Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Texas Point NWR

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July 1, 2011

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Information for this project was provided 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.

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 (Clough and Larson 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 meters width are assumed to undergo overwash during each specified interval for large storms. Beach migration and transport of sediments are calculated.

- **Saturation:** Coastal swamps and fresh marshes can migrate onto adjacent uplands as a response of the fresh water table to rising sea level close to the coast.
- **Accretion:** Sea level rise is offset by sedimentation and vertical accretion using average or site-specific values for each wetland category. Accretion rates may be spatially variable within a given model domain 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 will be used in USFWS simulations, but only where adequate data exist for parameterization.
- Salinity Model: Multiple time-variable freshwater flows may be specified. Salinity is estimated and mapped at MLLW, MHHW, and MTL. Habitat switching may be specified as a function of salinity. This optional sub-model is not utilized in USFWS simulations.
- Integrated Elevation Analysis: SLAMM will summarize site-specific categorized elevation ranges for wetlands as derived from LiDAR data or other high-resolution data sets. This functionality is used in 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

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

The latest literature (Chen et al. 2006; Monaghan et al. 2006) indicates that the eustatic rise in sea levels is progressing more rapidly than was previously assumed, perhaps due to the dynamic changes in ice flow omitted within the IPCC report's calculations. A recent paper in the journal *Science* (Rahmstorf 2007) suggests that, taking into account possible model error, a feasible range by 2100 of 50 to 140 cm. This work was recently updated and the ranges were increased to 75 to 190 cm (Vermeer and Rahmstorf 2009). Pfeffer et al. (2008) suggests that 2 meters by 2100 is at the upper end of plausible scenarios due to physical limitations on glaciological conditions. A recent US intergovernmental report states "Although no ice-sheet model is currently capable of capturing the glacier speedups in Antarctica or Greenland that have been observed over the last decade, including these processes in models will very likely show that IPCC AR4 projected sea level rises for the end of the 21st century are too low." (Clark 2009) A recent paper by Grinsted et al. (2009) states that "sea level 2090-2099 is projected to be 0.9 to 1.3 m for the A1B scenario…" Grinsted also states that there is a "low probability" that SLR will match the lower IPCC estimates.

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

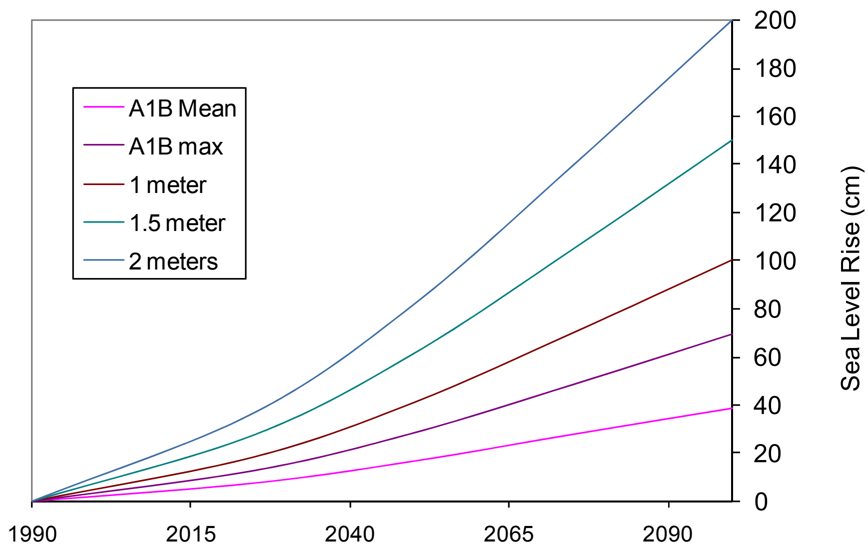


Figure 1: Summary of SLR scenarios utilized

Methods and Data Sources

This study of Texas Point NWR was derived from a previously conducted project of The Nature Conservancy to analyze the coastal portion of Jefferson County, Texas (Clough and Larson 2011).

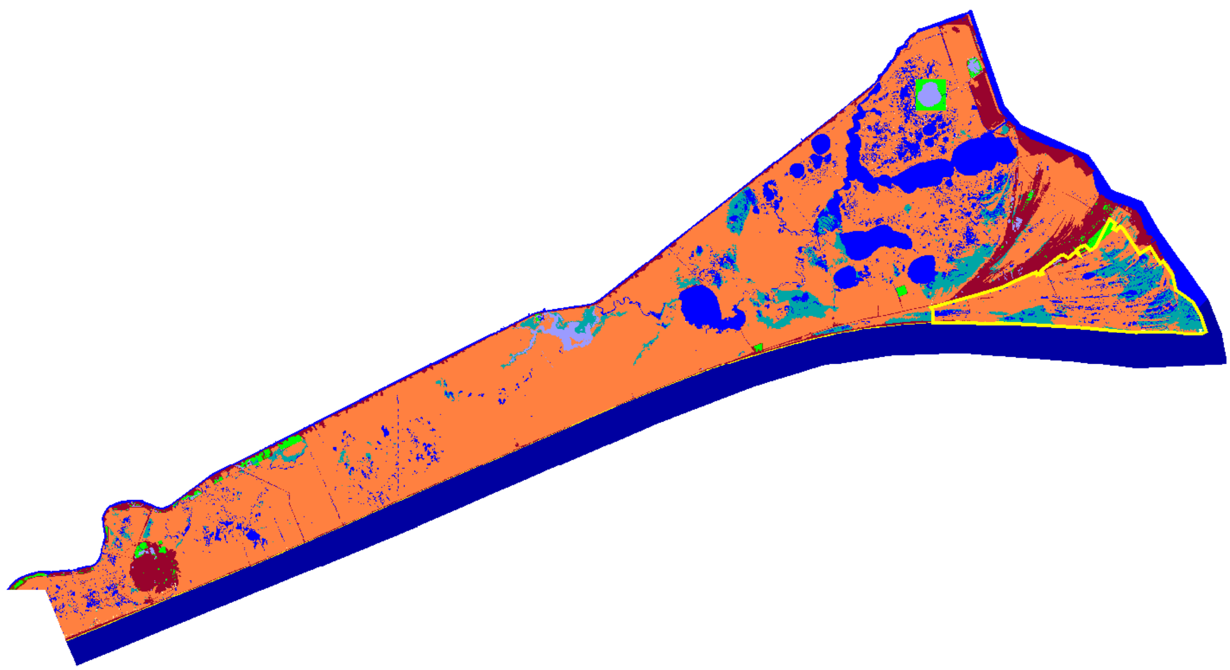


Figure 2. Jefferson County study area with Texas Point NWR boundary shown in yellow

Elevation data utilized was 2006 LIDAR data provided by the Texas Water Development Board (TWDB) and the Federal Emergency Management Agency (FEMA). The National Wetlands Inventory for the study area was fairly recently updated and is based on 2004 photography.

Converting the NWI survey into 10 meter cells indicated that the approximately 9570 acres of the refuge included in this study (approved acquisition boundary including water) are composed of the following categories:

Table 1. Land cover categories and their abundance Texas Point NWR according to the 2004 NWI layer

		% of Study Area	Acres
	Irregularly Flooded Marsh	60%	5783.3
	Regularly Flooded Marsh	23%	2197.5
	Estuarine Open Water	11%	1080.6
	Undeveloped Dry Land	3%	259.1
	Inland Fresh Marsh	1%	110.2
	Ocean Beach	< 1 %	79.6
	Open Ocean	< 1 %	19.5
	Estuarine Beach	< 1 %	18.5
	Inland Open Water	< 1 %	17.1
	Developed Dry Land	< 1 %	3.5
	Inland Shore	< 1 %	0.5
	Total (incl. water)	**100%**	**9569.6**

According to the National Wetland Inventory, there were no impounded or diked areas within Texas Point NWR.

The historic trend for sea level rise was estimated at 6 mm/year using the value of the two closest tide stations (NOAA gauge #8770570, Sabine Pass, Texas; NOAA gauge #8771510, Galveston Pleasure Pier, TX). This measured rate is higher than the global average for the last 100 years (approximately 1.5-2.0 mm/year) reflecting local land subsidence at this site. Within SLAMM relative sea level change is estimated as the sum of the historic eustatic trend, the site-specific rate of change of elevation due to subsidence, and the accelerated rise depending on the scenario chosen (IPCC 2001; Titus et al. 1991). The local rate of land subsidence is therefore predicted to remain constant through 2100 and will result in significantly more relative sea level rise at this site than may be present at other sites.

The tide range at this site was estimated at 0.449 m using the closest NOAA stations with tide range data (8770971, Rollover Pass, TX; 8770570, Sabine Pass North, TX).

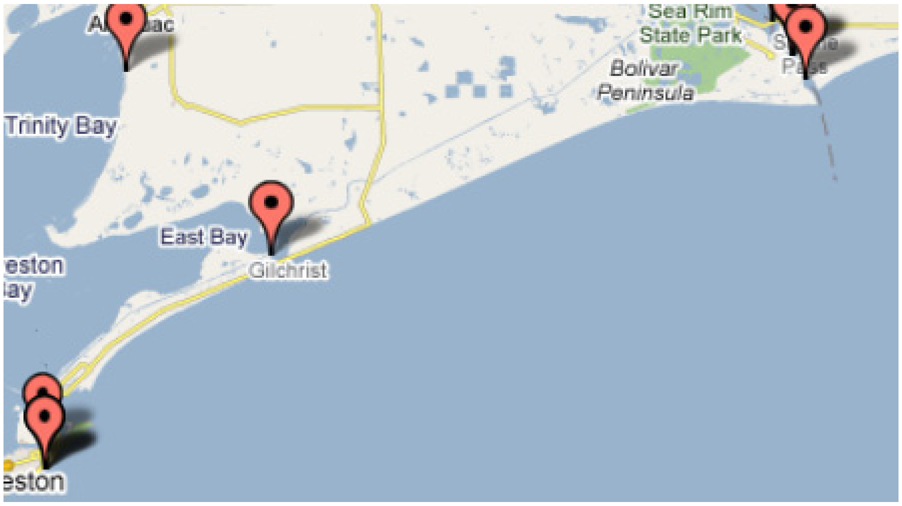


Figure 3. NOAA Gauges relevant to the Study area

Accretion rates for this site in regularly-flooded (salt) marshes were set to 10.43 mm/yr. (Cahoon et al. 1999) to 7.67 mm/yr. in irregularly-flooded (brackish) marshes, and to 7.73 mm/yr. in tidal fresh marshes (Cahoon 1994; Cahoon et al. 1995; Stevenson et al. 1986; White et al. 2002).

The study of Jefferson County (from which the Texas Point NWR results were derived) relied on three input sites to incorporate accurate site-specific data. Figure 4 presents the location of each of the three input sites. Specific data parameters applied to each of these subsites are shown in Table 2. A small strip of beach subject to Gulf-of-Mexico tide ranges was broken out into a "Jefferson County Beach" subsite (subsite 2).

The cell-size used for this analysis was 10 meter by 10 meter cells. SLAMM will also track partial conversion of cells based on elevation and slope.

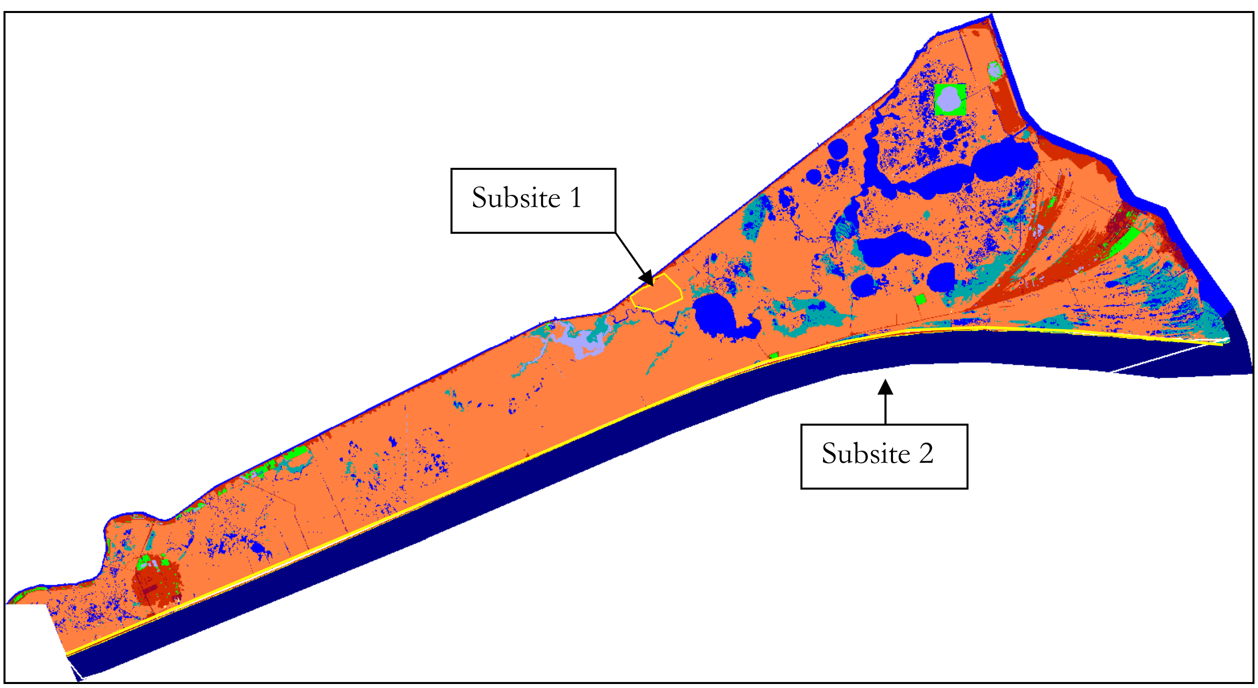


Figure 4. Study area parameter input sites

Table 2. Summary of SLAMM Parameters for Jefferson County Study Area, which includes Texas Point NWR

Parameter	Global	Subsite 1	Subsite 2
Description	Jefferson County	Jefferson County Area 3	Jefferson County Beach
NWI Photo Date (YYYY)	2004	2004	2004
DEM Date (YYYY)	2006	2006	2006
Direction Offshore [n,s,e,w]	South	South	South
Historic Trend (mm/yr)	6	6	6
MTL-NAVD88 (m)	0.155	-0.345	0.155
GT Great Diurnal Tide Range (m)	0.036	0.036	0.449
Salt Elev. (m above MTL)	0.049	0.049	0.539
Marsh Erosion (horz. m /yr)	1.8	1.8	1.8
Swamp Erosion (horz. m /yr)	1	1	1
T.Flat Erosion (horz. m /yr)	2	2	2
Reg. Flood Marsh Accr (mm/yr)	10.43	10.43	10.43
Irreg. Flood Marsh Accr (mm/yr)	7.67	7.67	7.67
Tidal Fresh Marsh Accr (mm/yr)	7.73	7.73	7.73
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5
Freq. Overwash (years)	30	30	30
Use Elev Pre-processor	FALSE	FALSE	FALSE

Results

This simulation of the Texas Point NWR was completed using a SLAMM model that was calibrated to historical data for a previous project examining the coastal portion of Jefferson County, TX (Clough and Larson 2011). This calibrated model predicts that Texas Point NWR will be severely impacted depending on the SLR scenario and wetland class.

Table 3 presents the predicted loss of each wetland category by 2100 for each of the five SLR scenarios examined. 73% of the area of Texas Point NWR is composed of regularly and irregularly flooded marsh. At 1 meter of SLR by 2100, a level that some scientists consider to be the "most likely" scenario", 75% of refuge irregularly-flooded marsh is predicted to be lost. Conversely, regularly-flooded marsh is predicted to increase due to conversion of irregularly-flooded marsh to regularly-flooded at all but the 1.5 and 2 meter SLR by 2100 scenarios.

In these simulations the dry land categories were not assumed to be protected by anthropogenic action, providing a worst-cast scenario for loss of these categories. Both developed and undeveloped dry land are predicted to be lost at high rate, resulting in 82% loss of undeveloped and 75% loss of developed dry land under 1m of SLR by 2100.

Under the "worst-case" scenario of 2m of SLR by 2100, the entire refuge is predicted to have converted to tidal flat or open water, with only the northern-most portion remaining as regularly-flooded marsh.

