Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Ernest F. Hollings ACE Basin 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 plan for and potentially mitigate the effects of sea-level rise on the U.S. National Wildlife Refuge System (Refuge System), the U. S. Fish and Wildlife Service (FWS) uses a variety of analytical approaches, most notably the SLAMM model. FWS conducts some SLAMM analysis in-house and, more commonly, contracts the application of the SLAMM model. In most cases Refuge System SLAMM analyses are designed to assist in the development of comprehensive conservation plans (CCPs), land acquisition plans, habitat management plans, and other land and resource management plans.

This is the second application of SLAMM to ACE Basin NWR. The first application of SLAMM to the refuge, carried out in 2008, did not include LiDAR-derived elevation data. In that application land elevations were derived from a 1974 contour map. The current application uses a bare-earth LiDAR elevation data obtained in 2009 that covers the majority of the refuge.

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. This feedback is used 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 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.

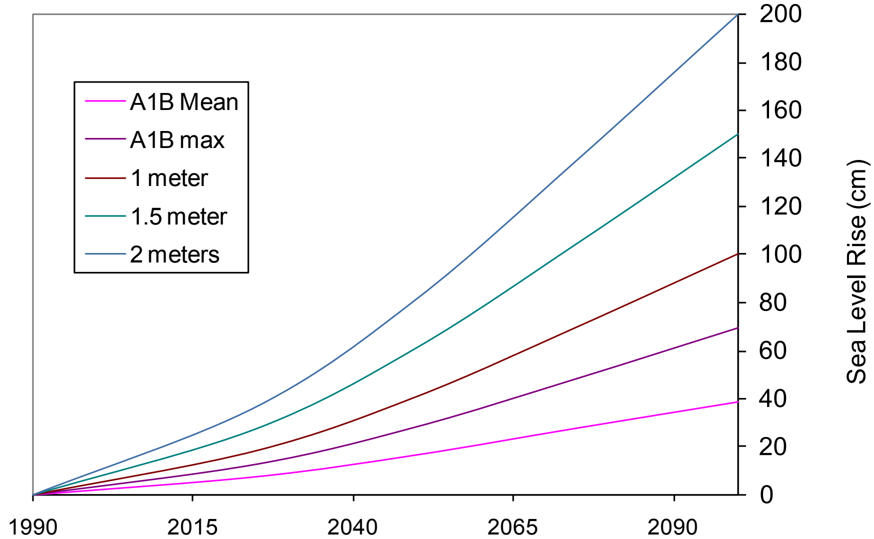

Figure 1. Summary of SLR scenarios utilized.

Data Sources and Methods

Wetland layer.

Figure 2 shows the most recent available wetland layer derived from National Wetland Inventory (NWI) surveys dated 1989 and 2006 for Ernest F. Hollings ACE Basin NWR (henceforth referred to as ACE Basin). Converting the surveys into 10 m x 10 m cells indicated that the approximately 21,065 acre refuge (approved acquisition boundary including water) is composed of the following categories:

Land cover type		Area (acres)	Percentage (%)
	Undeveloped Dry Land	5348	25
	Tidal Fresh Marsh	4002	19
	Tidal Swamp	2469	12
	Swamp	2299	11
	Regularly Flooded Marsh	2232	11
	Irregularly Flooded Marsh	1783	8
	Inland Fresh Marsh	1194	6
	Inland Open Water	684	3
	Estuarine Open Water	525	2
	Riverine Tidal	375	2
	Transitional Salt Marsh	66	<1
	Inland Shore	54	<1
	Estuarine Beach	28	<1
	Developed Dry Land	7	<1
	Total (incl. water)	**21065**	**100**

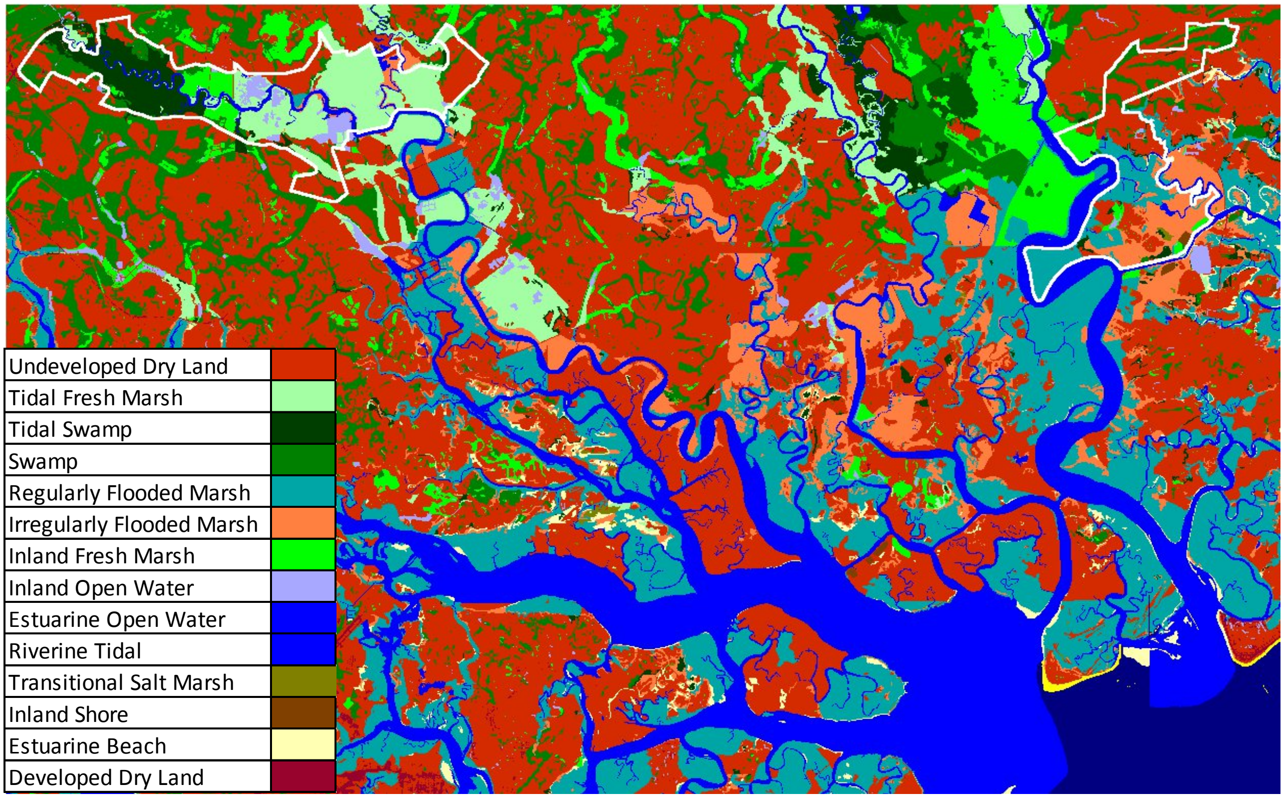

Figure 2. NWI coverage of the study area. Approved refuge boundaries are indicated in white.

Elevation Data. The elevation layer covering the study area is based on LiDAR data collected in 2007 and 2009 by the South Carolina Department of Natural Resources and then converted to bare-earth coverage. LiDAR data were not available for the entire refuge areas therefore NED contour data from 1952 to 1981 were used, as shown in Figure 3 . In areas without LiDAR coverage, the elevation pre-processor module of SLAMM was used to estimate elevations for wetlands as a function of the local tide range.

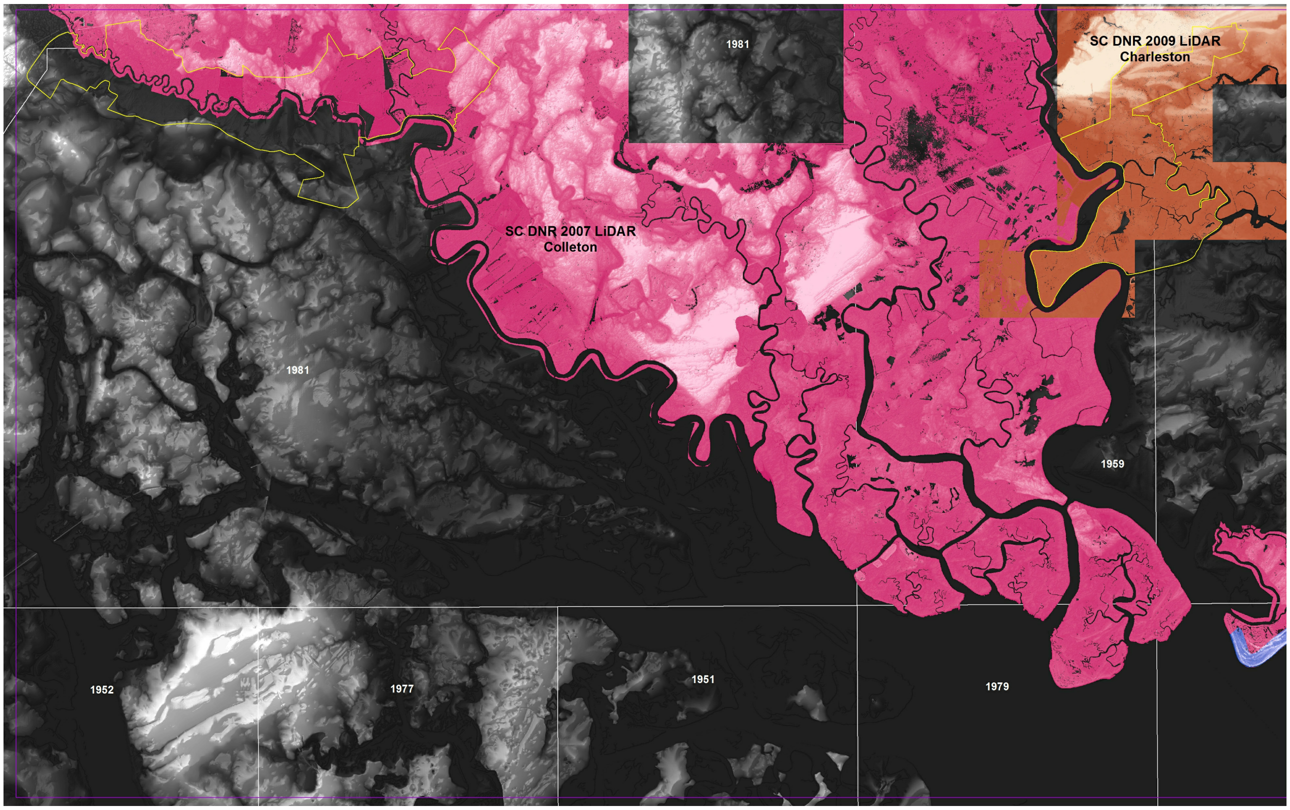

Figure 3. Elevation data applied for Ace Basin simulation

Dikes and Impoundments. According to the National Wetland Inventory, most of the areas protected by dikes or impoundments are outside the refuge, as shown in Figure 4. In addition, the connectivity algorithm was also used in this simulation to capture the effects of any natural or man-made impoundments that may not have been marked as diked in the NWI wetland layer. The connectivity module of SLAMM ensures that dry land only converts to wetland if there is an unimpeded path from open water to the dry land in question.

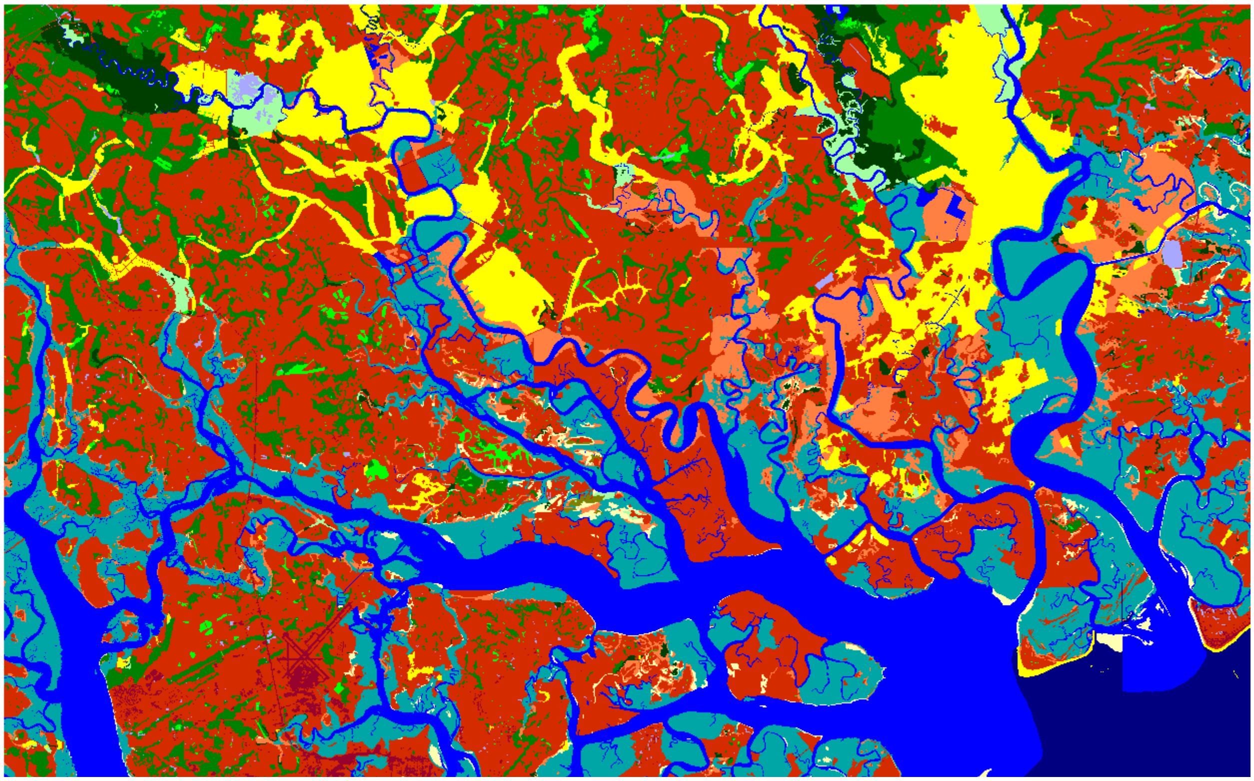
Figure 4. Dikes and impoundments within the study area marked in yellow.

Historic sea level rise rates. The historic trend for relative sea level rise rate applied is 3.07 mm/yr, the average of the mean sea level trends measured at Fort Pulaski, GA (2.98 mm/yr; NOAA gauge # 8670870) and Charleston, SC (3.15 mm/yr; NOAA gauge # 8665530). This rate is somewhat higher than the global (eustatic) SLR for the last 100 years (approximately 1.7 mm/yr), potentially indicating minor subsidence in the region or some other factor causing local SLR to be higher than the global average.

Tide Ranges. The great diurnal range (GT) was estimated at 2 m using the information from NOAA gauge stations in the surrounding area. This value was also used in the previous application of SLAMM to Ace Basin.

Salt elevation. This parameter within SLAMM designates the boundary between wet and dry lands or saline wetlands and fresh water wetlands. Based on regional data for this application, salt elevation was estimated at 1.3 Half Tide Units (HTU), corresponding to 1.3 m above MTL in the area within the refuge.

Accretion rates. Accretion rates in regularly-flooded and irregularly-flooded marshes were set to 1.9 mm/year and 4.3 mm/yr respectively. Rates in tidal fresh and inland fresh marshes to 4.8 mm/year. These values were derived from studies conducted in Georgia marshes (Craft 2008) and are the same as those used in the 2008 application of SLAMM 5 to Ace Basin NWR.

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Erosion rates. Horizontal erosion of marshes and swamps occurs in SLAMM only at the wetland-to-open-water interface and only when adequate open water (fetch) exists for wave setup. Due to a lack of site-specific data, erosion rates for swamps and marshes were set to the SLAMM defaults of 1 m/yr and 2 mm/yr, respectively, while tidal flat erosion was set to 6 m/yr as used in the previous application of SLAMM 5 to Ace Basin NWR.

Elevation correction. MTL to NAVD88 correction is quite variable over the study area (ranging from -0.17 m to 0.23 m). Therefore a raster of elevation corrections was created using the NOAA VDATUM software and incorporated into model simulations.

