Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Brazoria 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 2 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. As noted above, this analysis is a summary of model runs produced by The Nature Conservancy through grant from the Gulf of Mexico Foundation, Inc., to support the Gulf of Mexico Alliance (Warren Pinnacle Consulting, Inc. 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). The first phase of this work was completed using SLAMM 5, while the second phase simulations were run with SLAMM 6.

Within SLAMM, there are five primary processes that affect wetland fate under different scenarios of sea-level rise:

- **Inundation:** The rise of water levels and the salt boundary are tracked by reducing elevations of each cell as sea levels rise, thus keeping mean tide level (MTL) constant at zero. The effects on each cell are calculated based on the minimum elevation and slope of that cell.
- **Erosion:** Erosion is triggered based on a threshold of maximum fetch and the proximity of the marsh to estuarine water or open ocean. When these conditions are met, horizontal erosion occurs at a rate based on site-specific data.

- **Overwash:** Barrier islands of under 500 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 or 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 in USFWS simulations 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 (CREM, 2008). Site-specific factors that increase or decrease model uncertainty may be covered in the *Discussion* section of this report.

Sea Level Rise Scenarios

Forecast simulations used scenario A1B from the Special Report on Emissions Scenarios (SRES) – mean and maximum estimates. The A1 family of scenarios assumes that the future world includes rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. In particular, the A1B scenario assumes that energy sources will be balanced across all sources. Under the A1B scenario, the IPCC WGI Fourth Assessment Report (IPCC 2007) suggests a likely range of 0.21 to 0.48 m of sea level rise by 2090-2099 "excluding future rapid dynamical changes in ice flow." The A1B-mean scenario that was run as a part of this project falls near the middle of this estimated range, predicting 0.39 m of global sea level rise by 2100. A1B-maximum predicts 0.69 m of global SLR by 2100.

The latest literature (Chen et al. 2006; Monaghan et al. 2006) indicates that the eustatic rise in sea levels is progressing more rapidly than was previously assumed, perhaps due to the dynamic changes in ice flow omitted within the IPCC report's calculations. A recent paper in the journal *Science* (Rahmstorf 2007) suggests that, taking into account possible model error, a feasible range by 2100 of 50 to 140 cm. This work was recently updated and the ranges were increased to 75 to 190 cm (Vermeer and Rahmstorf 2009). Pfeffer et al. (2008) suggests that 2 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 sea level rises for the end of the 21st century are too low." (Clark 2009) A recent paper by Grinsted et al. (2009) states that "sea level 2090-2099 is projected to be 0.9 to 1.3 m for the A1B scenario…" Grinsted also states that there is a "low probability" that SLR will match the lower IPCC estimates.

To allow for flexibility when interpreting the results, SLAMM was also run assuming 1 m, 1½ m, and 2 m of eustatic sea-level rise by the year 2100. The A1B- maximum scenario was scaled up to produce these bounding scenarios (Figure 1).

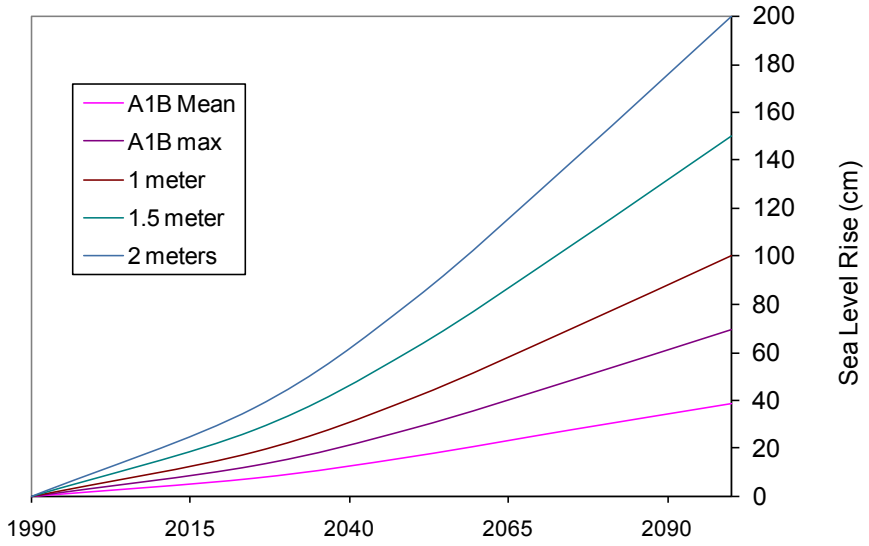


Figure 1: **Summary of SLR scenarios utilized**

Methods and Data Sources

This study of Brazoria NWR was derived from a previously conducted project of The Nature Conservancy to analyze Galveston Bay, Texas (Warren Pinnacle Consulting, Inc. 2011).

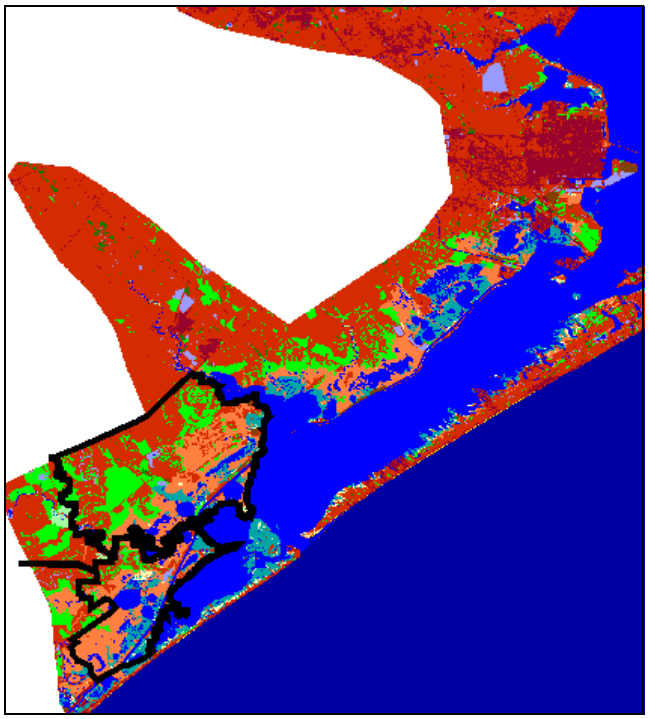


Figure 2. Portion of Galveston Bay study area with Brazoria NWR boundary shown in black

The digital elevation map used in this simulation was derived from Sanborn 2007 and Tropical Storm Allison Recovery Project (TSARP) 2002 LiDAR (received from Harte Research Institute) and 2009 1/9 arc second NED (Figure 3) (Texas Water Development Board 2010).

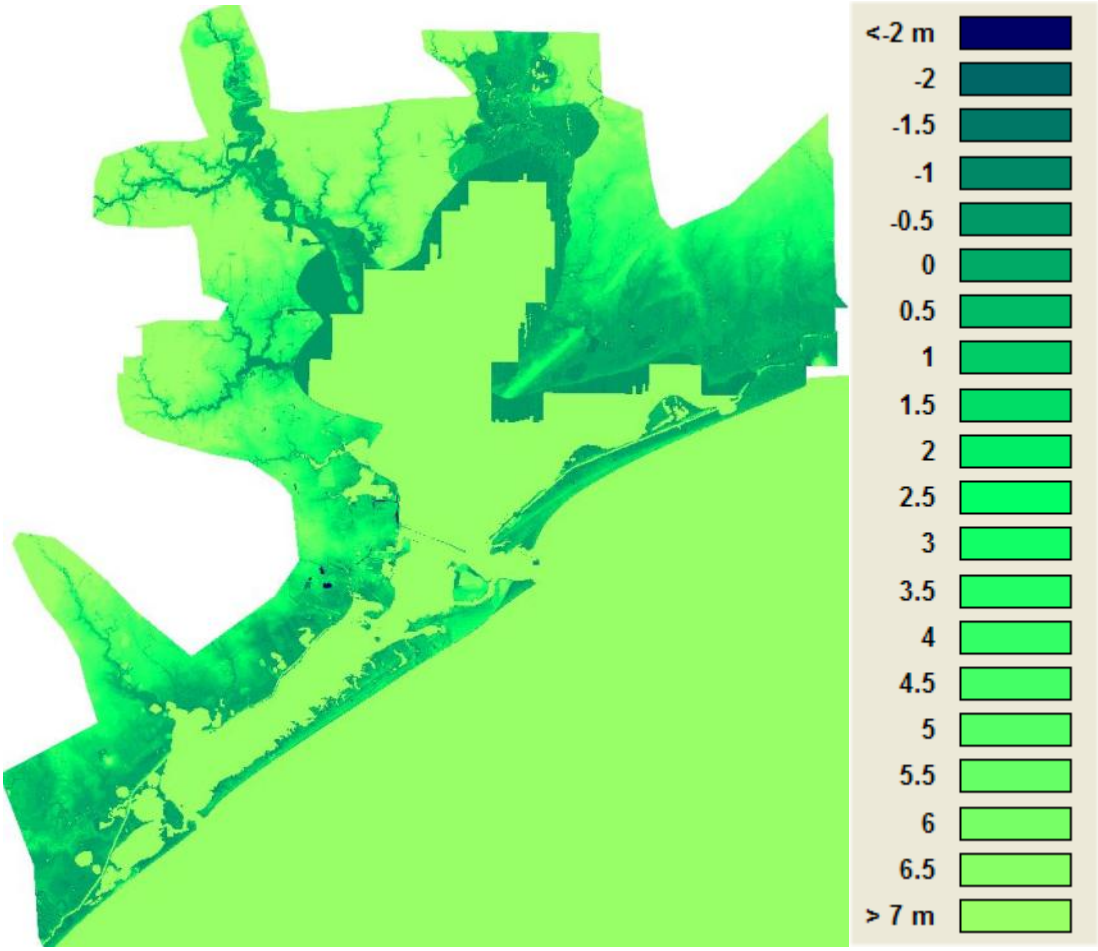


Figure 3. Shade-relief elevation map of Galveston study area

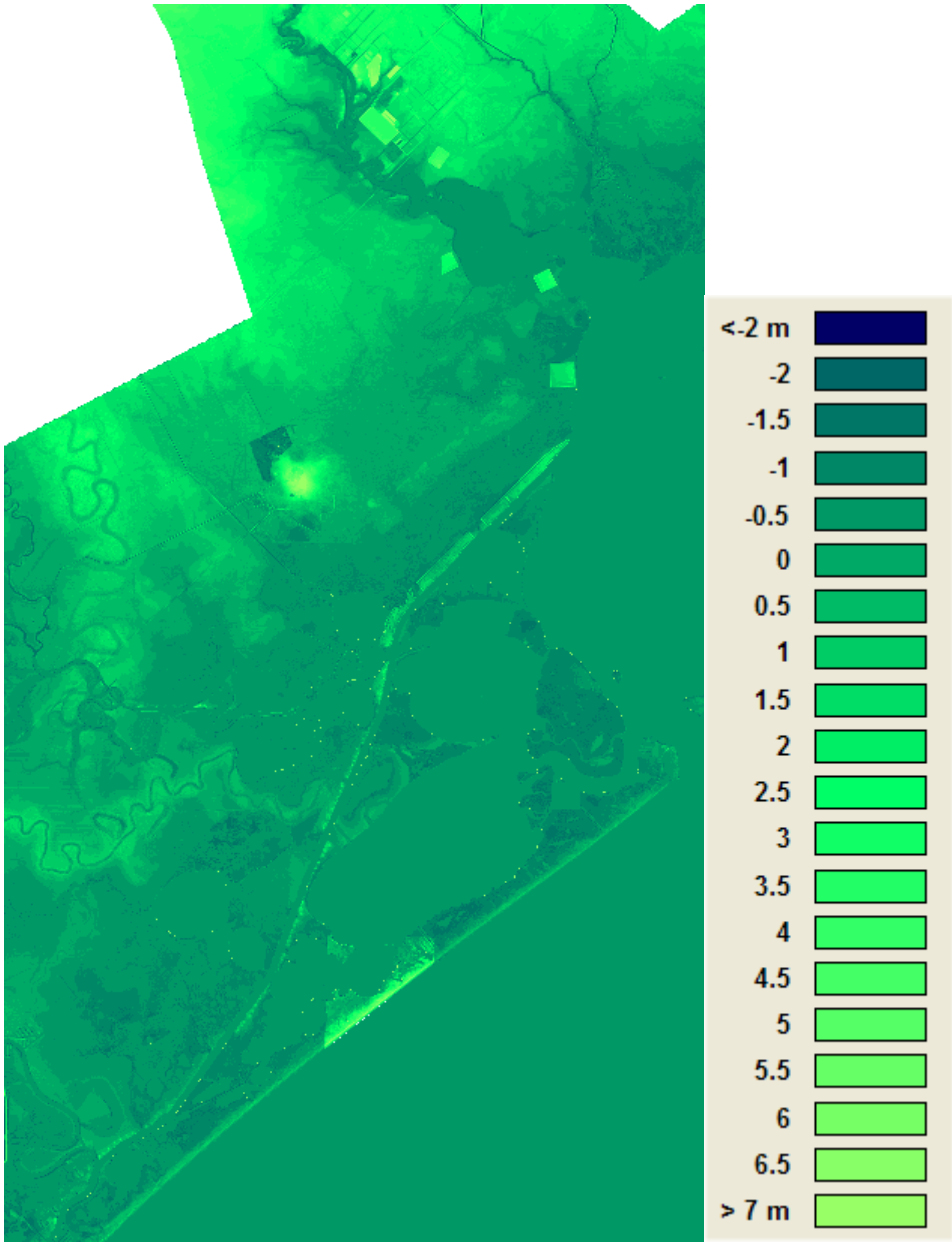


Figure 4. Detail of elevation data in Brazoria NWR

The wetlands layer for the study area was produced in 2009 by the National Wetlands Inventory (Figure 5), but was based on aerial photos taken in August and October of 2004. Therefore, in this report the 2009 NWI layer will be referred to as the 2004 NWI layer.

Converting the NWI survey into 10 m cells indicated that the approximately 52,154 acre refuge (approved acquisition boundary including water) is composed of the following categories:

Land cover type		Area (acres)	Percentage (%)
	Undeveloped Dry Land	14,884	29
	Irregularly Flooded Marsh	14,698	28
	Inland Fresh Marsh	9,783	19
	Estuarine Open Water	6,569	13
	Regularly Flooded Marsh	4,314	8
	Inland Open Water	620	1
	Estuarine Beach	580	1
	Inland Shore	329	1
	Tidal Fresh Marsh	213	< 1
	Swamp	86	< 1
	Developed Dry Land	46	< 1
	Transitional Salt Marsh	23	< 1
	Riverine Tidal	8	< 1
	Total (incl. water)	**52,154**	**100**

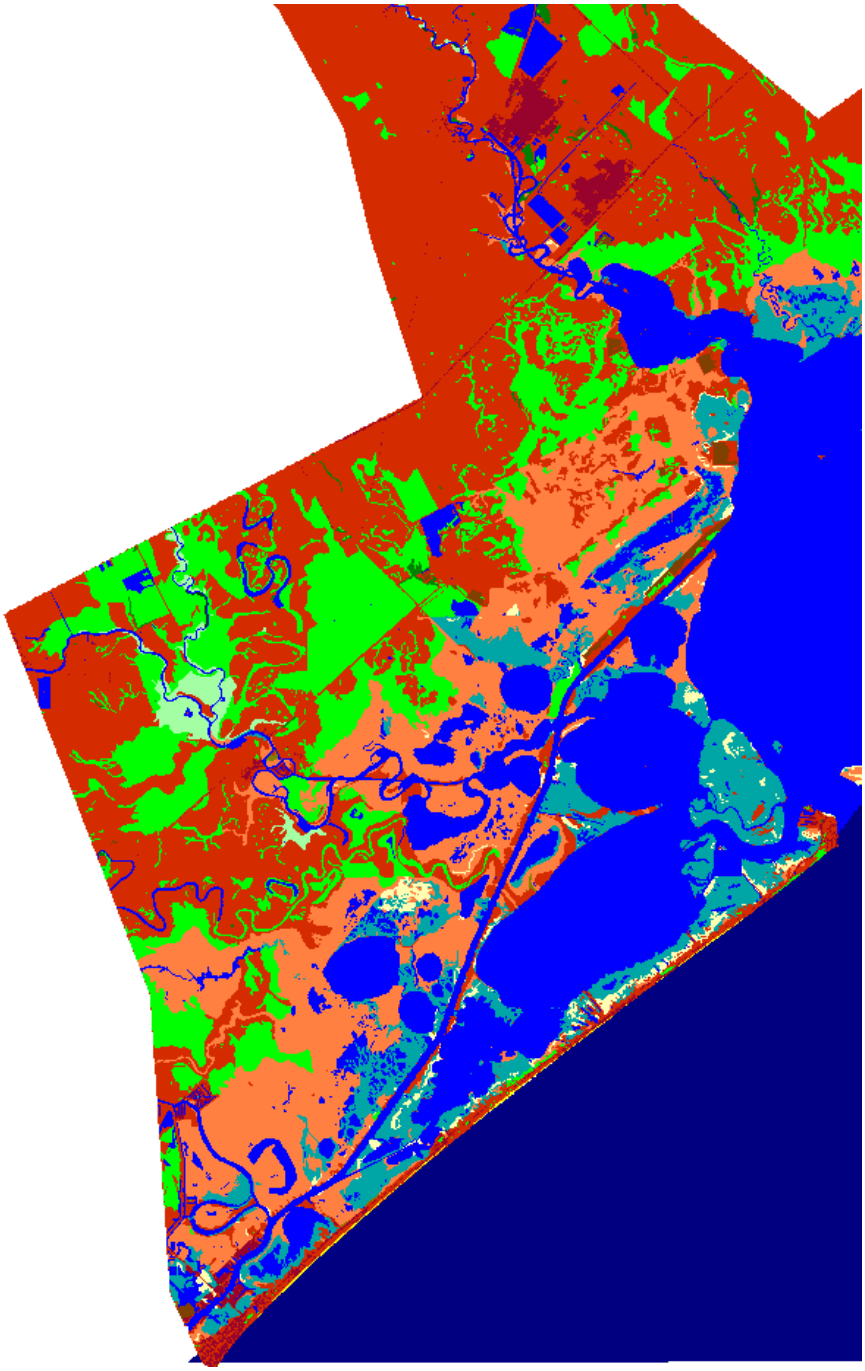


Figure 5. 2004 NWI data layer used for Brazoria NWR

According to the National Wetland Inventory, there are diked areas within Brazoria NWR. These are shown in Figure 6.

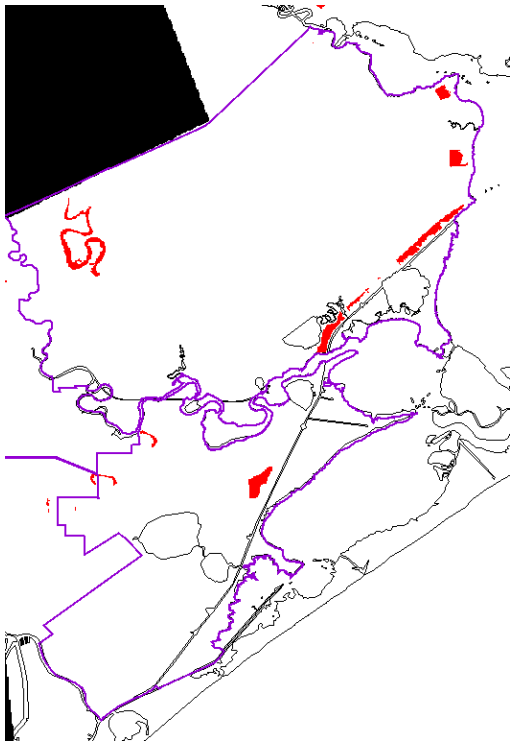


Figure 6. Location of land protected by dikes (red) in Brazoria NWR (boundary in purple)

Historic SLR trends have been measured at two sites in the study area: Galveston Pier 21 (6.39 ± 0.28 mm/year) on the Bay side of Galveston Island and Galveston Pleasure Pier (6.84 ±0.81 mm/year) on the Ocean side of Galveston Island. The observed rate of SLR at these gauges has been significantly higher than the average for the last 100 years (approximately 1.7 mm/year, IPCC 2007).

The higher-than-average historic SLR observed in Galveston Bay can be attributed to land subsidence. However, because of decreased groundwater withdrawals, the pattern of subsidence in the Galveston area significantly changed after 1978 (Gabrysch and Coplin 1990). In addition, recent measurements in East Houston have shown that historic subsidence in this area has stopped completely (Buckley et al. 2003). Given that both the simulations started after 1978, a rate of 0.305 m/century (1 ft./century) was applied to both the hindcast and forecast modeling efforts. This parameter choice was based on information from the Harris-Galveston Subsidence District who advised that subsidence from anthropogenic sources is not anticipated in the future (Michel 2010).

This "natural subsidence rate" of 3.05 mm/yr. was applied within the model by modifying the "Historic Trend" parameter for model forecasts[1]. A rate of 3.05 mm/year is lower than subsidence that would be estimated using measured historic SLR trends from Galveston Island (5.1 mm/year at

[1] The "Historic Trend" parameter is used to input an estimate of historic local SLR. The difference between this historic local trend and the historic eustatic trend is then used to adjust global estimates of SLR utilized by SLAMM. In model forecasts the "Historic Trend" parameter was set to 4.75 mm/yr., which is equal to the 1.7 mm/year historic eustatic SLR trend plus the 3.05 mm/yr. local subsidence rate. The model then interprets this parameter by applying a subsidence rate of 3.05 mm/year throughout the study area.

Galveston Pleasure pier and 4.7 mm/yr. at Pier 21)[2]. This discrepancy may be caused by the averaging period for these gauges as they include years prior to 1978, when subsidence in the Houston-Galveston area was more substantial (Buckley et al. 2003; Gabrysch and Coplin 1990; Michel 2010).

The great diurnal tide range at this site was estimated at 0.32 m using local water level data. This value was determined by averaging the tidal data at the closest NOAA gauge station (Christmas Bay, TX, #8772132) along with NOAA tide prediction values.

The "salt elevation" parameter within SLAMM designates the boundary between coastal wetlands and dry lands or fresh water wetlands. An estimate of this elevation may be derived by examining historical tide gauge data to determine how frequently different elevations are flooded with ocean water. Within SLAMM modeling simulations this elevation is usually defined as the elevation over which flooding is predicted less than once in every 30 days. Dry lands and fresh-water wetlands are assumed to be located above that elevation. In this study of Brazoria NWR, the salt elevation was designated ad 0.401 m above MTL.

Accretion rates in salt marshes were subject to feedback based on elevation. For Brazoria, the maximum accretion rate applied was 4 mm/yr. and minimum was 1.6 mm/yr., resulting in an average rate of 3.1 mm/yr. Tidal Fresh Marsh accretion feedbacks were also applied to all subsites based on data reported by White and coworkers (2002). This curve resulted in an average accretion rate of 4.86 mm/yr. The accretion rate of 2.9 mm/yr. applied to inland fresh marsh was derived from the average accretion rate of all fresh marsh values reported by White and coworkers (2002; 4.9 mm/yr.) averaged with the rate of 2.5 mm/yr. observed by Williams et al. (2003) and the rate of 1.3 mm/yr. observed by Yeager and coworkers (2007).

Erosion rates observed from 1931-2000 were applied to the SLAMM model based on data from the Texas Hazard Mitigation Package (Texas Geographic Society, http://www.thmp.info/data_layers/coastal-erosion.html). Erosion rates for the Brazoria area were taken from a more detailed erosion study conducted by Gibeaut and coworkers (2003). Their work suggested the western shore of West Galveston Bay and the northern shore of Galveston Island (represented by subsite West Bay 2 shown in Figure 7) had a much higher erosion rate (approximately 2.3 m/yr.).

[2] For example, at Galveston Pleasure Pier, 6.8 mm/year observed minus 1.7 mm/year of eustatic SLR observed would suggest a rate of 5.1 mm/year due to subsidence.

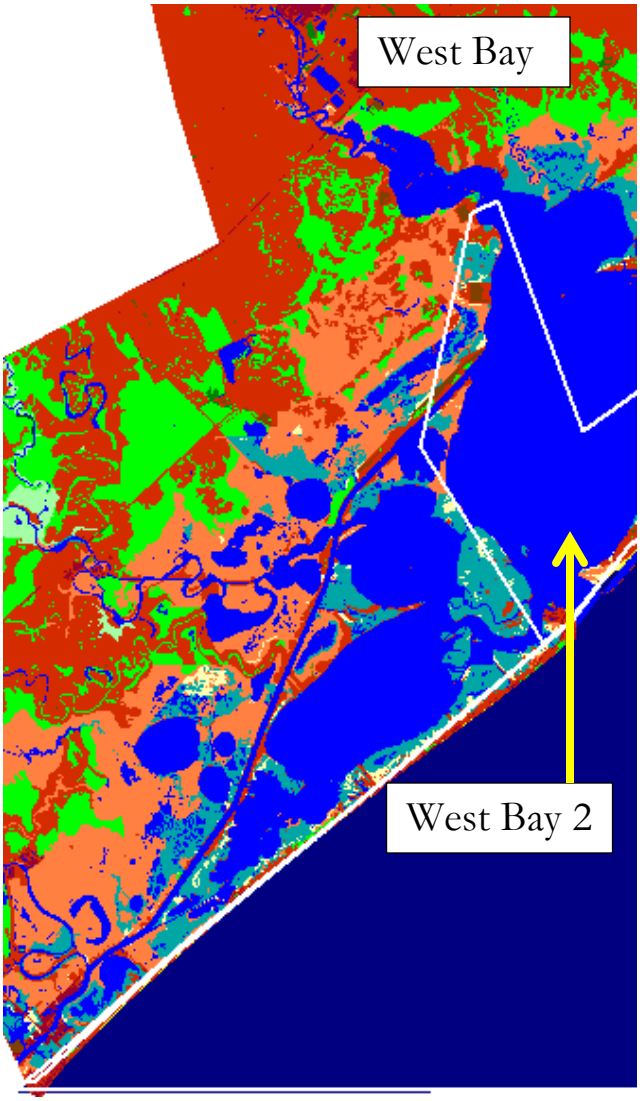


Figure 7. Input subsites

An MTL to NAVD88 correction was applied via input raster. However, the correction value was not highly variable over the area of the refuge, as shown in Figure 8.

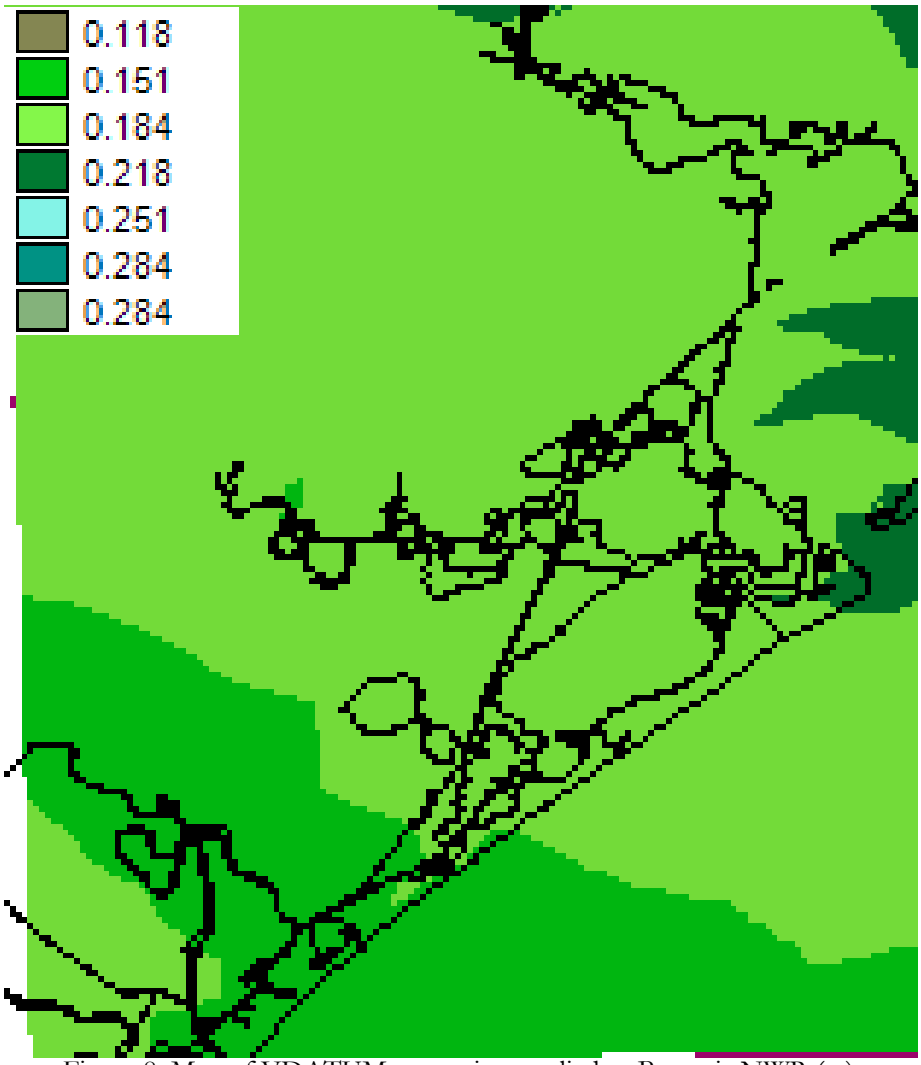


Figure 8. Map of VDATUM correction applied to Brazoria NWR (m)

Modeled U.S. Fish and Wildlife Service refuge boundaries for Texas are based on Approved Acquisition Boundaries as published on the FWS National Wildlife Refuge Data and Metadata website. The cell-size used for this analysis was 10 m by 10 m cells. Note that the SLAMM model will track partial conversion of cells based on elevation and slope.

