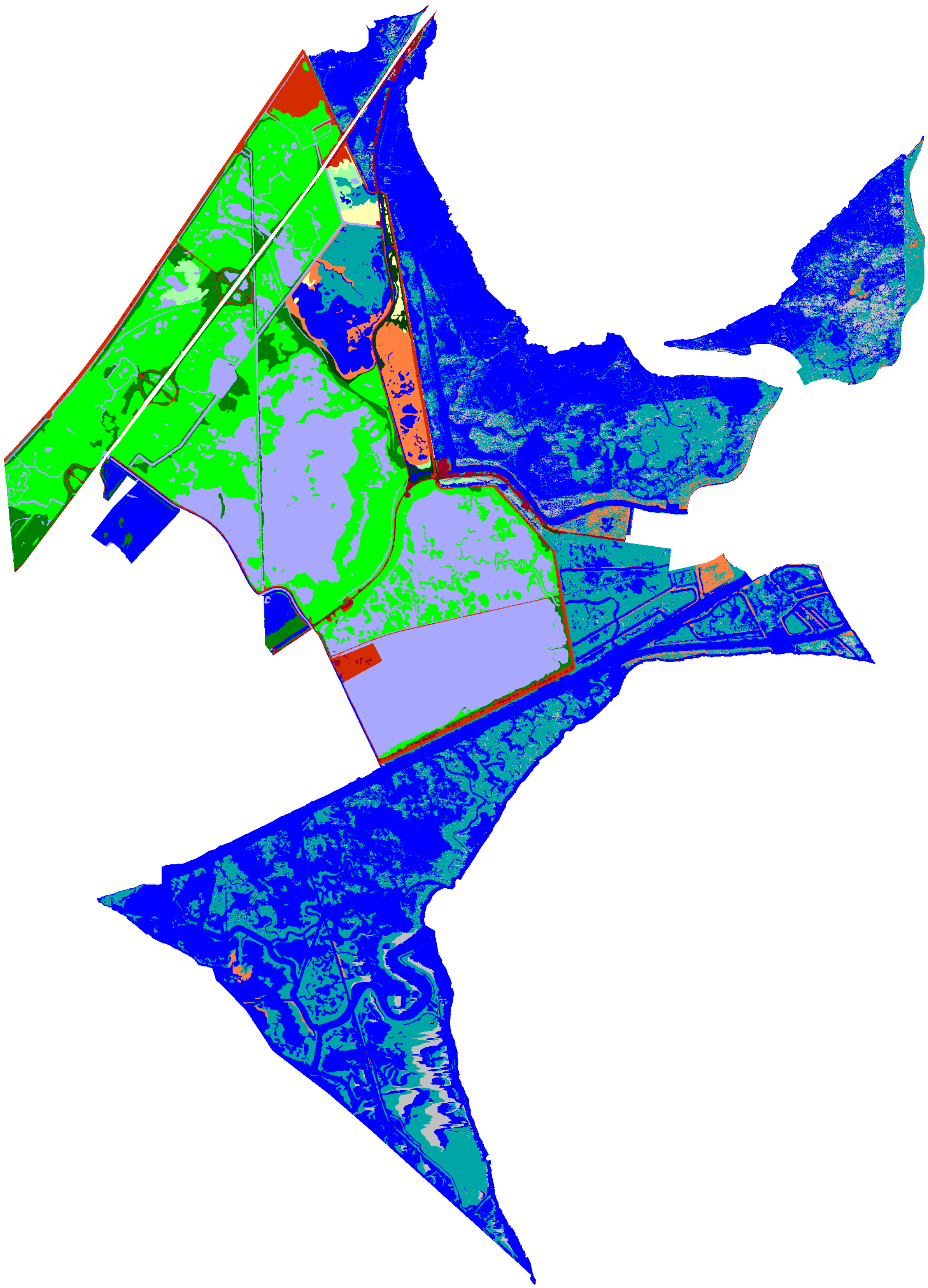
Bayou Sauvage NWR, 2025, Scenario A1B Mean, 0.39 m SLR



Bayou Sauvage NWR, 2050, Scenario A1B Mean, 0.39 m SLR



Bayou Sauvage NWR, 2075, Scenario A1B Mean, 0.39 m SLR

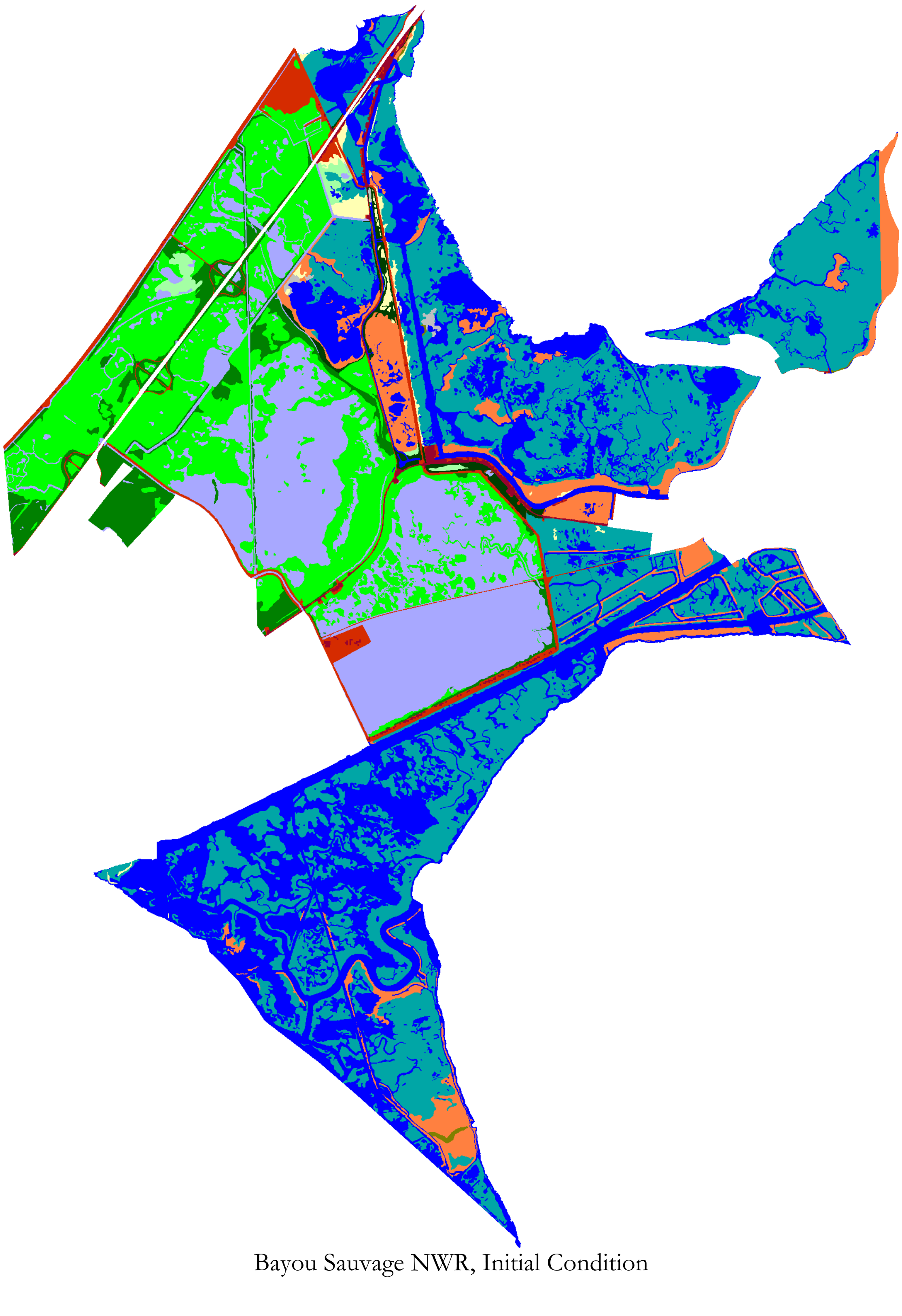


Bayou Sauvage NWR, 2100, Scenario A1B Mean, 0.39 m SLR

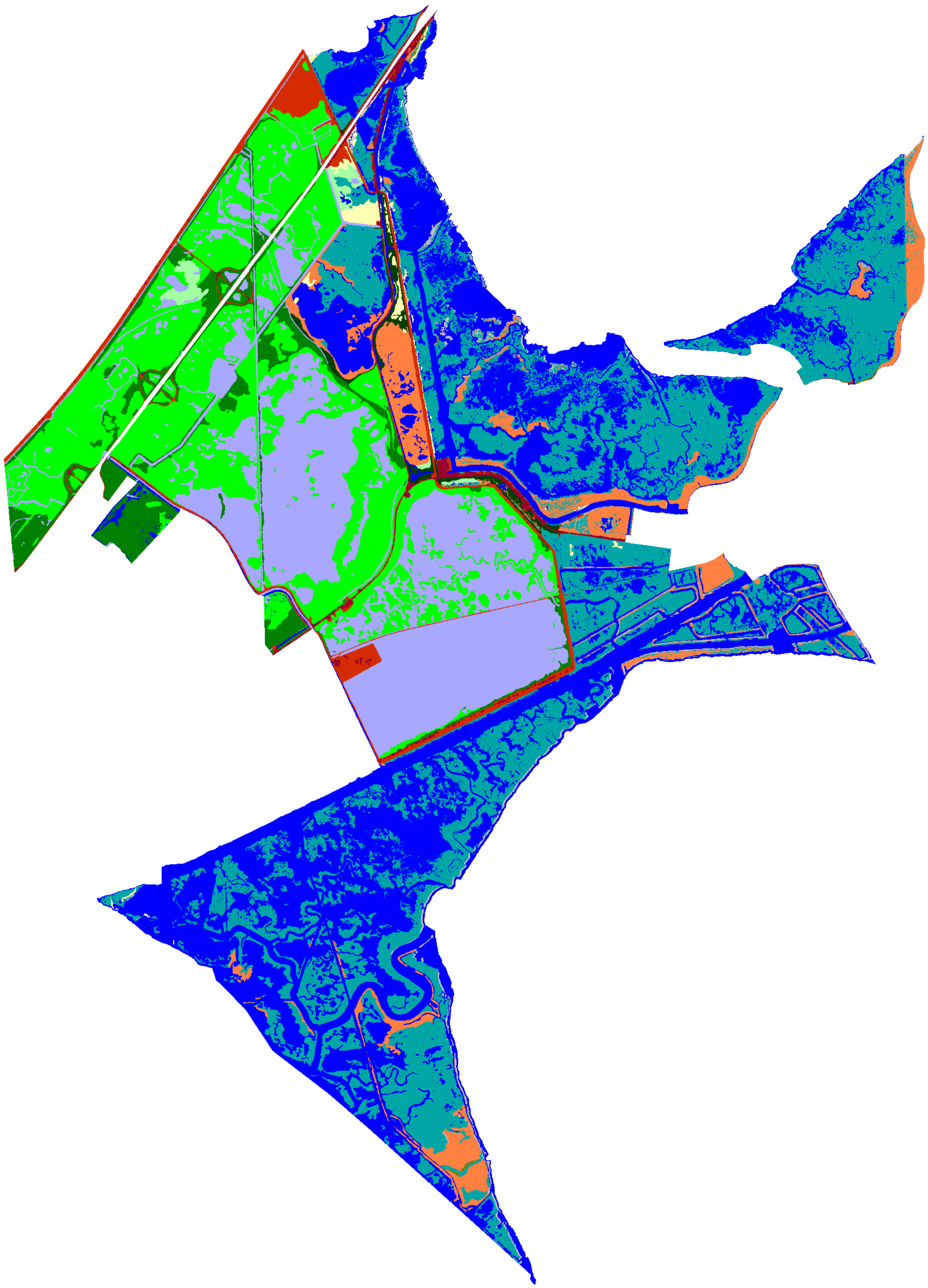
IPCC Scenario A1B-Max, 0.69 m SLR eustatic by 2100

Results in Acres

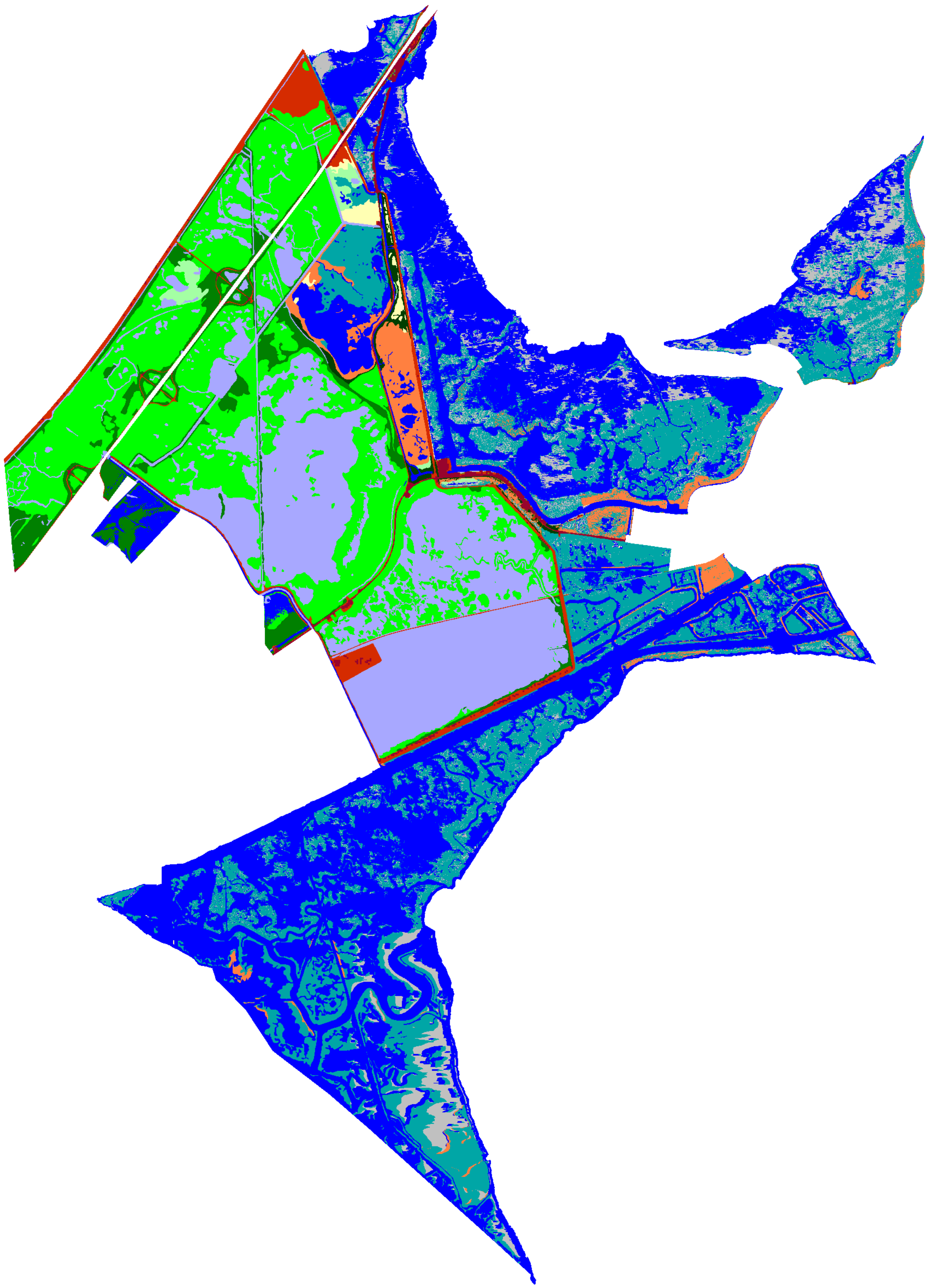
		Initial	2025	2050	2075	2100
	Regularly-flooded Marsh	9796	8283	6232	2528	832
	Estuarine Open Water	8013	9759	11281	14451	18012
	Inland Open Water	5445	5443	5442	5442	5442
	Inland Fresh Marsh	5308	5302	5248	5231	5207
	Irregularly-flooded Marsh	1899	1559	931	585	476
	Swamp	1318	1268	1131	1003	950
	Undeveloped Dry Land	884	831	798	760	719
	Developed Dry Land	243	243	243	243	243
	Tidal Swamp	221	203	170	149	143
	Estuarine Beach	195	171	120	111	110
	Tidal Fresh Marsh	149	147	144	140	134
	Tidal Flat	36	302	1764	2859	1240
	Transitional Salt Marsh	27	23	29	32	26
	Inland Shore	1	1	0	0	0
	Total (incl. water)	**33535**	**33535**	**33535**	**33535**	**33535**



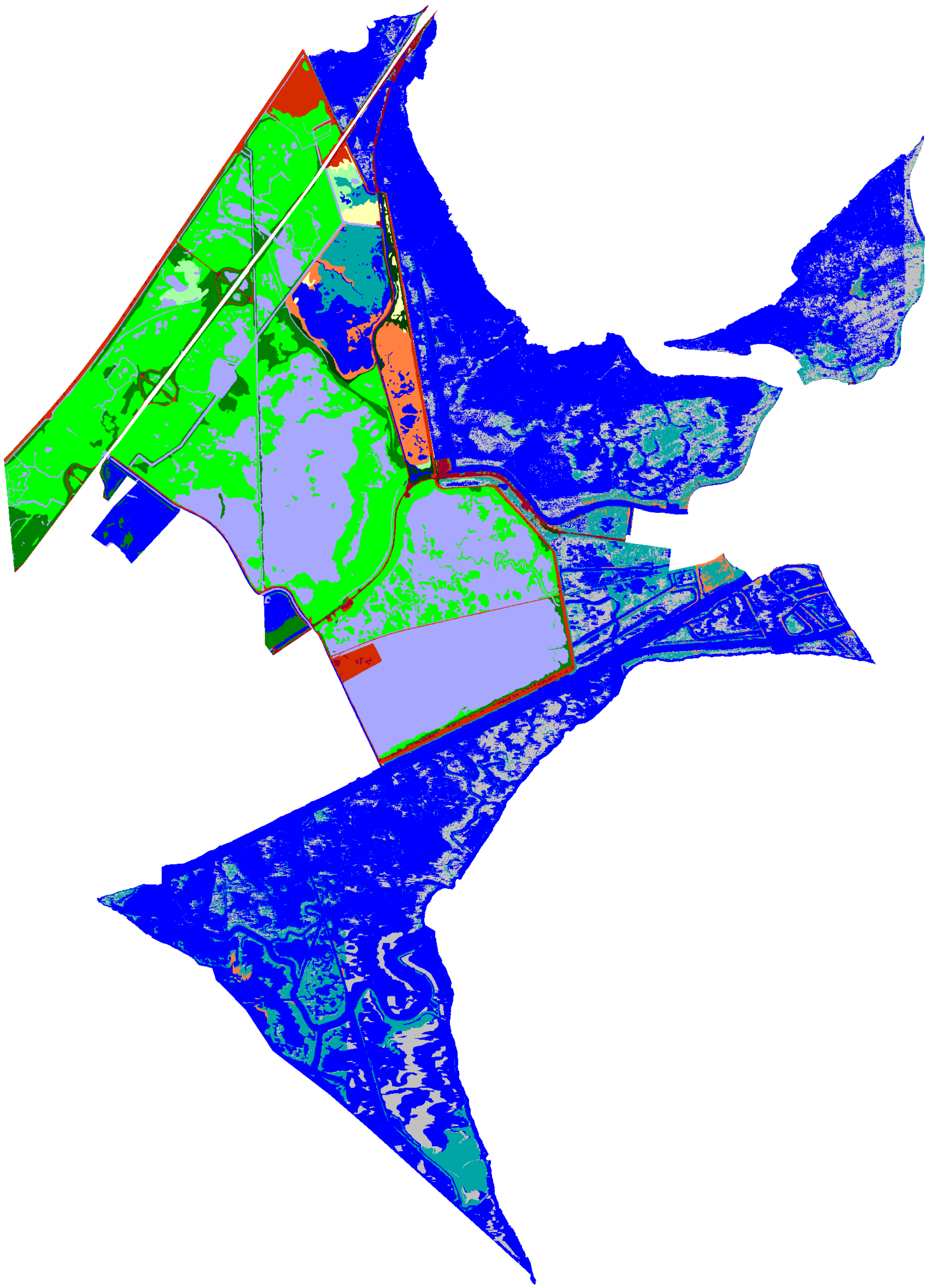
Bayou Sauvage NWR, Initial Condition



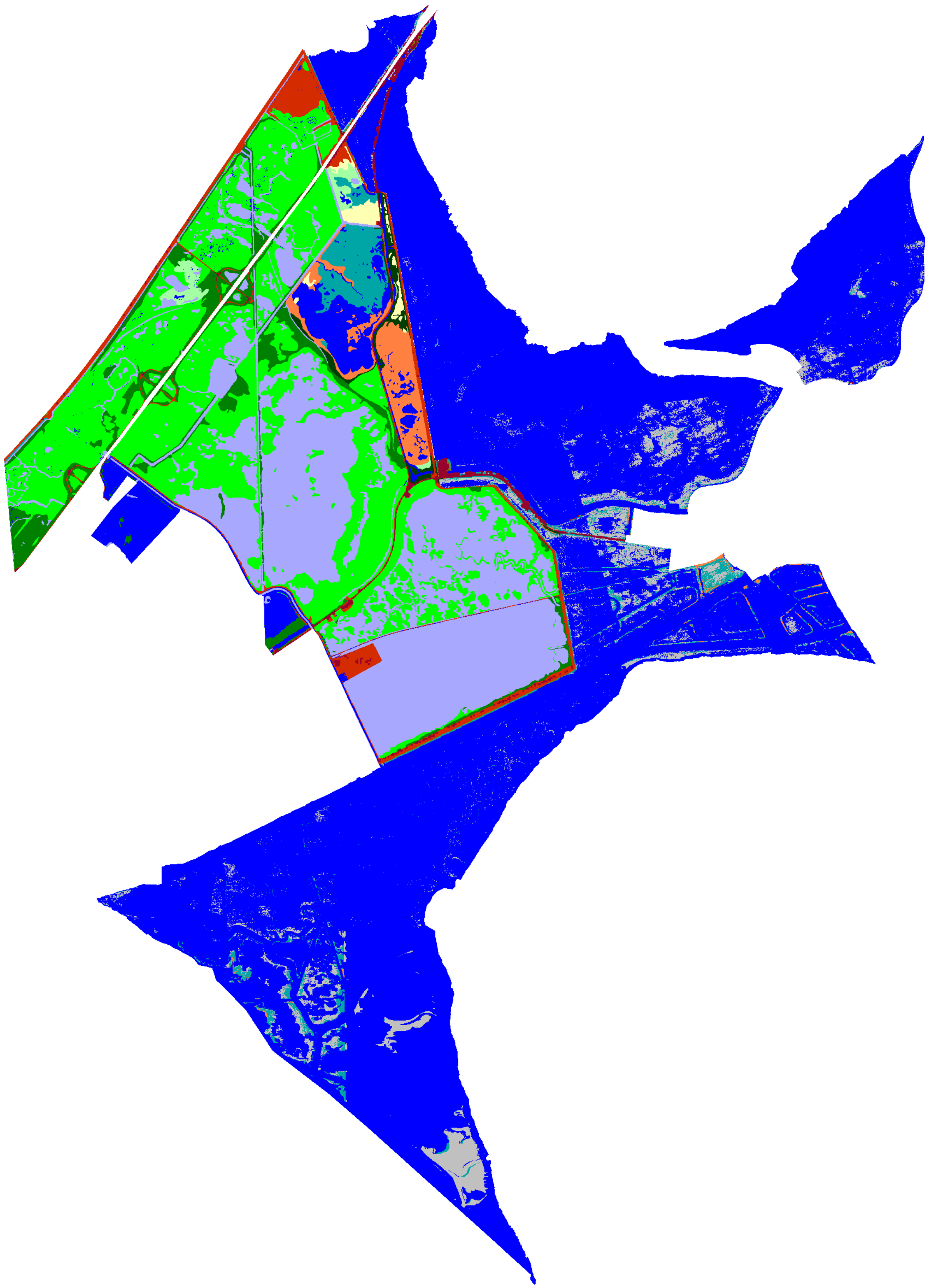
Bayou Sauvage NWR, 2025, Scenario A1B Maximum, 0.69 m SLR



