Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Big Branch Marsh 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.

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.

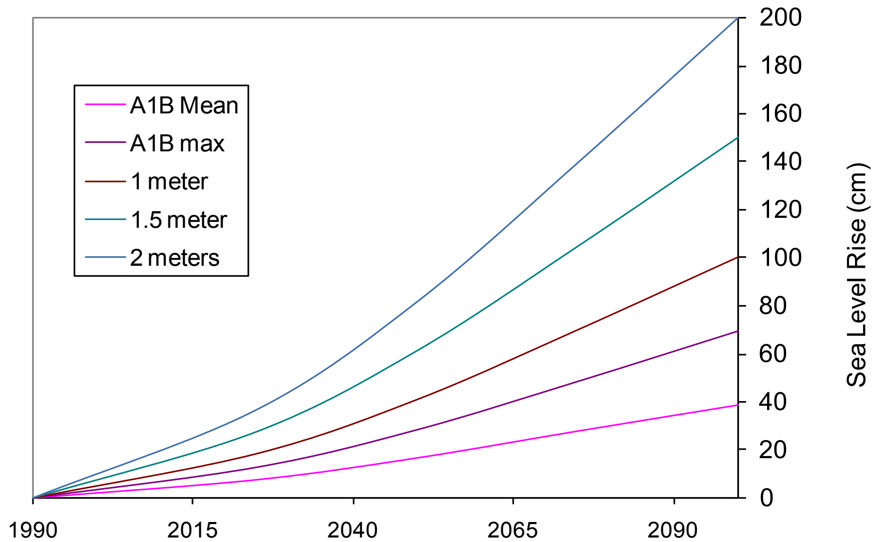


Figure 1. Summary of SLR scenarios utilized.

Data Sources and Methods

Elevation Data. The refuge area covered US Army Corps of Engineers LiDAR data collected in 2009 and 2006 NED LiDAR. However, parts of the surrounding area (outside of the study area) did not have LiDAR data. For these areas elevations were assigned based on contour maps of the National Elevation Database collected in 1999, 1998, as shown in Figure 2. In areas lacking LiDAR data (outside the primary study area) the elevation pre-processor module of SLAMM was then used to assign elevations for wetlands as a function of the local tide range.

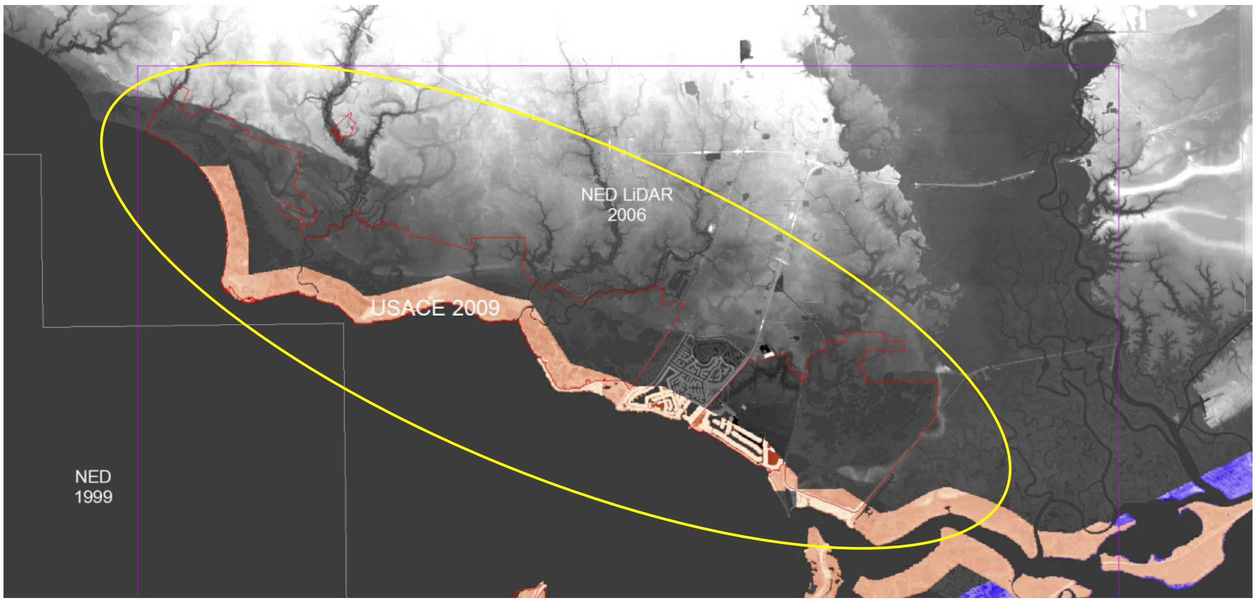


Figure 2. Location of LiDAR and NED-derived elevation data.
Approved acquisition boundaries shown in red.

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 28,000 acre Big Branch Marsh NWR (approved acquisition boundary including water) is composed of the categories presented in Table 3. Since this wetland layer was created, additional dredge material placement has occurred within the refuge in Goose Point/Point Platte CWPPRA Unit E, which is not fully included in the wetland layer used.

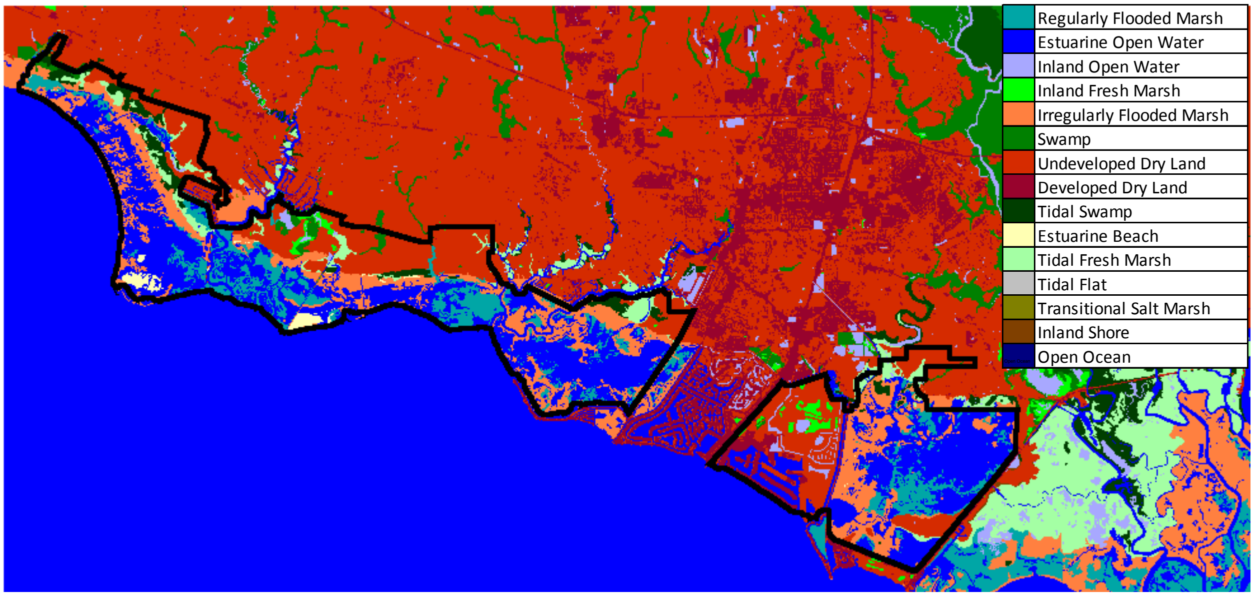


Figure 3. 2009 NWI coverage of the study area. Refuge boundaries are indicated in black.

Table 1. Wetland categories and distribution in Big Branch Marsh NWR.

Land cover type	Area (acres)	Percentage (%)
Estuarine Open Water	9,587	34
Undeveloped Dry Land	6,260	22
Irregularly Flooded Marsh	5,402	19
Regularly Flooded Marsh	3,187	11
Tidal Fresh Marsh	991	4
Tidal Swamp	797	3
Developed Dry Land	593	2
Inland Open Water	327	1
Swamp	316	1
Inland Fresh Marsh	312	1
Estuarine Beach	264	1
Riverine Tidal	38	< 1
Transitional Salt Marsh	15	< 1
Inland Shore	2	< 1
Total (incl. water)	**28,091**	**100**

Dikes and Impoundments. According to the National Wetland Inventory, there are areas protected by dikes in and around the refuge. In addition, discussions with refuge staff indicated the low-lying areas of dry land adjacent to I-10 are protected by levees on 3 sides and actively under development. Therefore this large area was also specified as diked. Areas designated as protected by dikes or levees are shown in yellow in Figure 4.

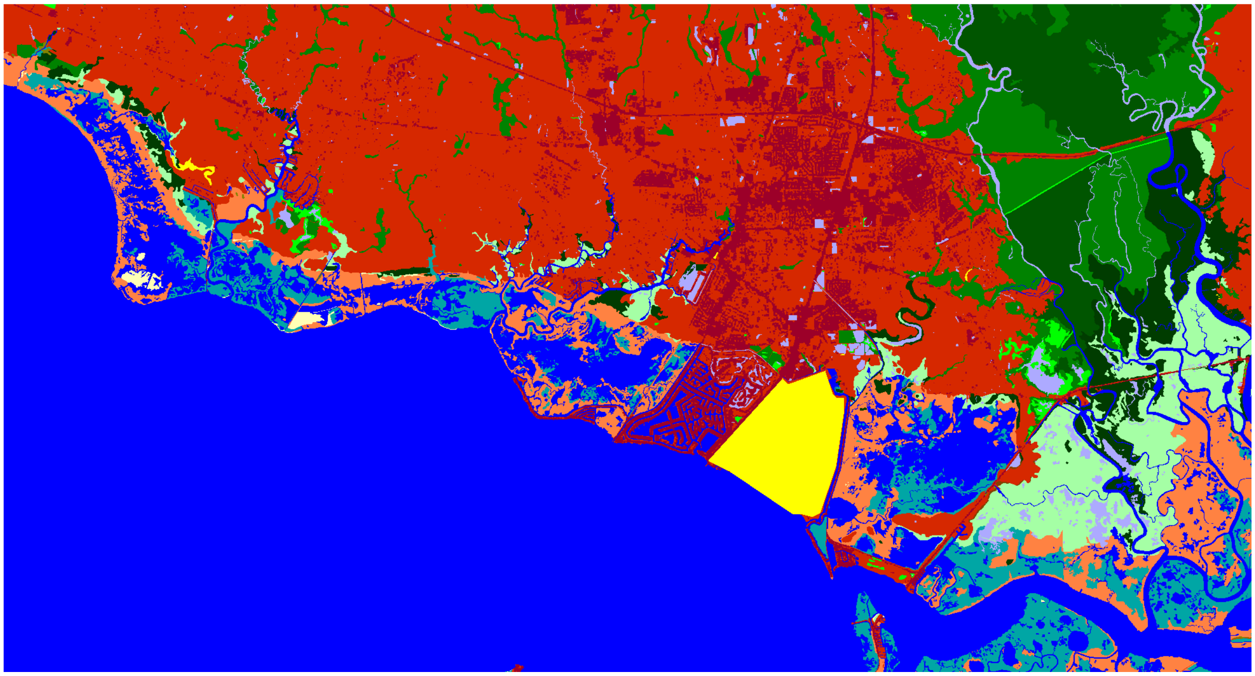


Figure 4. Location of dikes in Big Branch Marsh NWR (shown in yellow).

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).

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). The rate of sea level rise for this refuge is more than 7 mm/yr. 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. A subsidence rate of 7 mm/yr. 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).

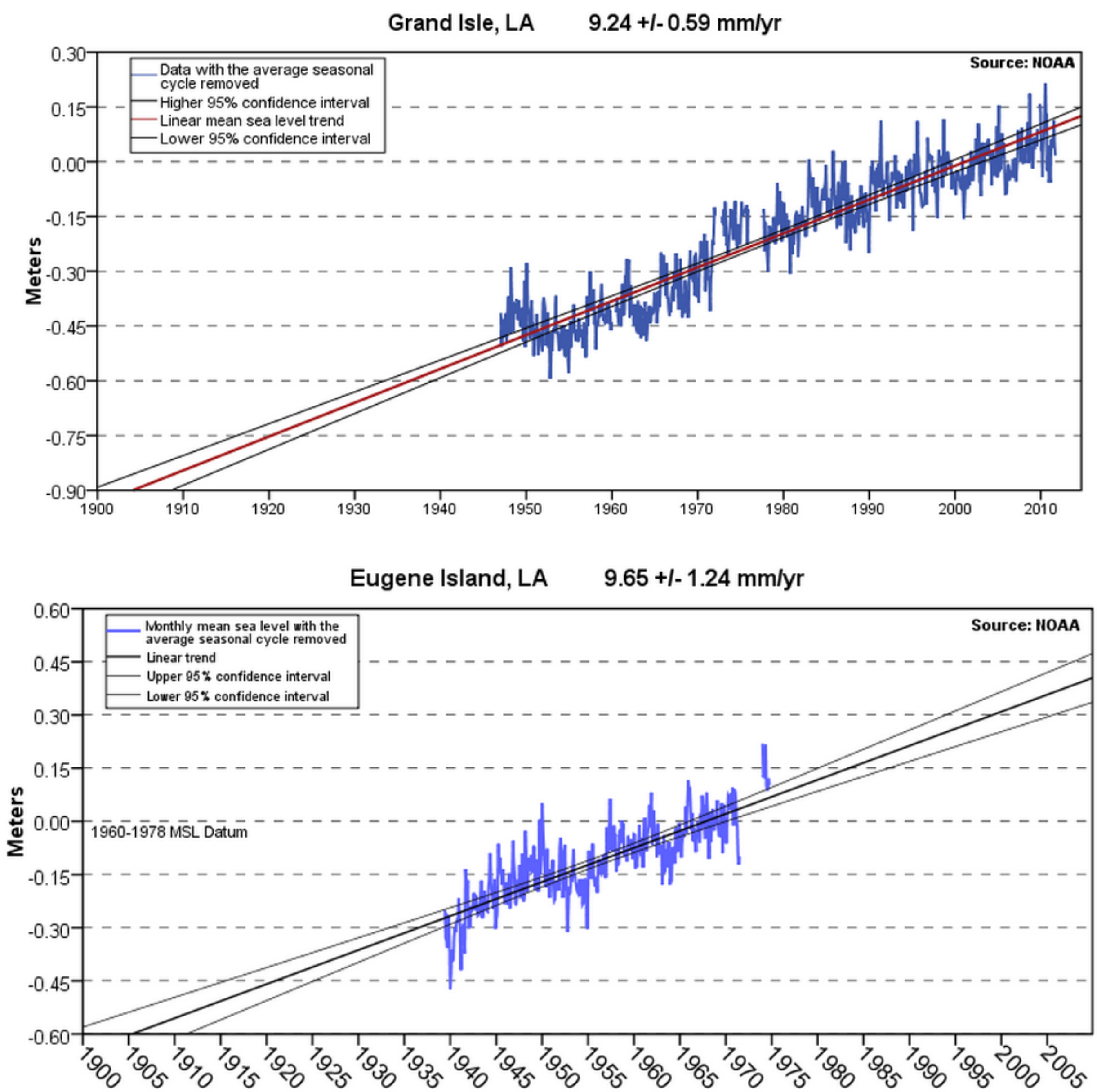


Figure 5. Historic sea level trends at the Grand Isle and Eugene Island NOAA gauge stations.

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 Big Branch Marsh refuge, a GT of 1.5 m was applied based on NOAA tide table data.

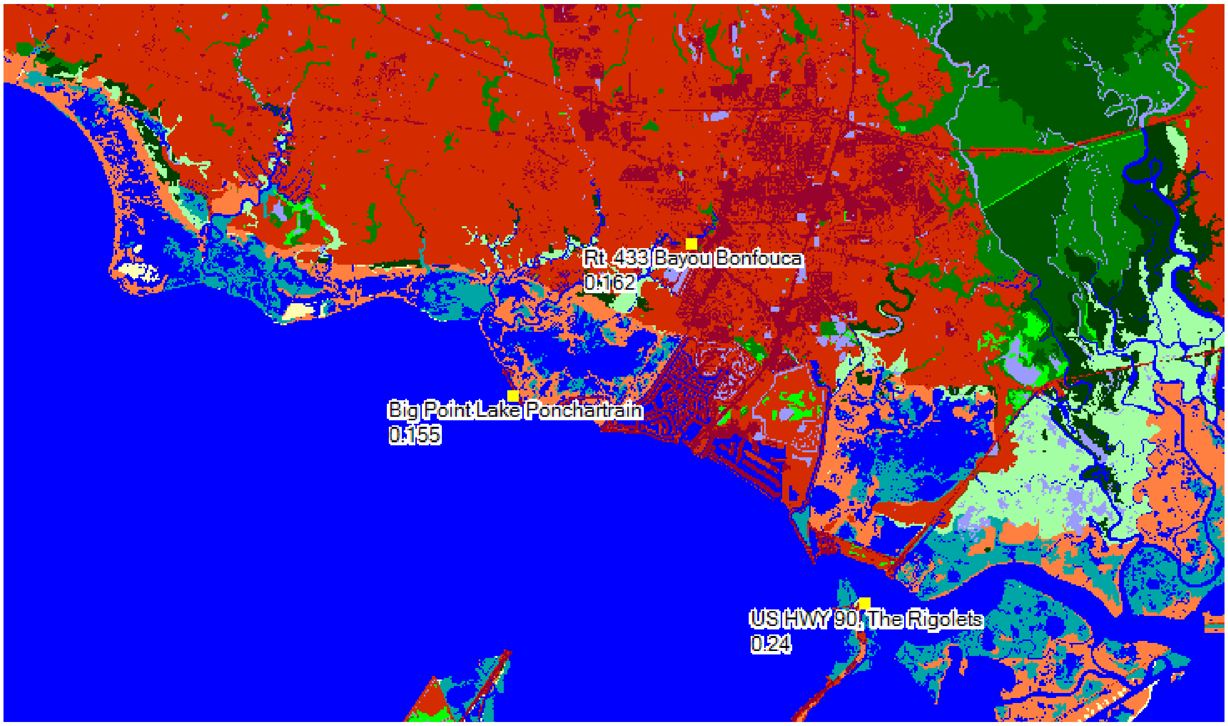


Figure 6. NOAA tide station locations used for this study (yellow icons with GT in meters).

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.

Accretion rates. The accretion rates applied in a SLAMM model that was calibrated and applied to southern Louisiana were used in simulations of the Big Branch Marsh 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 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 negative 114 mm/year to positive 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.

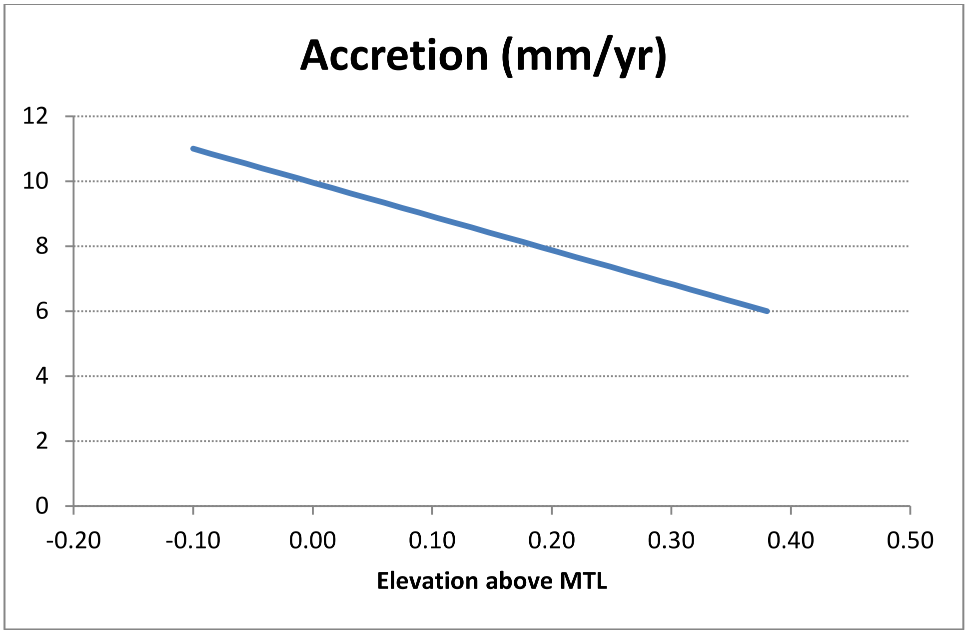


Figure 7. Relationship between predicted accretion rates and elevation used for regularly-flooded marsh.

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 for this region. Tidal flat erosion was set to 2 m/yr., marshes were set to 1.8 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. A value of 0.1 m was applied to the subsite containing the Big Branch Marsh NWR.

Parameter summary. Parameters were applied to the Big Branch Marsh refuge by dividing the study area into two subsites in order to represent differences in tide ranges. Subsites were defined as shown in Figure 8. The parameters assigned to each subsite are presented in Table 2. The cell size used for this analysis was 10 m by 10 m. The connectivity module of SLAMM was used in this model application in order to ensure dry land only converts to wetland if there is an unimpeded path from open water to the dry land in question.

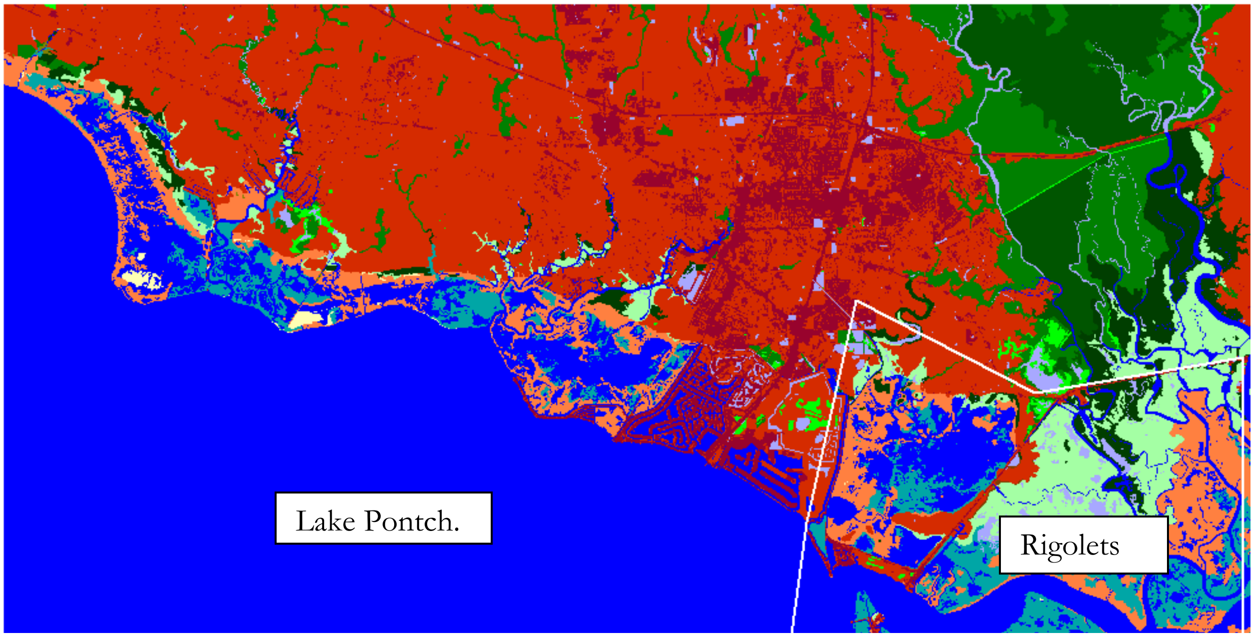


Figure 8. Subsites.

Table 2. Summary of SLAMM input parameters for Big Branch Marsh NWR.

Parameter	Lake Pontch.	Rigolets
NWI Photo Date (YYYY)	2009	2009
DEM Date (YYYY)	2008	2008
Direction Offshore [n,s,e,w]	East	East
Historic Trend (mm/yr.)	9.44	9.44
MTL-NAVD88 (m)	0.1	0.2
GT Great Diurnal Tide Range (m)	0.155	0.24
Salt Elev. (m above MTL)	0.13175	0.204
Marsh Erosion (horz. m /yr.)	1.8	1.8
Swamp Erosion (horz. m /yr.)	1	1
T.Flat Erosion (horz. m /yr.)	2	2
Reg.-Flood Marsh Accr (mm/yr.)	8.5	8.5
Irreg.-Flood Marsh Accr (mm/yr.)	8.5	8.5
Tidal-Fresh Marsh Accr (mm/yr.)	9.8	9.8
Inland-Fresh Marsh Accr (mm/yr.)	5.9	5.9
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.)	1	1
Freq. Overwash (years)	30	30
Use Elev Pre-processor [True,False]	FALSE	FALSE
Reg Flood Max. Accr. (mm/year)	11	11
Reg Flood Min. Accr. (mm/year)	6	6
Reg Flood Elev c coeff. (linear)	1	1
Irreg Flood Max. Accr. (mm/year)	11	11
Irreg Flood Min. Accr. (mm/year)	6	6
Irreg Flood Elev c coeff. (linear)	1	1
Tidal Fresh Max. Accr. (mm/year)	11	11
Tidal Fresh Min. Accr. (mm/year)	6	6
Tidal Fresh Elev c coeff. (linear)	1	1

Results

Table 3 presents the predicted losses for each land cover type by 2100 within the total approved acquisition boundary of Big Branch Marsh NWR 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.