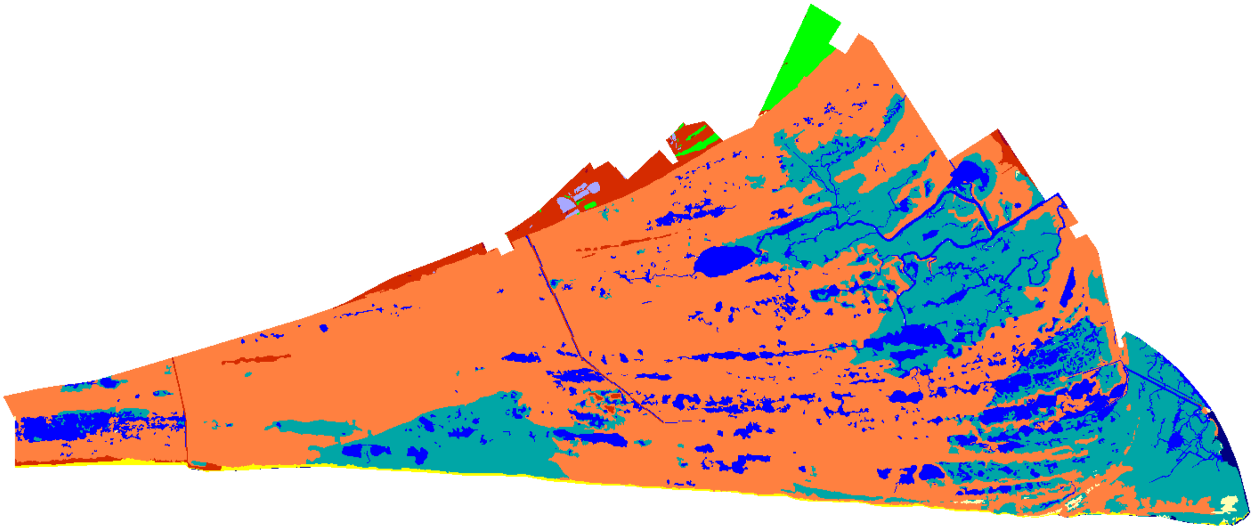
Table 3. Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise.
Negative values represent increases while positive values represent losses

SLR by 2100 (m)	0.39	0.69	1	1.5	2
Irregularly Flooded Marsh	3%	22%	75%	100%	100%
Regularly Flooded Marsh	0%	-46%	-104%	43%	89%
Undeveloped Dry Land	31%	56%	82%	99%	100%
Inland Fresh Marsh	3%	6%	38%	99%	100%
Ocean Beach	99%	99%	93%	99%	100%
Estuarine Beach	94%	93%	87%	87%	99%
Developed Dry Land	31%	45%	75%	98%	100%
Inland Shore	89%	100%	100%	100%	100%
Swamp	33%	76%	100%	100%	100%

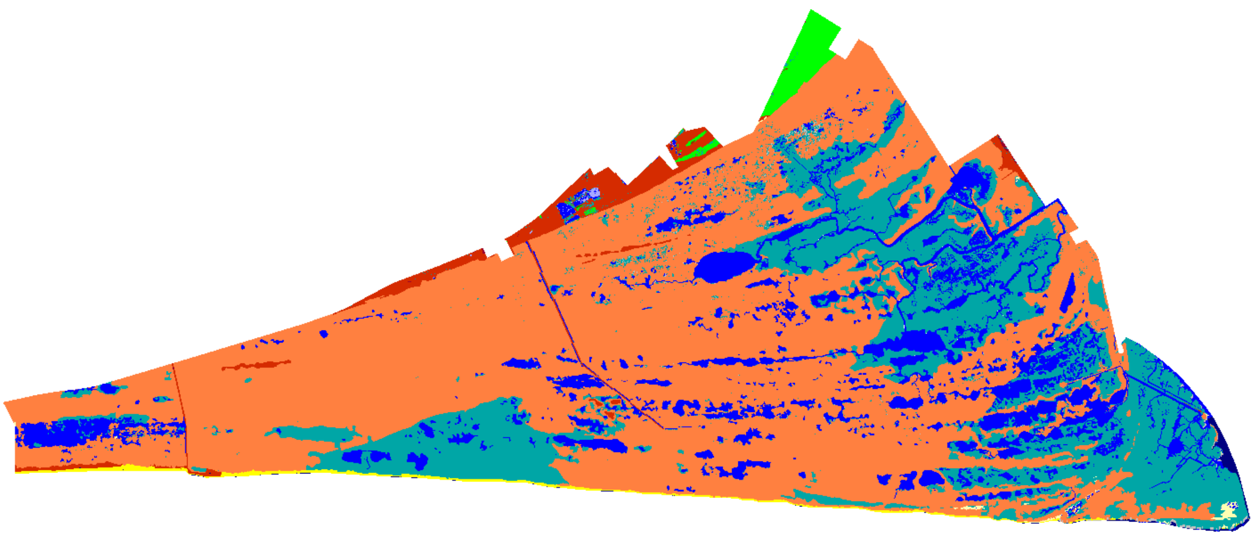
Texas Point NWR
IPCC Scenario A1B-Mean, 0.39 m SLR Eustatic by 2100

Results in Acres

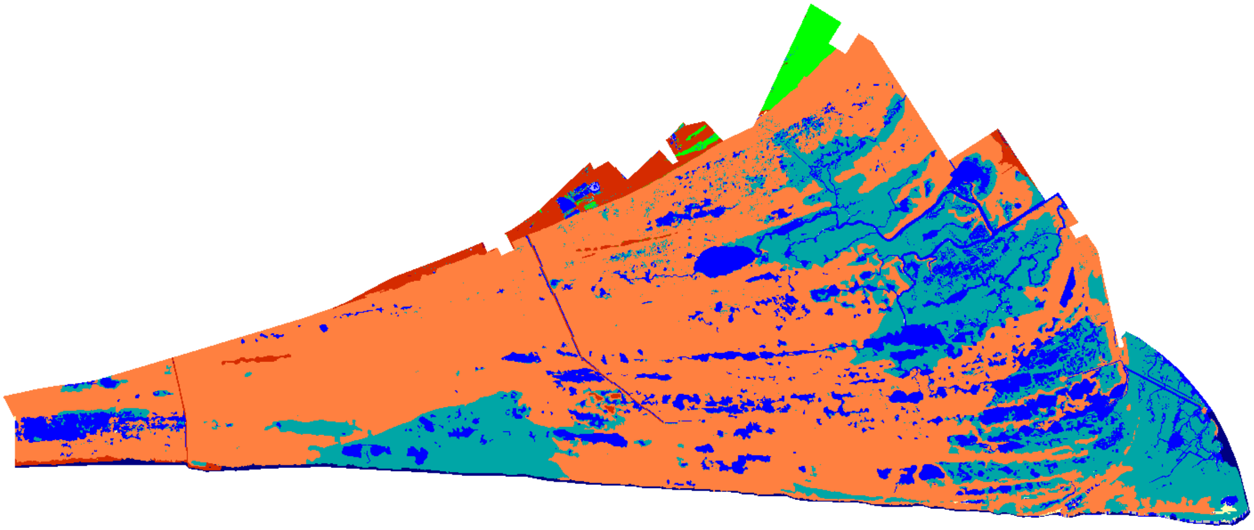
		Initial	2025	2050	2075	2100
	Irregularly Flooded Marsh	5783.3	5675.8	5674.7	5616.5	5582.1
	Regularly Flooded Marsh	2197.5	2179.2	2177.4	2157.7	2195.8
	Estuarine Open Water	1080.6	1206.3	1239.9	1252.1	1333.3
	Undeveloped Dry Land	259.1	251.2	245.9	218.9	179.1
	Inland Fresh Marsh	110.2	107.1	107.0	106.9	106.7
	Ocean Beach	79.6	48.2	0.0	1.5	1.0
	Open Ocean	19.5	51.0	99.3	99.8	105.3
	Estuarine Beach	18.5	14.6	7.7	3.0	1.1
	Inland Open Water	17.1	4.9	2.1	0.4	0.1
	Developed Dry Land	3.5	3.0	2.9	2.7	2.4
	Inland Shore	0.5	0.5	0.5	0.3	0.1
	Swamp	0.2	0.2	0.2	0.2	0.1
	Transitional Salt Marsh	0.0	2.8	6.4	25.8	50.6
	Tidal Flat	0.0	24.8	5.8	83.8	11.7
	Total (incl. water)	**9569.6**	**9569.6**	**9569.6**	**9569.6**	**9569.6**



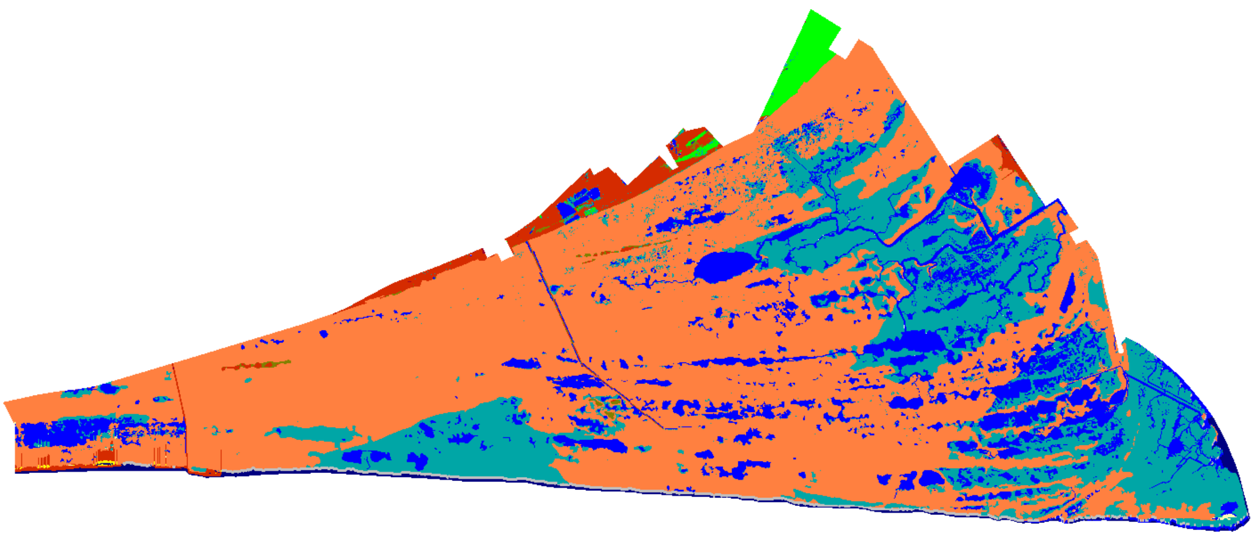
Texas Point NWR, Initial Condition



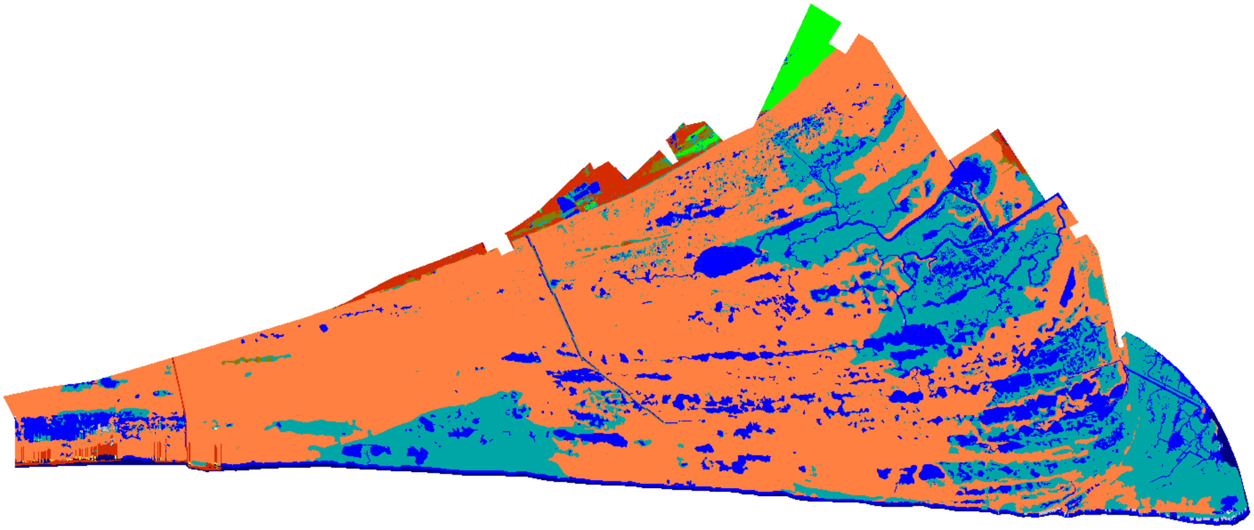
Texas Point NWR, 2025, Scenario A1B Mean



Texas Point NWR, 2050, Scenario A1B Mean



Texas Point NWR, 2075, Scenario A1B Mean

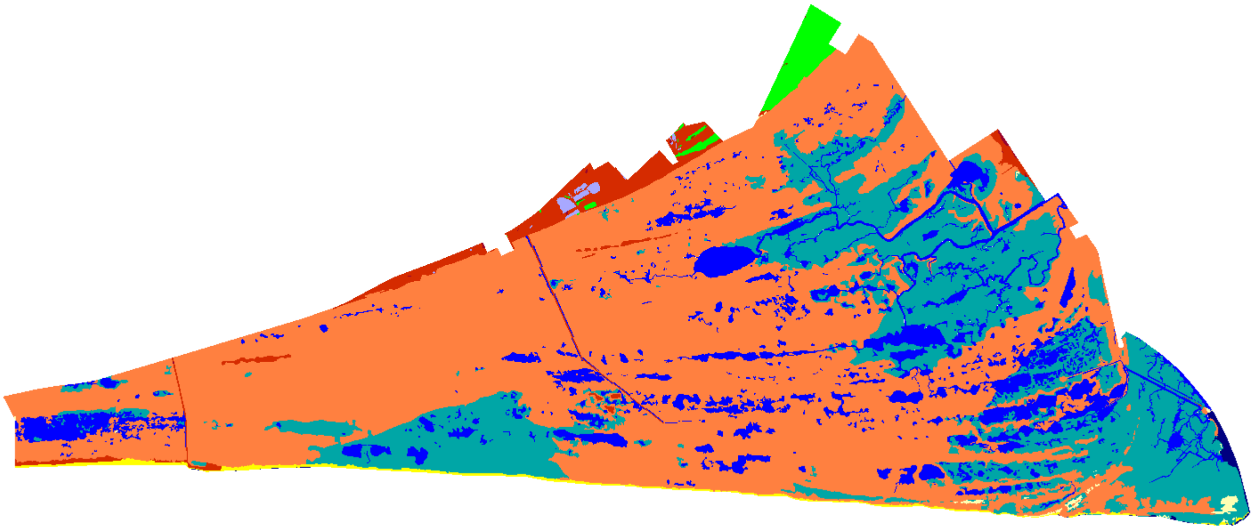


Texas Point NWR, 2100, Scenario A1B Mean

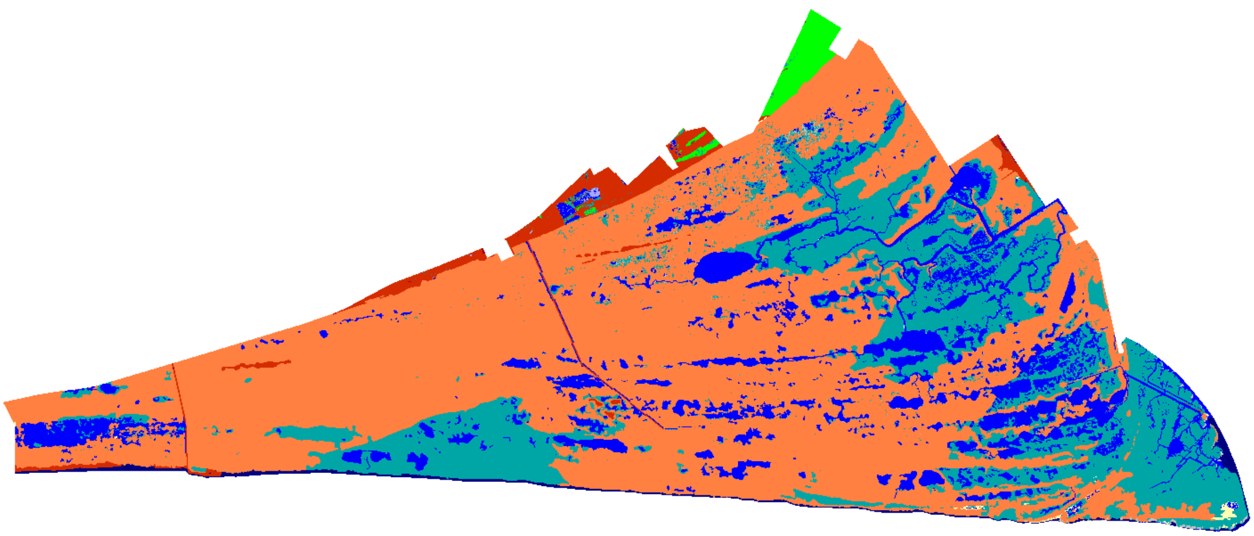
Texas Point NWR
IPCC Scenario A1B-Max, 0.69 m SLR Eustatic by 2100