Model Timesteps. Model forecast data is output for years 2025, 2050, 2075 and 2100 with the initial condition date set to 2006, the most recent wetland data available

Refuge boundaries. Modeled USFWS refuge boundaries for South Carolina are based on Approved Acquisition Boundaries as published on the USFWS National Wildlife Refuge Data and Metadata website. The cell-size used for this analysis is 10 m.

Input subsites and parameter summary. Table 1 summarizes all SLAMM input parameters for the study area. Values for parameters with no specific local information were kept at the model default value.

Table 1. Summary of SLAMM input parameters for ACE Basin NWR.

Parameter	Value applied	Notes
NWI Photo Date (YYYY)	1989/2006	Variable based on subsite
DEM Date (YYYY)	1957-2009	Variable based on subsite
Direction Offshore [n,s,e,w]	East	
Historic Trend (mm/yr)	3.07	
Historic Eustatic Trend (mm/yr)	1.7	
MTL-NAVD88 (m)	N/A	Cell-by-cell values applied
GT Great Diurnal Tide Range (m)	2	
Salt Elev. (m above MTL)	1.33	
Marsh Erosion (horz. m /yr)	2	Used in previous SLAMM application
Swamp Erosion (horz. m /yr)	1	Used in previous SLAMM application
T.Flat Erosion (horz. m /yr)	6	Used in previous SLAMM application
Reg.-Flood Marsh Accr (mm/yr)	1.9	Used in previous SLAMM application
Irreg.-Flood Marsh Accr (mm/yr)	4.3	Used in previous SLAMM application
Tidal-Fresh Marsh Accr (mm/yr)	4.8	Used in previous SLAMM application
Inland-Fresh Marsh Accr (mm/yr)	4.8	Used in previous SLAMM application
Mangrove Accr (mm/yr)	7	SLAMM Default
Tidal Swamp Accr (mm/yr)	1.1	SLAMM Default
Swamp Accretion (mm/yr)	0.3	SLAMM Default
Beach Sed. Rate (mm/yr)	0.5	SLAMM Default
Freq. Overwash (years)	25	Used in previous SLAMM application
Use Elev Pre-processor [True,False]	TRUE where no LiDAR data available FALSE where LiDAR data available	

Changes to the SLAMM conceptual model

Based on the areas with LiDAR elevation data, the SLAMM conceptual model was adjusted to better represent the locations of certain land-cover types in the tidal frame. The minimum elevations of Tidal Fresh Marsh and Tidal Swamp were decreased based on the 5th percentiles of the LiDAR-derived elevations of these categories. In addition, the lower bound of Inland-Fresh Marsh was reduced from the salt elevation to 1 HTU. These changes improved the "time zero" calibration of the model.

Calibration of the initial conditions

Initially, SLAMM simulates a "time zero" step, in which the consistency of model assumptions for wetland elevations is validated with respect to available wetland coverage information, elevation data and tidal frames. Due to simplifications within the SLAMM conceptual model, DEM and wetland layer uncertainty, or other local factors, some cells may fall below their lowest allowable elevation category and would be immediately converted by the model to a different land cover category. For example, an area categorized in the wetland layer as swamp that would be regularly inundated by tidal water according to its elevation and tidal information will be converted to a tidal marsh. These cells represent outliers on the distribution of elevations for a given land-cover type. SLAMM predictions suggest that 760 acres of dry land and swamp are currently inundated frequently enough to start transitioning to salt marsh as shown in the dry-land, swamp, and transitional-salt-marsh categories (presented in the table below).

Because of these differences, predicted gains and losses of wetland categories are made with respect to the initial coverage predicted by SLAMM at time zero. These results are summarized in the following table as "SLAMM 2006."

	Land-cover Type	Initial (Acres)	Time Zero 2006 (Acres)	Difference
	Undeveloped Dry Land	5348	4774	10.7%
	Tidal Fresh Marsh	4002	3965	0.9%
	Tidal Swamp	2469	2446	0.9%
	Swamp	2299	2079	9.5%
	Regularly Flooded Marsh	2232	2364	-5.9%
	Irregularly Flooded Marsh	1783	1728	3.1%
	Inland Fresh Marsh	1194	1191	0.3%
	Inland Open Water	684	671	1.9%
	Estuarine Open Water	525	565	-7.7%
	Riverine Tidal	375	349	6.9%
	Transitional Salt Marsh	66	832	-1156.6%

Results

Percentage losses by 2100 for each land-cover type given different SLR scenarios are presented in Table 2. As discussed above, land-cover losses are calculated in comparison to the "time zero" or "SLAMM 2006" wetland coverage.

The predominant land-cover types in the refuge at present are dry land, tidal-fresh marsh, tidal swamp, regularly-flooded marsh, and swamp. Each of these land-cover categories are predicted to suffer losses under each accelerated SLR scenario examined with the exception regularly-flooded marsh. Increases in regularly-flooded marsh are predicted, with a maximum increase occurring under the 1 m SLR by 2100 scenario and then a loss of 13% as compared to the 2006 condition predicted under the 2 m by 2100 scenario. A small increase in irregularly-flooded marsh is also observed under the 0.39 m by 2100 scenario (IPCC A1B Mean scenario). These increases are predicted to occur as low-lying dry lands are converted to marshes.

Despite the increase in irregularly-flooded or brackish marsh under the 0.39 m SLR by 2100 scenario, this wetland type, along with tidal swamp, is predicted to undergo the highest losses under the highest SLR scenarios. Under the 1 m SLR by 2100 scenario, both irregularly-flooded marsh and tidal swamp are predicted to lose more than 50% of their initial coverage by 2100. Tidal fresh and inland fresh marshes in the refuge appear relative resilient to SLR at the lower scenarios examined, but are predicted to sustain losses greater than 40% under the 2 m of SLR by 2100 scenario.

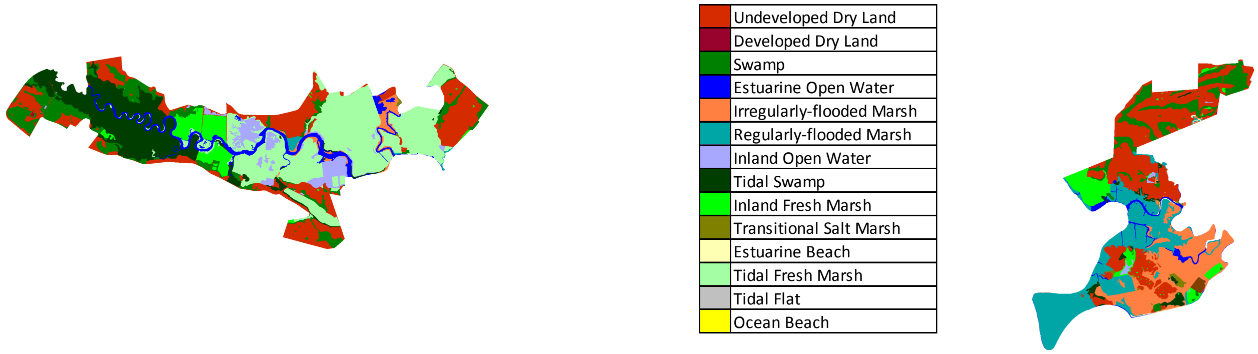
Table 2. Predicted loss rates of land categories by 2100 given simulated scenarios of eustatic SLR at ACE Basin NWR.

Land cover category	2006 predicted coverage (acres)	Land cover loss by 2100 for different SLR scenarios				
		0.39 m	0.69 m	1 m	1.5 m	2 m
Undeveloped Dry Land	4774	13%	23%	30%	40%	48%
Tidal Fresh Marsh	3965	0%	3%	7%	13%	44%
Tidal Swamp	2446	14%	42%	57%	71%	82%
Regularly Flooded Marsh	2364	-28%	-92%	-109%	-37%	13%
Swamp	2079	24%	34%	41%	54%	68%
Irregularly Flooded Marsh	1728	-4%	5%	60%	78%	77%
Inland Fresh Marsh	1191	0%	1%	2%	6%	45%

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

Results in Acres

		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	5348	4693	4559	4364	4152
	Tidal Fresh Marsh	4002	3965	3965	3963	3956
	Tidal Swamp	2469	2423	2352	2241	2100
	Swamp	2299	1986	1884	1694	1575
	Regularly Flooded Marsh	2232	2699	2712	2804	3026
	Irregularly Flooded Marsh	1783	1728	1775	1792	1790
	Inland Fresh Marsh	1194	1191	1191	1190	1190
	Inland Open Water	684	525	525	522	515
	Estuarine Open Water	525	885	932	964	994
	Riverine Tidal	375	175	132	111	96
	Transitional Salt Marsh	66	688	904	1243	1449
	Inland Shore	54	54	54	54	54
	Estuarine Beach	28	28	28	28	28
	Developed Dry Land	7	7	7	6	6
	Total (incl. water)	**21065**	**21065**	**21065**	**21065**	**21065**

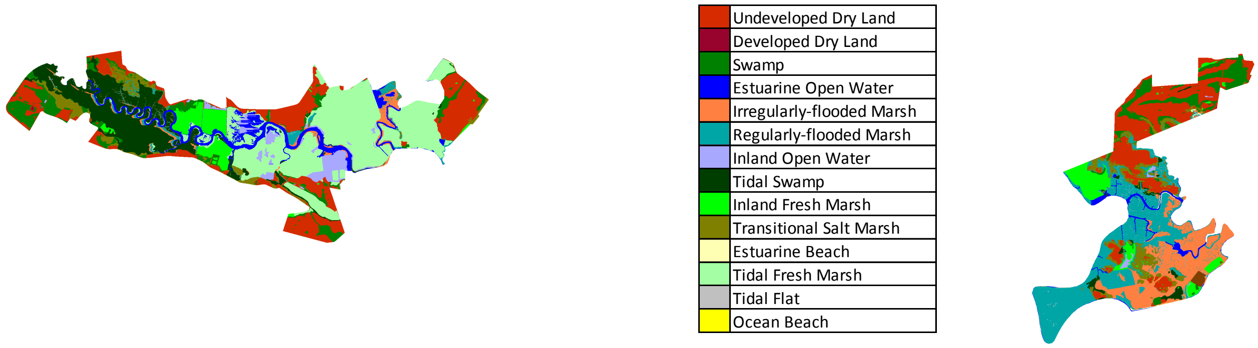


ACE Basin NWR, Initial Condition.

ACE Basin NWR, SLAMM 2006.

ACE Basin NWR, 2025, Scenario A1B Mean, 0.39 m SLR

ACE Basin NWR, 2050, Scenario A1B Mean, 0.39 m SLR by 2100.



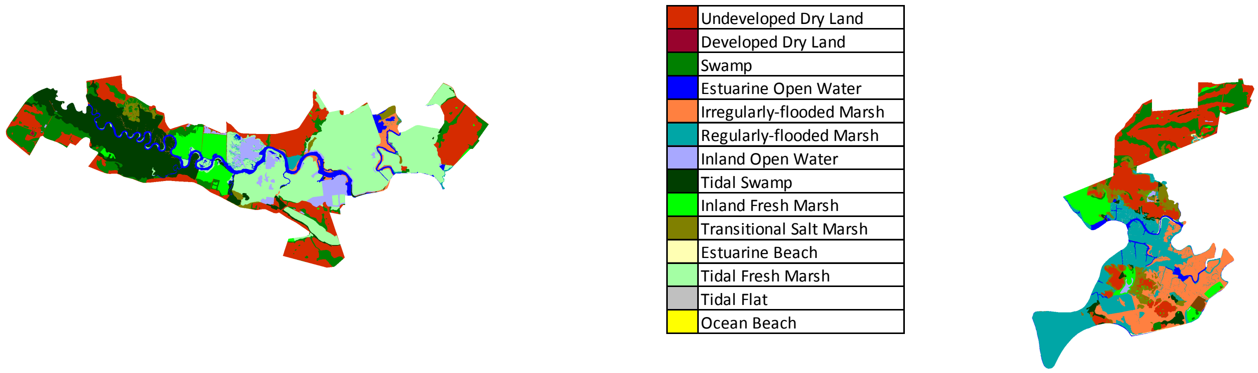
ACE Basin NWR, 2075, Scenario A1B Mean, 0.39 m SLR by 2100.

ACE Basin NWR, 2100, Scenario A1B Mean, 0.39 m SLR by 2100.

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

Results in Acres

		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	5348	4639	4416	4059	3640
	Tidal Fresh Marsh	4002	3957	3934	3895	3851
	Tidal Swamp	2469	2401	2259	1939	1417
	Swamp	2299	1950	1744	1531	1363
	Regularly Flooded Marsh	2232	2780	2950	3461	4573
	Irregularly Flooded Marsh	1783	1724	1746	1735	1633
	Inland Fresh Marsh	1194	1190	1190	1188	1184
	Inland Open Water	684	523	520	493	472
	Estuarine Open Water	525	897	962	1036	1164
	Riverine Tidal	375	166	117	87	54
	Transitional Salt Marsh	66	721	1040	1351	1097
	Inland Shore	54	54	54	54	54
	Estuarine Beach	28	28	28	28	27
	Developed Dry Land	7	7	6	6	6
	Tidal Flat	0	28	100	203	529
	Total (incl. water)	**21065**	**21065**	**21065**	**21065**	**21065**

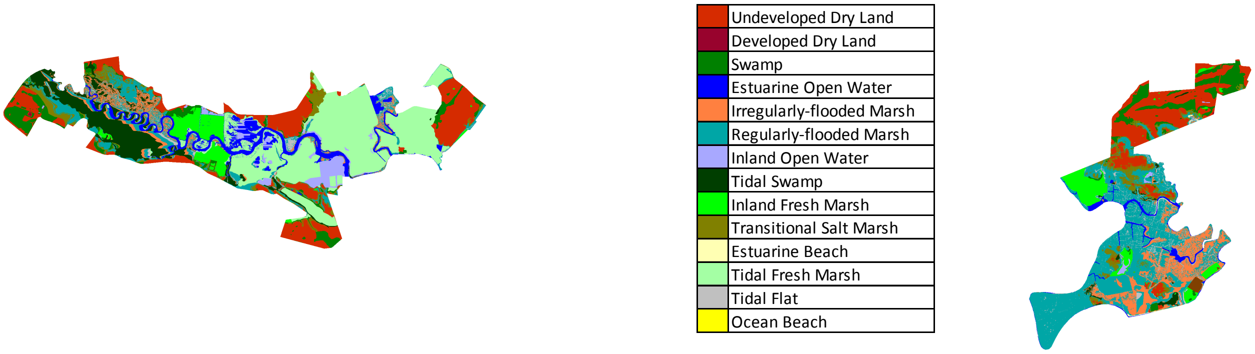


ACE Basin NWR, SLAMM 2006.

ACE Basin NWR, 2025, Scenario A1B Maximum, 0.69 m SLR by 2100.

ACE Basin NWR, 2050, Scenario A1B Maximum, 0.69 m SLR by 2100.

ACE Basin NWR, 2075, Scenario A1B Maximum, 0.69 m SLR by 2100.

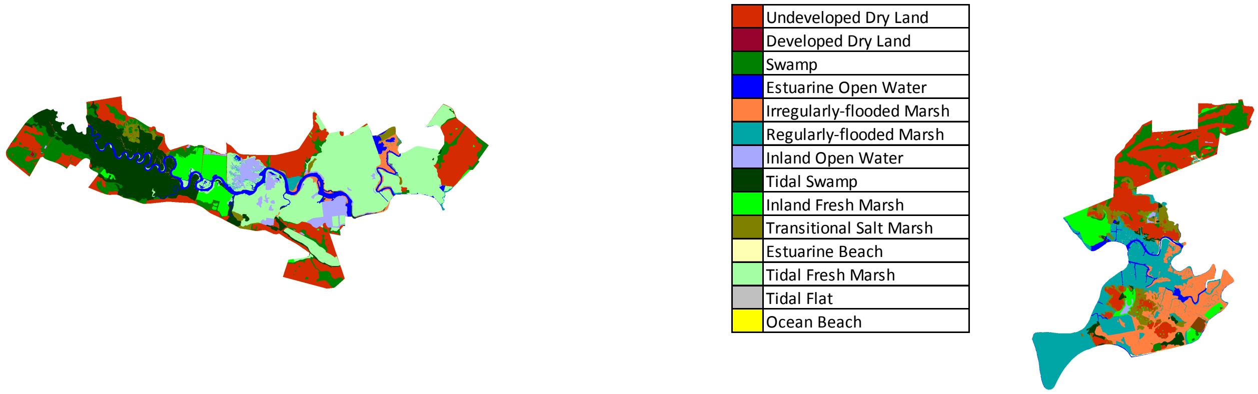


ACE Basin NWR, 2100, Scenario A1B Maximum, 0.69 m SLR by 2100.