Table 1. Summary of SLAMM input parameters for Brazoria NWR

Subsite Description	West Bay	West Bay 2
NWI Photo Date (YYYY)	2004	2004
DEM Date (YYYY)	2007	2007
Direction Offshore [n,s,e,w]	East	East
Historic Trend (mm/yr.)	4.75	4.75
GT Great Diurnal Tide Range (m)	0.32	0.32
Salt Elev. (m above MTL)	0.40	0.40
Marsh Erosion (horz. m /yr)	0.77	2.3
Swamp Erosion (horz. m /yr.)	0.77	2.3
T.Flat Erosion (horz. m /yr)	0.77	2.3
Inland-Fresh Marsh Accr (mm/yr.)	2.9	2.9
Tidal Swamp Accr (mm/yr.)	1.1	1.1
Swamp Accretion (mm/yr.)	0.3	0.3
Beach Sed. Rate (mm/yr.)	1	1
Hindcast - Use Elev Pre-processor [True,False]	TRUE	TRUE
Forecast - Use Elev Pre-processor [True,False]	FALSE	FALSE
Reg Flood Max. Accr. (mm/year)	4	4
Reg Flood Min. Accr. (mm/year)	1.6	1.6
Reg Flood Elev a coeff. (cubic)	-1	-1
Reg Flood Elev b coeff. (square)	0.8	0.8
Reg Flood Elev c coeff. (linear)	1	1
Irreg Flood Max. Accr. (mm/year)	4	4
Irreg Flood Min. Accr. (mm/year)	1.6	1.6
Irreg Flood Elev a coeff. (cubic)	-1	-1
Irreg Flood Elev b coeff. (square)	0.8	0.8
Irreg Flood Elev c coeff. (linear)	1	1
Irreg Flood D.Effect Max (meters)	0	0
Irreg Flood D min. (unitless)	1	1
Tidal Fresh Max. Accr. (mm/year)	6.5	6.5
Tidal Fresh Min. Accr. (mm/year)	3.2	3.2
Tidal Fresh Elev a coeff. (cubic)	0	0
Tidal Fresh Elev b coeff. (square)	0	0
Tidal Fresh Elev c coeff. (linear)	1	1

Results

This simulation of the Brazoria NWR was completed using a SLAMM model that was calibrated to historical data for a previous project (Warren Pinnacle Consulting, Inc. 2011). This calibrated model predicts that Brazoria NWR may be severely impacted depending on the SLR scenario and land-cover class examined. Table 2 presents the predicted loss of each wetland category by 2100 for each of the five SLR scenarios examined.

Irregularly-flooded marsh makes up nearly 30% of the refuge. Under the IPCC A1B mean scenario (0.39 m of eustatic SLR by 2100), 37% of irregularly-flooded marsh is predicted to be converted to other land cover categories. In the 1 m scenario (considered a likely scenario by many climate scientists, e.g. Vermeer and Rahmstorf 2009) 93% of the irregularly-flooded marsh in the refuge is predicted to be lost, as is 44% of the inland fresh marsh. Conversely, regularly-flooded marsh is projected to increase over each scenario as irregularly-flooded marsh coverts to regularly-flooded as sea-level rises.

Estuarine Beach comprises only 1% of the refuge but is also predicted by SLAMM to be significantly impacted by SLR. At a minimum 78% of the estuarine beach is predicted to be lost under the SLR scenarios tested.

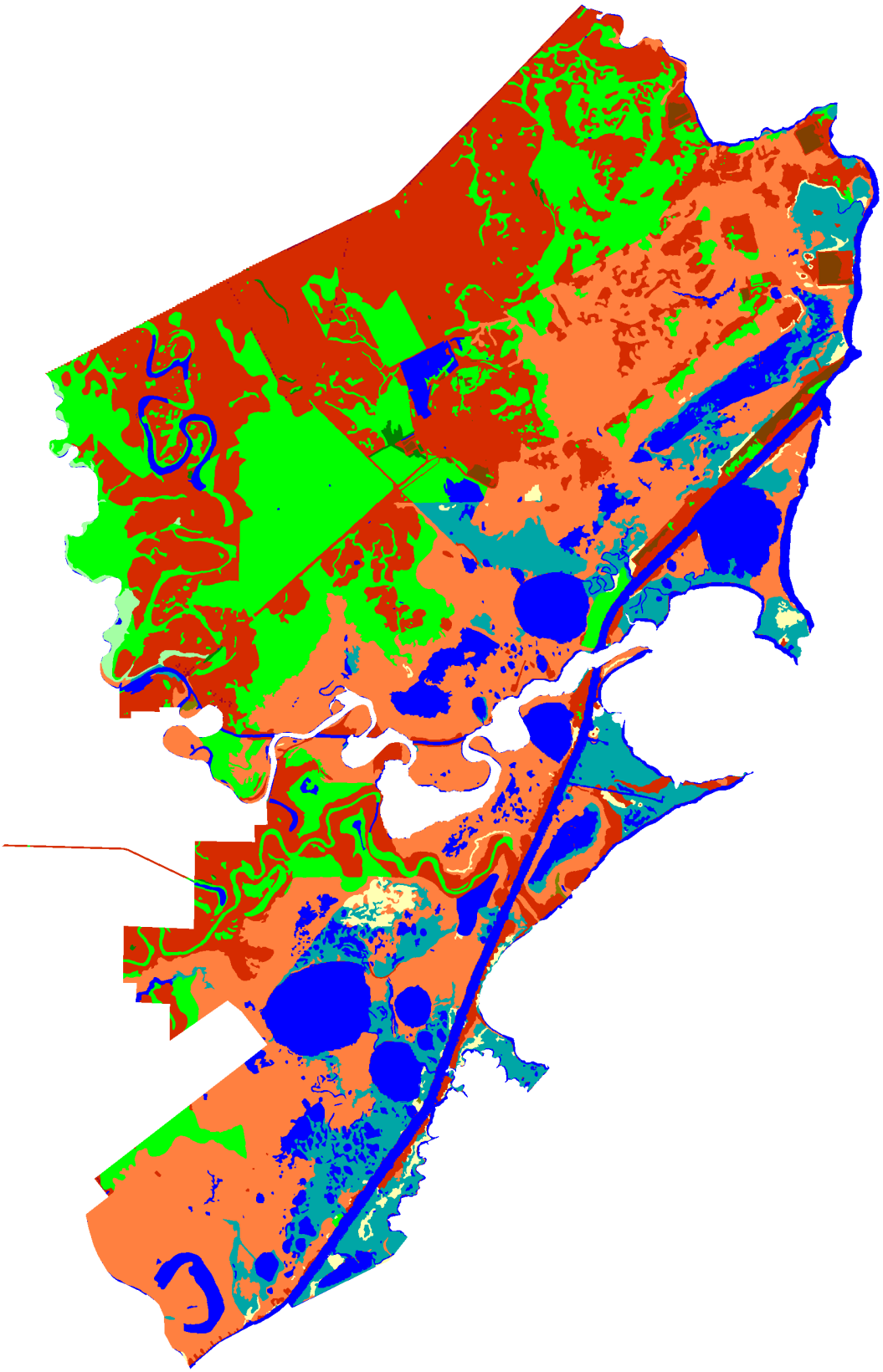
Table 2. Predicted Change Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise. *Negative values indicate losses and positive indicate gains.*

Land cover category	**Land cover change by 2100 for different SLR scenarios (%)**				
	0.39 m	**0.69 m**	**1 m**	**1.5 m**	**2 m**
Undeveloped Dry Land	-24	-34	-45	-63	-77
Irregularly Flooded Marsh	-37	-74	-93	-99	-100
Inland Fresh Marsh	1	-23	-44	-72	-90
Regularly Flooded Marsh	12	30	69	59	82
Estuarine Beach	-78	-93	-97	-99	-99
Inland Shore	-7	-13	-18	-27	-35
Tidal Fresh Marsh	-1	-7	-53	-92	-99
Swamp	-20	-31	-48	-88	-94
Developed Dry Land	-3	-7	-11	-34	-50

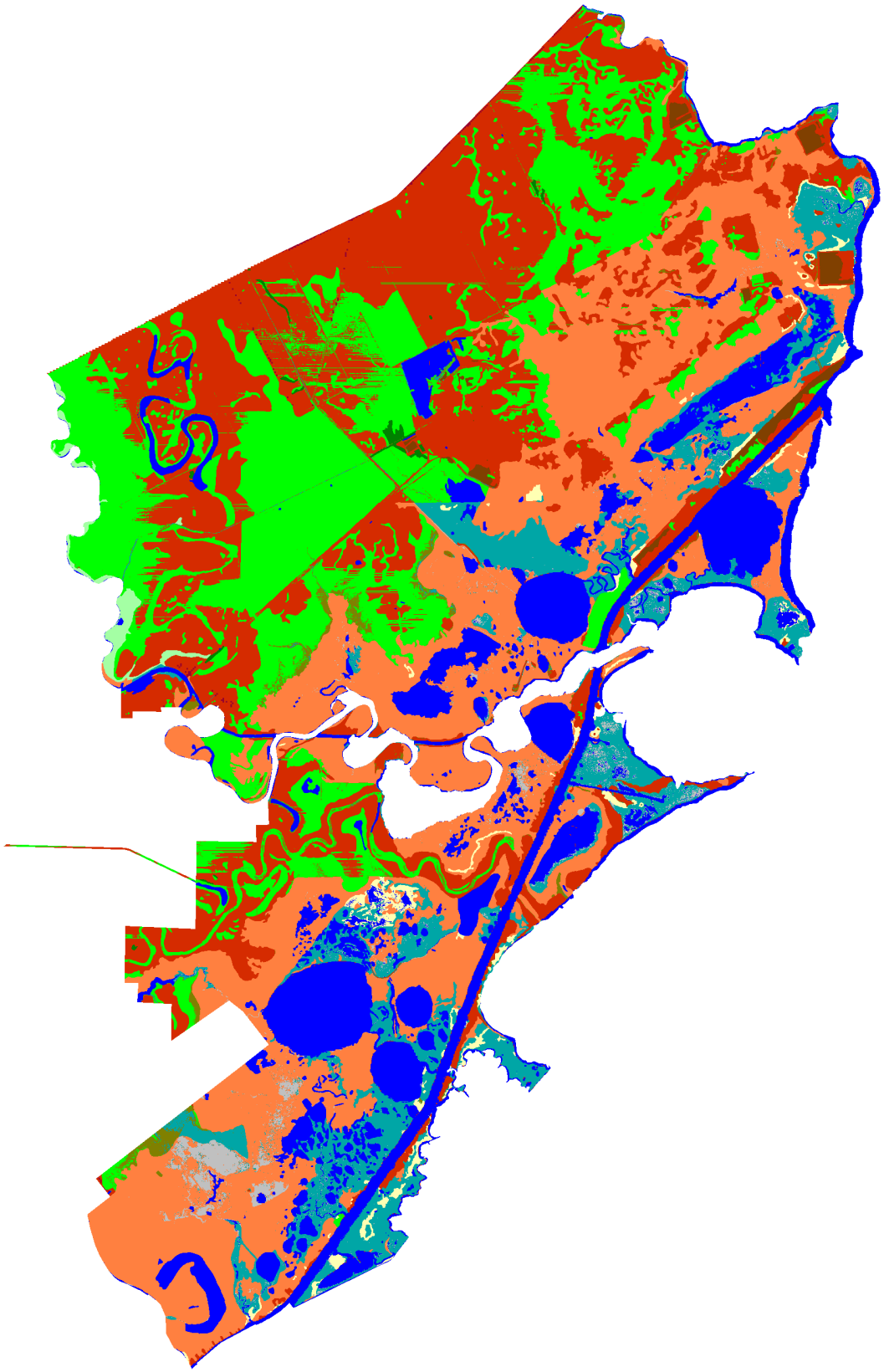
IPCC Scenario A1B-Mean, 0.39 m SLR eustatic by 2100

Results in Acres

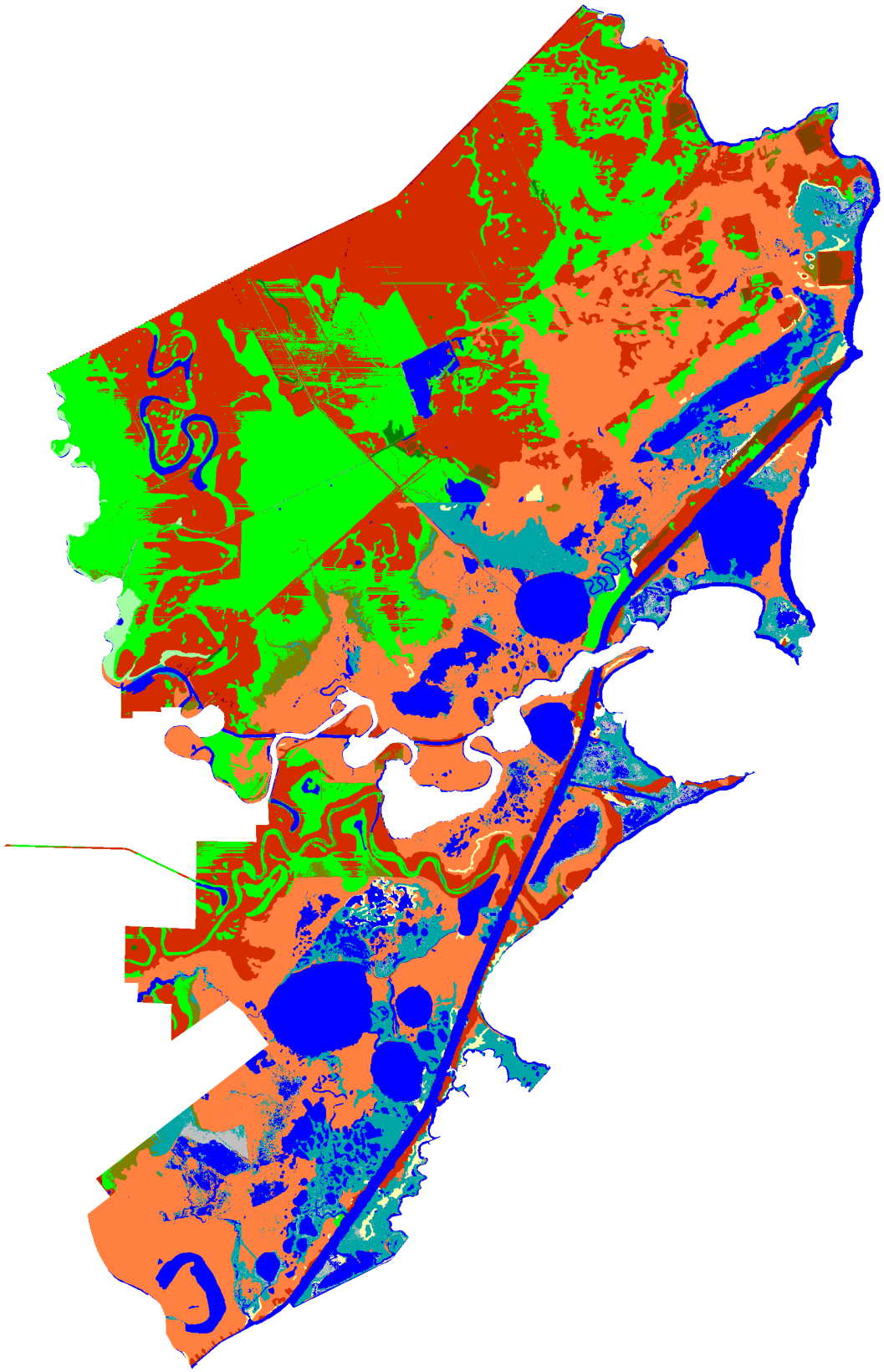
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	14884	13484	13053	12307	11257
	Irregularly Flooded Marsh	14698	14182	13932	12657	9261
	Inland Fresh Marsh	9783	10498	10436	10260	9853
	Estuarine Open Water	6569	6992	7716	8723	11189
	Regularly Flooded Marsh	4314	4248	3984	3336	4825
	Inland Open Water	620	499	473	453	439
	Estuarine Beach	580	504	428	284	128
	Inland Shore	329	329	328	316	305
	Tidal Fresh Marsh	213	211	211	211	211
	Swamp	86	85	83	77	69
	Developed Dry Land	46	46	46	46	45
	Transitional Salt Marsh	23	481	800	1353	2179
	Riverine Tidal	8	6	6	5	3
	Tidal Flat	0	588	658	2126	2389
	Total (incl. water)	**52154**	**52154**	**52154**	**52154**	**52154**



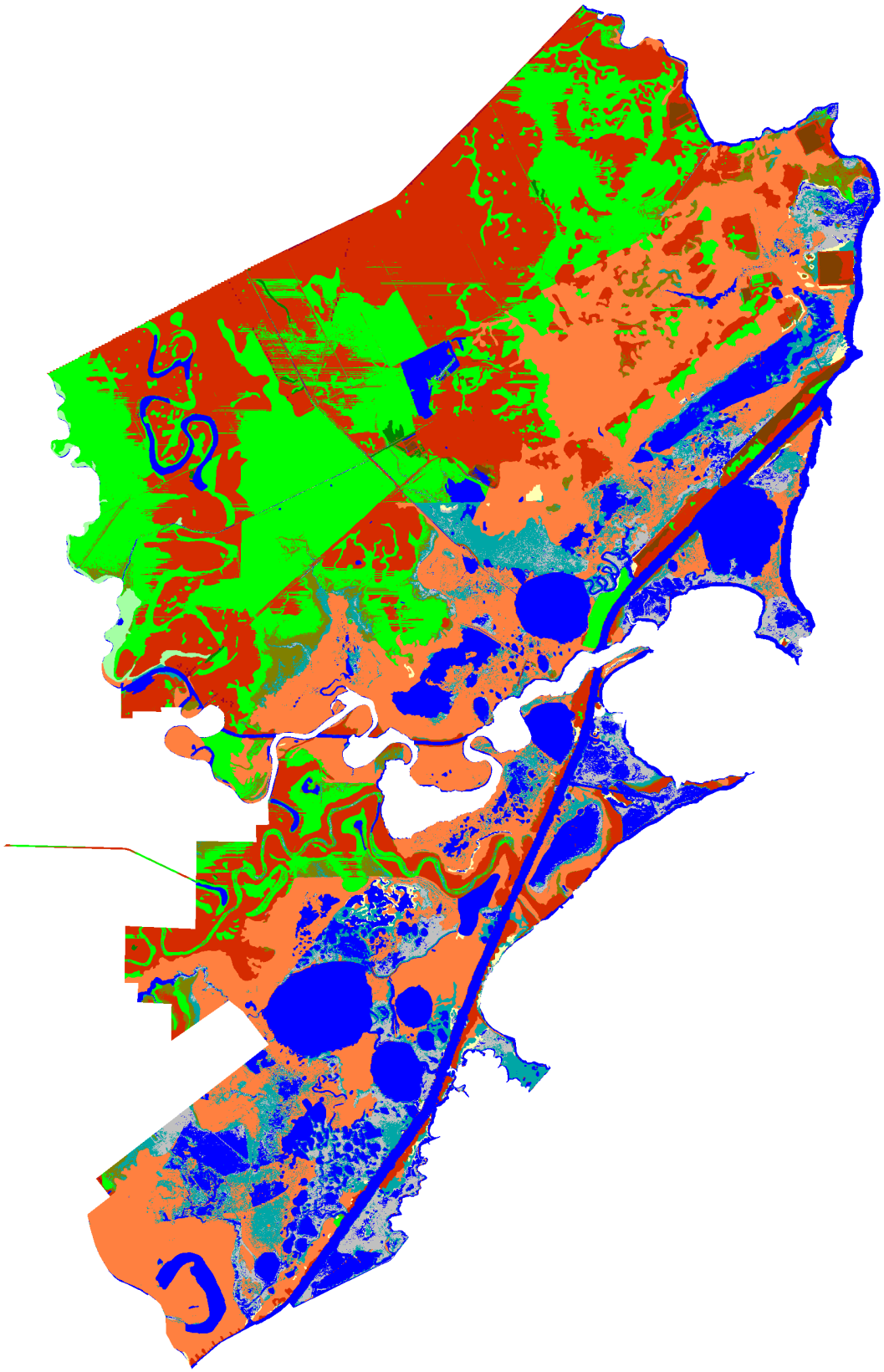
Brazoria NWR, Initial Condition



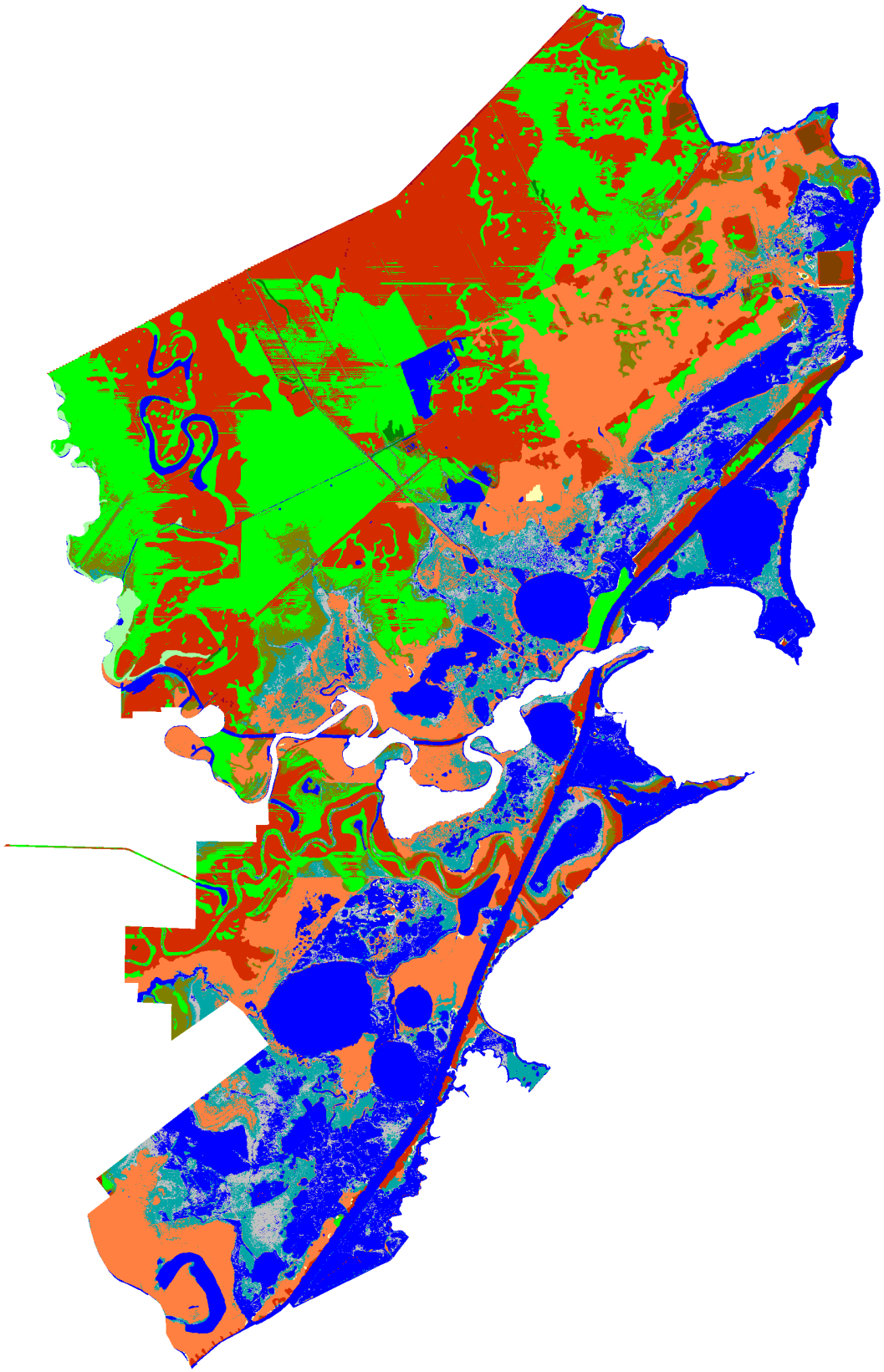
Brazoria NWR, 2025, Scenario A1B Mean



Brazoria NWR, 2050, Scenario A1B Mean



Brazoria NWR, 2075, Scenario A1B Mean

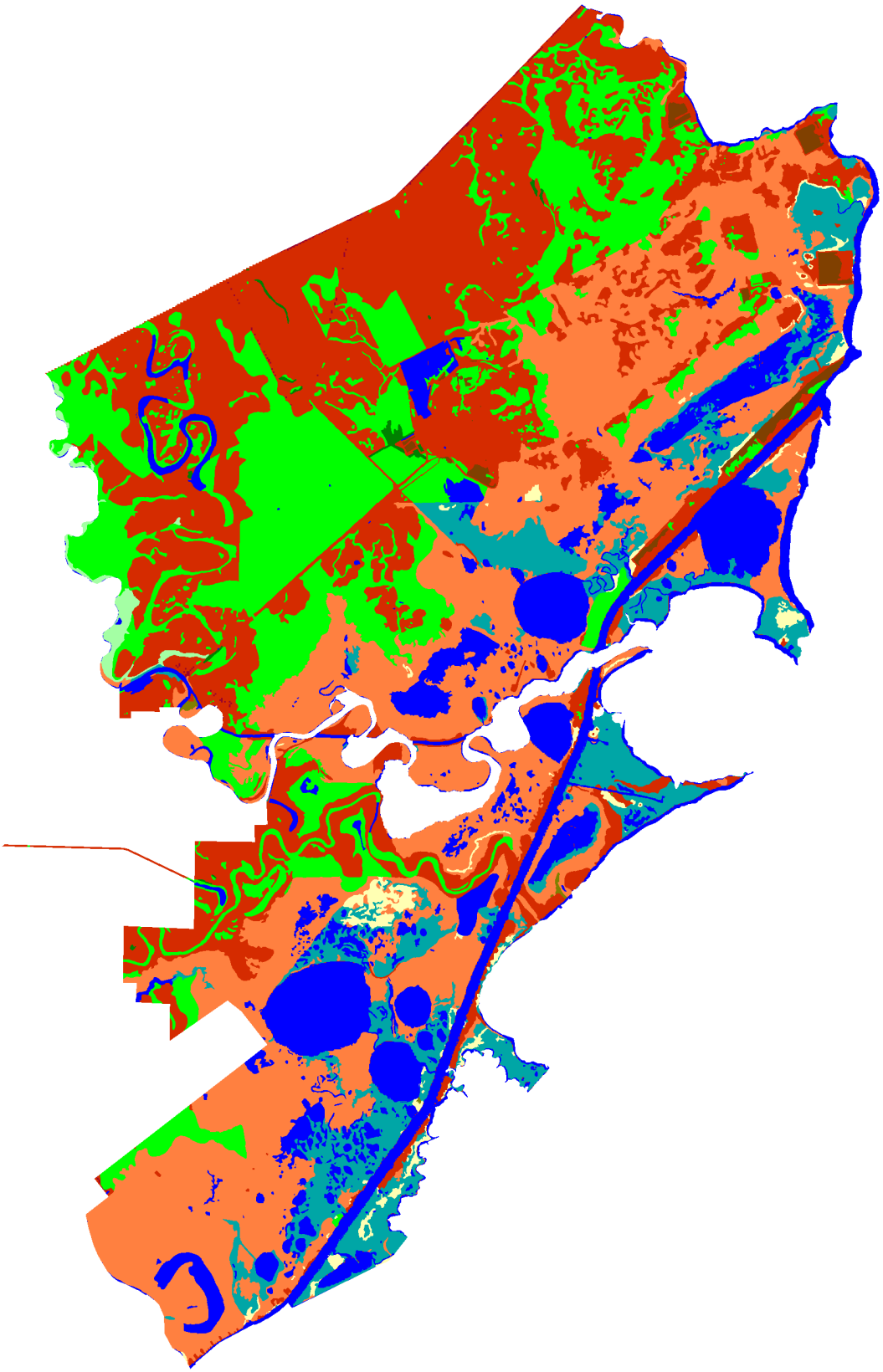


Brazoria NWR, 2100, Scenario A1B Mean

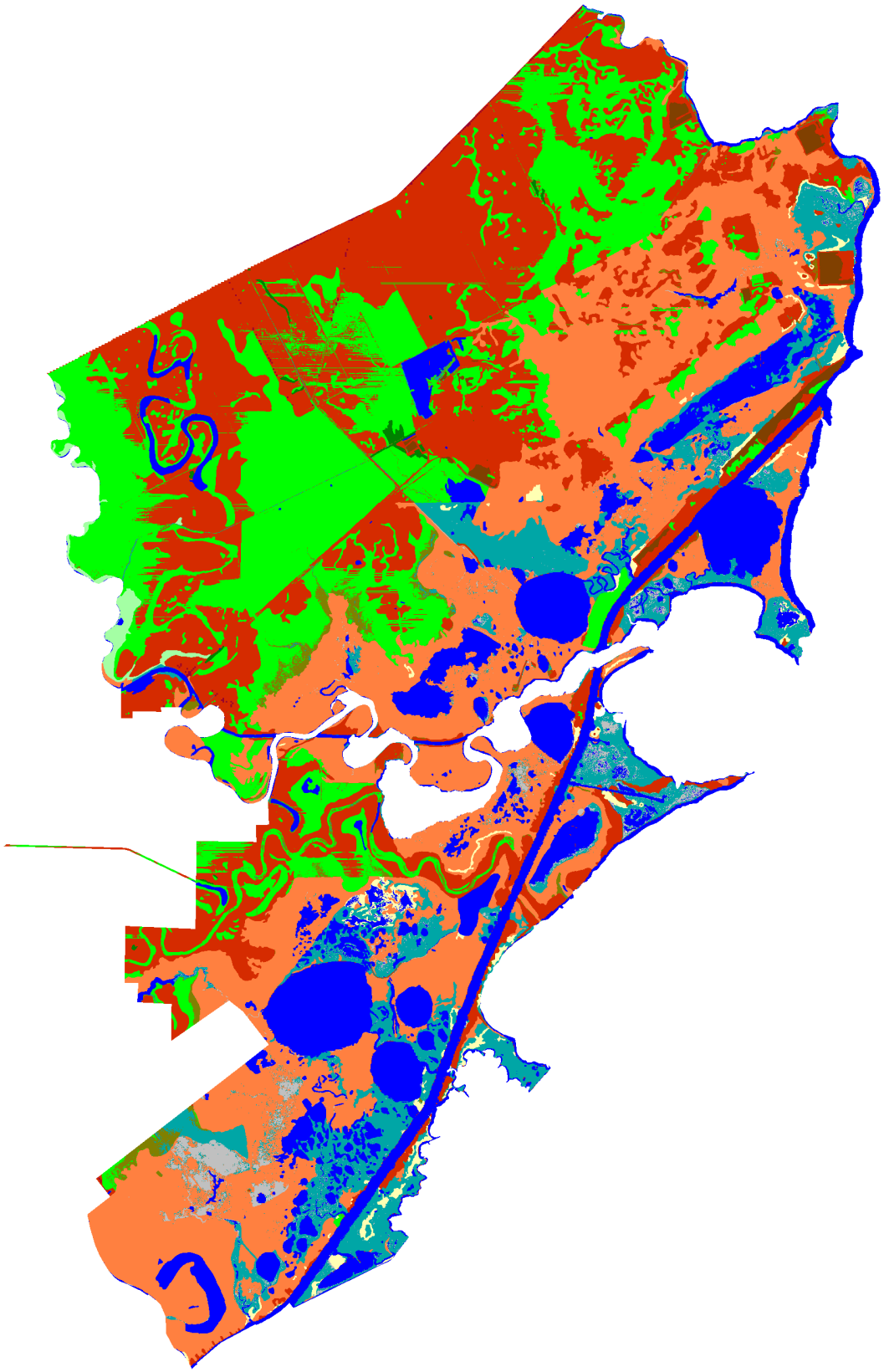
IPCC Scenario A1B-Max, 0.69 m SLR eustatic by 2100