Results in Acres

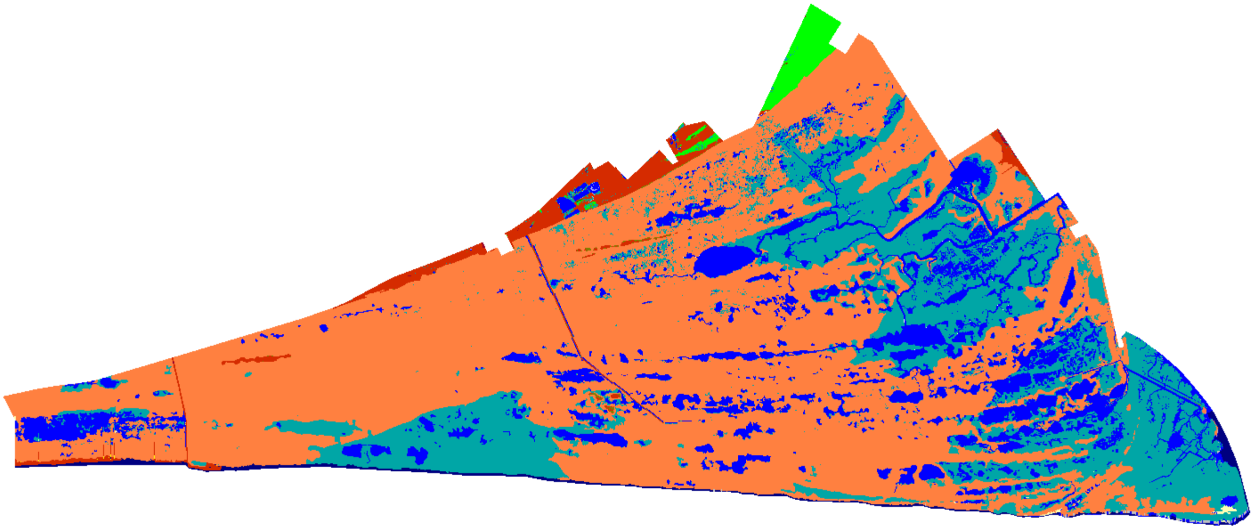
		Initial	2025	2050	2075	2100
	Irregularly Flooded Marsh	5783.3	5672.2	5610.0	5283.8	4506.9
	Regularly Flooded Marsh	2197.5	2178.8	2235.2	2478.2	3218.7
	Estuarine Open Water	1080.6	1208.7	1247.3	1264.6	1368.5
	Undeveloped Dry Land	259.1	250.8	238.4	176.3	113.1
	Inland Fresh Marsh	110.2	107.0	106.4	105.3	104.1
	Ocean Beach	79.6	24.5	0.2	1.5	1.2
	Open Ocean	19.5	74.7	99.4	102.3	112.6
	Estuarine Beach	18.5	13.3	5.9	1.3	1.3
	Inland Open Water	17.1	4.3	1.0	0.2	0.0
	Developed Dry Land	3.5	3.0	2.8	2.4	1.9
	Inland Shore	0.5	0.5	0.5	0.1	0.0
	Swamp	0.2	0.2	0.2	0.2	0.1
	Transitional Salt Marsh	0.0	2.8	12.7	61.1	74.1
	Tidal Flat	0.0	28.7	9.5	92.3	67.2
	Total (incl. water)	**9569.6**	**9569.6**	**9569.6**	**9569.6**	**9569.6**



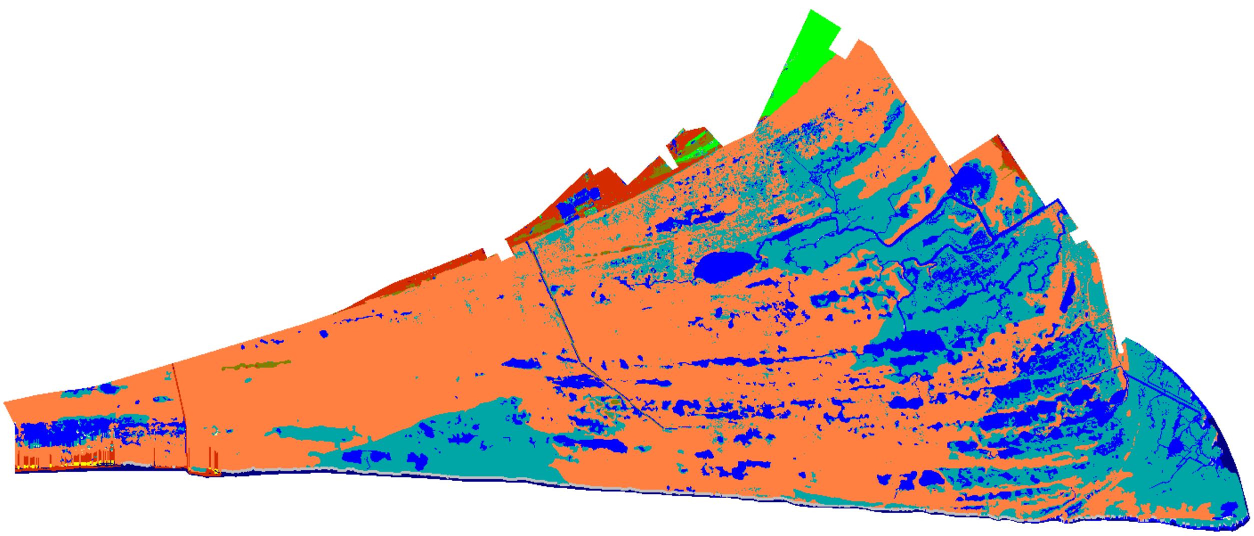
Texas Point NWR, Initial Condition



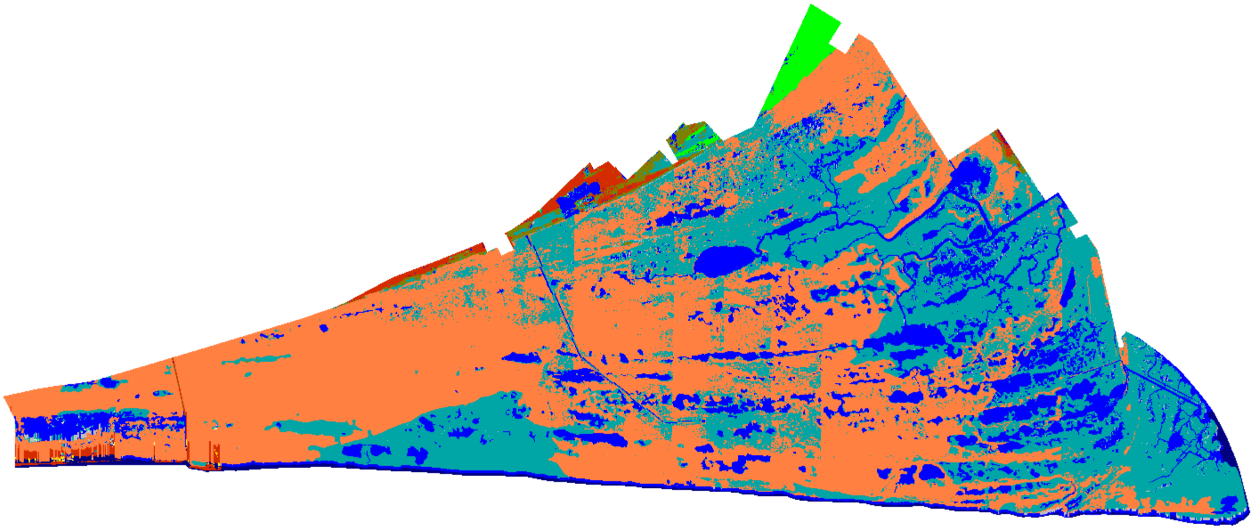
Texas Point NWR, 2025, Scenario A1B Maximum



Texas Point NWR, 2050, Scenario A1B Maximum



Texas Point NWR, 2075, Scenario A1B Maximum

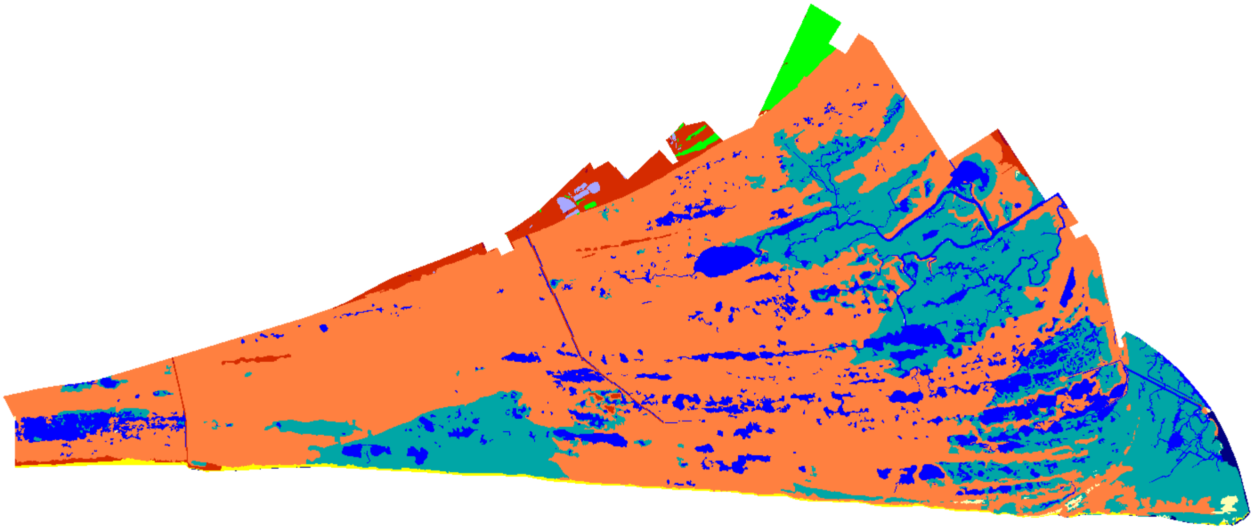


Texas Point NWR, 2100, Scenario A1B Maximum

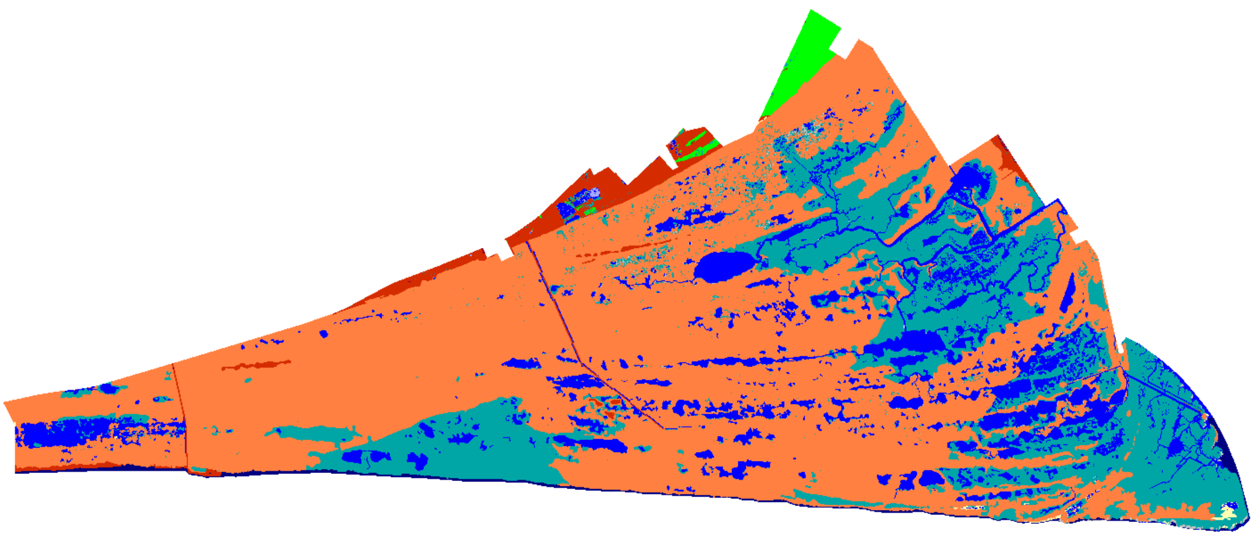
Texas Point NWR
1 m Eustatic SLR by 2100

Results in Acres

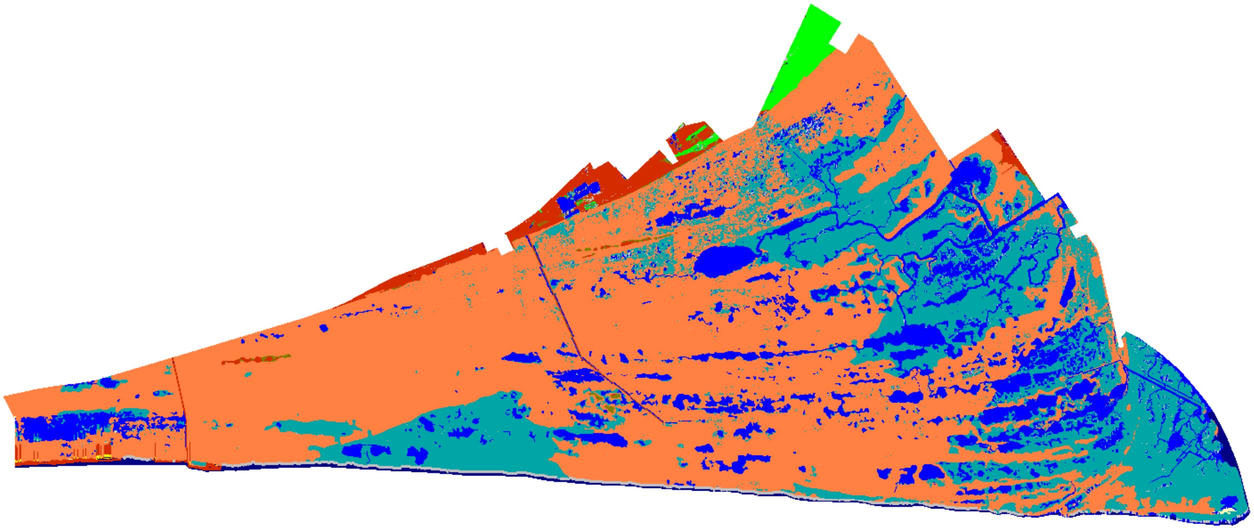
		Initial	2025	2050	2075	2100
	Irregularly Flooded Marsh	5783.3	5648.7	5340.7	3880.8	1424.5
	Regularly Flooded Marsh	2197.5	2196.4	2360.6	3518.6	4486.0
	Estuarine Open Water	1080.6	1211.6	1272.8	1460.7	1939.2
	Undeveloped Dry Land	259.1	250.1	222.9	133.9	45.8
	Inland Fresh Marsh	110.2	106.8	105.4	102.7	68.2
	Ocean Beach	79.6	0.0	0.6	0.8	5.8
	Open Ocean	19.5	99.3	100.3	107.6	120.3
	Estuarine Beach	18.5	11.9	3.1	0.7	2.5
	Inland Open Water	17.1	3.8	0.4	0.1	0.0
	Developed Dry Land	3.5	3.0	2.8	2.1	0.9
	Inland Shore	0.5	0.5	0.4	0.0	0.0
	Swamp	0.2	0.2	0.2	0.1	0.0
	Transitional Salt Marsh	0.0	3.2	27.0	94.1	112.6
	Tidal Flat	0.0	34.2	132.3	267.4	1364.0
	Total (incl. water)	**9569.6**	**9569.6**	**9569.6**	**9569.6**	**9569.6**