Bayou Sauvage NWR, 2050, Scenario A1B Maximum, 0.69 m SLR



Bayou Sauvage NWR, 2075, Scenario A1B Maximum, 0.69 m SLR

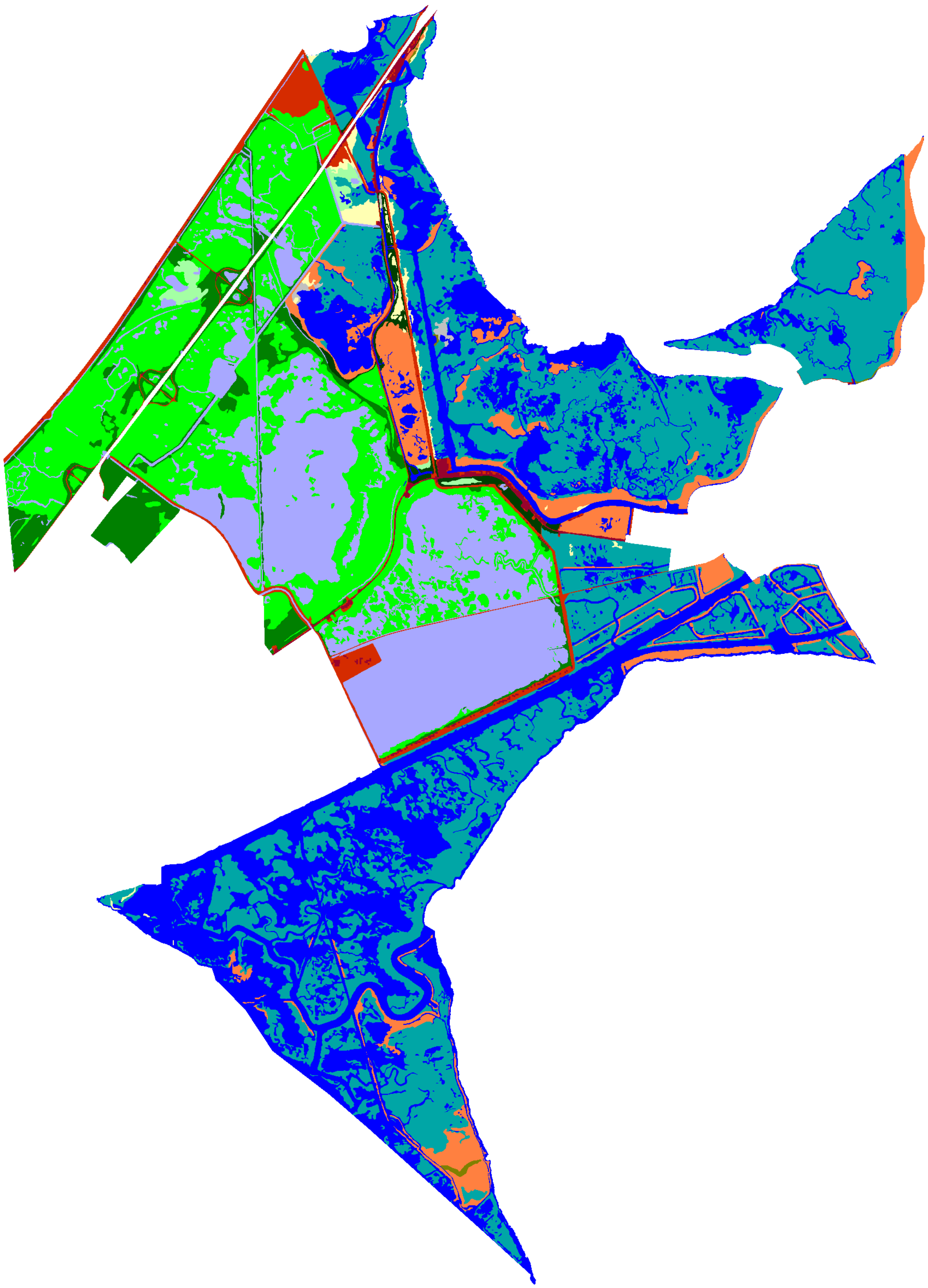


Bayou Sauvage NWR, 2100, Scenario A1B Maximum, 0.69 m SLR

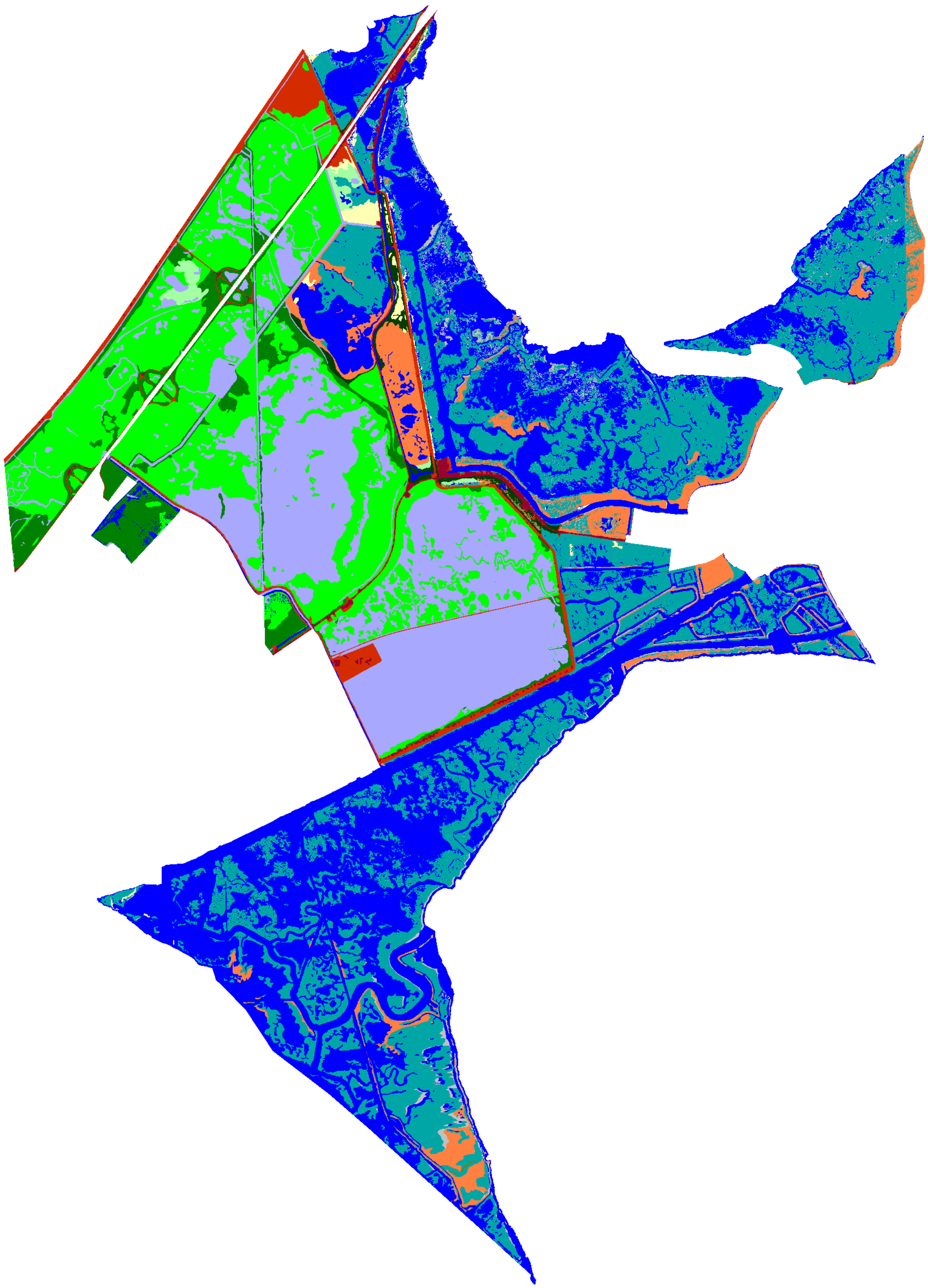
1 m eustatic SLR by 2100

Results in Acres

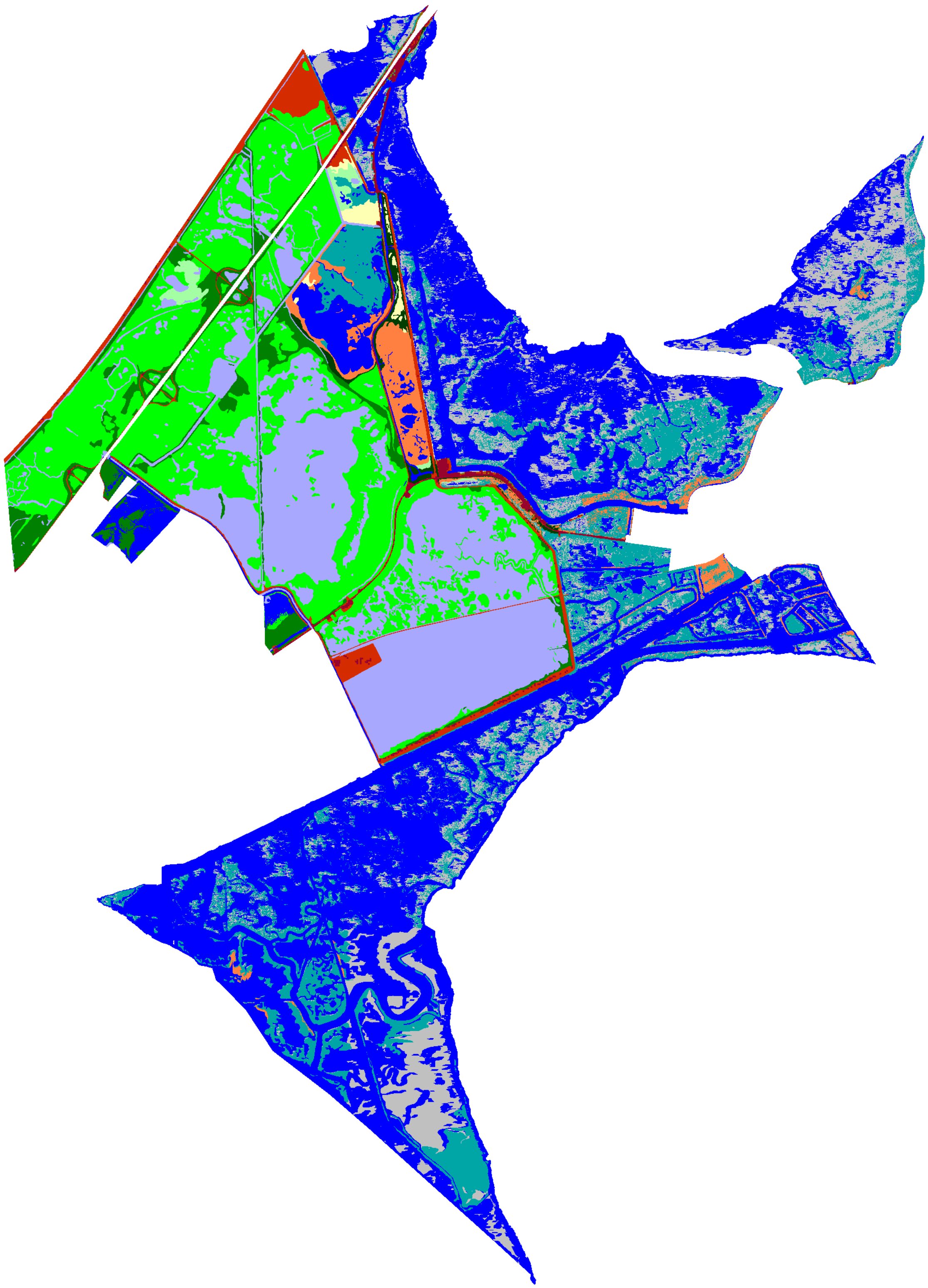
		Initial	2025	2050	2075	2100
	Regularly-flooded Marsh	9796	8017	3902	932	440
	Estuarine Open Water	8013	9876	12201	16763	20917
	Inland Open Water	5445	5443	5442	5442	5442
	Inland Fresh Marsh	5308	5299	5242	5230	3988
	Irregularly-flooded Marsh	1899	1390	735	490	352
	Swamp	1318	1262	1093	975	818
	Undeveloped Dry Land	884	829	790	742	633
	Developed Dry Land	243	243	243	243	243
	Tidal Swamp	221	200	163	145	126
	Estuarine Beach	195	167	115	111	79
	Tidal Fresh Marsh	149	146	141	137	95
	Tidal Flat	36	641	3435	2286	348
	Transitional Salt Marsh	27	21	32	38	55
	Inland Shore	1	1	0	0	0
	Total (incl. water)	**33535**	**33535**	**33535**	**33535**	**33535**