Results in Acres

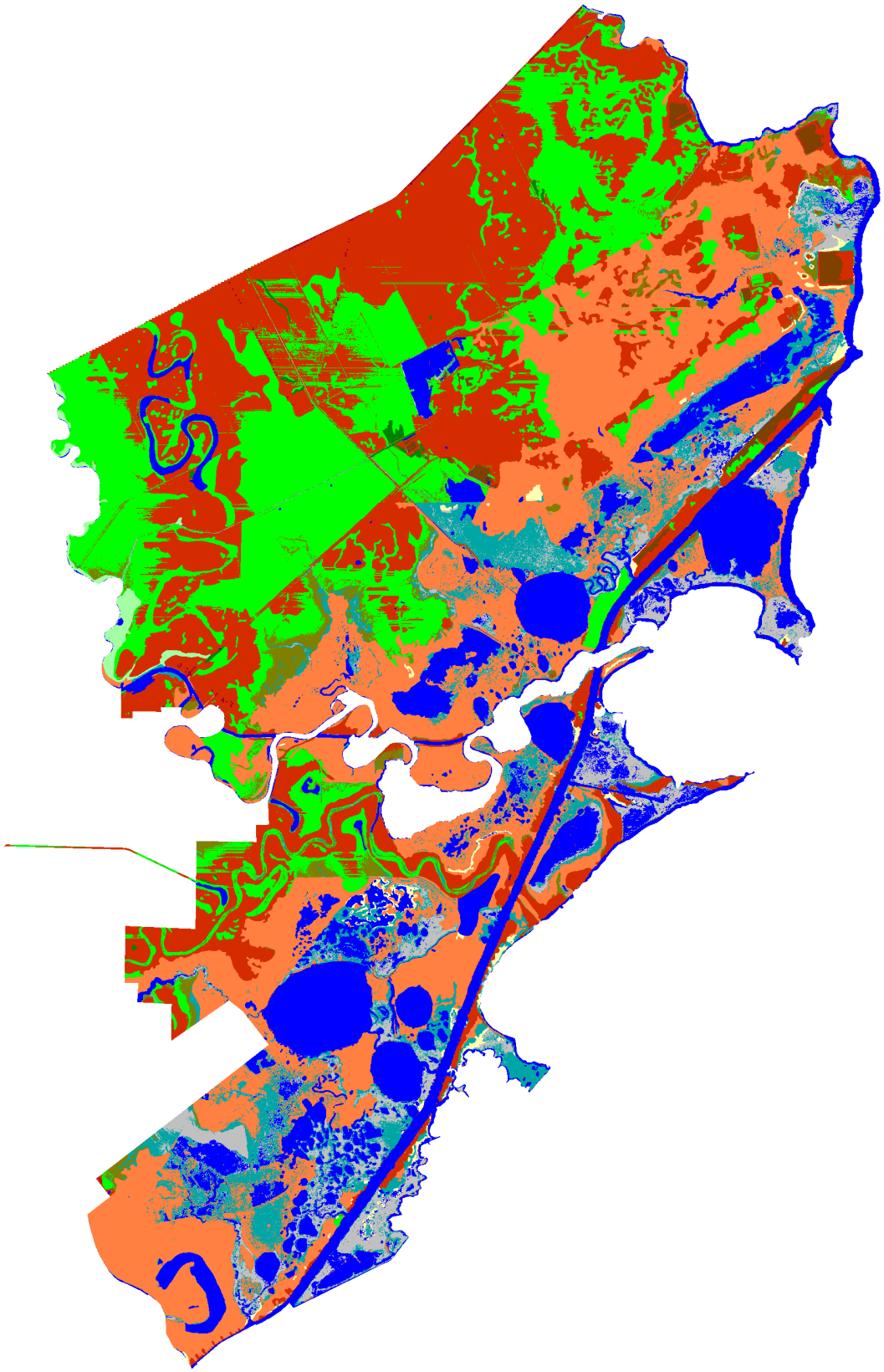
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	14884	13452	12847	11530	9764
	Irregularly Flooded Marsh	14698	14089	12592	6824	3853
	Inland Fresh Marsh	9783	10403	10092	8932	7543
	Estuarine Open Water	6569	7058	8075	10999	14467
	Regularly Flooded Marsh	4314	4246	3608	7170	5627
	Inland Open Water	620	495	465	441	414
	Estuarine Beach	580	482	351	109	40
	Inland Shore	329	329	327	305	285
	Tidal Fresh Marsh	213	211	211	209	199
	Swamp	86	85	80	69	60
	Developed Dry Land	46	46	46	45	43
	Transitional Salt Marsh	23	575	1134	2542	3185
	Riverine Tidal	8	6	5	3	1
	Tidal Flat	0	676	2320	2975	6673
	Total (incl. water)	**52154**	**52154**	**52154**	**52154**	**52154**



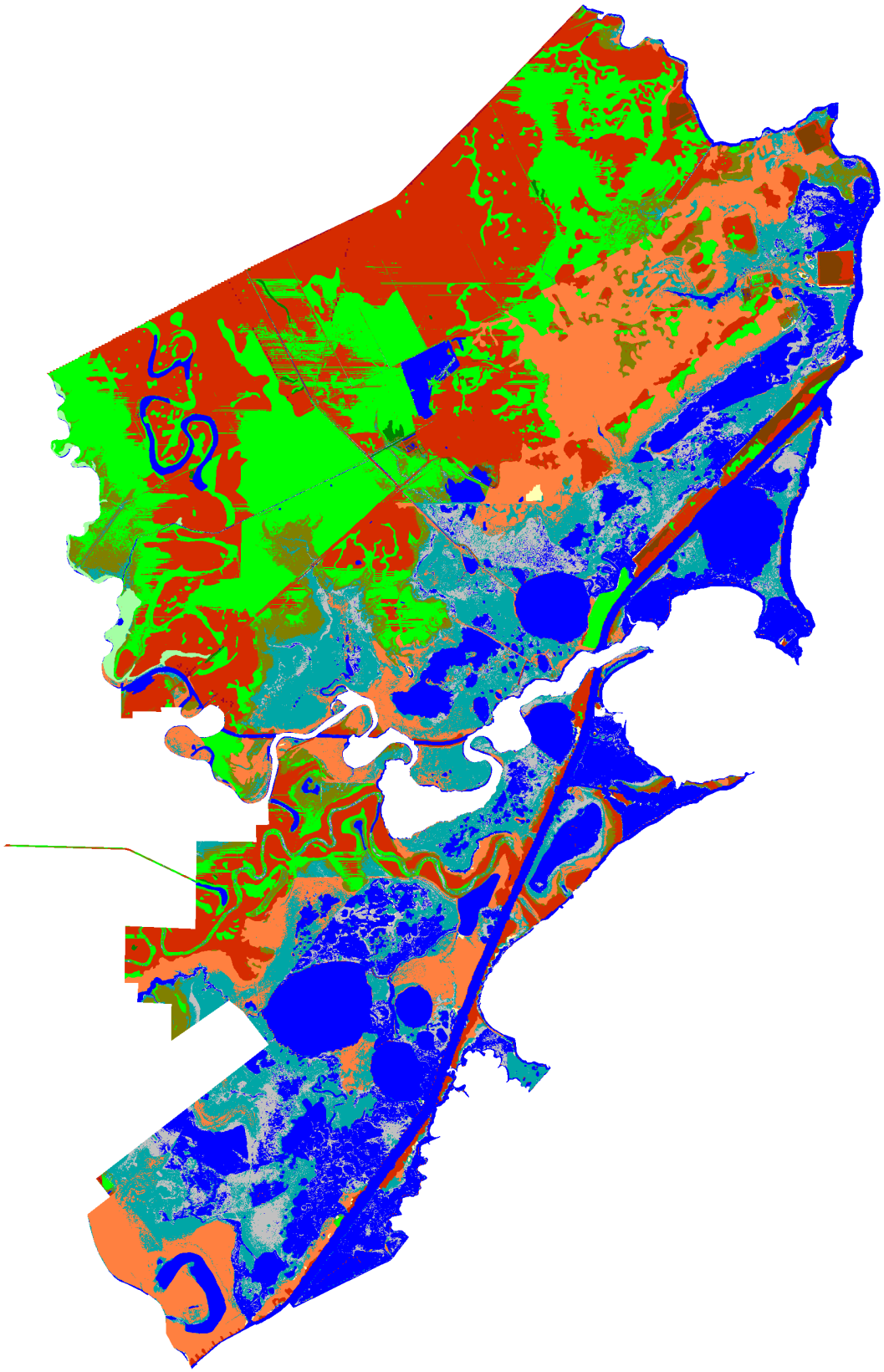
Brazoria NWR, Initial Condition



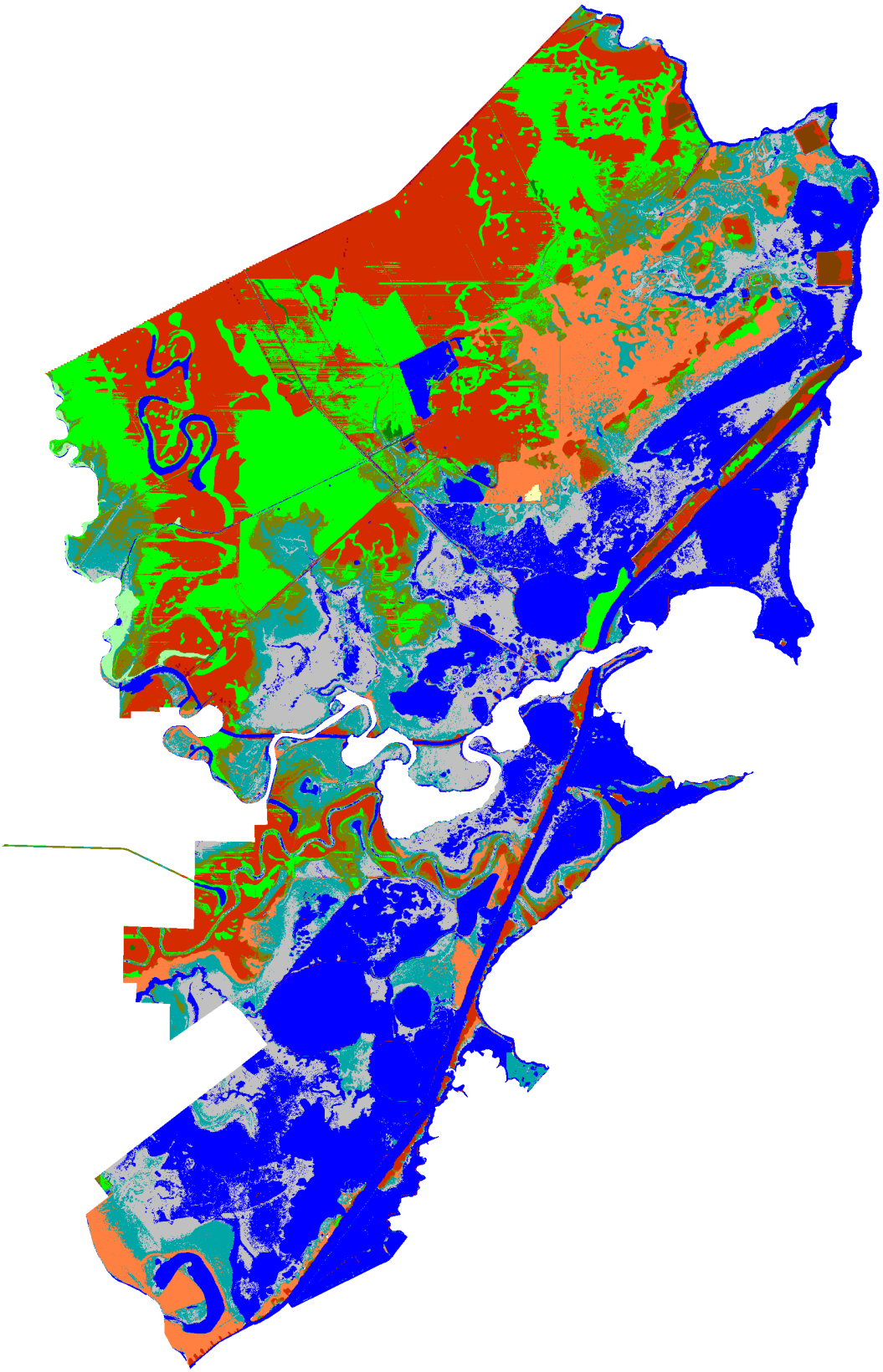
Brazoria NWR, 2025, Scenario A1B Maximum



Brazoria NWR, 2050, Scenario A1B Maximum



Brazoria NWR, 2075, Scenario A1B Maximum

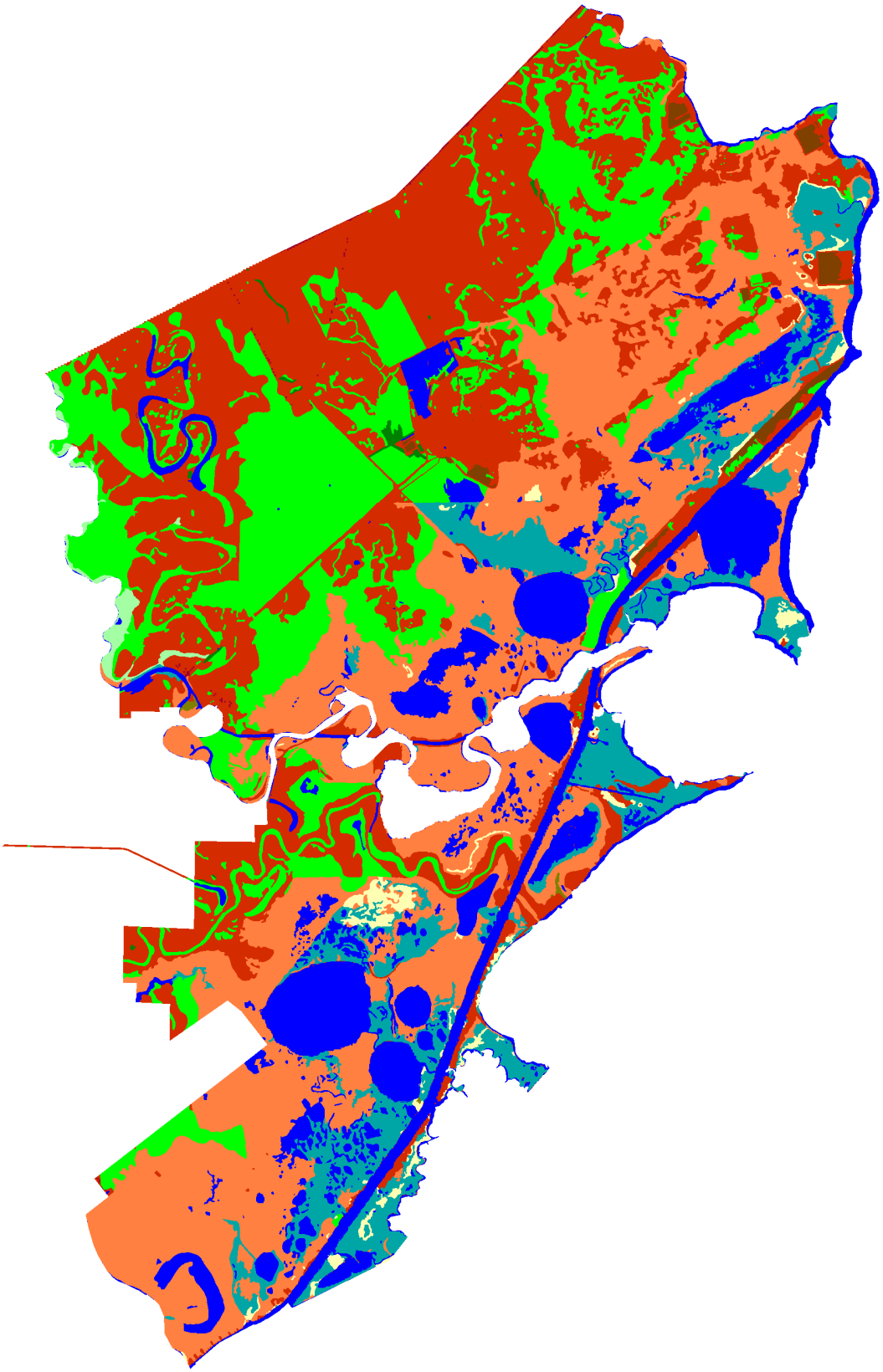


Brazoria NWR, 2100, Scenario A1B Maximum

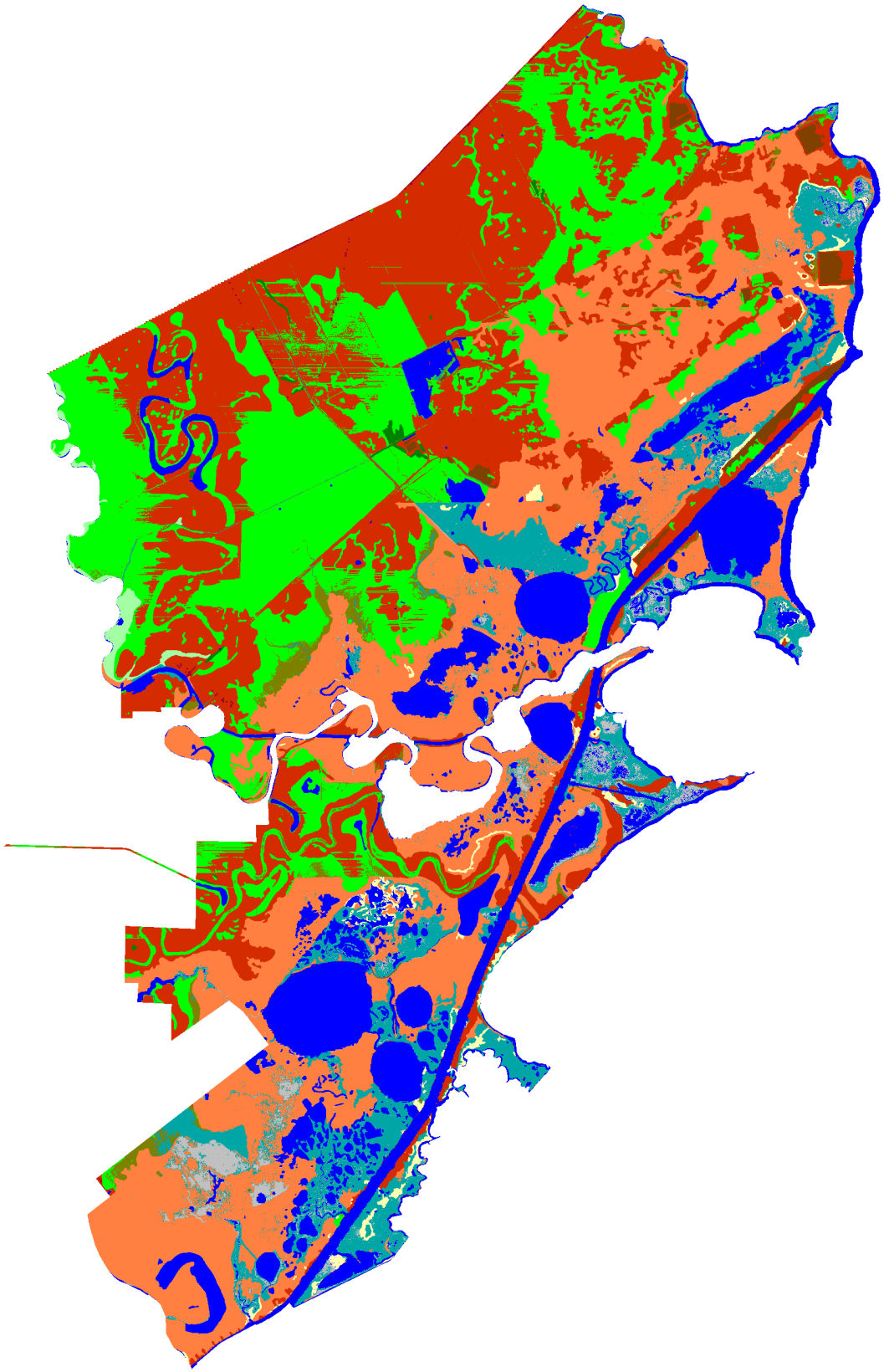
1 m eustatic SLR by 2100

Results in Acres

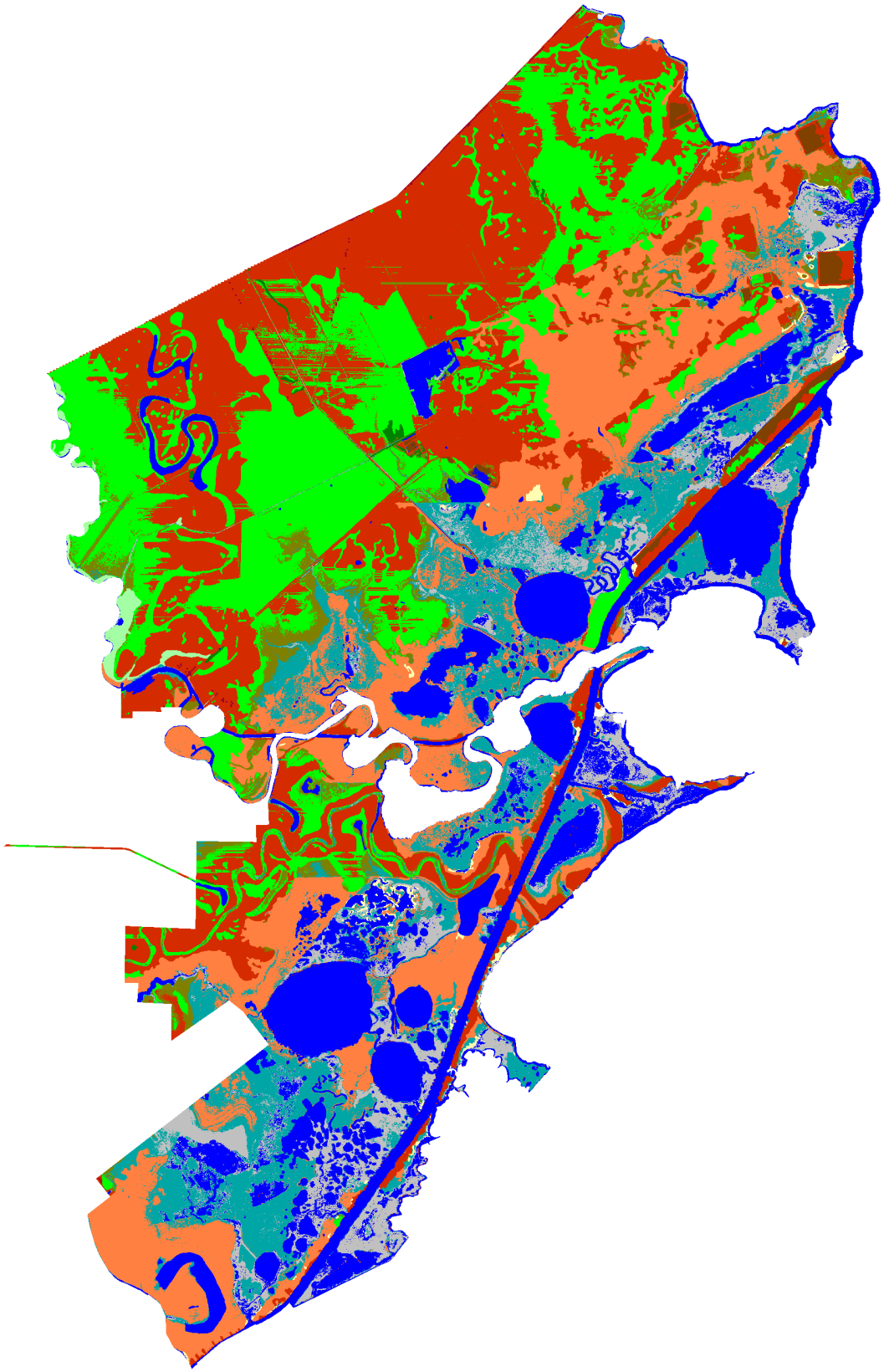
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	14884	13413	12496	10536	8193
	Irregularly Flooded Marsh	14698	13948	9303	4161	1014
	Inland Fresh Marsh	9783	10296	9506	7440	5479
	Estuarine Open Water	6569	7146	8533	12220	18256
	Regularly Flooded Marsh	4314	4183	6111	7006	7284
	Inland Open Water	620	490	459	429	400
	Estuarine Beach	580	462	247	49	18
	Inland Shore	329	329	315	291	268
	Tidal Fresh Marsh	213	211	209	186	100
	Swamp	86	85	76	63	45
	Developed Dry Land	46	46	46	43	41
	Transitional Salt Marsh	23	678	1738	4059	4335
	Riverine Tidal	8	6	5	1	0
	Tidal Flat	0	862	3110	5669	6722
	Total (incl. water)	**52154**	**52154**	**52154**	**52154**	**52154**