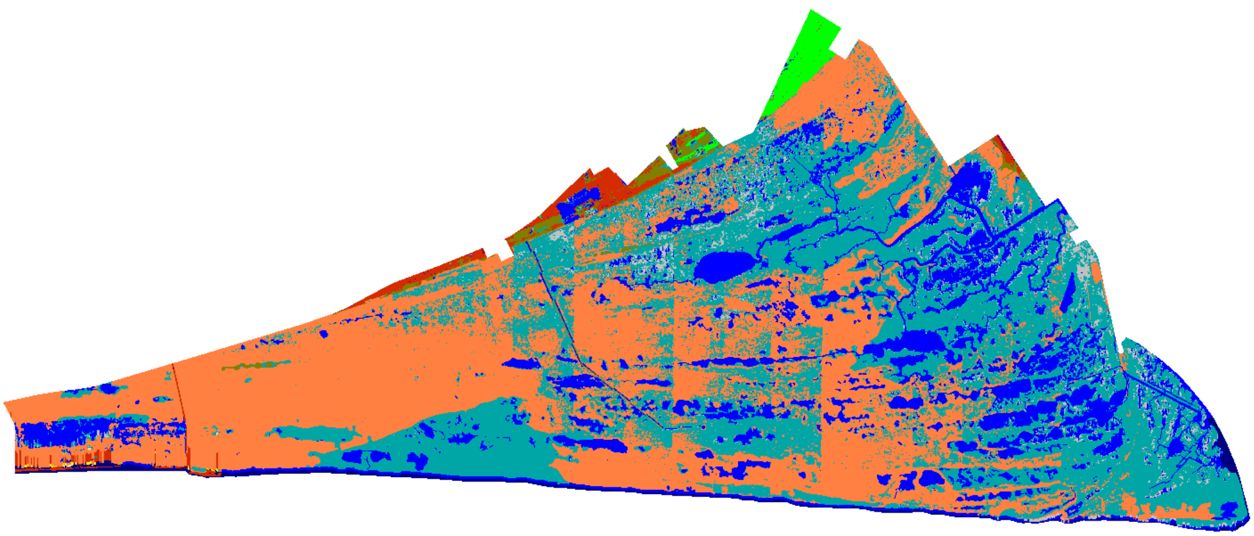
Texas Point NWR, Initial Condition



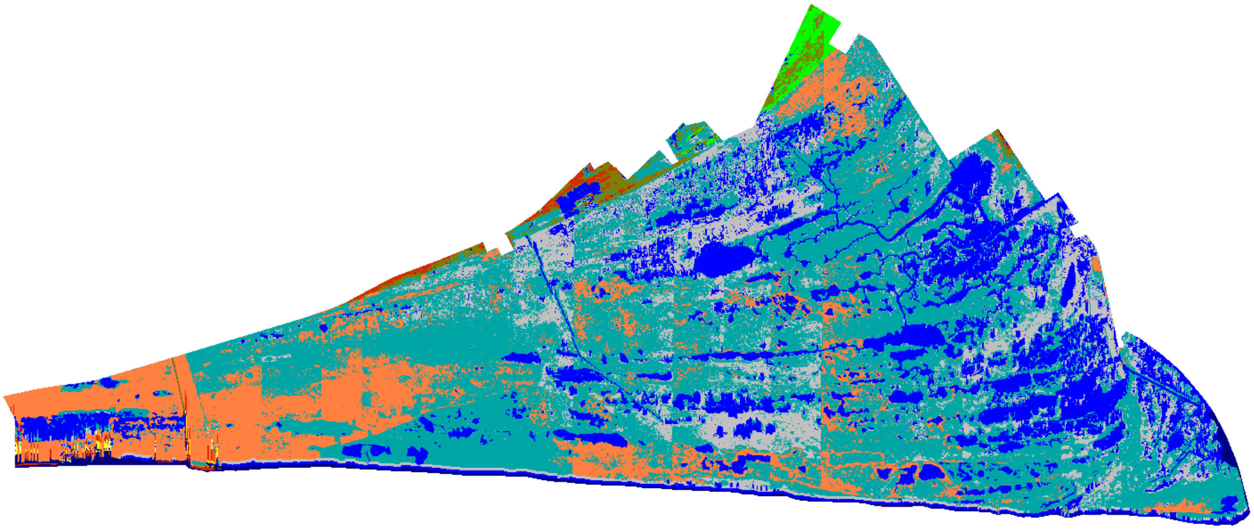
Texas Point NWR, 2025, 1 m



Texas Point NWR, 2050, 1 m



Texas Point NWR, 2075, 1 m

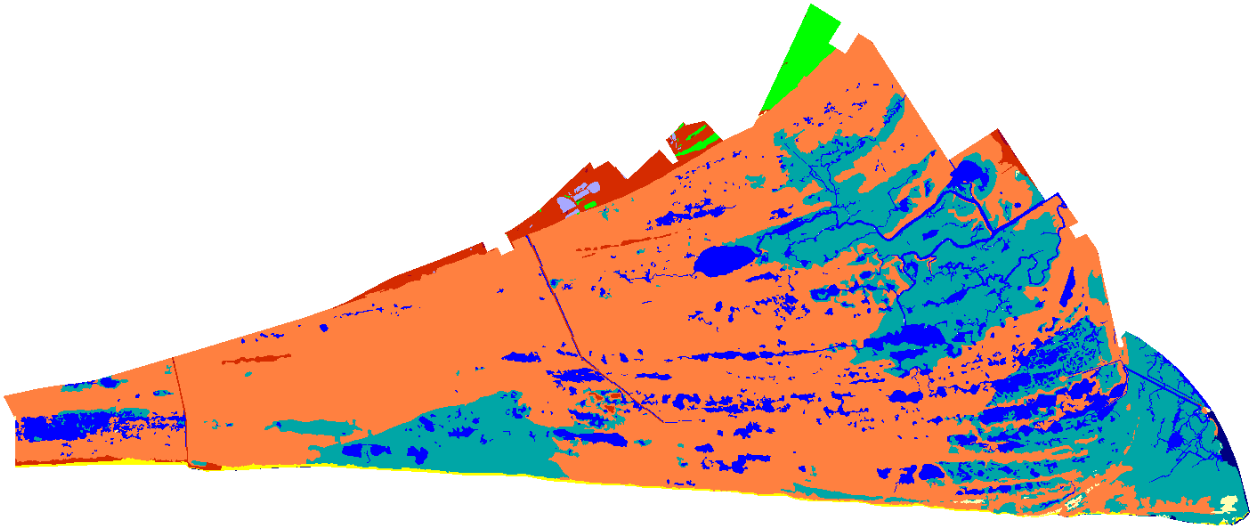


Texas Point NWR, 2100, 1 m

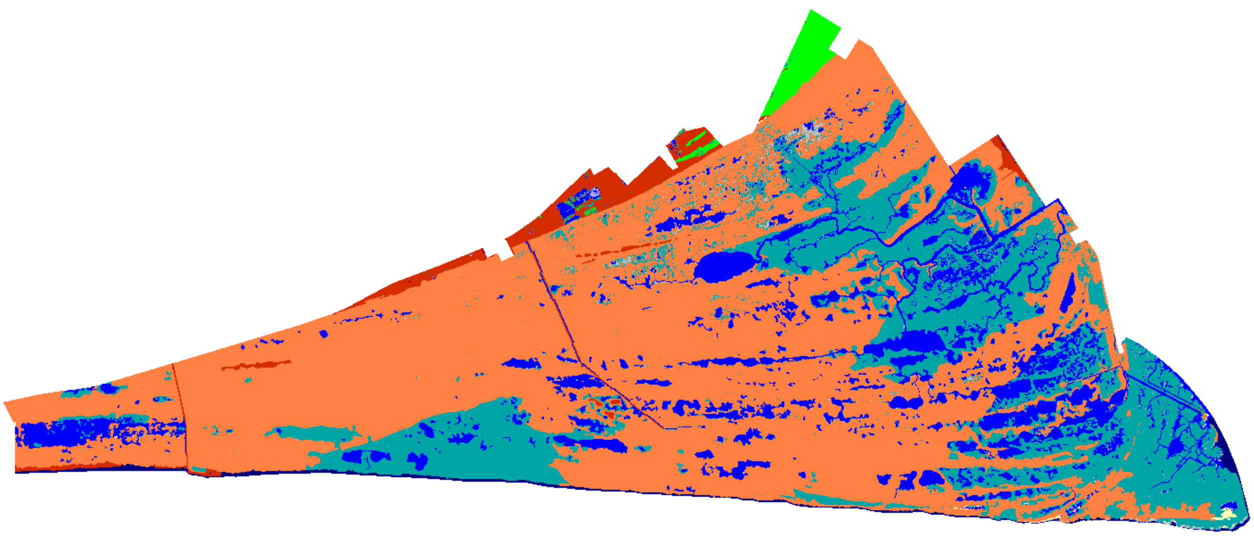
Texas Point NWR
1.5 m Eustatic SLR by 2100

Results in Acres

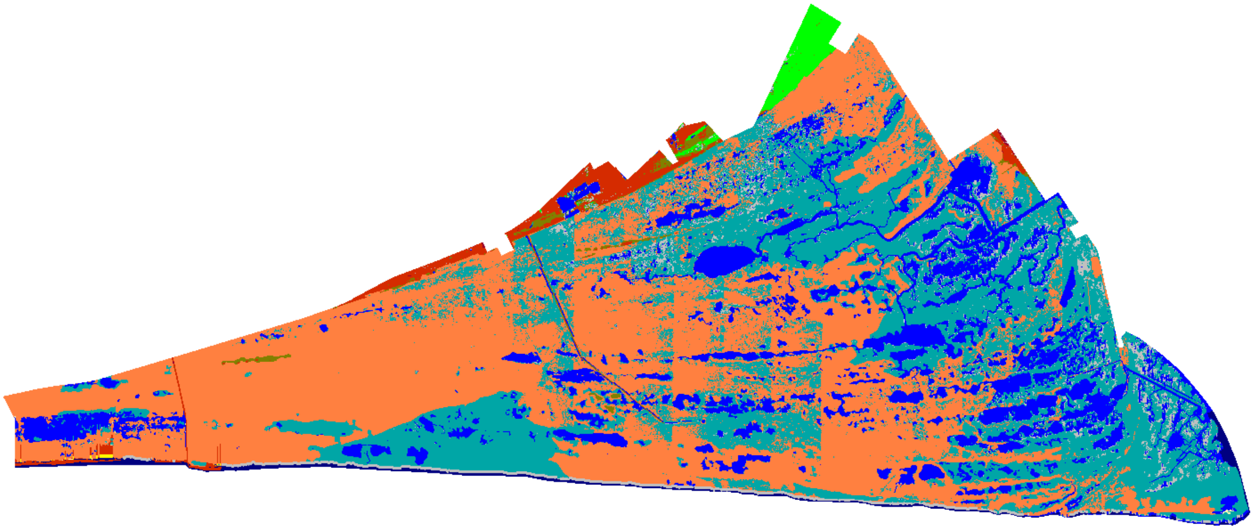
		Initial	2025	2050	2075	2100
	Irregularly Flooded Marsh	5783.3	5589.9	4276.0	739.4	13.7
	Regularly Flooded Marsh	2197.5	2211.8	3118.8	4731.5	1256.2
	Estuarine Open Water	1080.6	1220.0	1370.5	2047.8	4310.6
	Undeveloped Dry Land	259.1	248.7	184.0	60.7	3.0
	Inland Fresh Marsh	110.2	106.3	103.6	36.7	1.6
	Ocean Beach	79.6	0.0	0.4	3.2	0.8
	Open Ocean	19.5	99.3	102.7	115.1	127.6
	Estuarine Beach	18.5	9.9	1.5	1.9	2.4
	Inland Open Water	17.1	3.0	0.2	0.0	0.0
	Developed Dry Land	3.5	3.0	2.5	1.3	0.1
	Inland Shore	0.5	0.5	0.1	0.0	0.0
	Swamp	0.2	0.2	0.2	0.0	0.0
	Transitional Salt Marsh	0.0	5.1	63.9	183.3	86.3
	Tidal Flat	0.0	71.9	345.2	1648.7	3767.3
	Total (incl. water)	**9569.6**	**9569.6**	**9569.6**	**9569.6**	**9569.6**



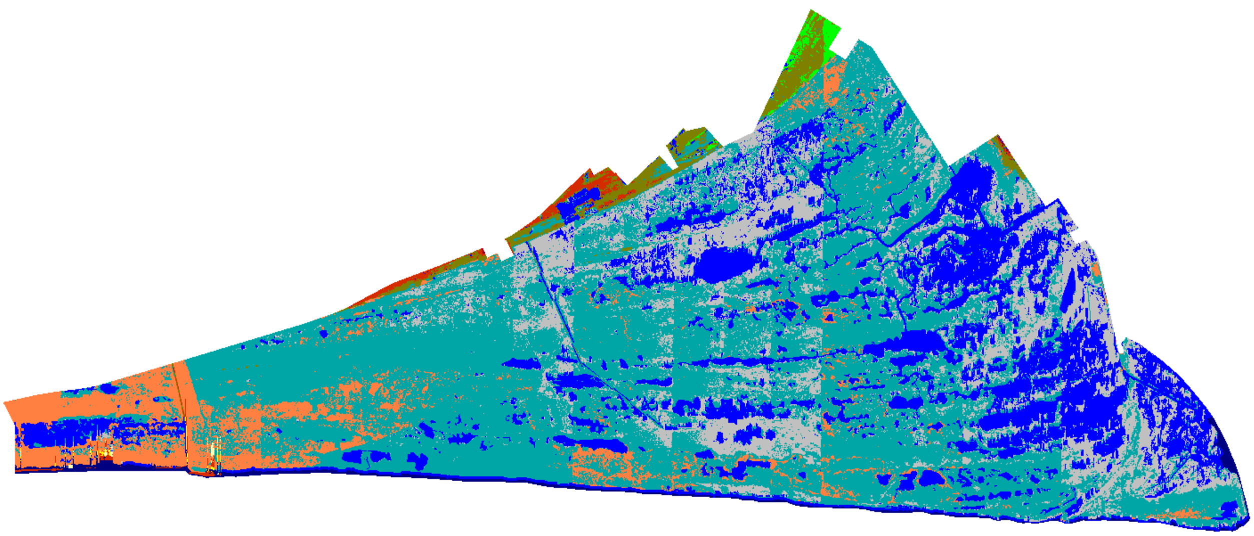
Texas Point NWR, Initial Condition



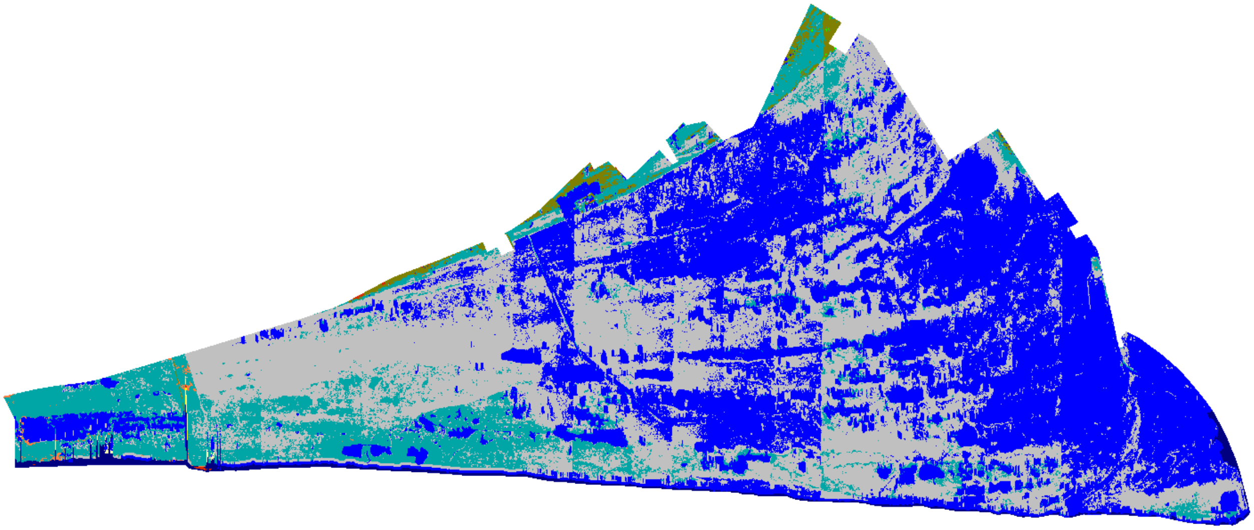
Texas Point NWR, 2025, 1.5 m



Texas Point NWR, 2050, 1.5 m



Texas Point NWR, 2075, 1.5 m

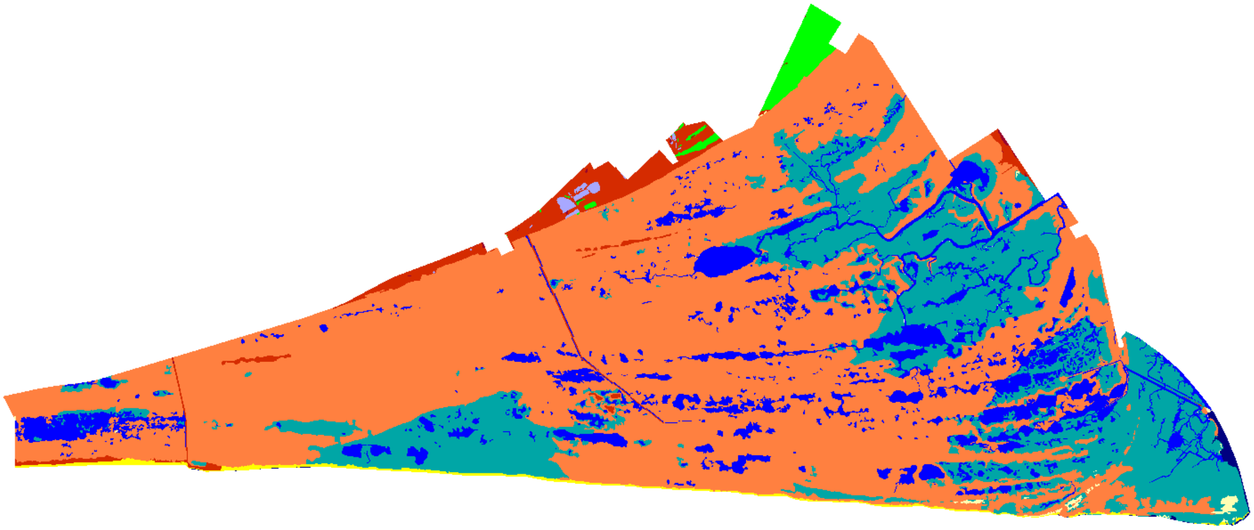


Texas Point NWR, 2100, 1.5 m

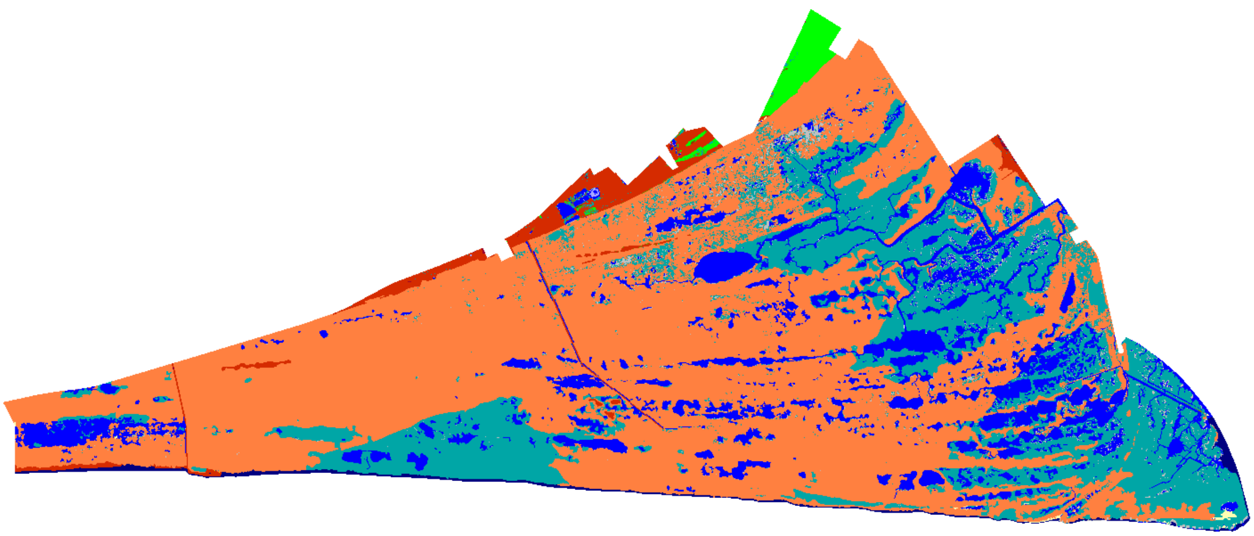
Texas Point NWR
2 m Eustatic SLR by 2100