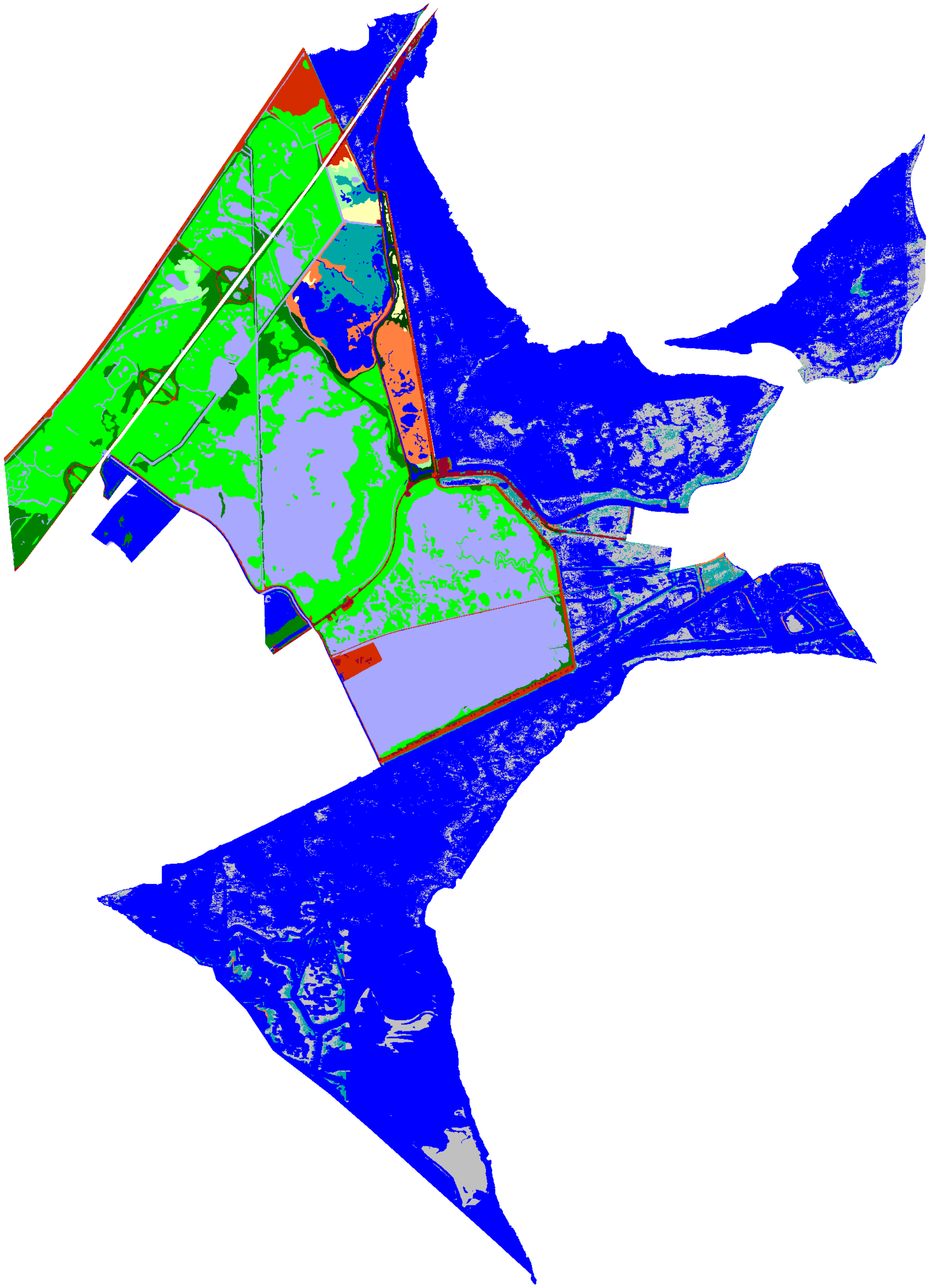
Bayou Sauvage NWR, Initial Condition



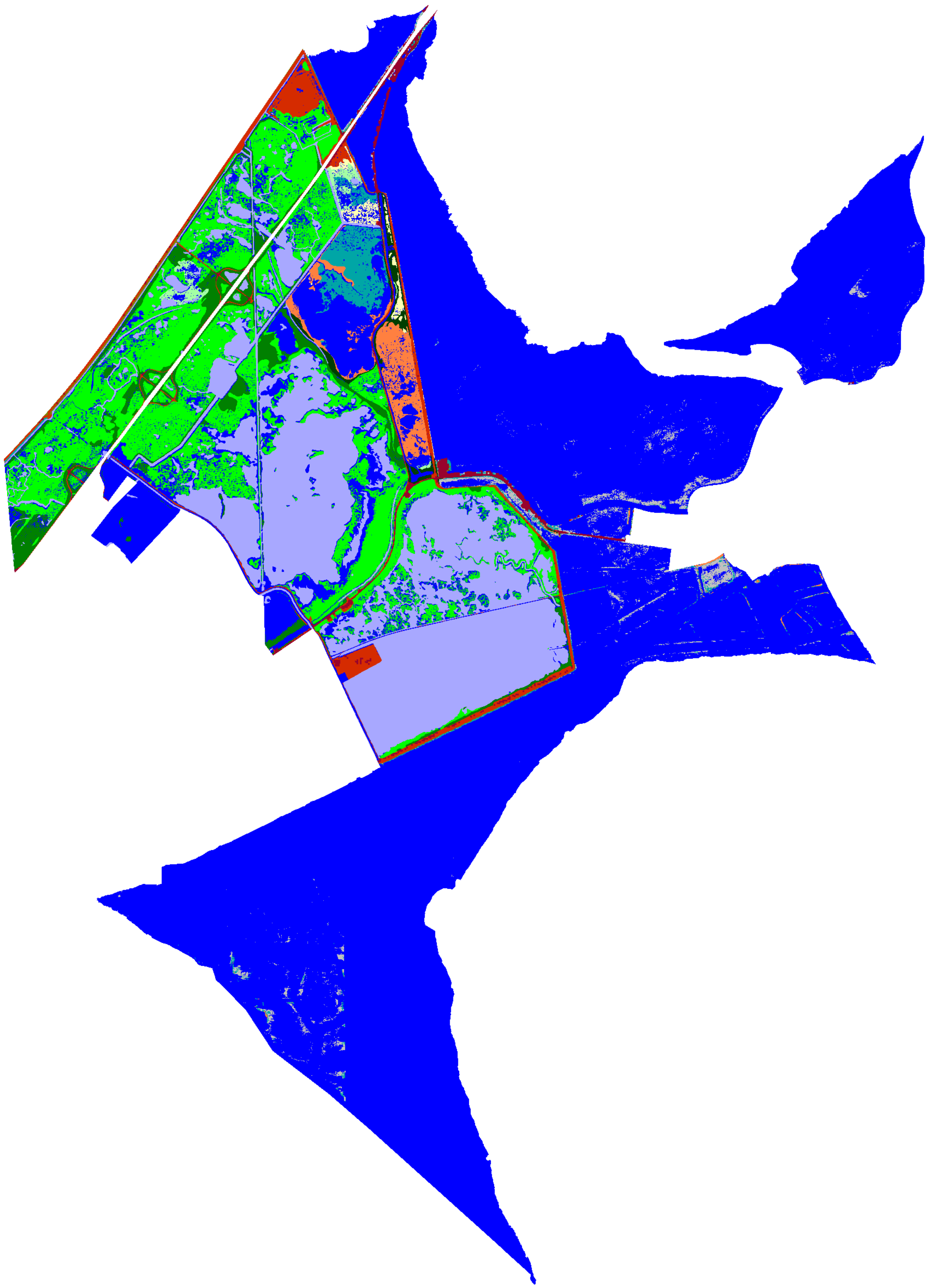
Bayou Sauvage NWR, 2025, 1 m SLR



Bayou Sauvage NWR, 2050, 1 m SLR



Bayou Sauvage NWR, 2075, 1 m SLR

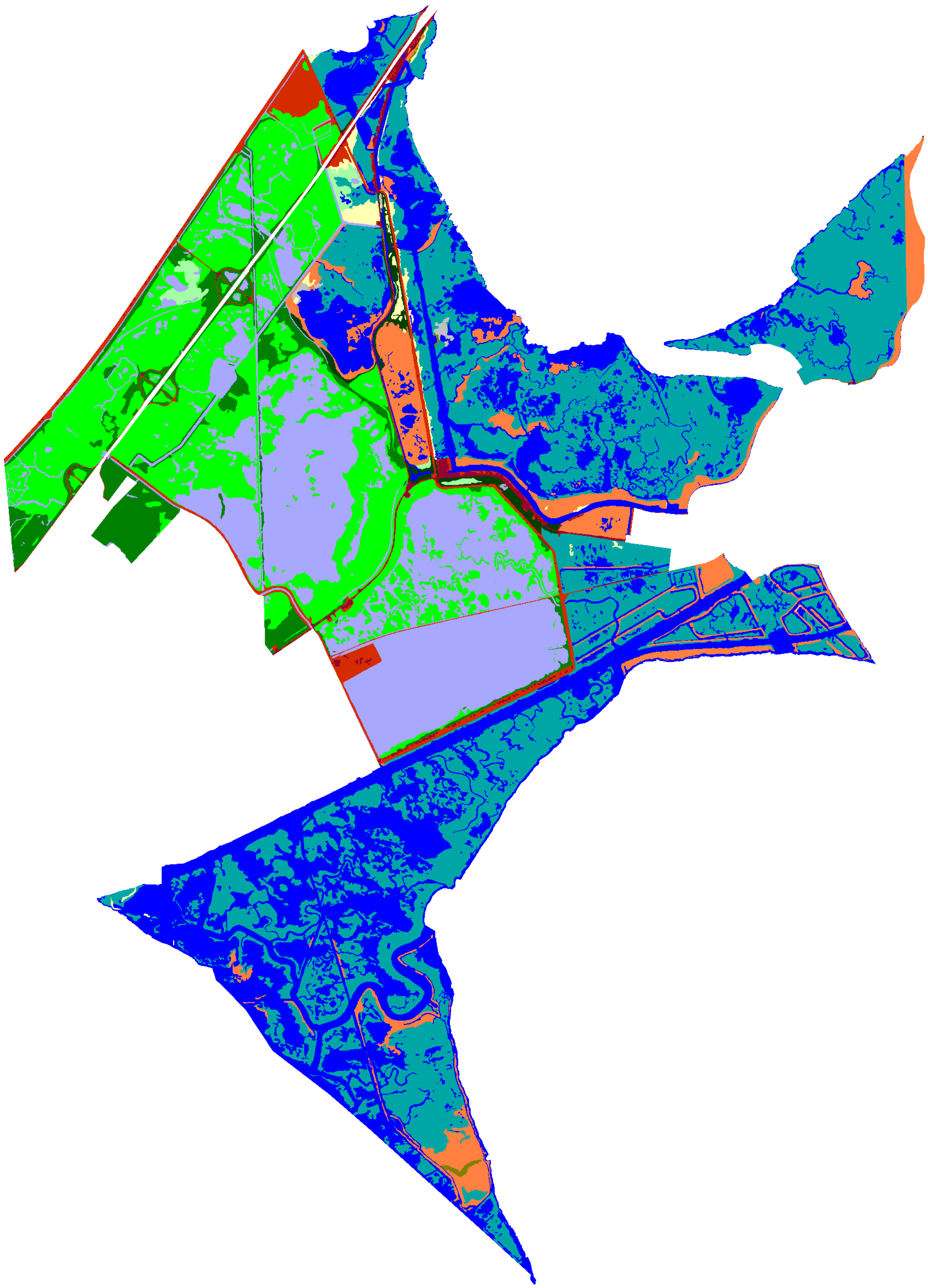


Bayou Sauvage NWR, 2100, 1 m SLR

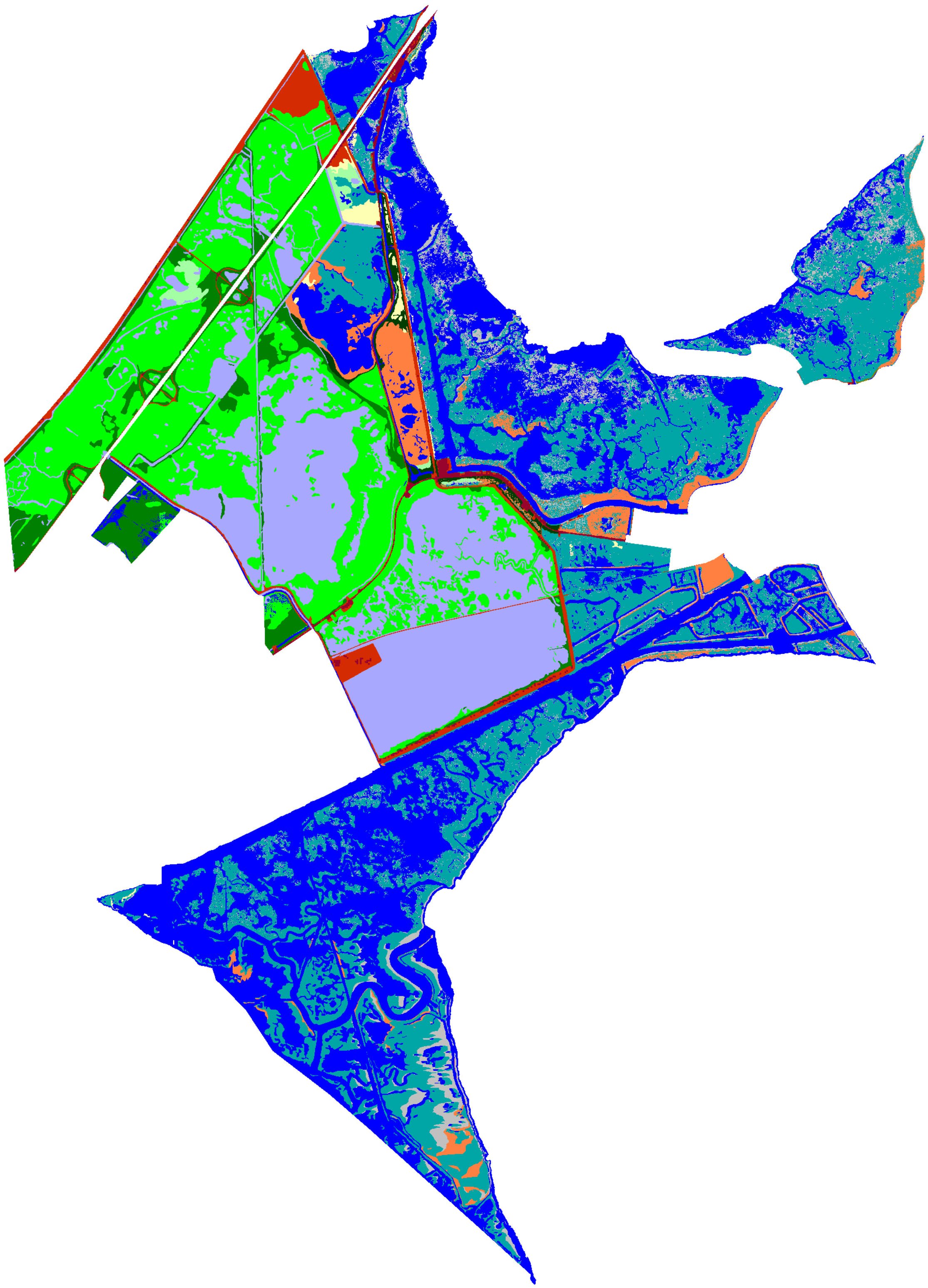
1.5 m eustatic SLR by
2100

Results in Acres

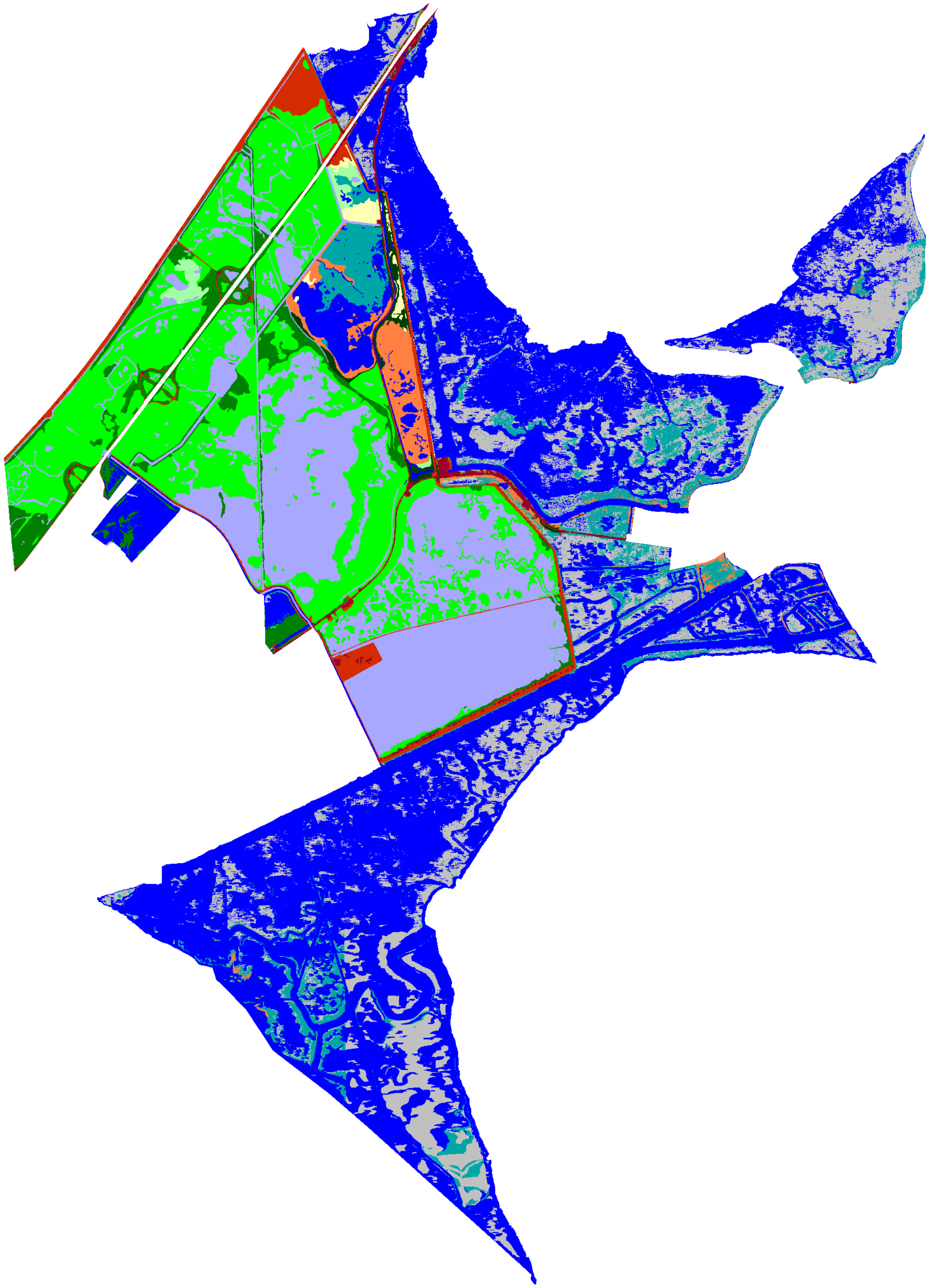
		Initial	2025	2050	2075	2100
	Regularly-flooded Marsh	9796	7313	1870	579	62
	Estuarine Open Water	8013	10045	13389	18523	26721
	Inland Open Water	5445	5443	5442	5442	5442
	Inland Fresh Marsh	5308	5292	5233	5167	206
	Irregularly-flooded Marsh	1899	1129	577	450	14
	Swamp	1318	1248	1041	937	193
	Undeveloped Dry Land	884	825	772	707	405
	Developed Dry Land	243	243	243	243	243
	Tidal Swamp	221	196	153	140	28
	Estuarine Beach	195	158	112	110	4
	Tidal Fresh Marsh	149	145	138	130	0
	Tidal Flat	36	1477	4521	1069	137
	Transitional Salt Marsh	27	20	42	37	79
	Inland Shore	1	1	0	0	0
	Total (incl. water)	**33535**	**33535**	**33535**	**33535**	**33535**