SLAMM simulations suggest Big Branch Marsh will be severely affected by increases in sea level. Due to its low elevation, irregularly-flooded marsh is predicted to be converted to regularly-flooded marsh, even under the lowest SLR scenario examined, with 100% of this habitat type predicted to be lost by 2100 under the 1.5 m of SLR by 2100 scenario. In comparison, regularly-flooded marsh appears to be relatively resilient to the effects of SLR, with a net loss of 50% of this habitat type by 2100 under the most extreme SLR scenario examined (2 m by 2100).

Estuarine beach represents the areas where dredge spoil has been placed in the refuge. SLAMM simulations suggest these habitats to be lost to inundation by 2100 under all the SLR scenarios examined. Similarly, swamp and tidal swamp are both predicted to be lost under low rates of SLR. Riverine tidal and inland shore habitats are particularly endangered as they are projected to be completely lost under each SLR scenario examined. Although these habitat types make up only a small fraction of the refuge, their loss results in a loss of habitat richness in the area.

Table 3. Predicted loss rates of land categories by 2100 given simulated scenarios of eustatic SLR at Big Branch Marsh 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
Undeveloped Dry Land	62%	76%	87%	94%	96%
Irregularly-flooded Marsh	83%	98%	99%	100%	100%
Regularly-flooded Marsh	-42%	36%	40%	45%	50%
Tidal Fresh Marsh	13%	36%	70%	94%	100%
Tidal Swamp	89%	95%	99%	100%	100%
Swamp	99%	100%	100%	100%	100%
Inland Fresh Marsh	53%	58%	69%	97%	100%
Estuarine Beach	98%	100%	100%	100%	100%

Losses of wetland habitats in Big Branch Marsh NWR are coupled with gains in open water, transitional salt marsh, and tidal flat, as shown in Table 4. Gains in transitional salt marsh acreage are projected to vary depending on the SLR rate applied. However, open water and tidal flat steadily increase with increases in the SLR rate. Overall, simulations predict much of the refuge will convert to open water.

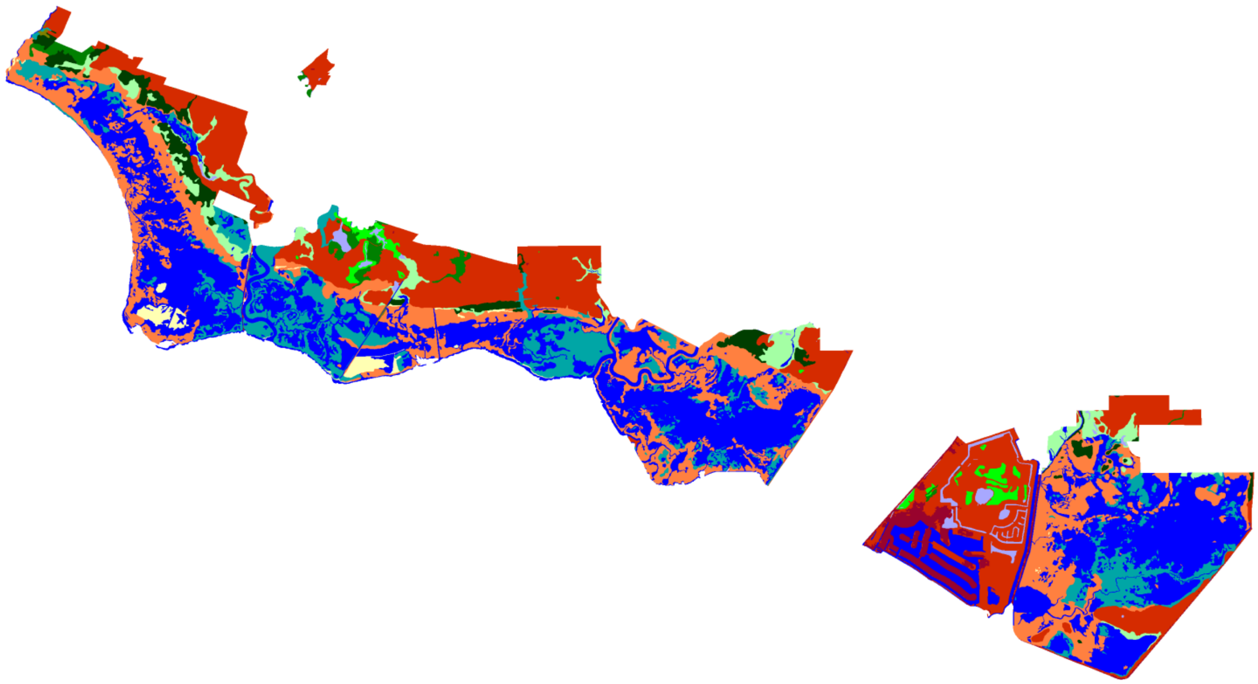
Table 4. Predicted land cover gains by 2100 given simulated scenarios of eustatic SLR at Big Branch Marsh NWR.

	Initial Coverage	Land cover gain by 2100 for different SLR scenarios (Acres)				
		0.39 m	**0.69 m**	**1 m**	**1.5 m**	**2 m**
Estuarine Open Water	9587	5855	9827	11016	12144	12633
Transitional Salt Marsh	15	889	870	960	538	143
Tidal Flat	0	2022	2472	2510	2780	3025

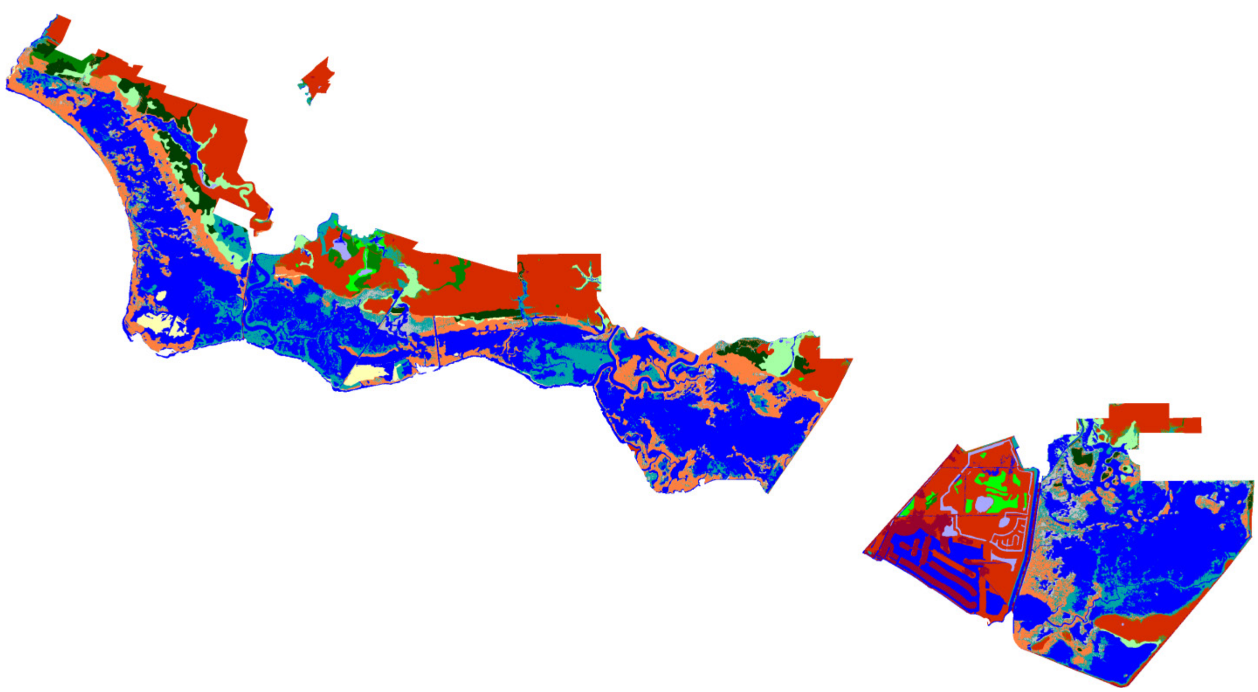
IPCC Scenario A1B-Mean, 0.39 m SLR eustatic by 2100

Results in Acres

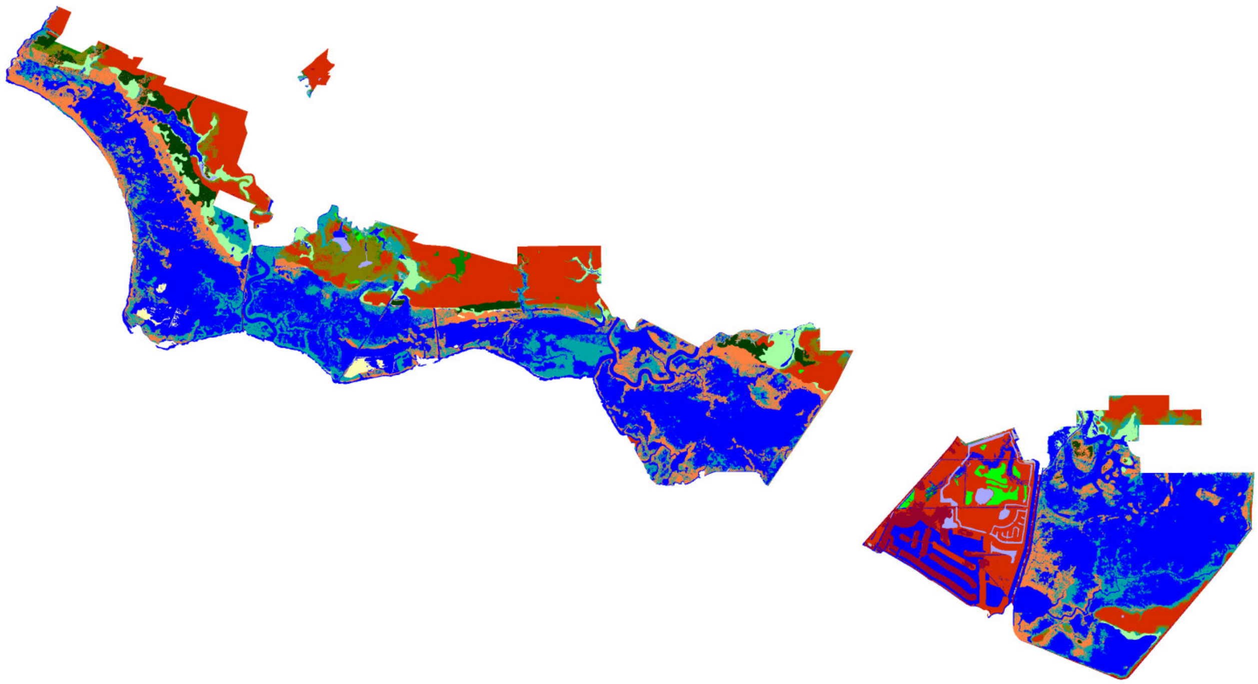
		Initial	2025	2050	2075	2100
	Estuarine Open Water	9587	11325	12390	13500	15443
	Undeveloped Dry Land	6260	5826	4906	3546	2356
	Irregularly Flooded Marsh	5402	3539	2961	1668	904
	Regularly Flooded Marsh	3187	3097	3843	5047	4525
	Tidal Fresh Marsh	991	885	885	877	866
	Tidal Swamp	797	746	596	303	91
	Developed Dry Land	593	593	593	593	593
	Inland Open Water	327	286	270	234	234
	Swamp	316	284	103	18	2
	Inland Fresh Marsh	312	248	189	166	148
	Estuarine Beach	264	251	130	36	4
	Riverine Tidal	38	8	4	0	0
	Transitional Salt Marsh	15	222	1069	1267	904
	Inland Shore	2	0	0	0	0
	Tidal Flat	0	781	152	834	2022
	Total (incl. water)	**28091**	**28091**	**28091**	**28091**	**28091**



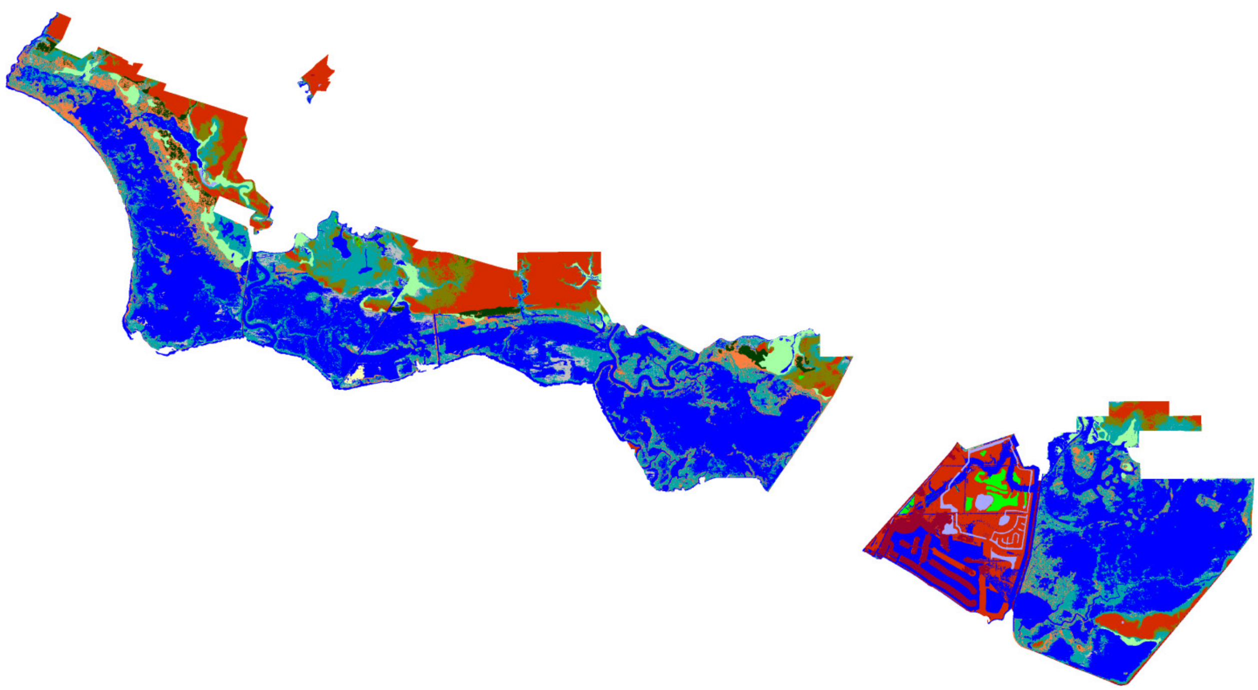
Big Branch Marsh NWR, Initial Condition.



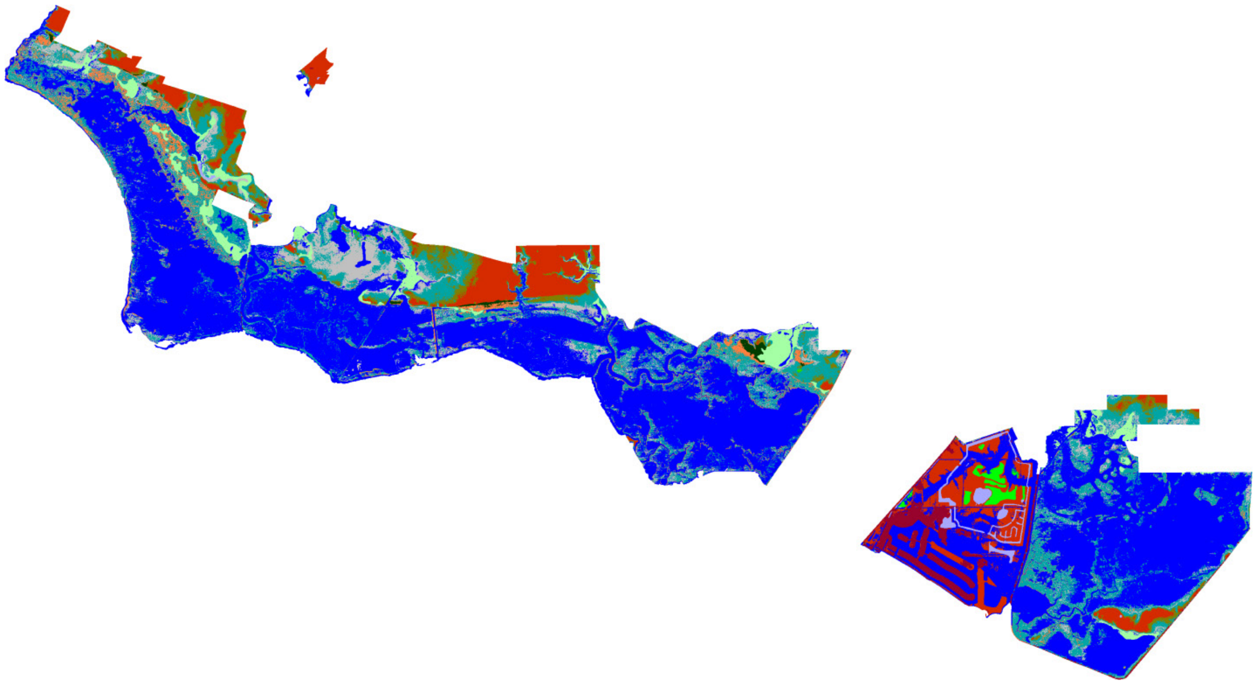
Big Branch Marsh NWR, 2025, Scenario A1B Mean, 0.39 m SLR.



Big Branch Marsh NWR, 2050, Scenario A1B Mean, 0.39 m SLR.



Big Branch Marsh NWR, 2075, Scenario A1B Mean, 0.39 m SLR.

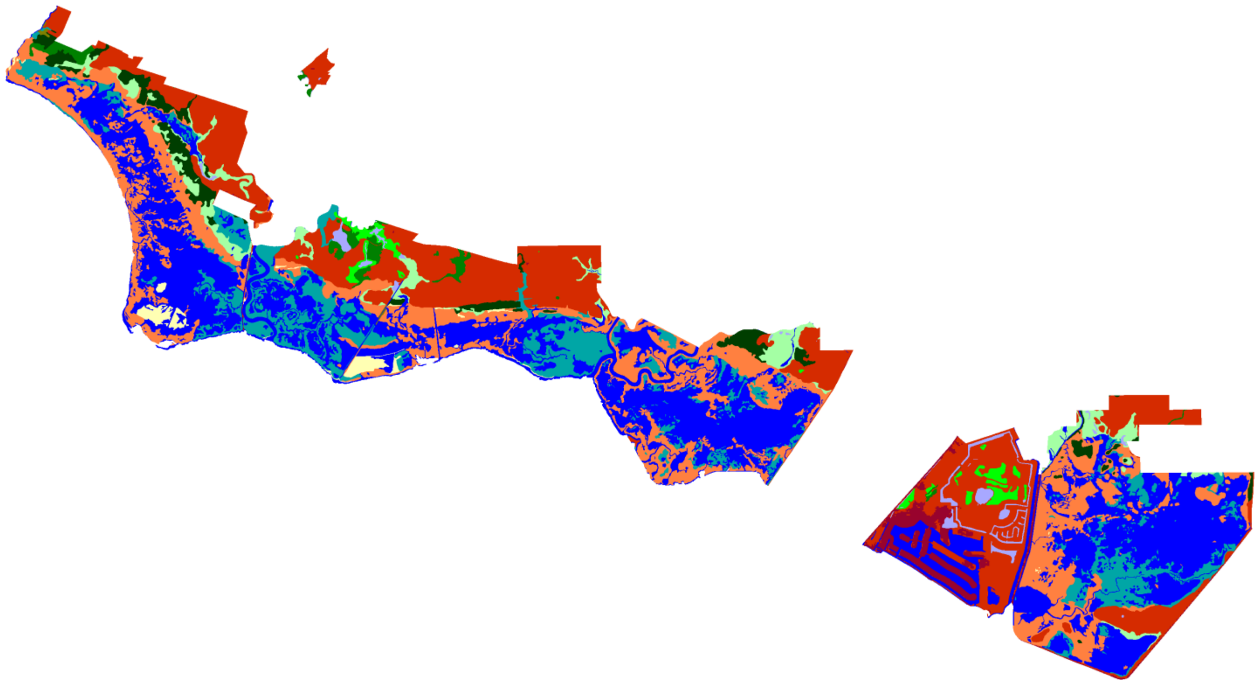


Big Branch Marsh NWR, 2100, Scenario A1B Mean, 0.39 m SLR.

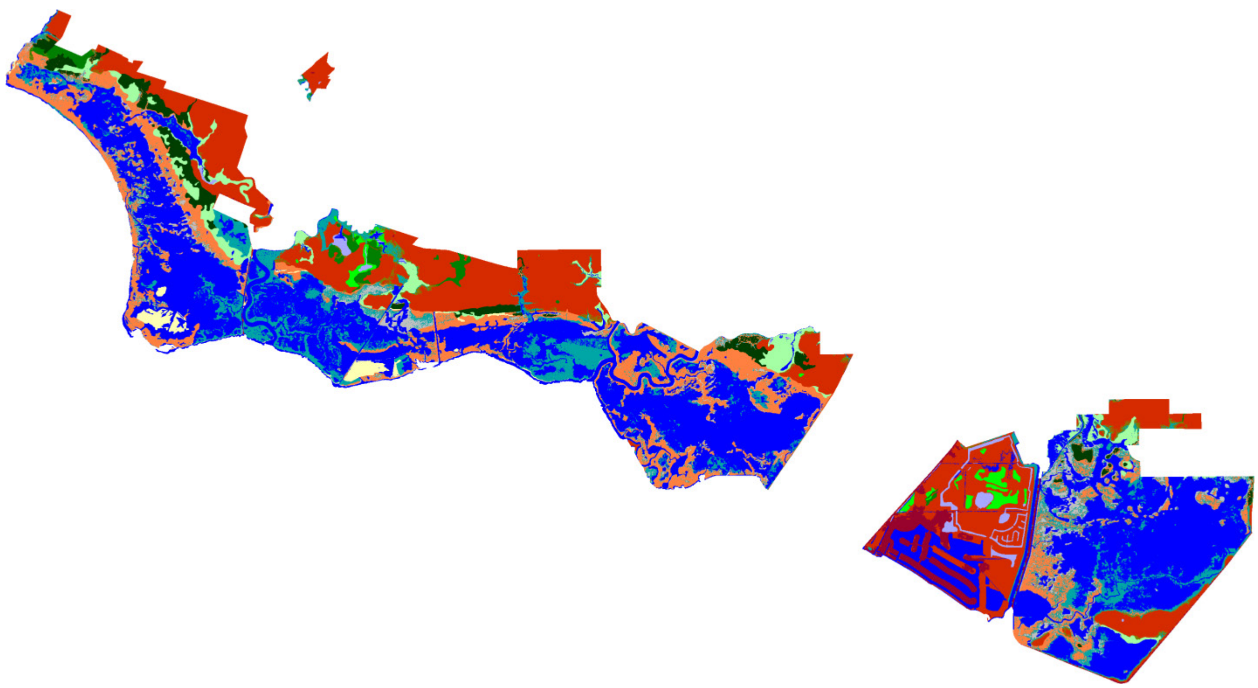
IPCC Scenario A1B-Max, 0.69 m SLR eustatic by 2100

Results in Acres

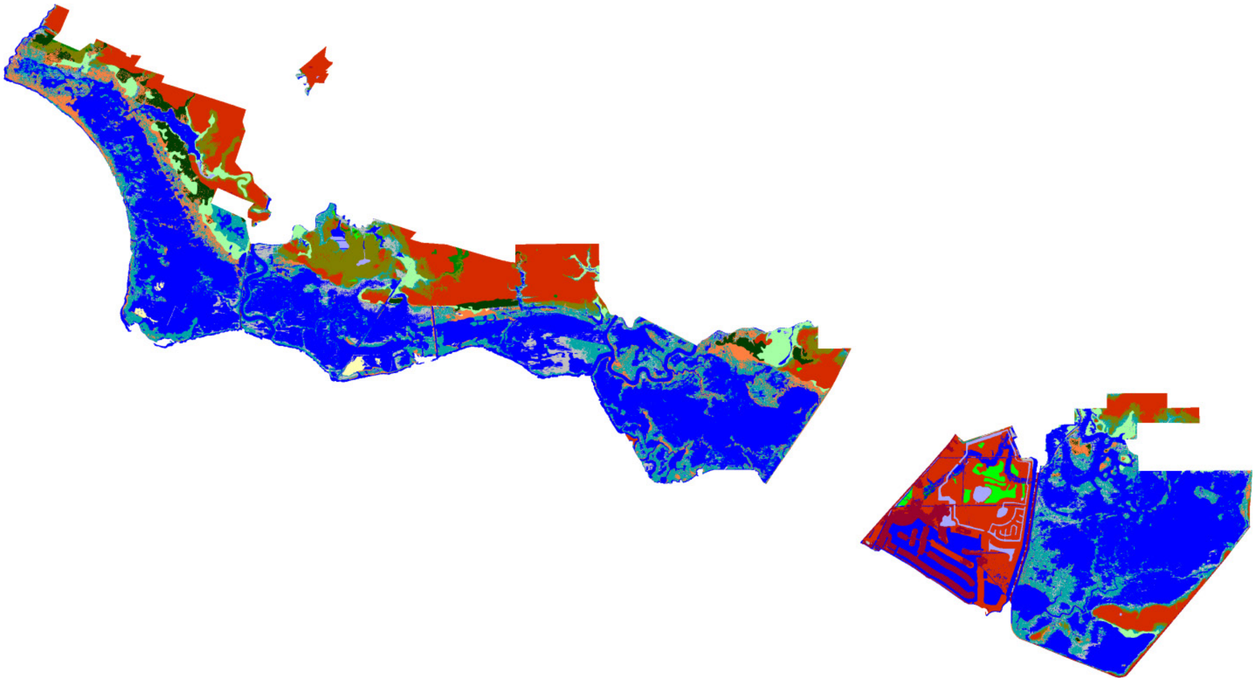
		Initial	2025	2050	2075	2100
	Estuarine Open Water	9587	11353	13219	16108	19414
	Undeveloped Dry Land	6260	5776	4540	2791	1526
	Irregularly Flooded Marsh	5402	3485	1407	550	125
	Regularly Flooded Marsh	3187	3034	3682	2788	2040
	Tidal Fresh Marsh	991	883	852	770	633
	Tidal Swamp	797	737	516	138	39
	Developed Dry Land	593	593	593	593	593
	Inland Open Water	327	285	265	233	232
	Swamp	316	280	69	4	0
	Inland Fresh Marsh	312	246	177	153	132
	Estuarine Beach	264	249	86	11	0
	Riverine Tidal	38	8	2	0	0
	Transitional Salt Marsh	15	265	1383	1497	885
	Inland Shore	2	0	0	0	0
	Tidal Flat	0	896	1299	2456	2472
	Total (incl. water)	**28091**	**28091**	**28091**	**28091**	**28091**