ACE Basin NWR
1 m eustatic SLR by 2100

Results in Acres

		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	5348	4582	4225	3680	3280
	Tidal Fresh Marsh	4002	3938	3892	3812	3683
	Tidal Swamp	2469	2372	2121	1438	1061
	Swamp	2299	1910	1623	1381	1204
	Regularly Flooded Marsh	2232	2905	3304	4642	5030
	Irregularly Flooded Marsh	1783	1698	1670	1579	682
	Inland Fresh Marsh	1194	1190	1188	1183	1167
	Inland Open Water	684	513	502	469	441
	Estuarine Open Water	525	915	1007	1149	1427
	Riverine Tidal	375	161	103	62	47
	Transitional Salt Marsh	66	746	1171	1017	772
	Inland Shore	54	54	54	54	54
	Estuarine Beach	28	28	28	27	23
	Developed Dry Land	7	7	6	6	6
	Tidal Flat	0	47	170	565	2188
	Total (incl. water)	**21065**	**21065**	**21065**	**21065**	**21065**

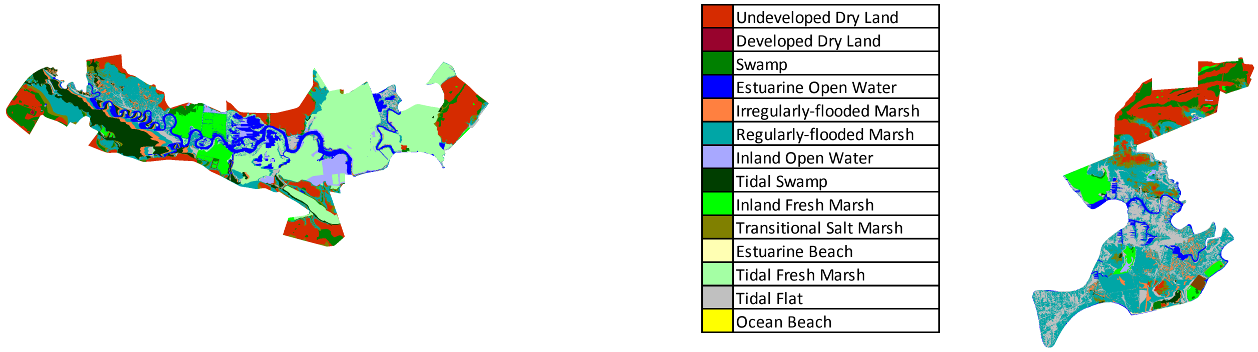


ACE Basin NWR, SLAMM 2006.

ACE Basin NWR, 2025, 1 m SLR by 2100.

ACE Basin NWR, 2050, 1 m SLR by 2100.

ACE Basin NWR, 2075, 1 m SLR by 2100.

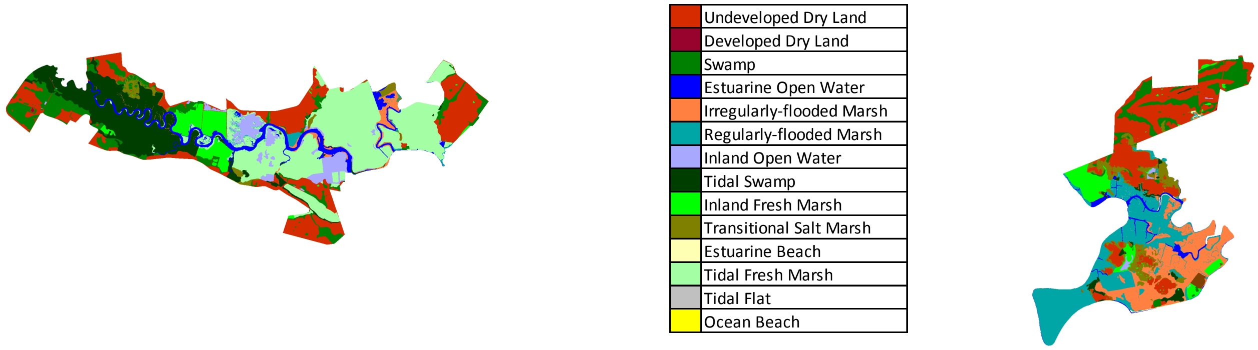


ACE Basin NWR, 2100, 1 m SLR by 2100.

ACE Basin NWR
1.5 m eustatic SLR by
2100

Results in Acres

		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	5348	4491	3921	3272	2816
	Tidal Fresh Marsh	4002	3908	3812	3606	3426
	Tidal Swamp	2469	2319	1658	1049	695
	Swamp	2299	1852	1488	1202	939
	Regularly Flooded Marsh	2232	3133	4190	4532	3359
	Irregularly Flooded Marsh	1783	1631	1588	722	371
	Inland Fresh Marsh	1194	1189	1184	1164	1123
	Inland Open Water	684	504	484	442	431
	Estuarine Open Water	525	938	1074	1469	2563
	Riverine Tidal	375	152	86	49	43
	Transitional Salt Marsh	66	770	1068	947	730
	Inland Shore	54	54	54	54	54
	Estuarine Beach	28	28	27	21	11
	Developed Dry Land	7	7	6	6	5
	Tidal Flat	0	92	424	2529	4498
	Total (incl. water)	**21065**	**21065**	**21065**	**21065**	**21065**

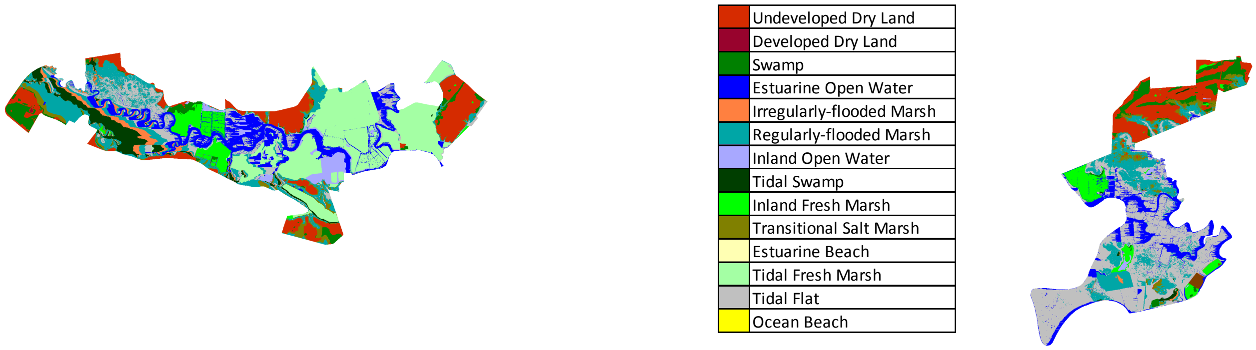


ACE Basin NWR, SLAMM 2006.


ACE Basin NWR, 2025, 1.5 m SLR by 2100.


ACE Basin NWR, 2050, 1.5 m SLR by 2100.


ACE Basin NWR, 2075, 1.5 m SLR by 2100.

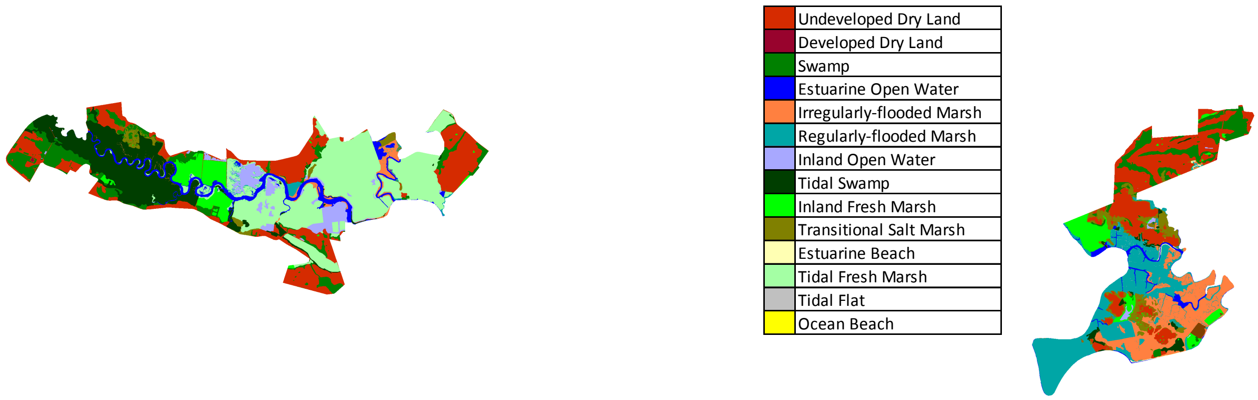


ACE Basin NWR, 2100, 1.5 m SLR by 2100.

ACE Basin NWR
2 m eustatic SLR by 2100

Results in Acres

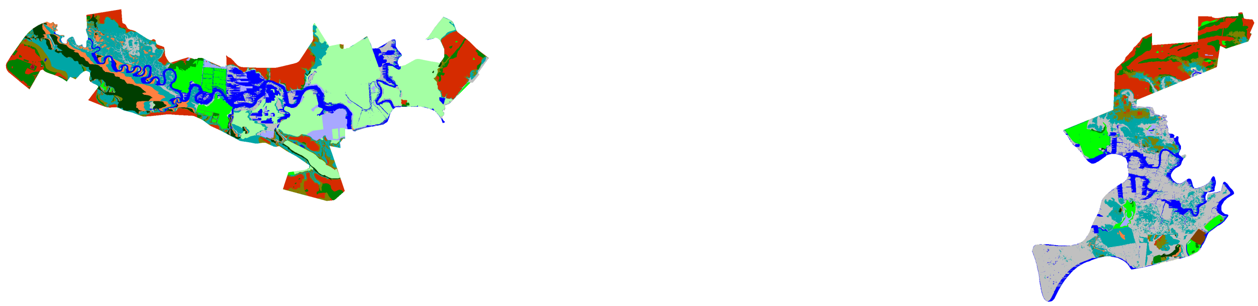
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	5348	4362	3585	2949	2415
	Tidal Fresh Marsh	4002	3877	3692	3454	2180
	Tidal Swamp	2469	2246	1326	790	429
	Swamp	2299	1737	1351	1027	641
	Regularly Flooded Marsh	2232	3433	4578	3540	2162
	Irregularly Flooded Marsh	1783	1530	1300	554	372
	Inland Fresh Marsh	1194	1188	1176	1143	654
	Inland Open Water	684	497	461	436	426
	Estuarine Open Water	525	956	1168	2101	6358
	Riverine Tidal	375	146	70	45	43
	Transitional Salt Marsh	66	861	1174	974	926
	Inland Shore	54	54	54	54	54
	Estuarine Beach	28	28	26	12	4
	Developed Dry Land	7	6	6	6	5
	Tidal Flat	0	144	1098	3980	4396
	Total (incl. water)	**21065**	**21065**	**21065**	**21065**	**21065**



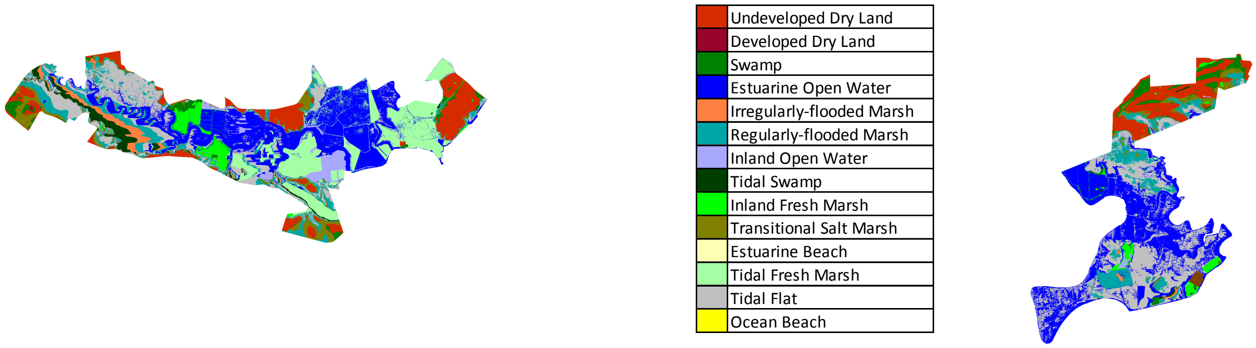
ACE Basin NWR, SLAMM 2006.

ACE Basin NWR, 2025, 2 m SLR by 2100.

ACE Basin NWR, 2050, 2 m SLR by 2100.



ACE Basin NWR, 2075, 2 m SLR by 2100.



ACE Basin NWR, 2100, 2 m SLR by 2100.

Discussion

SLAMM predictions suggest Ernest F. Hollings ACE Basin NWR has some vulnerability to accelerated SLR. While increases in regularly and, to a much lesser extent, irregularly flooded marsh are predicted under some accelerated SLR scenarios, these occur due to losses in dry land, swamp (both tidal and non-tidal) and irregularly-flooded marsh habitat. Even under the lowest SLR scenario examined, SLAMM predicts a potential loss of the wetland-habitat richness currently covering the refuge. At SLR scenarios above 1 meter by 2100, major wetland composition changes are predicted.

Although elevation data quality has improved, the entire refuge still lacks LiDAR-derived elevation data. This lack of high-resolution data increases the uncertainty in model predictions, not only for those areas not covered by LiDAR, but also affects predictions in adjacent wetlands due to potentially mischaracterized hydraulic conductivity. Compared to the previous SLAMM analysis of the refuge conducted in 2008, in general, wetlands appear more resilient to accelerated SLR than reported. The exception is swamps, which are predicted to be lost at a higher rate than suggested by the previous model application.