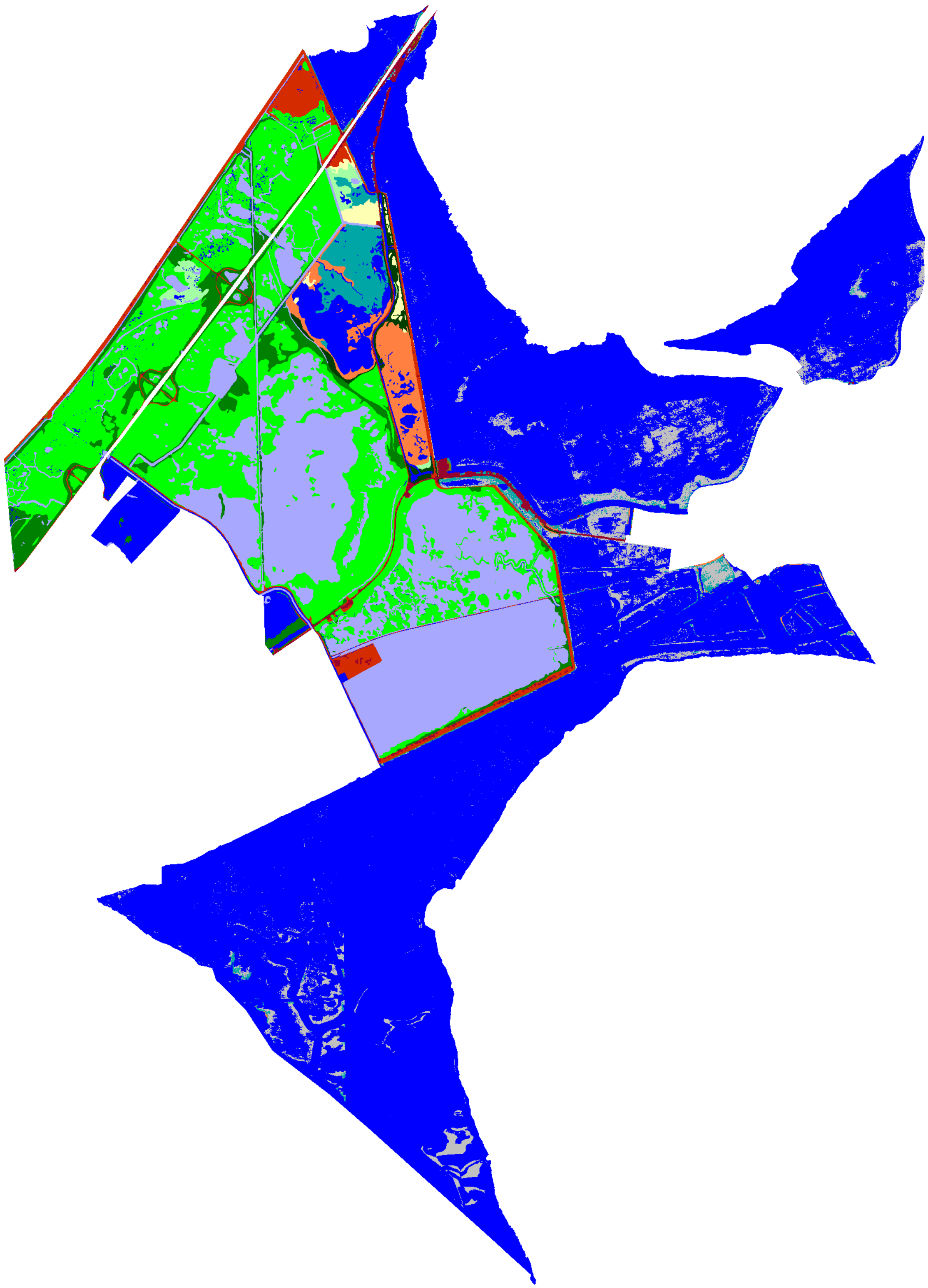
Bayou Sauvage NWR, Initial Condition



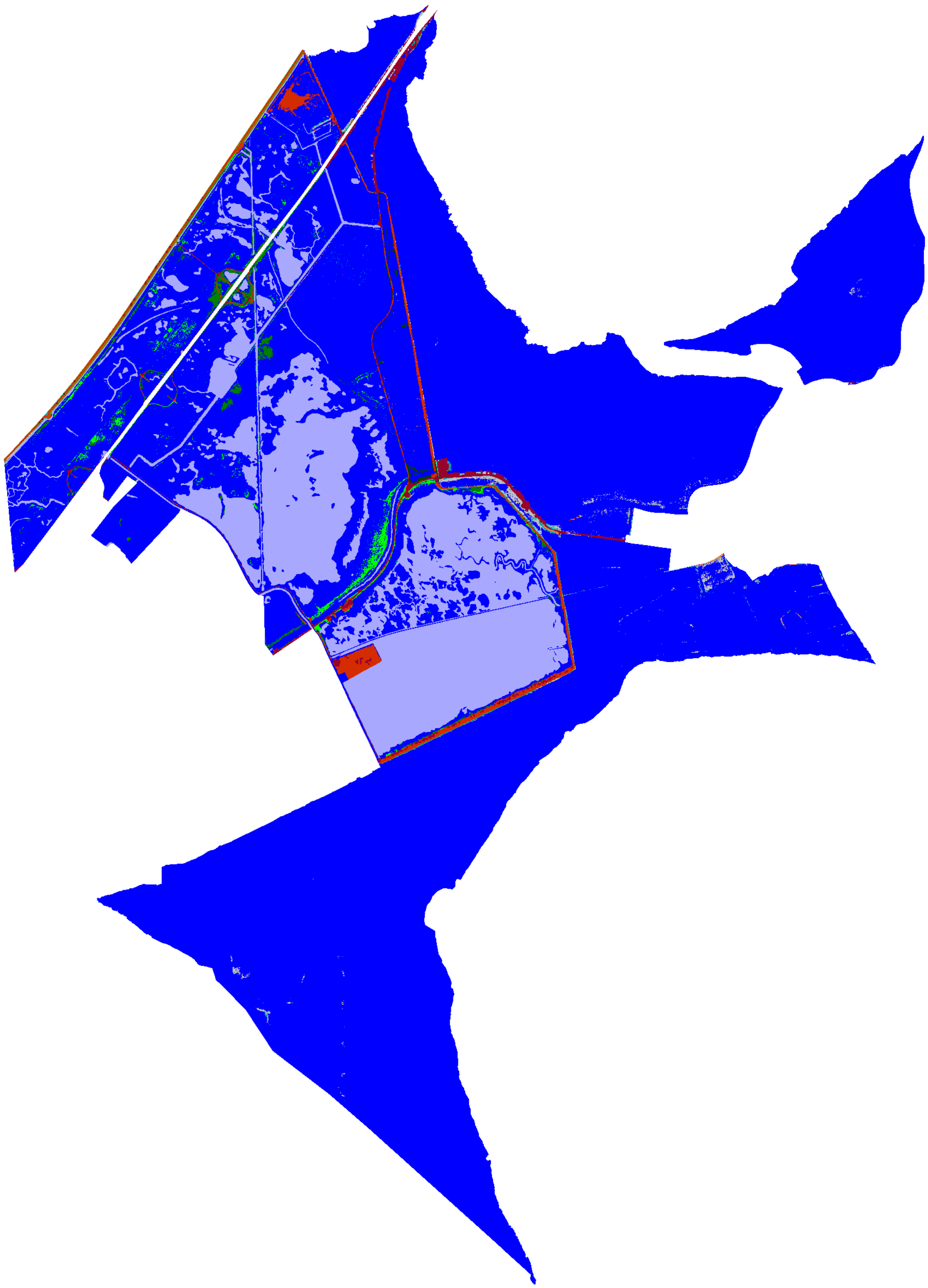
Bayou Sauvage NWR, 2025, 1.5 m SLR



Bayou Sauvage NWR, 2050, 1.5 m SLR



Bayou Sauvage NWR, 2075, 1.5 m SLR

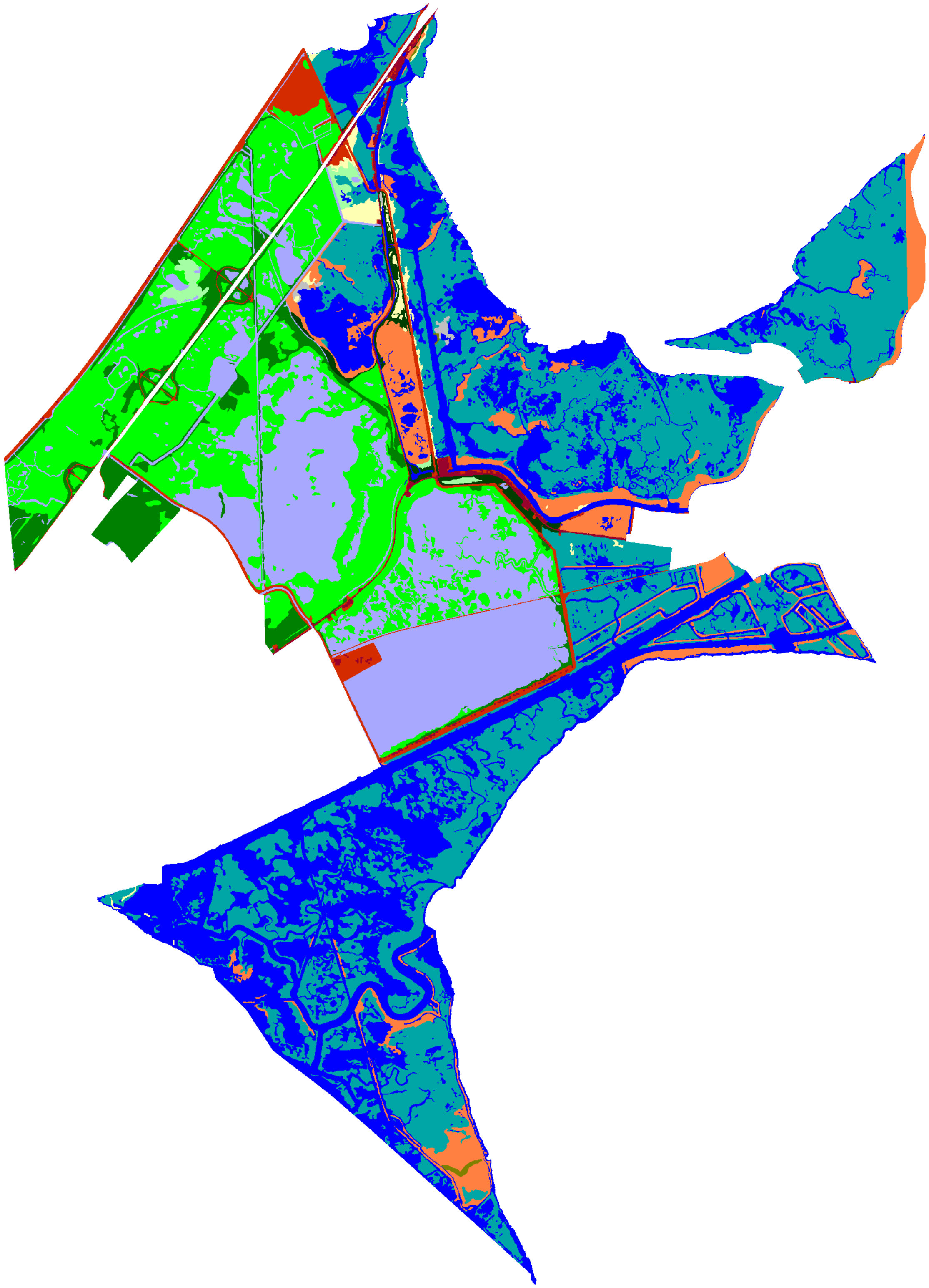


Bayou Sauvage NWR, 2100, 1.5 m SLR

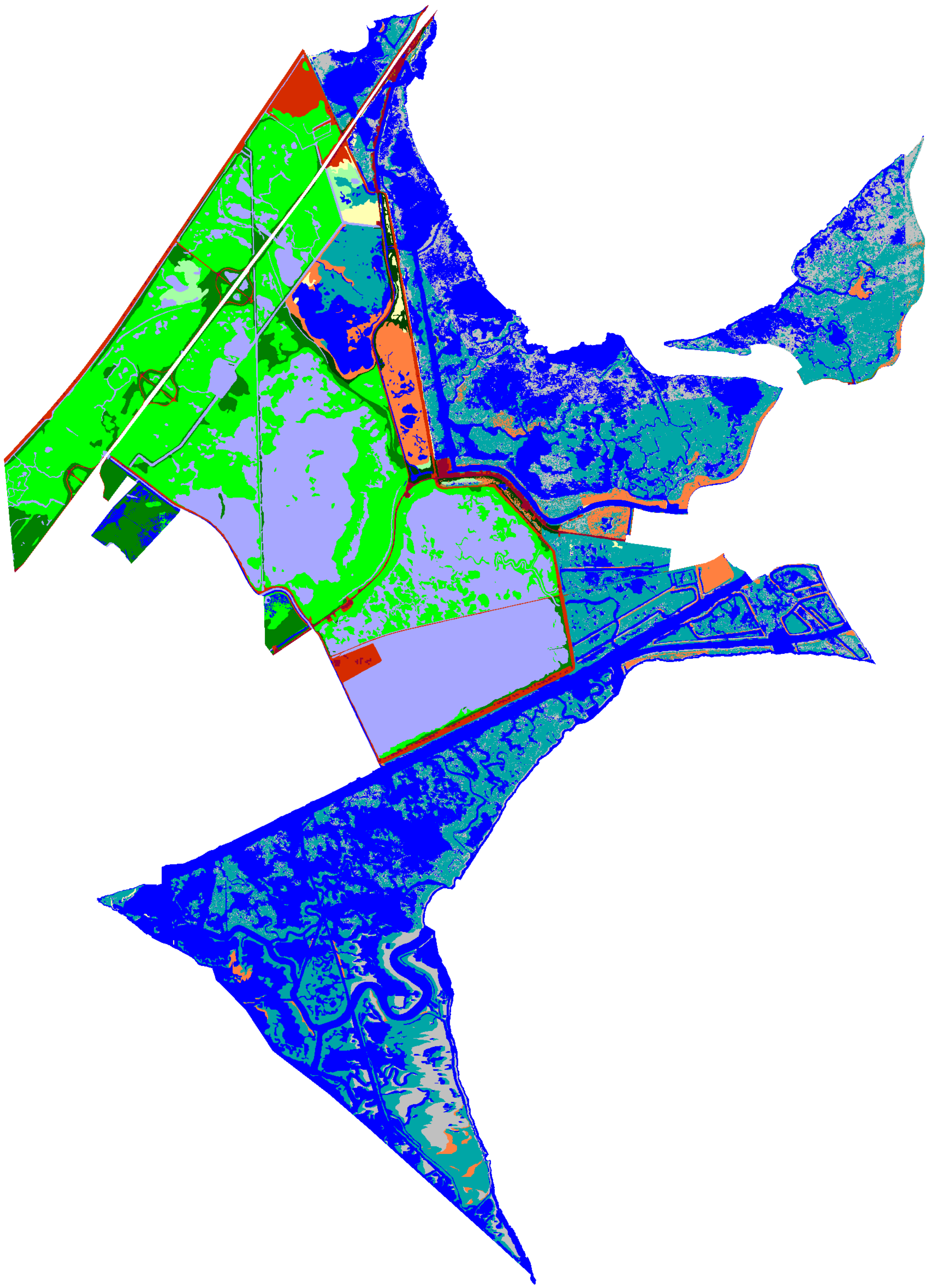
2 m eustatic SLR by 2100

Results in Acres

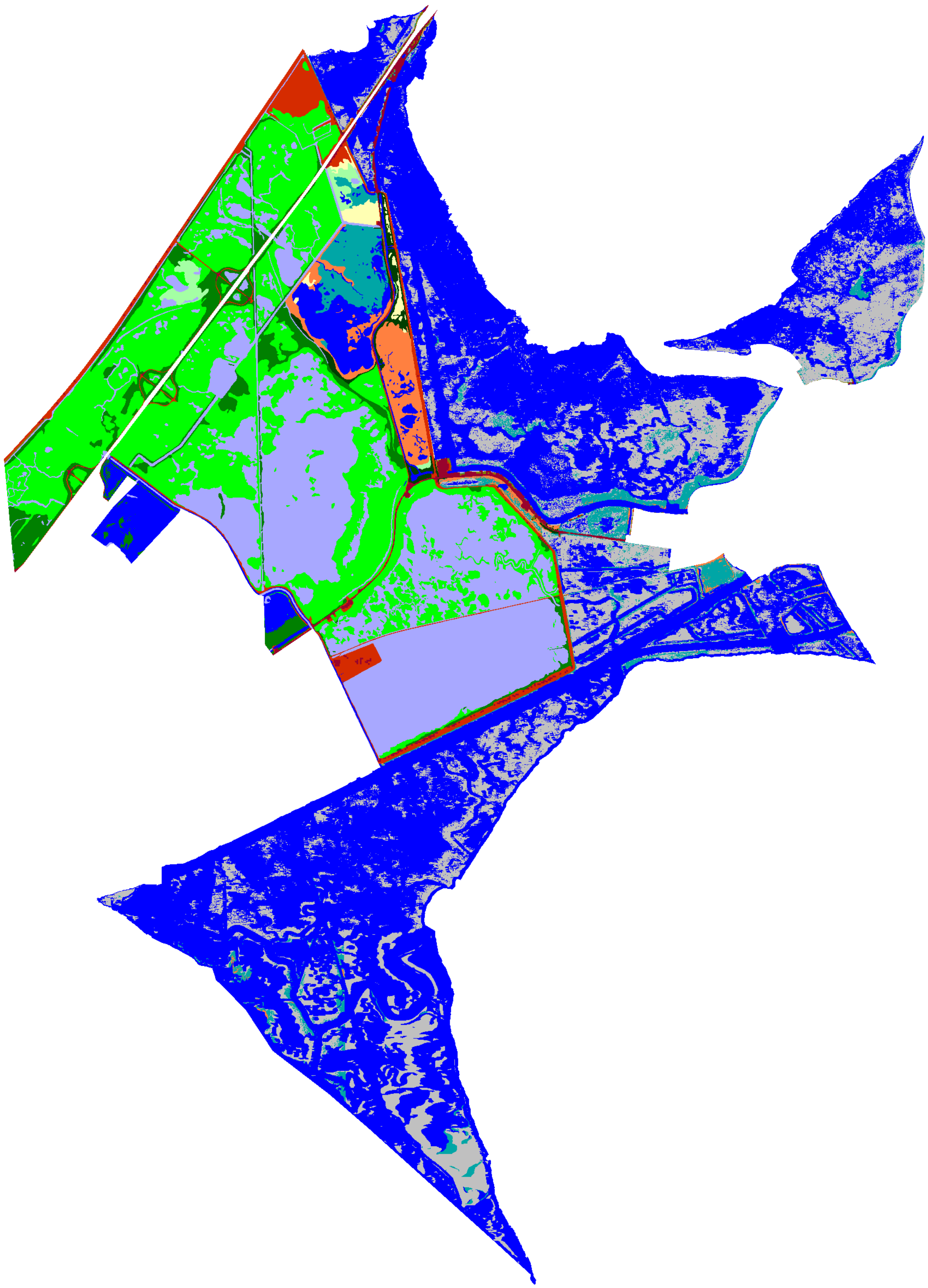
		Initial	2025	2050	2075	2100
	Regularly-flooded Marsh	9796	6393	1122	341	94
	Estuarine Open Water	8013	10309	14470	22718	27277
	Inland Open Water	5445	5442	5442	5442	5442
	Inland Fresh Marsh	5308	5284	5231	2541	12
	Irregularly-flooded Marsh	1899	981	515	211	6
	Swamp	1318	1231	1001	681	31
	Undeveloped Dry Land	884	821	758	570	282
	Developed Dry Land	243	243	243	243	243
	Tidal Swamp	221	191	148	111	9
	Estuarine Beach	195	43	2	1	2
	Tidal Fresh Marsh	149	143	136	49	0
	Tidal Flat	36	2430	4416	541	98
	Transitional Salt Marsh	27	22	49	87	39
	Inland Shore	1	0	0	0	0
	Total (incl. water)	**33535**	**33535**	**33535**	**33535**	**33535**



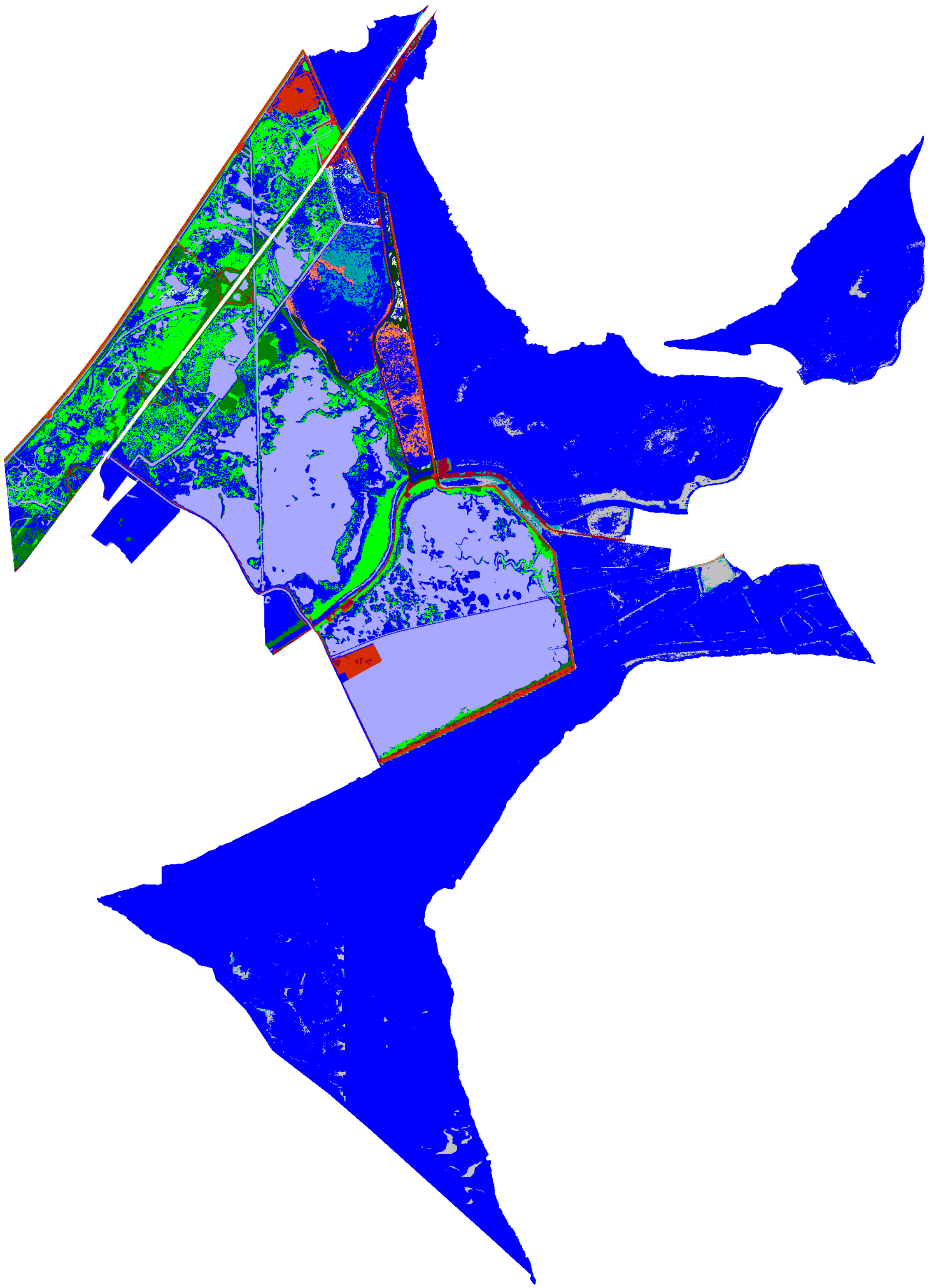
Bayou Sauvage NWR, Initial Condition



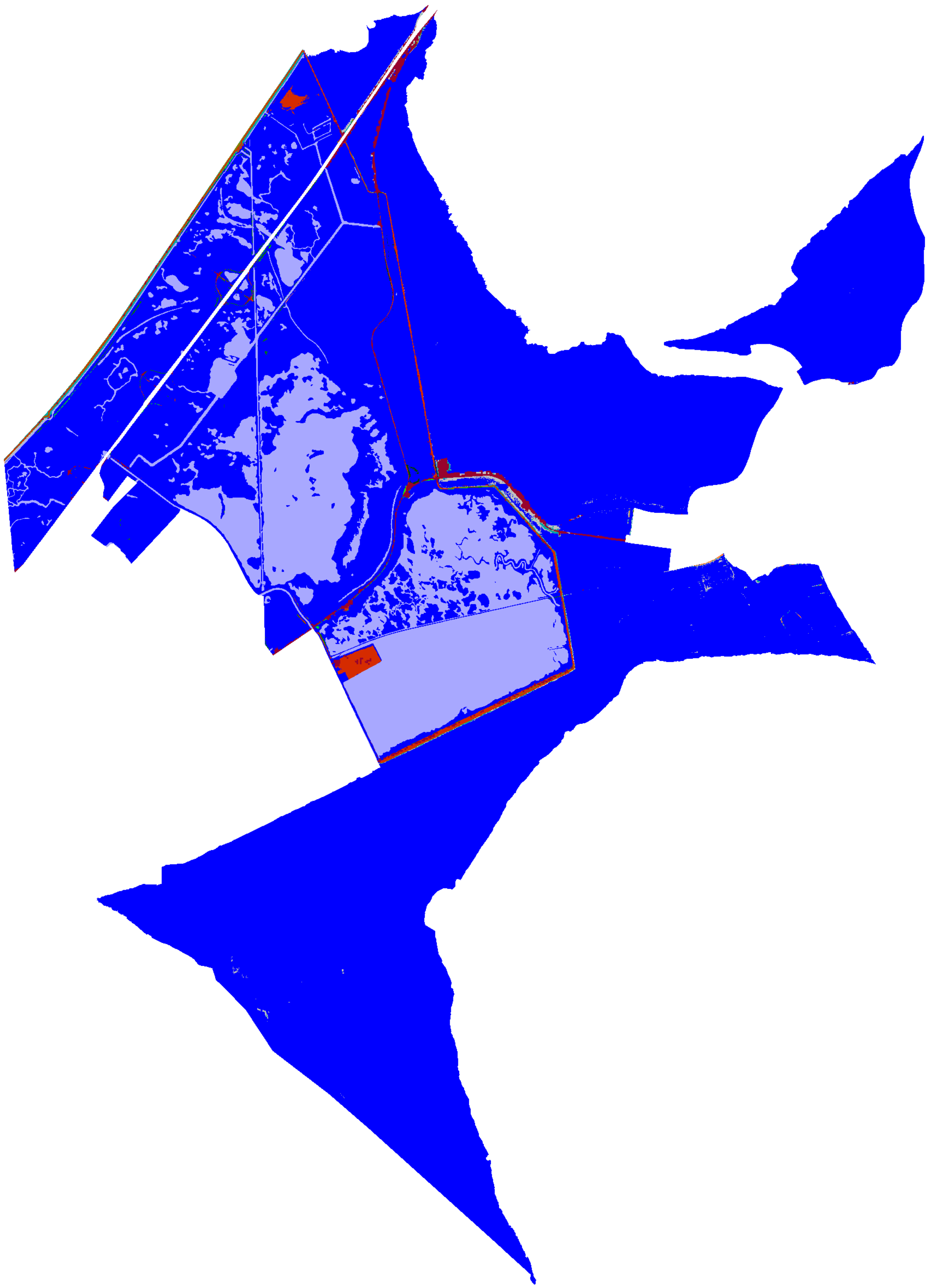
Bayou Sauvage NWR, 2025, 2 m SLR



Bayou Sauvage NWR, 2050, 2 m SLR



Bayou Sauvage NWR, 2075, 2 m SLR



Bayou Sauvage NWR, 2100, 2 m SLR

Discussion

SLAMM simulations indicate future SLR will have an important impact on the wetland composition of Bayou Sauvage NWR. Due to the low elevations and high measured and predicted subsidence rates for this region, wetland losses for this area are predicted to be severe.

This application of SLAMM has incorporated subsidence information and previously-calibrated accretion feedbacks for this refuge, allowing for a refined model application. However, important caveats for the results presented here should be mentioned. The effects of storms on wetlands are difficult to predict and can have profound repercussions for these habitats. This model application does not estimate the potential losses that may occur based on storm effects. In addition, according to the Comprehensive Conservation Plan (CCP) for Bayou Sauvage, the management approach for this marsh is to implement restoration of fresh and brackish marsh and hardwood forest habitats. Future restoration efforts are not considered in the model results presented here.

An important issue in this model application is the levees that protect the majority of the current refuge area. Levees, which interrupt the natural flow of water, are included in model simulations. However, since SLAMM is not a hydrodynamic model, the anthropogenic control of water through pumps and flap gates is not accounted for. Moreover, the SLAMM model default is to assume that dikes or levees are maintained until the elevation of the land protected is 2 m (6.6 ft.) below sea level. This assumption is not likely to accurately reflect the newly-refurbished levee system that protects East Orleans Parish.

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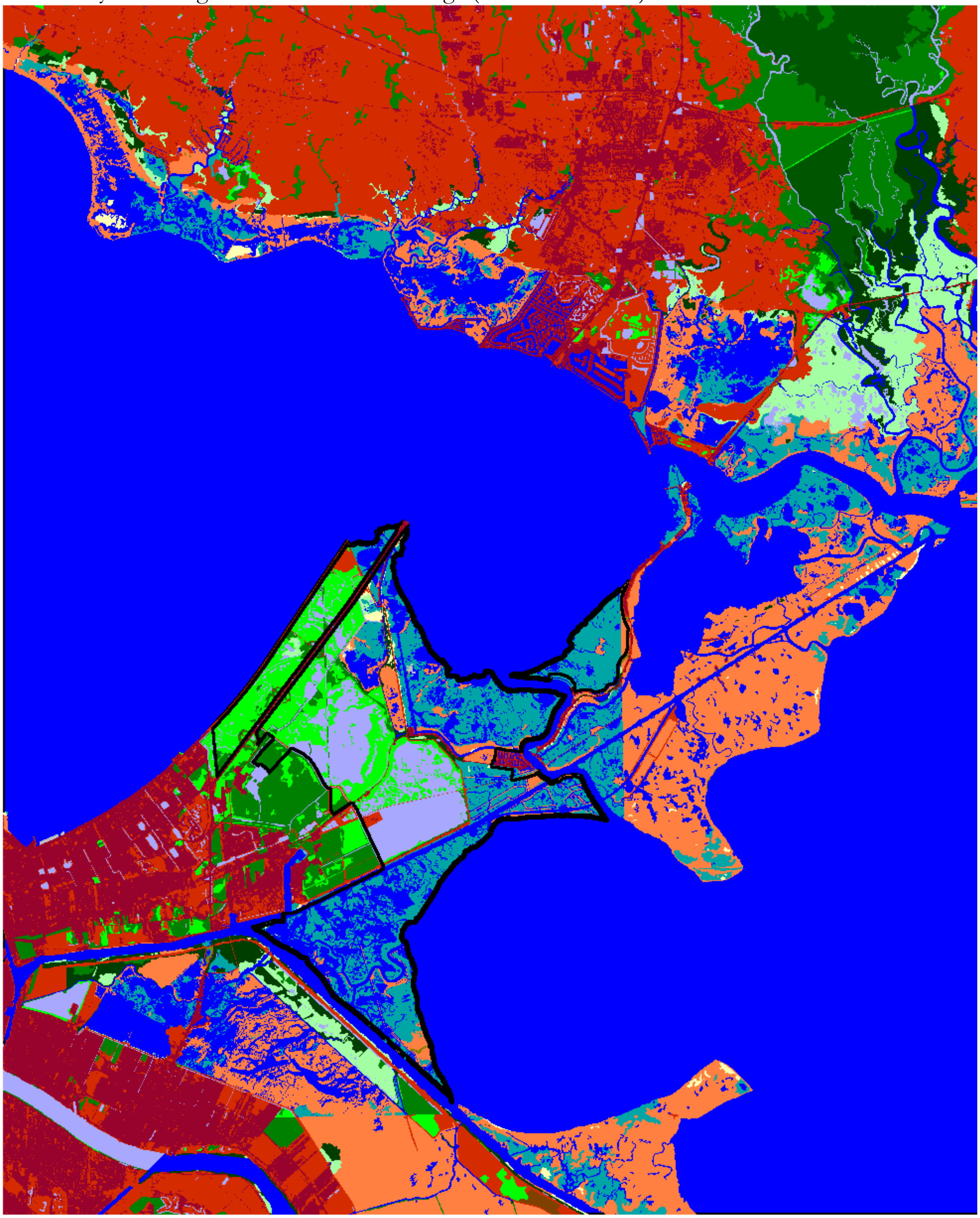
Appendix A: Contextual Results

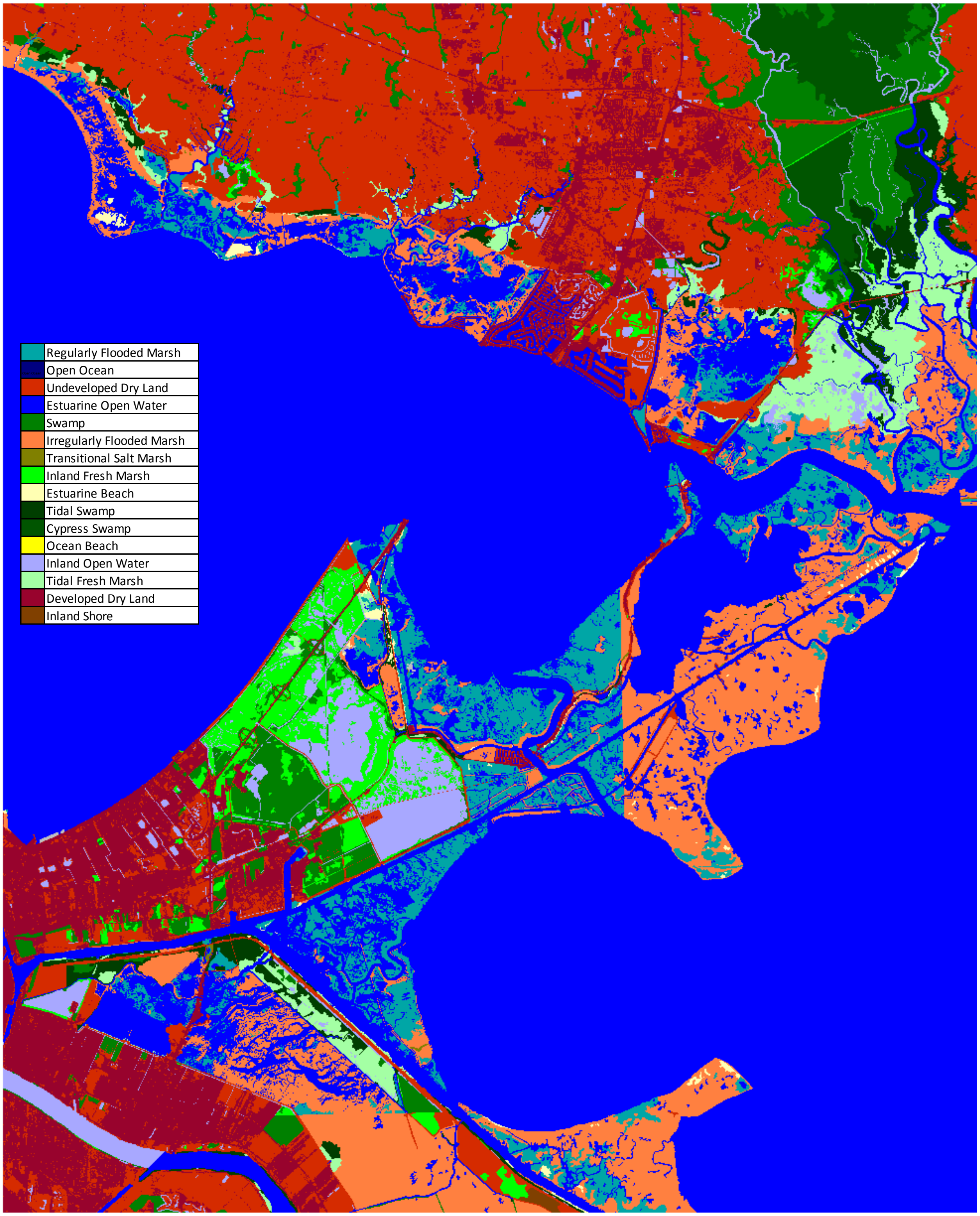
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