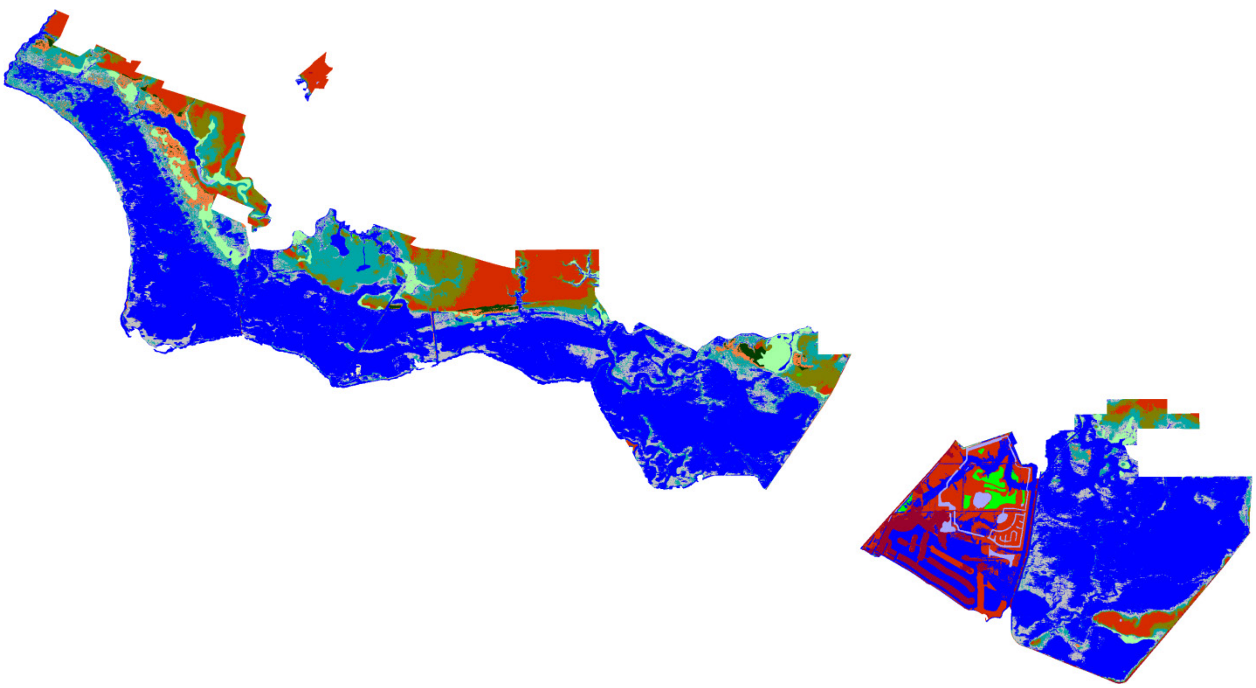
Big Branch Marsh NWR, Initial Condition.



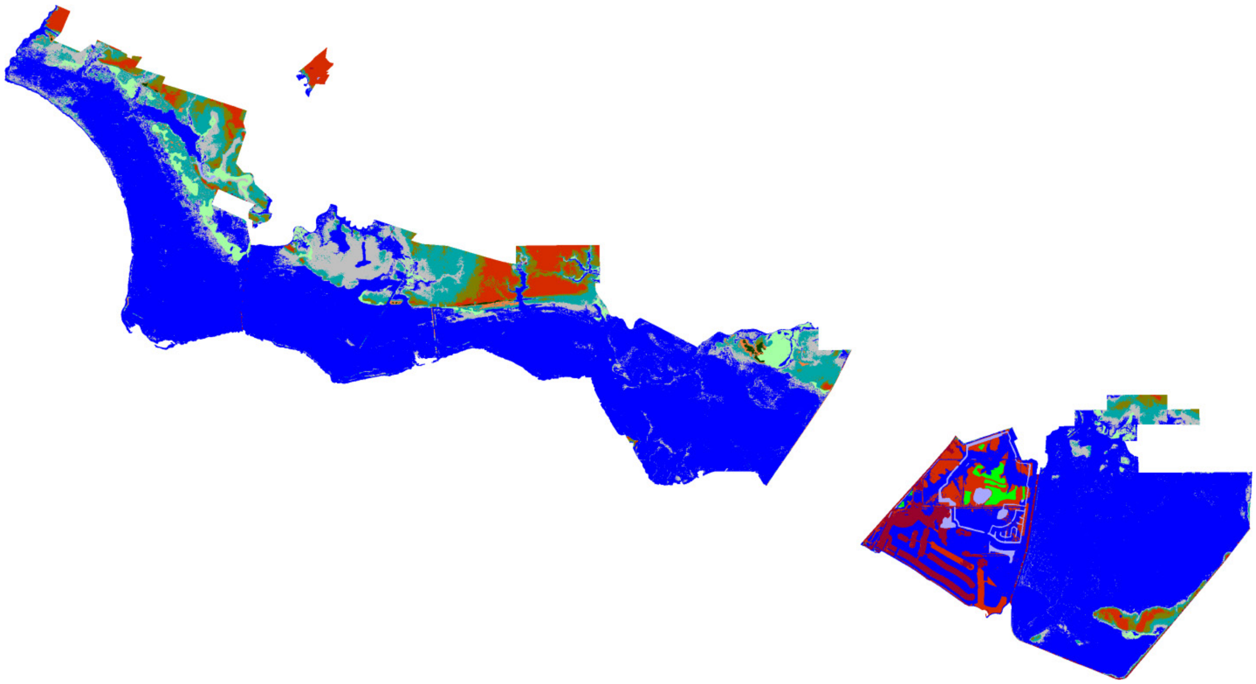
Big Branch Marsh NWR, 2025, Scenario A1B Maximum, 0.69 m SLR.



Big Branch Marsh NWR, 2050, Scenario A1B Maximum, 0.69 m SLR.



Big Branch Marsh NWR, 2075, Scenario A1B Maximum, 0.69 m SLR.

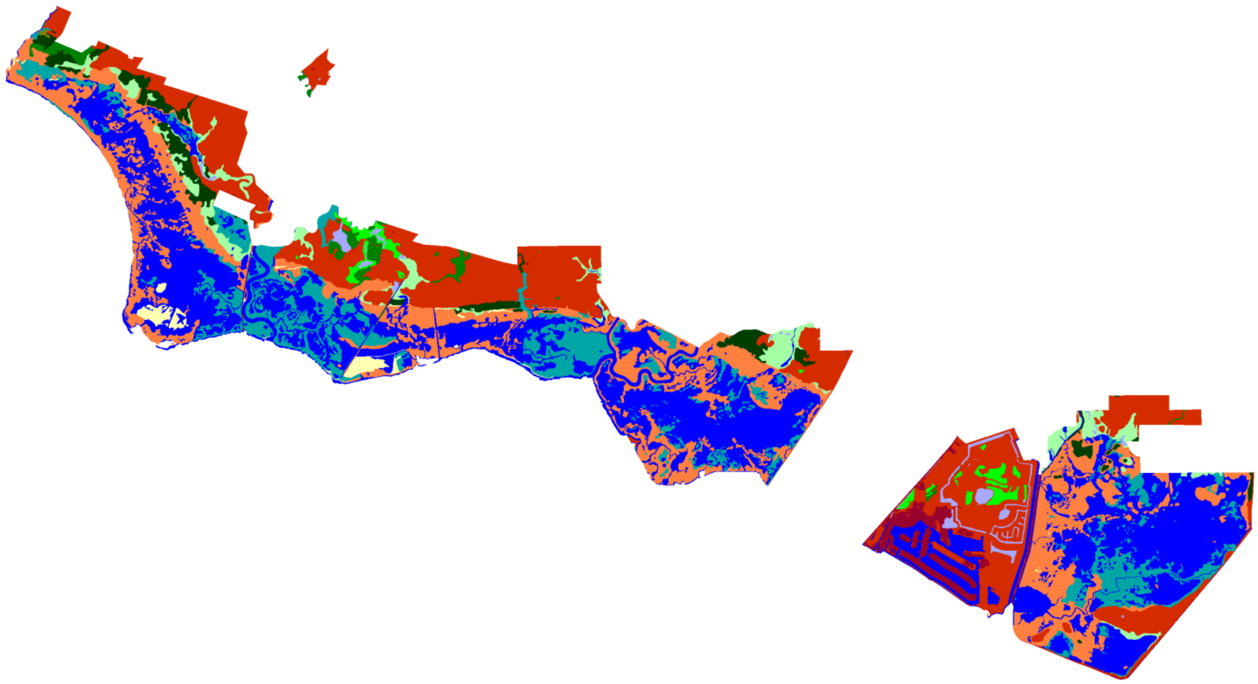


Big Branch Marsh NWR, 2100, Scenario A1B Maximum, 0.69 m SLR.

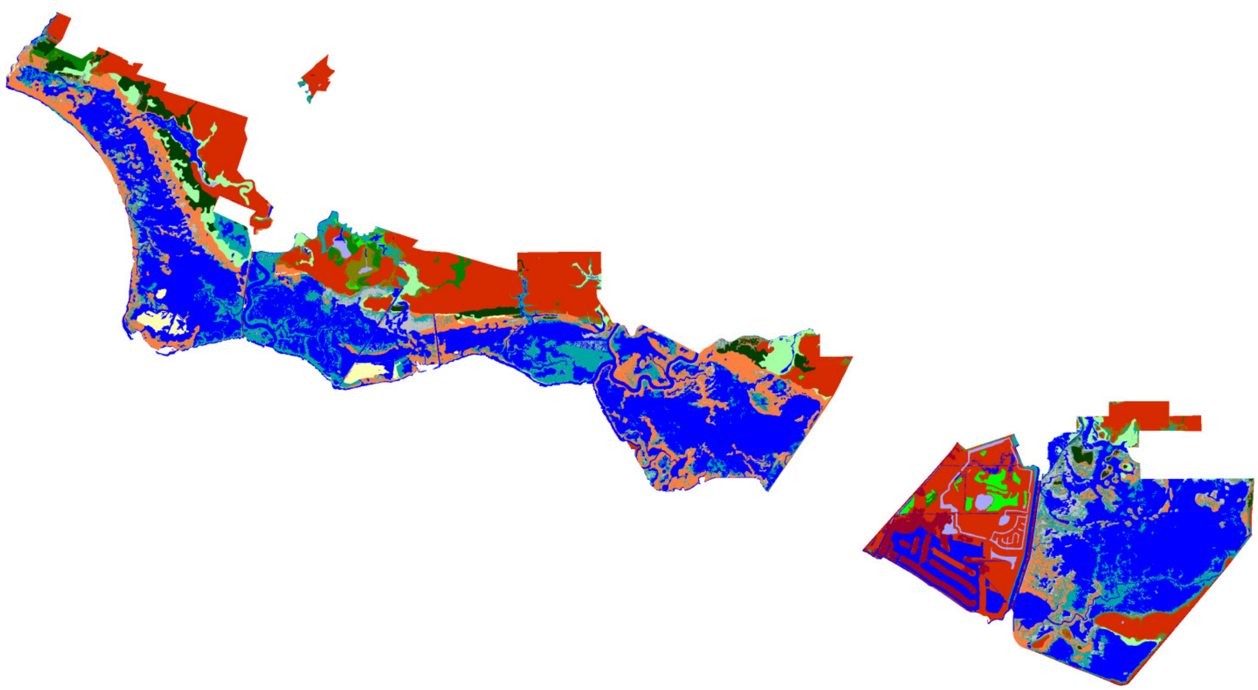
1 m eustatic SLR by 2100

Results in Acres

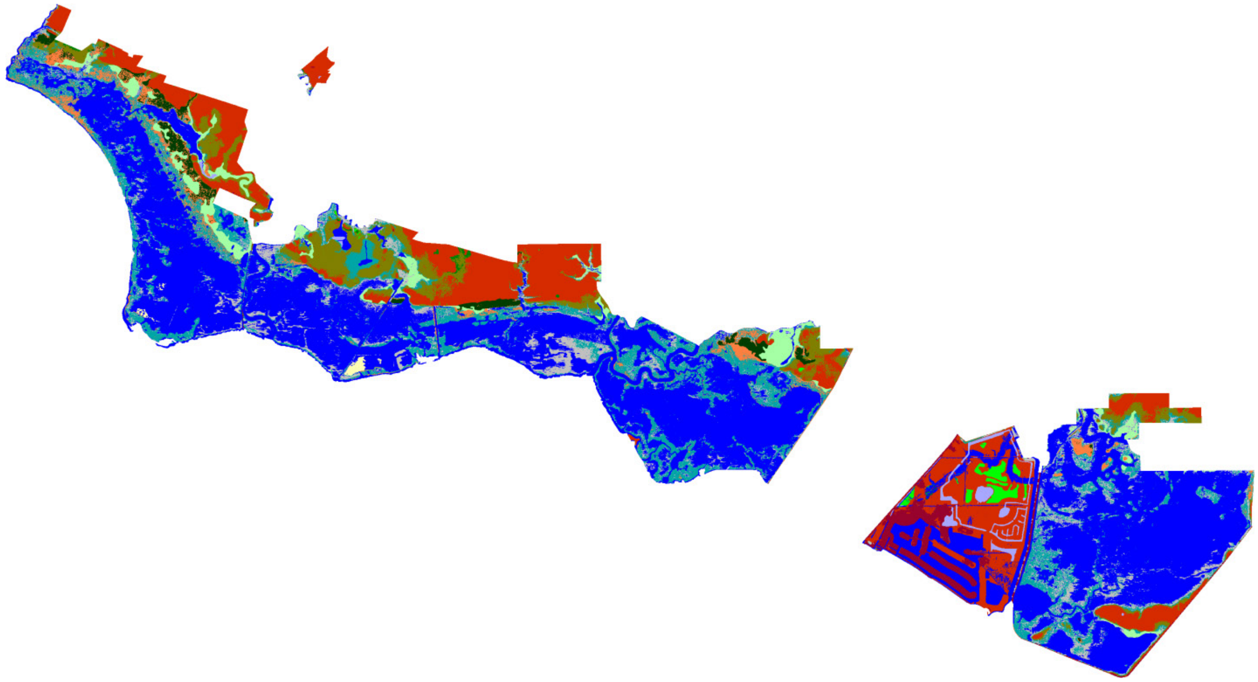
		Initial	2025	2050	2075	2100
	Estuarine Open Water	9587	11410	13880	17304	20603
	Undeveloped Dry Land	6260	5688	4116	2171	802
	Irregularly Flooded Marsh	5402	3052	802	377	71
	Regularly Flooded Marsh	3187	3170	3374	2413	1907
	Tidal Fresh Marsh	991	874	793	577	295
	Tidal Swamp	797	726	414	71	8
	Developed Dry Land	593	593	593	593	593
	Inland Open Water	327	284	244	232	232
	Swamp	316	247	42	1	0
	Inland Fresh Marsh	312	208	167	141	97
	Estuarine Beach	264	247	59	1	0
	Riverine Tidal	38	8	1	0	0
	Transitional Salt Marsh	15	417	1632	1536	974
	Inland Shore	2	0	0	0	0
	Tidal Flat	0	1168	1975	2673	2510
	Total (incl. water)	**28091**	**28091**	**28091**	**28091**	**28091**



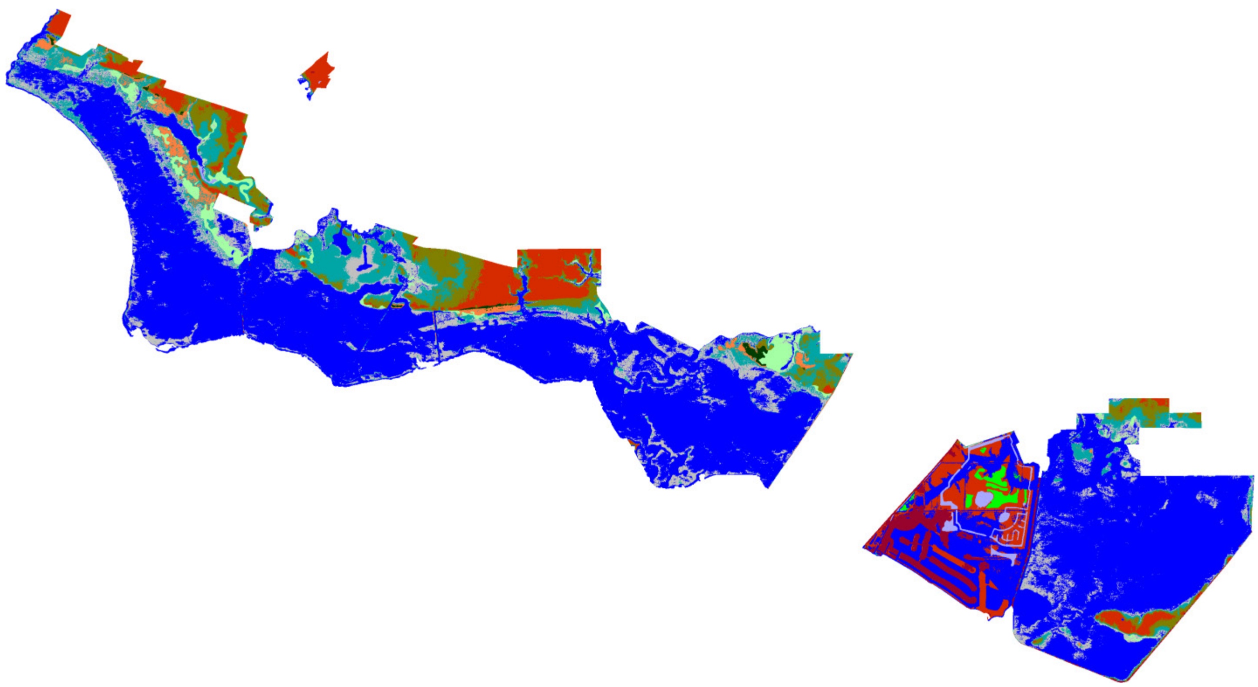
Big Branch Marsh NWR, Initial Condition.



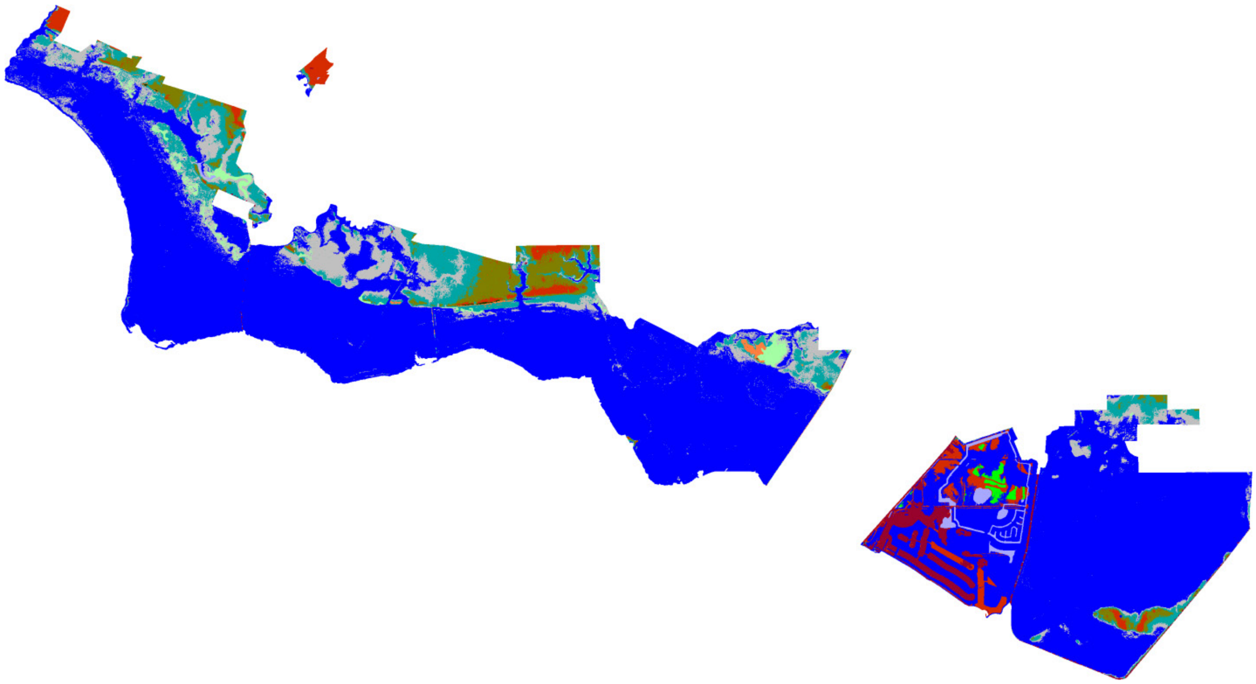
Big Branch Marsh NWR, 2025, 1 m SLR.



Big Branch Marsh NWR, 2050, 1 m SLR.



Big Branch Marsh NWR, 2075, 1 m SLR.

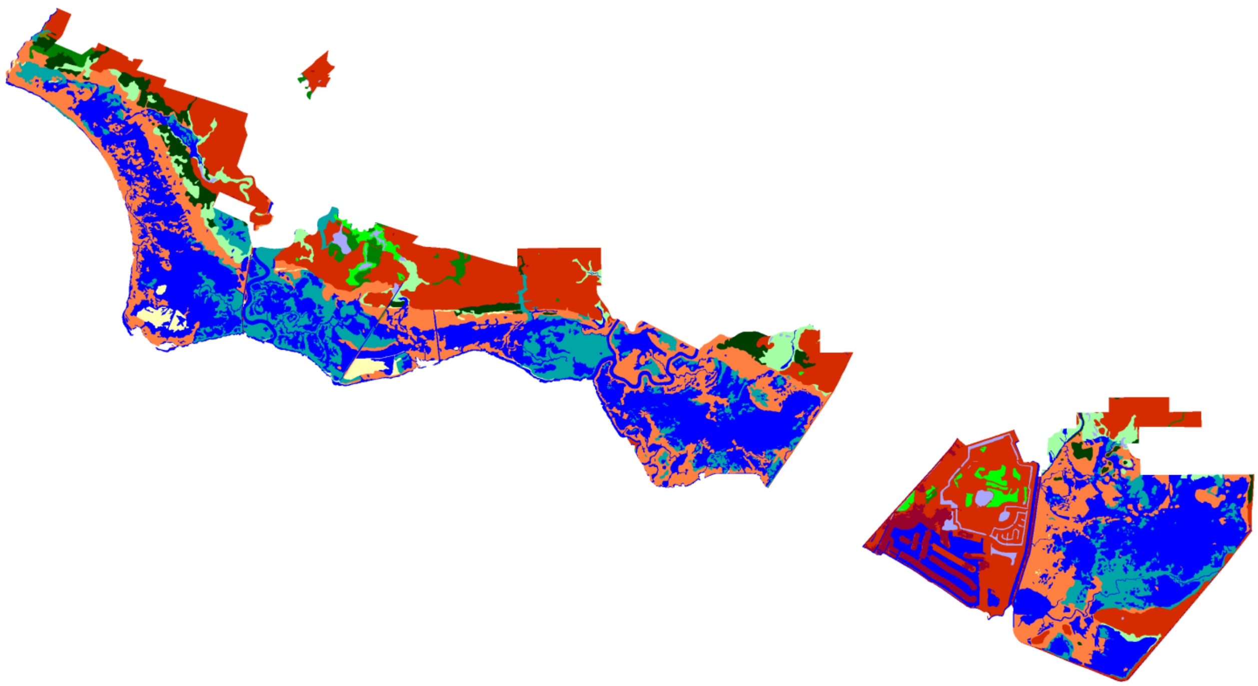


Big Branch Marsh NWR, 2100, 1 m SLR.