While data-layer updates have considerably improved the SLAMM projections reported here, input layers, parameter inputs (as mentioned above), and the conceptual model continue to have uncertainties that should be kept in mind when interpreting these 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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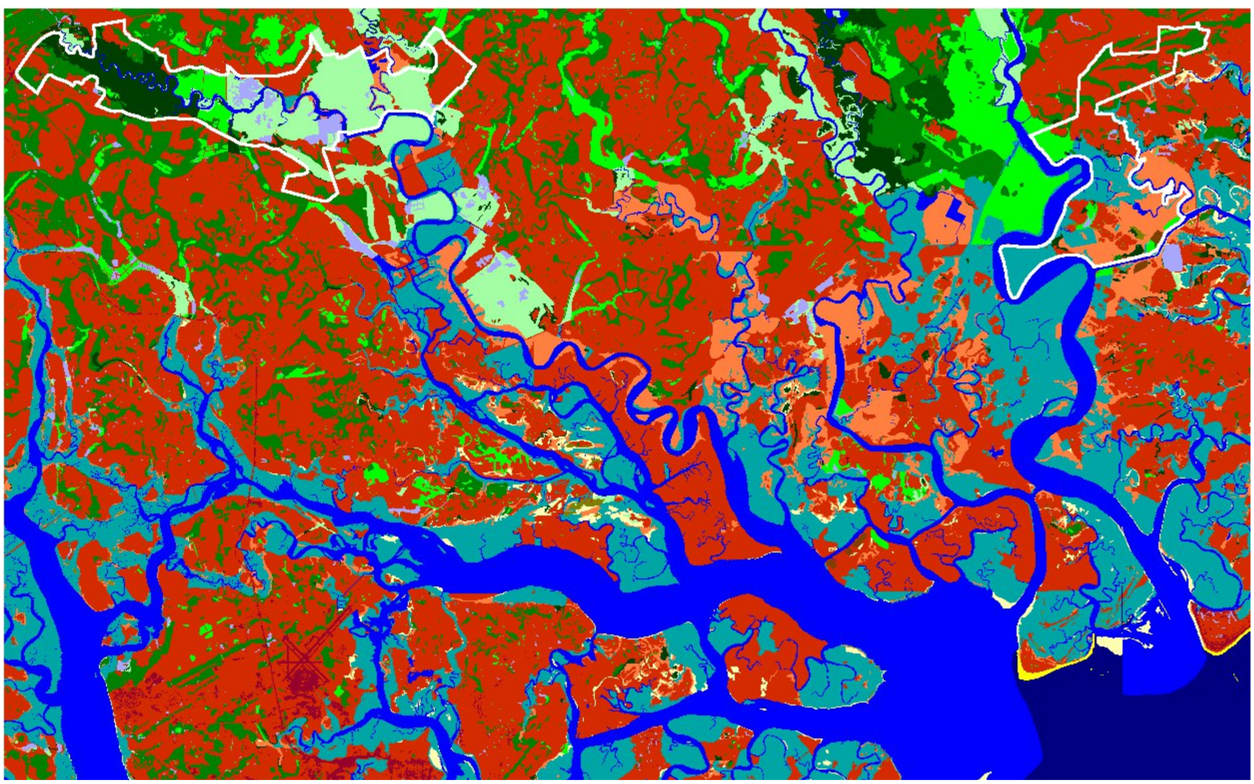
Appendix A: Contextual Results

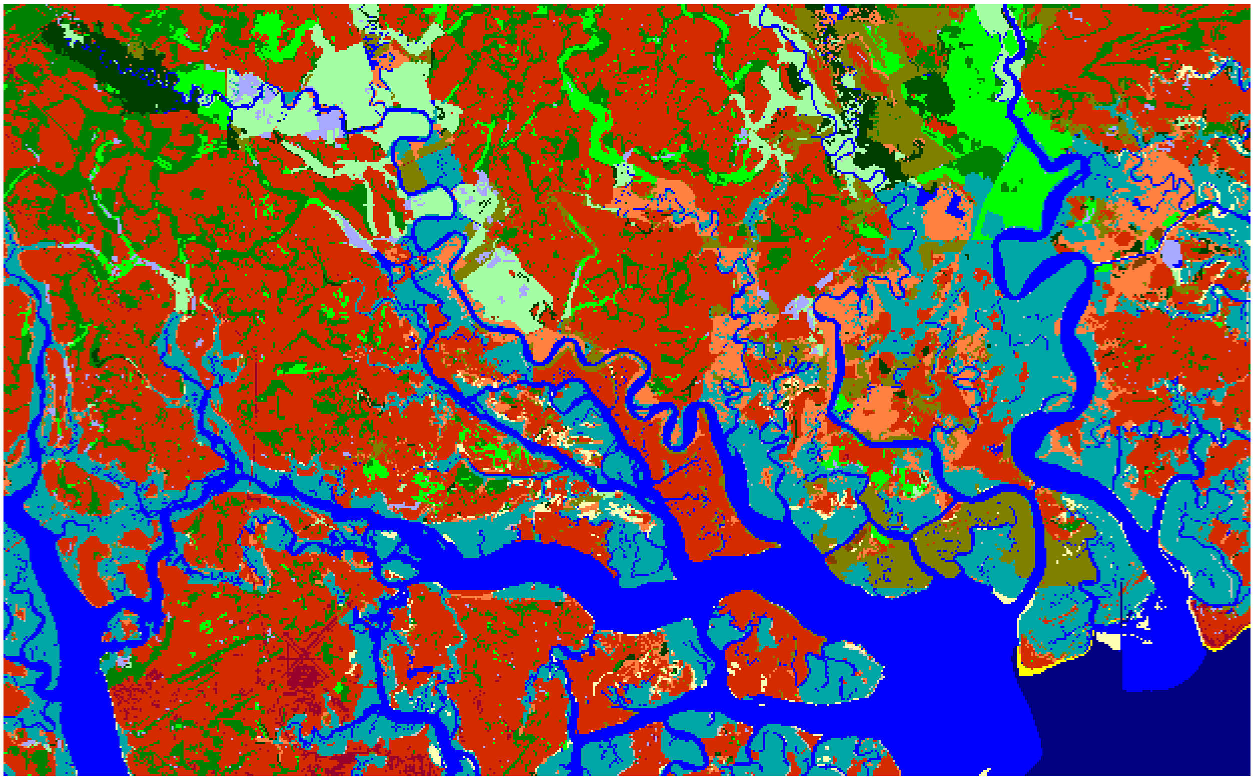
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated dry lands will convert to marshes or ocean beach depending on their proximity to open ocean. Therefore, 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 critically examined within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to assess the probable location and effects of dikes for USFWS refuges, but this effort was not made for surrounding areas.

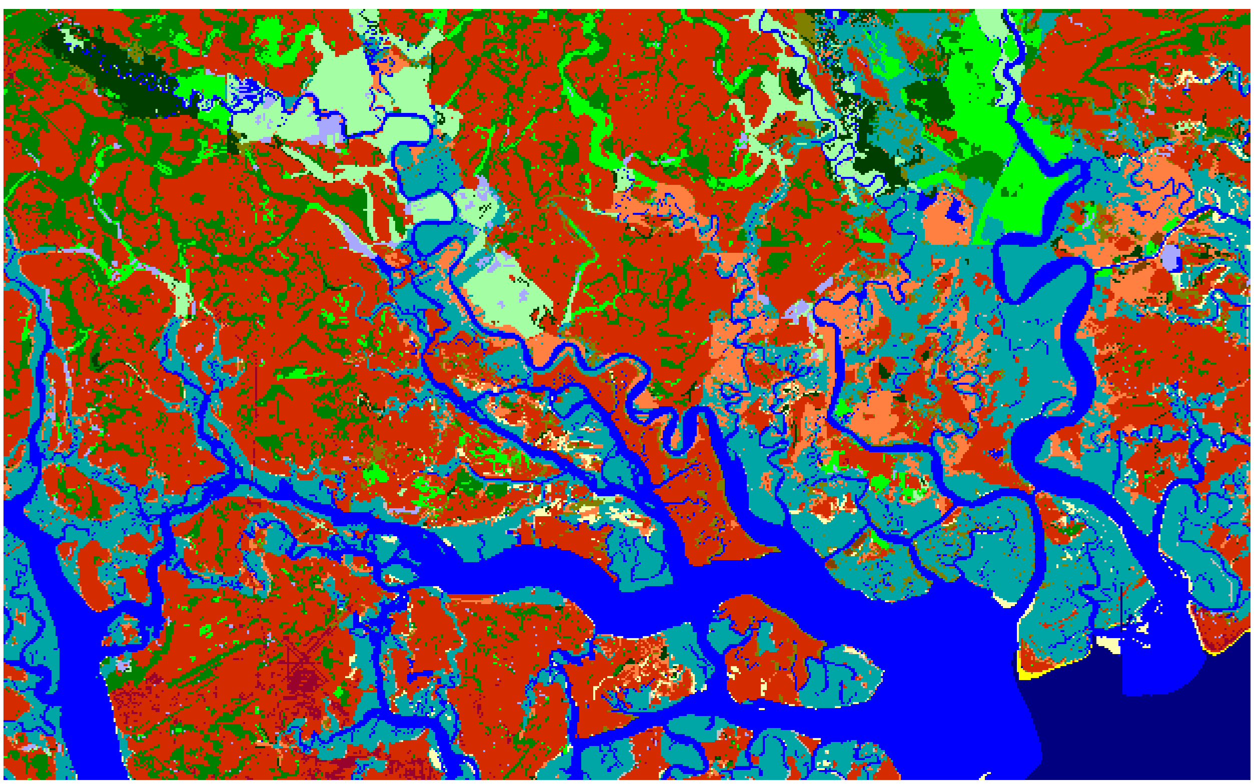


ACE Basin National Wildlife Refuge within simulation context (black).Initial NWI condition

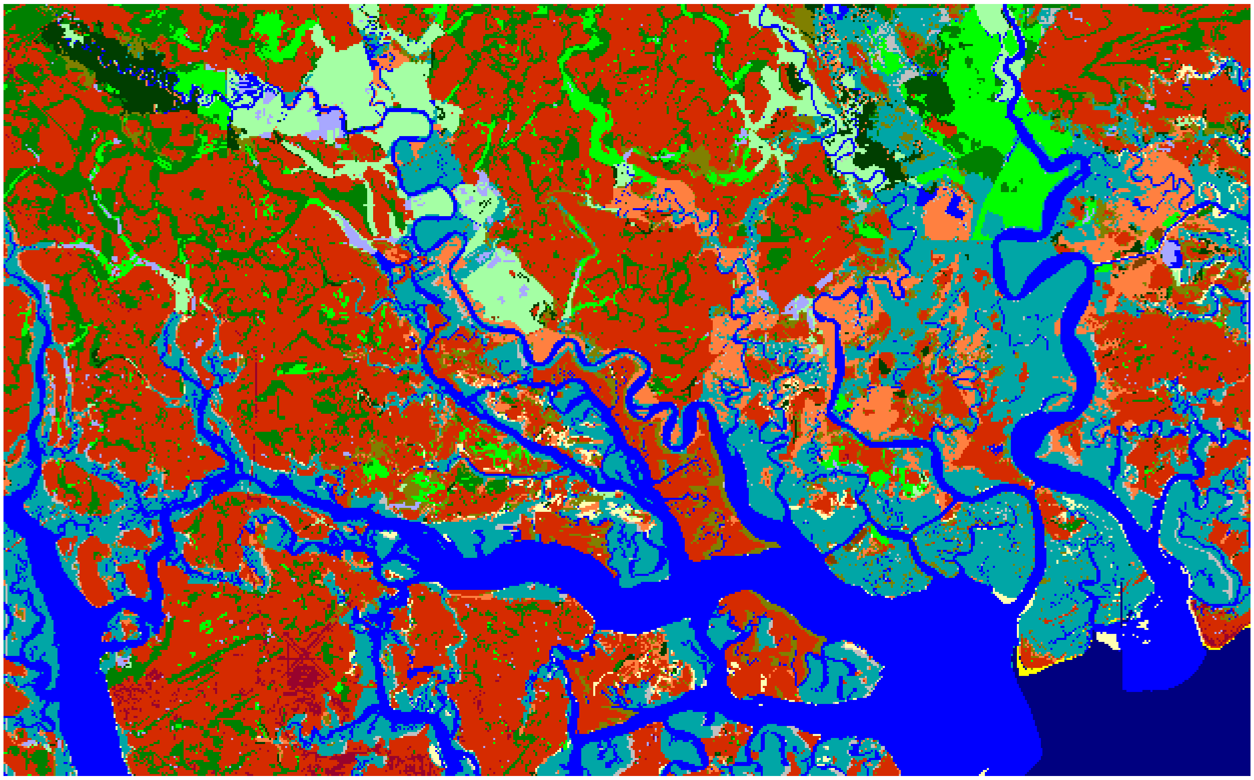
Undeveloped Dry Land
Developed Dry Land
Open Ocean
Estuarine Open Water
Inland Open Water
Swamp
Irregularly-flooded Marsh
Regularly-flooded Marsh
Estuarine Beach
Ocean Beach
Transitional Salt Marsh
Tidal Swamp
Inland Fresh Marsh
Tidal Fresh Marsh
Tidal Flat



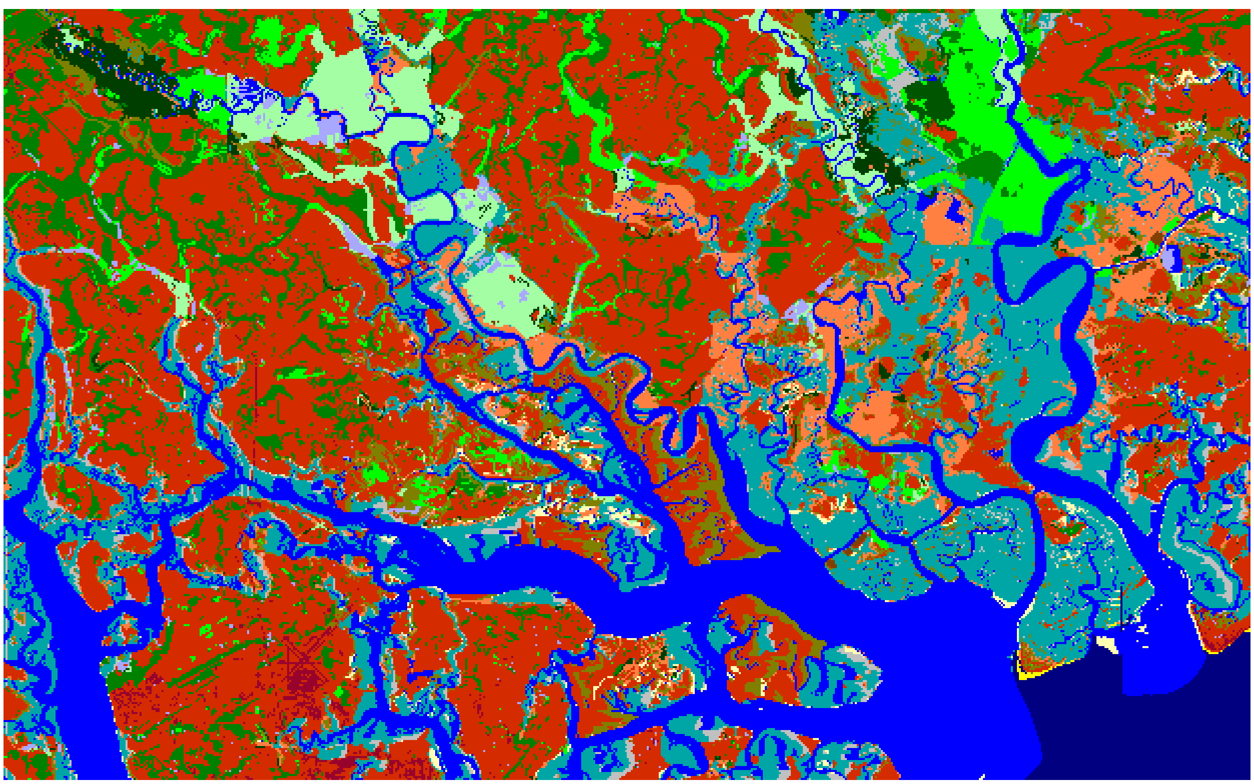
ACE Basin NWR, SLAMM 2006.



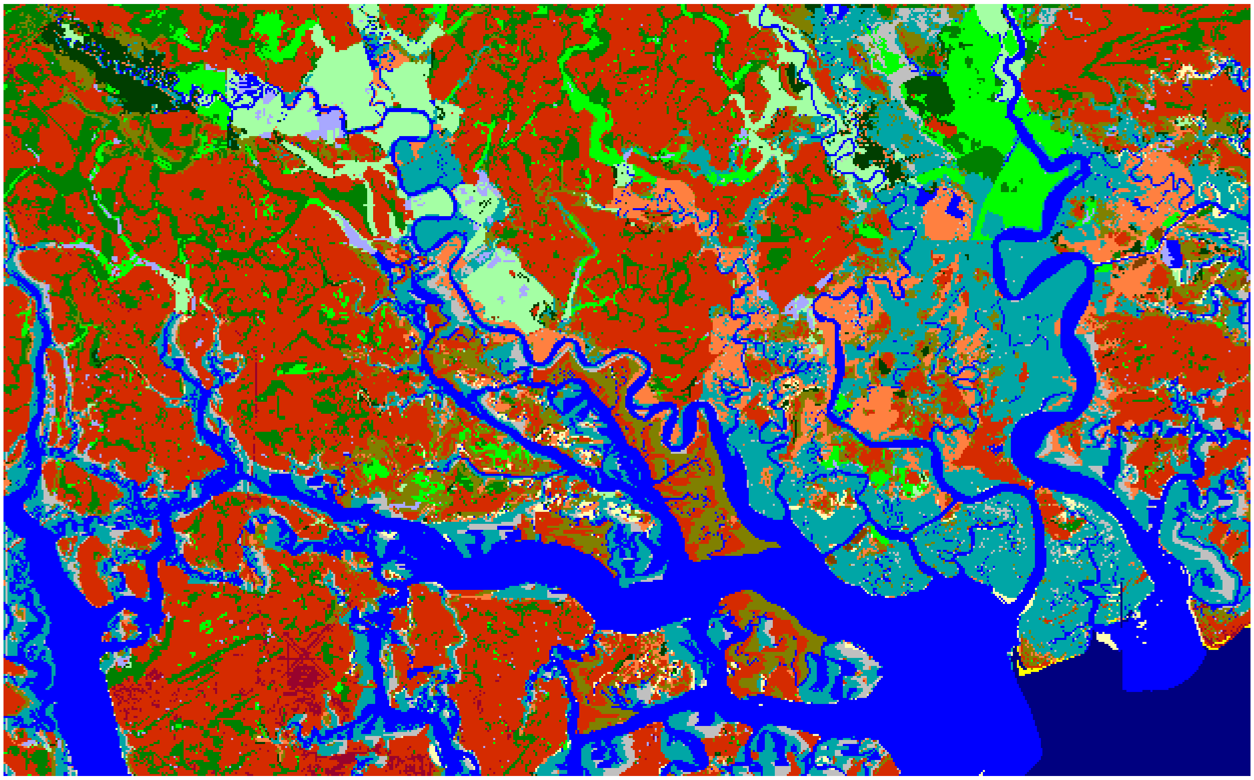
ACE Basin NWR, 2025, Scenario A1B Mean, 0.39 m SLR by 2100.