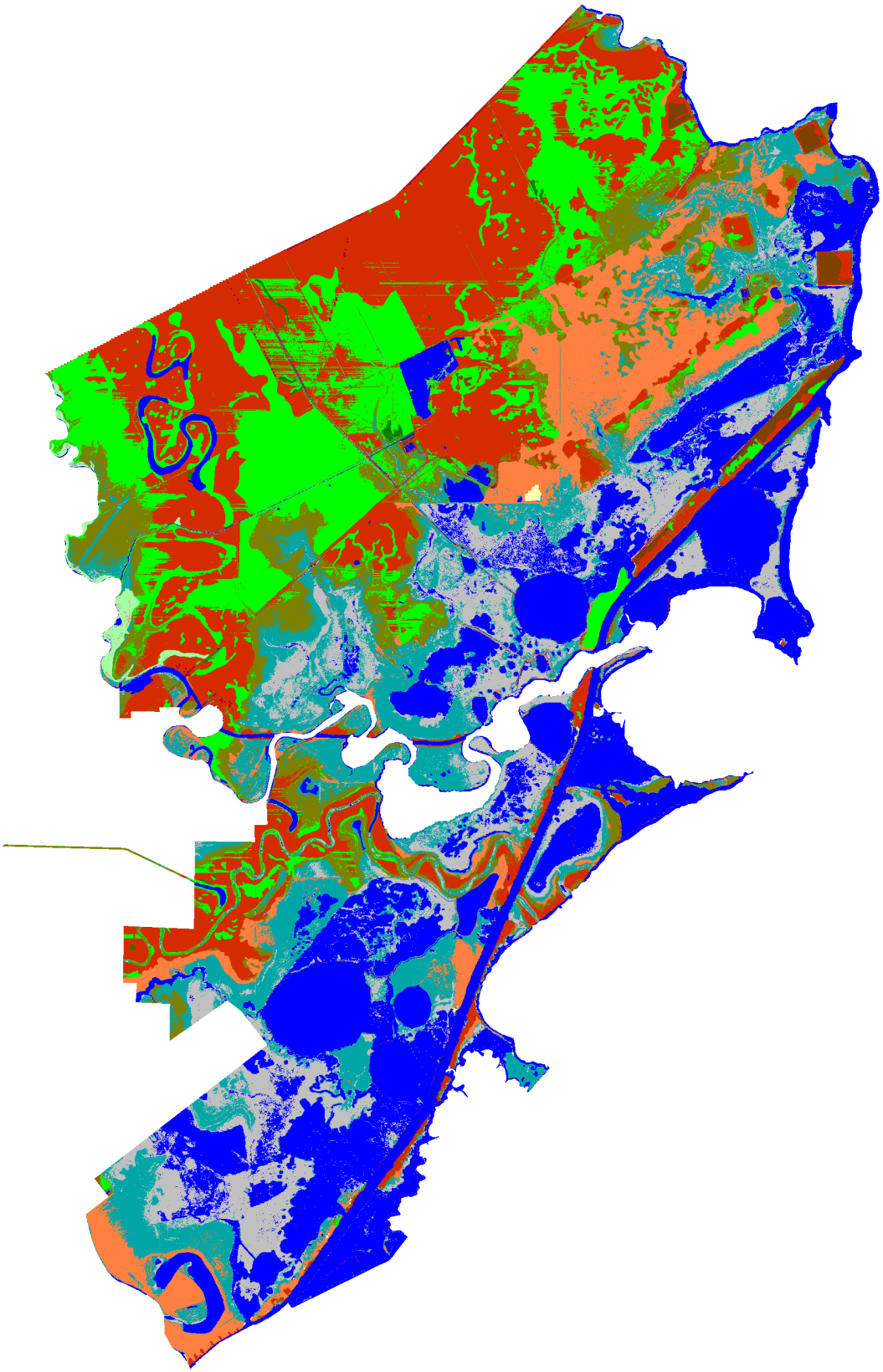
Brazoria NWR, Initial Condition



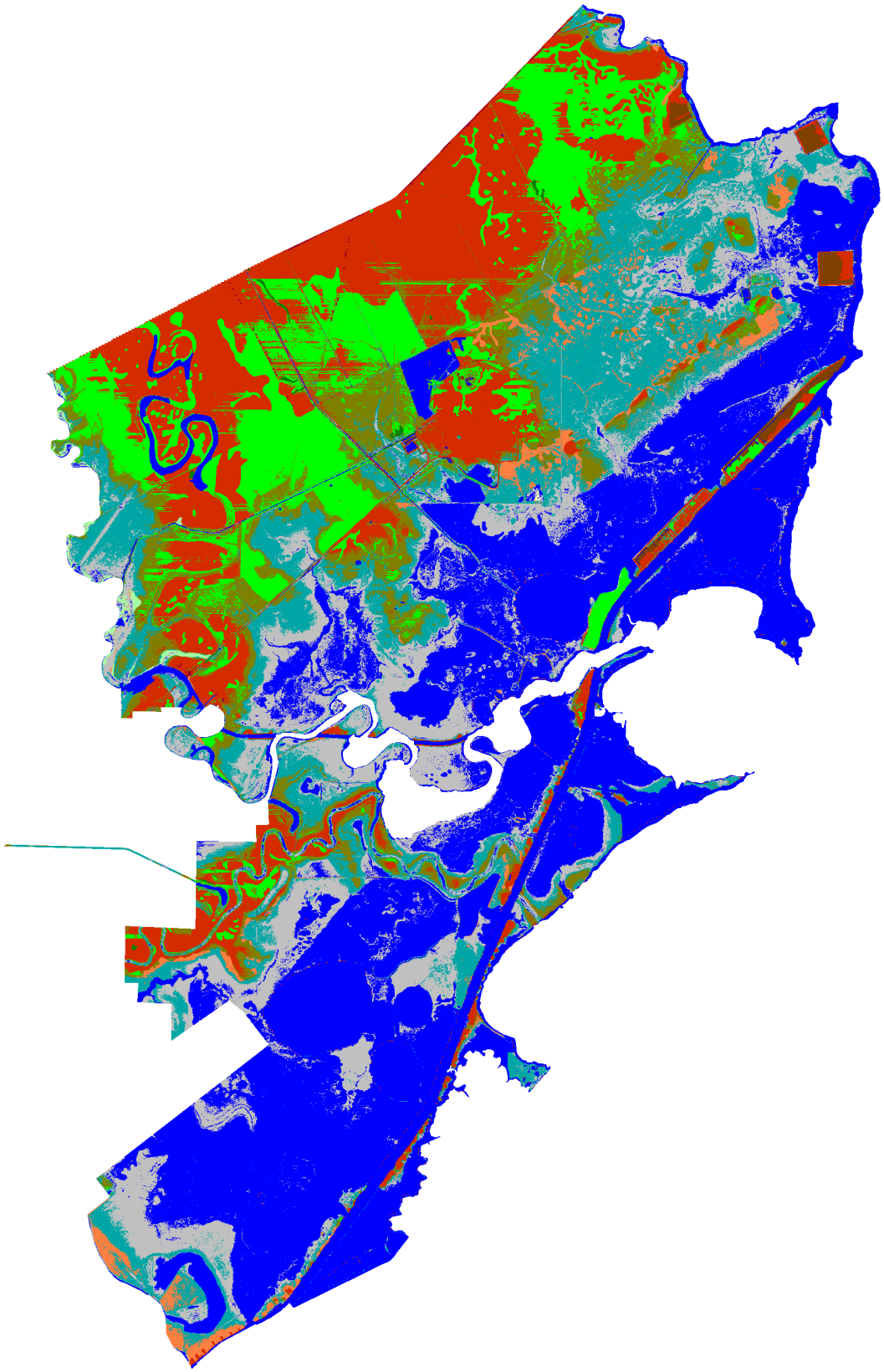
Brazoria NWR, 2025, 1 Meter



Brazoria NWR, 2050, 1 Meter



Brazoria NWR, 2075, 1 Meter

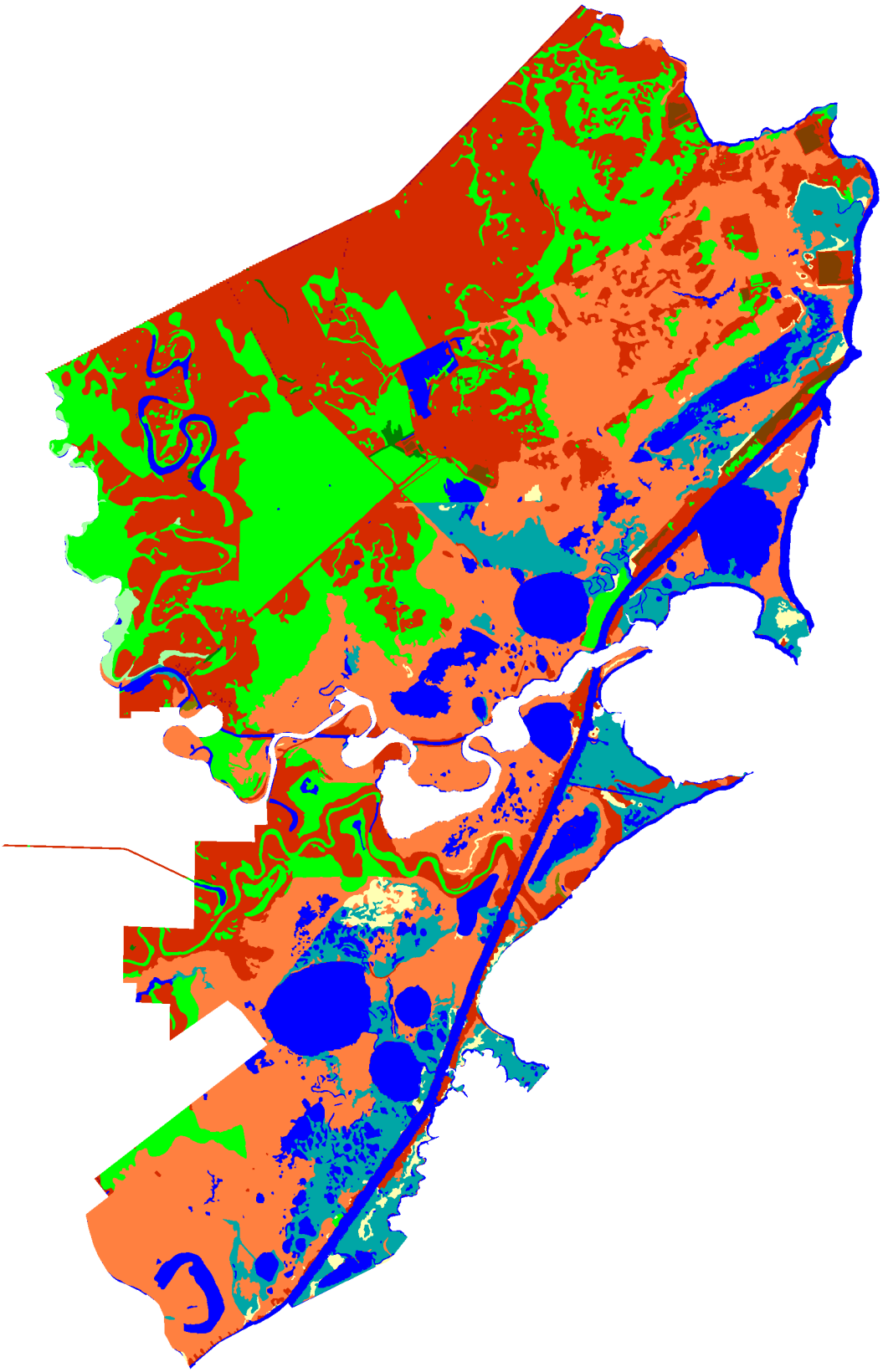


Brazoria NWR, 2100, 1 Meter

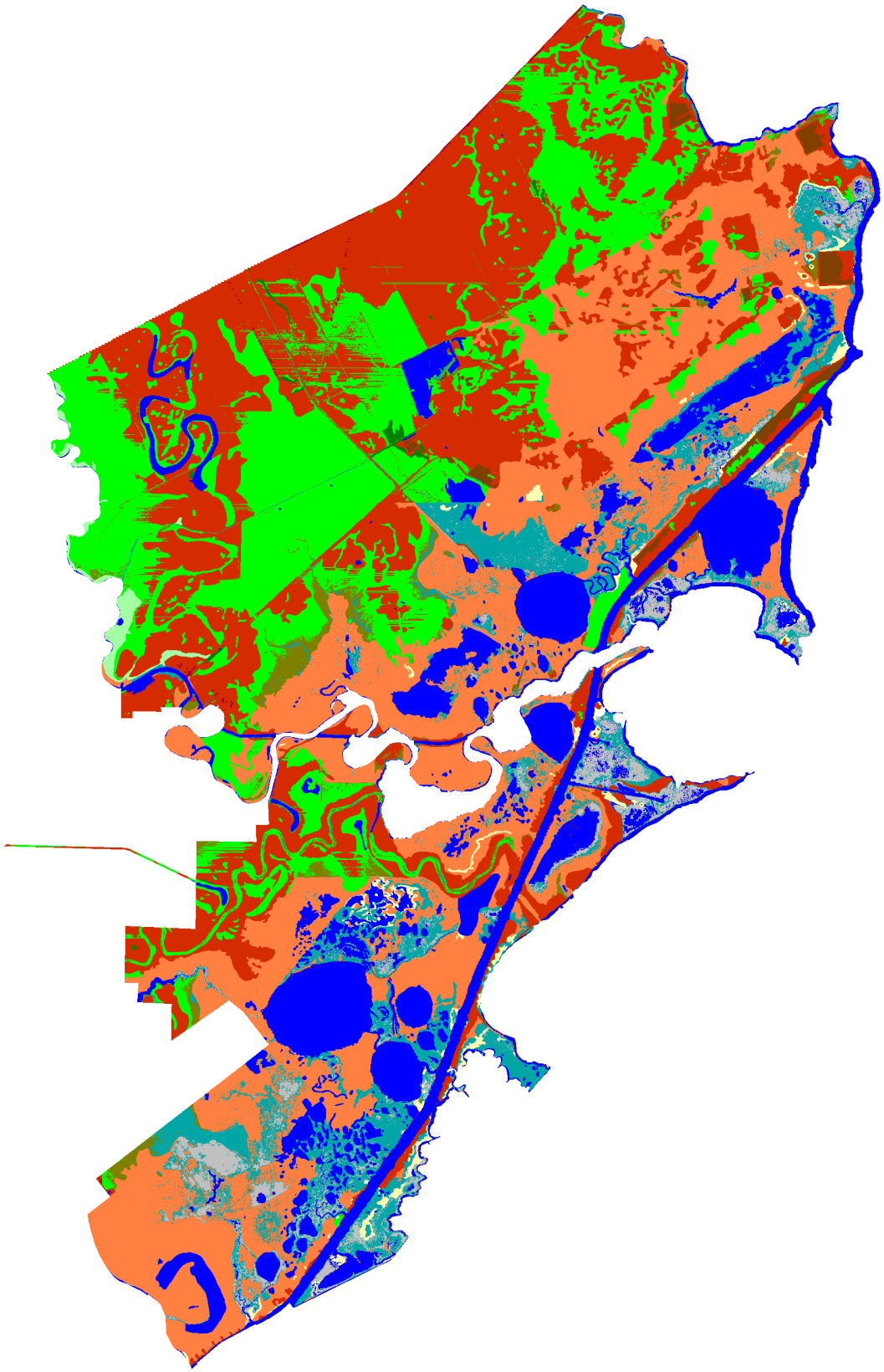
1.5 m eustatic SLR by
2100

Results in Acres

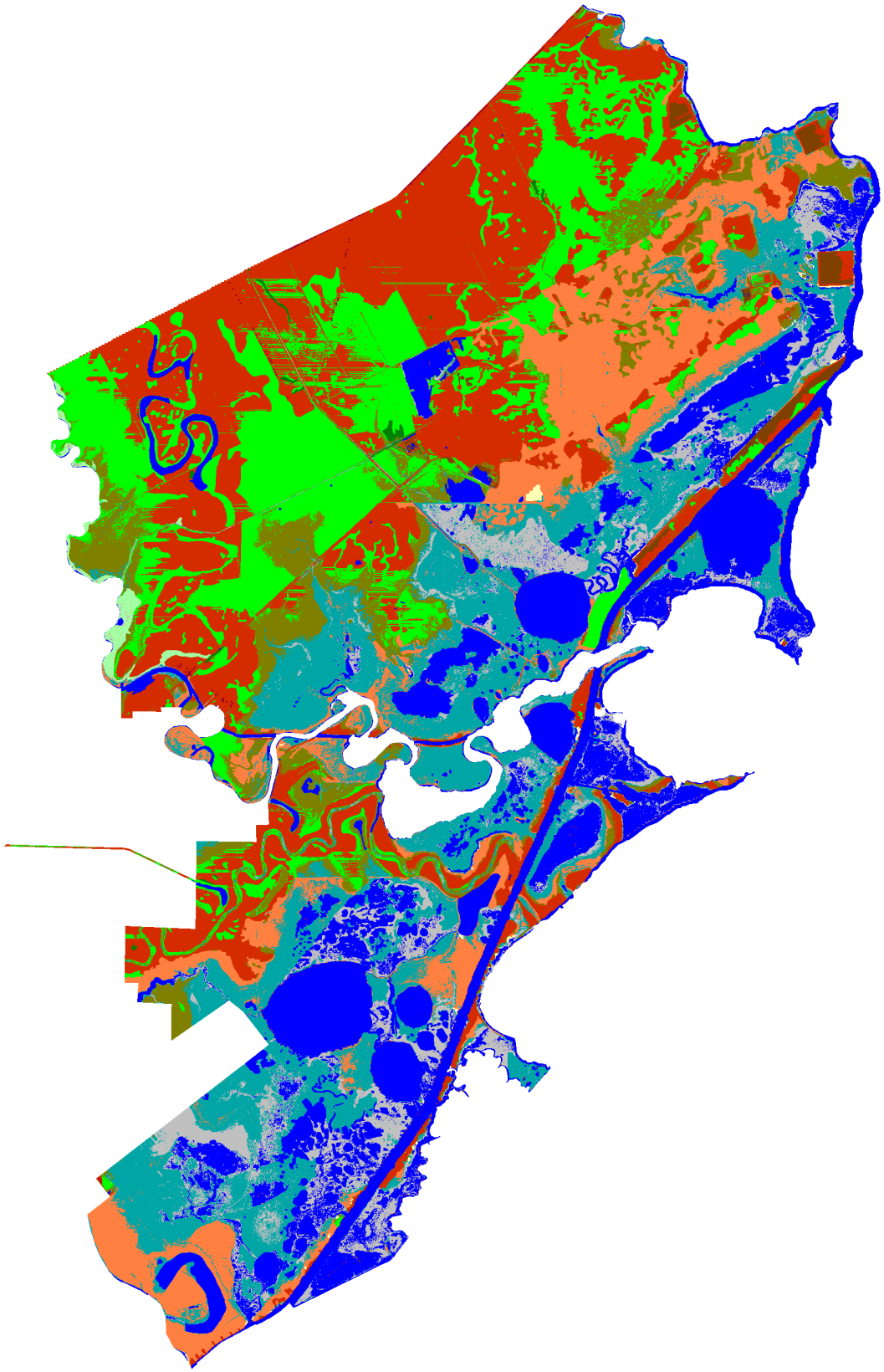
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	14884	13340	11806	8771	5515
	Irregularly Flooded Marsh	14698	13462	5697	1029	90
	Inland Fresh Marsh	9783	10118	8100	5266	2709
	Estuarine Open Water	6569	7230	9463	13468	22231
	Regularly Flooded Marsh	4314	4014	8841	8333	6876
	Inland Open Water	620	481	446	408	377
	Estuarine Beach	580	439	98	22	6
	Inland Shore	329	329	306	273	239
	Tidal Fresh Marsh	213	210	196	77	18
	Swamp	86	84	69	47	11
	Developed Dry Land	46	46	45	41	30
	Transitional Salt Marsh	23	843	3587	5903	5862
	Riverine Tidal	8	6	4	0	0
	Tidal Flat	0	1552	3497	8515	8189
	Total (incl. water)	**52154**	**52154**	**52154**	**52154**	**52154**