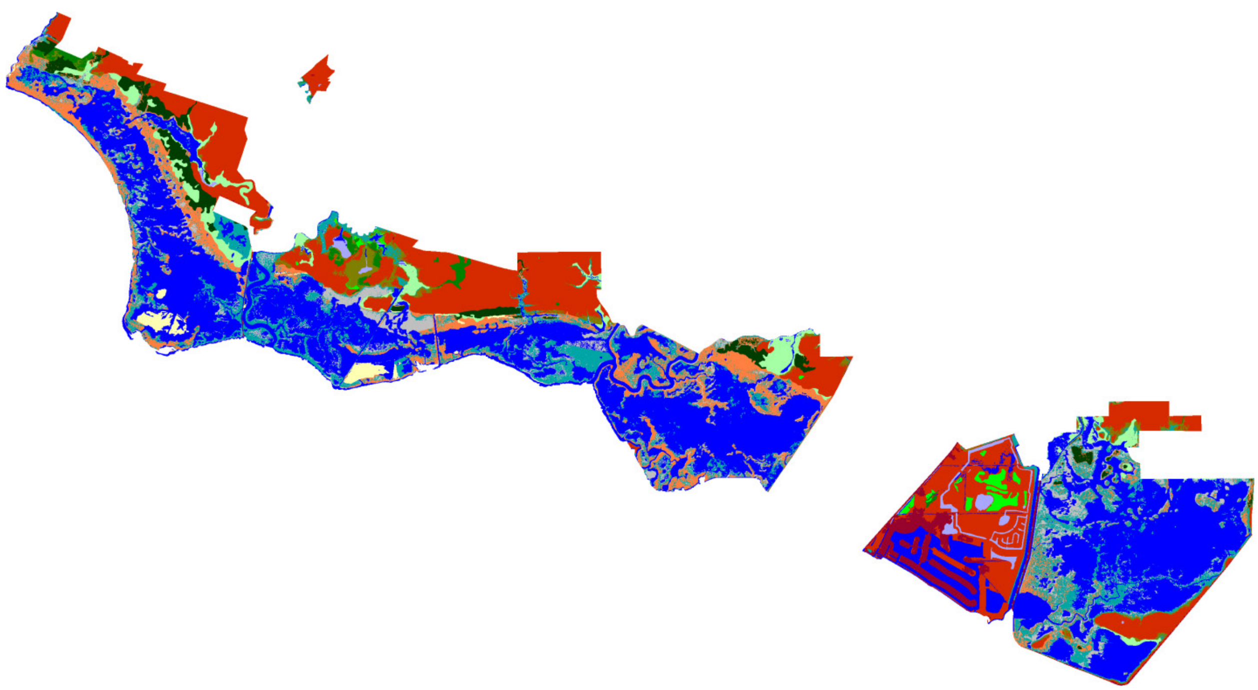
1.5 m eustatic SLR by 2100

Results in Acres

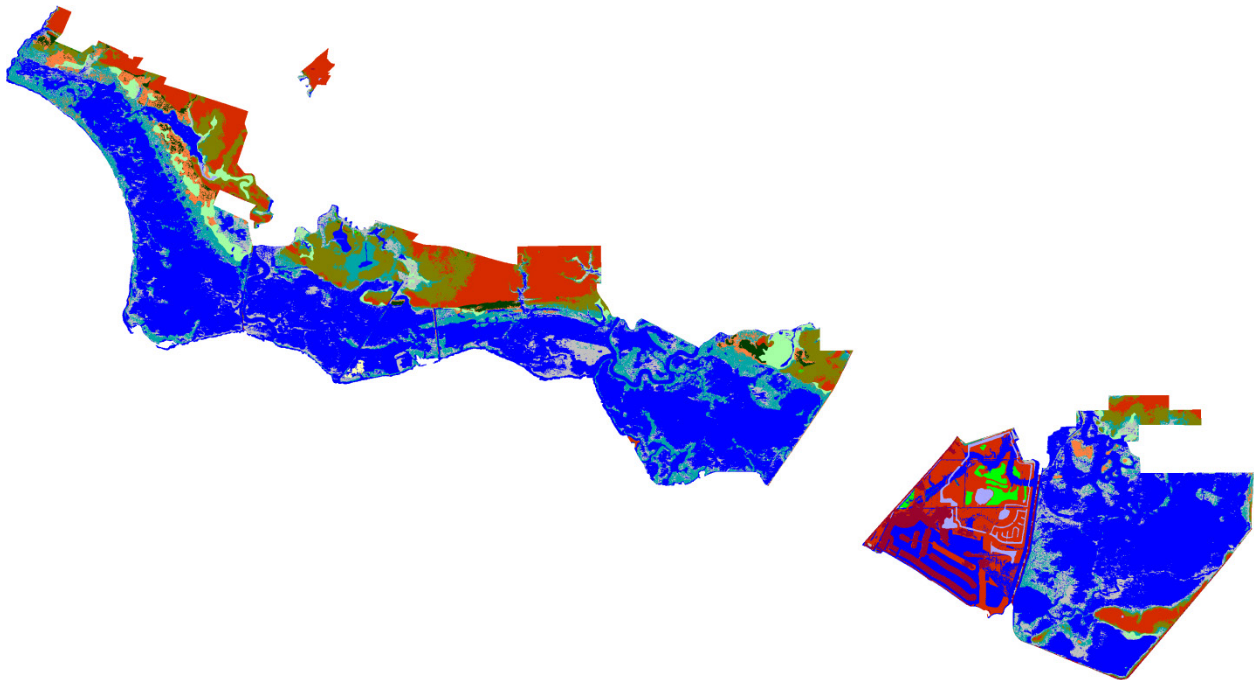
		Initial	2025	2050	2075	2100
	Estuarine Open Water	9587	11535	14708	18510	21731
	Undeveloped Dry Land	6260	5584	3397	1276	352
	Irregularly Flooded Marsh	5402	2364	594	222	24
	Regularly Flooded Marsh	3187	3219	2863	2725	1759
	Tidal Fresh Marsh	991	856	647	224	58
	Tidal Swamp	797	705	236	21	1
	Developed Dry Land	593	593	593	593	593
	Inland Open Water	327	283	236	232	231
	Swamp	316	222	12	0	0
	Inland Fresh Marsh	312	202	158	127	9
	Estuarine Beach	264	242	26	0	0
	Riverine Tidal	38	8	1	0	0
	Transitional Salt Marsh	15	540	2138	1540	553
	Inland Shore	2	0	0	0	0
	Tidal Flat	0	1738	2481	2620	2780
	Total (incl. water)	**28091**	**28091**	**28091**	**28091**	**28091**



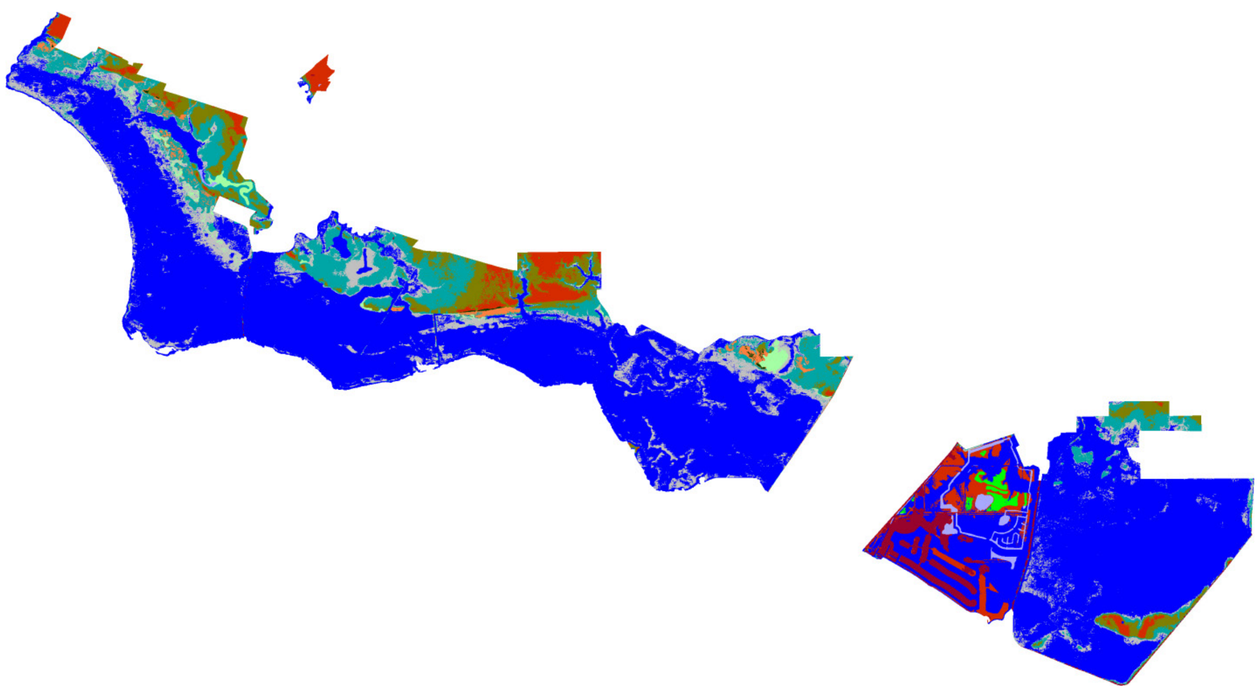
Big Branch Marsh NWR, Initial Condition.



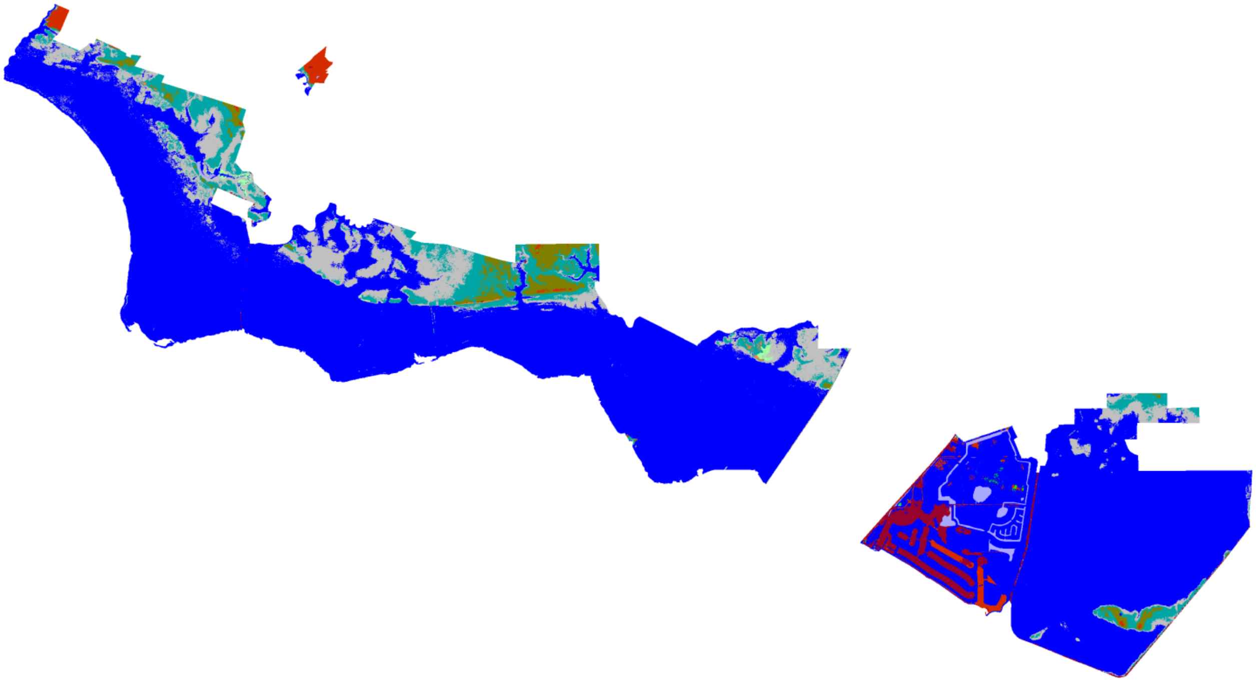
Big Branch Marsh NWR, 2025, 1.5 m SLR.



Big Branch Marsh NWR, 2050, 1.5 m SLR.



Big Branch Marsh NWR, 2075, 1.5 m SLR.

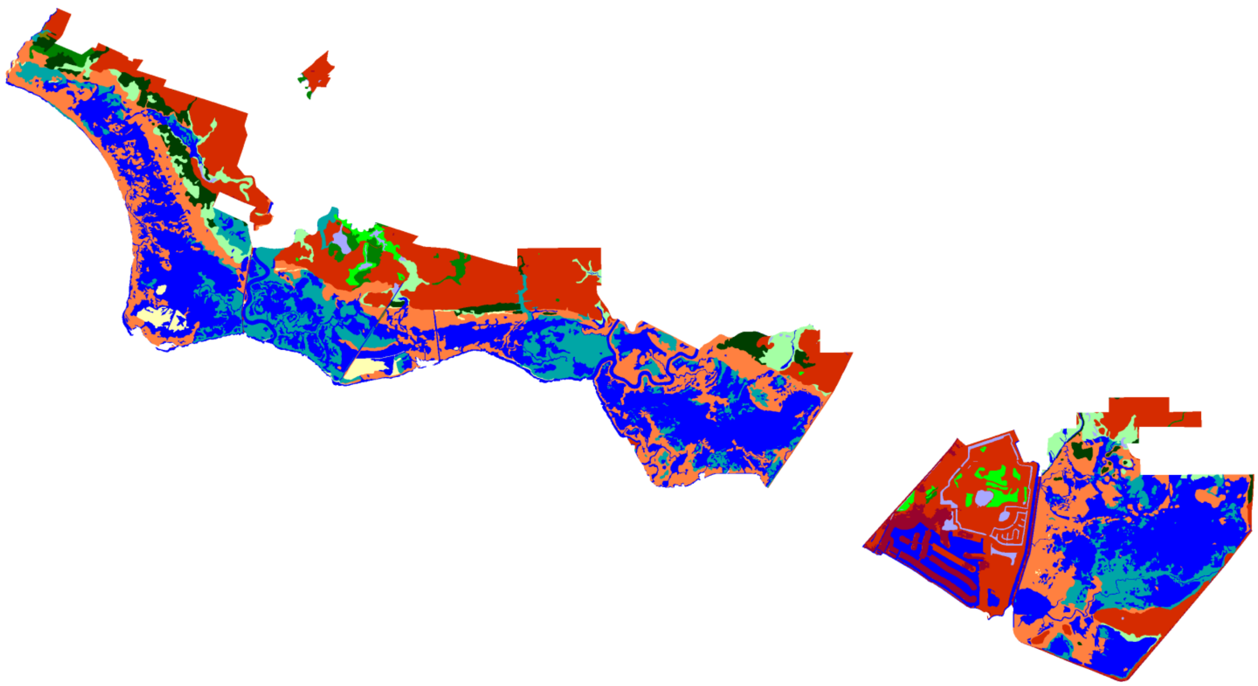


Big Branch Marsh NWR, 2100, 1.5 m SLR.

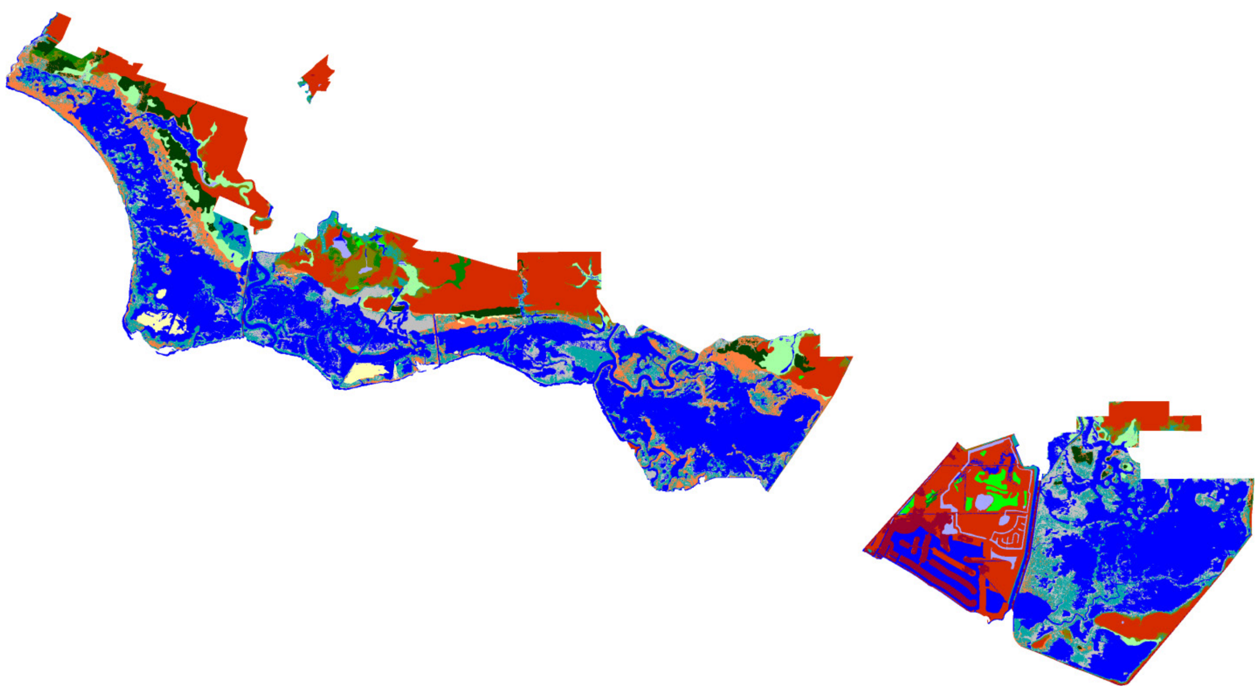
2 m eustatic SLR by 2100

Results in Acres

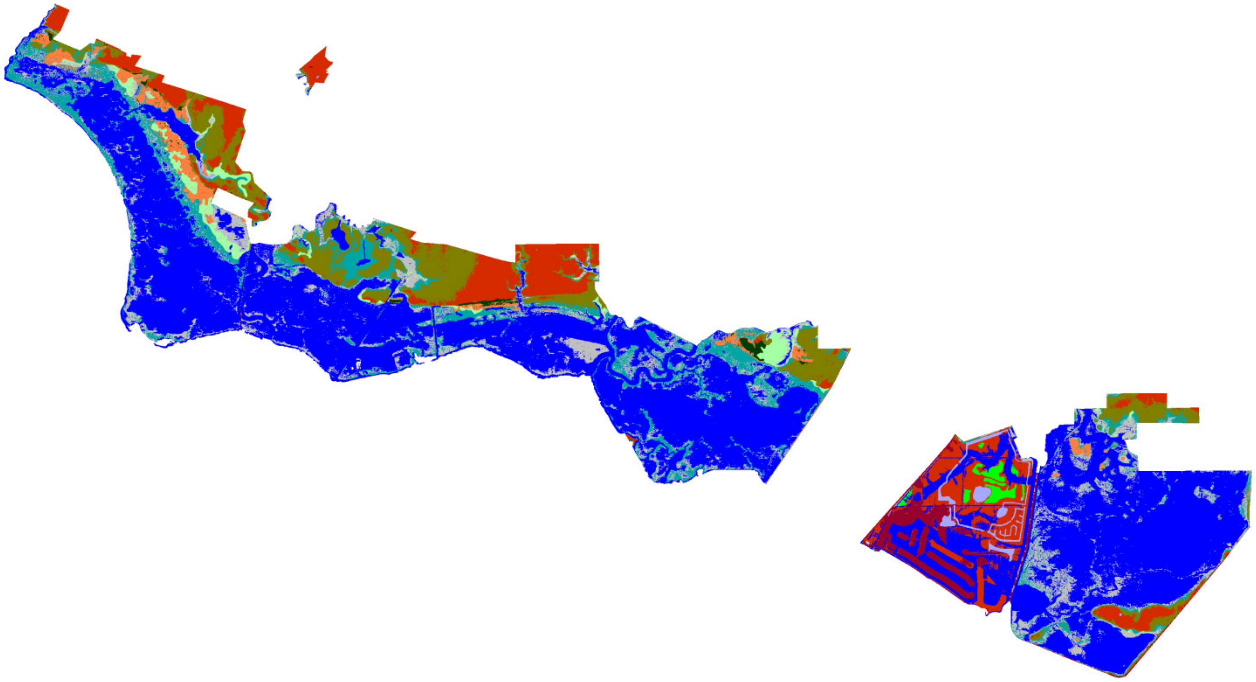
		Initial	2025	2050	2075	2100
	Estuarine Open Water	9587	11630	15388	19345	22220
	Undeveloped Dry Land	6260	5444	2754	664	273
	Irregularly Flooded Marsh	5402	1841	602	116	7
	Regularly Flooded Marsh	3187	3216	2519	3069	1582
	Tidal Fresh Marsh	991	834	472	89	2
	Tidal Swamp	797	682	116	5	0
	Developed Dry Land	593	593	593	593	593
	Inland Open Water	327	282	235	232	231
	Swamp	316	196	3	0	0
	Inland Fresh Marsh	312	195	150	82	0
	Estuarine Beach	264	233	8	0	0
	Riverine Tidal	38	8	0	0	0
	Transitional Salt Marsh	15	700	2471	1468	158
	Inland Shore	2	0	0	0	0
	Tidal Flat	0	2236	2778	2430	3025
	Total (incl. water)	**28091**	**28091**	**28091**	**28091**	**28091**



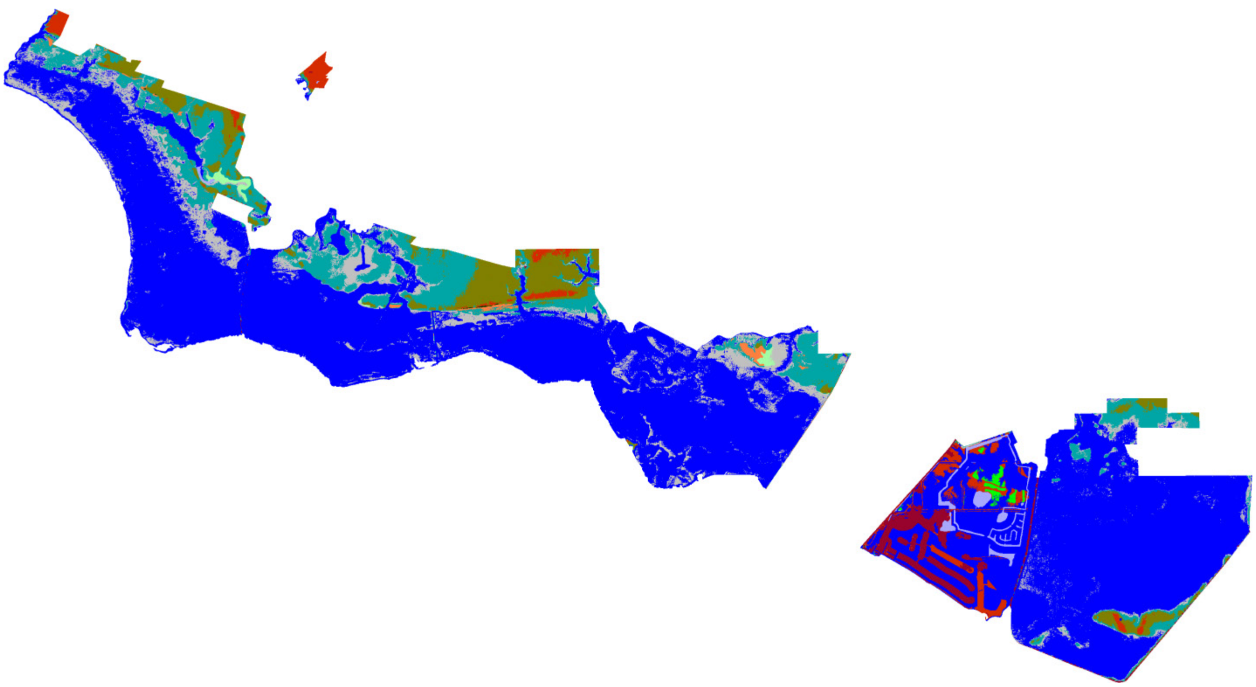
Big Branch Marsh NWR, Initial Condition.