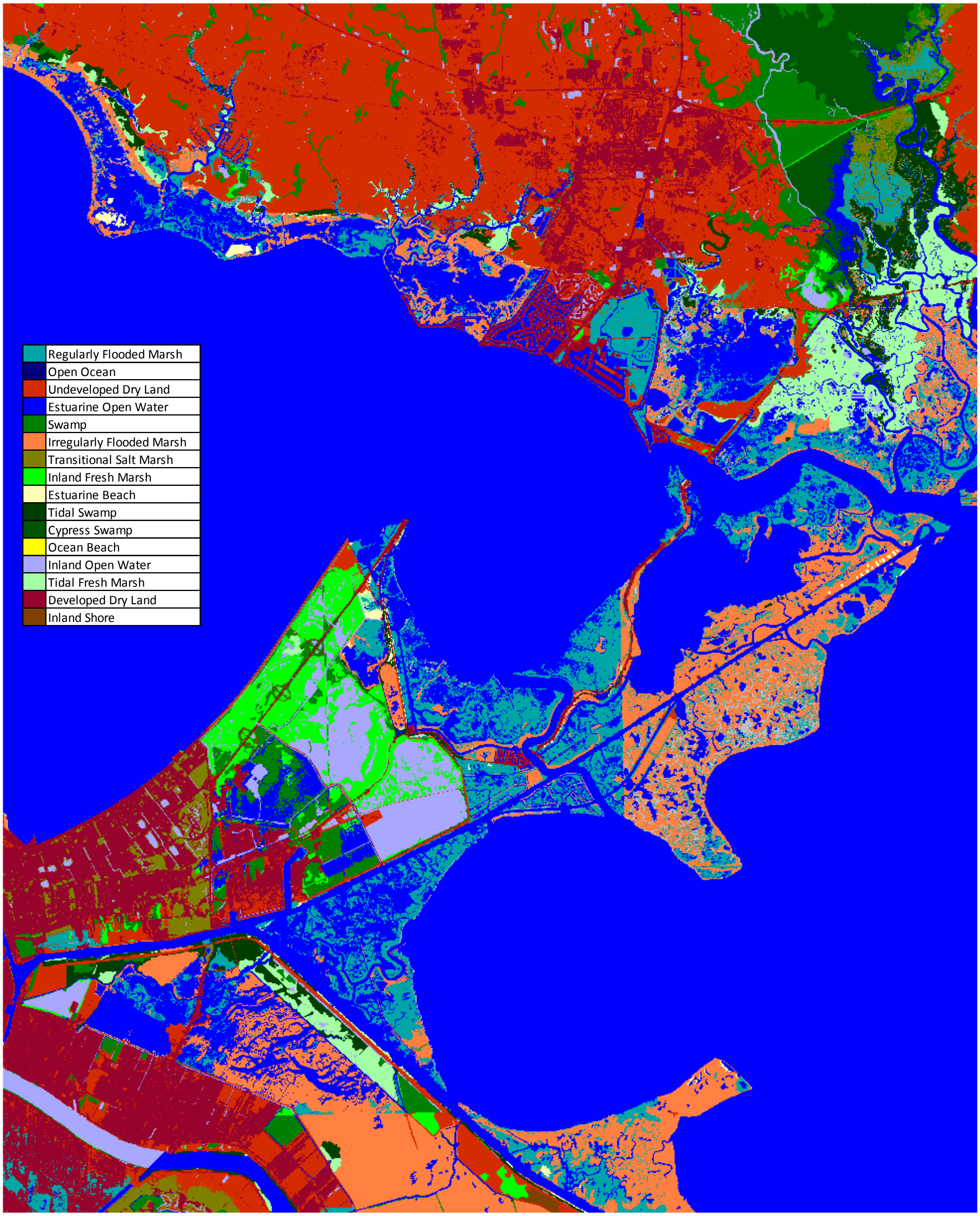
- Results were closely examined within USFWS refuges but not as closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to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

Bayou Sauvage National Wildlife Refuge (outlined in black) within simulation context.

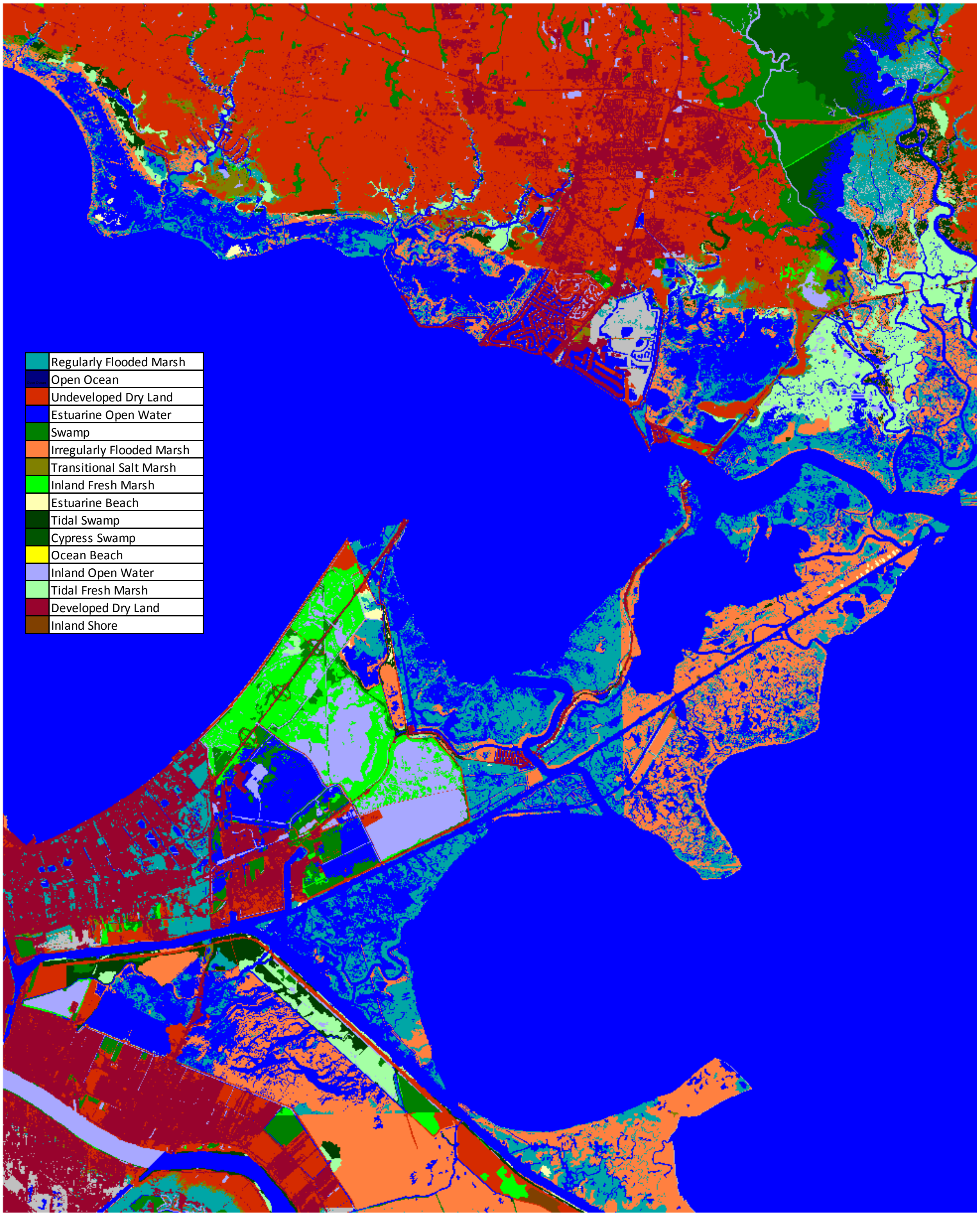




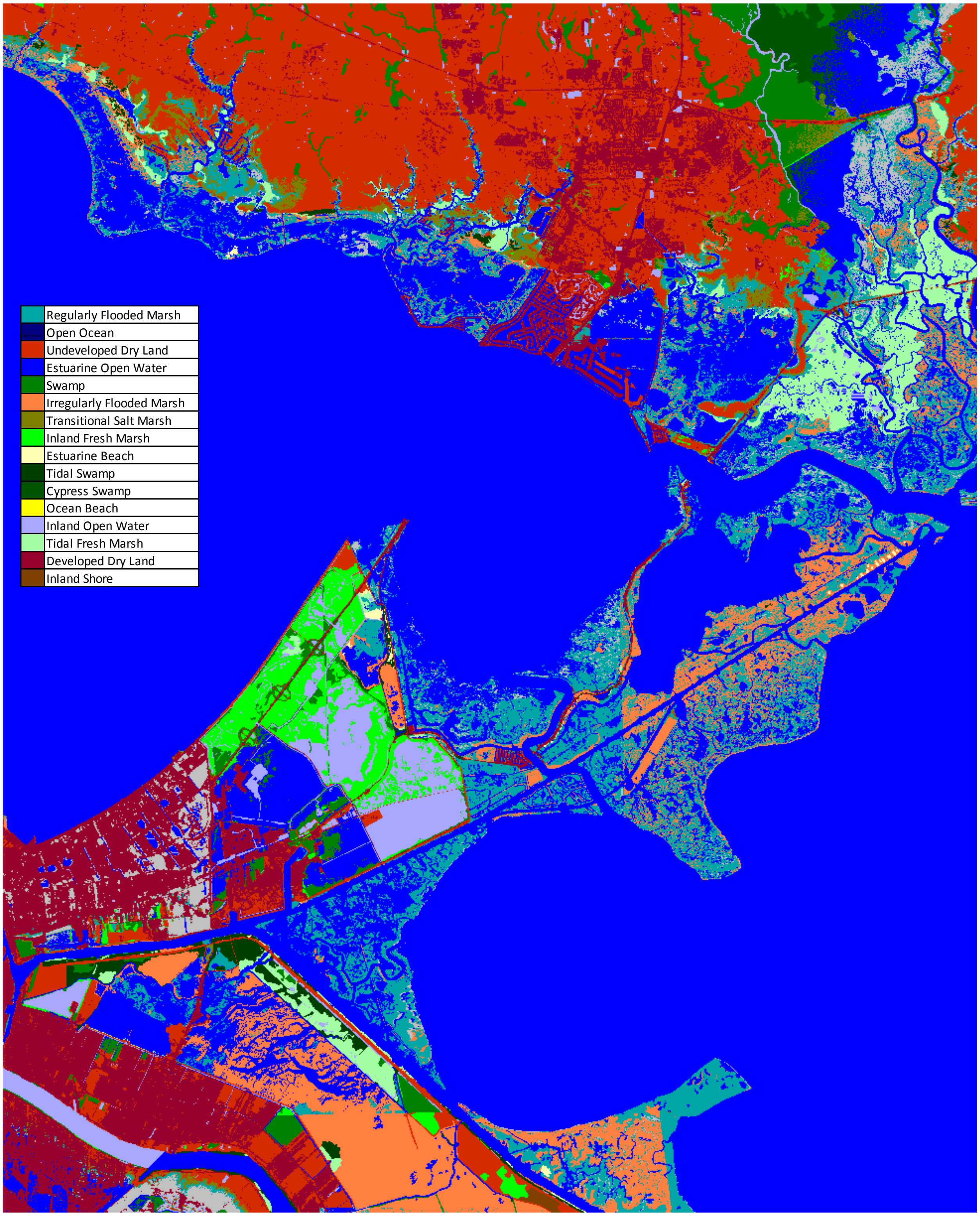
Bayou Sauvage NWR, Initial Condition



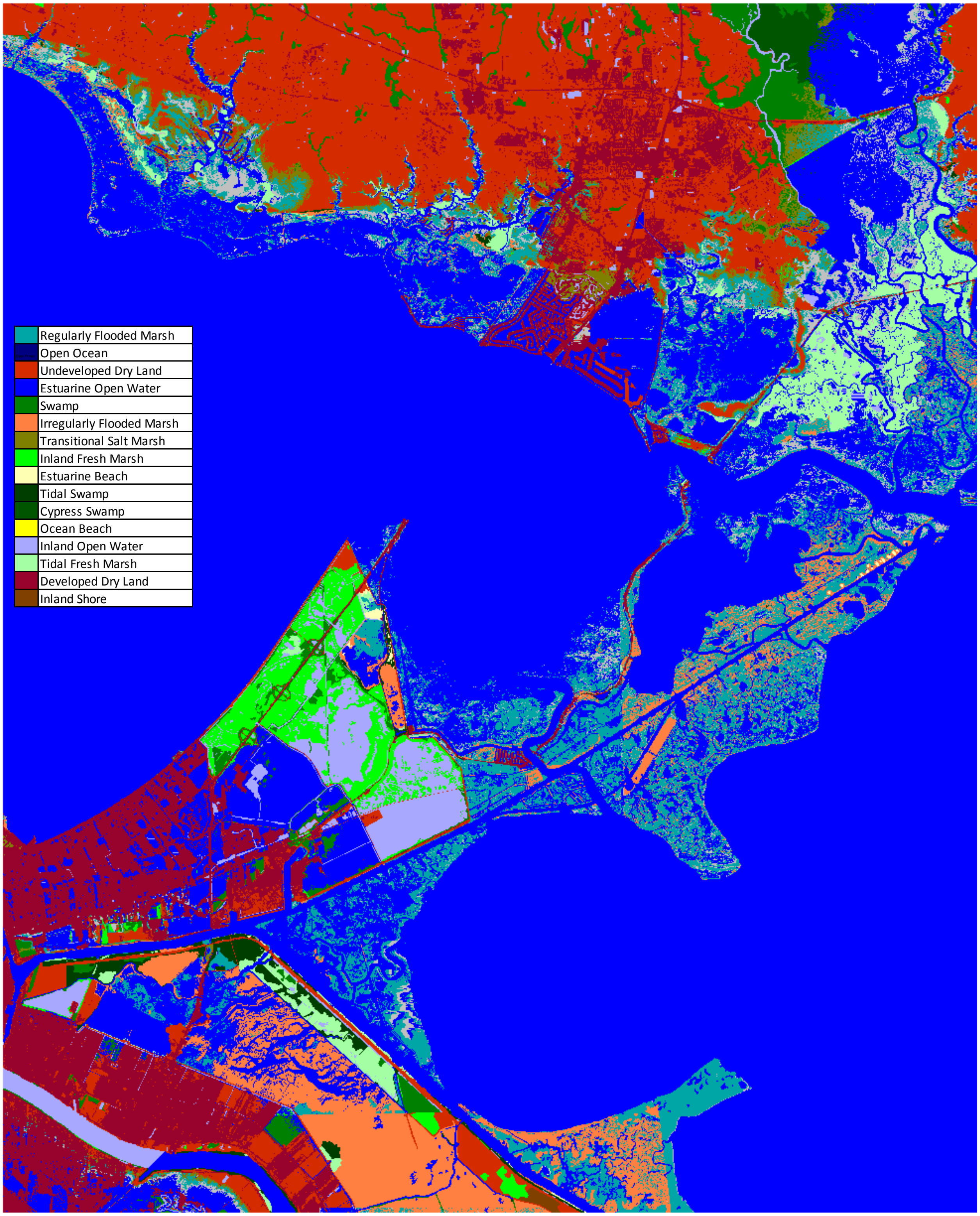
Bayou Sauvage NWR, 2025, Scenario A1B Mean, 0.39 m SLR



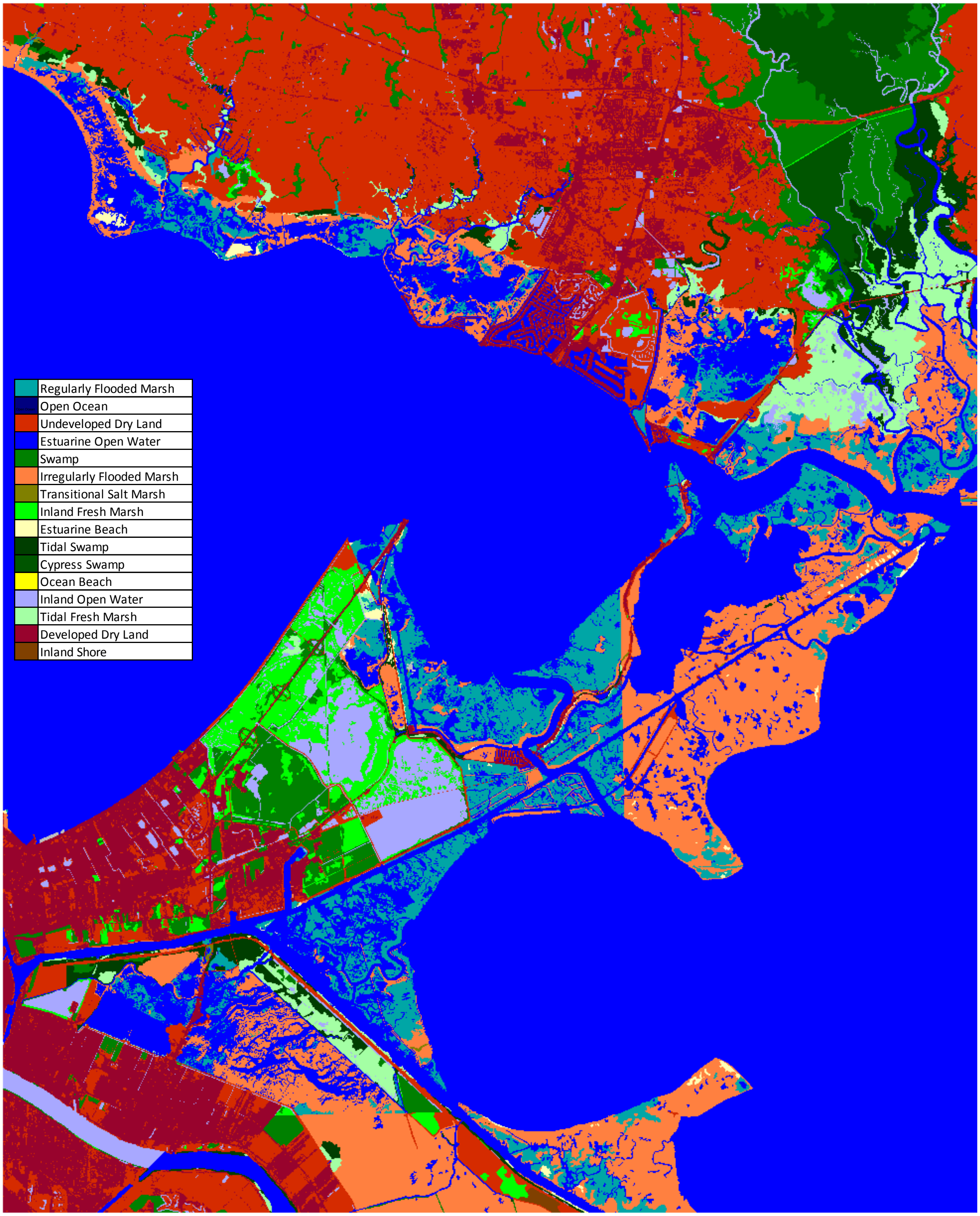
Bayou Sauvage NWR, 2050, Scenario A1B Mean, 0.39 m SLR



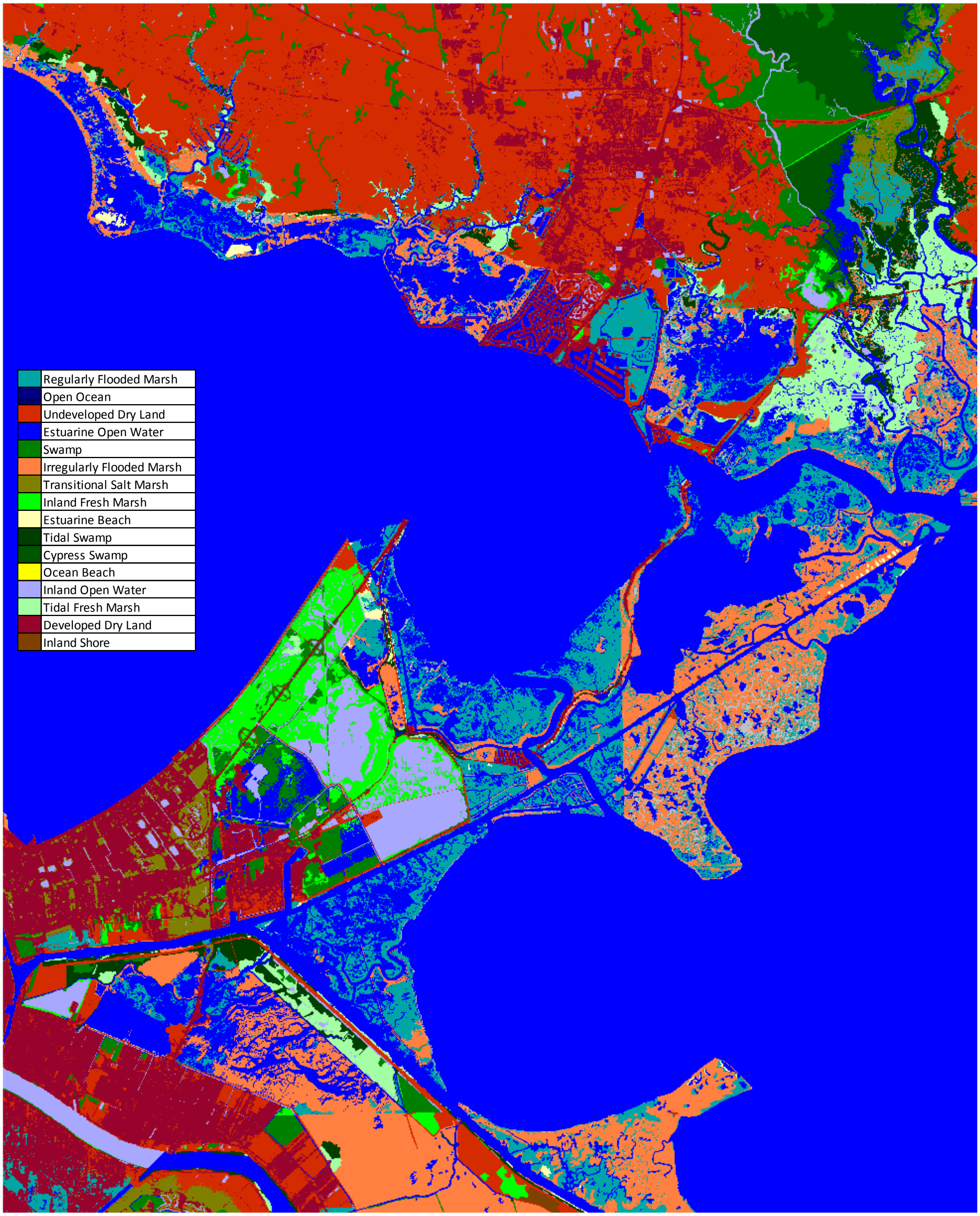
Bayou Sauvage NWR, 2075, Scenario A1B Mean, 0.39 m SLR