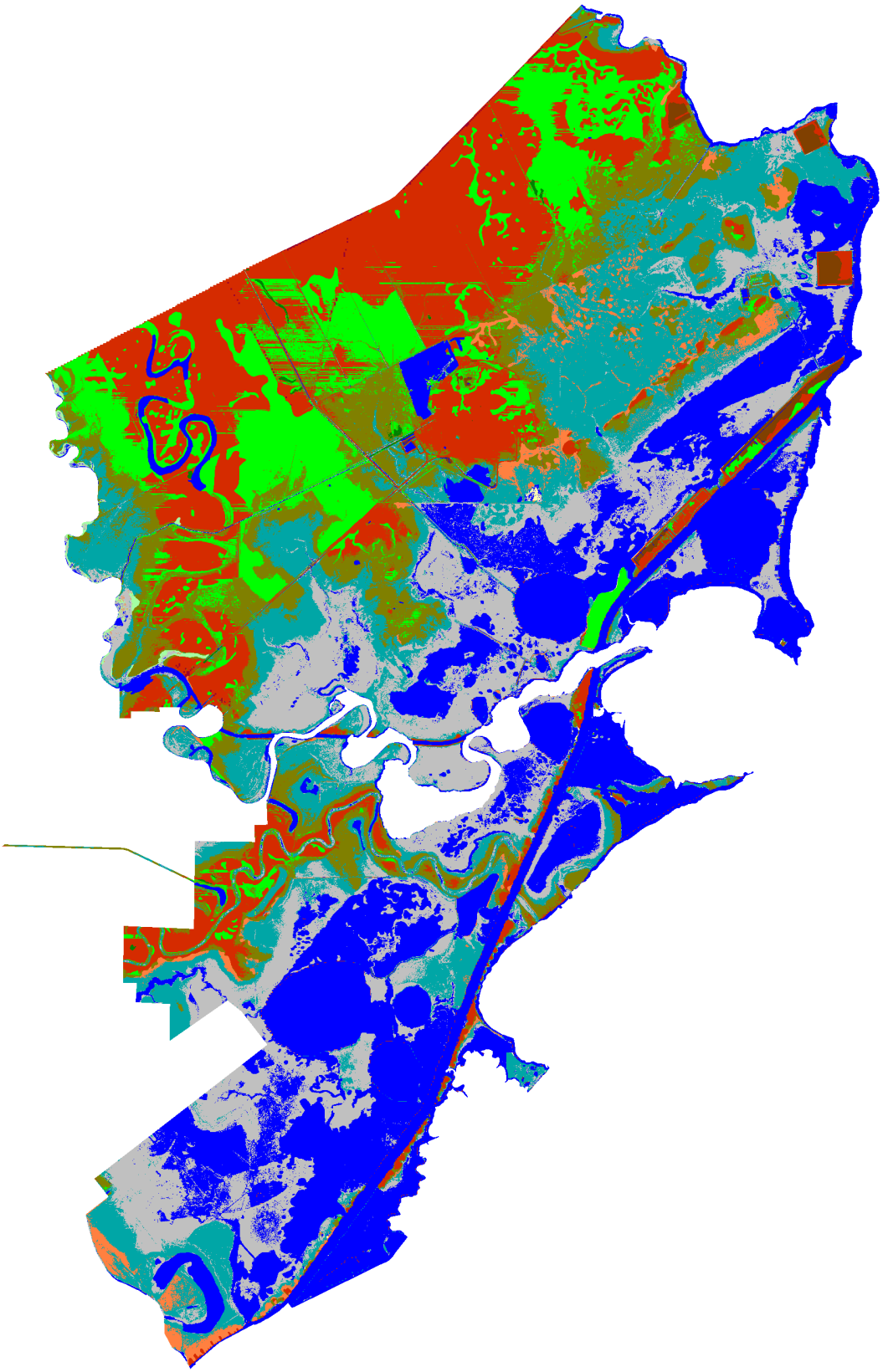
Brazoria NWR, Initial Condition



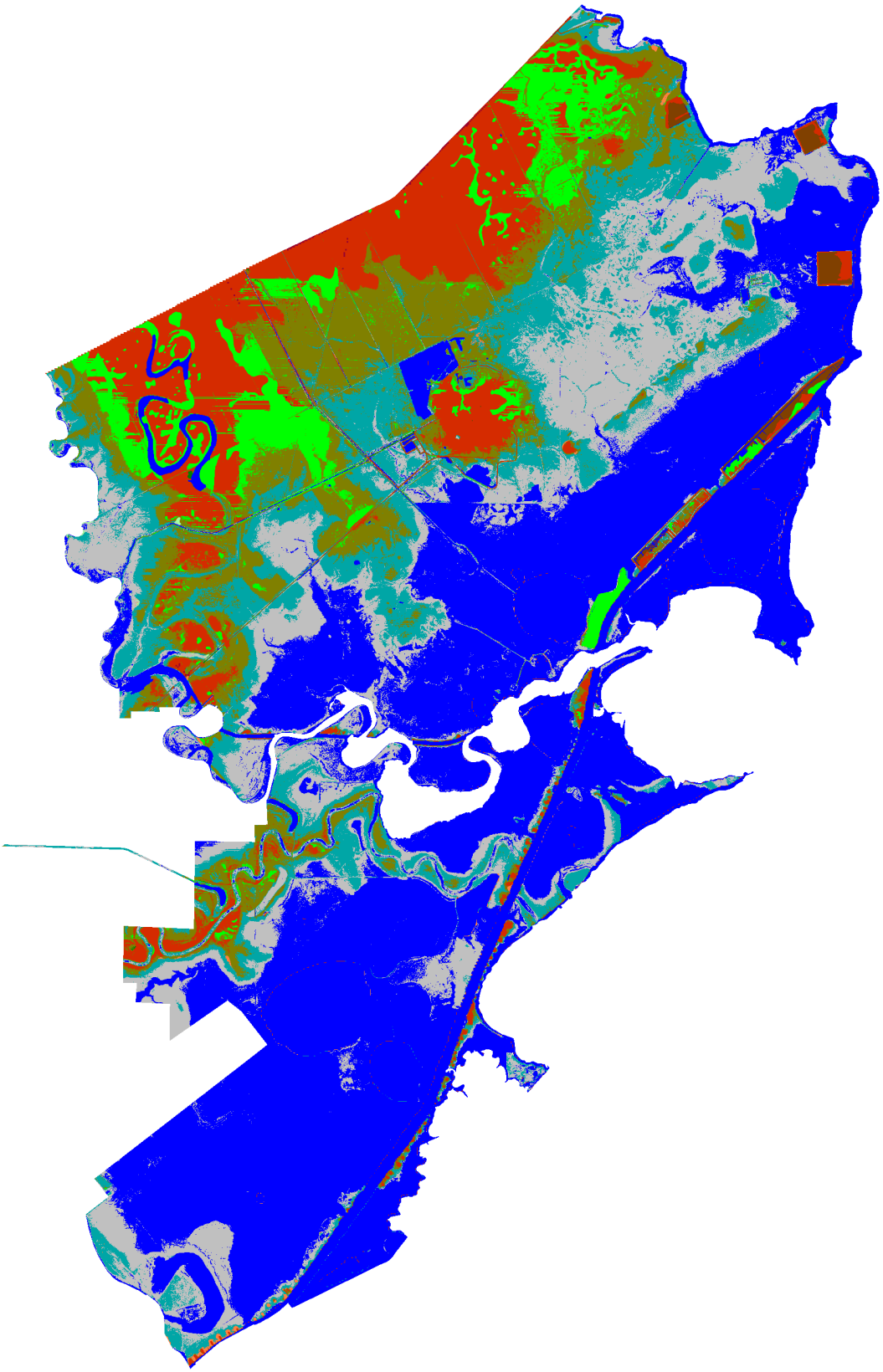
Brazoria NWR, 2025, 1.5 Meters



Brazoria NWR, 2050, 1.5 Meters



Brazoria NWR, 2075, 1.5 Meters

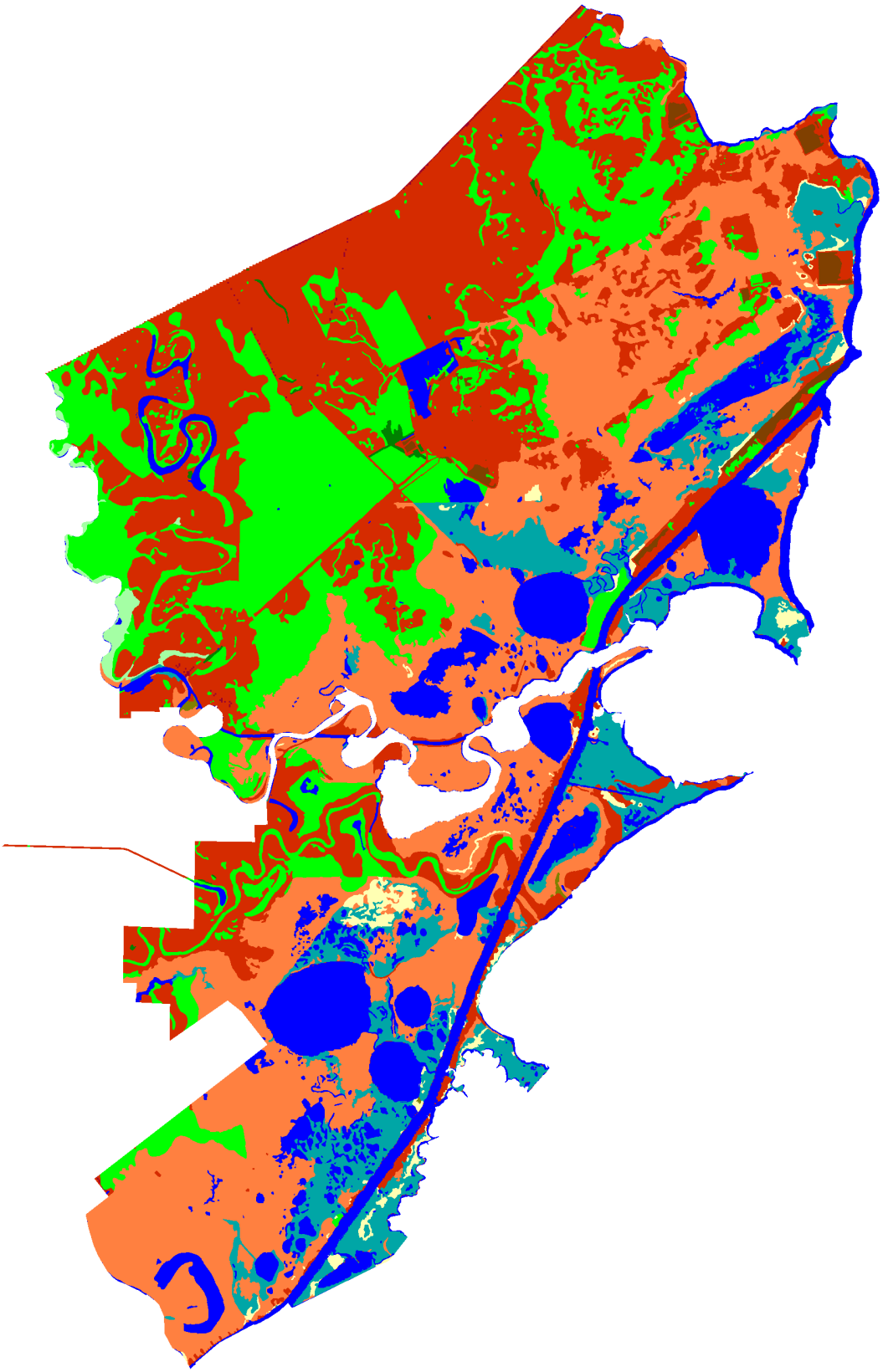


Brazoria NWR, 2100, 1.5 Meters

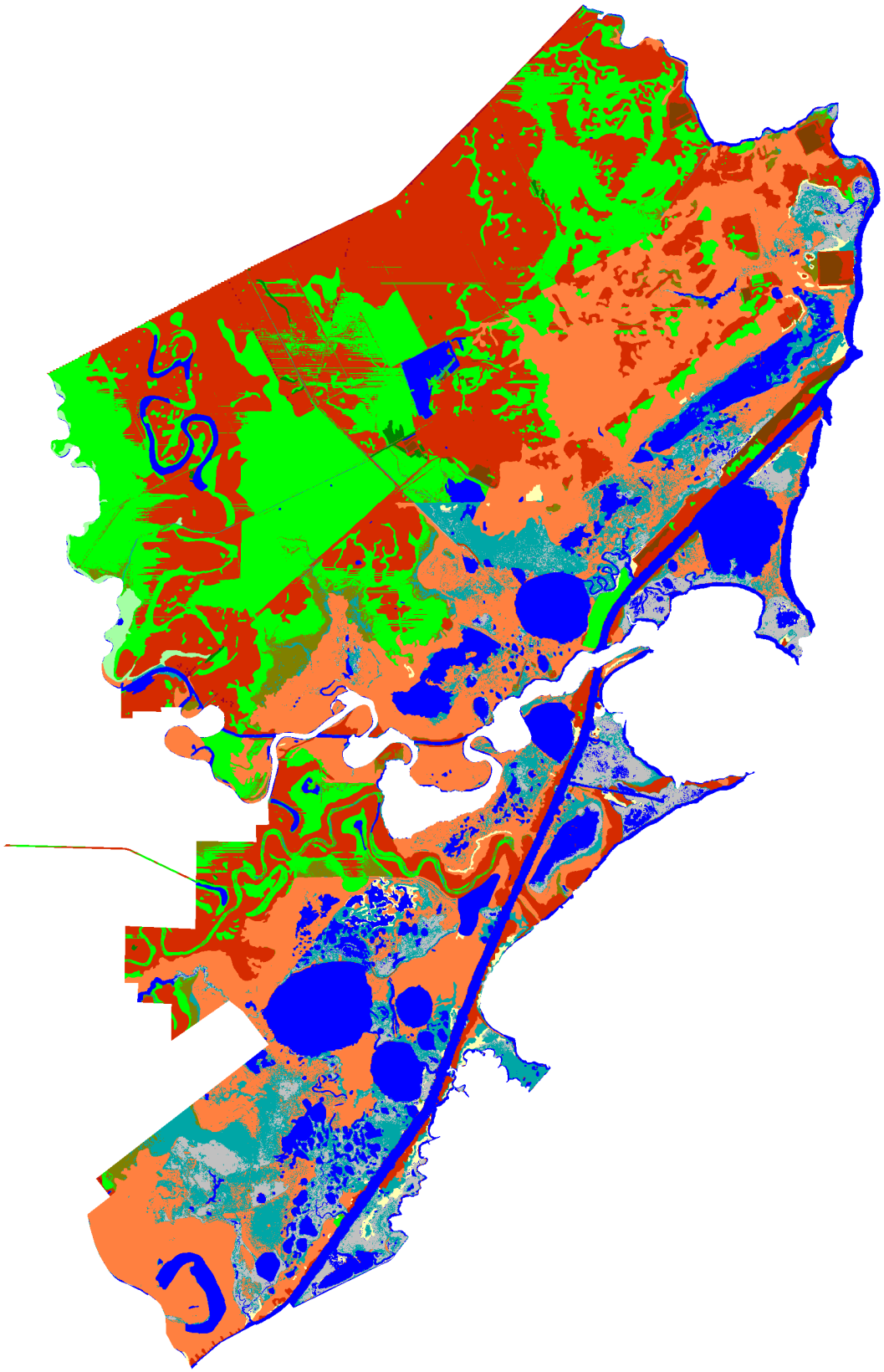
2 m eustatic SLR by 2100

Results in Acres

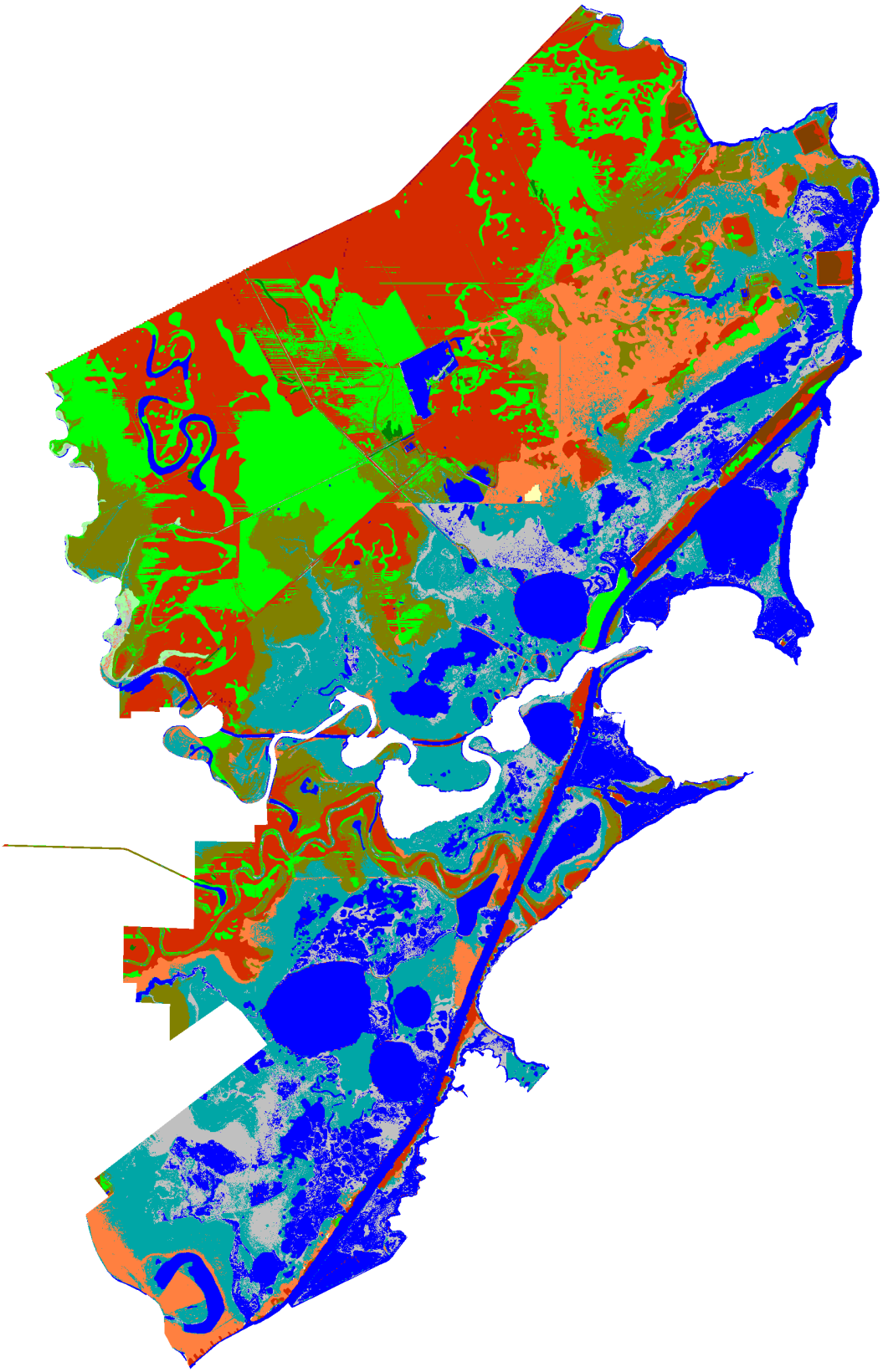
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	14884	13259	10920	6791	3409
	Irregularly Flooded Marsh	14698	12443	3829	177	35
	Inland Fresh Marsh	9783	9913	6932	3421	1023
	Estuarine Open Water	6569	7287	10206	14798	24500
	Regularly Flooded Marsh	4314	4439	9780	9061	7850
	Inland Open Water	620	476	441	396	356
	Estuarine Beach	580	409	50	7	4
	Inland Shore	329	328	293	253	214
	Tidal Fresh Marsh	213	210	137	26	1
	Swamp	86	82	64	25	5
	Developed Dry Land	46	46	43	36	23
	Transitional Salt Marsh	23	1034	5358	7689	5813
	Riverine Tidal	8	6	3	0	0
	Tidal Flat	0	2222	4098	9473	8920
	Total (incl. water)	**52154**	**52154**	**52154**	**52154**	**52154**



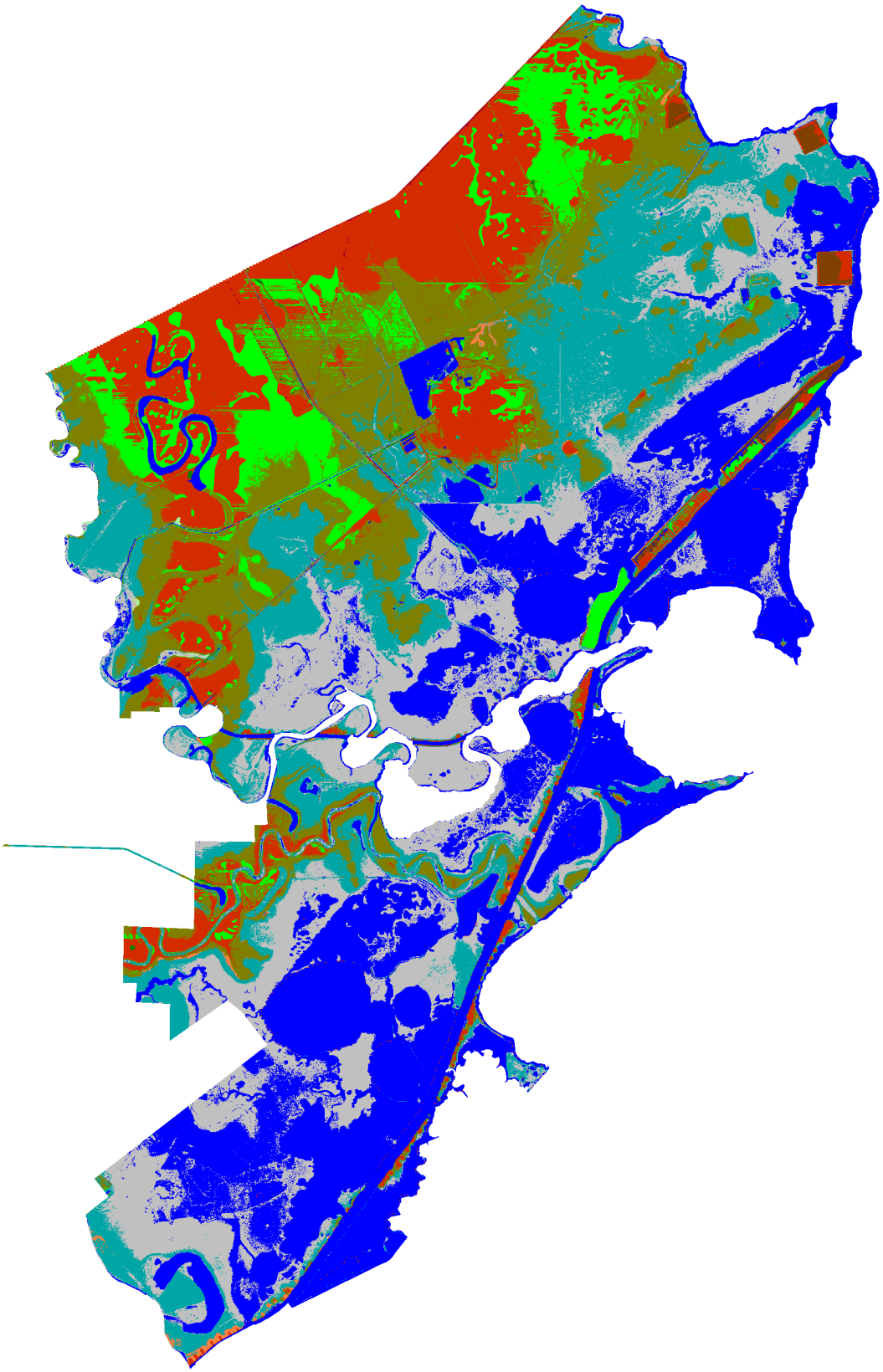
Brazoria NWR, Initial Condition



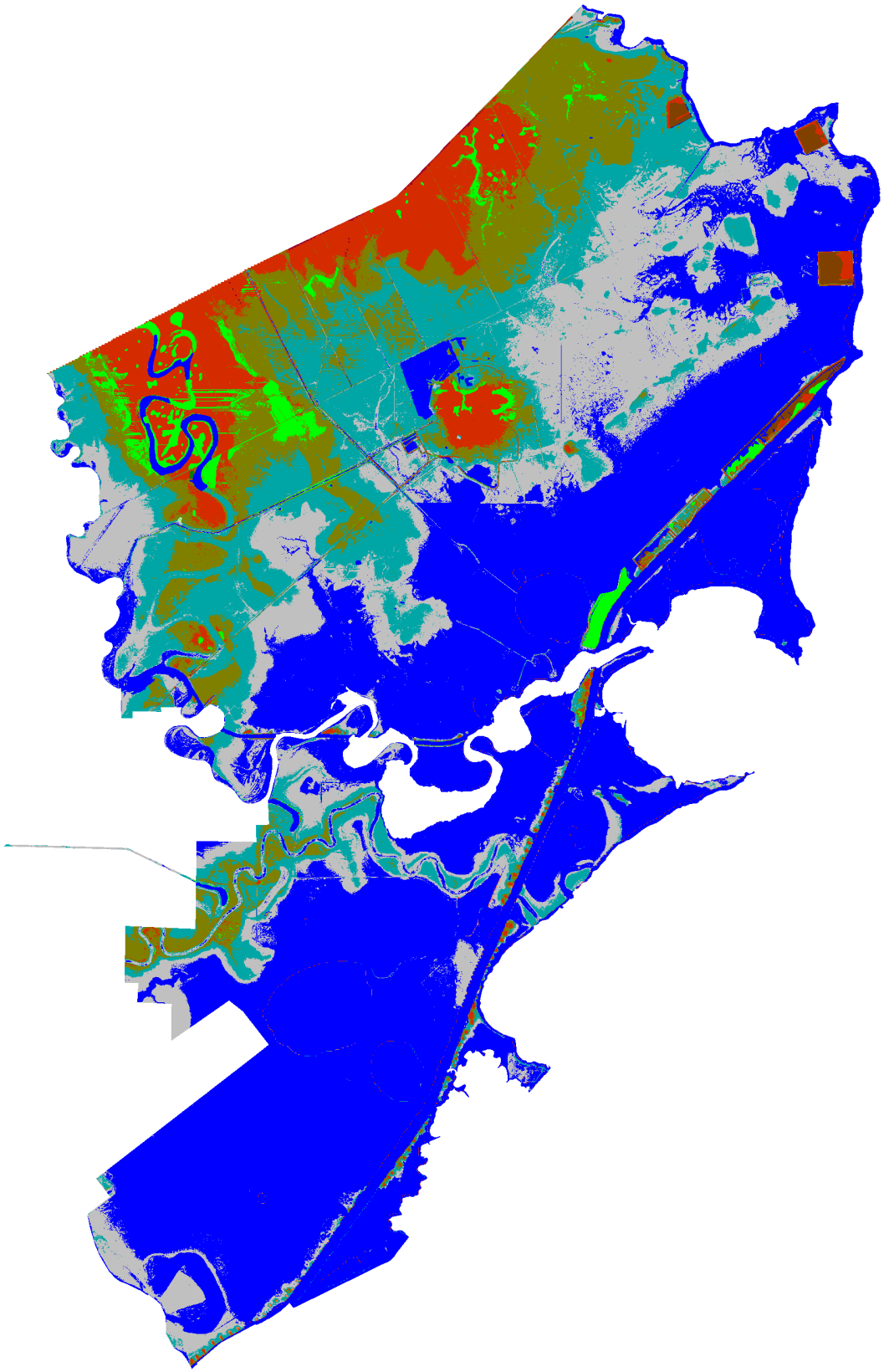
Brazoria NWR, 2025, 2 Meters



Brazoria NWR, 2050, 2 Meters



Brazoria NWR, 2075, 2 Meters



Brazoria NWR, 2100, 2 Meters

Discussion

Model results for Brazoria NWR indicate that it is vulnerable to sea level rise, especially under the higher SLR scenarios examined. When rates of sea-level rise exceed measured accretion rates for irregularly-flooded marsh in this region, marshes are predicted to sustain considerable losses. Under all scenarios examined, SLAMM predicts the refuge to gain regularly-flooded marsh as it loses irregularly-flooded and inland-fresh marsh. The 1 m of eustatic SLR by 2100 scenario is considered a likely scenario by many climate scientists (e.g. Vermeer and Rahmstorf 2009). Under the 1m scenario more than 90% of the irregularly-flooded marsh in the refuge is predicted to be lost with a gain of nearly 70% in regularly-fresh marsh.

Model sensitivity analysis suggests that model predictions are quite sensitive to model inputs of accretion rates in the refuge (Warren Pinnacle Consulting, Inc. 2011). Local accretion data were taken from a study conducted nearby (East Bay Galveston; Ravens et al 2009). Despite being collected nearby, accretion data varies widely and may not be completely representative of the accretion rates in the multi-bayed system of Brazoria NWR. Local data regarding accretion rates within the refuge itself could provide better predictions of marsh losses in the future.

On the other hand, elevation data were based on high-vertical-resolution LiDAR data for the entire refuge, reducing model uncertainty considerably. An elevation uncertainty analysis found minimal variations in model predictions on the basis of elevation-data uncertainty (Warren Pinnacle Consulting, Inc. 2011).

Some of the area surrounding Brazoria was studied in a previous SLAMM analysis funded by The Nature Conservancy (Warren Pinnacle Consulting, Inc. 2011). Maps of results for the larger study area are presented in the "contextual maps" below.

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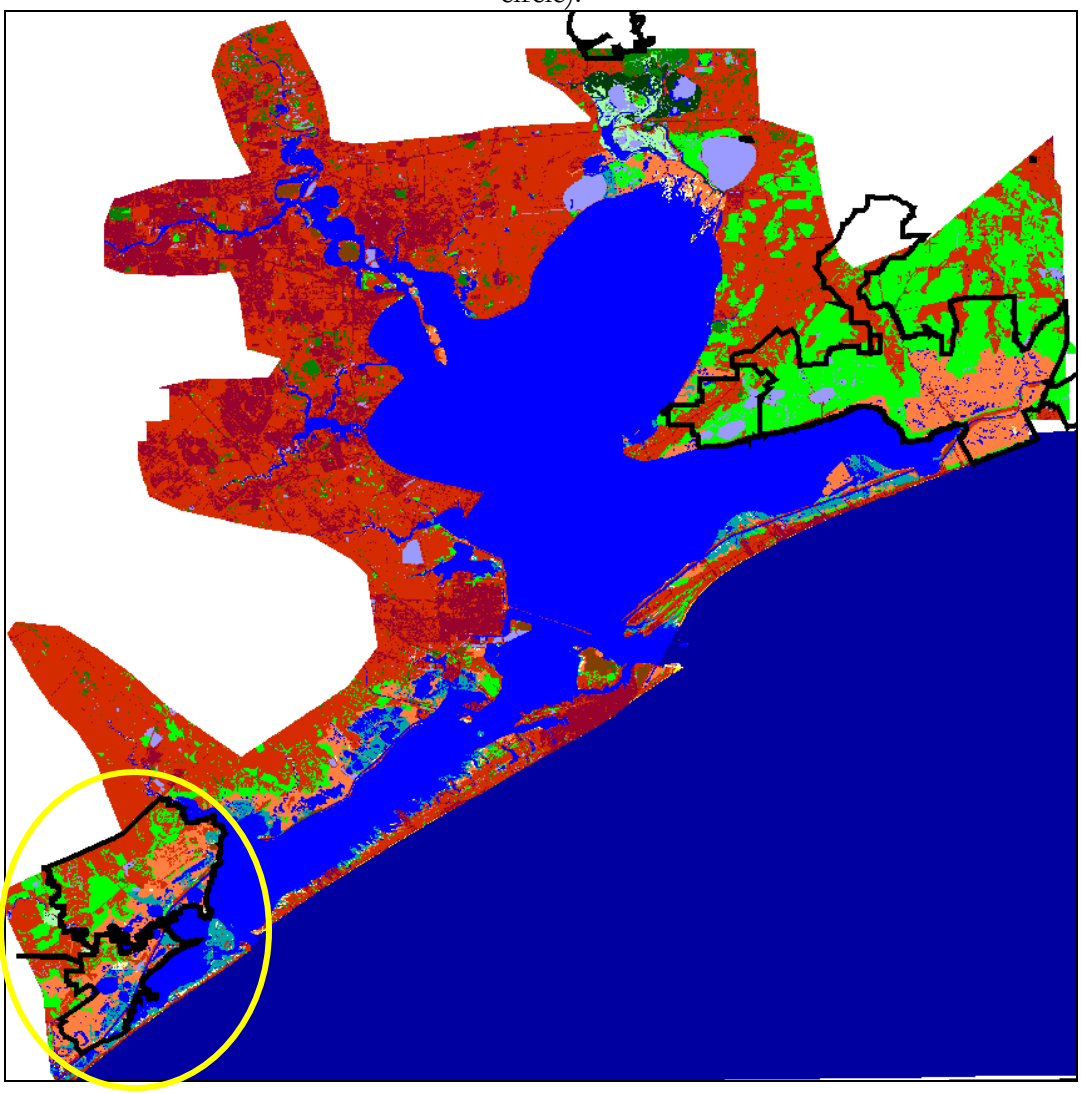
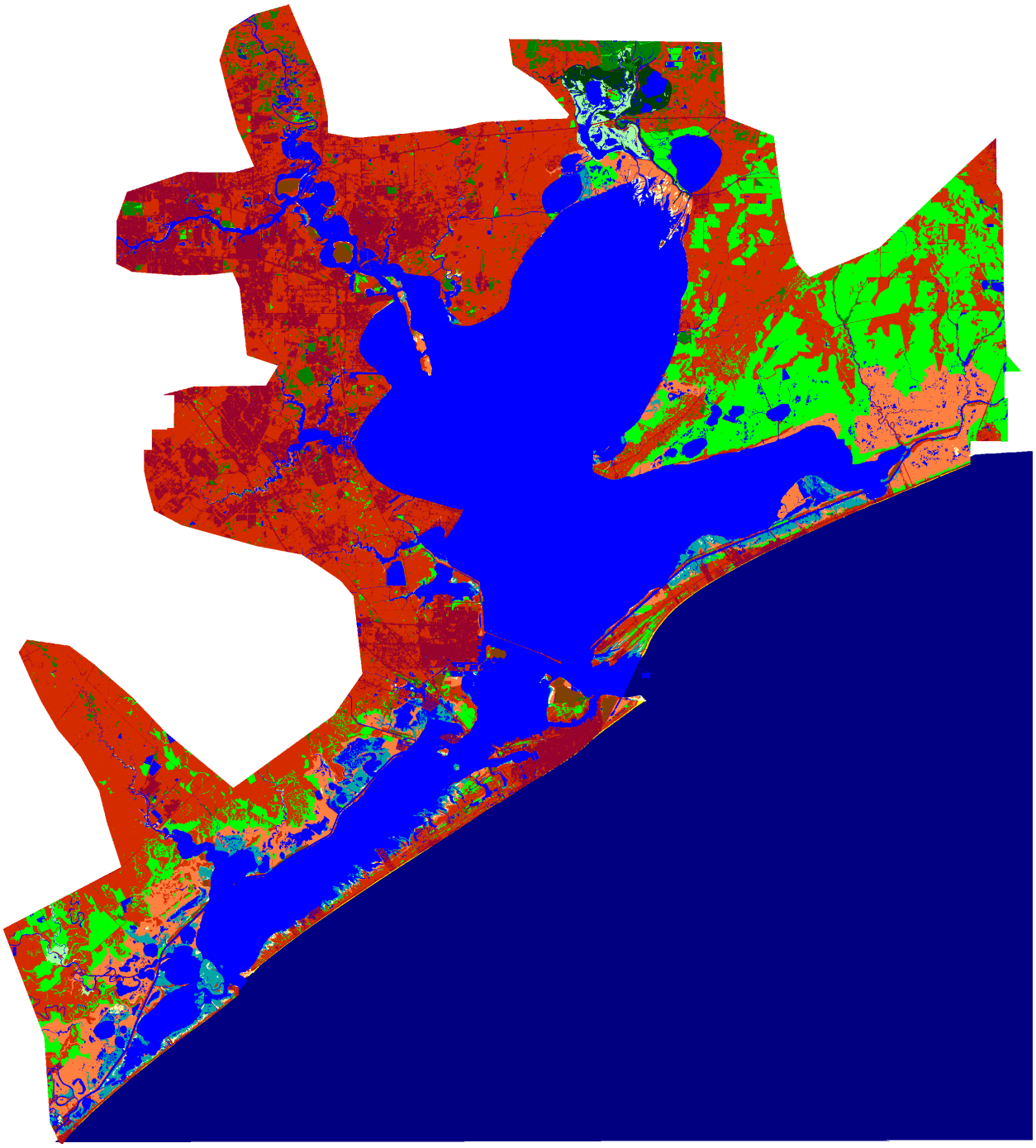
Appendix A: Contextual Results

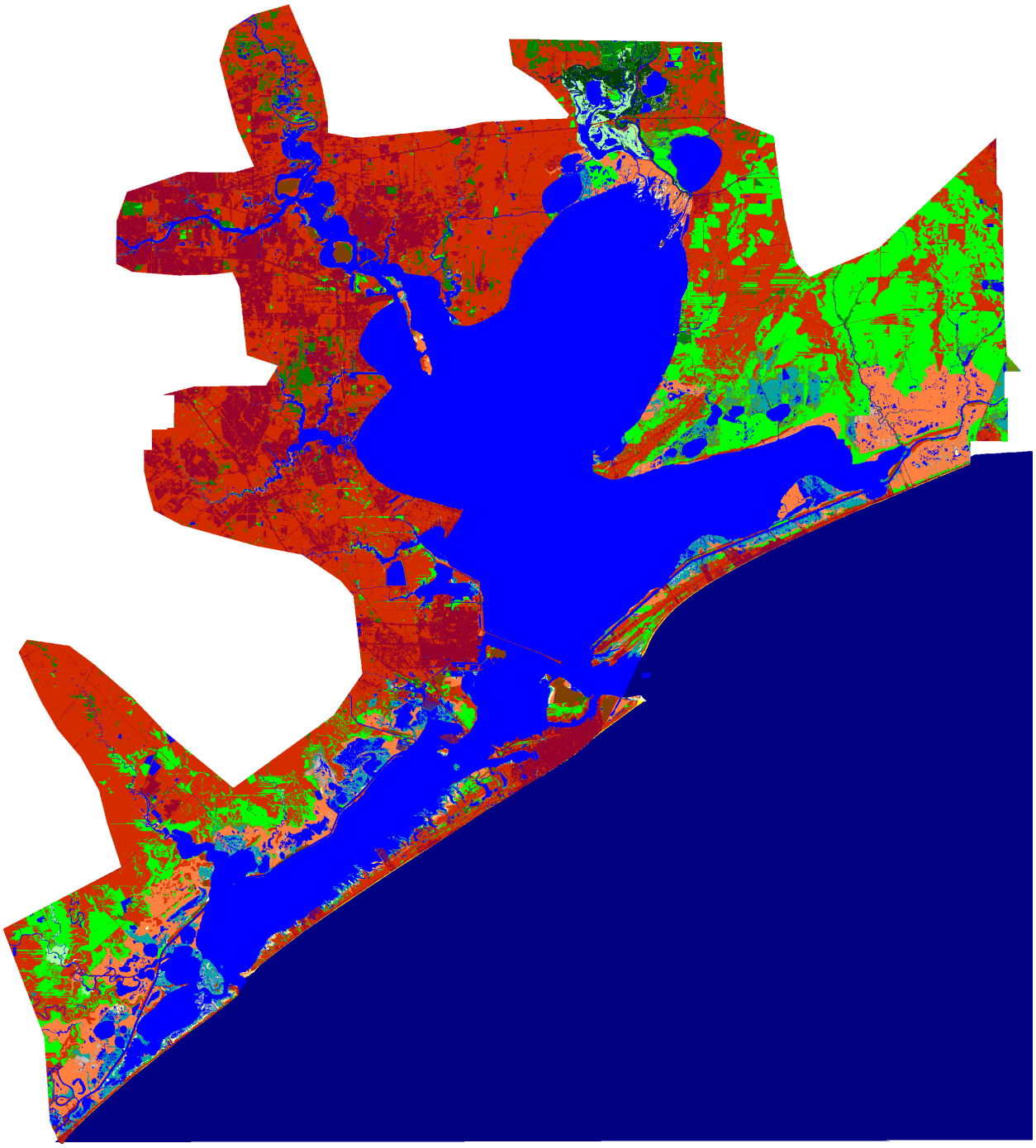
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated dry lands will convert to marshes or ocean beach depending on their proximity to open ocean. For this reason, an area larger than the boundaries of the USFWS refuge was modeled. A full analysis of this study are was funded by the Sea-Level Rise and Conservation Project of The Nature Conservancy who also provided GIS processing in support of these analyses. Funding for this project of The Nature Conservancy was provided through a grant from the Gulf of Mexico Foundation, Inc., to support the Gulf of Mexico Alliance.