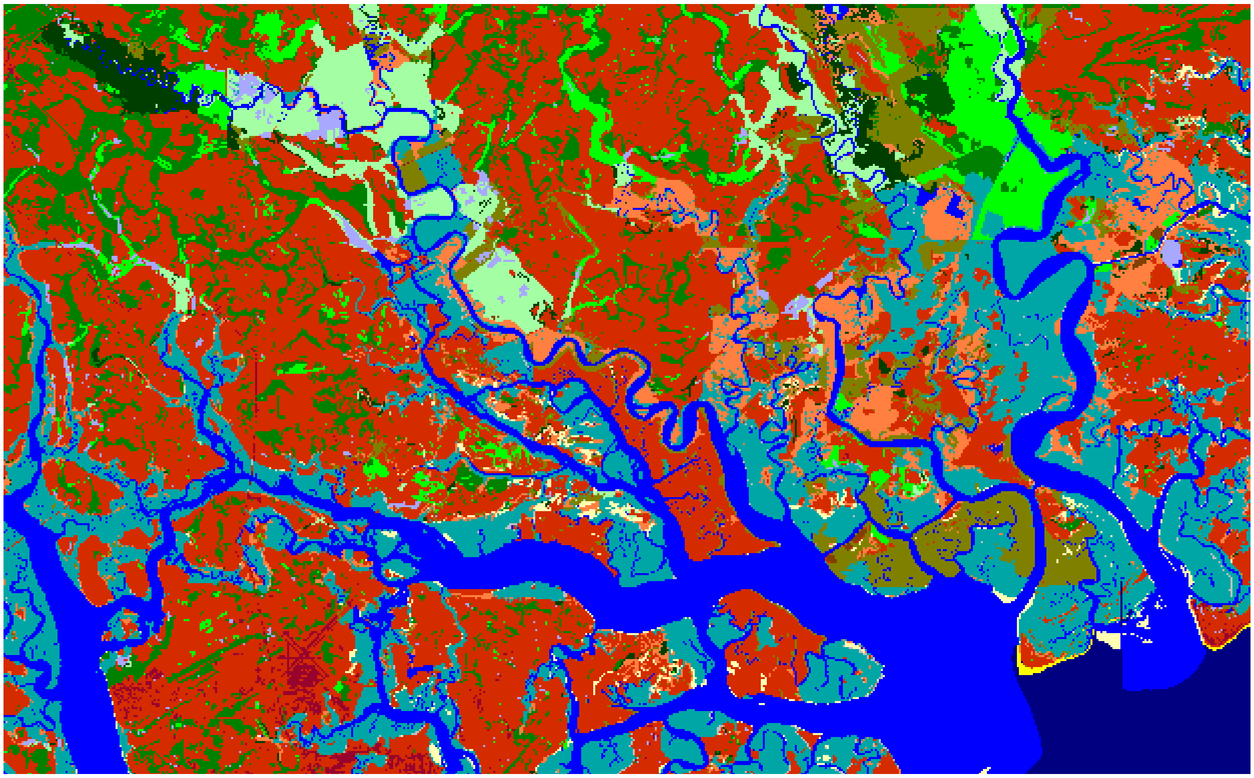


ACE Basin NWR, 2050, Scenario A1B Mean, 0.39 m SLR by 2100.

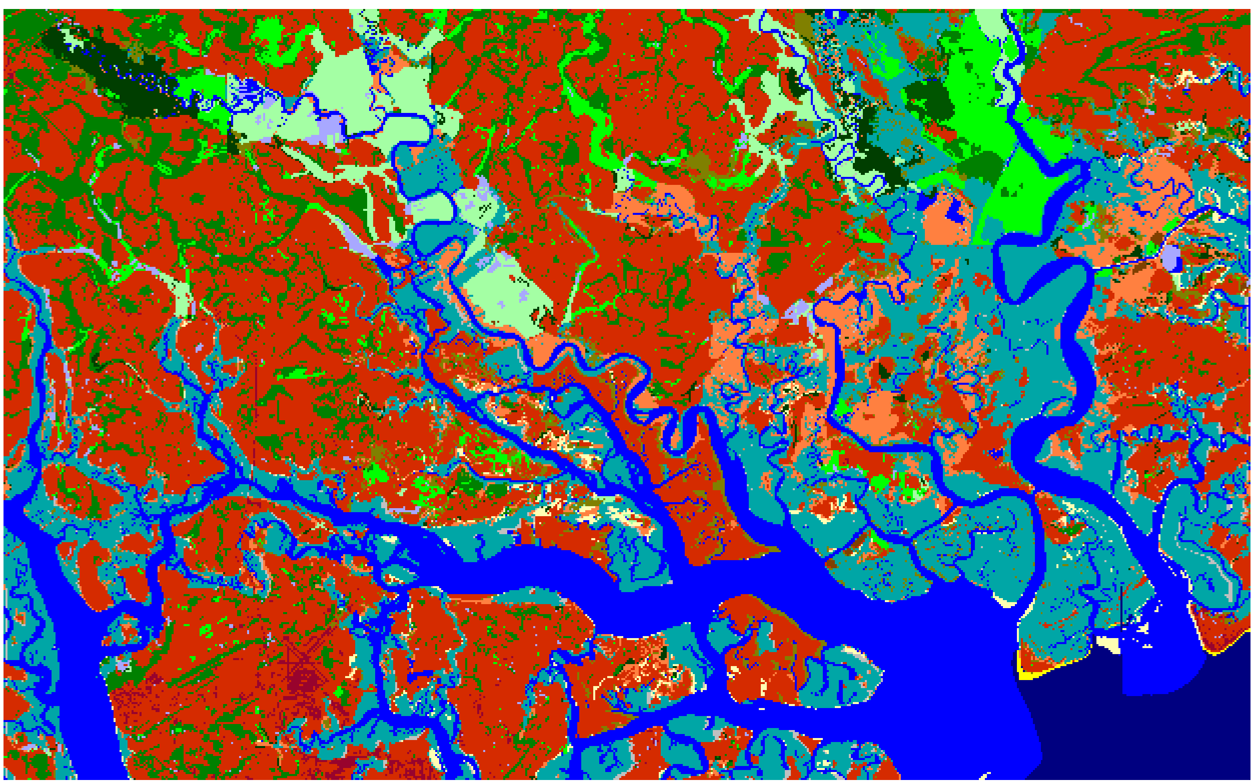


ACE Basin NWR, 2075, Scenario A1B Mean, 0.39 m SLR by 2100.

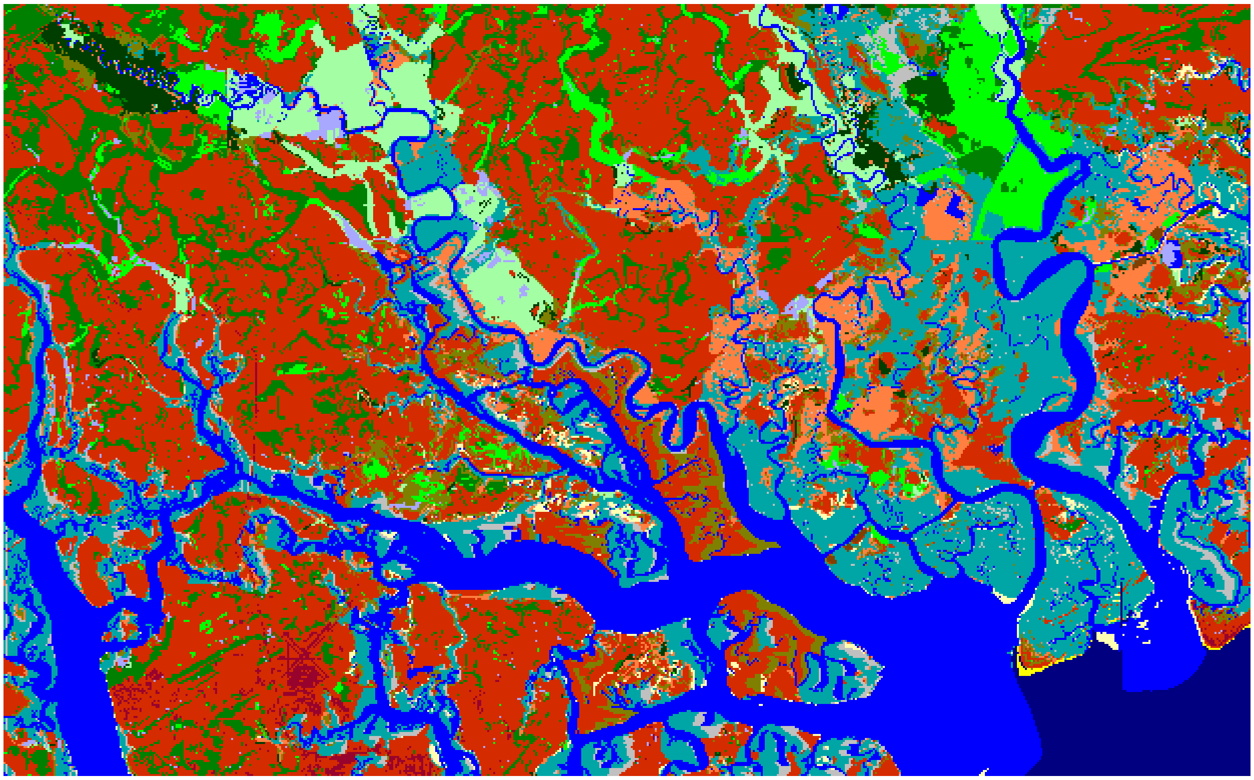

ACE Basin NWR, 2100, Scenario A1B Mean, 0.39 m SLR by 2100.



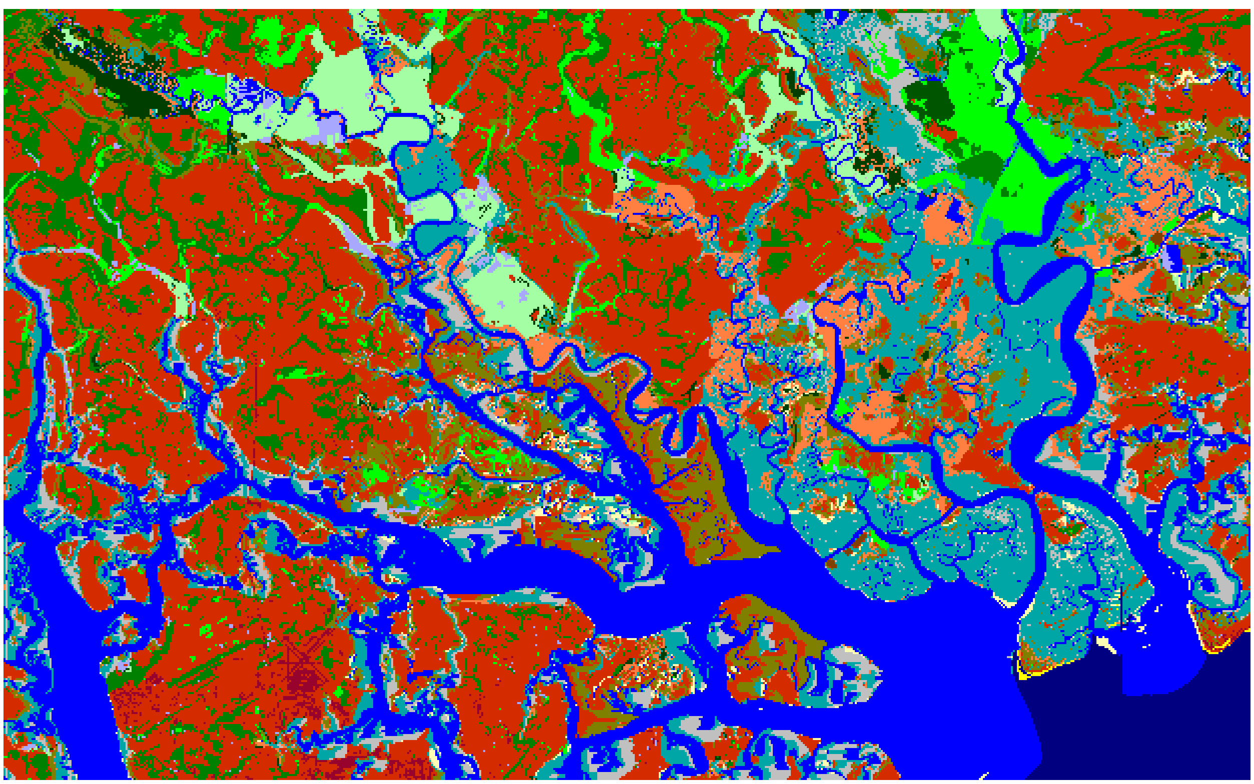
ACE Basin NWR, SLAMM 2006.



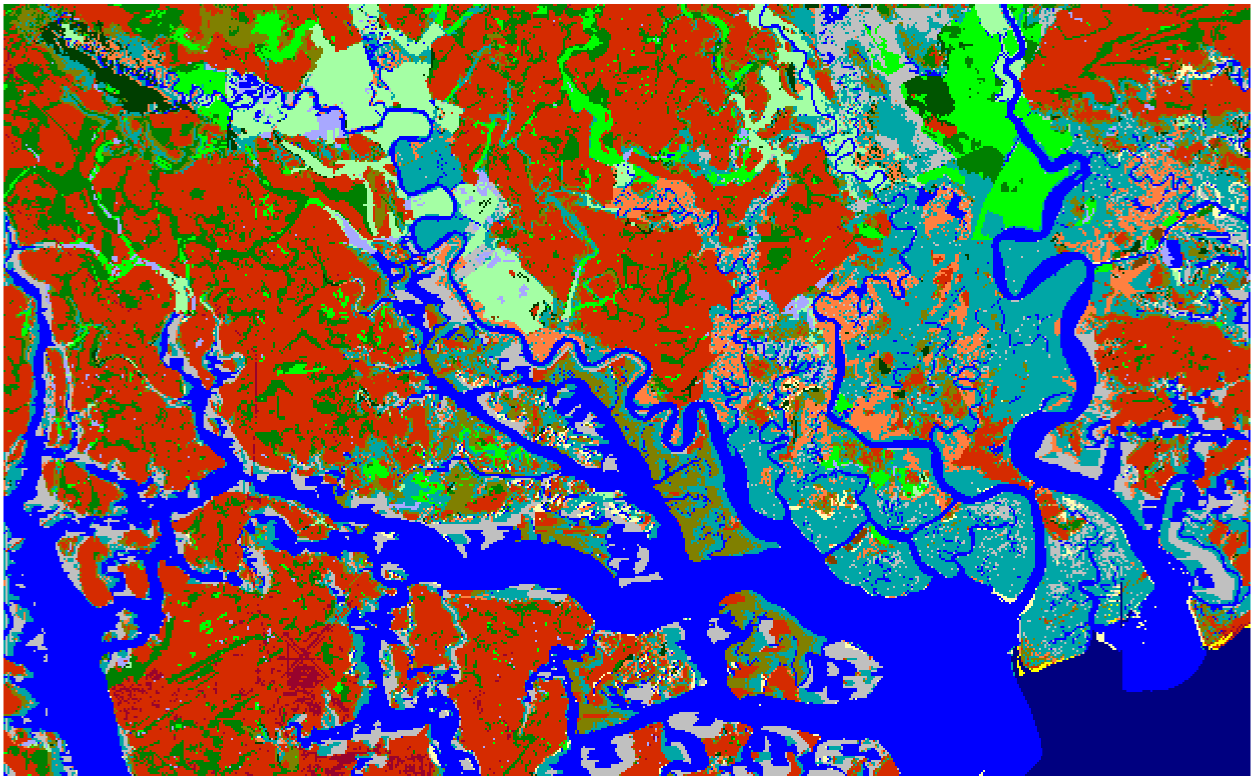
ACE Basin NWR, 2025, Scenario A1B Maximum, 0.69 m SLR by 2100.