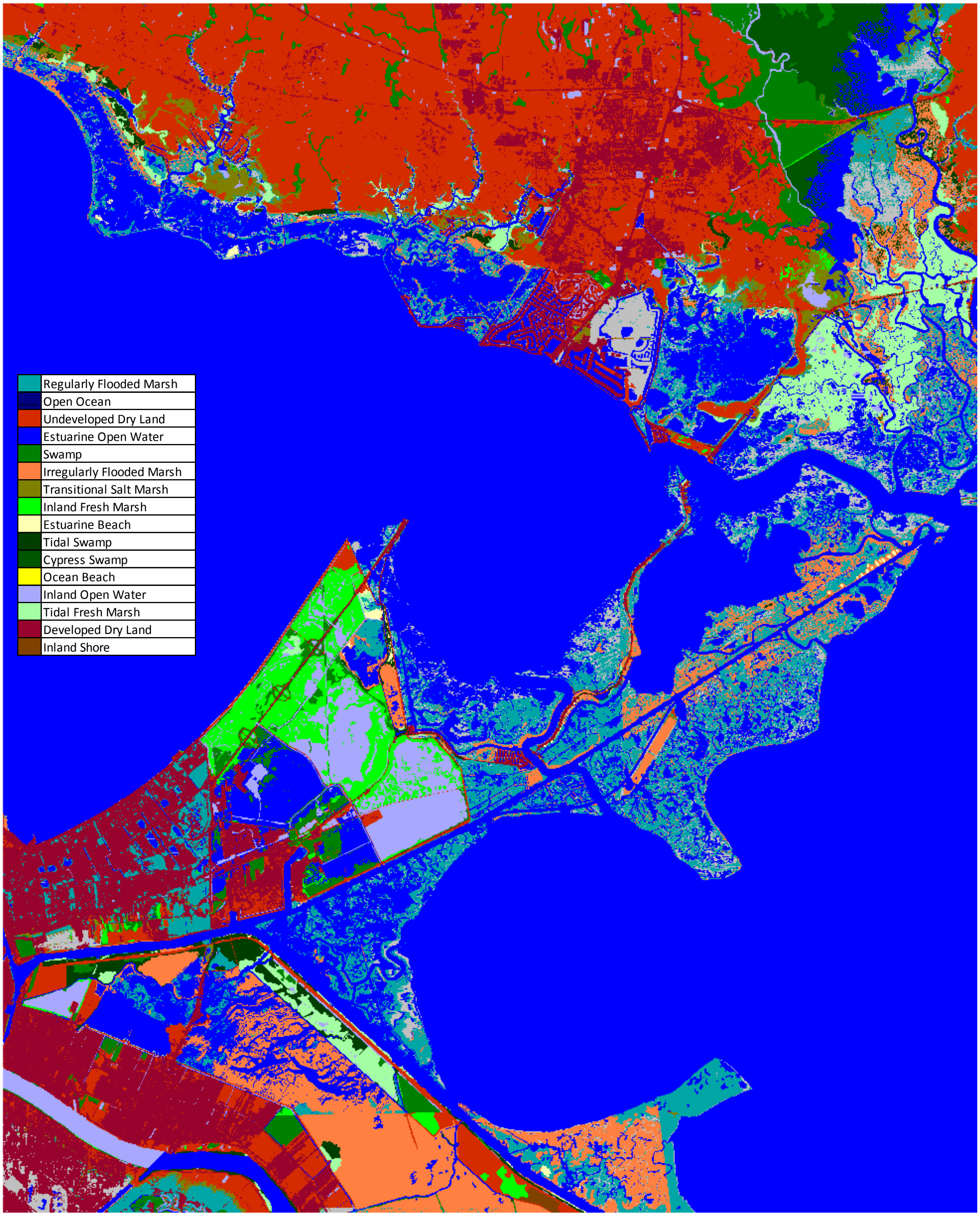
Bayou Sauvage NWR, 2100, Scenario A1B Mean, 0.39 m SLR



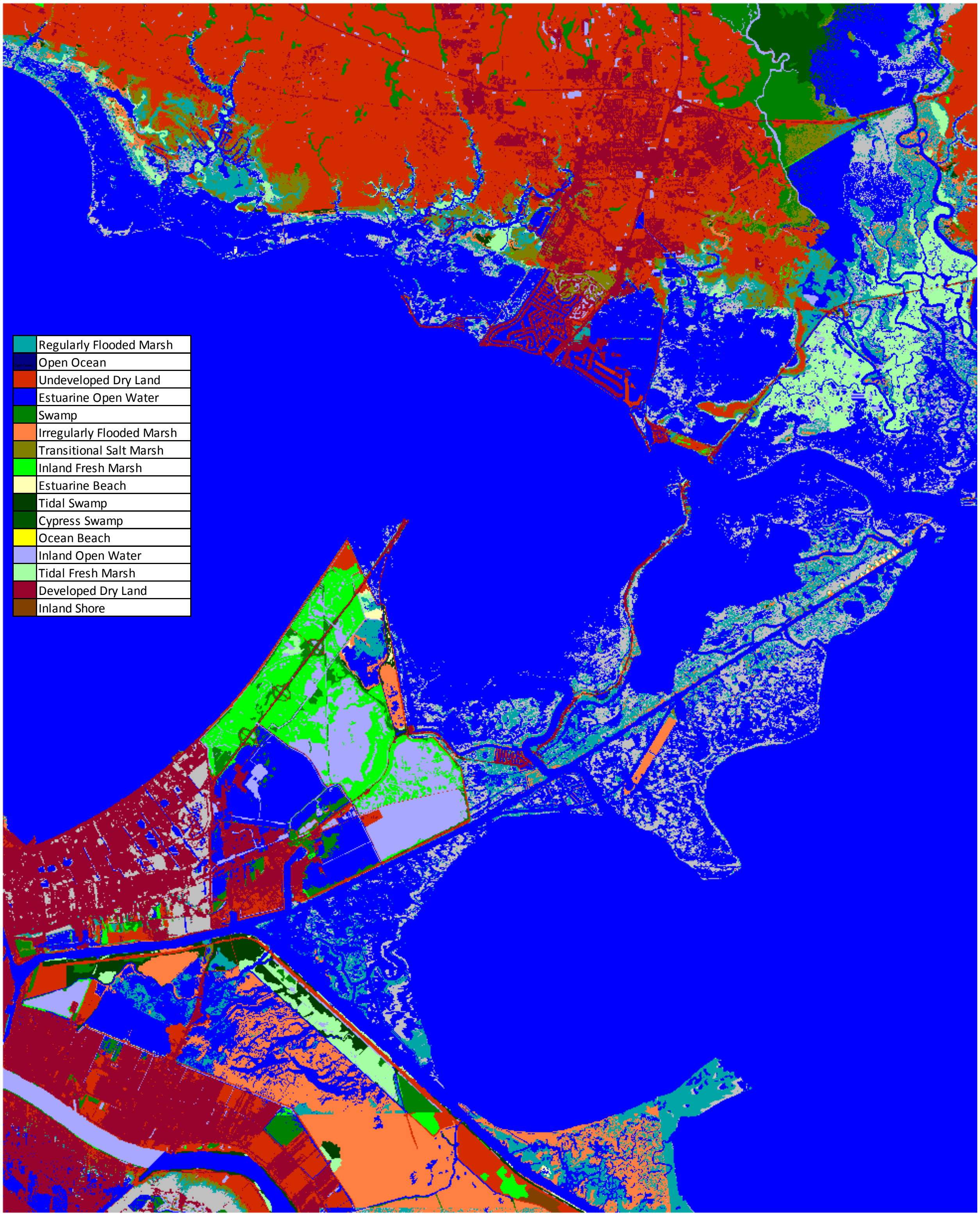
Bayou Sauvage NWR, Initial Condition



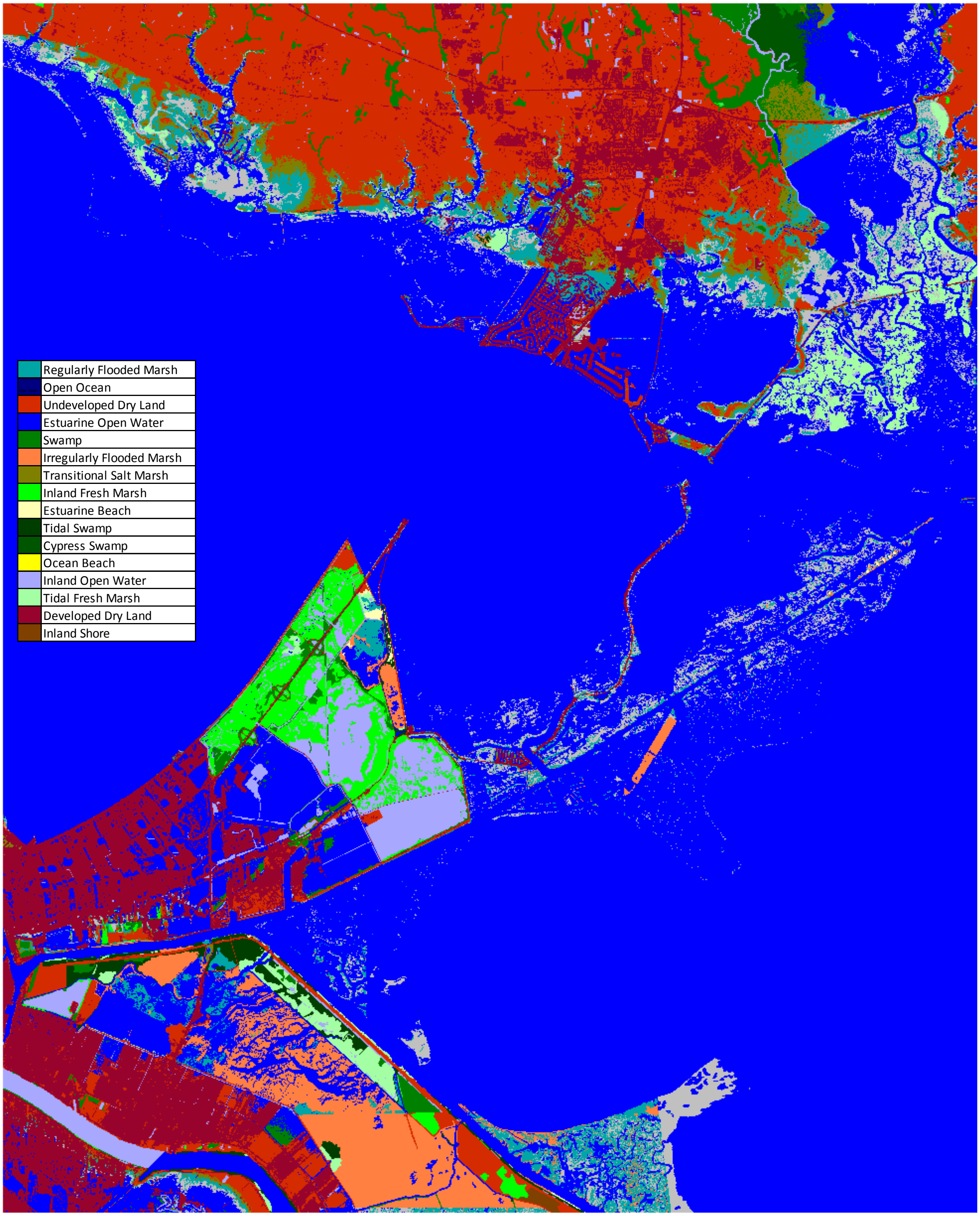
Bayou Sauvage NWR, 2025, Scenario A1B Maximum, 0.69 m SLR



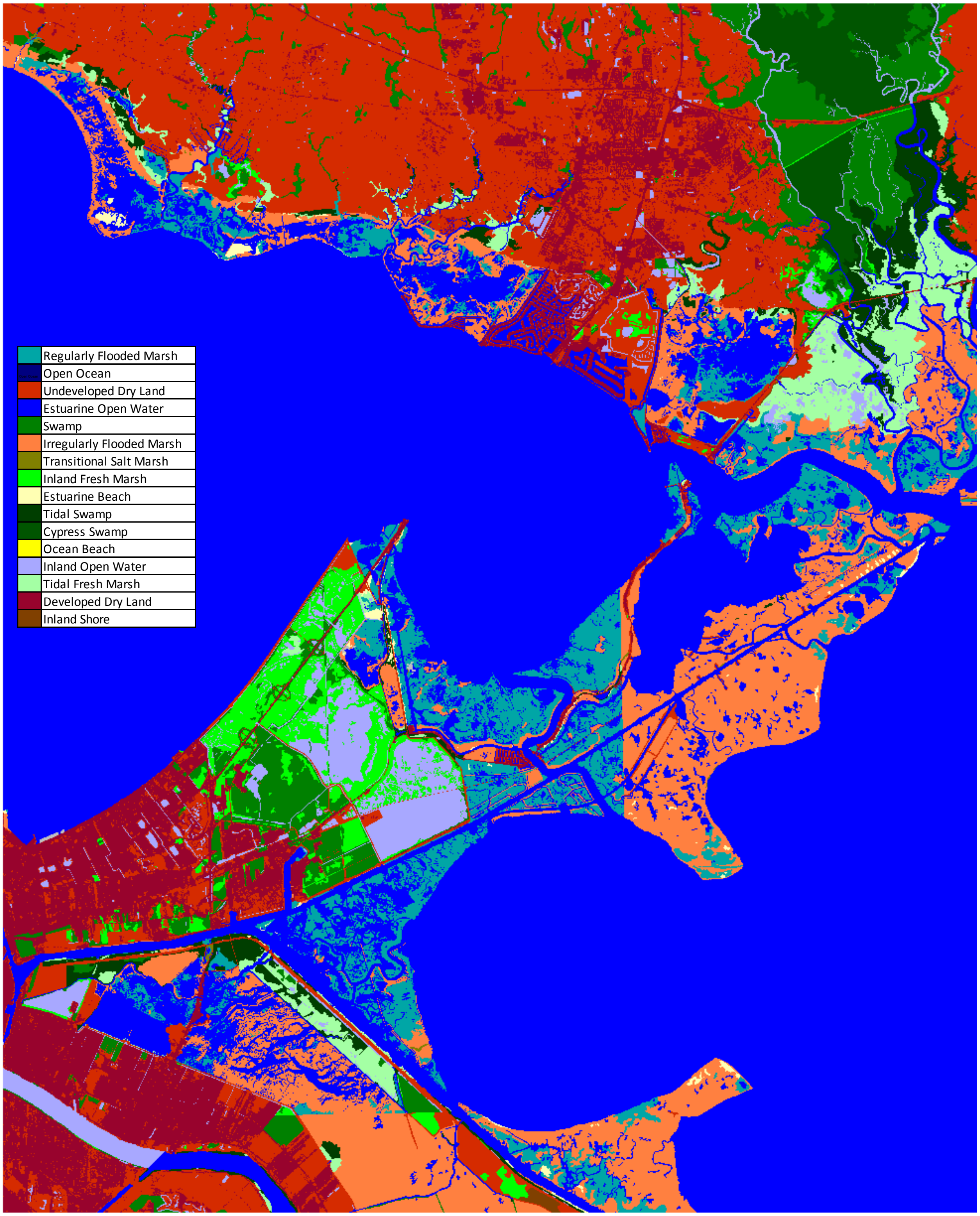
Bayou Sauvage NWR, 2050, Scenario A1B Maximum, 0.69 m SLR



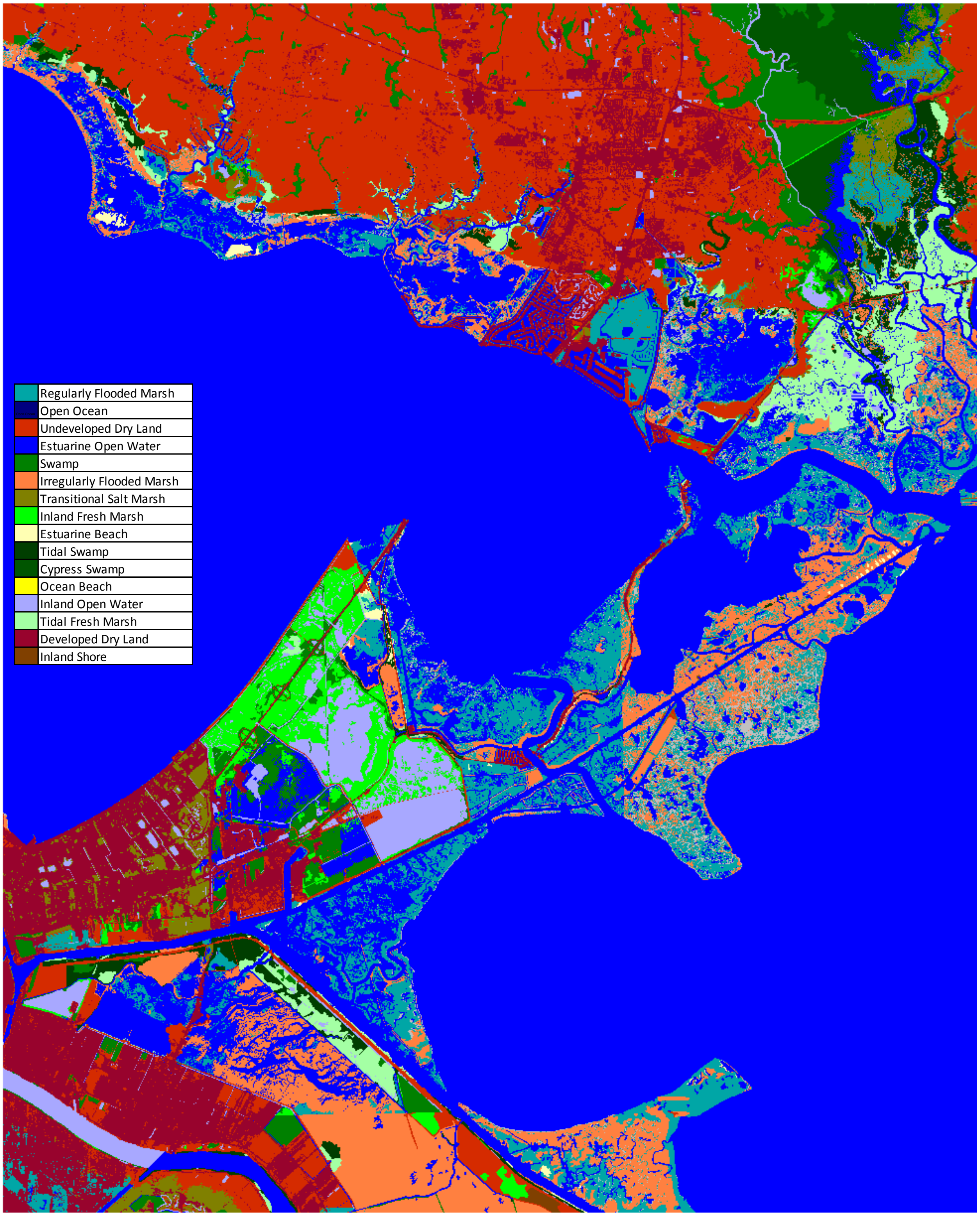
Bayou Sauvage NWR, 2075, Scenario A1B Maximum, 0.69 m SLR



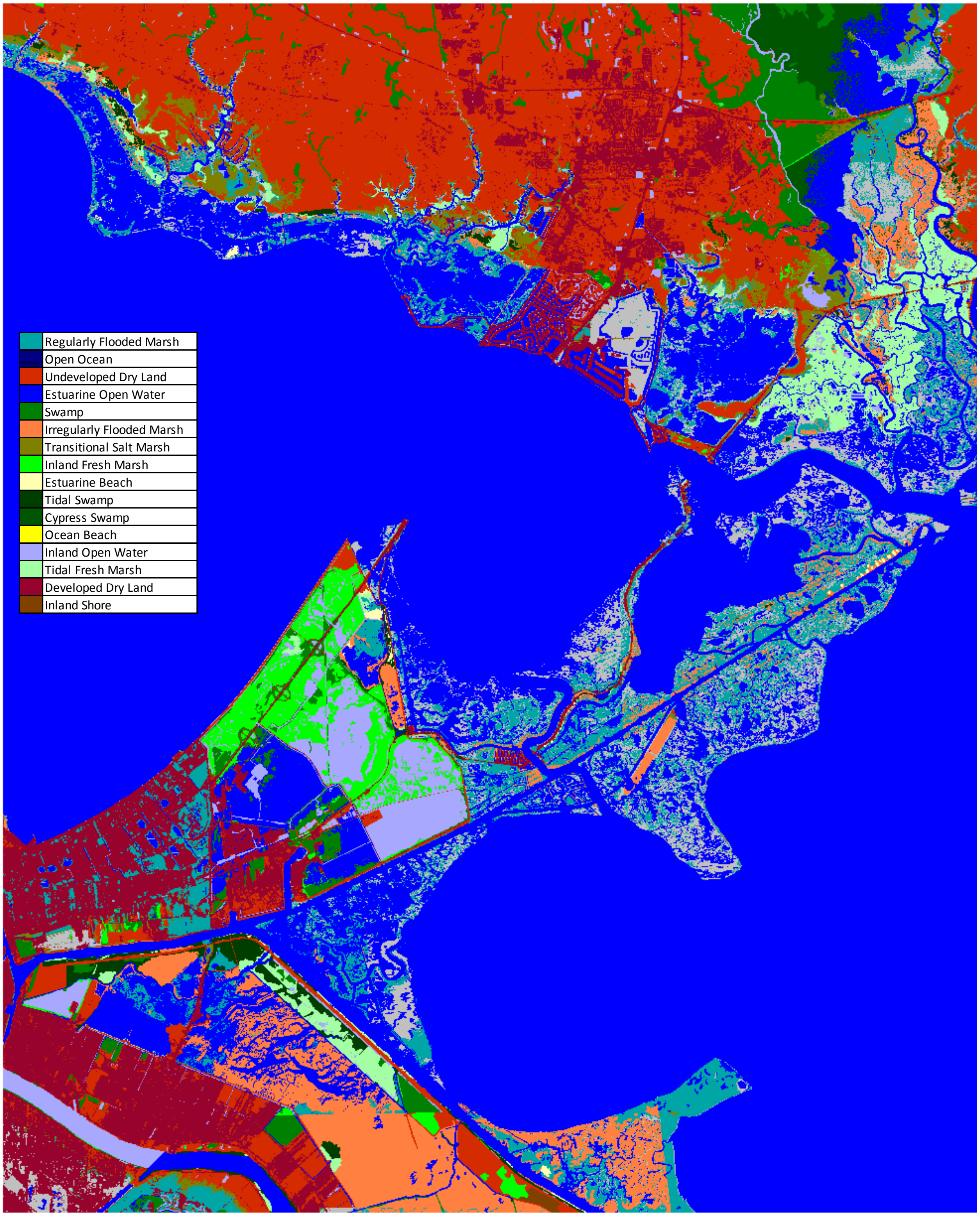
Bayou Sauvage NWR, 2100, Scenario A1B Maximum, 0.69 m SLR