Brazoria National Wildlife Refuge within simulation context (boundary outlined in black, in yellow circle).

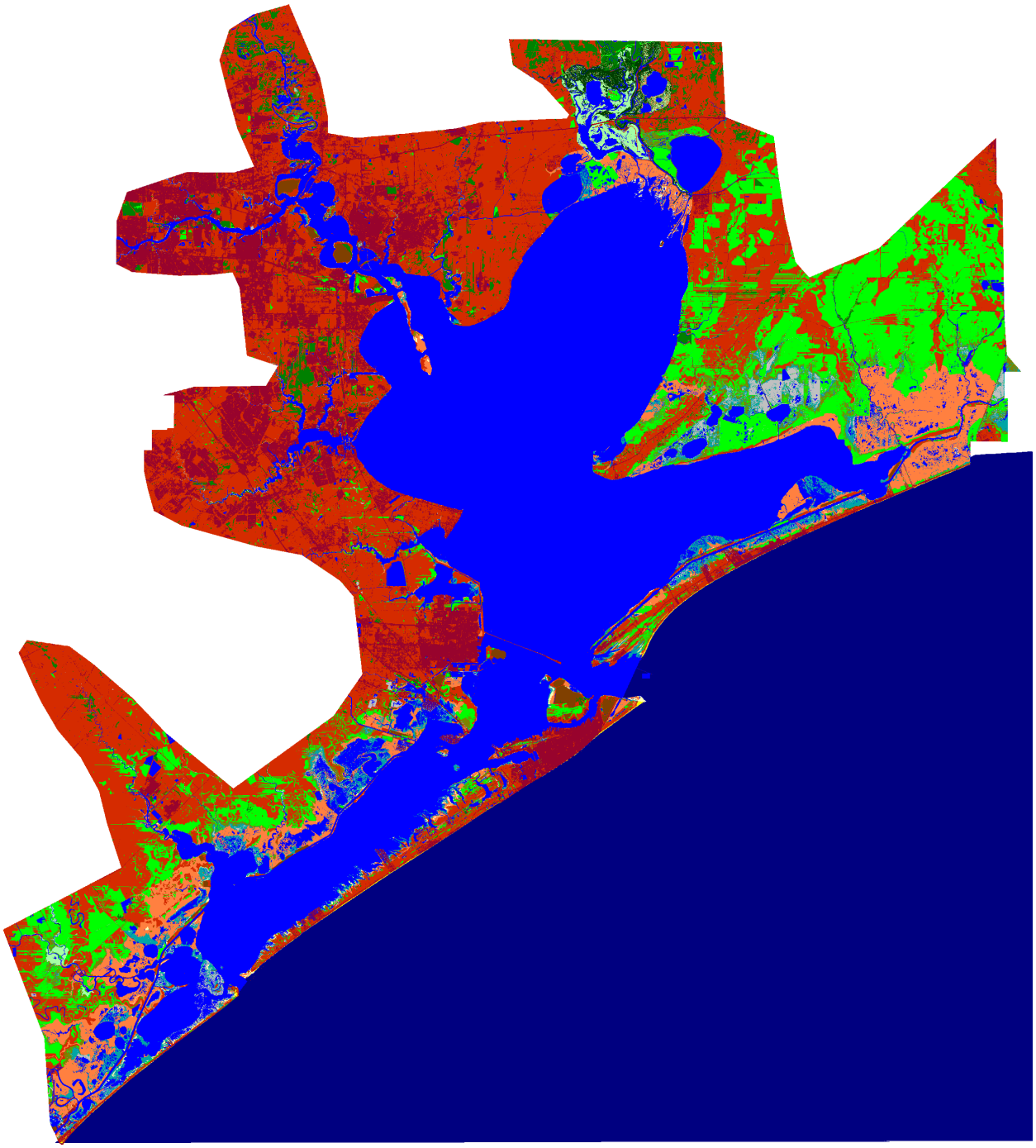




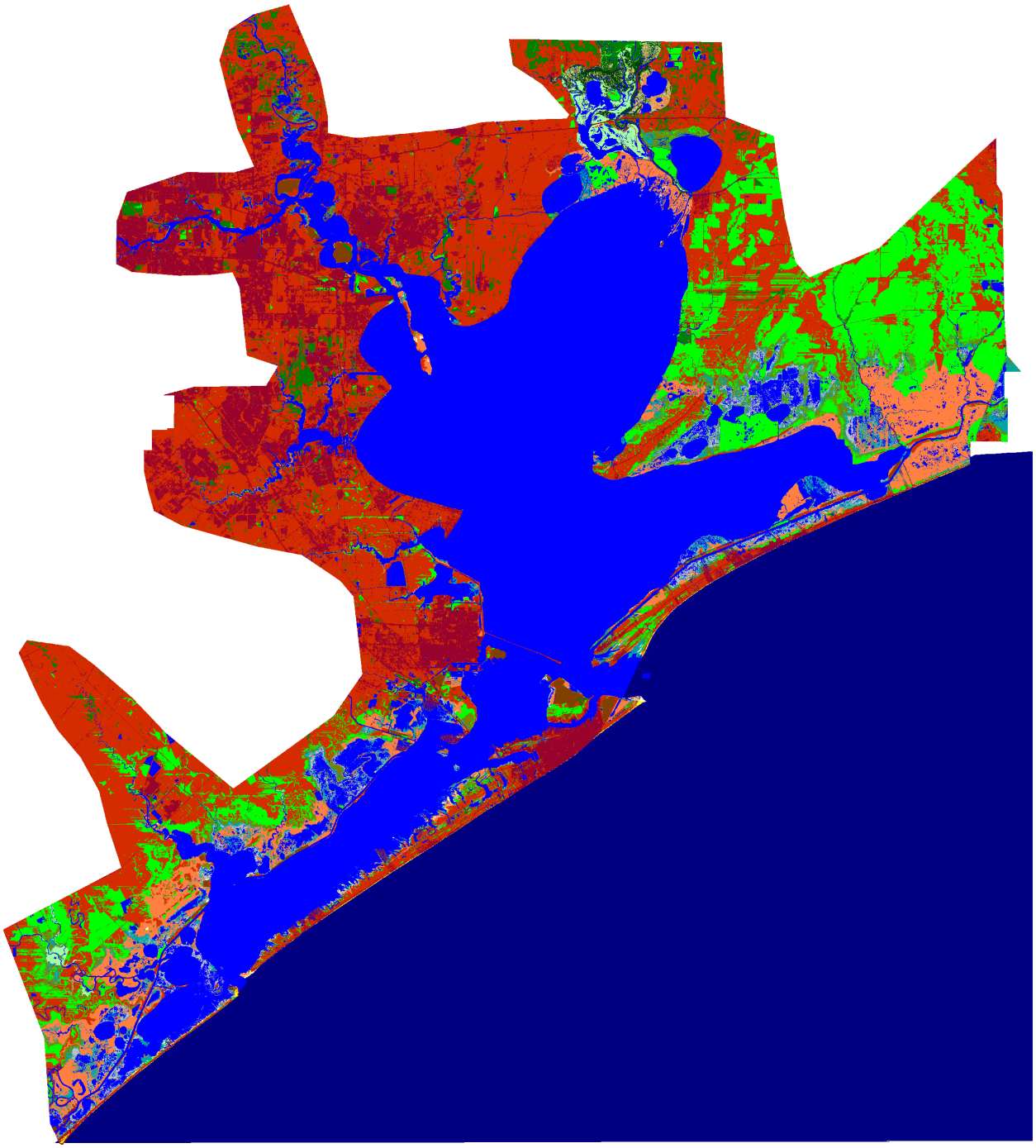
Brazoria Context, Initial Condition



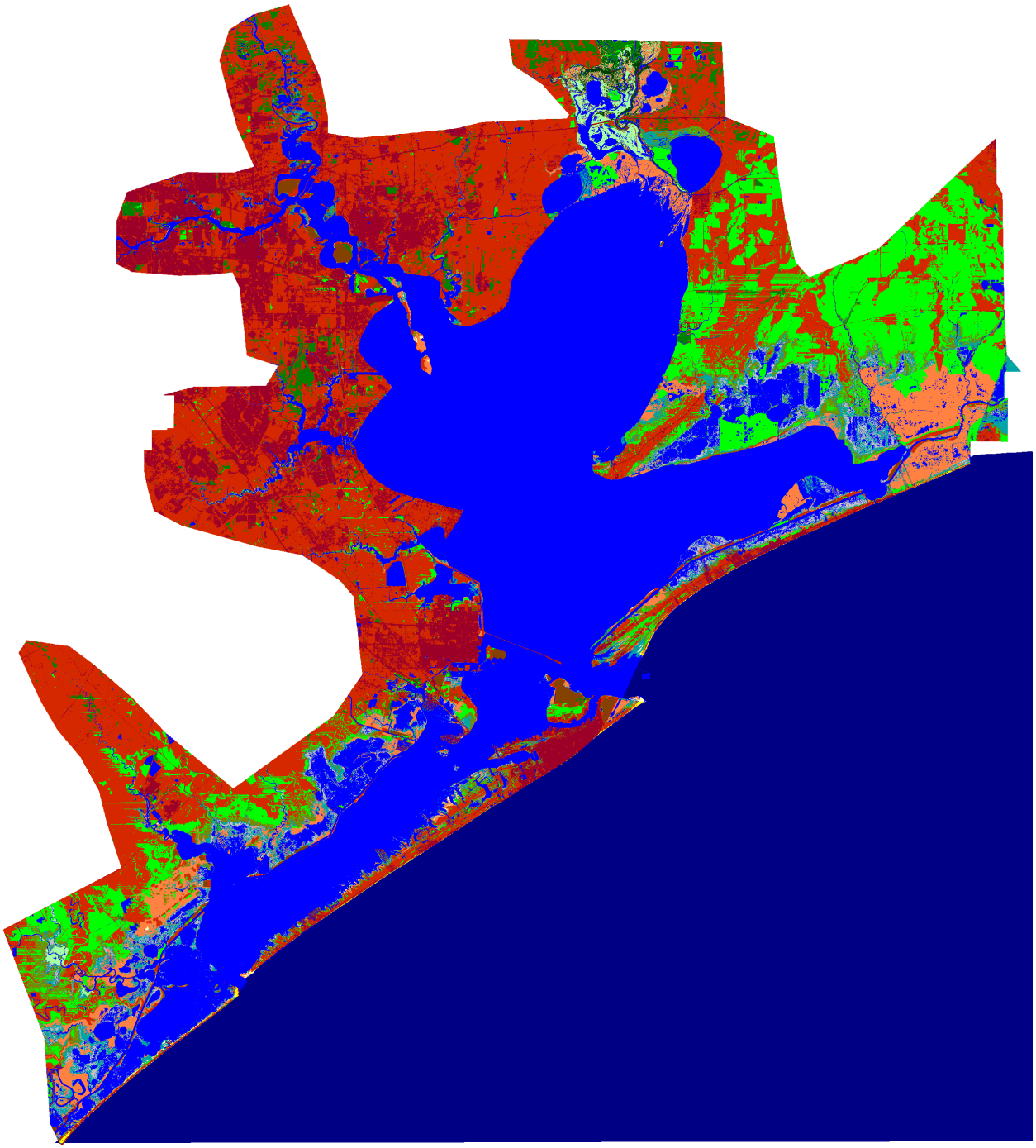
Brazoria Context, 2025, Scenario A1B Mean



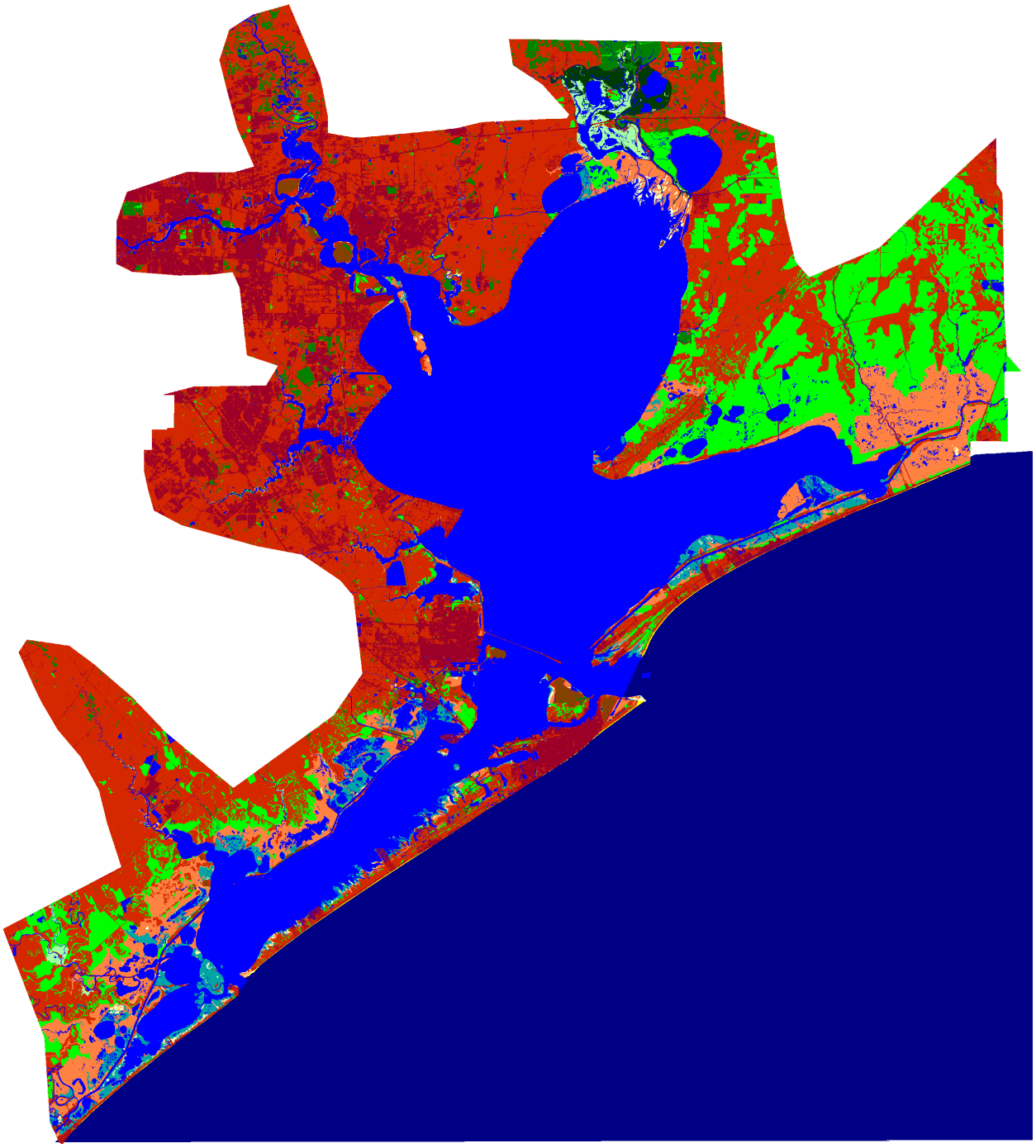
Brazoria Context, 2050, Scenario A1B Mean



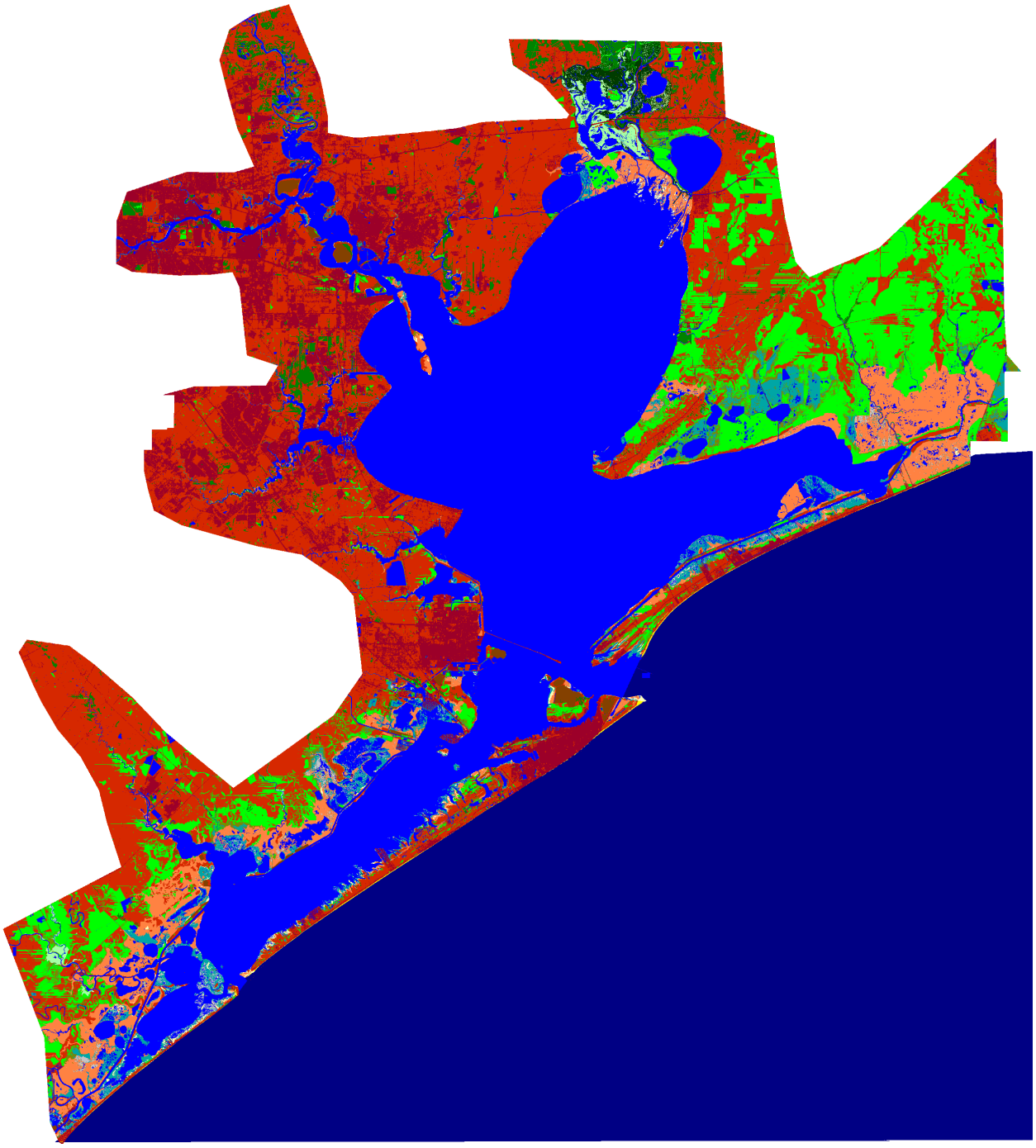
Brazoria Context, 2075, Scenario A1B Mean



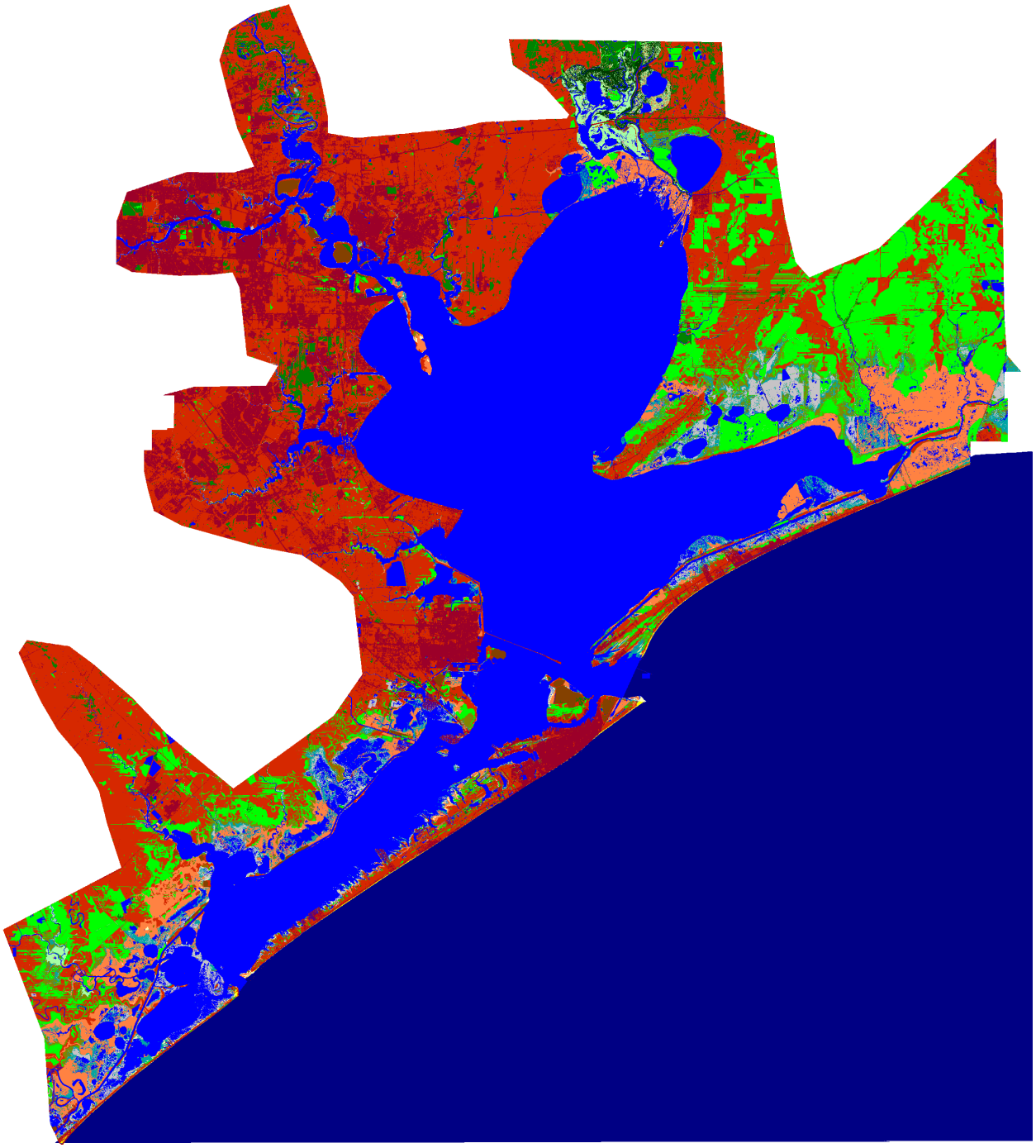
Brazoria Context, 2100, Scenario A1B Mean



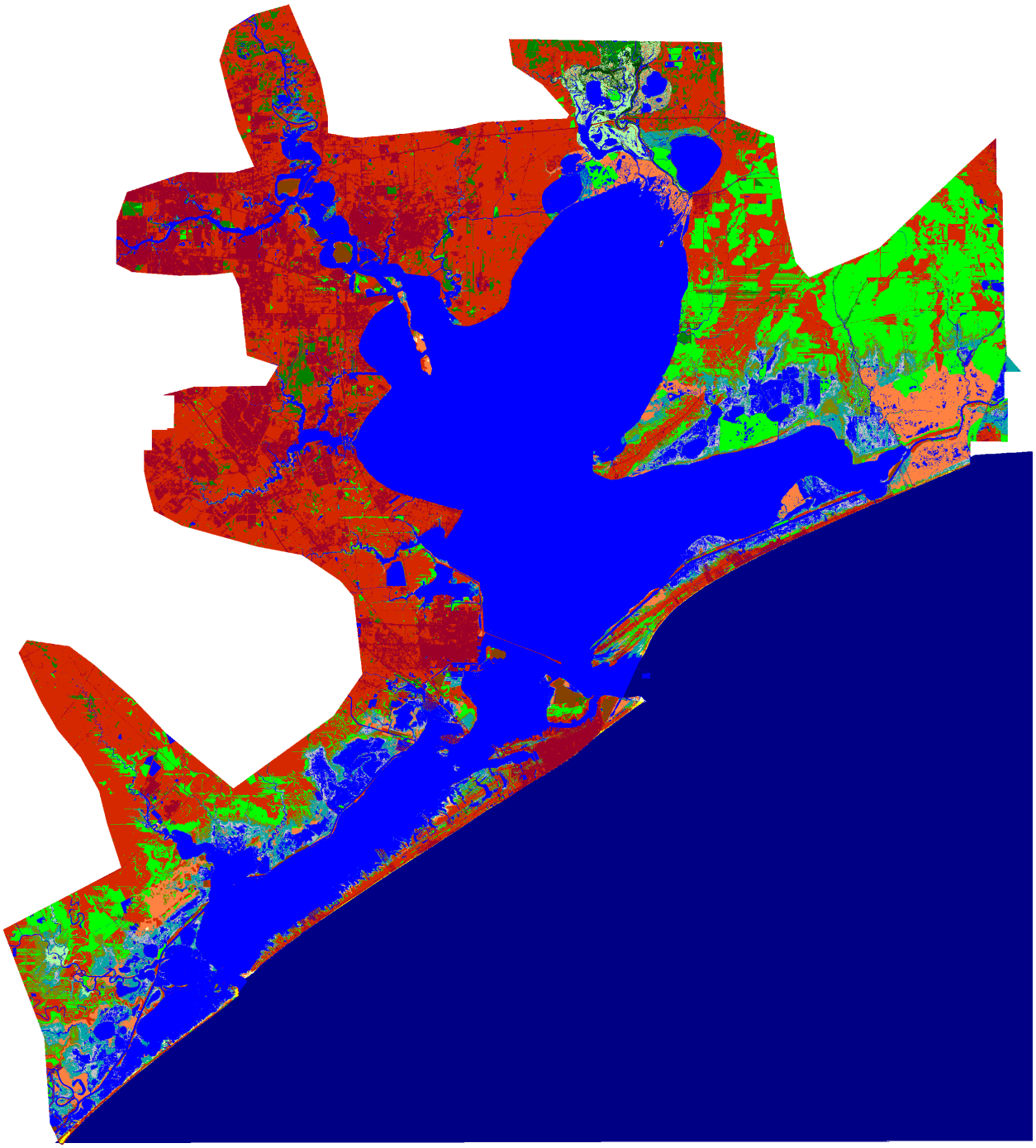
Brazoria Context, Initial Condition



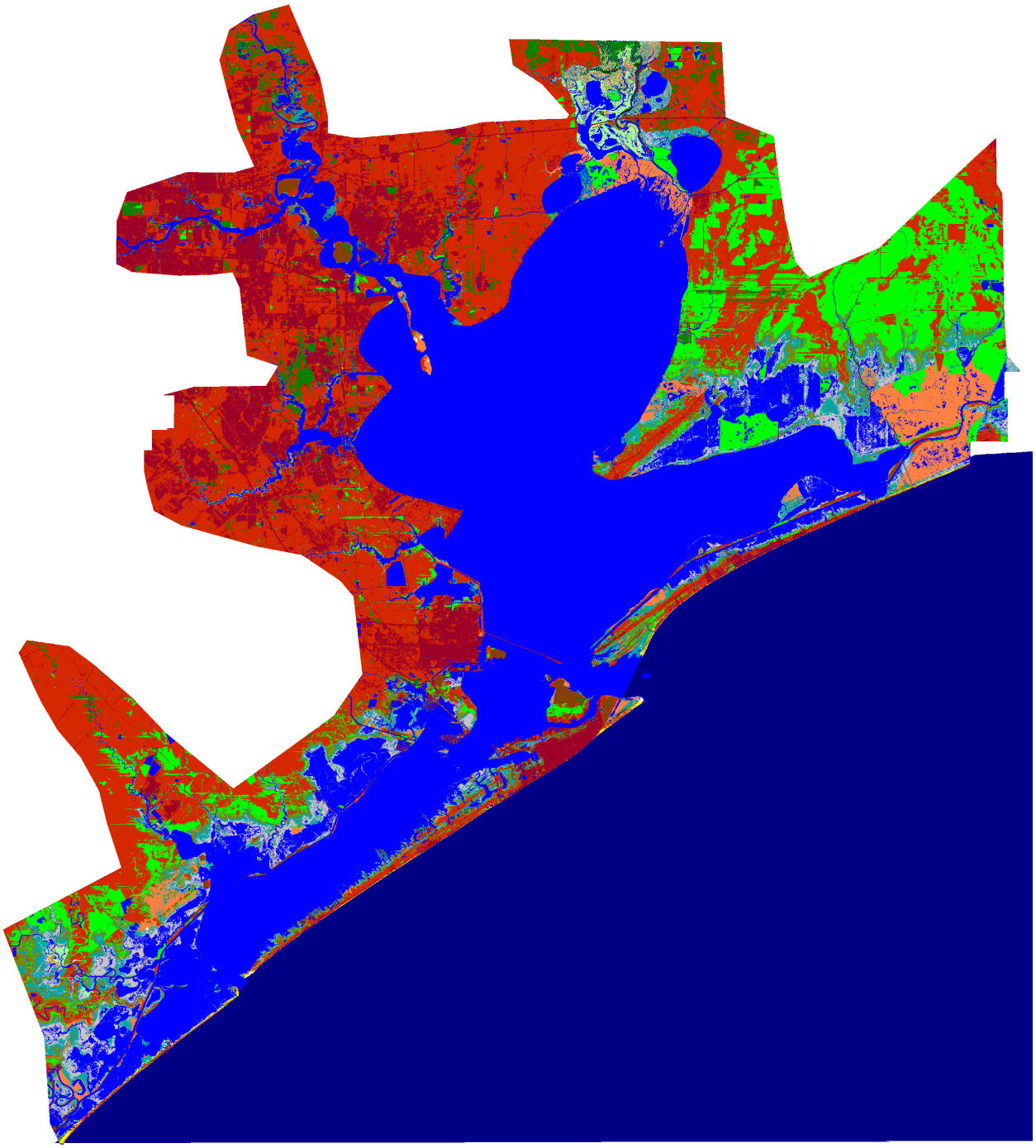
Brazoria Context, 2025, Scenario A1B Maximum