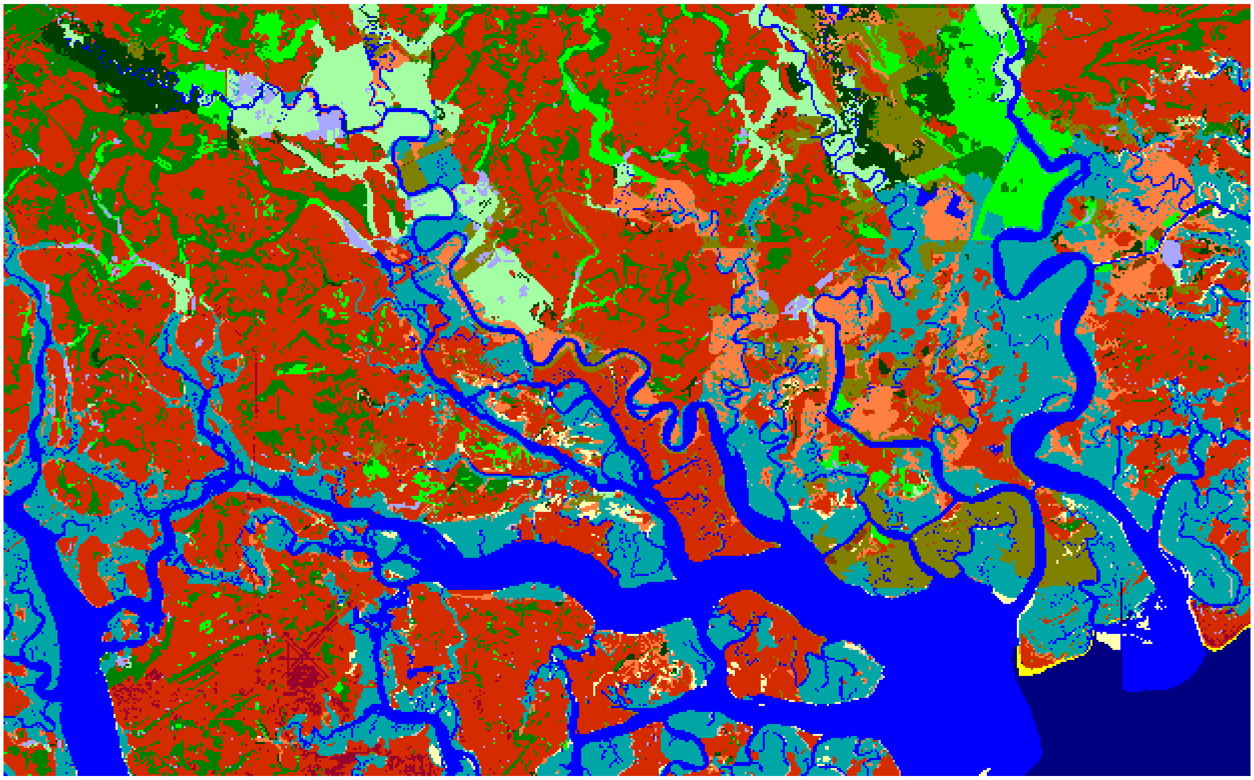
ACE Basin NWR, 2050, Scenario A1B Maximum, 0.69 m SLR by 2100.

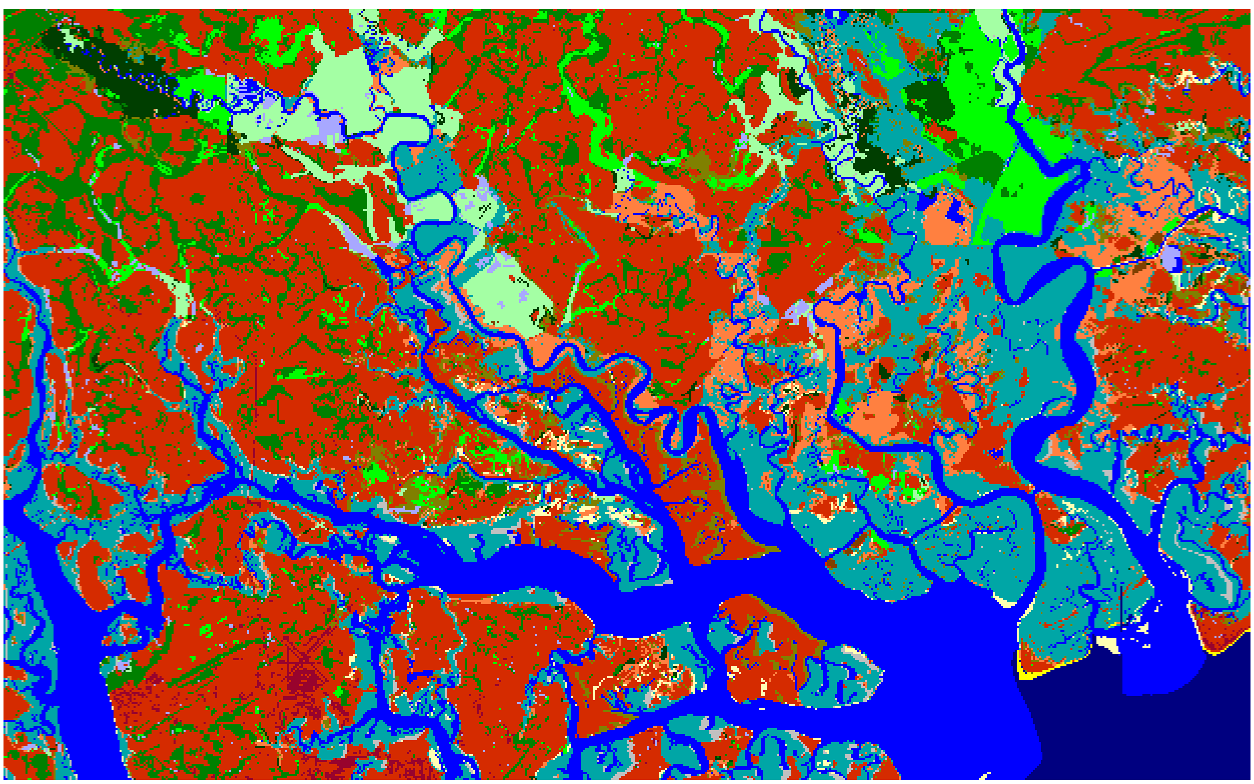


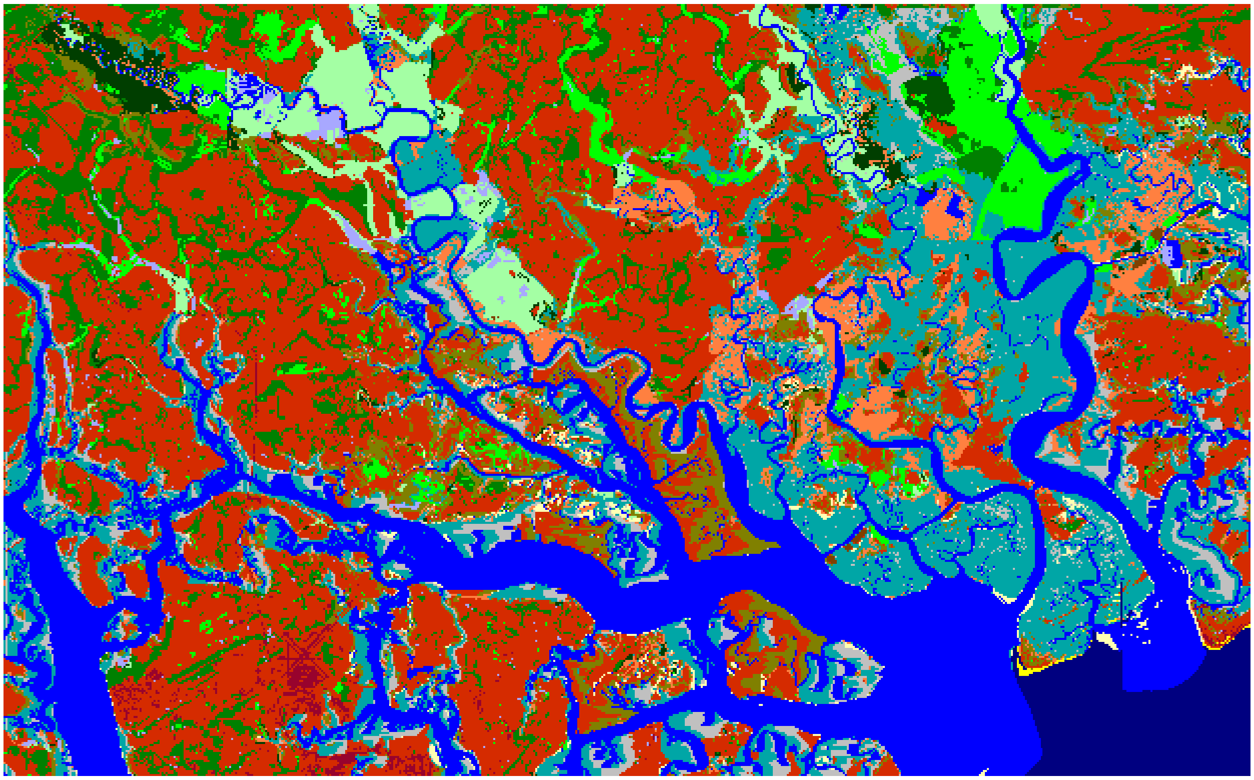
ACE Basin NWR, 2075, Scenario A1B Maximum, 0.69 m SLR by 2100.



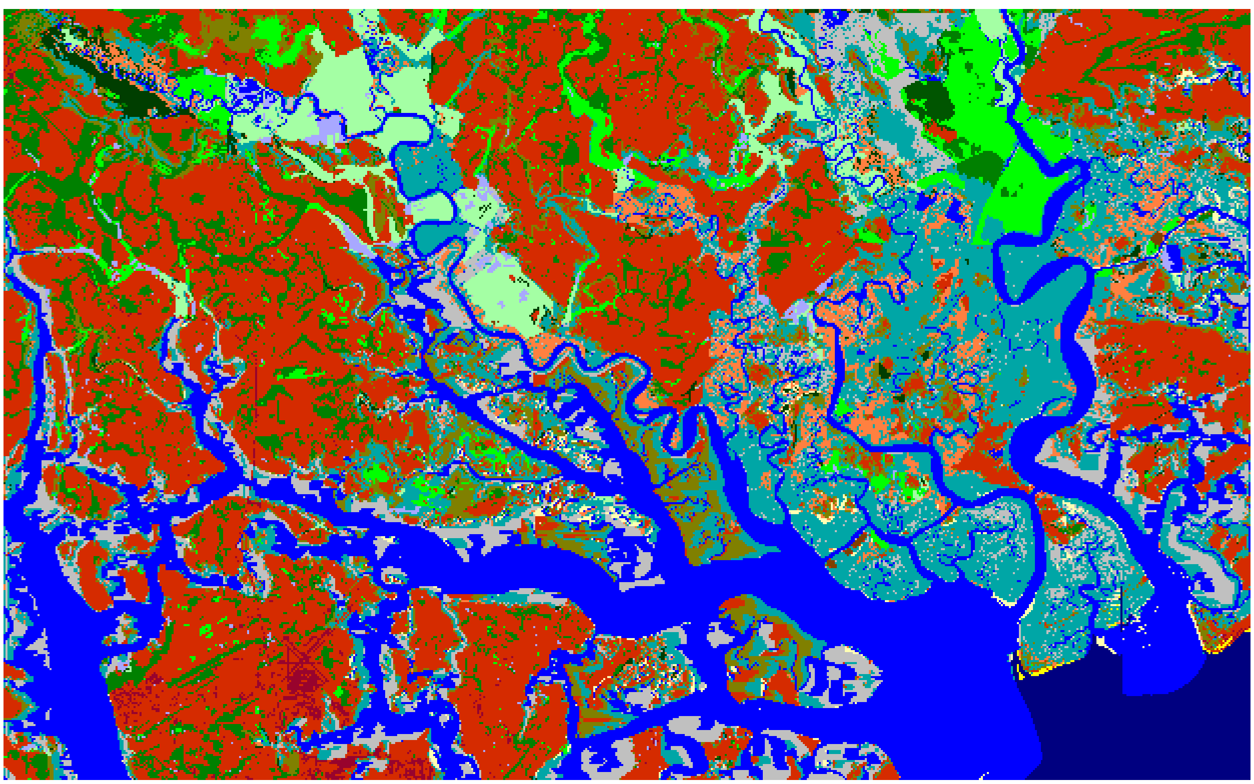
ACE Basin NWR, 2100, Scenario A1B Maximum, 0.69 m SLR by 2100.


ACE Basin NWR, SLAMM 2006.

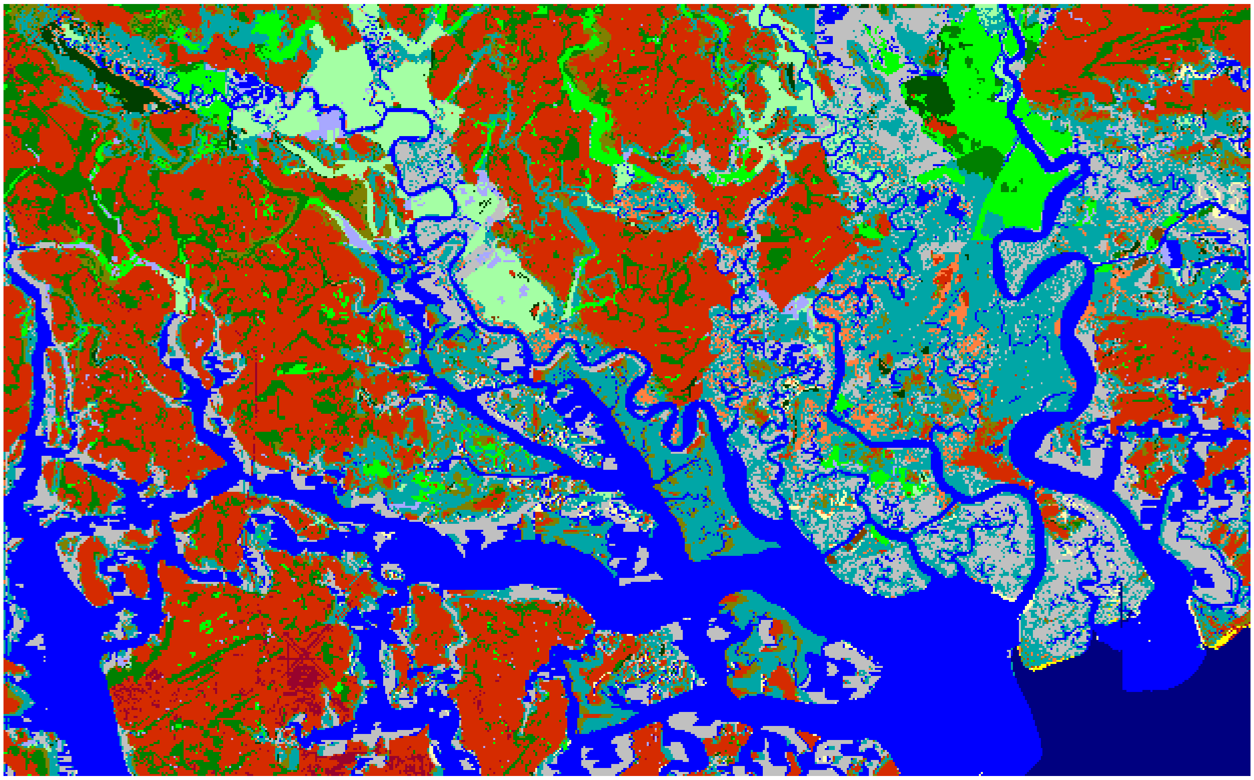

ACE Basin NWR, 2025, 1 m SLR by 2100.