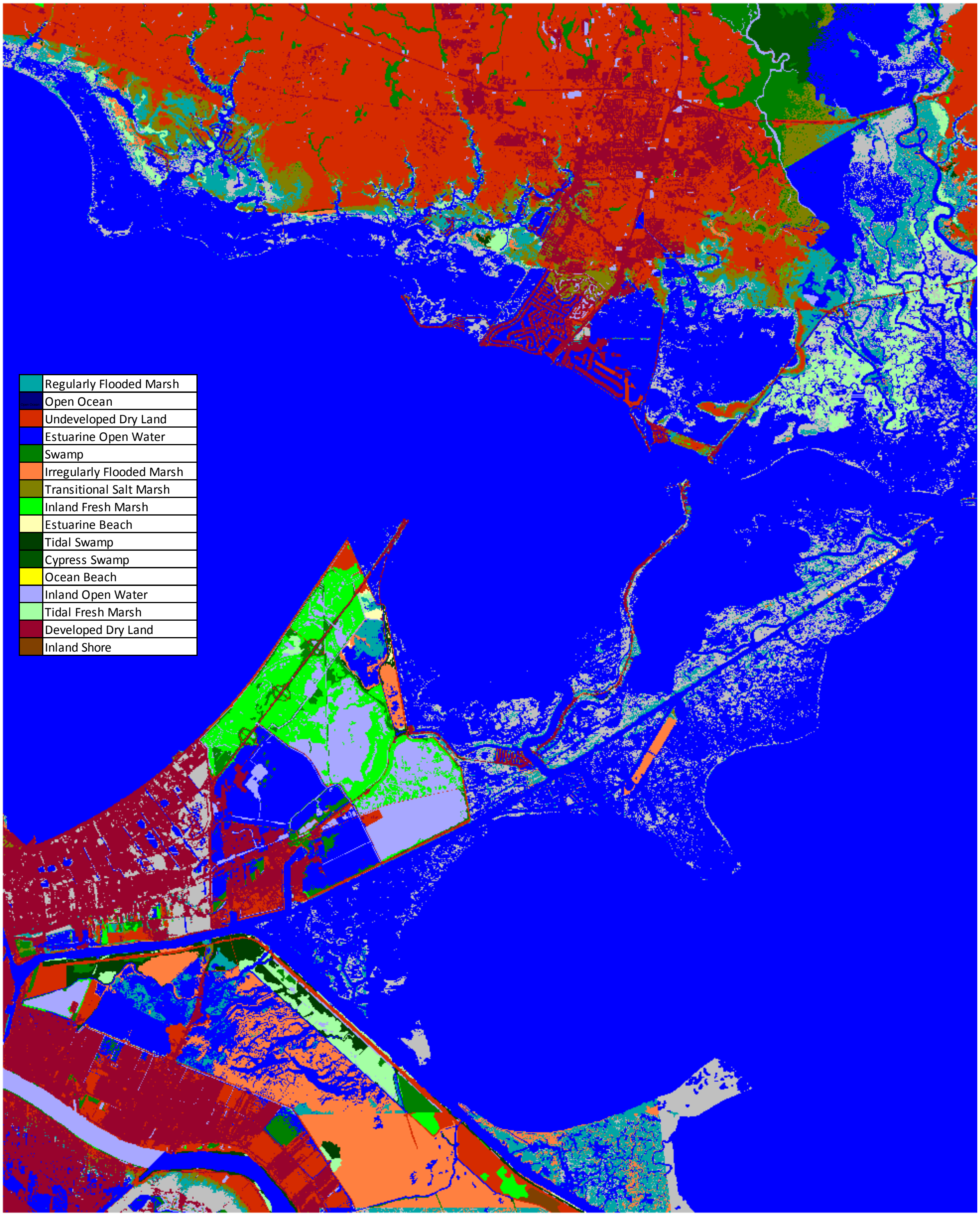
Bayou Sauvage NWR, Initial Condition



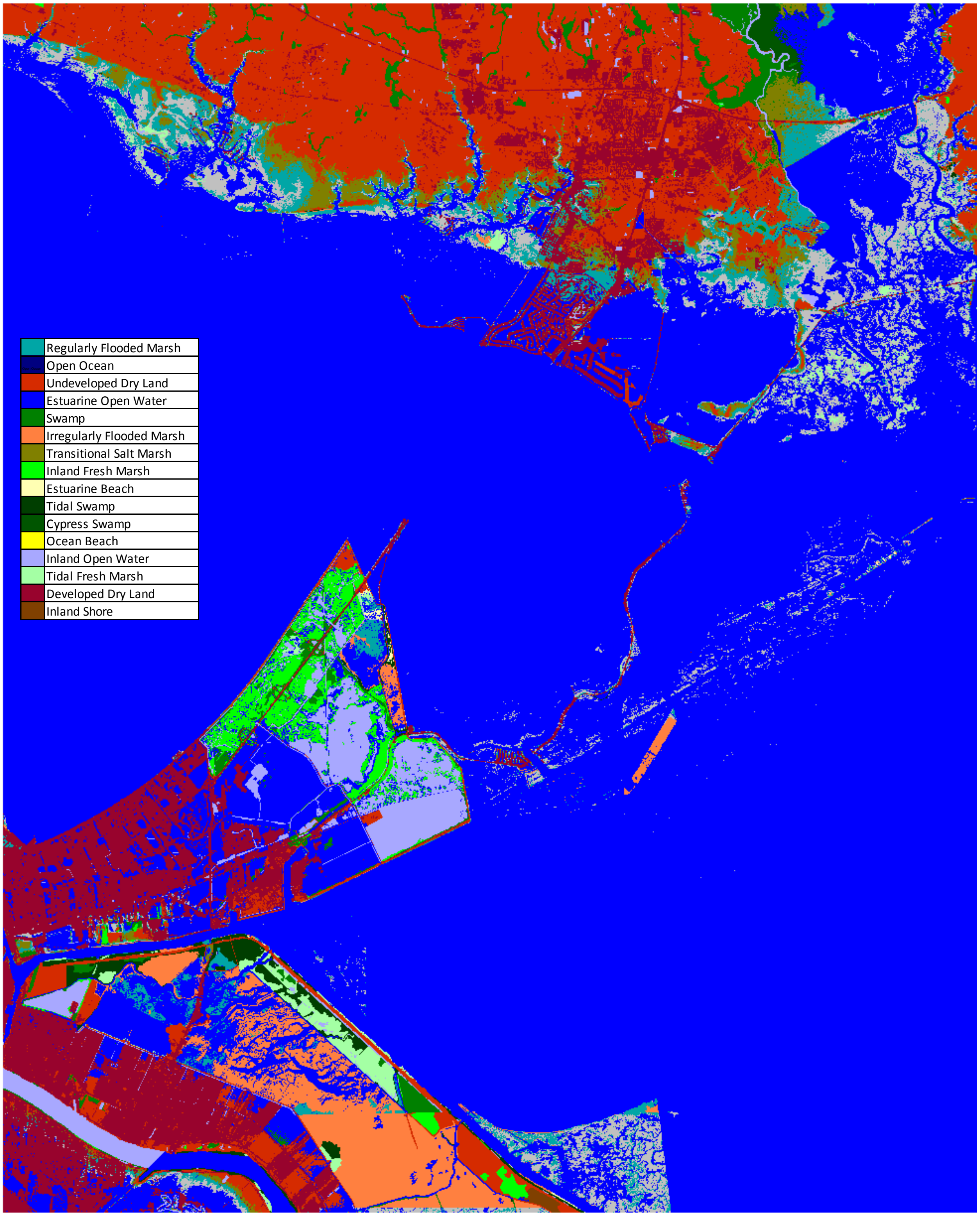
Bayou Sauvage NWR, 2025, 1 m SLR



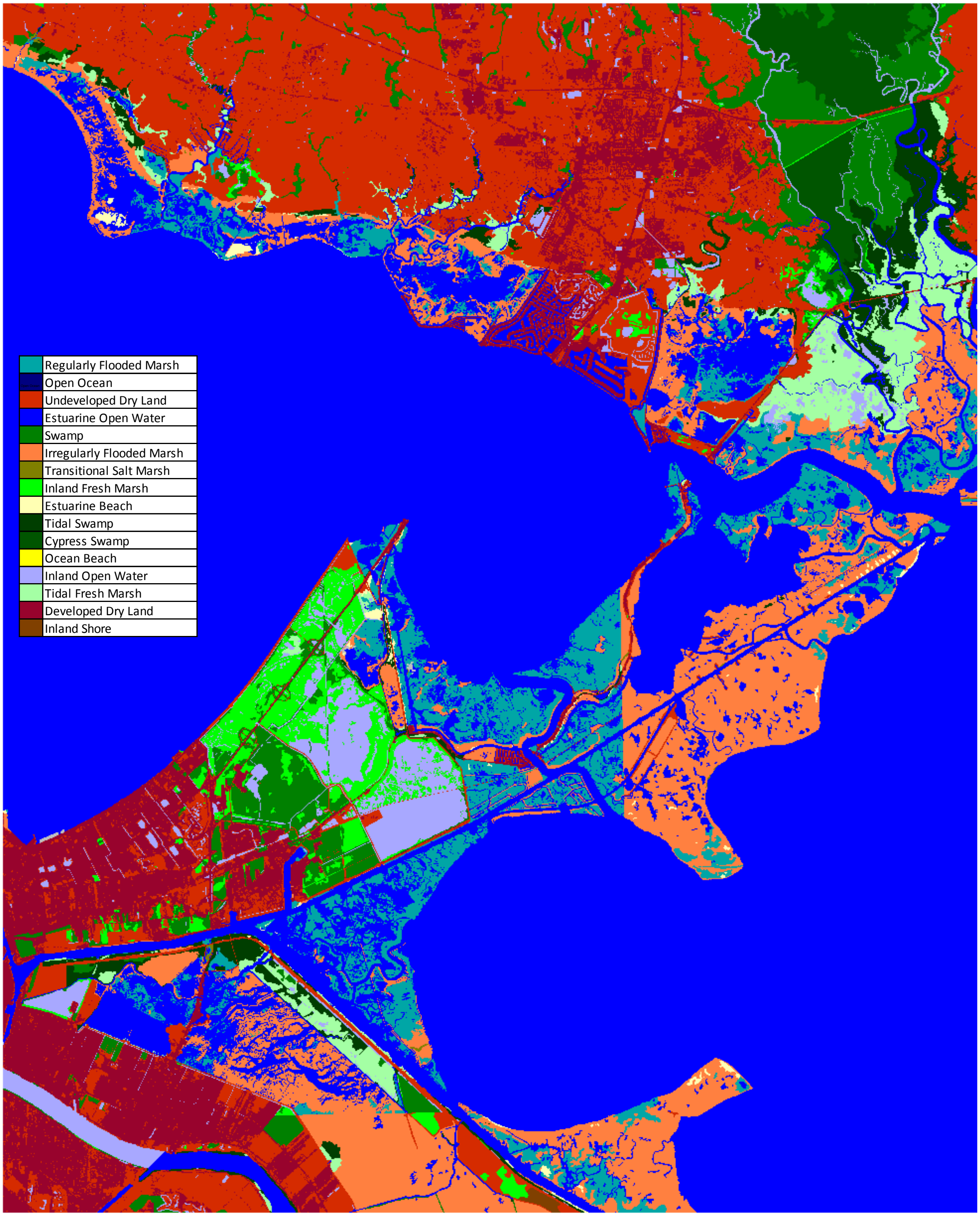
Bayou Sauvage NWR, 2050, 1 m SLR



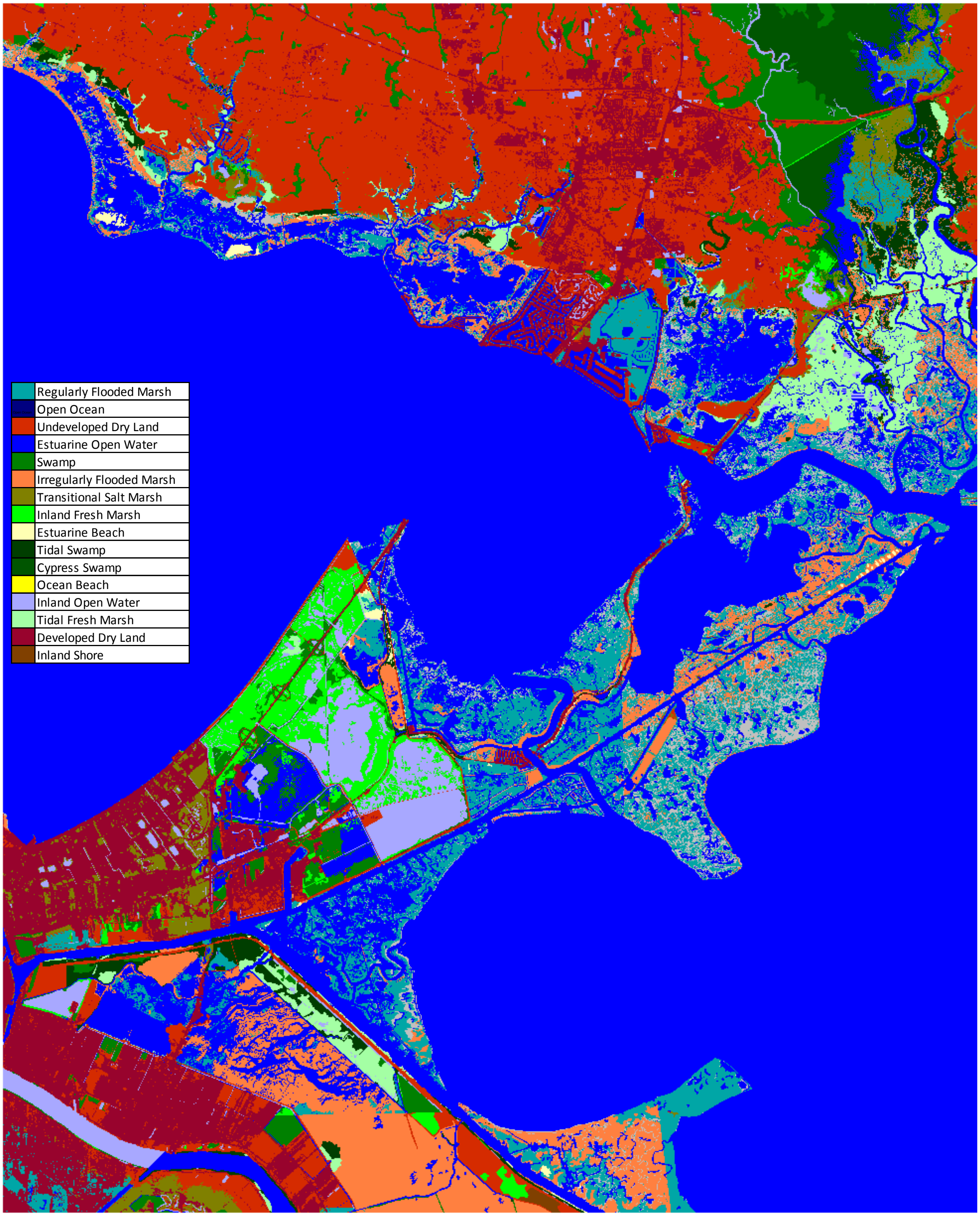
Bayou Sauvage NWR, 2075, 1 meter



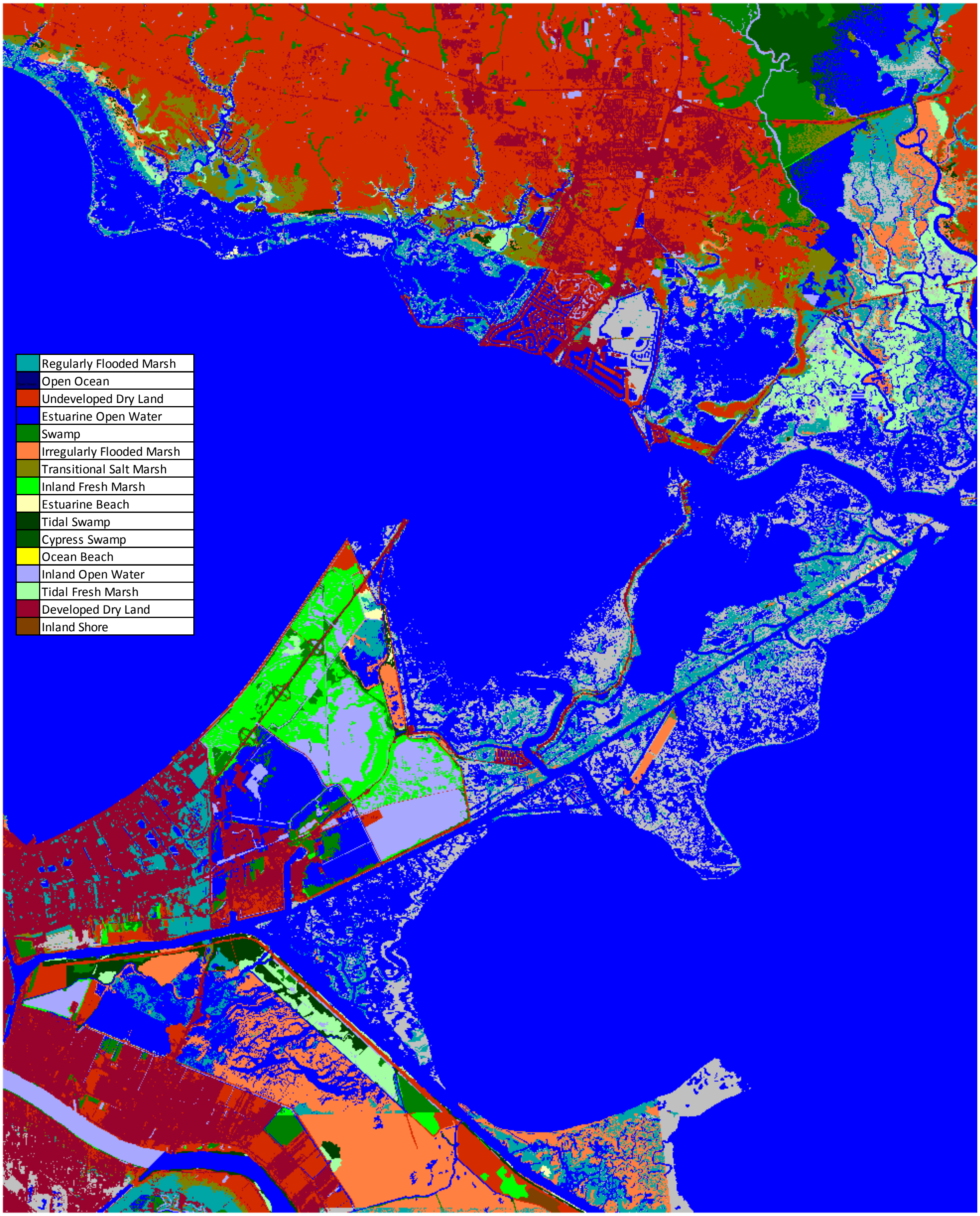
Bayou Sauvage NWR, 2100, 1 m SLR



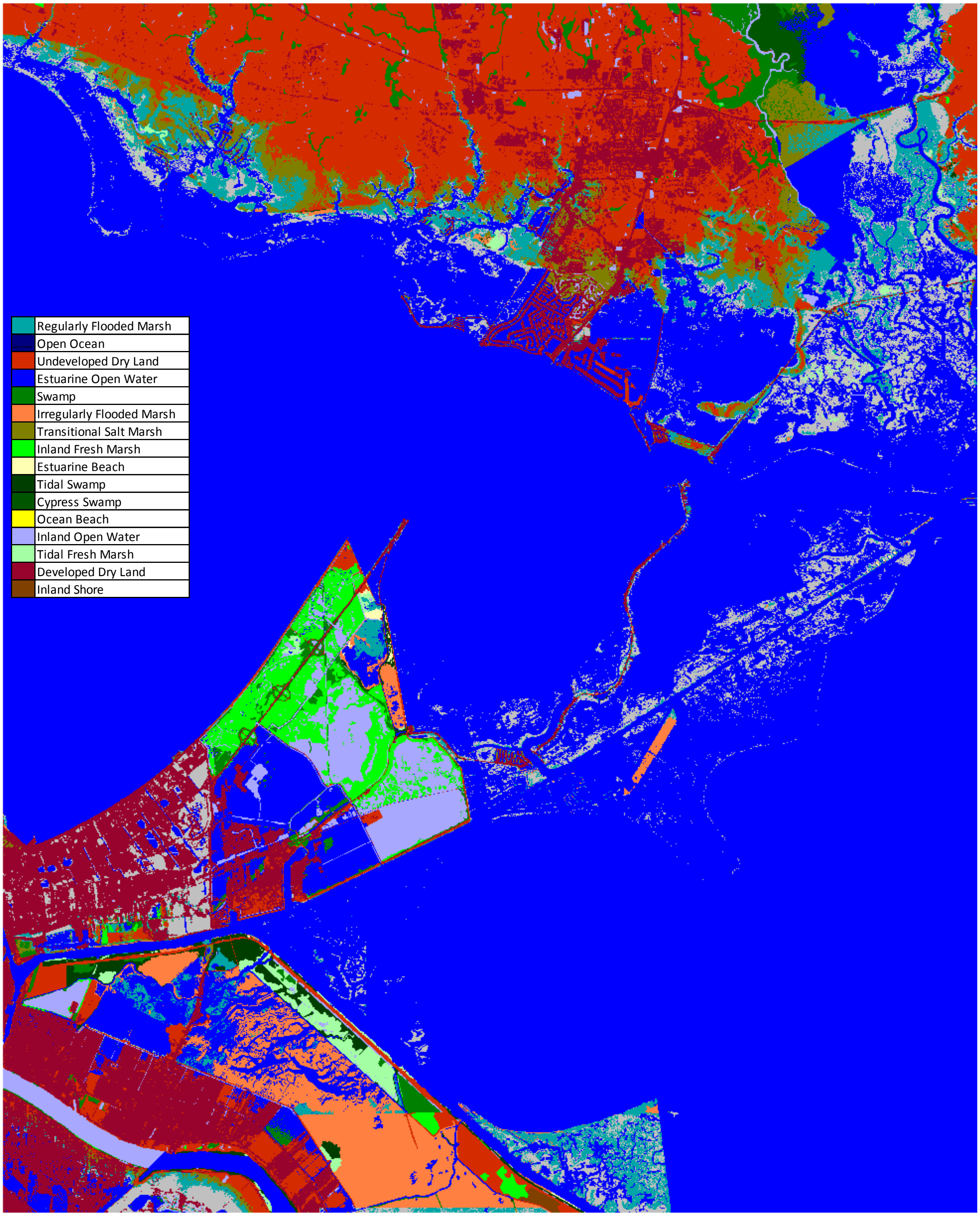
Bayou Sauvage NWR, Initial Condition



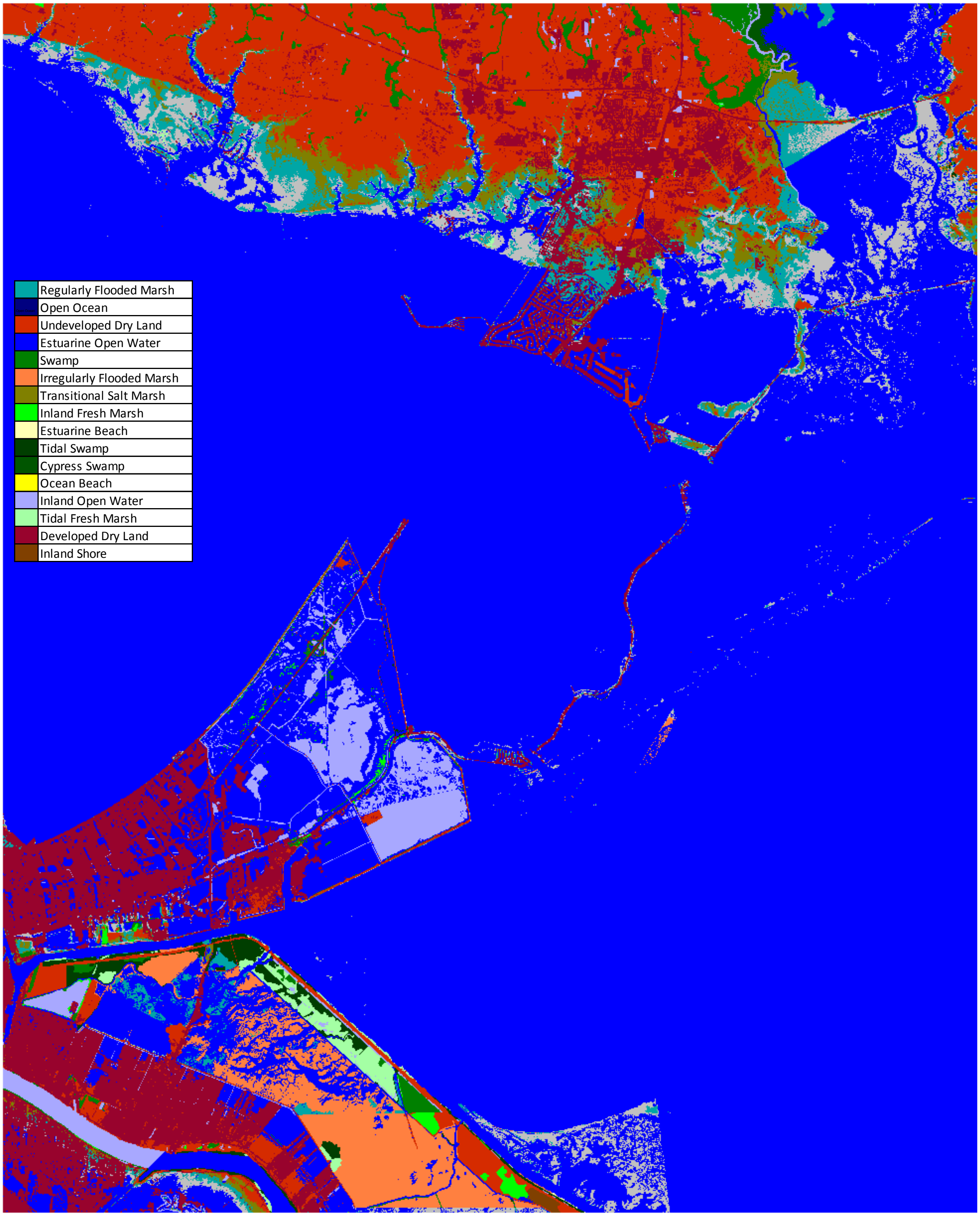