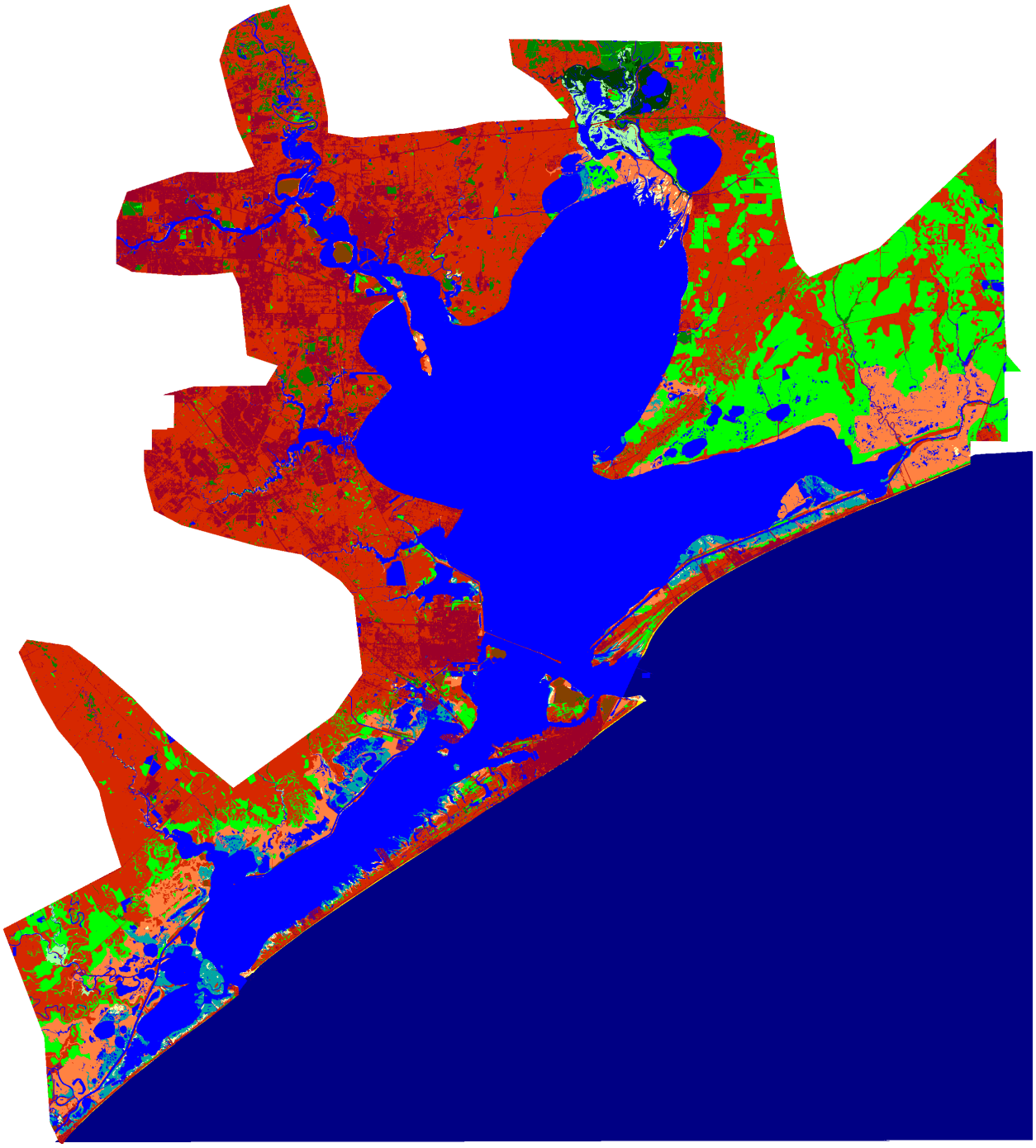
Brazoria Context, 2050, Scenario A1B Maximum



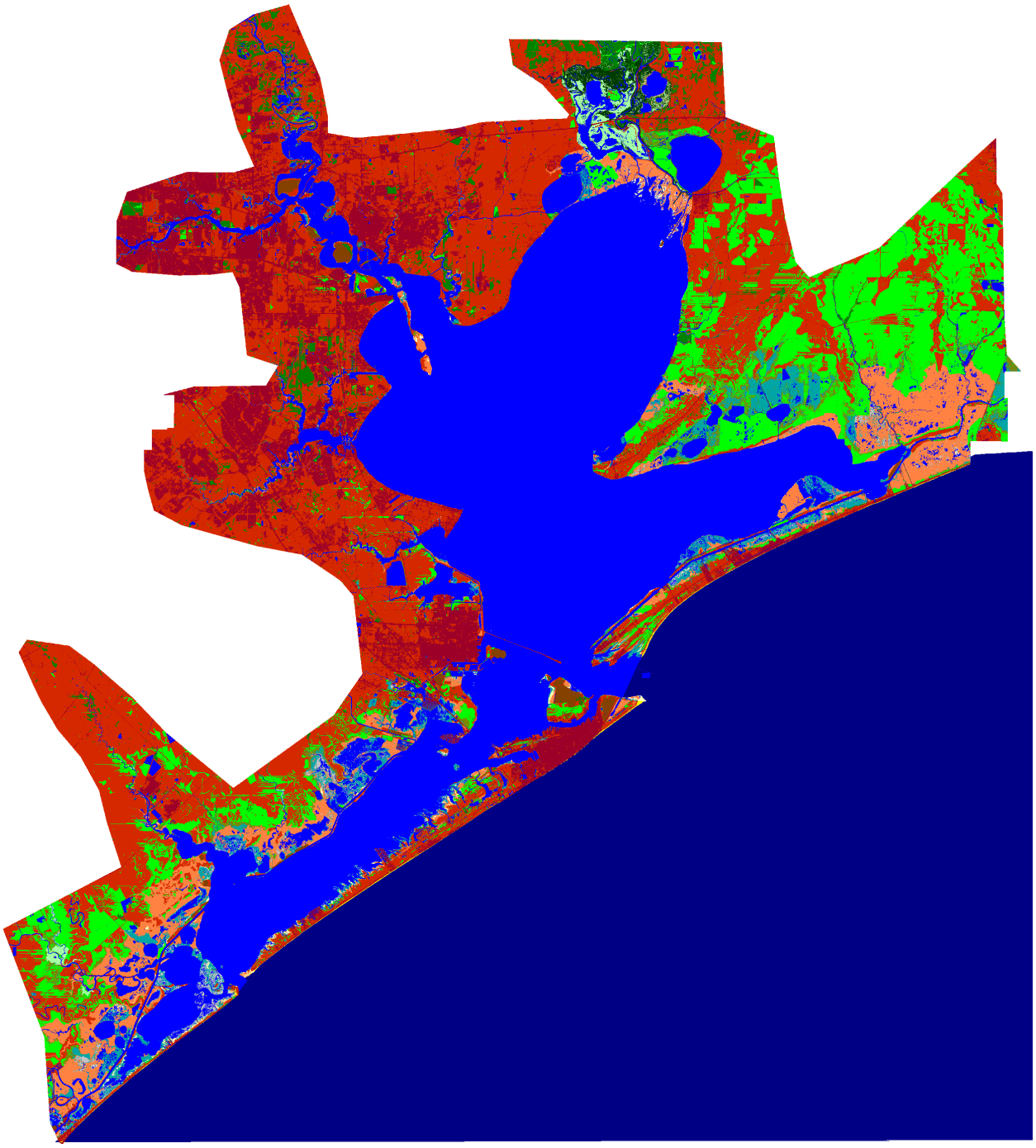
Brazoria Context, 2075, Scenario A1B Maximum



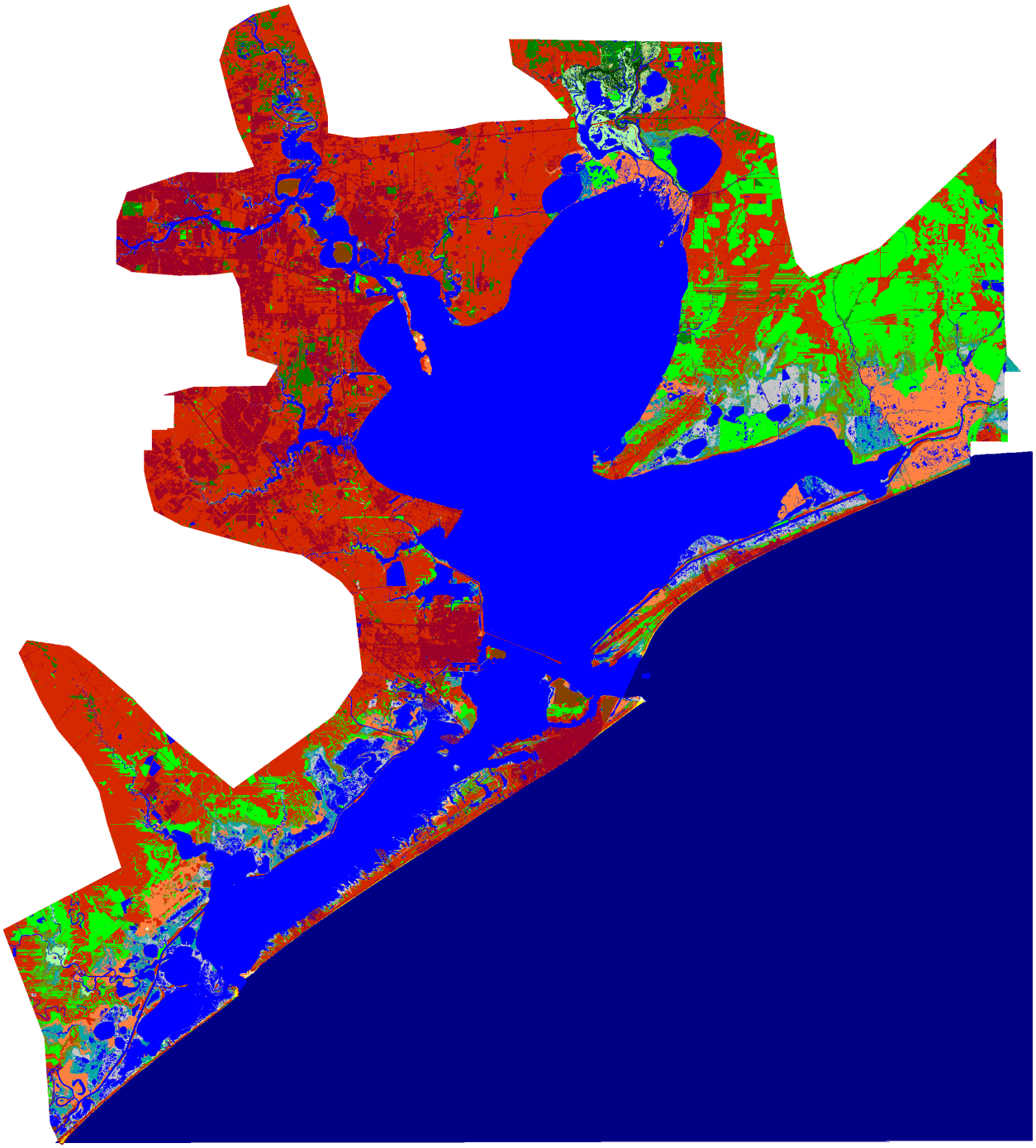
Brazoria Context, 2100, Scenario A1B Maximum