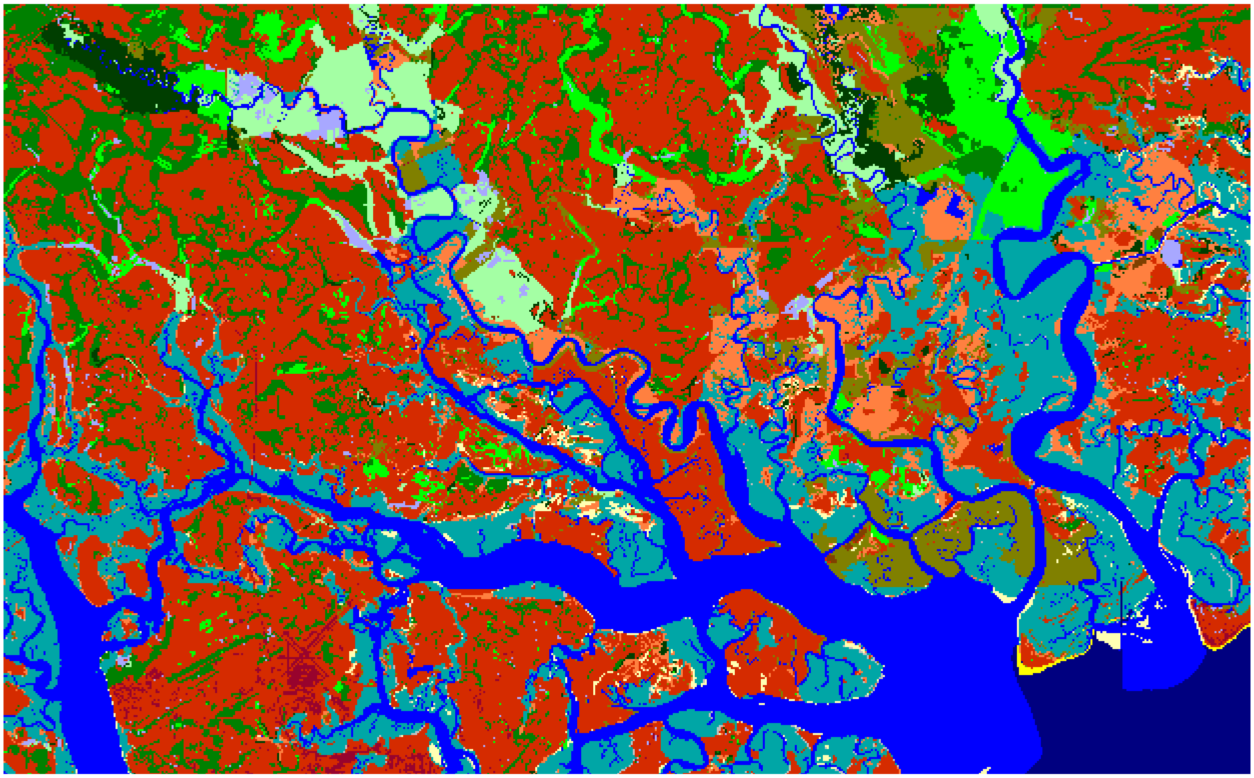
ACE Basin NWR, 2050, 1 m SLR by 2100.



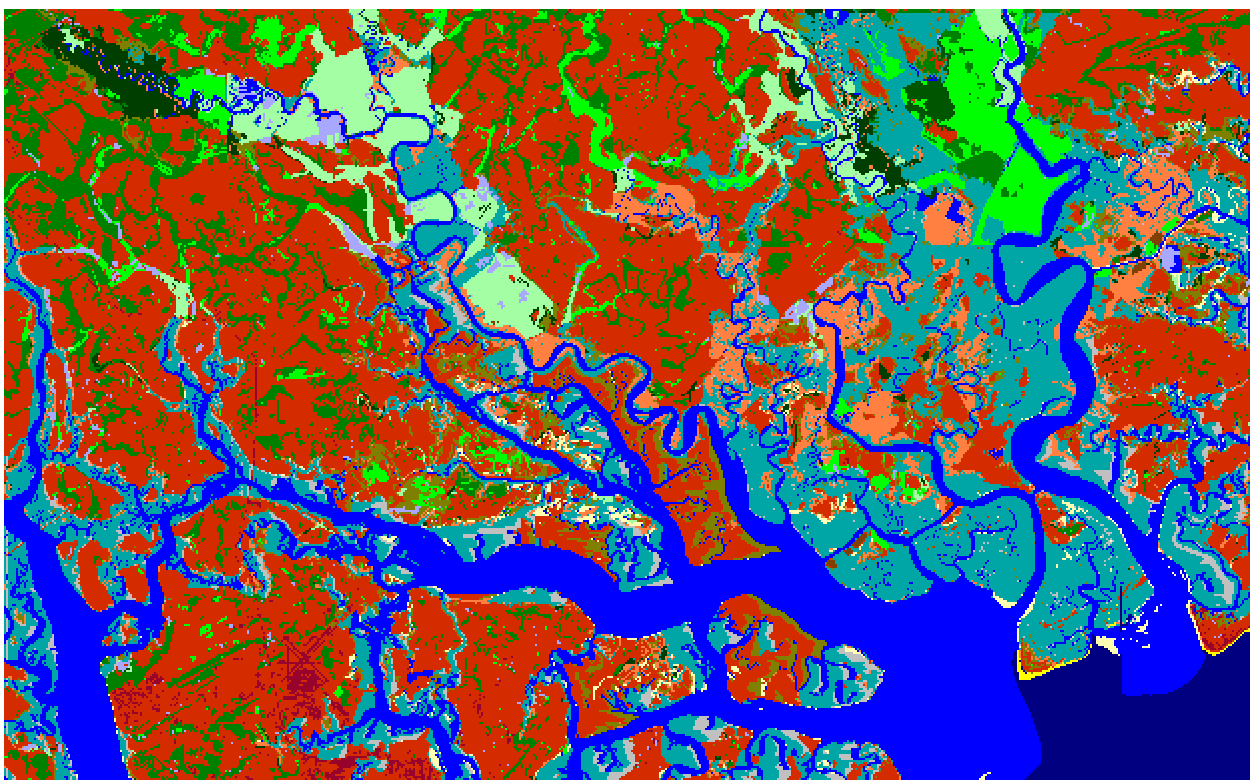
ACE Basin NWR, 2075, 1 m SLR by 2100.



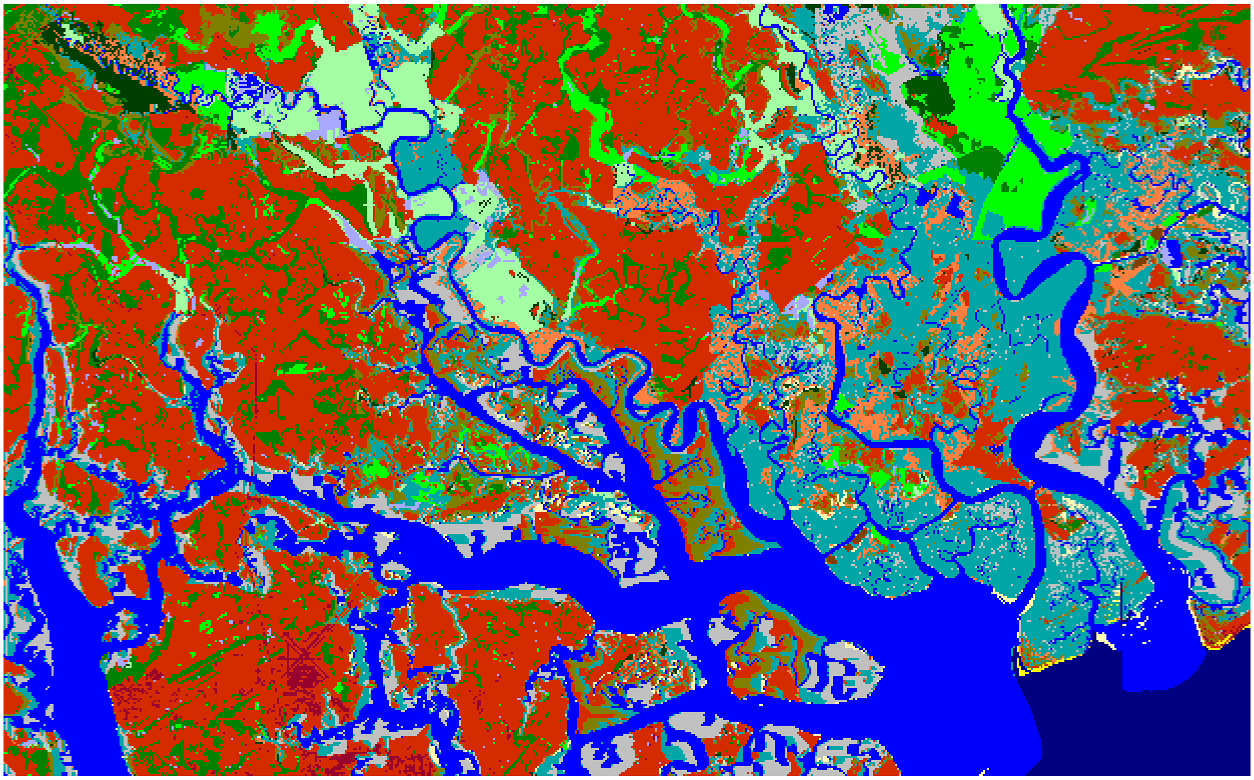
ACE Basin NWR, 2100, 1 m SLR by 2100.



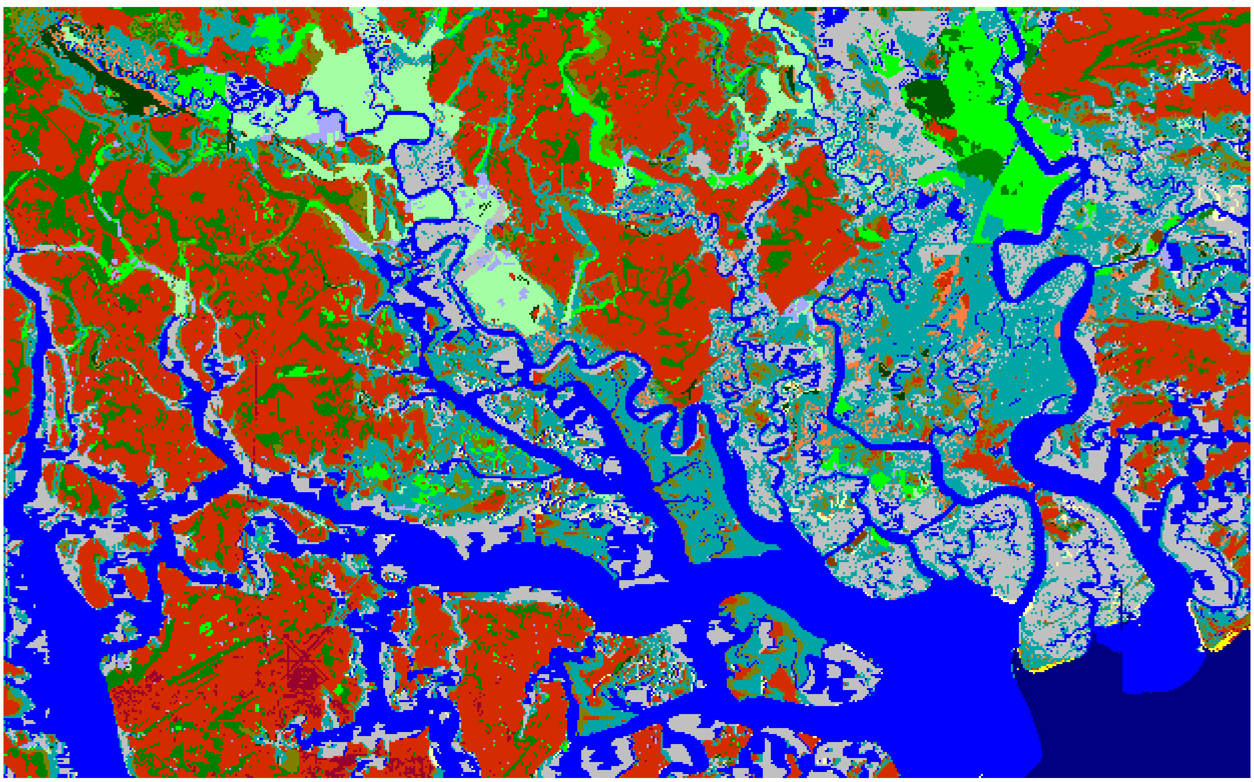
ACE Basin NWR, SLAMM 2006.



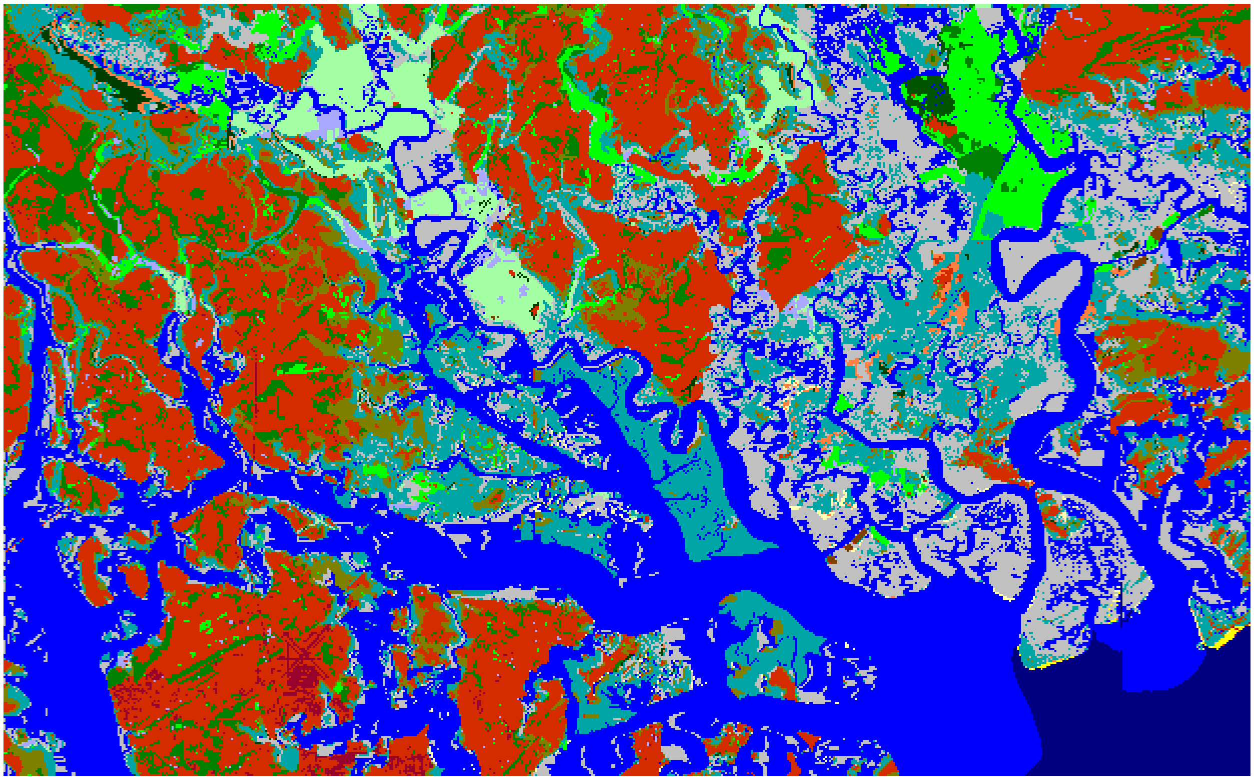
ACE Basin NWR, 2025, 1.5 m SLR by 2100.