Results in Acres

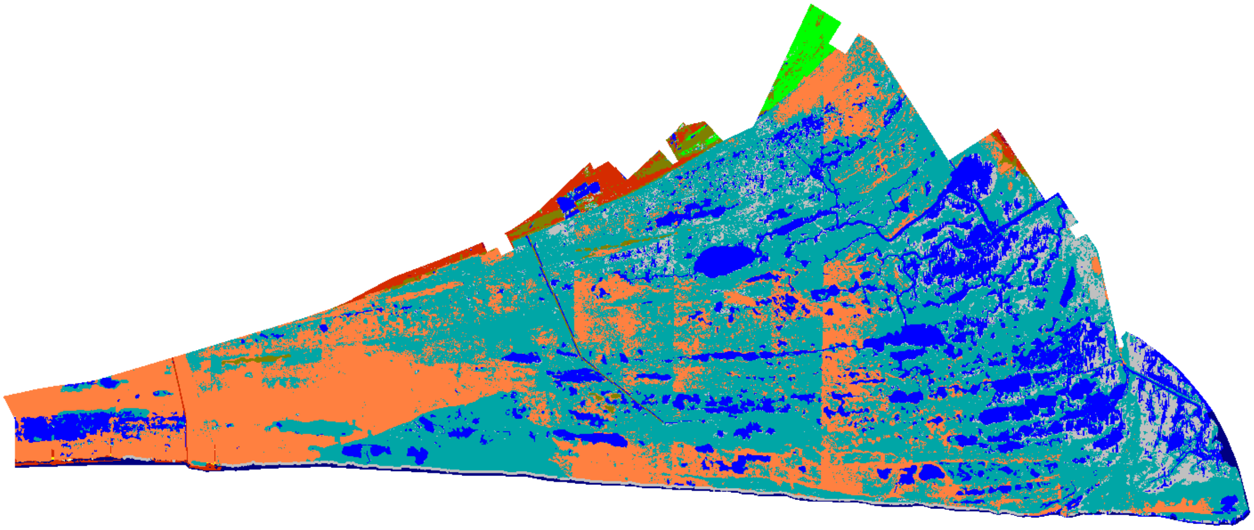
		Initial	2025	2050	2075	2100
	Irregularly Flooded Marsh	5783.3	5482.4	2378.1	30.1	0.1
	Regularly Flooded Marsh	2197.5	2256.6	4537.7	2826.1	238.1
	Estuarine Open Water	1080.6	1230.5	1524.2	2842.4	6750.5
	Undeveloped Dry Land	259.1	246.9	142.0	12.3	0.7
	Inland Fresh Marsh	110.2	105.8	92.2	2.5	0.1
	Ocean Beach	79.6	0.1	0.2	0.9	0.0
	Open Ocean	19.5	99.3	105.3	117.2	120.3
	Estuarine Beach	18.5	8.4	0.7	0.8	0.2
	Inland Open Water	17.1	2.4	0.1	0.0	0.0
	Developed Dry Land	3.5	2.9	2.3	0.2	0.0
	Inland Shore	0.5	0.5	0.0	0.0	0.0
	Swamp	0.2	0.2	0.1	0.0	0.0
	Transitional Salt Marsh	0.0	7.5	112.5	209.7	12.1
	Tidal Flat	0.0	126.3	674.2	3527.6	2447.6
	Total (incl. water)	**9569.6**	**9569.6**	**9569.6**	**9569.6**	**9569.6**



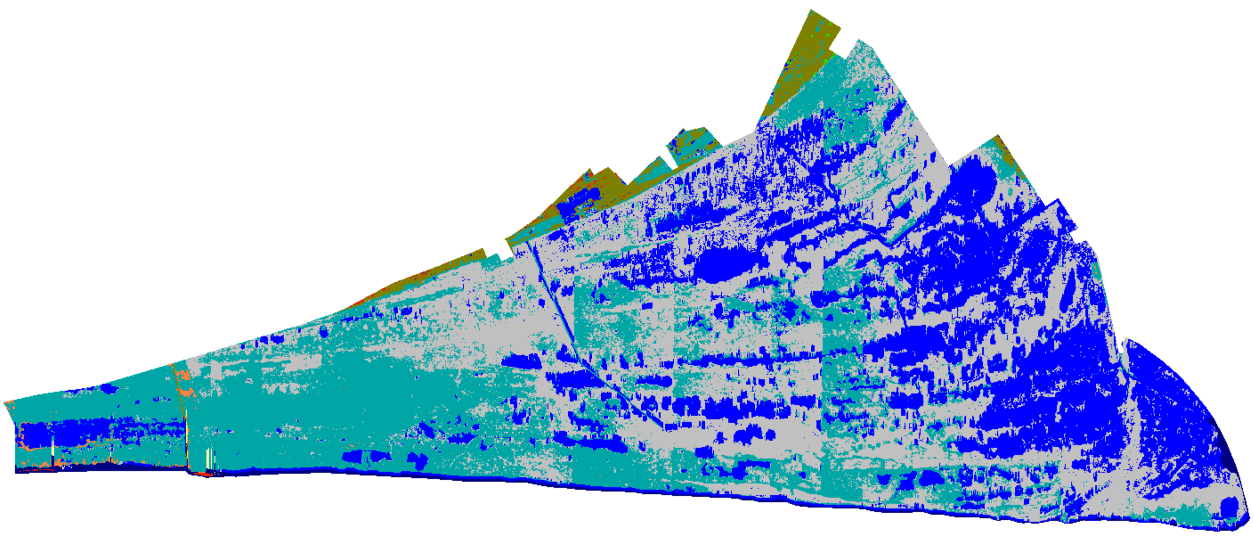
Texas Point NWR, Initial Condition



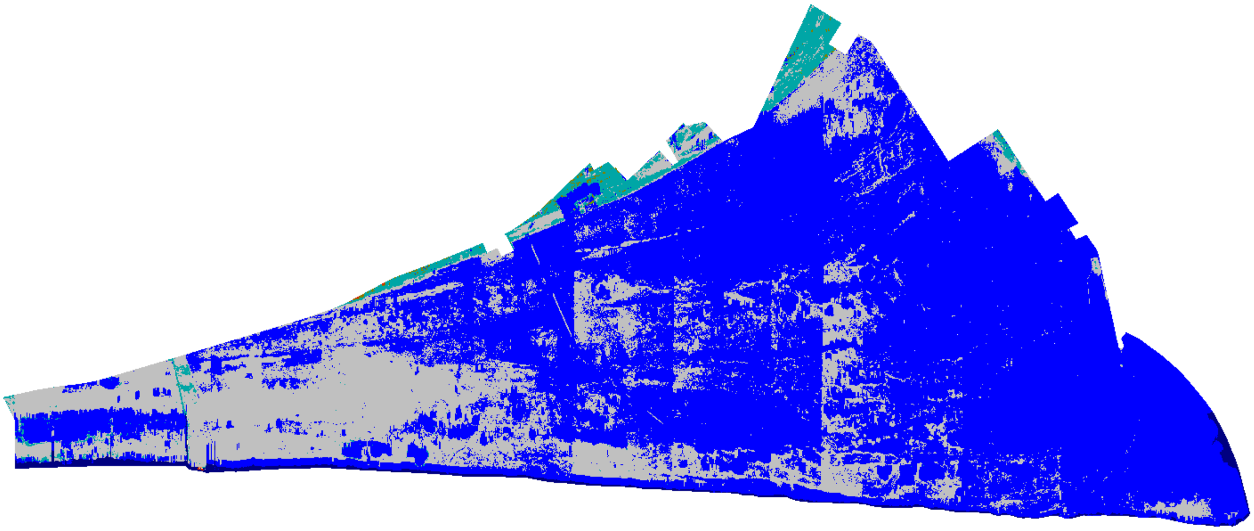
Texas Point NWR, 2025, 2 m



Texas Point NWR, 2050, 2 m



Texas Point NWR, 2075, 2 m



Texas Point NWR, 2100, 2 m

Discussion

The conclusions deduced in a previously conducted SLAMM analysis of Jefferson County (Clough and Larson 2011) also apply to Texas Point NWR. Within that report, it was found that this portion of coastal Texas is vulnerable to sea level rise under several likely scenarios of SLR by 2100. Quoting the larger report:

> Land subsidence, low land elevations relative to MTL and low tide ranges cause this system to lose extensive high marsh under SLR scenarios of over 0.6 m by 2100. However, measured accretion rates at this site (and regionally) are relatively high, helping to offset such vulnerabilities under lower scenarios of sea level rise.
>
> There are a few reasons why model results under lower rates of SLR may be somewhat conservative (i.e. additional marsh loss may actually occur). First, the SLAMM model has a very simple model of barrier island overwash that primarily affects detached barrier islands. For this reason, the model likely underestimates the effects of large storm events, sand transport, and the resulting conversion and breakup of marshes. Additionally, model inputs predate hurricane Ike in 2008 which had significant effects on this region.
>
> Secondly, the model does not account for peat collapse. When salt water penetrates high marsh in this region, death and breakup of the root mat can occur and marsh elevations can fall as a result. This process has been observed at McFaddin NWR within the study area (Cahoon et al. 2004). This peat collapse process and the potential effects on cell elevations were not included in the model.

Model sensitivity analysis suggests that model predictions are quite sensitive to model inputs of accretion rates in the refuge marsh accretion rates are an additional source of model uncertainty. Model parameters were set using site-specific accretion data (Cahoon et al. 1999). However, these accretion rates were then applied uniformly across the study area and were also kept constant over time. This model, therefore, provides an average condition for the marsh; some areas with lower rates of accretion may be vulnerable sooner.

Conversely, 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 (Clough and Larson 2011).

Although the majority of the Texas Point NWR is predicted to be resilient to the most conservative estimate of SLR (0.39 m by 2100), at higher SLR scenarios large sections of the refuge are predicted to convert to regularly-flooded marsh or become permanently inundated.

The area surrounding Texas Point was studied in a previous SLAMM analysis funded by The Nature Conservancy (Clough and Larson 2011). Maps of results for the larger study area are presented in the “contextual maps” below.

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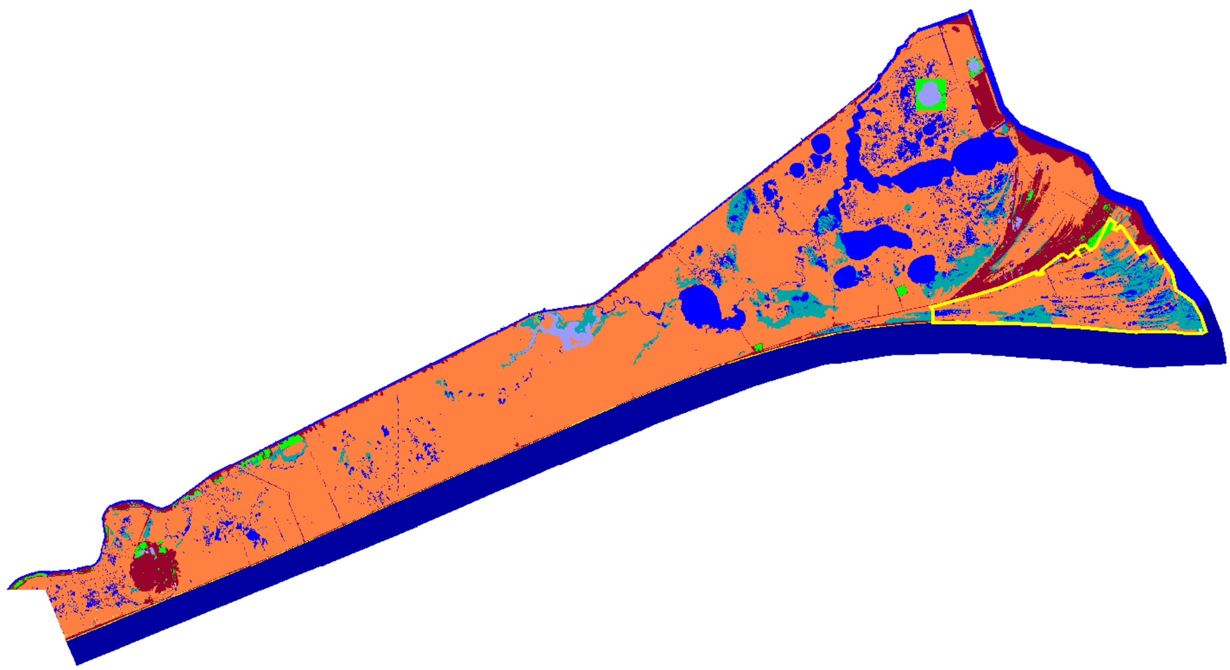
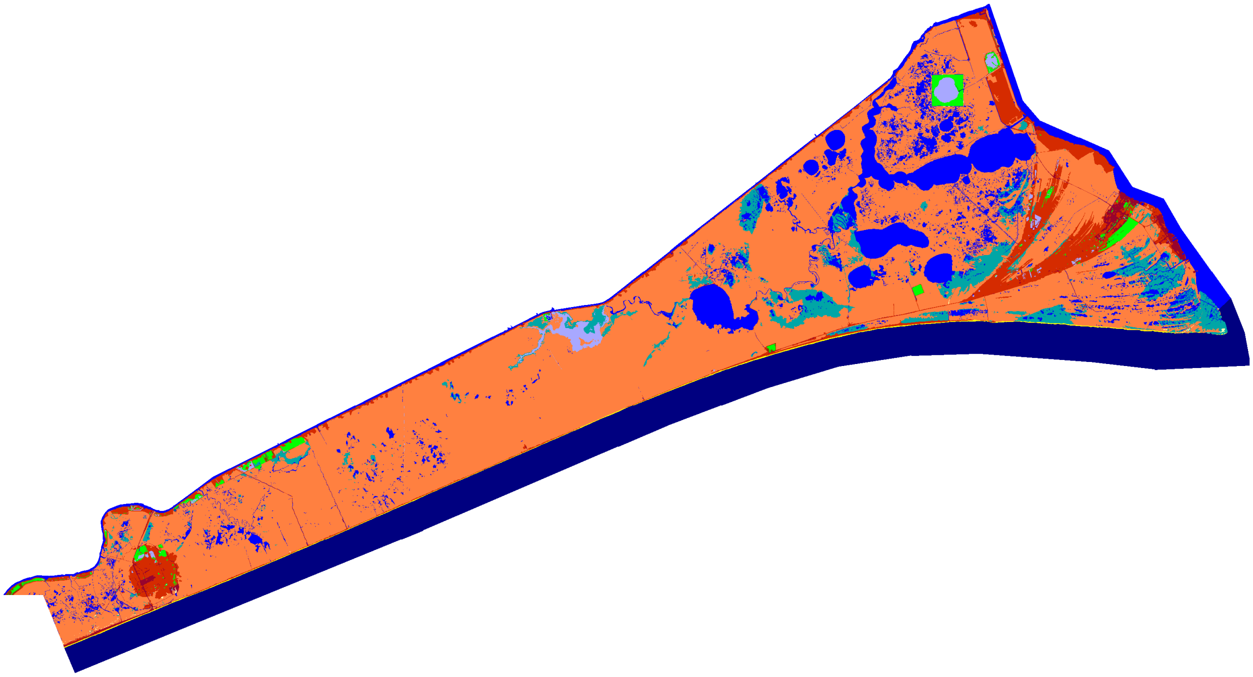
Appendix A: Contextual Results