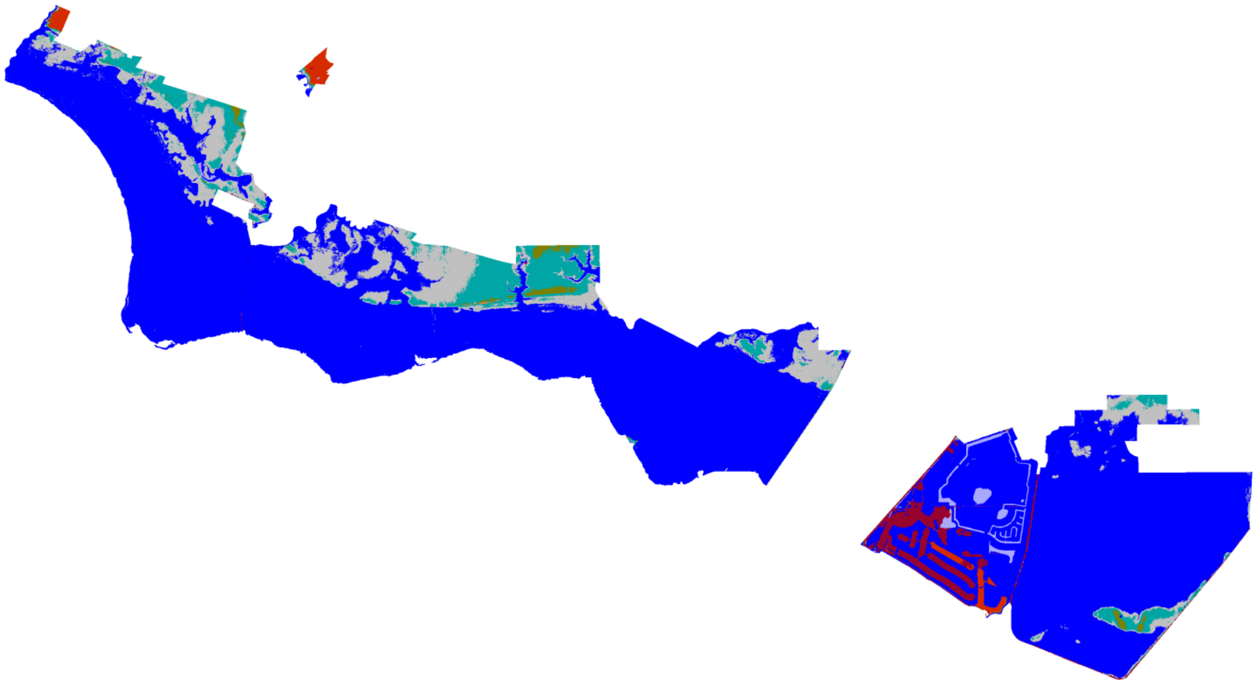
Big Branch Marsh NWR, 2025, 2 m SLR.



Big Branch Marsh NWR, 2050, 2 m SLR.



Big Branch Marsh NWR, 2075, 2 m SLR.



Big Branch Marsh NWR, 2100, 2 m SLR.

Discussion

SLAMM simulations indicate future SLR, coupled with low elevations and high subsidence rates in the region, will cause severe wetland losses in Big Branch Marsh NWR.

This application of SLAMM has incorporated subsidence information and previously-calibrated accretion feedbacks for the region (Glick et al. 2011), allowing for a refined model application. A subsidence rate of 7 mm/yr. was used based on the work of Shinkle and Dokka (2004); however, future subsidence is uncertain and is likely to be highly-spatially variable which could have an important effect on model results.

Several other caveats should be noted when interpreting the results of these SLAMM simulations. 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.

Although derived from the most recent data available, the NWI wetland layer applied in this study did not include full extents of the dredge fill/ marsh development areas in the refuge. In addition, active development or wetland restoration within the approved acquisition boundary is not accounted for in this simulation. Therefore, the effects of SLR on anthropogenic development or restoration efforts currently being implemented are uncertain. Since SLAMM is not a hydrodynamic model, uncertainties exist in the extent to which certain marshes, particularly those receiving water exclusively from Little Lagoon, are exposed to tides. As NOAA has not measured the tide range in this refuge unit, tide data from the closest gauge was applied.

This SLAMM simulation utilized the best available data layers and parameter inputs; however, these data and the conceptual model continue to have uncertainties that should be kept in mind when interpreting model results. Perhaps most importantly, the extent of future sea-level rise is unknown, as are the drivers of climate change used by scientists when projecting SLR rates. Future levels of economic activity, fuel type (e.g., fossil or renewable, etc.), fuel consumption, and greenhouse gas emissions are unknown and estimates of these driving variables are speculative. To account for these uncertainties, results presented here investigated effects for a wide range of possible sea level rise scenarios, from a more conservative rise (0.39 m by 2100) to a more accelerated process (2 m by 2100). To better support managers and decision-makers, the results presented here could be studied as a function of input-data uncertainty to provide a range of possible outcomes and their likelihood.

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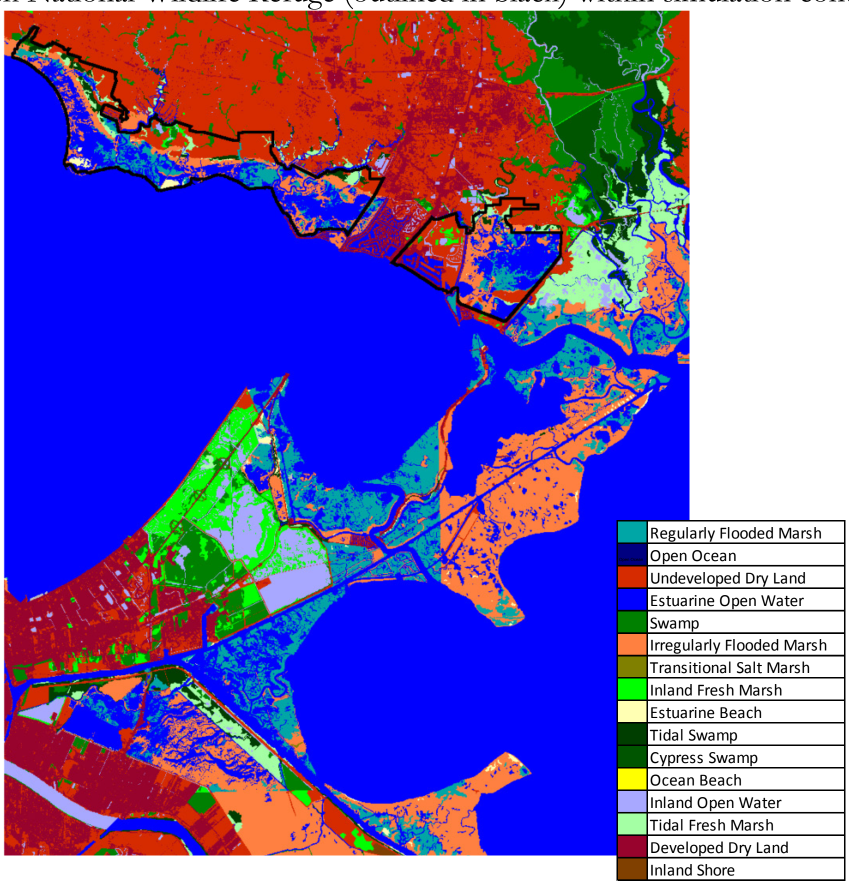
Appendix A: Contextual Results

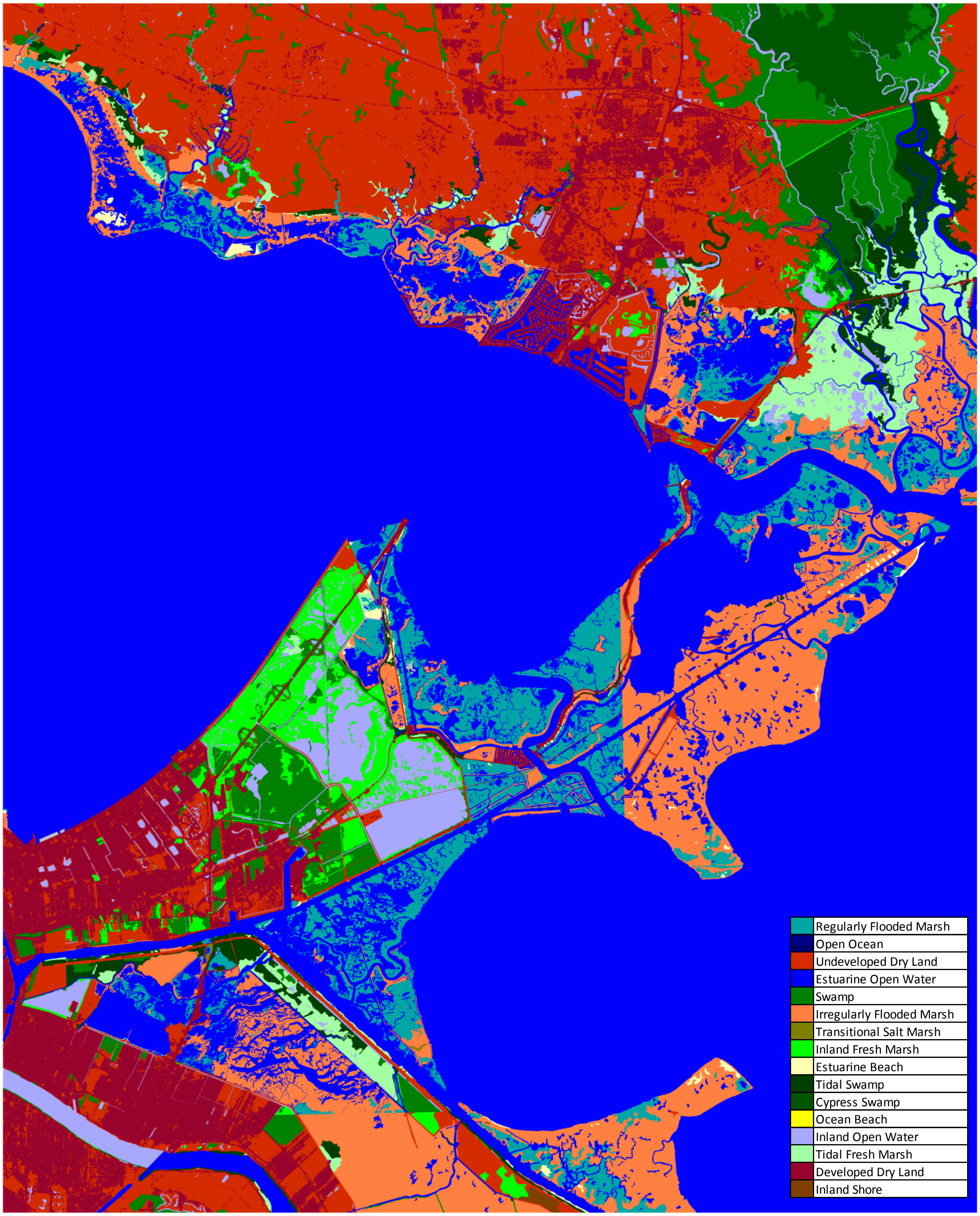
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

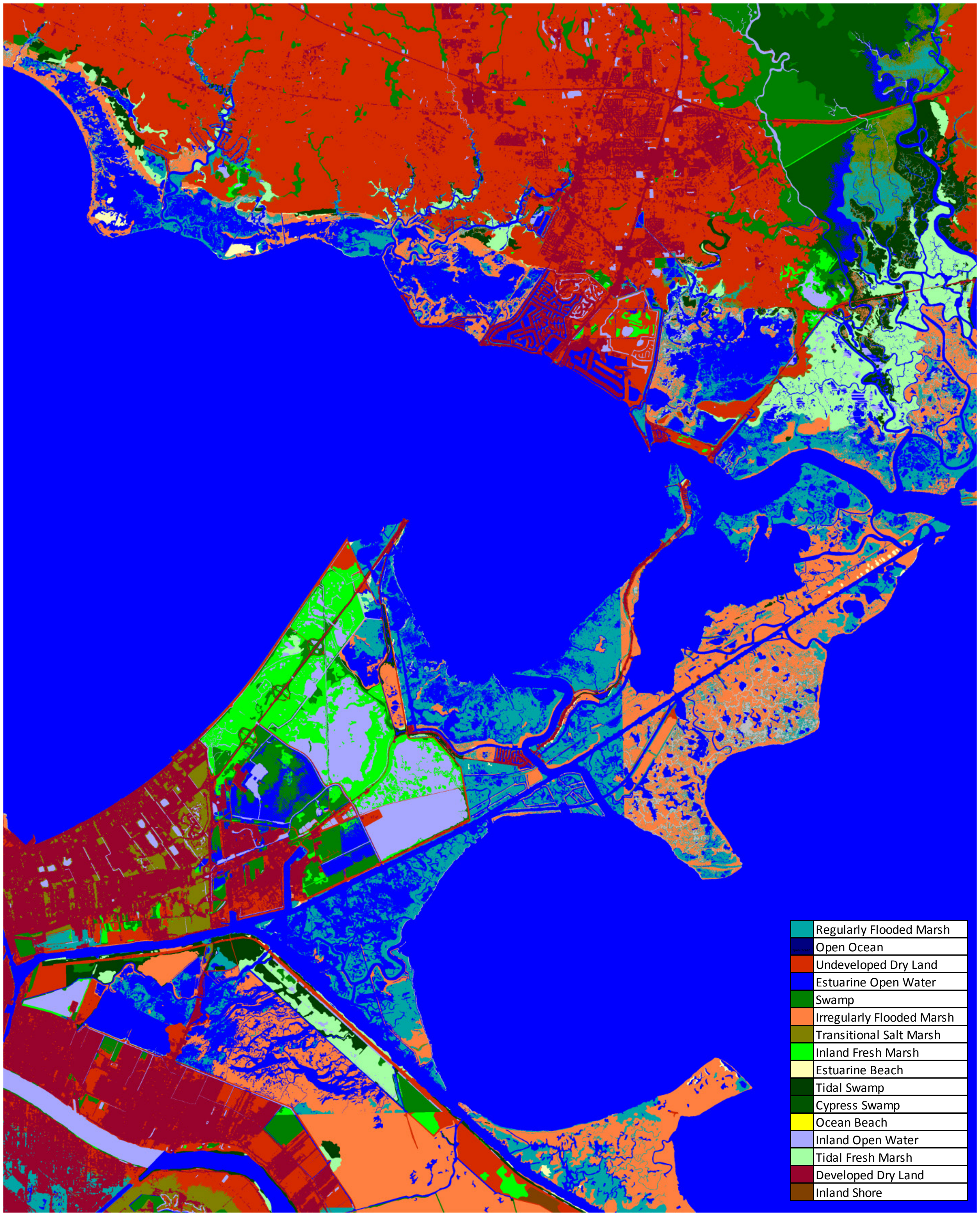
- Results were closely examined within USFWS refuges but not as closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to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

Big Branch Marsh National Wildlife Refuge (outlined in black) within simulation context.

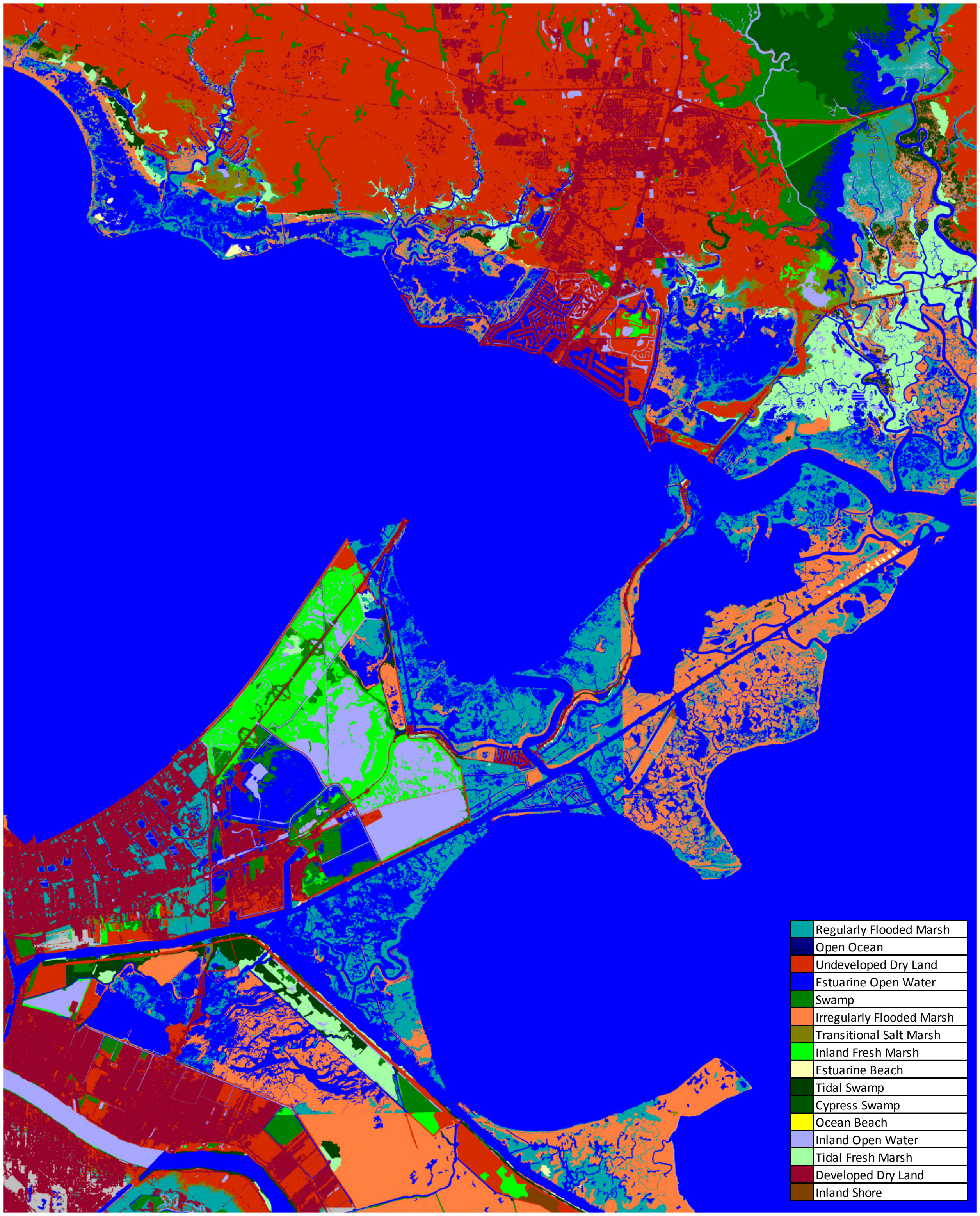




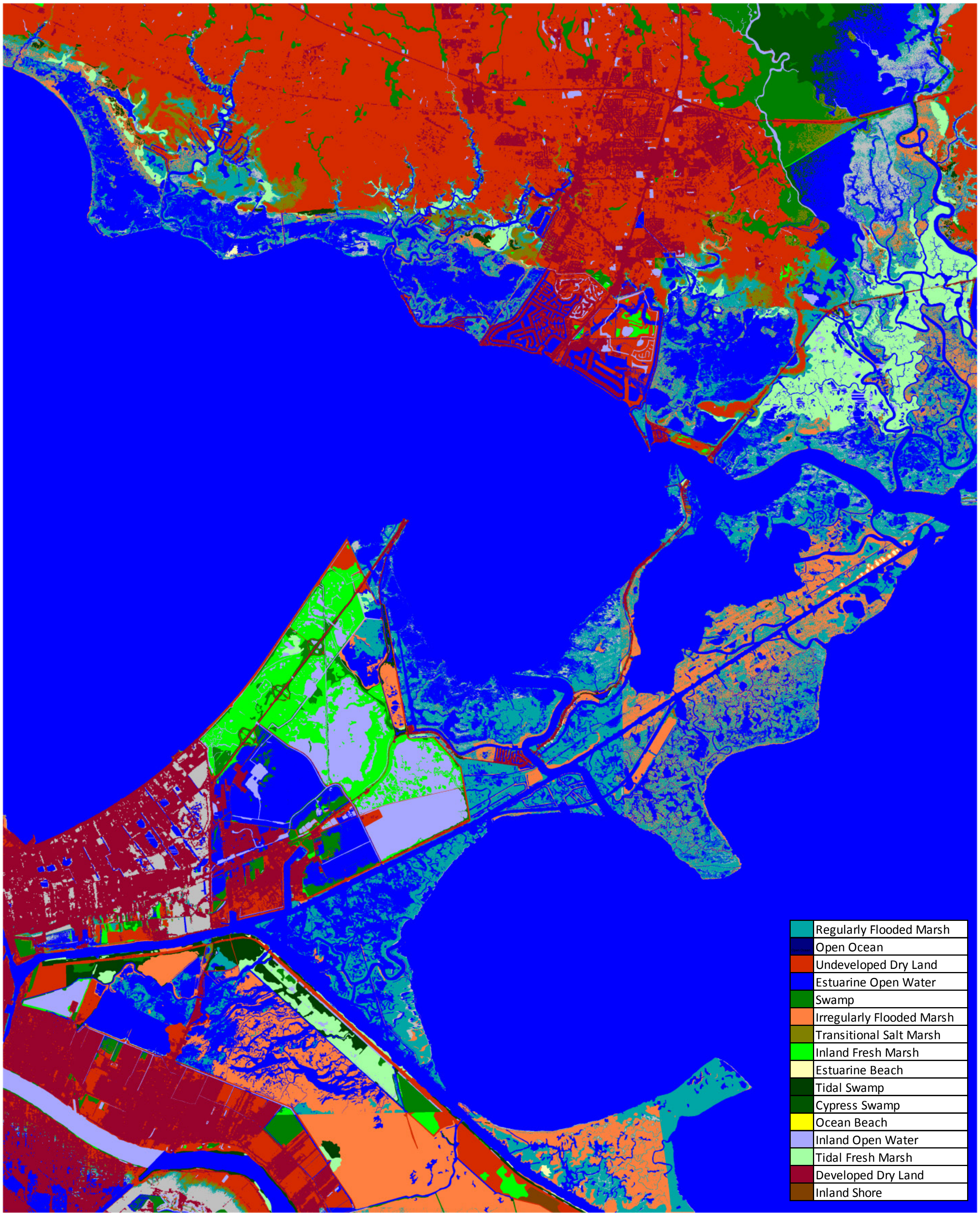
Big Branch Marsh NWR, Initial Condition.



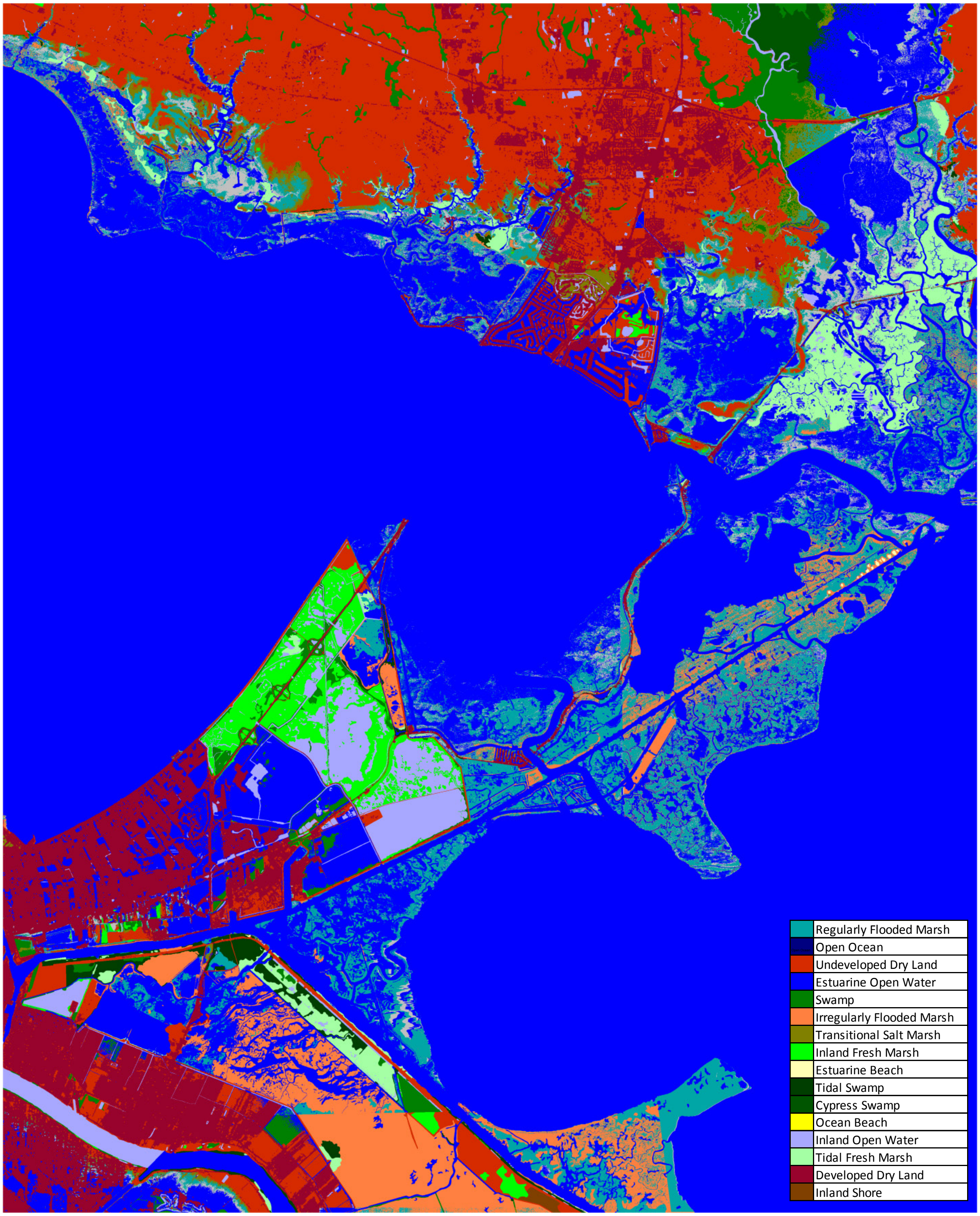
Big Branch Marsh NWR, 2025, Scenario A1B Mean, 0.39 m SLR.