Bayou Sauvage NWR, 2025, 1.5 m SLR



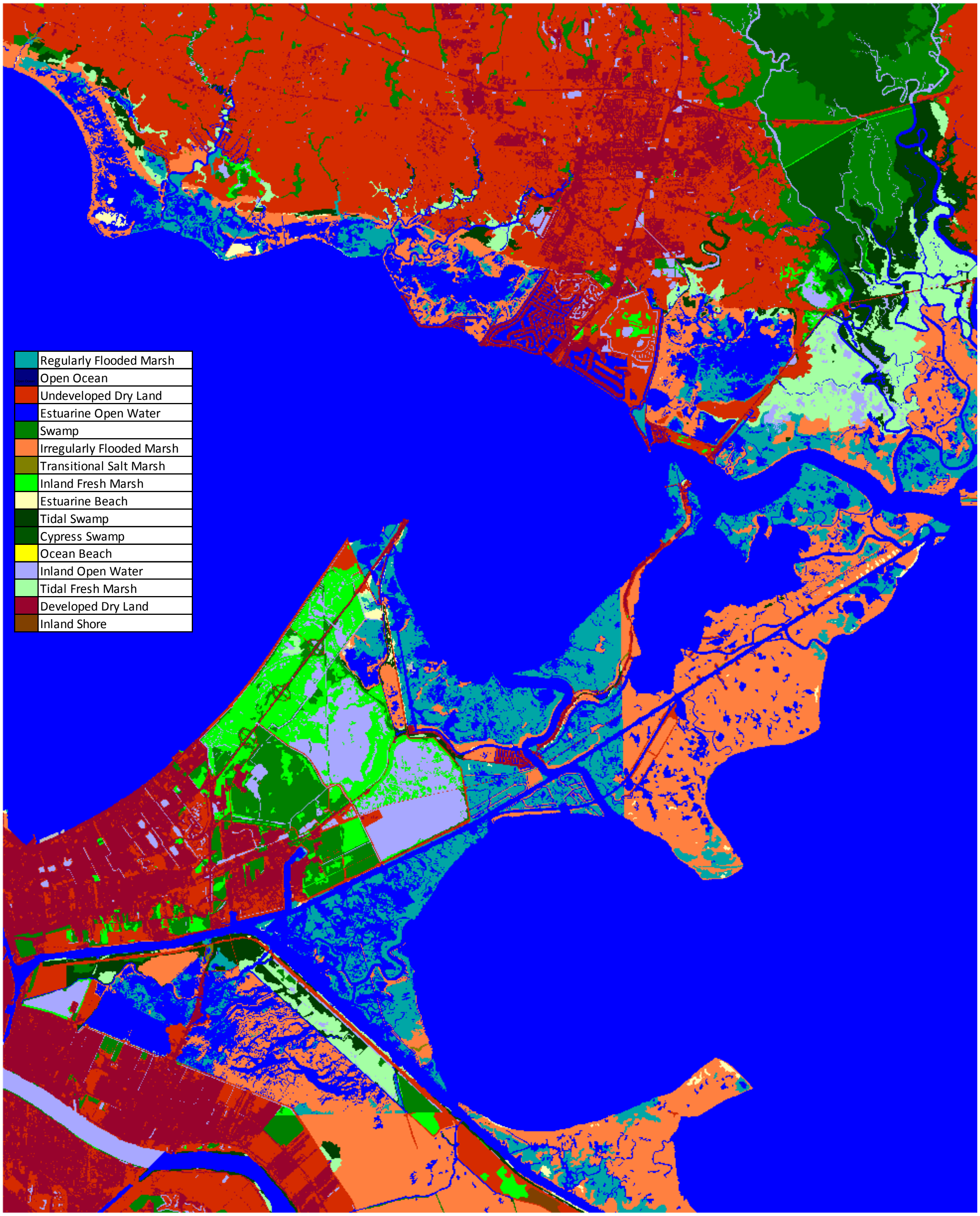
Bayou Sauvage NWR, 2050, 1.5 m SLR



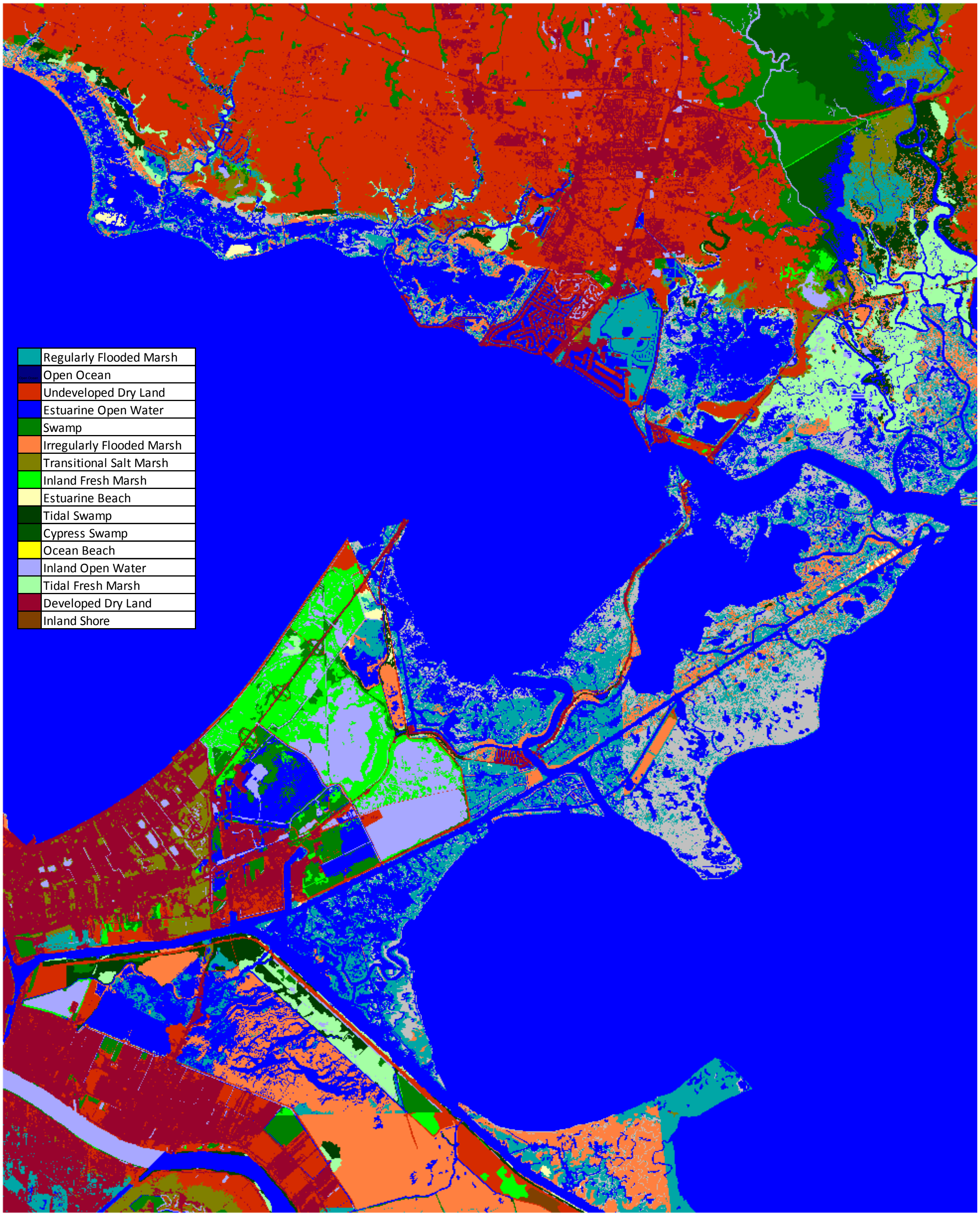
Bayou Sauvage NWR, 2075, 1.5 m SLR



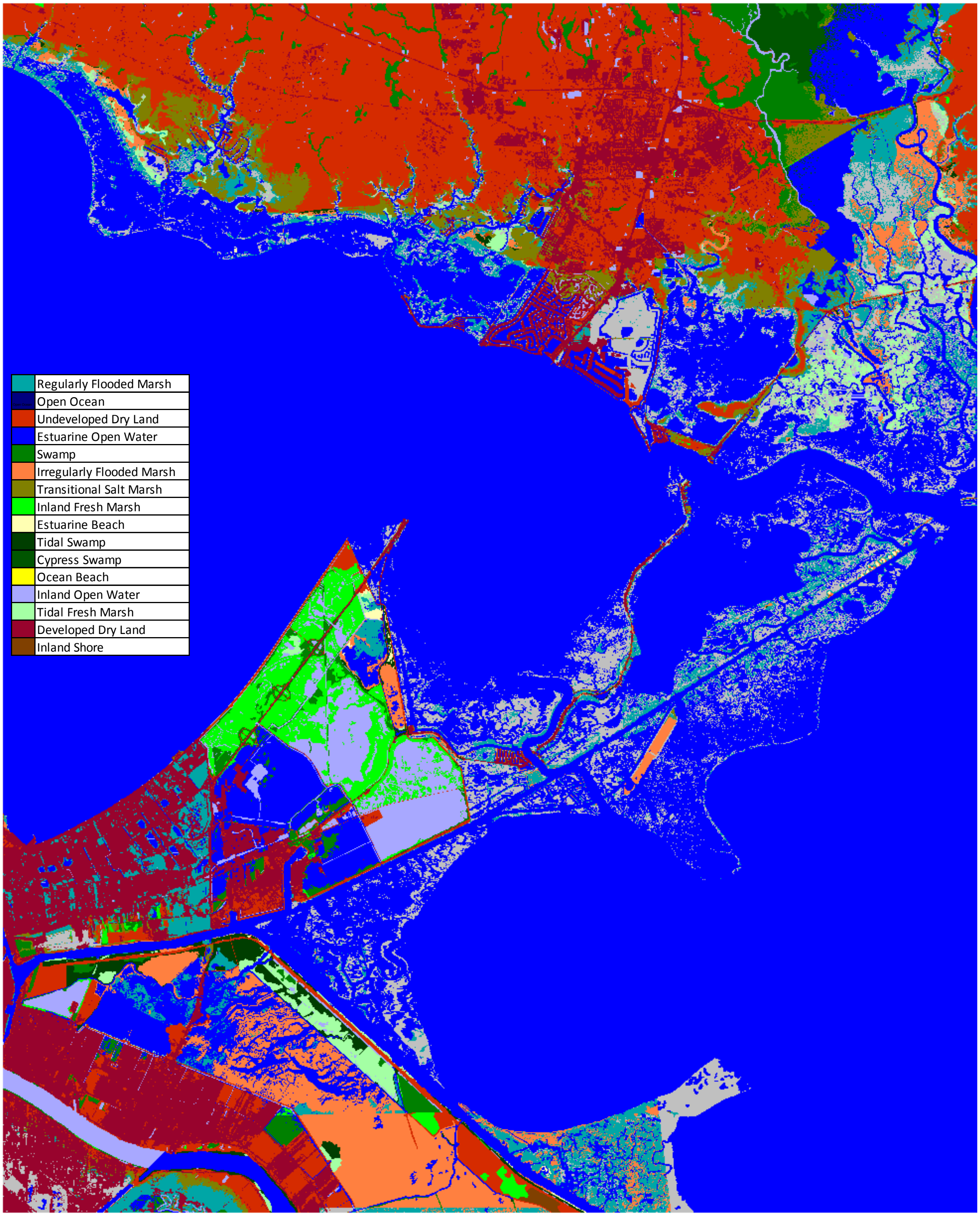
Bayou Sauvage NWR, 2100, 1.5 m SLR



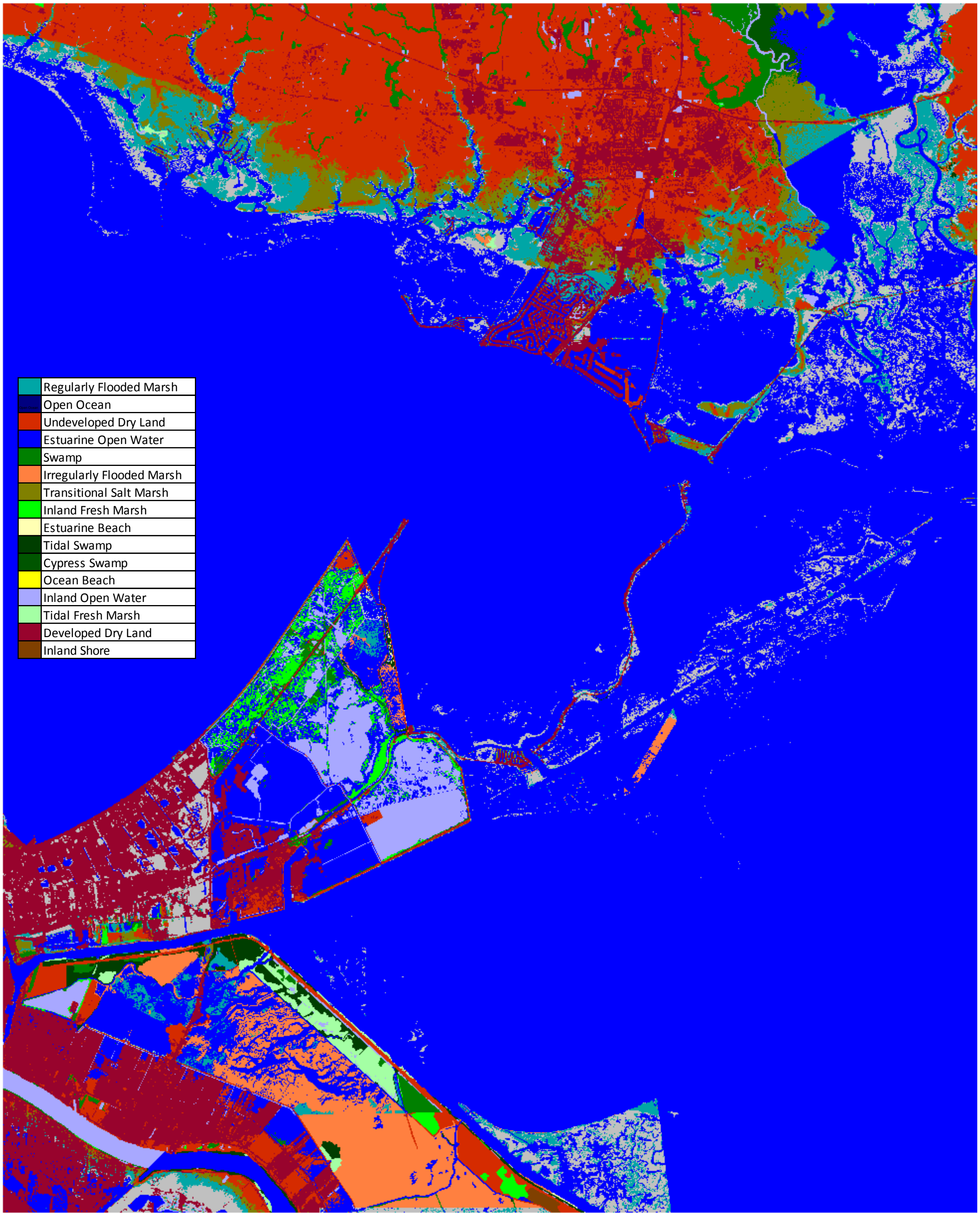
Bayou Sauvage NWR, Initial Condition



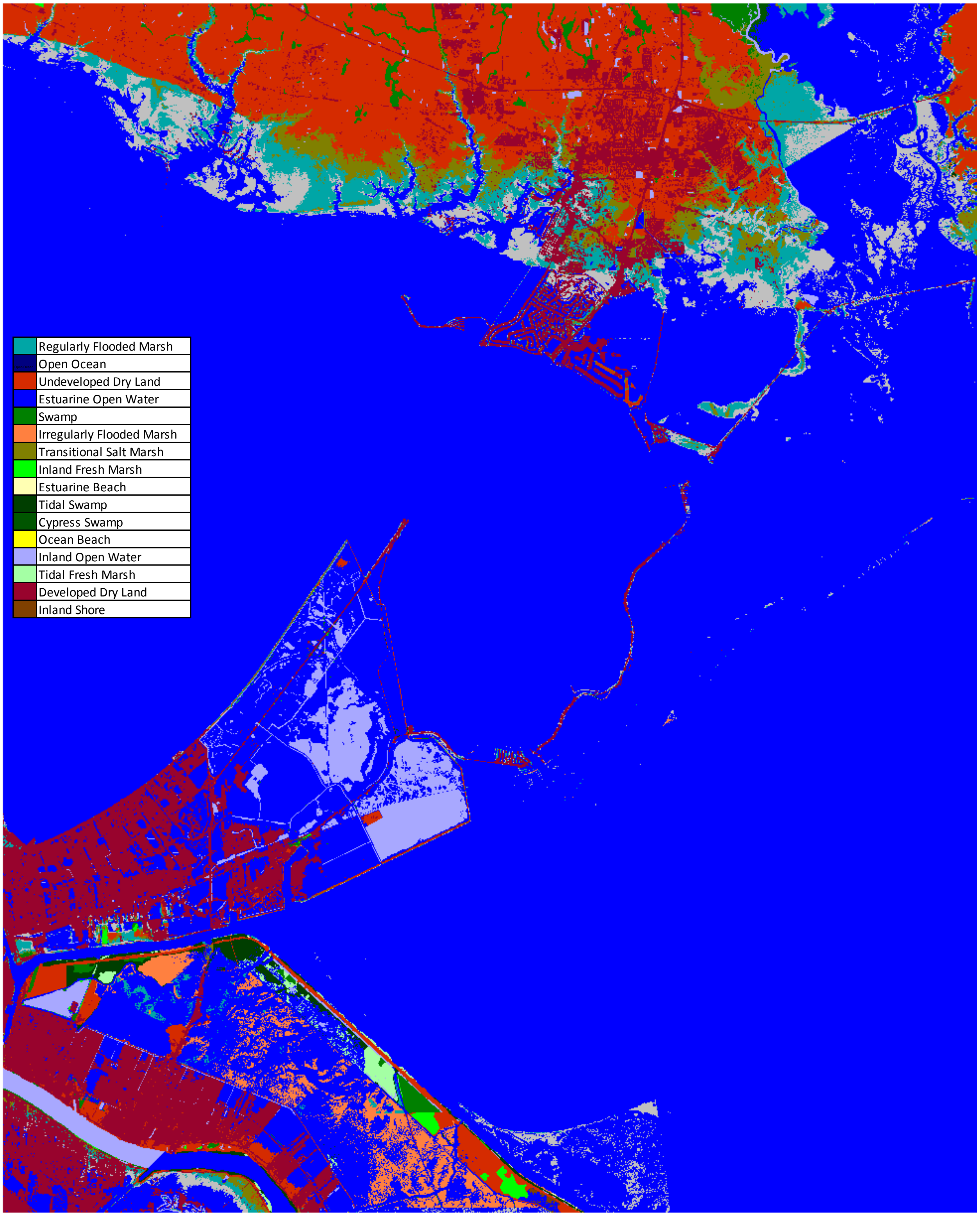
Bayou Sauvage NWR, 2025, 2 m SLR



Bayou Sauvage NWR, 2050, 2 m SLR



Bayou Sauvage NWR, 2075, 2 m SLR



Bayou Sauvage NWR, 2100, 2 m SLR