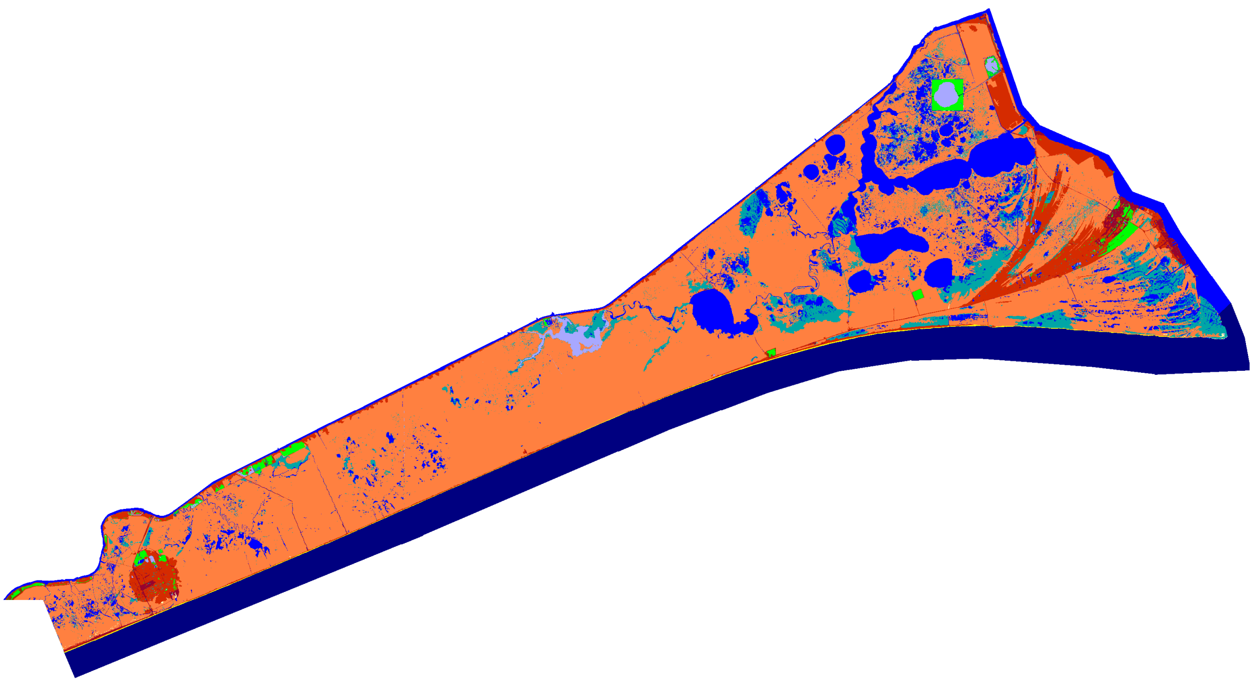
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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



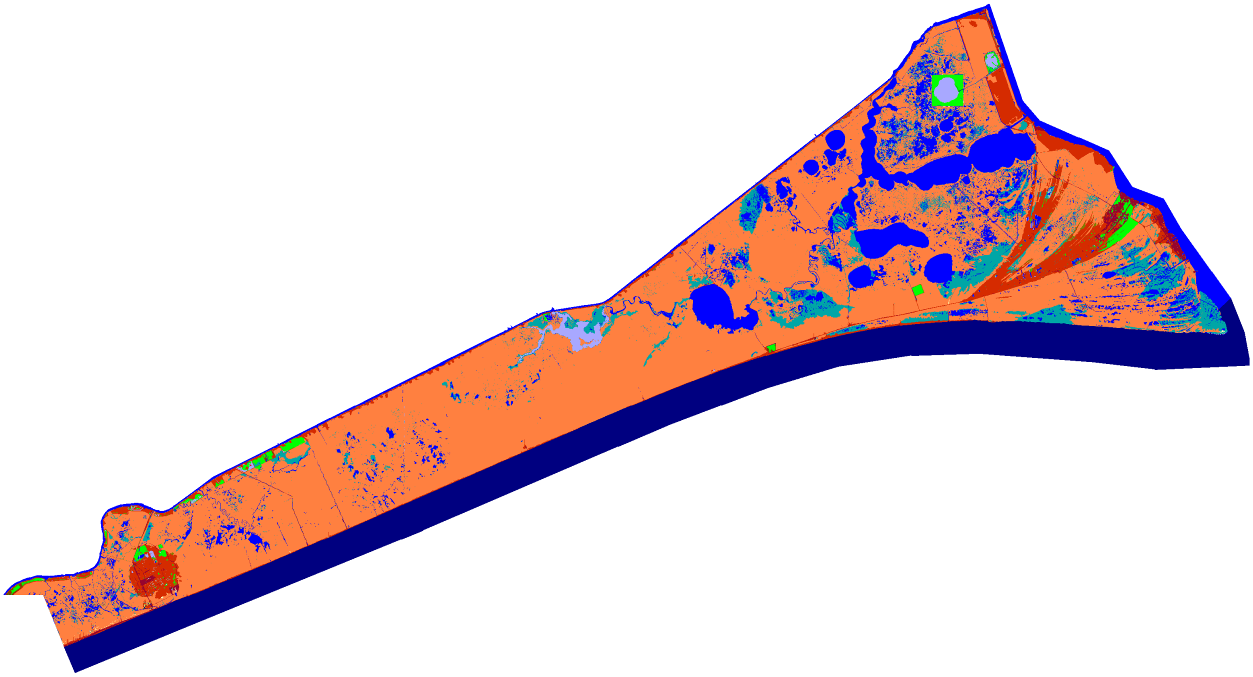
Texas Point National Wildlife Refuge within simulation context (outlined in yellow).



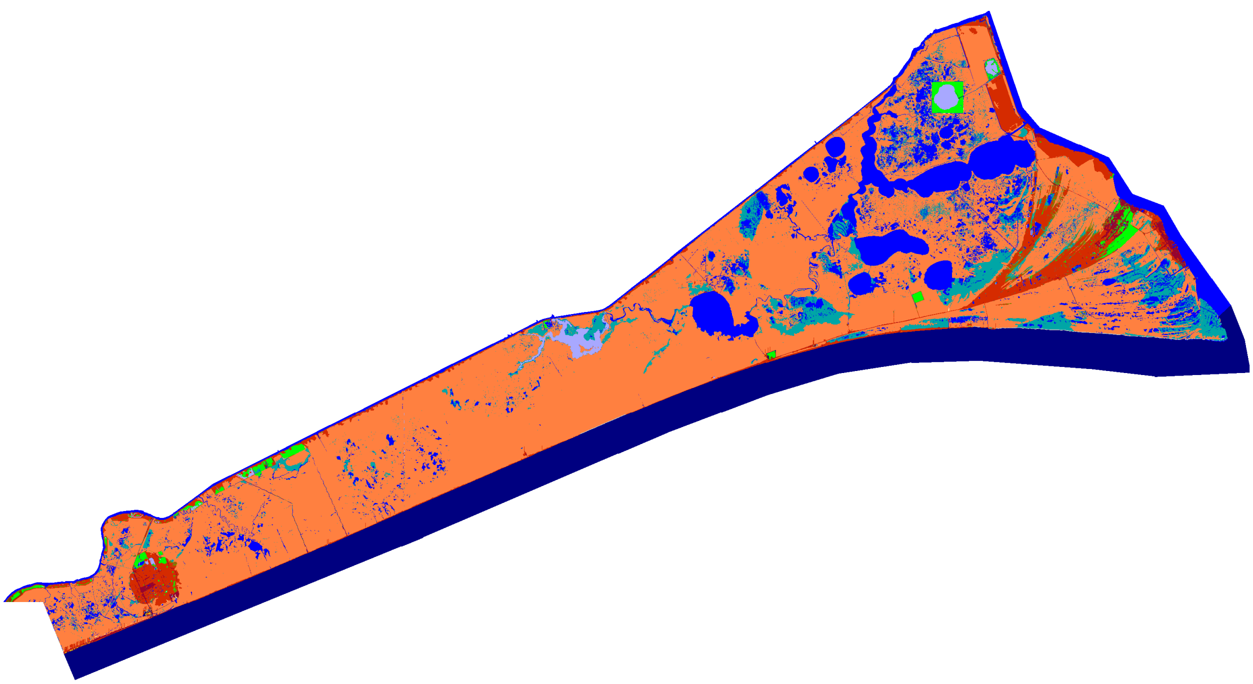
Texas Point Context, Initial Condition



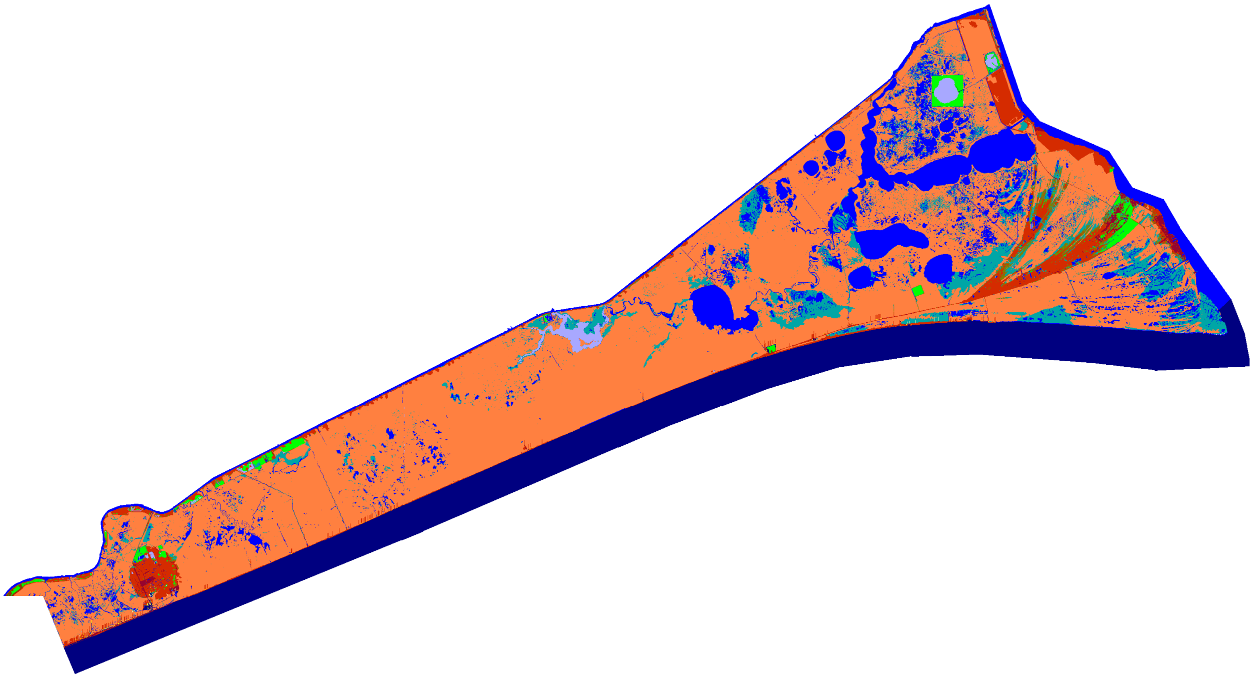
Texas Point Context, 2025, Scenario A1B Mean



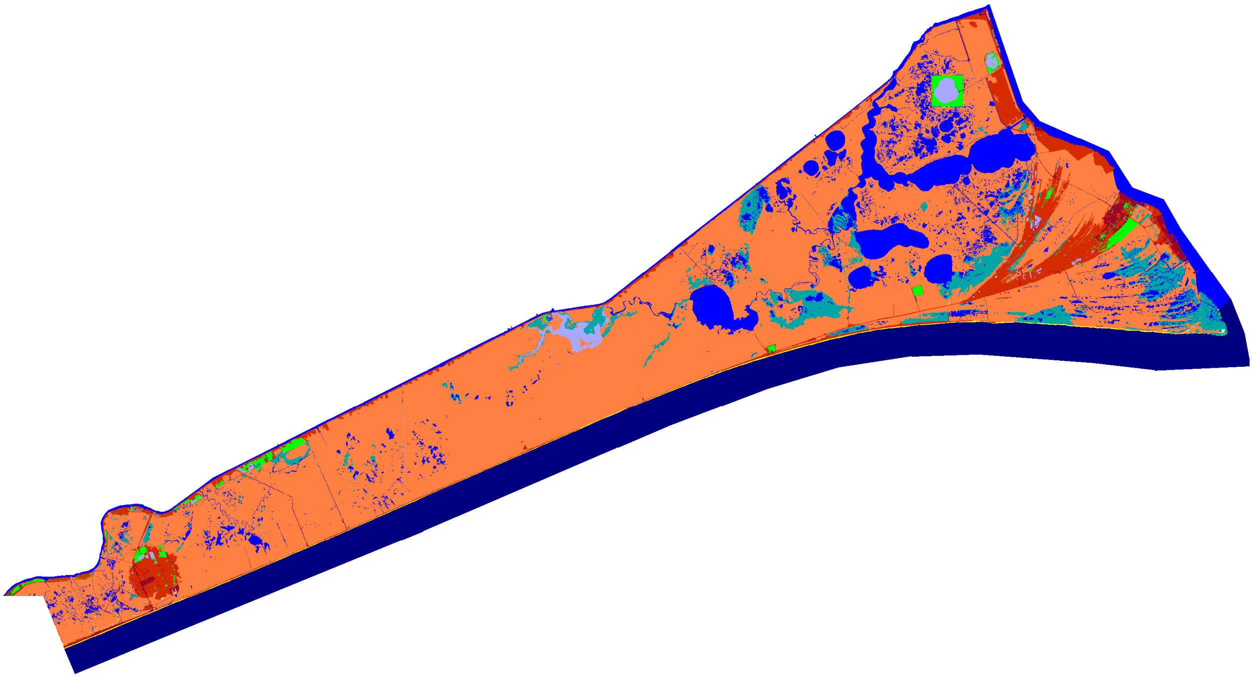
Texas Point Context, 2050, Scenario A1B Mean



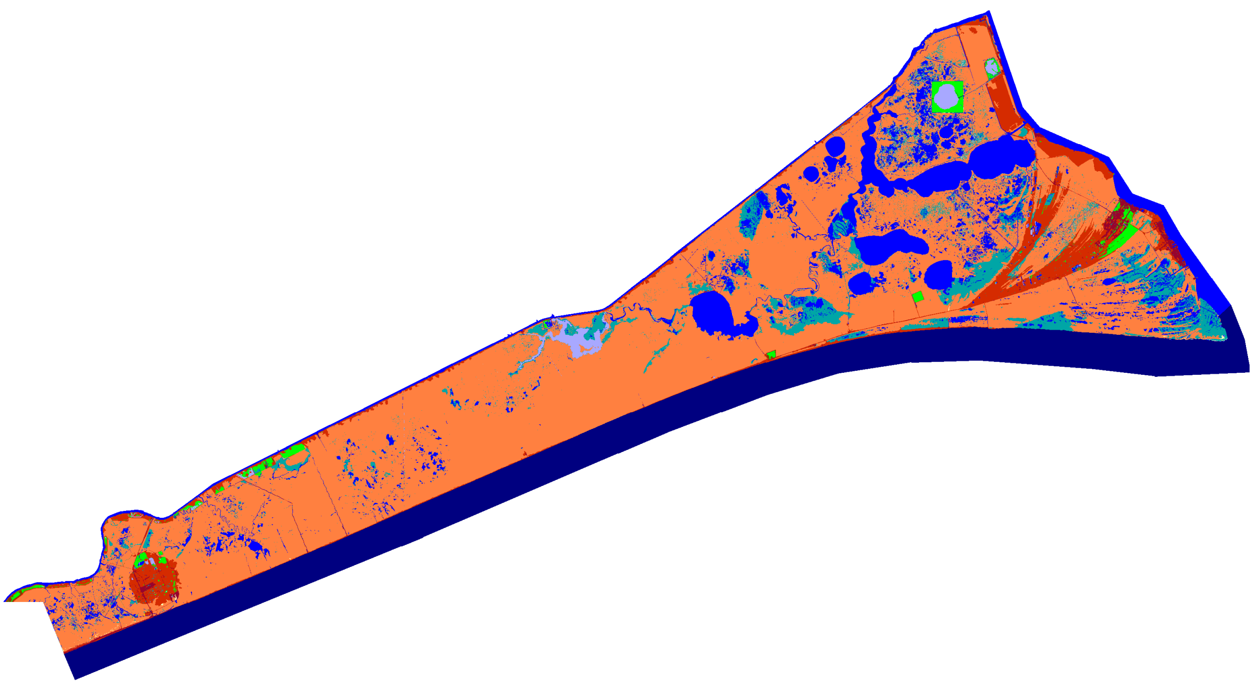
Texas Point Context, 2075, Scenario A1B Mean