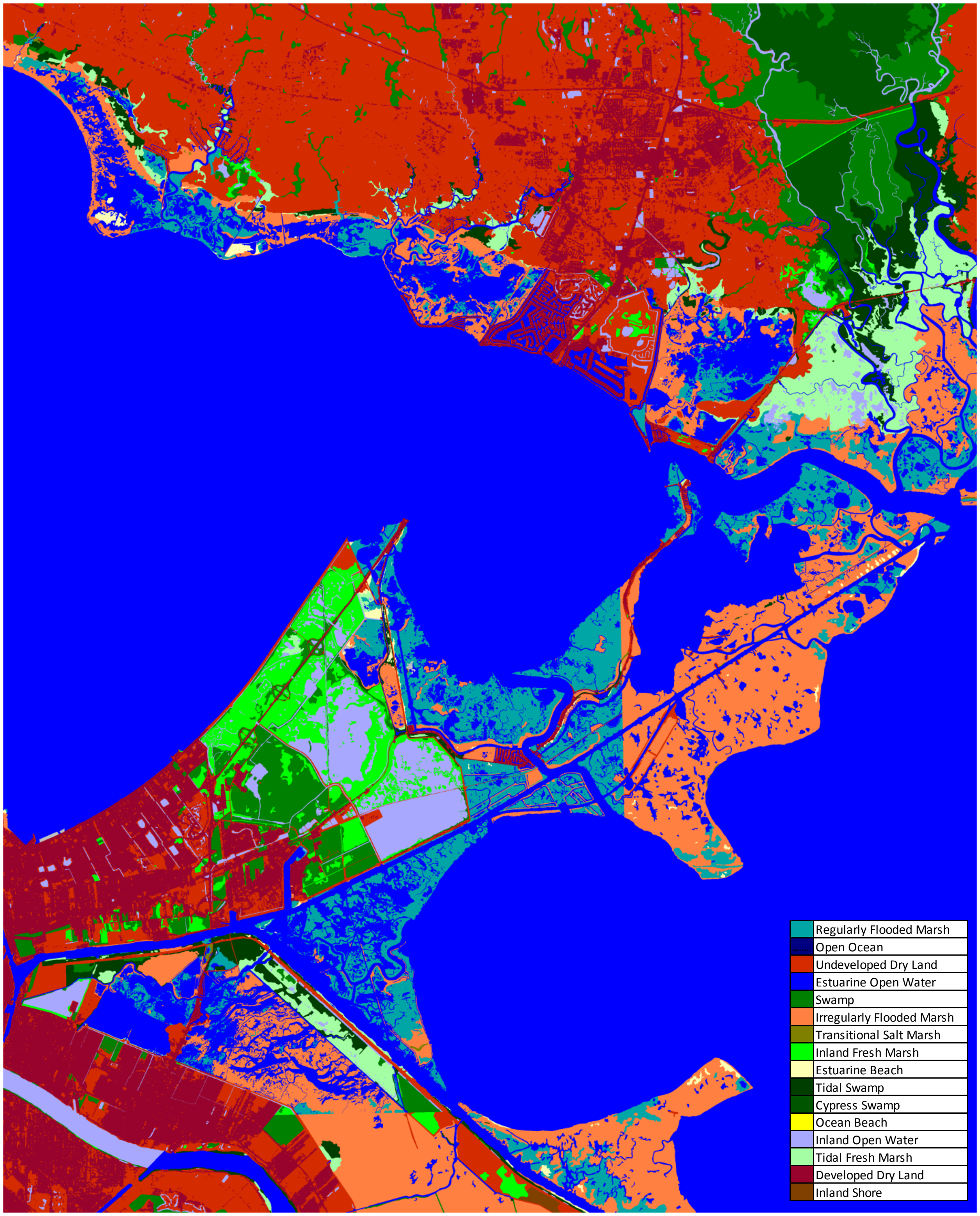
Big Branch Marsh NWR, 2050, Scenario A1B Mean, 0.39 m SLR.



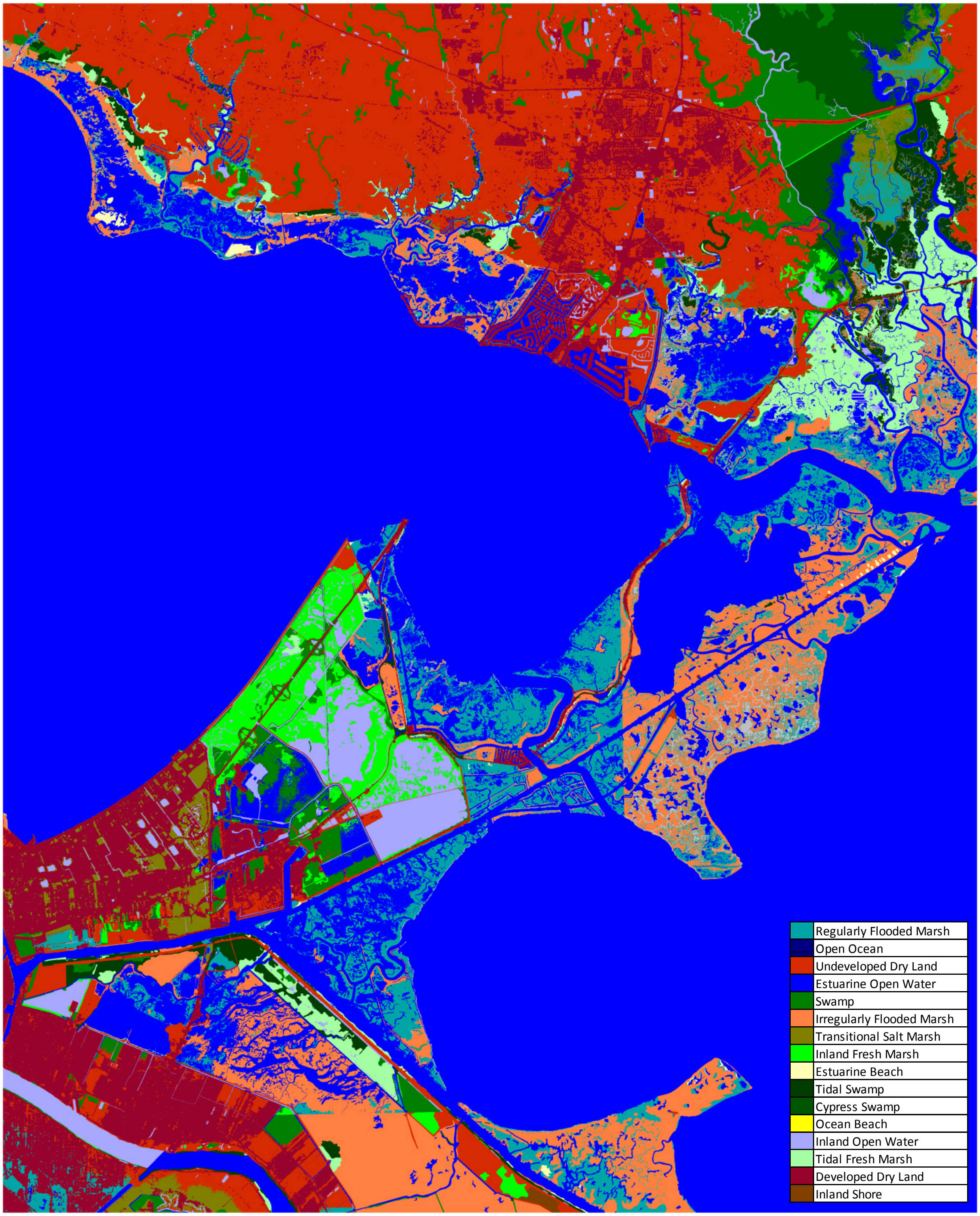
Big Branch Marsh NWR, 2075, Scenario A1B Mean, 0.39 m SLR.



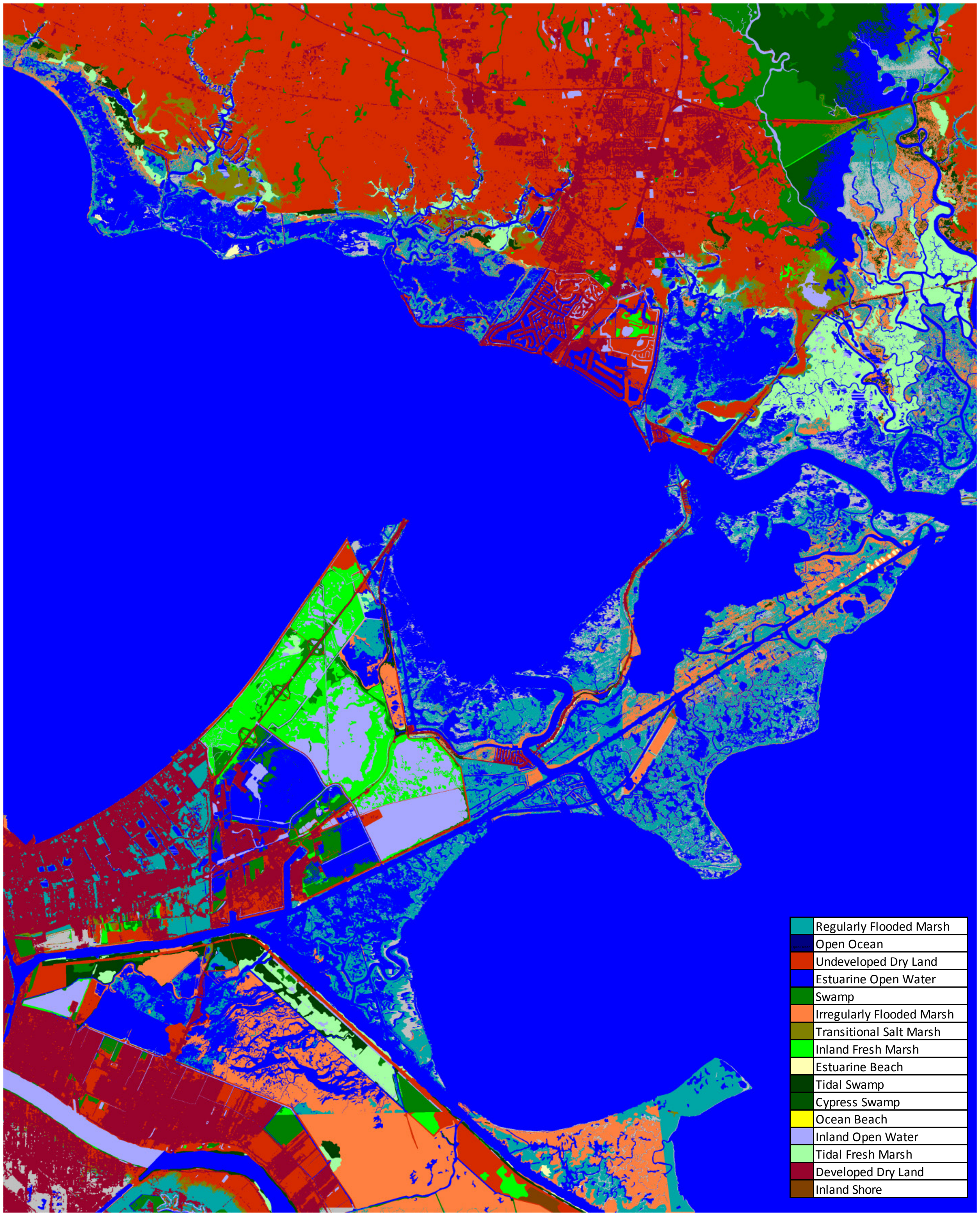
Big Branch Marsh NWR, 2100, Scenario A1B Mean, 0.39 m SLR.



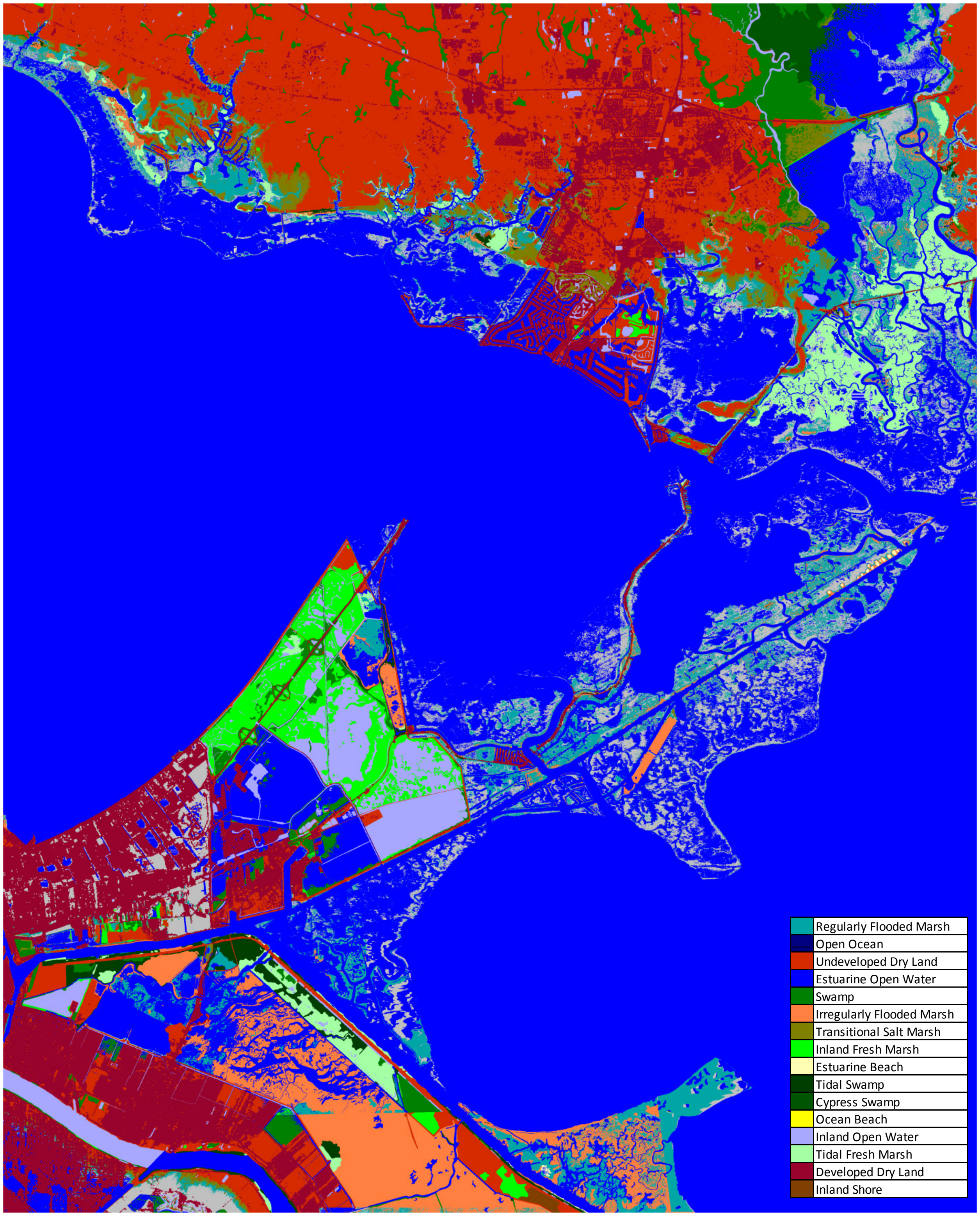
Big Branch Marsh NWR, Initial Condition.



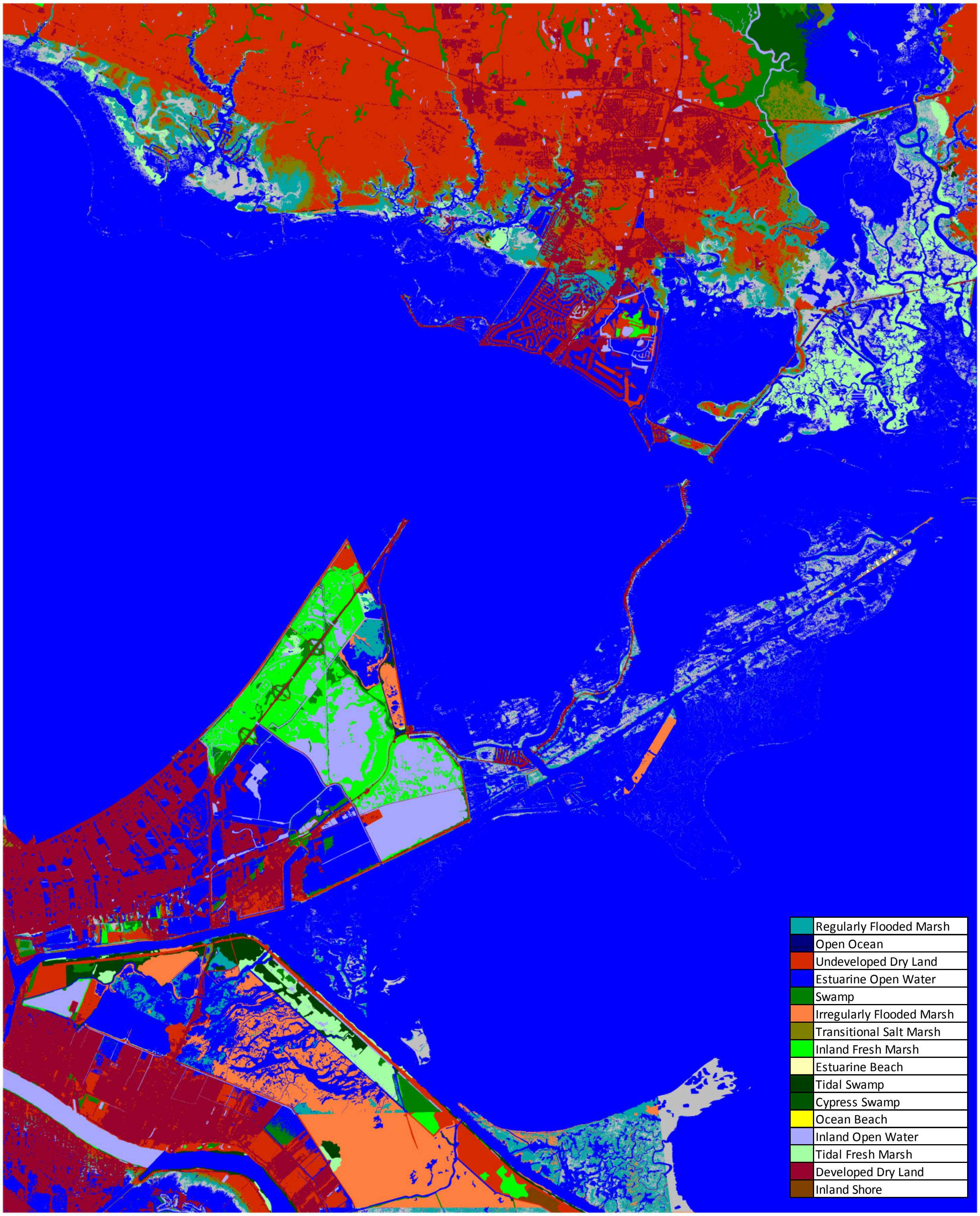
Big Branch Marsh NWR, 2025, Scenario A1B Maximum, 0.69 m SLR.



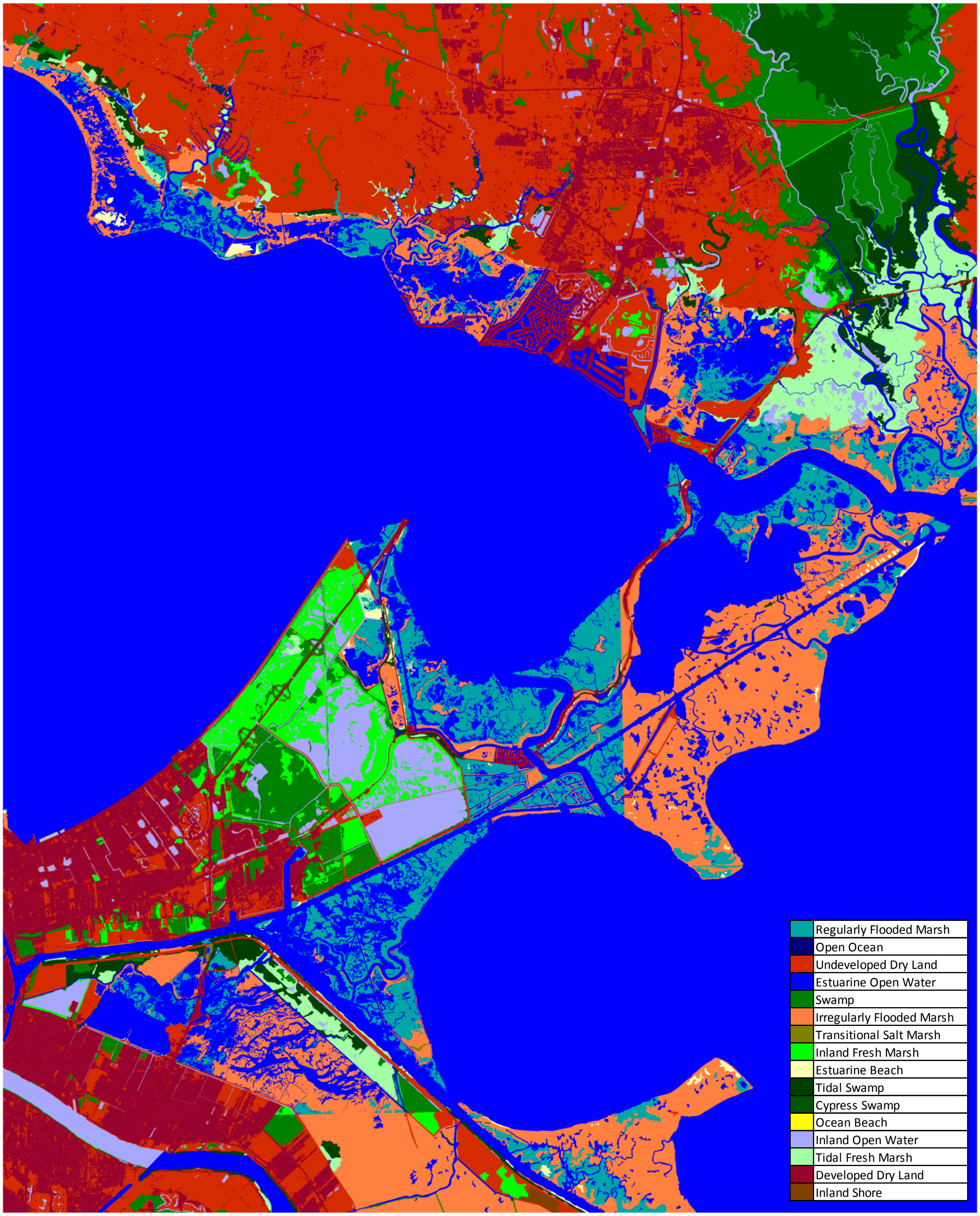
Big Branch Marsh NWR, 2050, Scenario A1B Maximum, 0.69 m SLR.



Big Branch Marsh NWR, 2075, Scenario A1B Maximum, 0.69 m SLR.



Big Branch Marsh NWR, 2100, Scenario A1B Maximum, 0.69 m SLR.