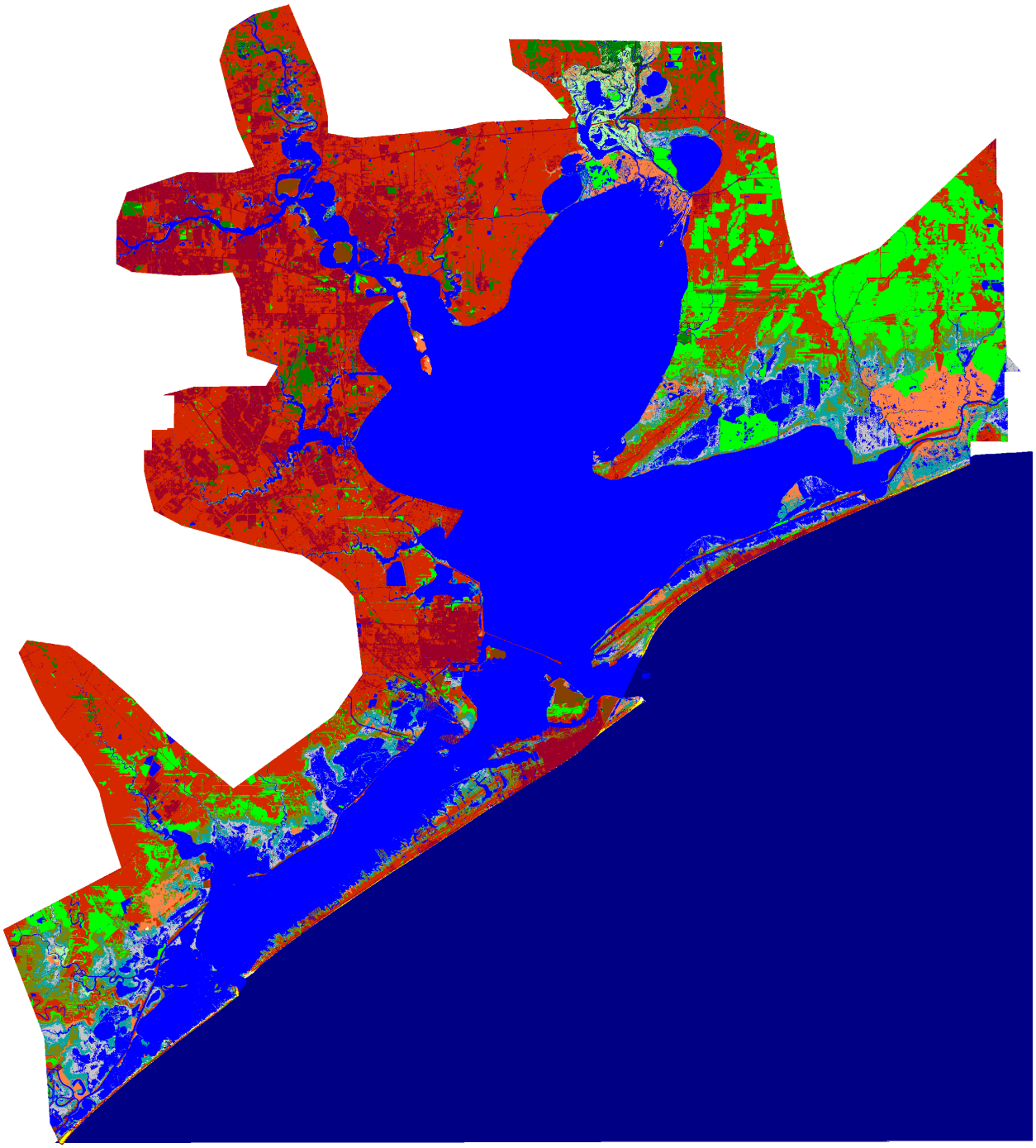
Brazoria Context, Initial Condition



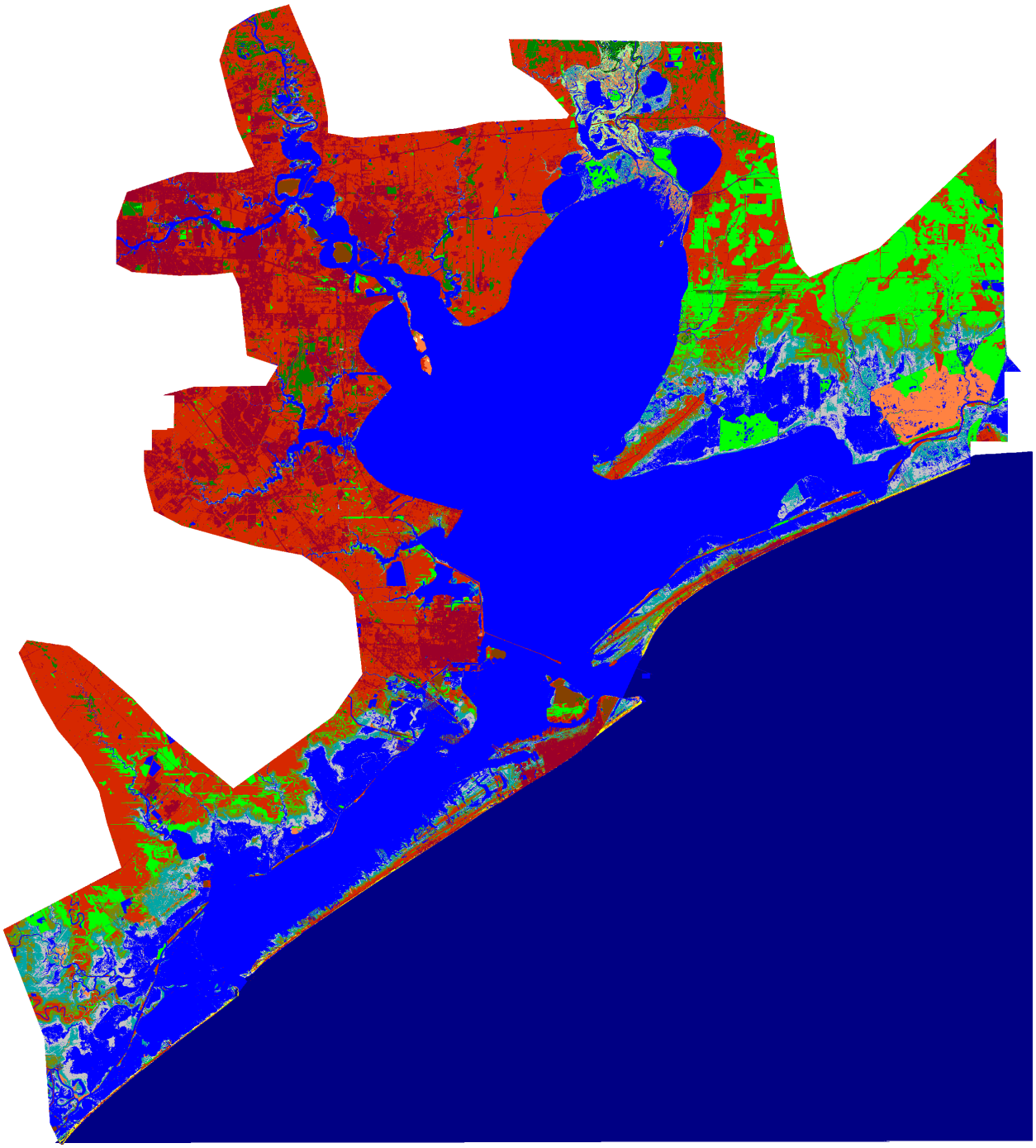
Brazoria Context, 2025, 1 m



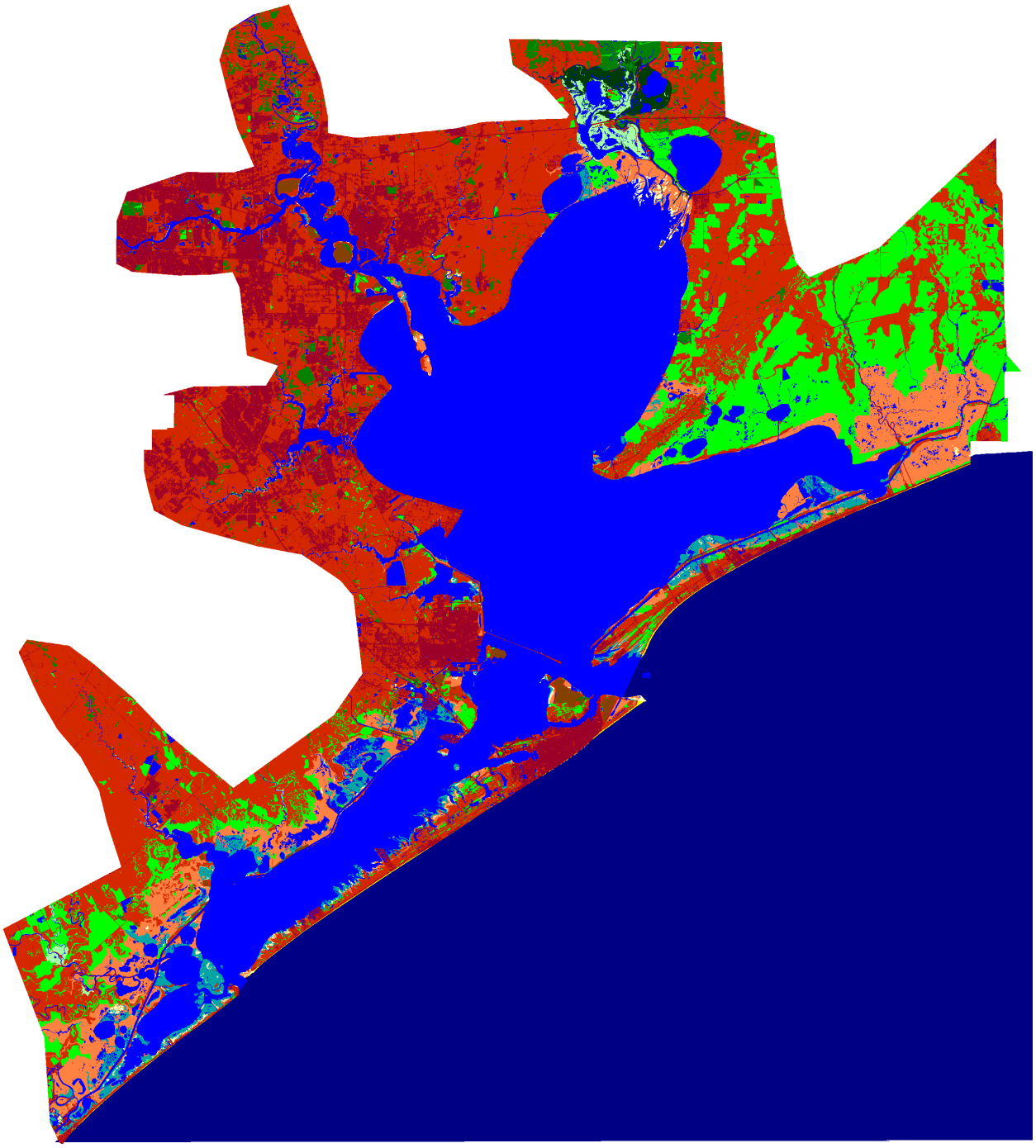
Brazoria Context, 2050, 1 m



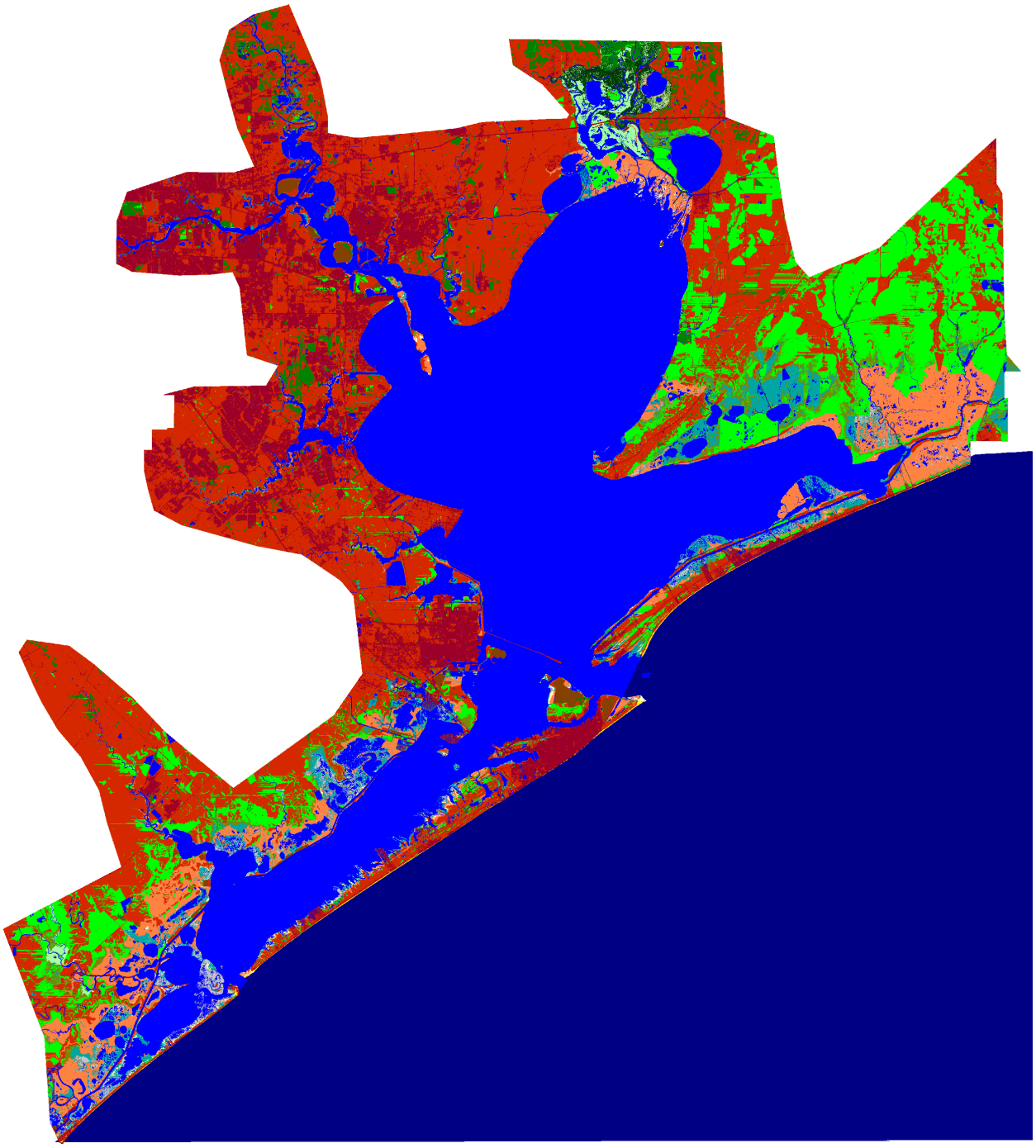
Brazoria Context, 2075, 1 m



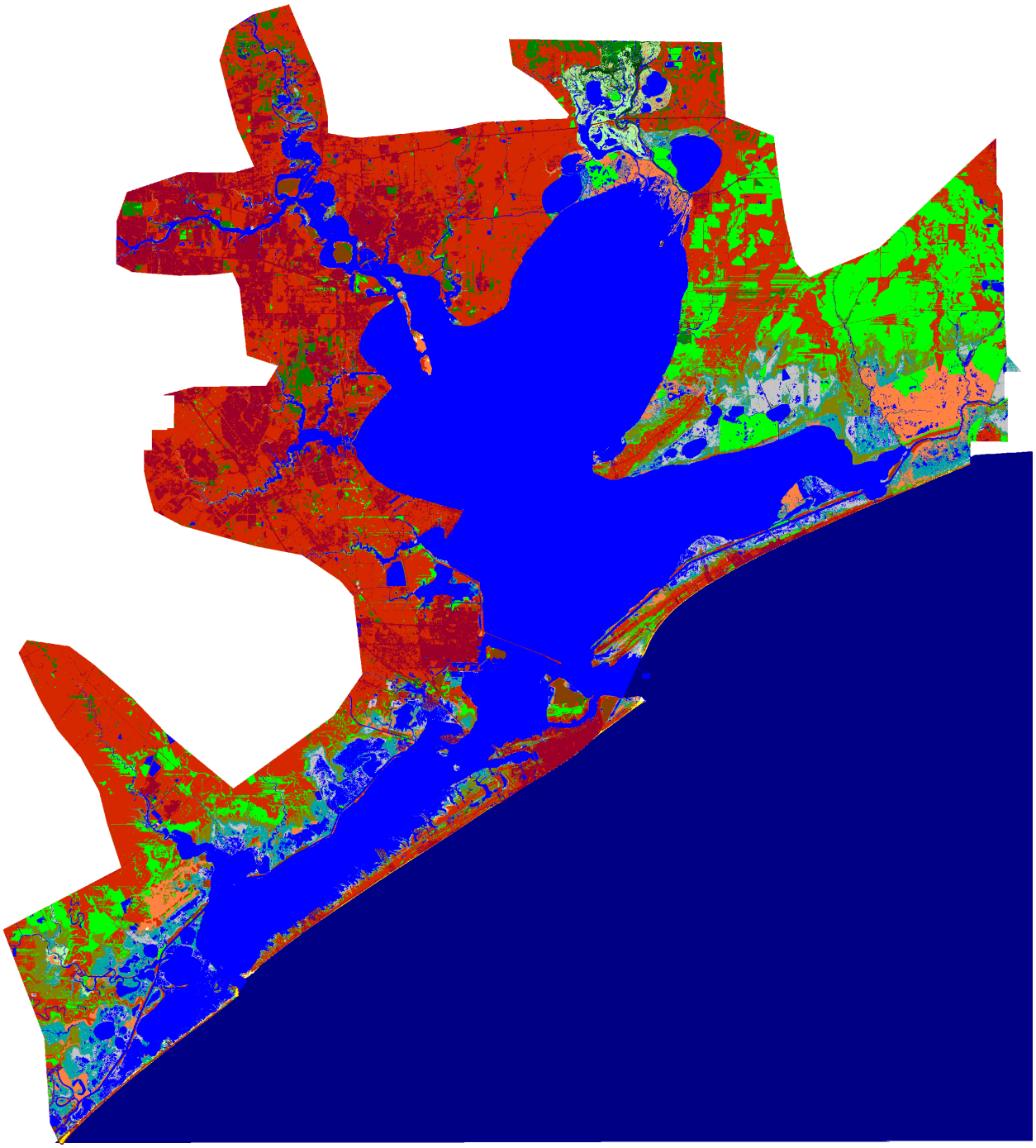
Brazoria Context, 2100, 1 m



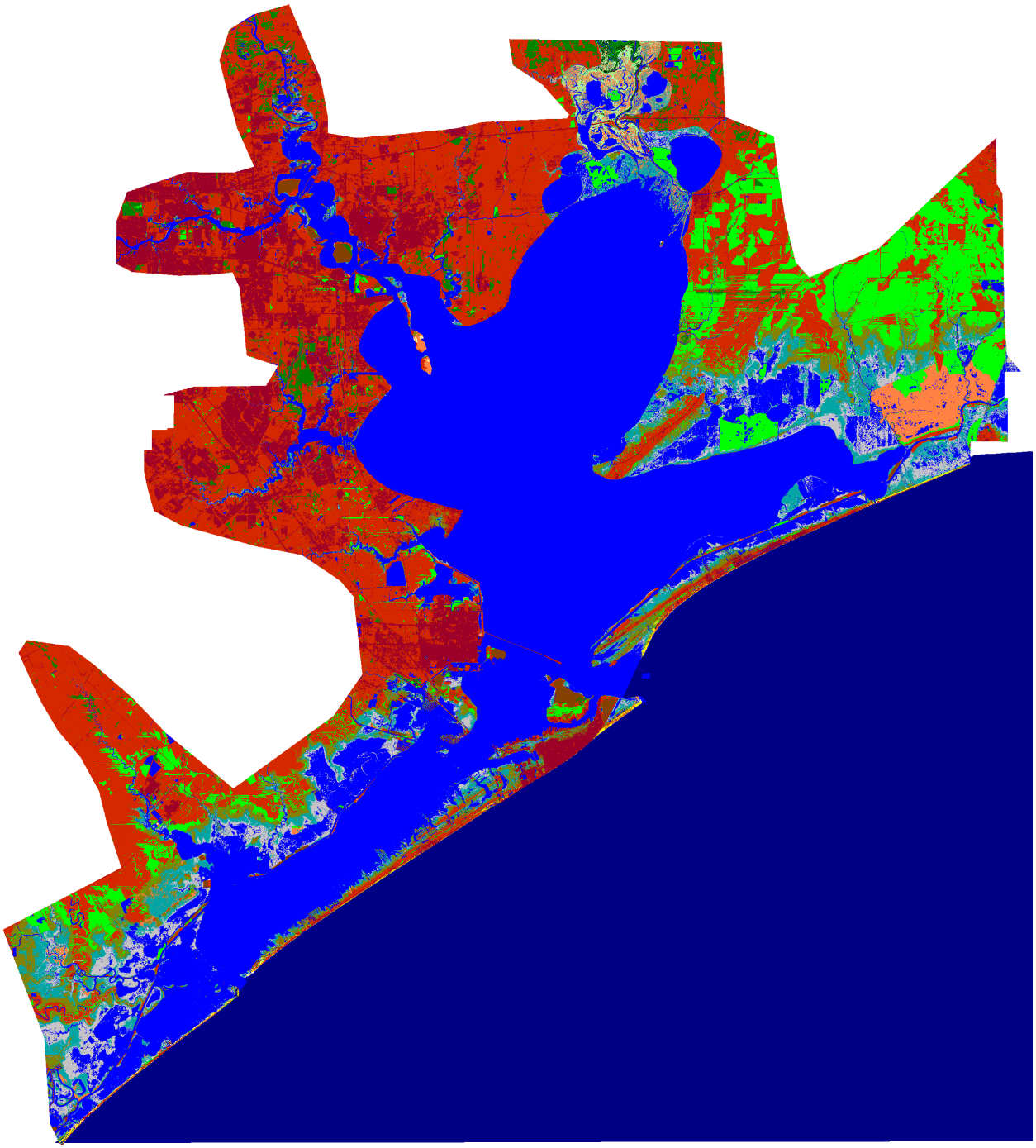
Brazoria Context, Initial Condition



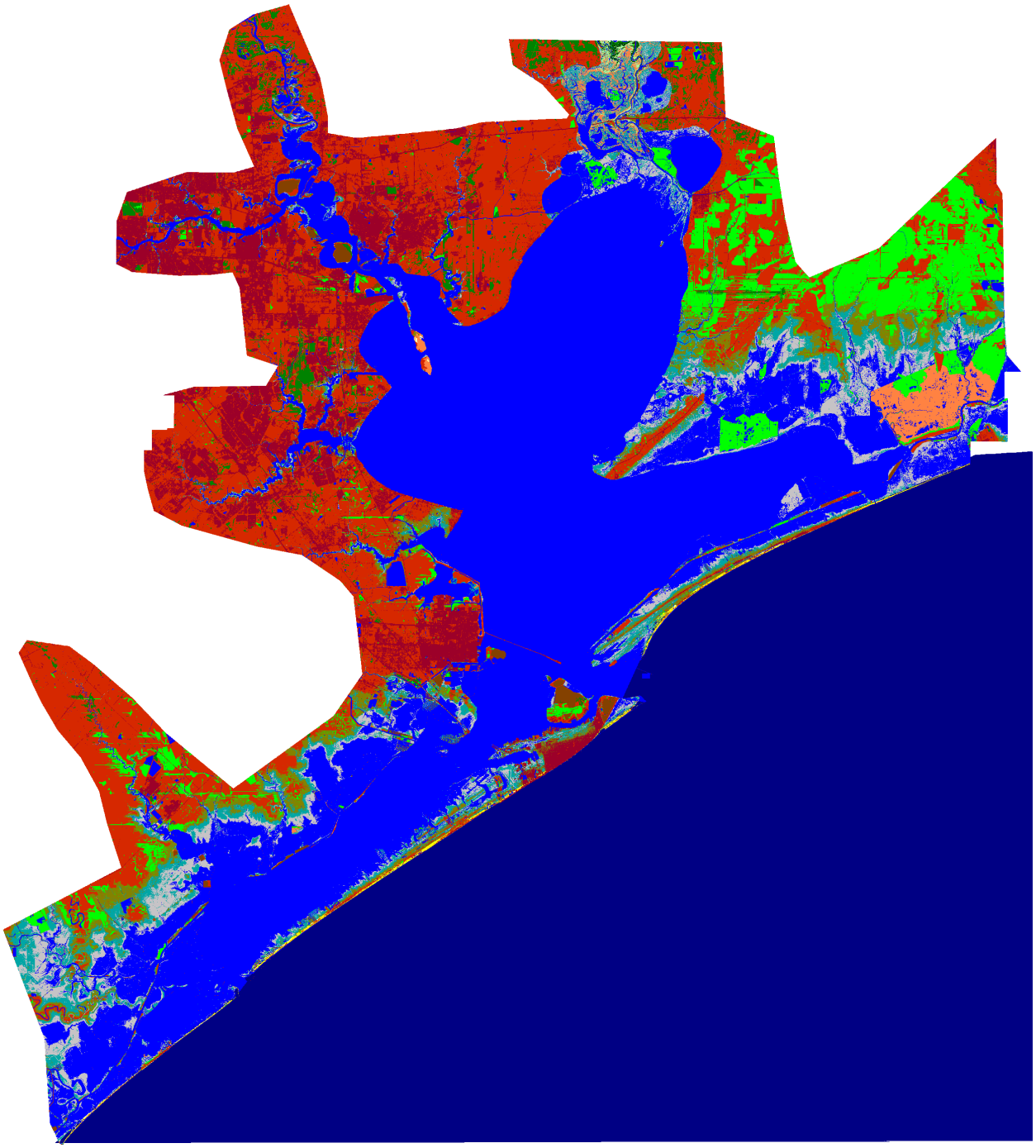
Brazoria Context, 2025, 1.5 m



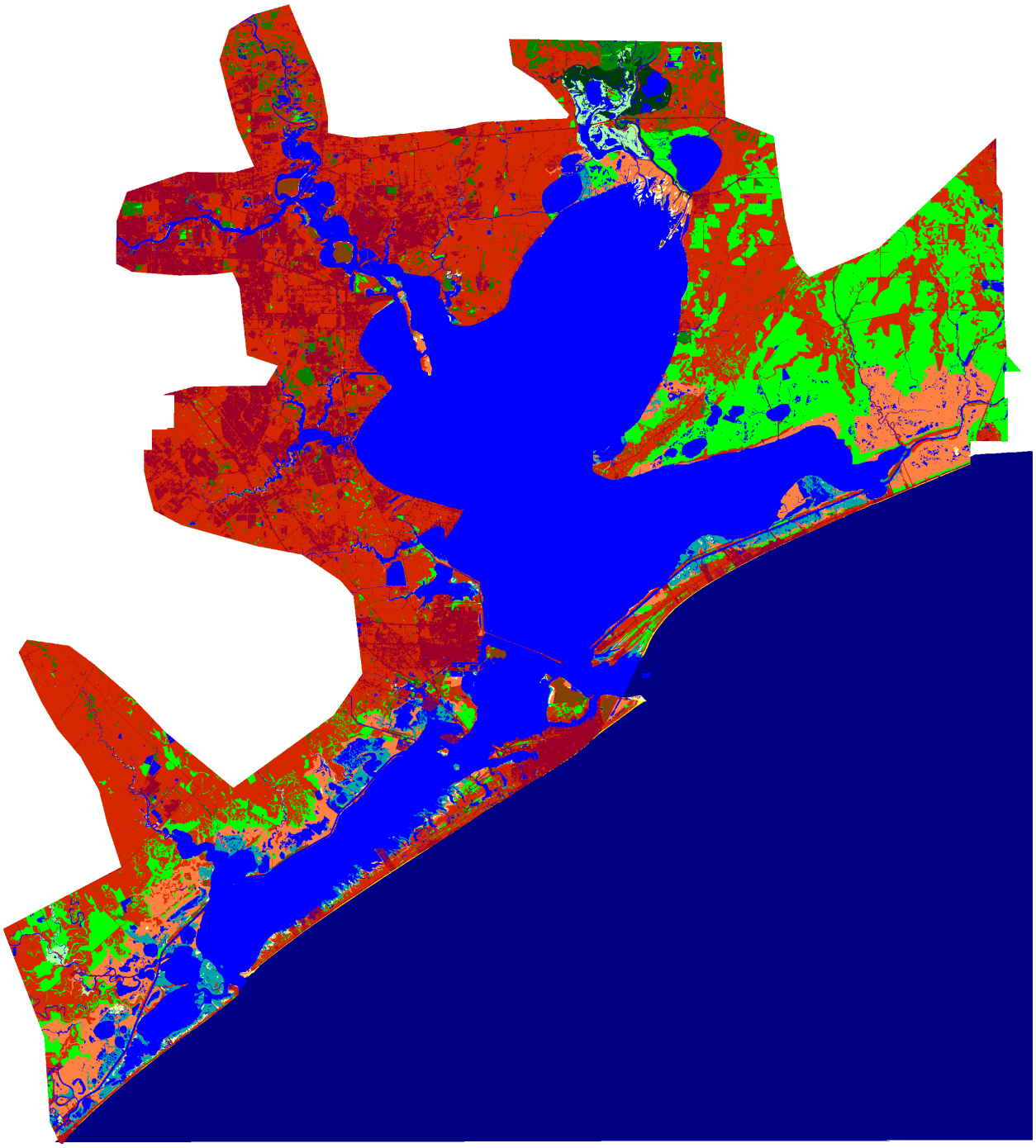
Brazoria Context, 2050, 1.5 m



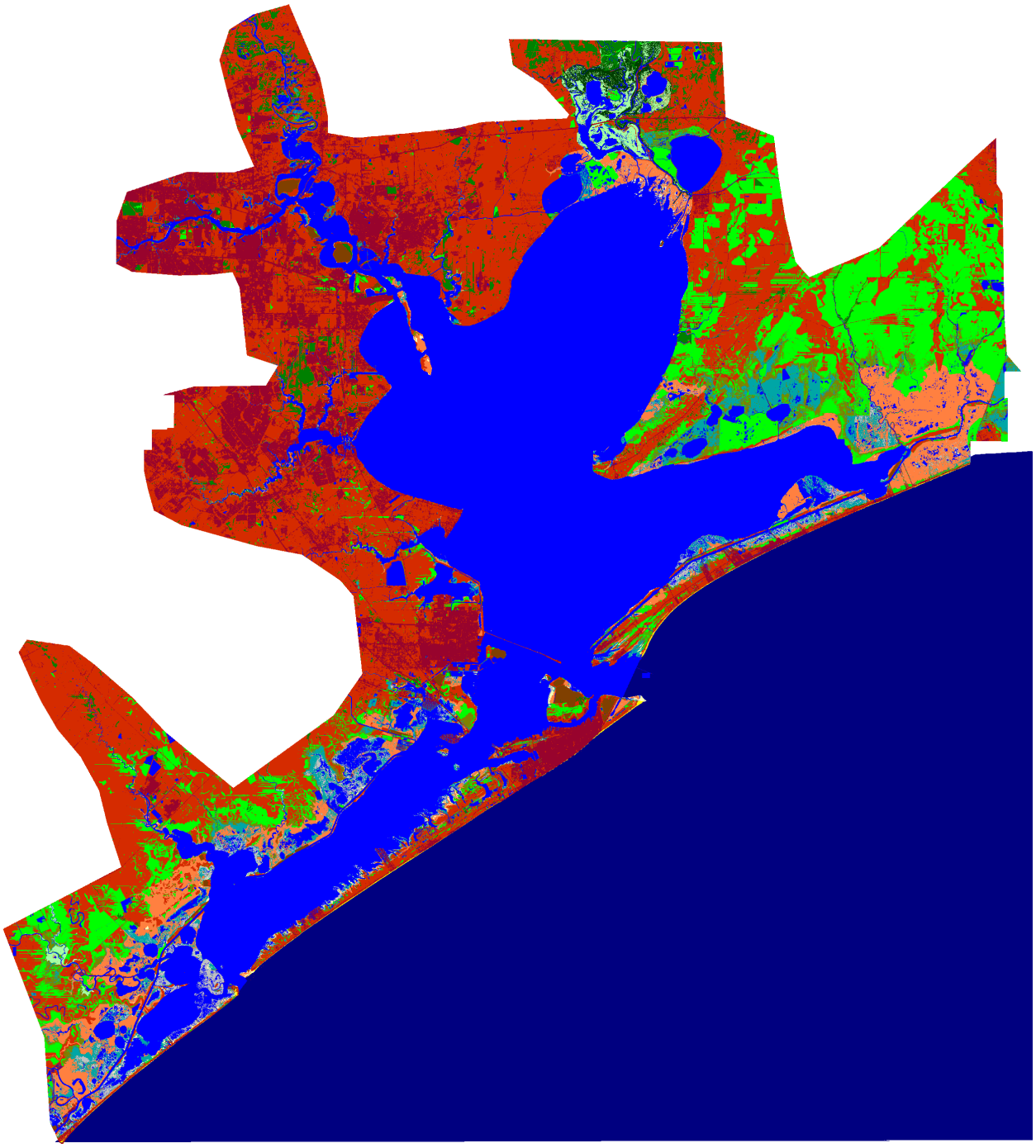
Brazoria Context, 2075, 1.5 m



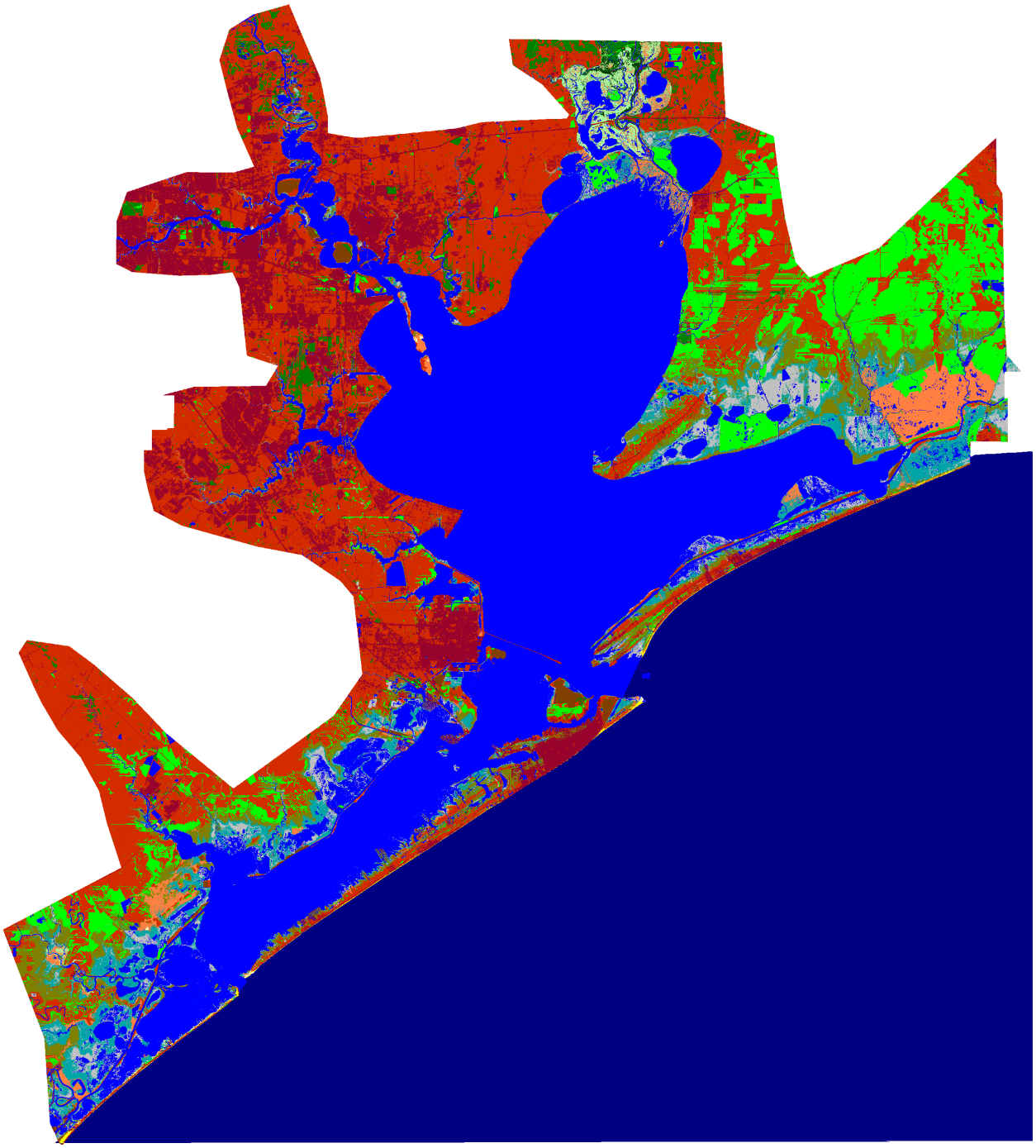
Brazoria Context, 2100, 1.5 m



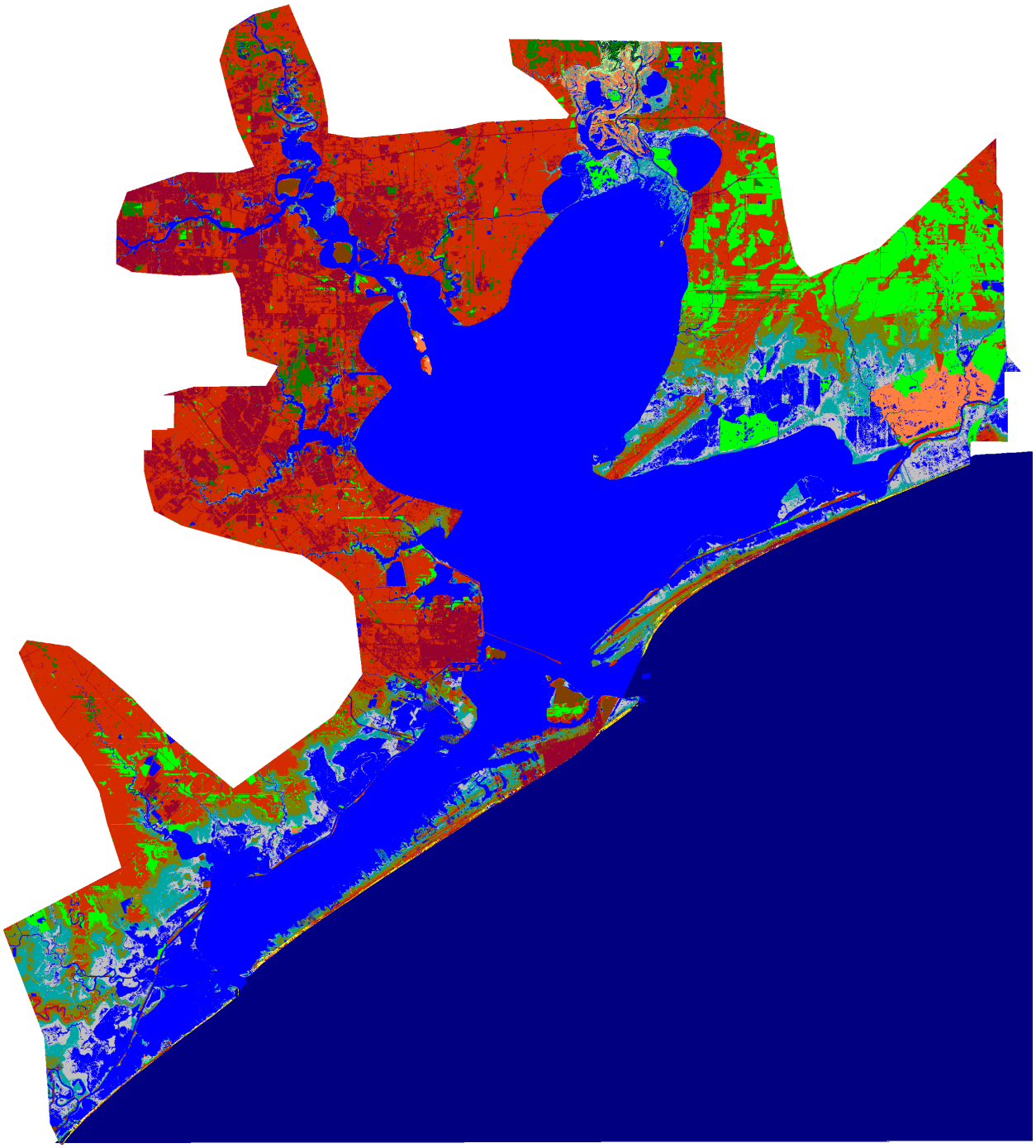
Brazoria Context, Initial Condition



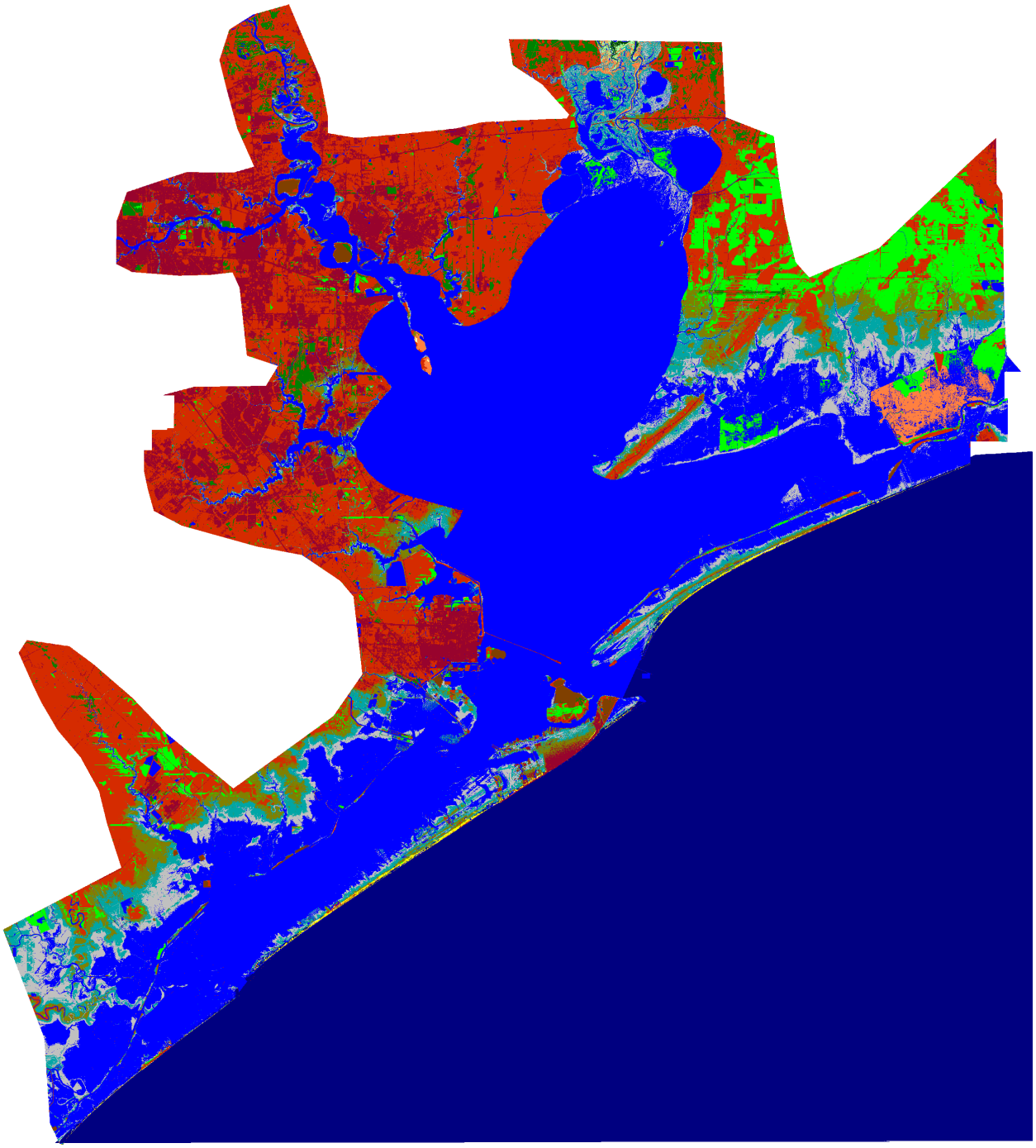
Brazoria Context, 2025, 2 m



Brazoria Context, 2050, 2 m



Brazoria Context, 2075, 2 m



Brazoria Context, 2100, 2 m