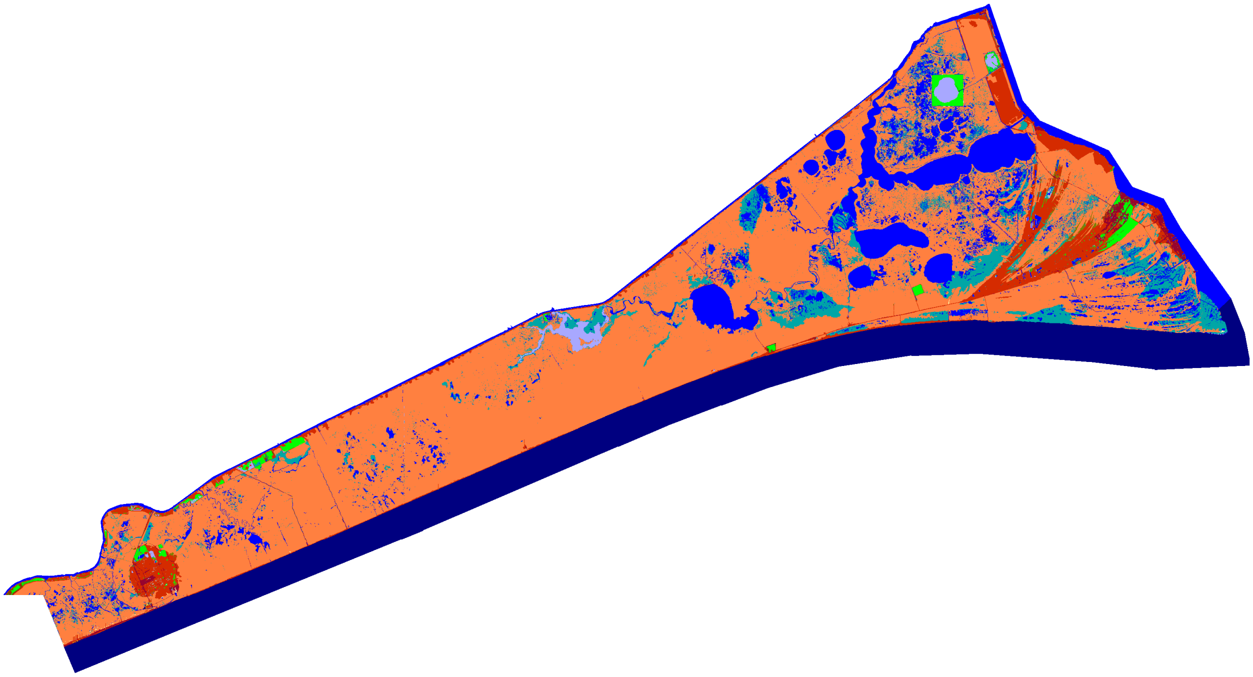
Texas Point Context, 2100, Scenario A1B Mean



Texas Point Context, Initial Condition



Texas Point Context, 2025, Scenario A1B Maximum



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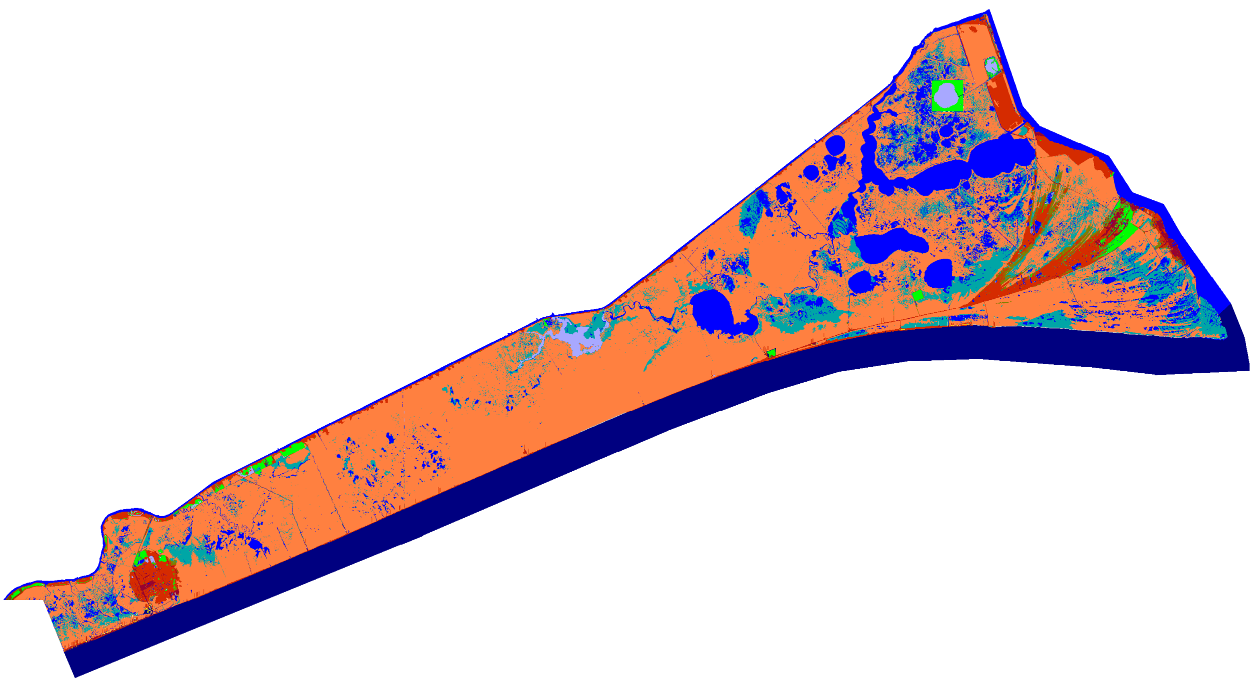
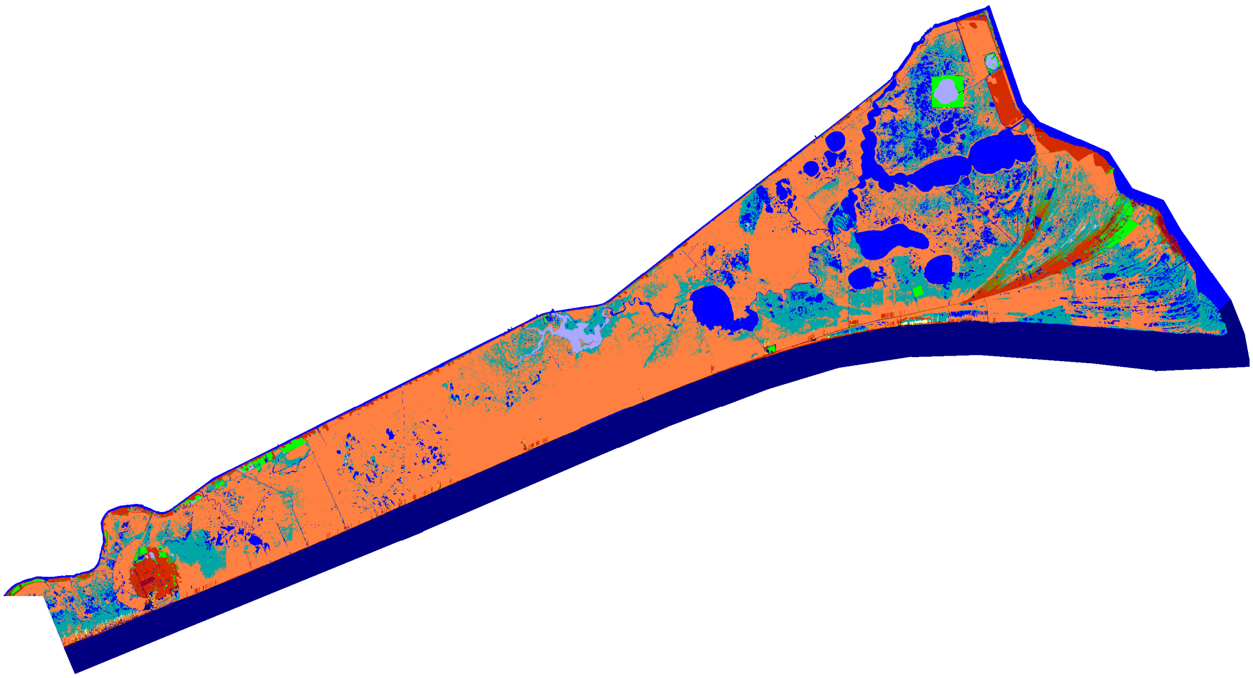


Texas Point Context, 2075, Scenario A1B Maximum



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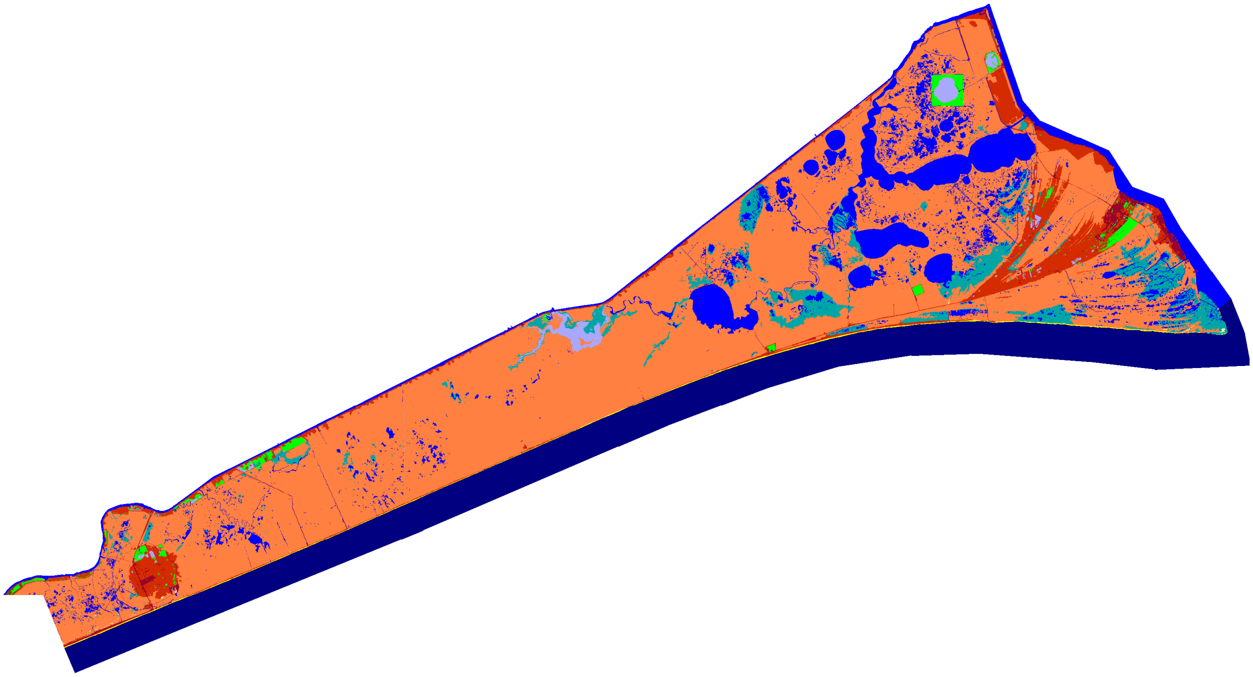
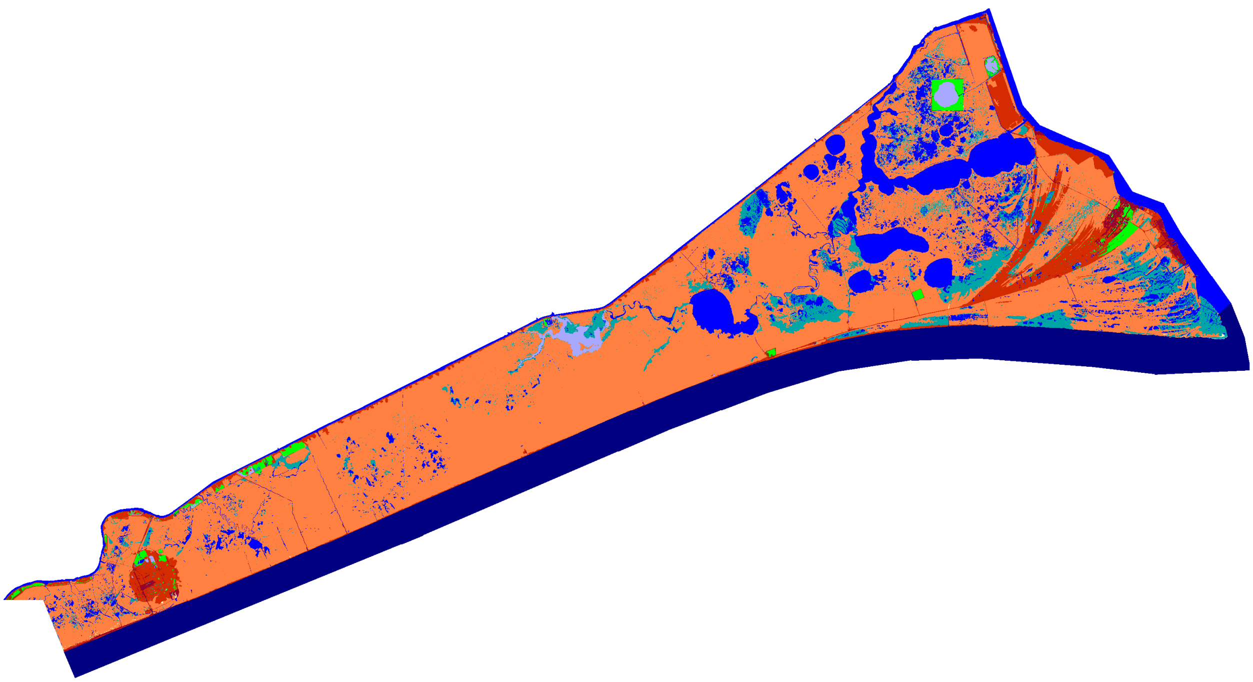
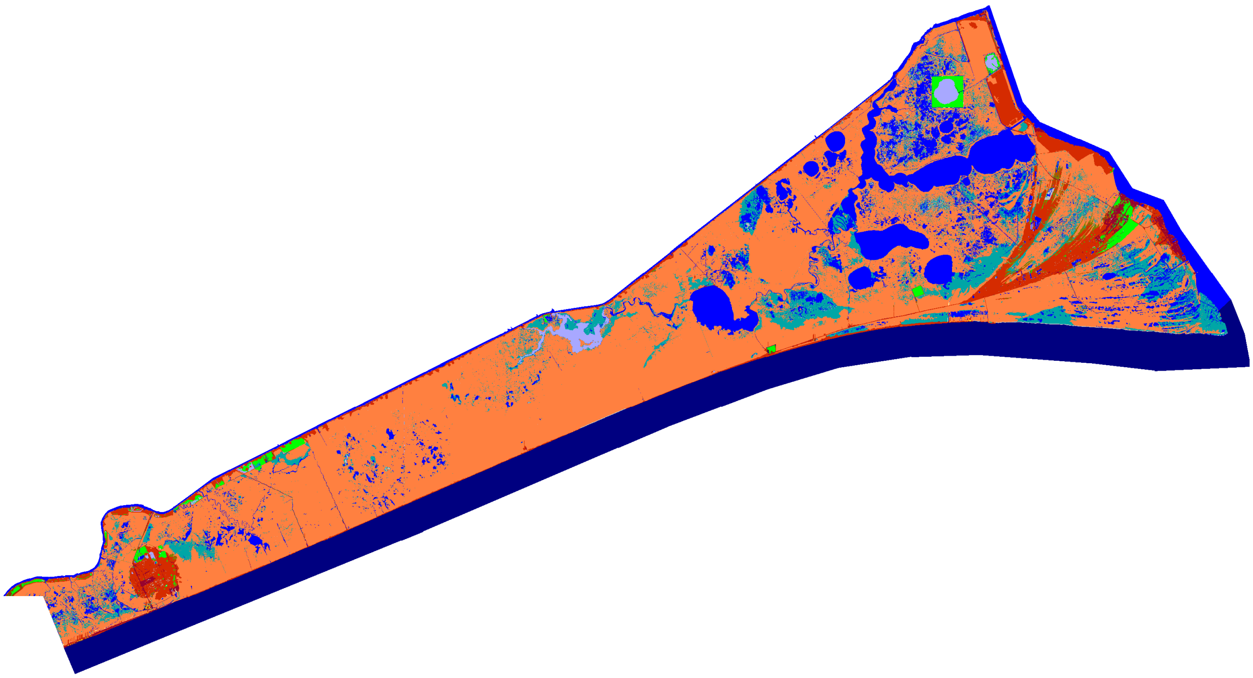