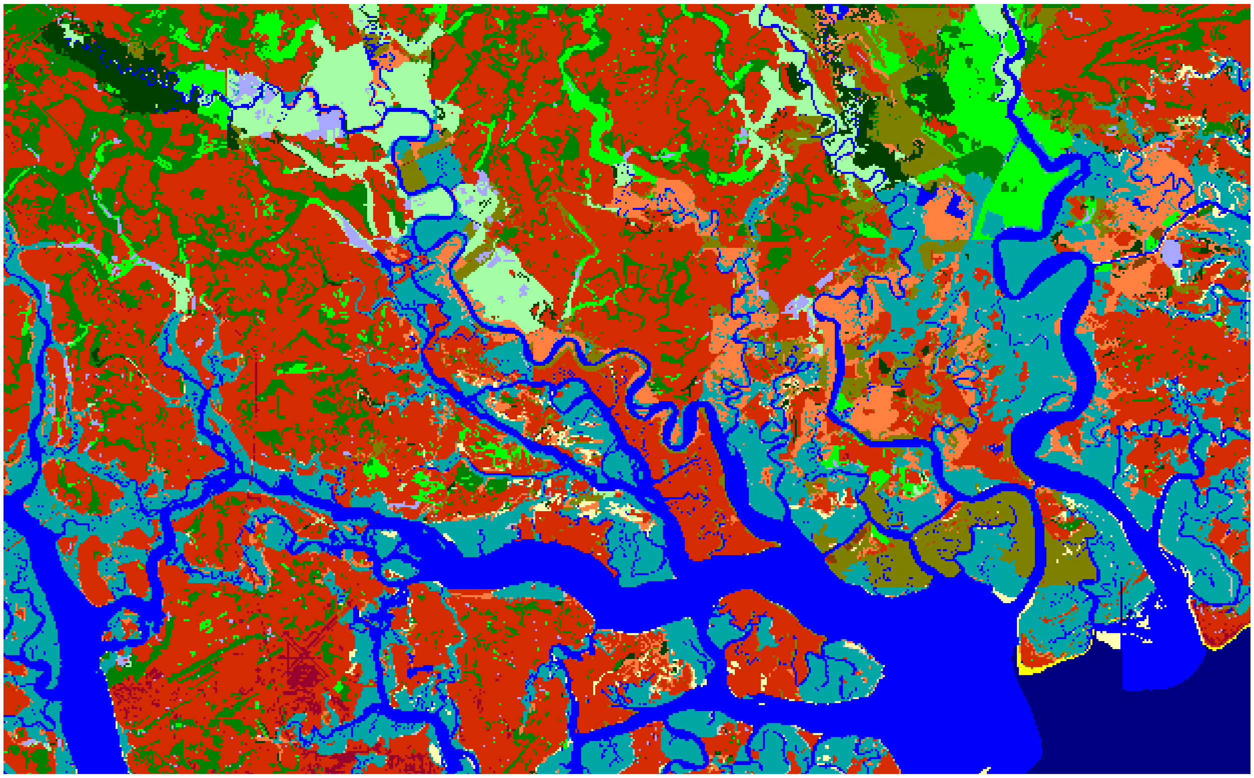
ACE Basin NWR, 2050, 1.5 m SLR by 2100.



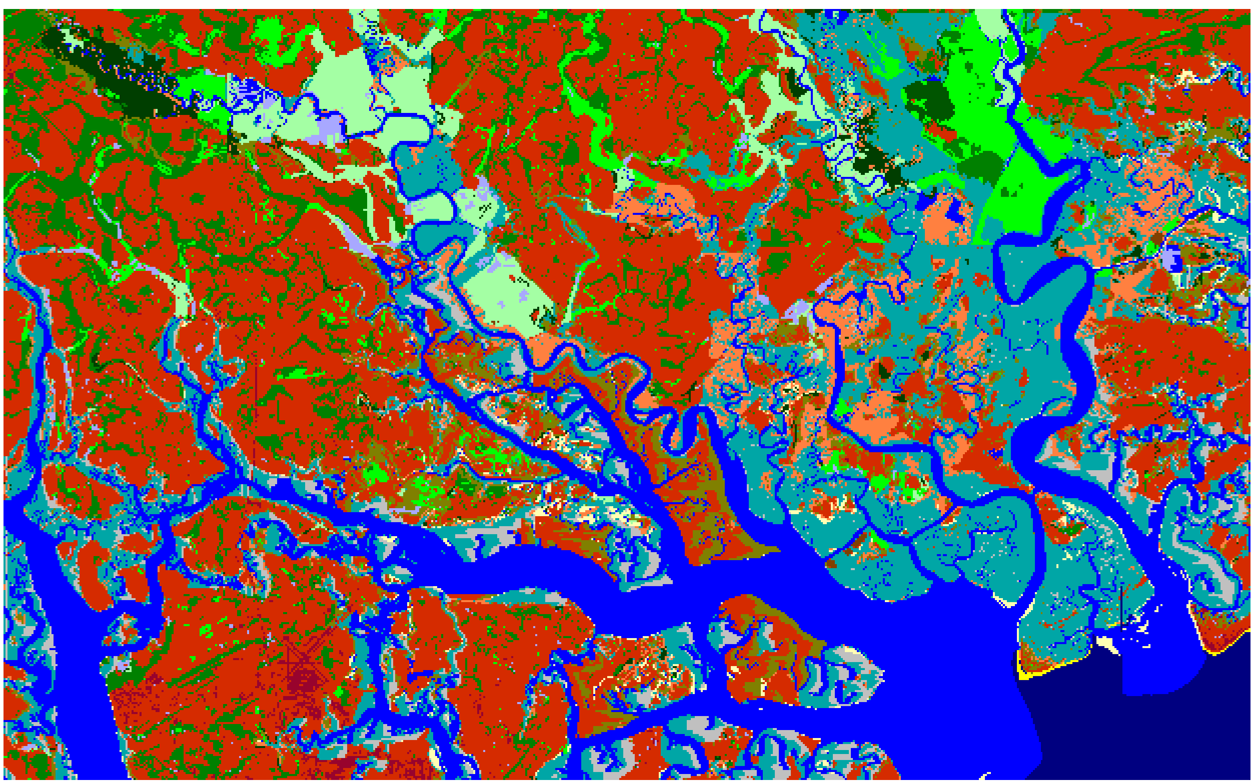
ACE Basin NWR, 2075, 1.5 m SLR by 2100.



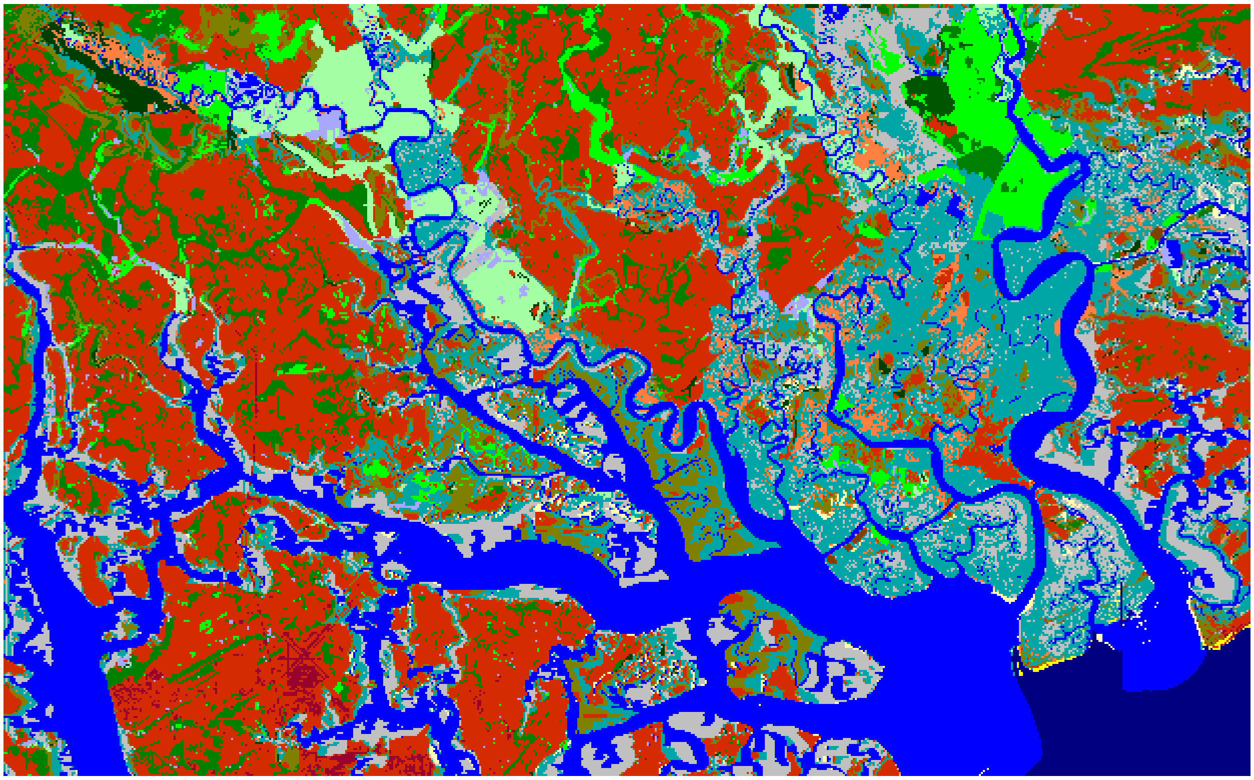
ACE Basin NWR, 2100, 1.5 m SLR by 2100.



ACE Basin NWR, SLAMM 2006.



ACE Basin NWR, 2025, 2 m SLR by 2100.



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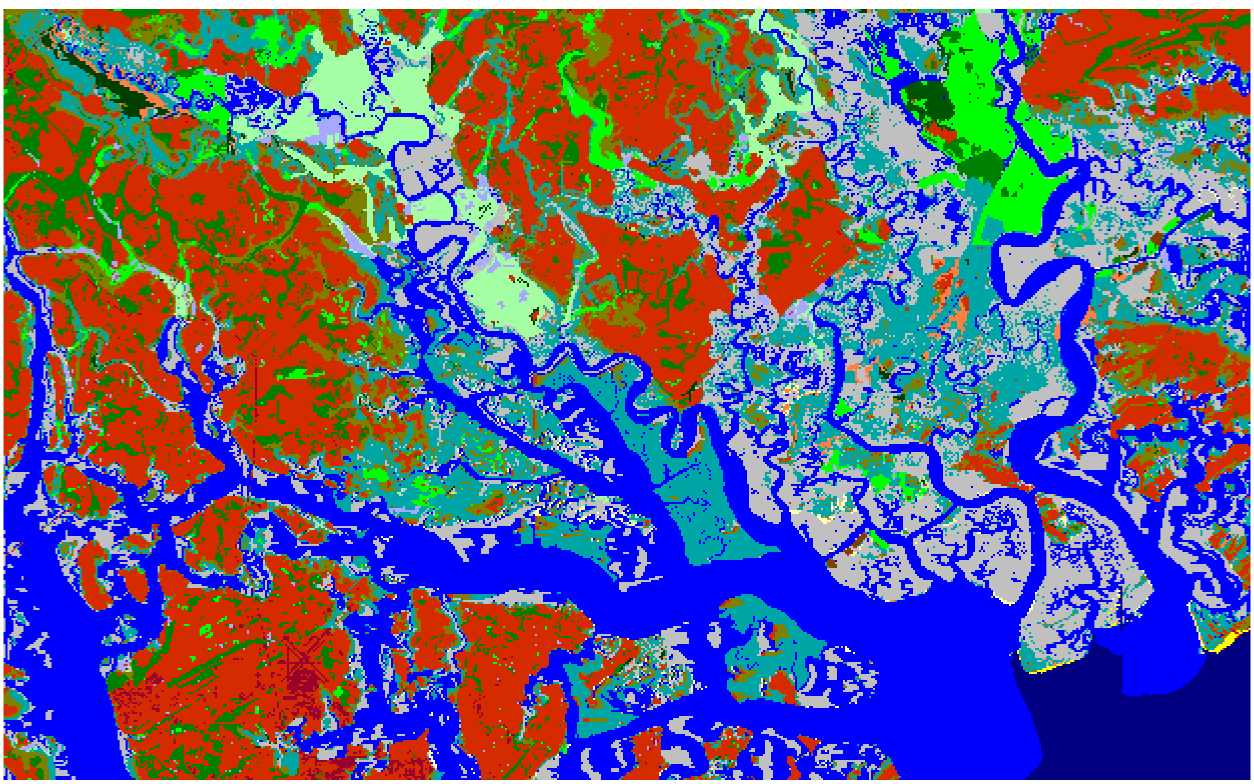

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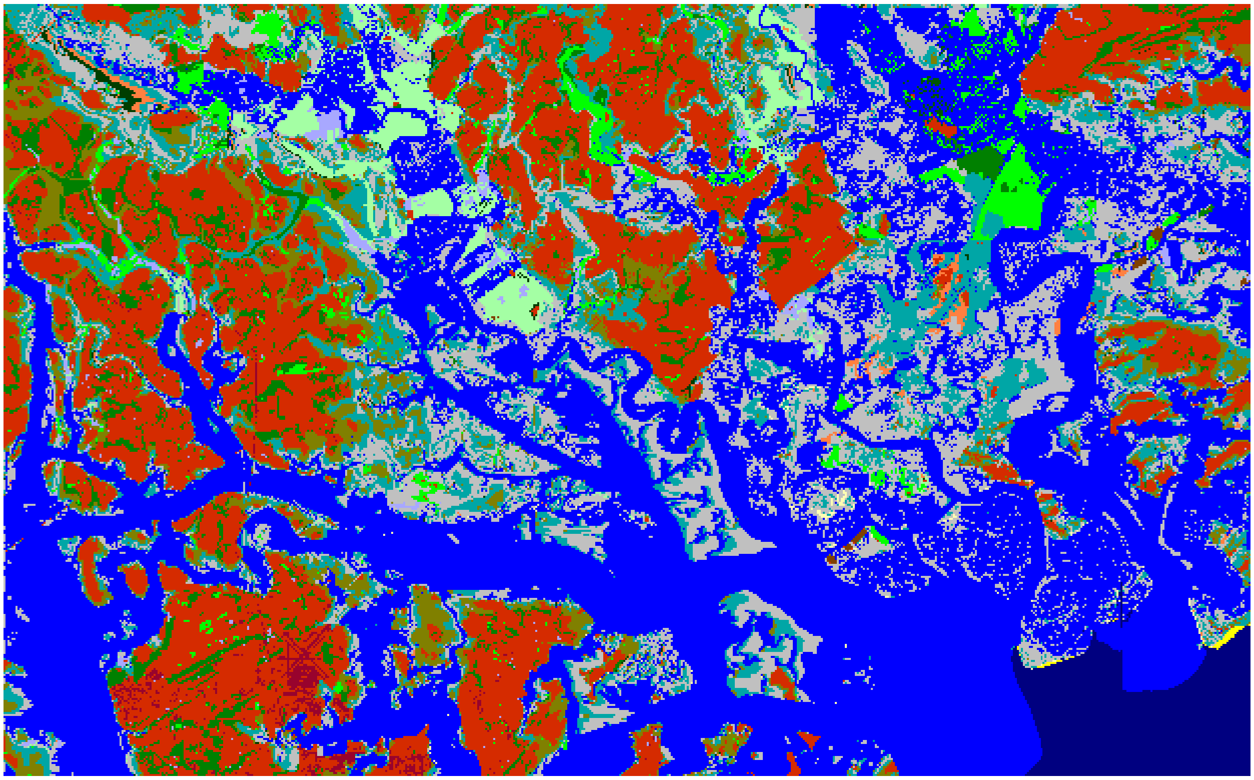

ACE Basin NWR, 2100, 2 m SLR by 2100.