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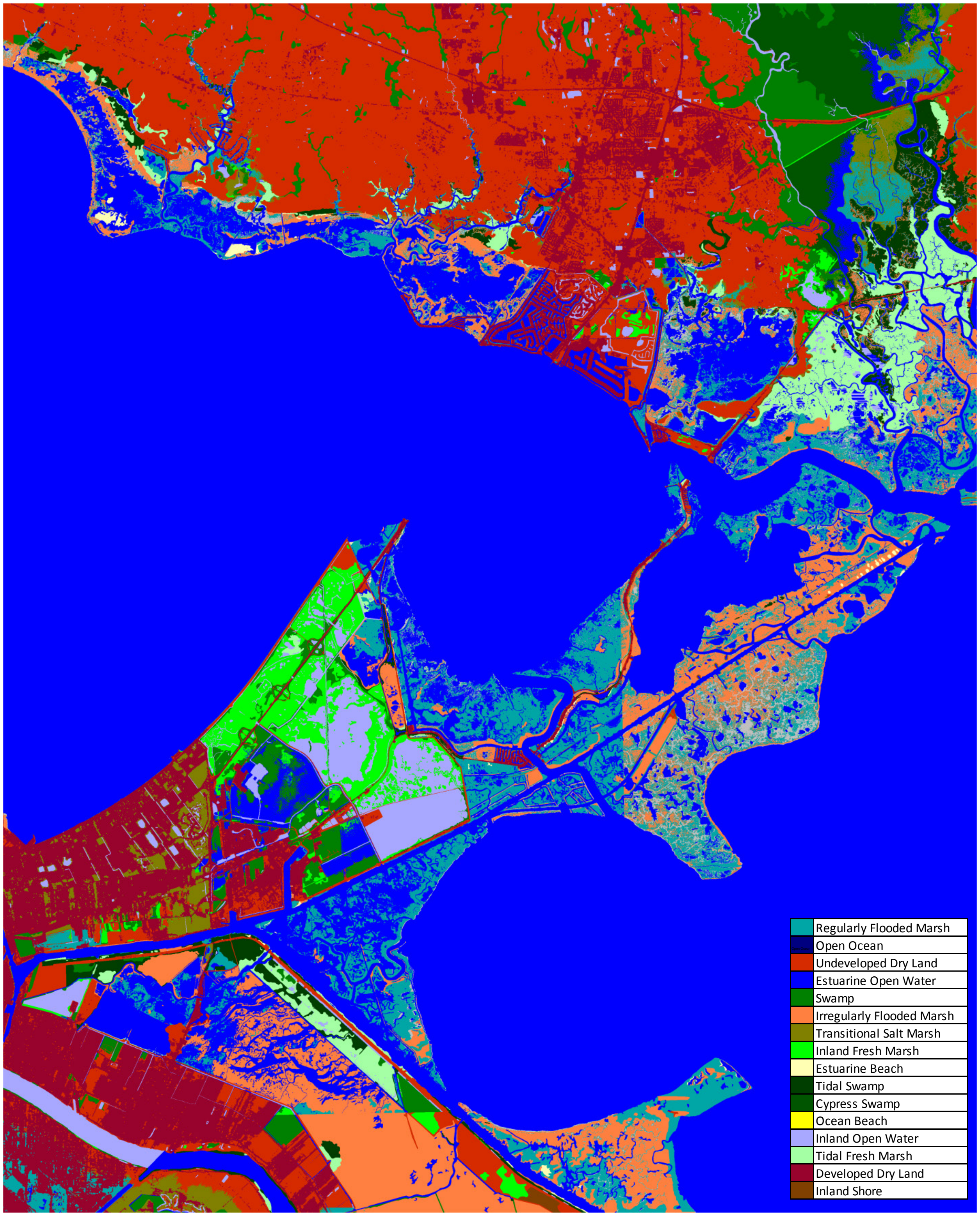
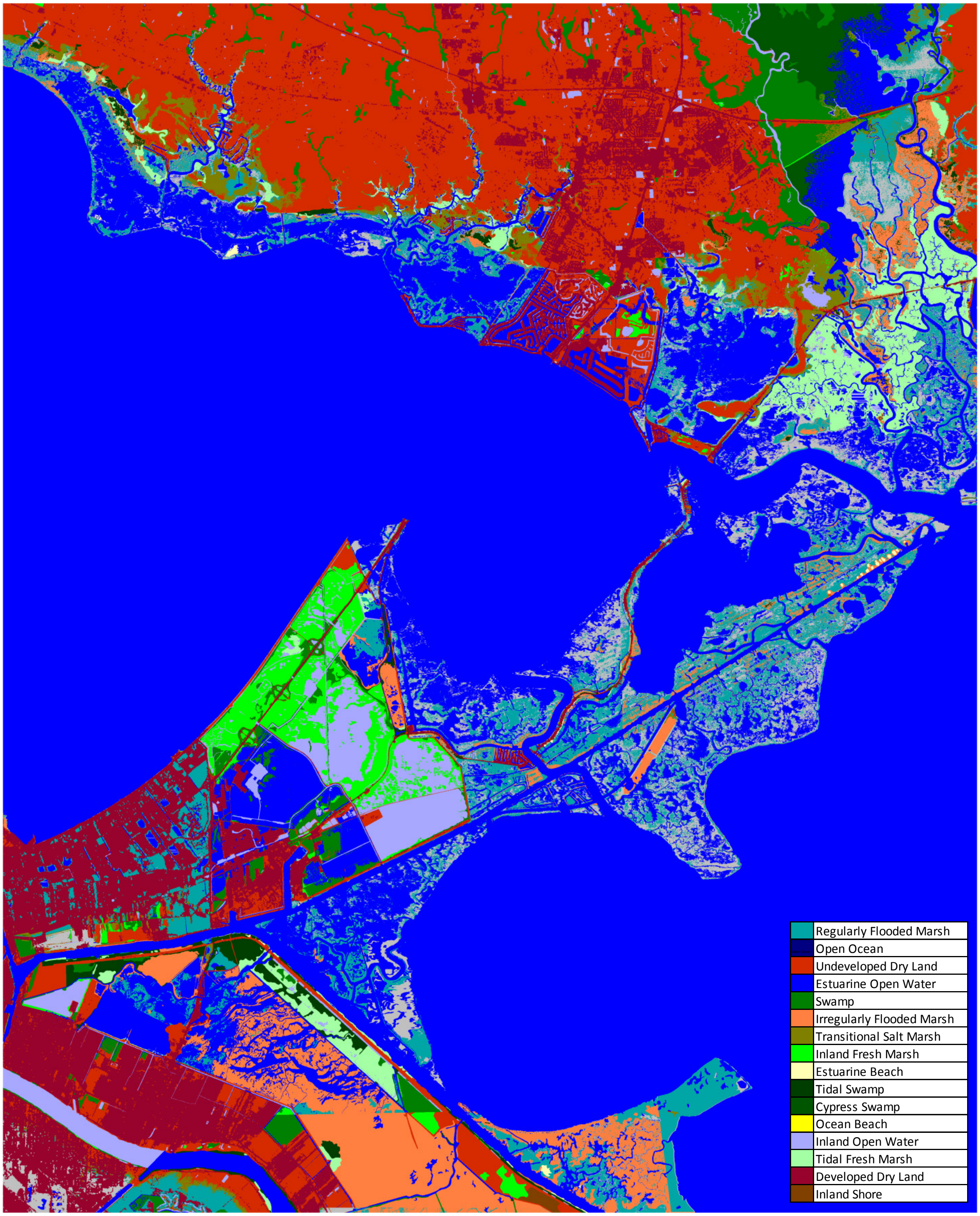
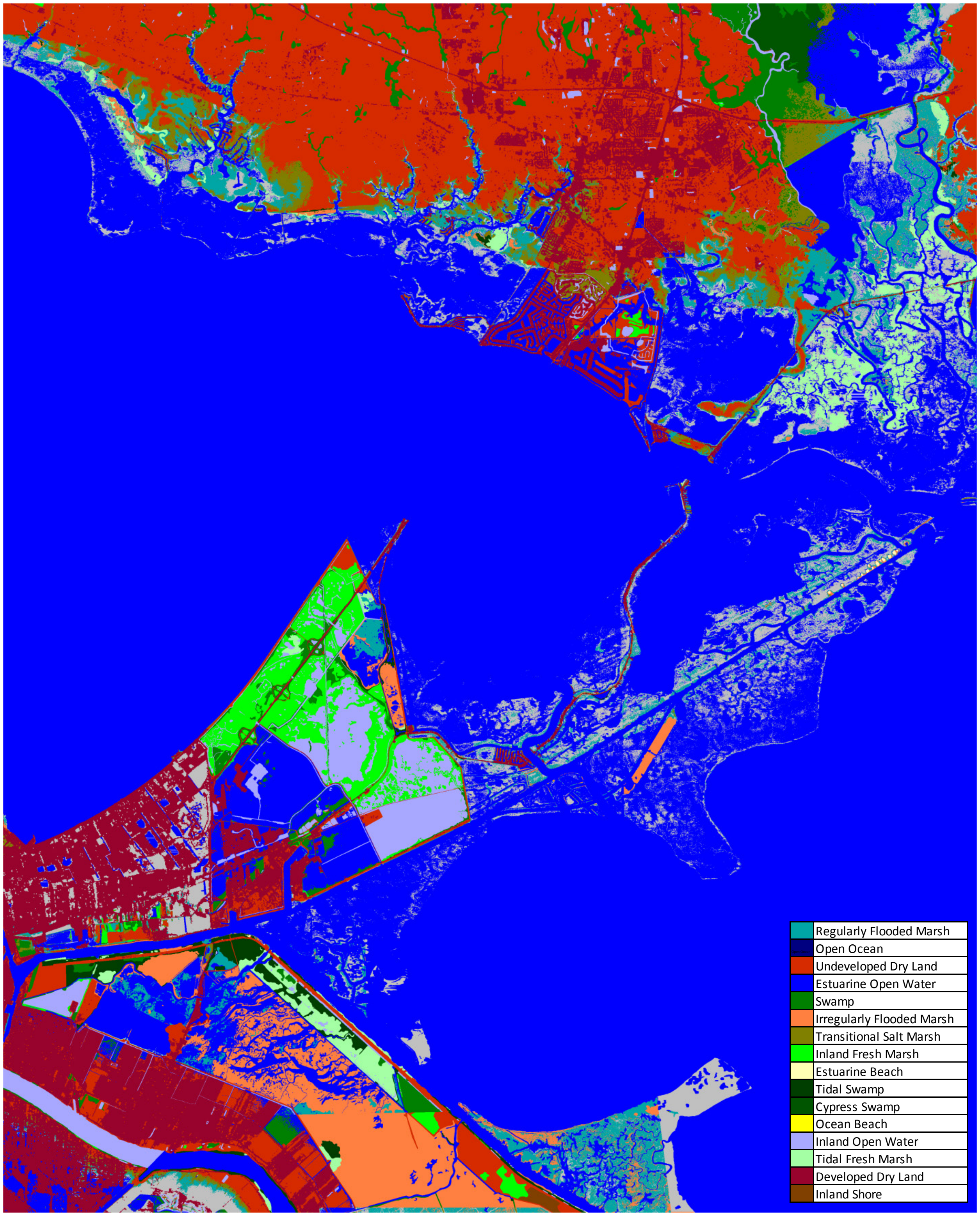


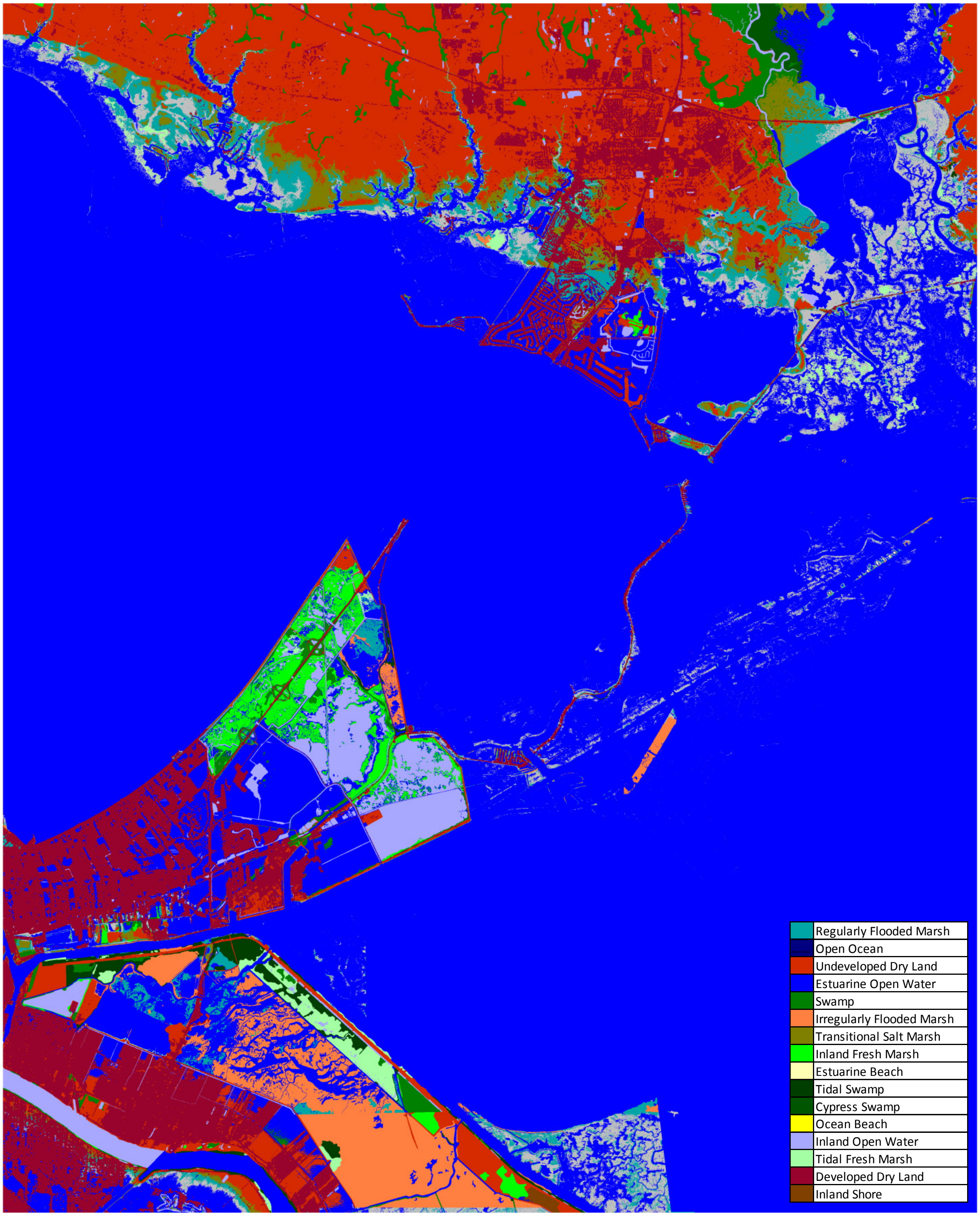
Big Branch Marsh NWR, 2025, 1 m SLR.



Big Branch Marsh NWR, 2050, 1 m SLR.



Big Branch Marsh NWR, 2075, 1 meter.



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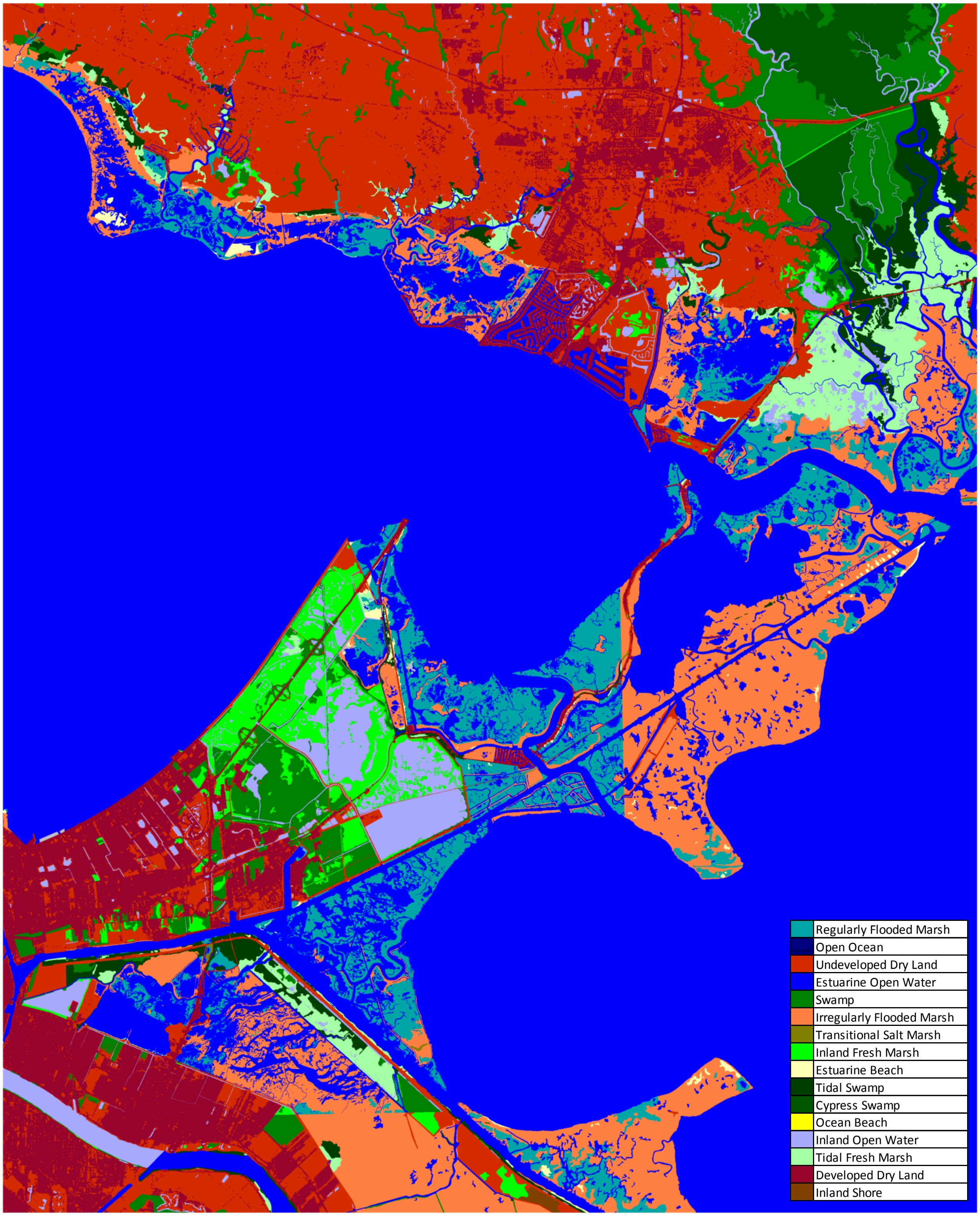

Big Branch Marsh NWR, Initial Condition.

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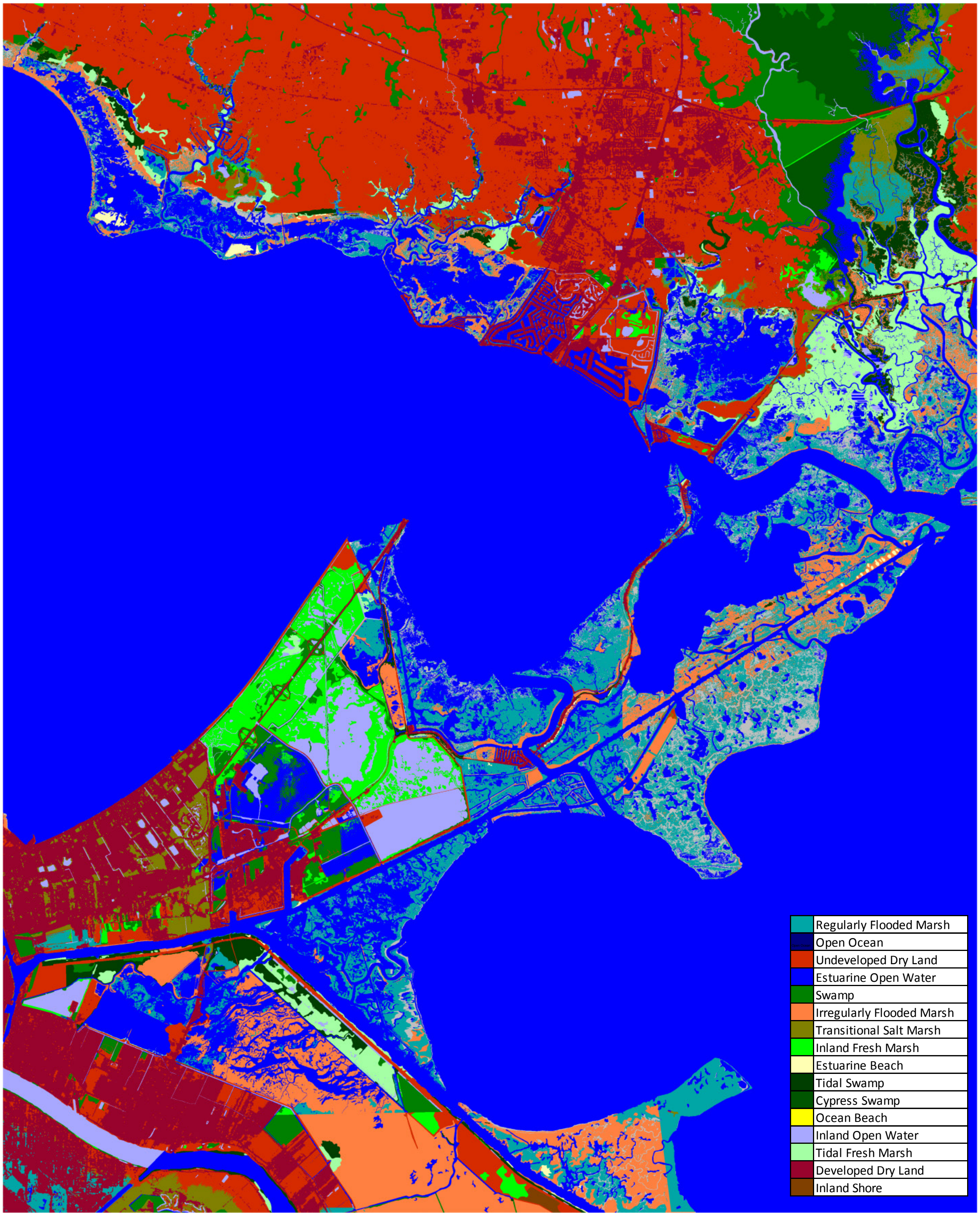
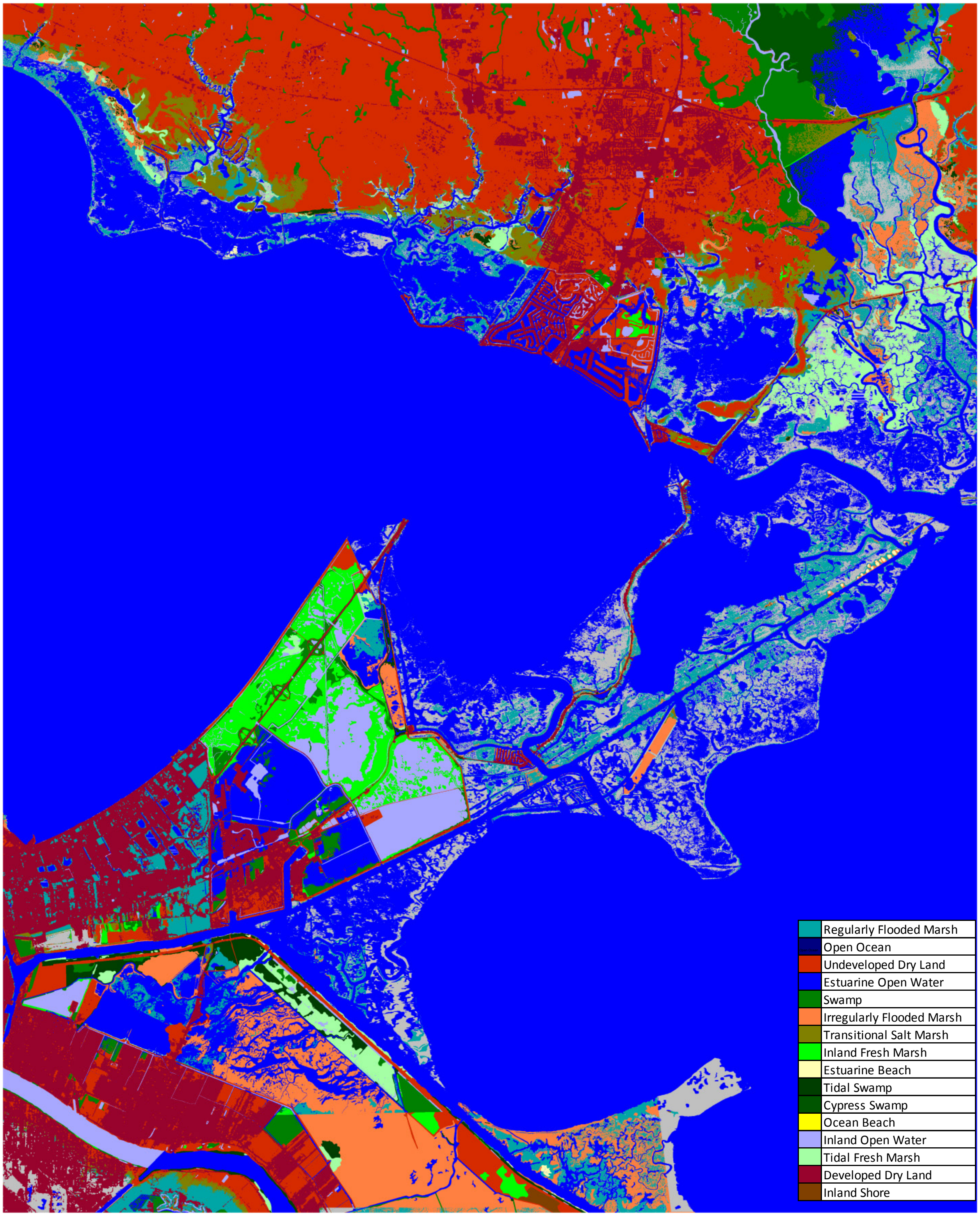
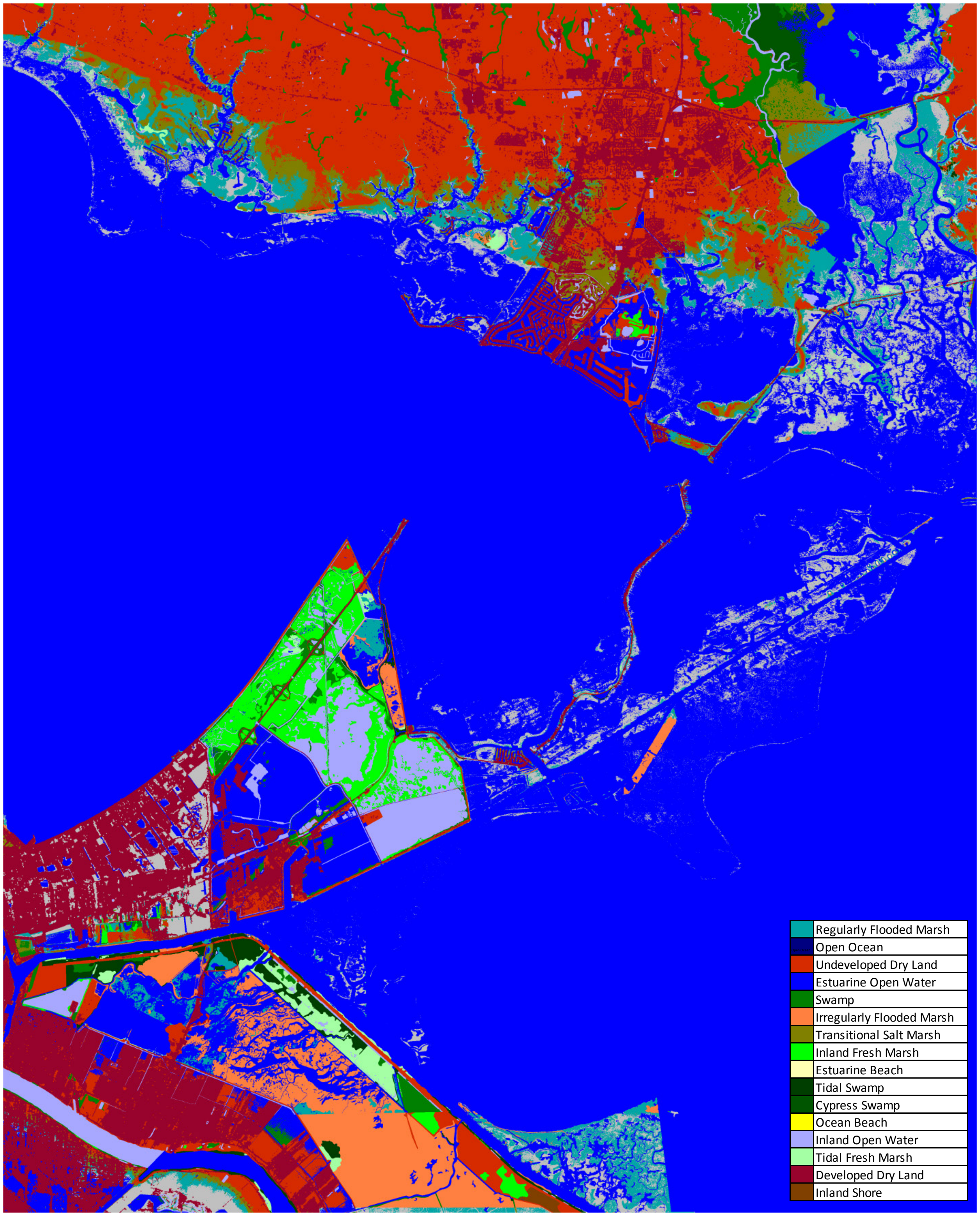


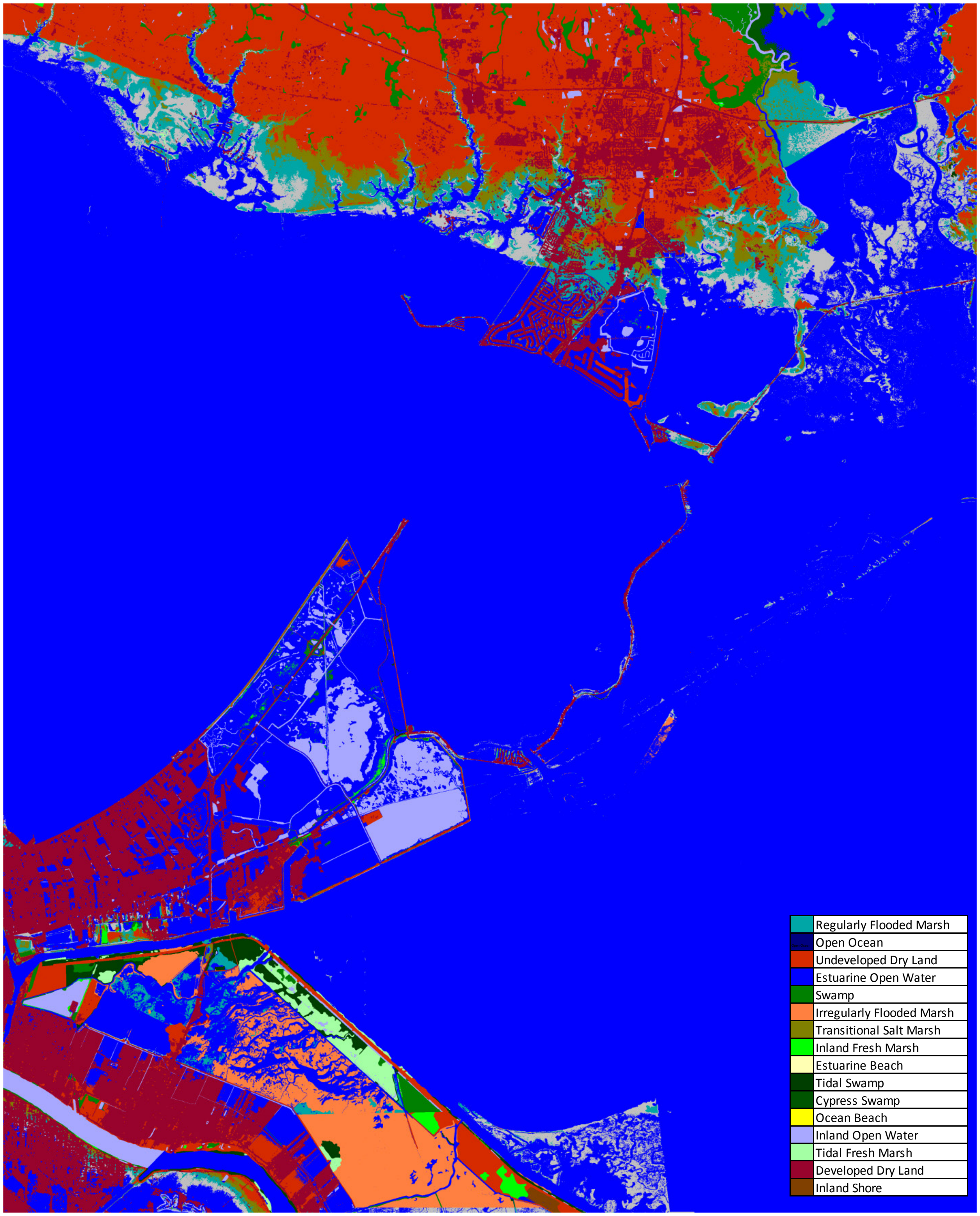
Big Branch Marsh NWR, 2025, 1.5 m SLR.



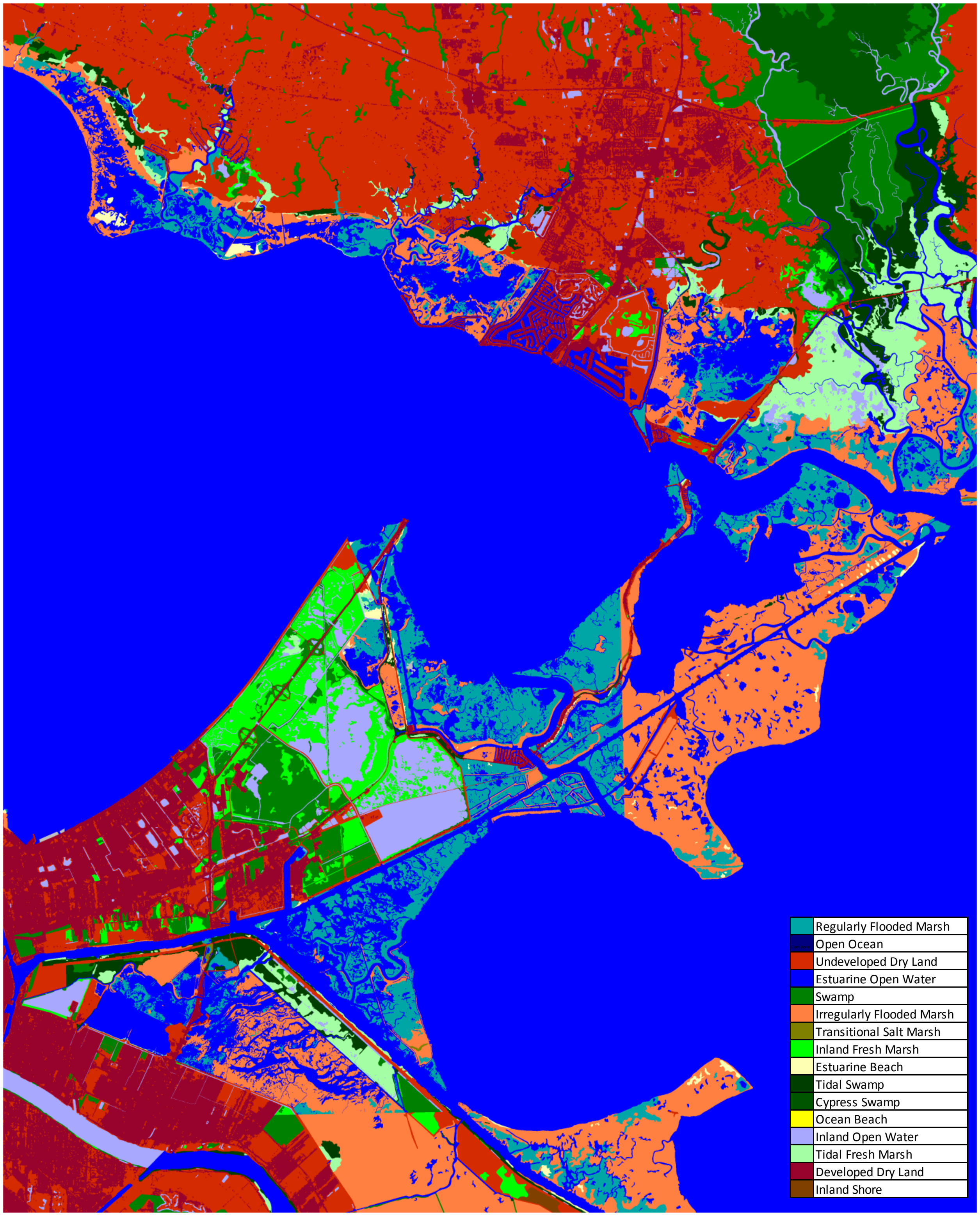
Big Branch Marsh NWR, 2050, 1.5 m SLR.



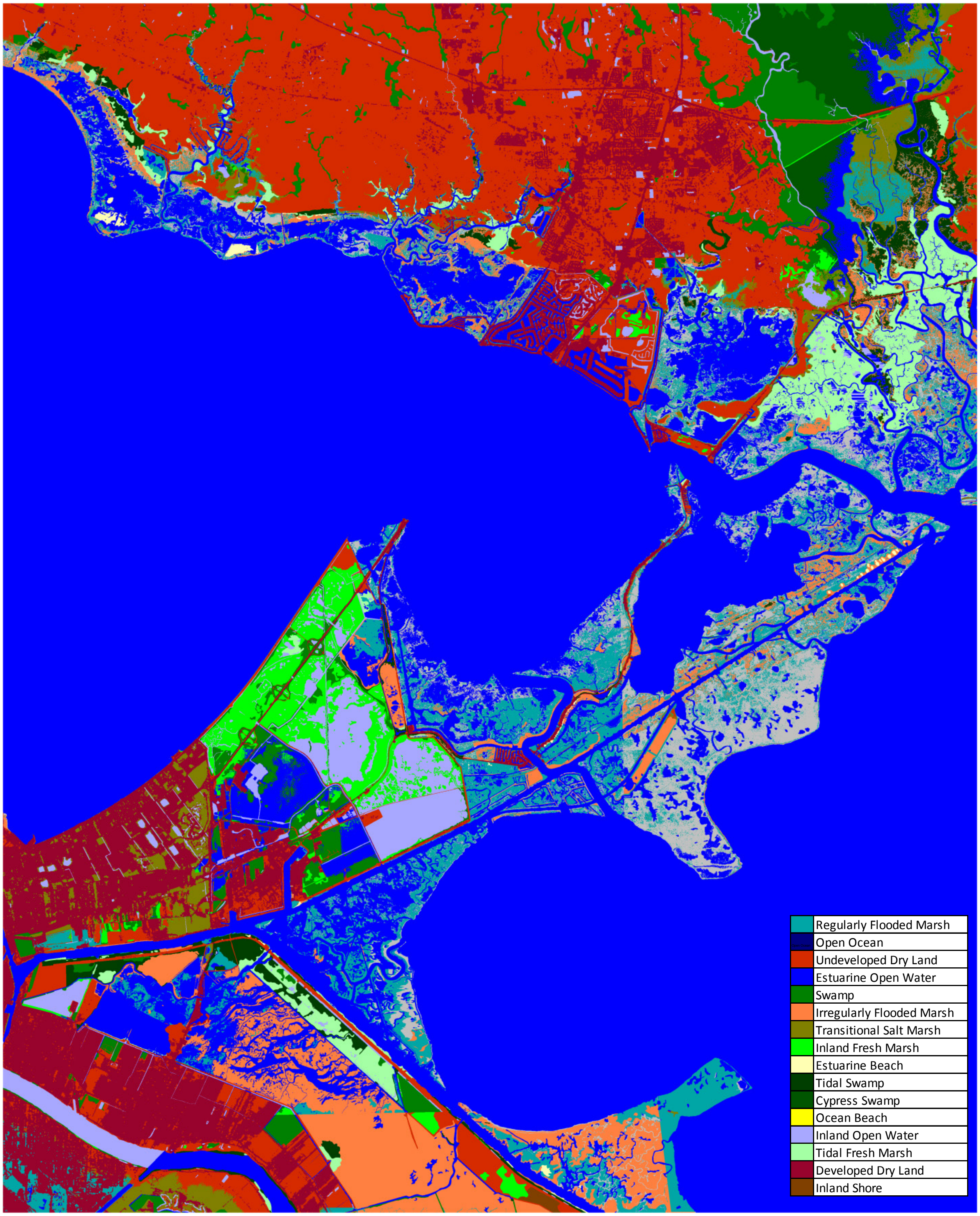
Big Branch Marsh NWR, 2075, 1.5 m SLR.



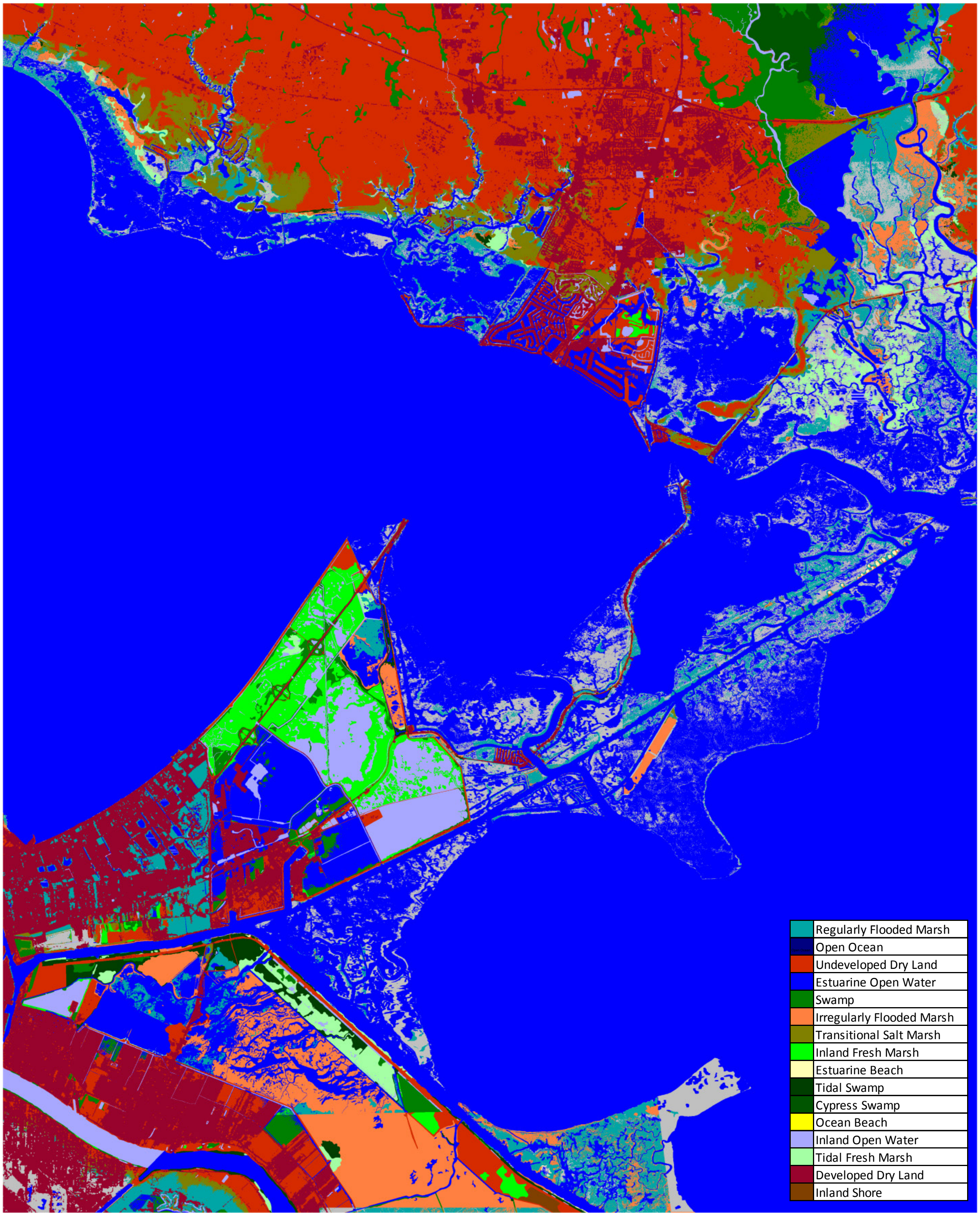
Big Branch Marsh NWR, 2100, 1.5 m SLR.



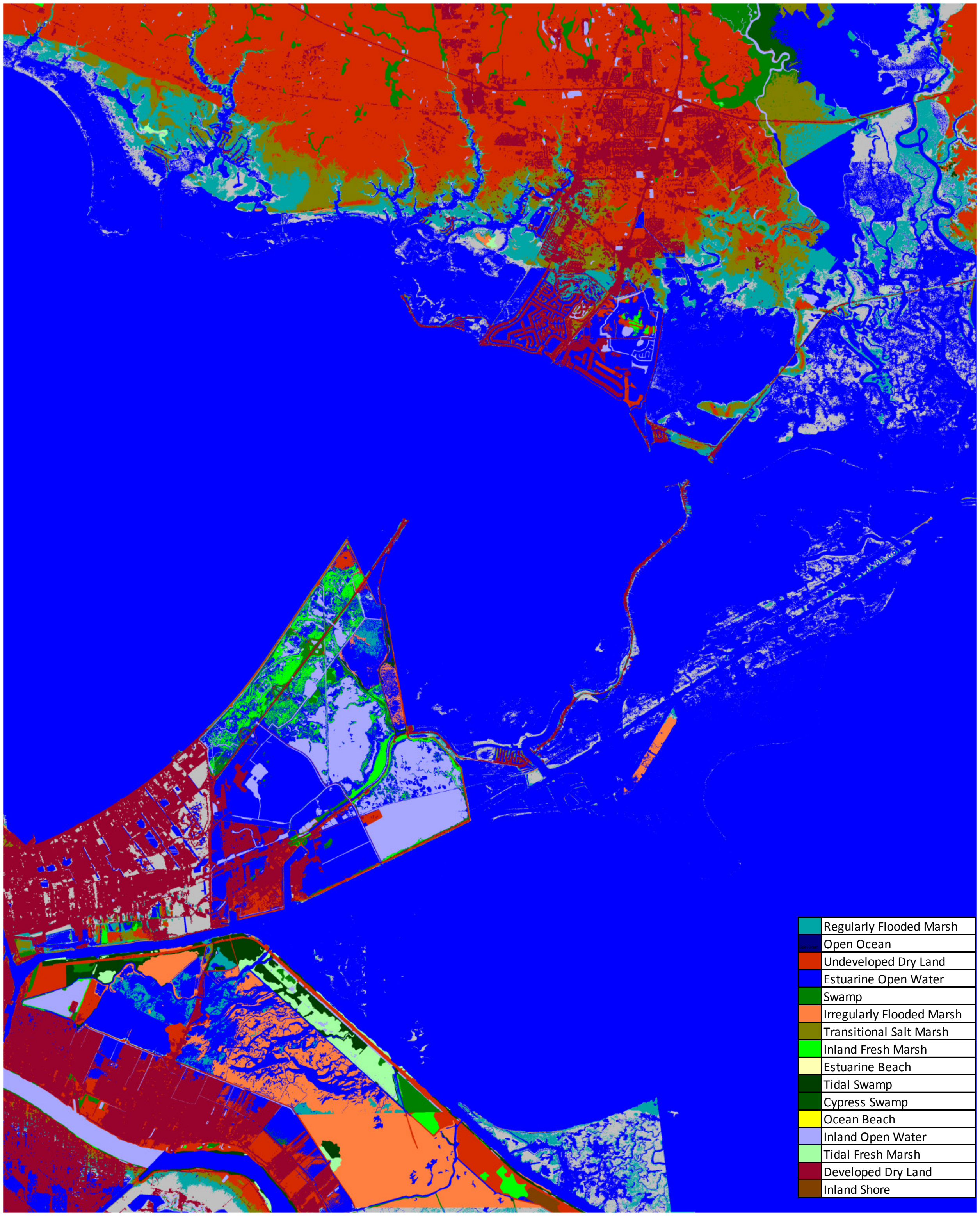
Big Branch Marsh NWR, Initial Condition.



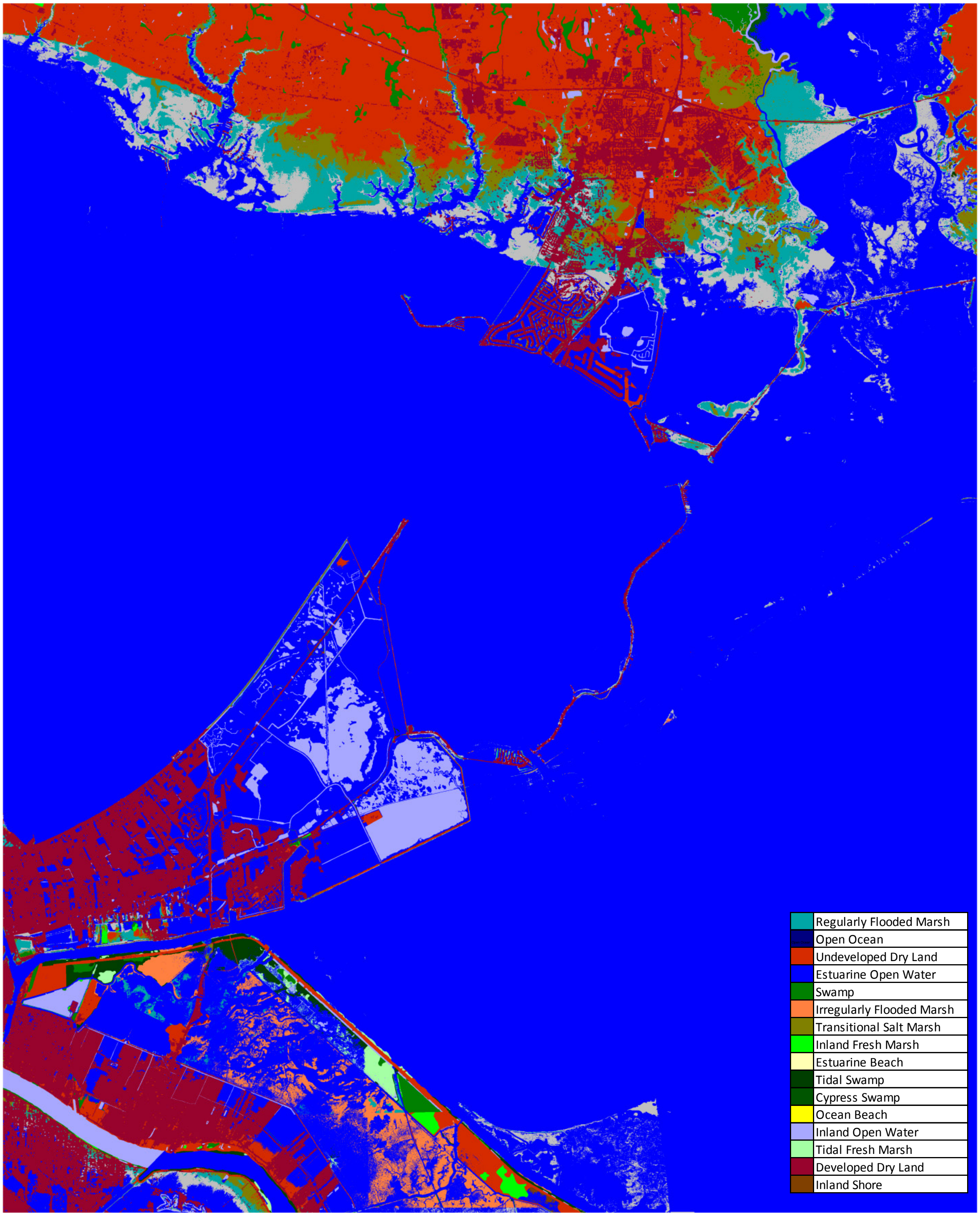
Big Branch Marsh NWR, 2025, 2 m SLR.



Big Branch Marsh NWR, 2050, 2 m SLR.



Big Branch Marsh NWR, 2075, 2 m SLR.



Big Branch Marsh NWR, 2100, 2 m SLR.