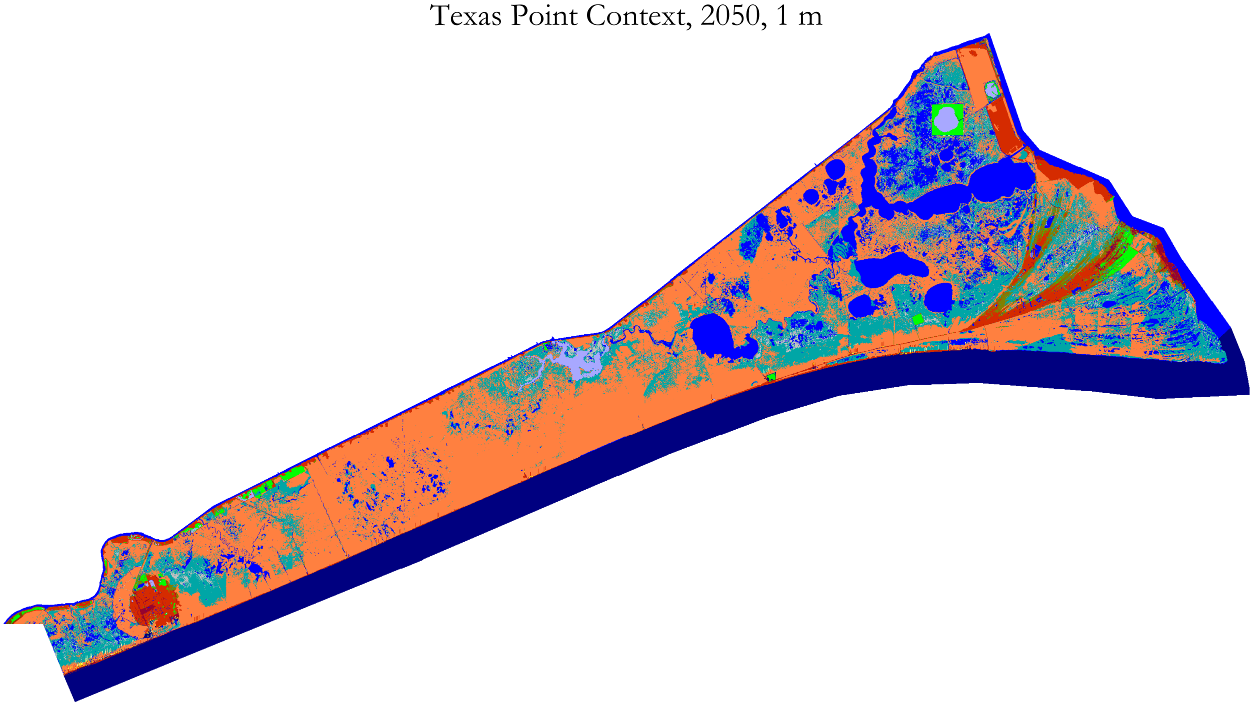
Texas Point Context, Initial Condition



Texas Point Context, 2025, 1 m



Texas Point Context, 2050, 1 m



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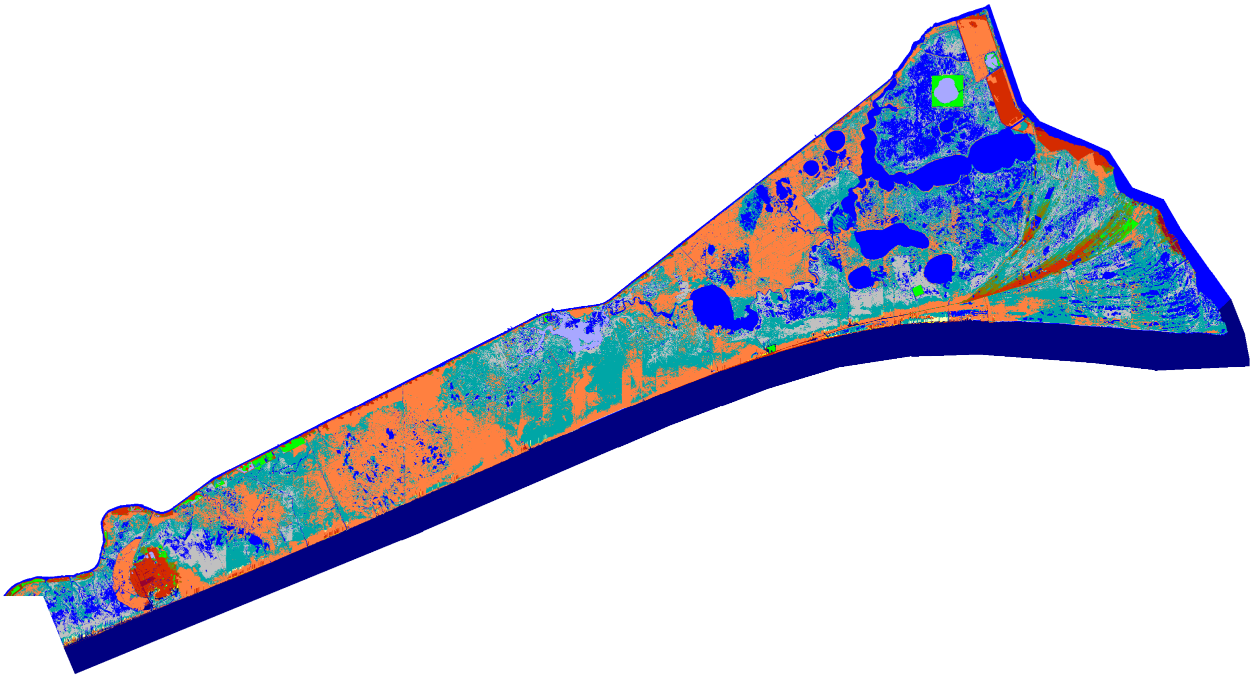
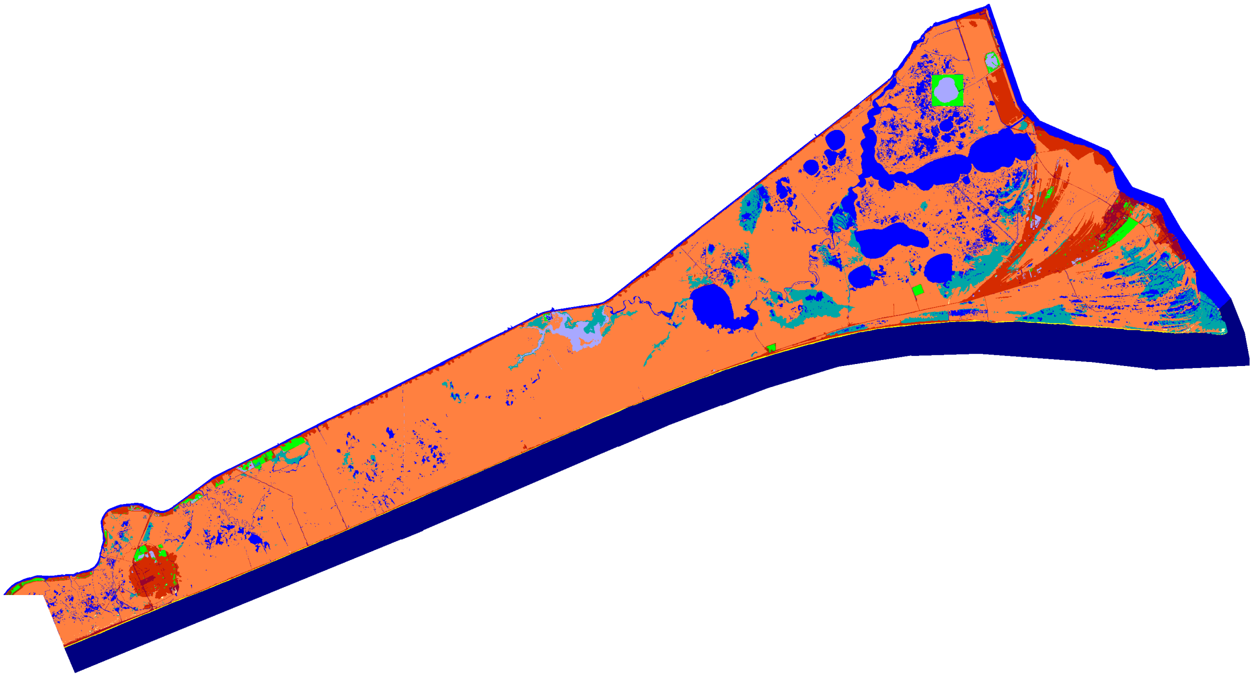


Texas Point Context, 2100, 1 m



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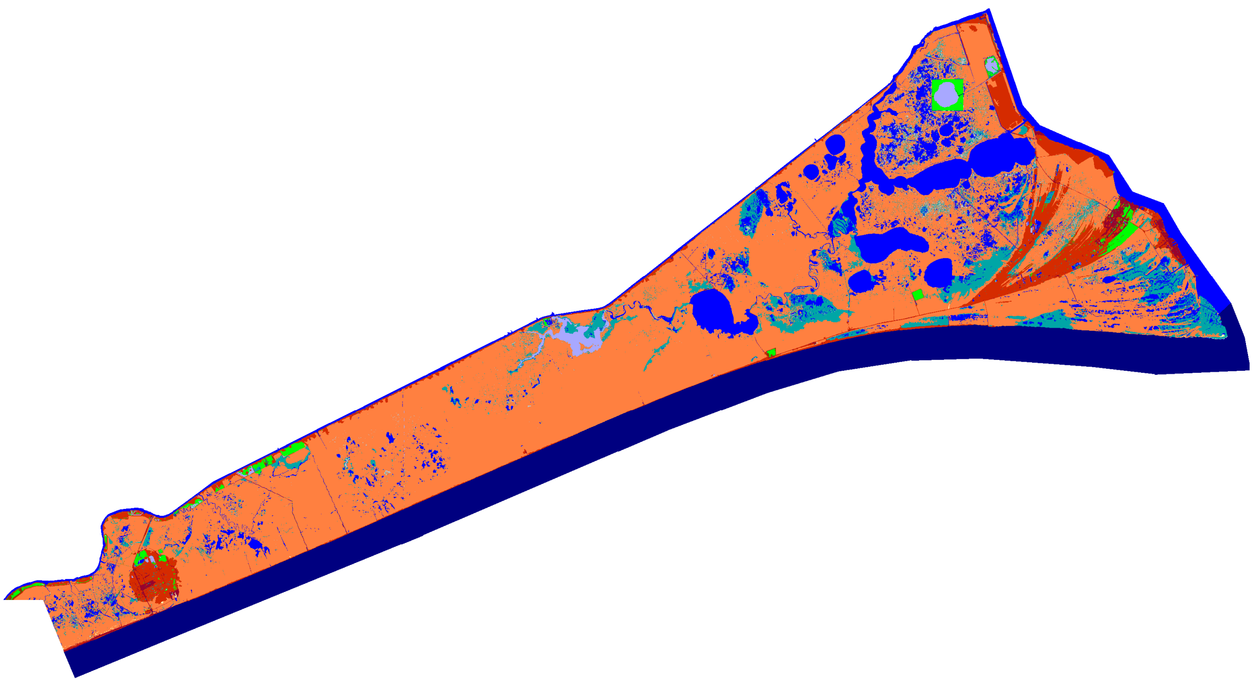
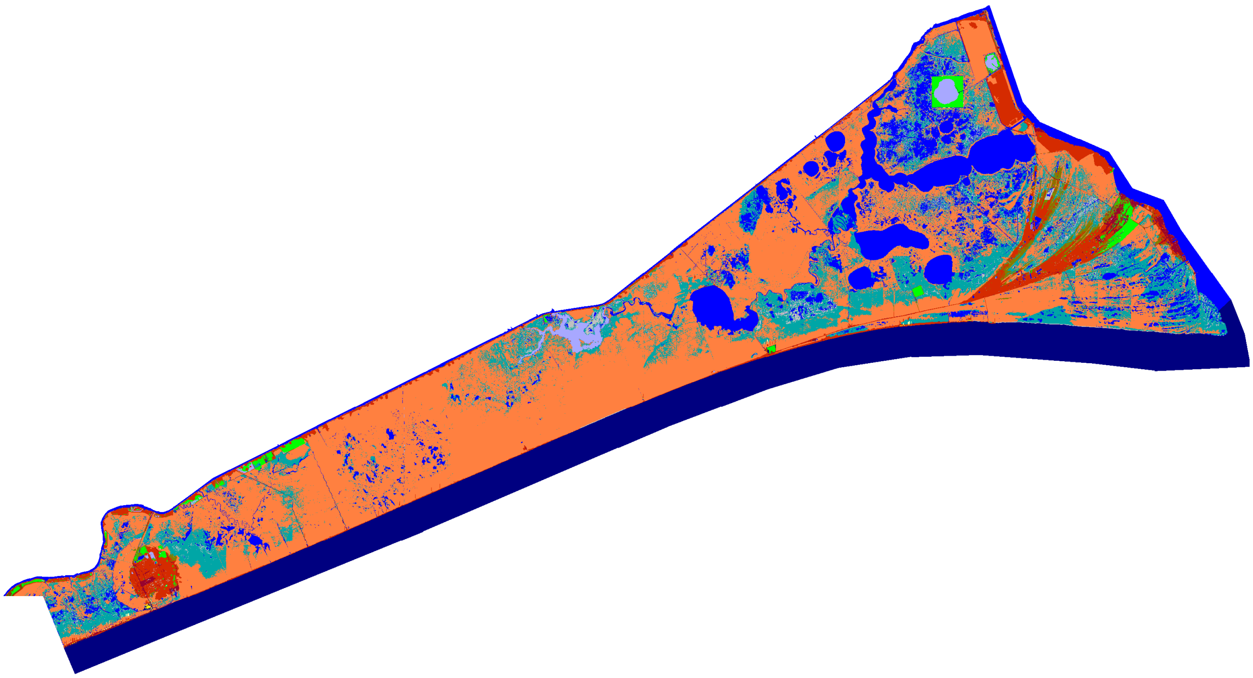


Texas Point Context, 2025, 1.5 m



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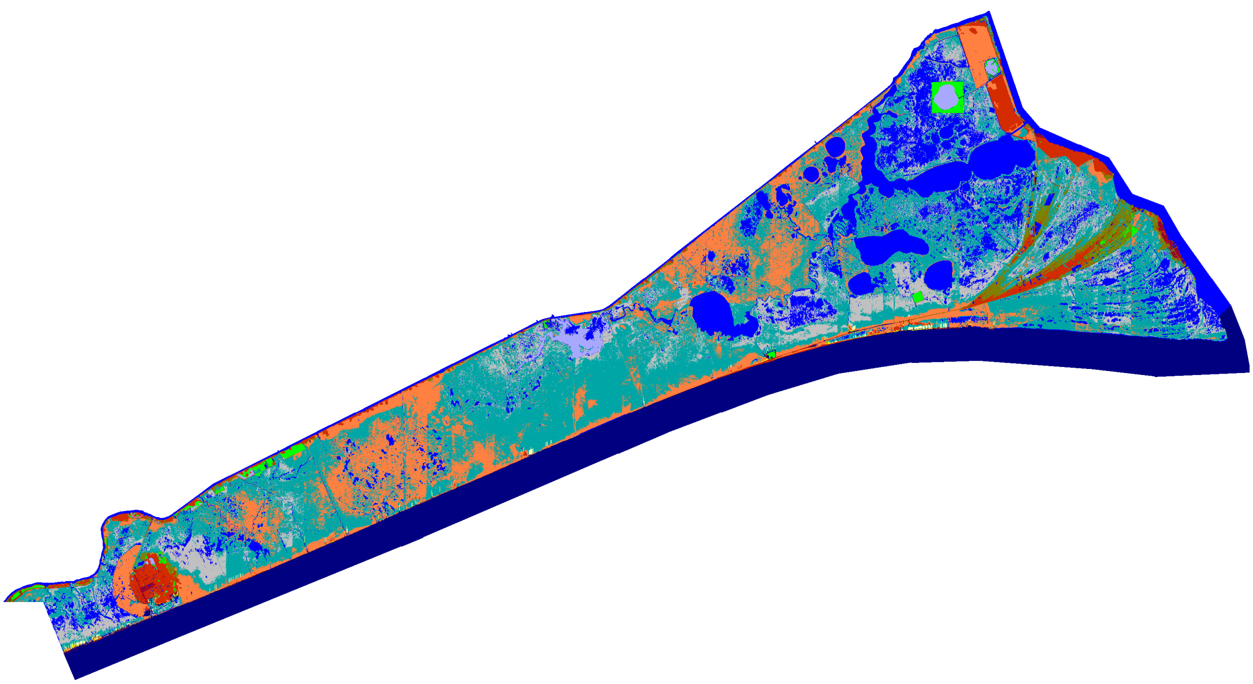

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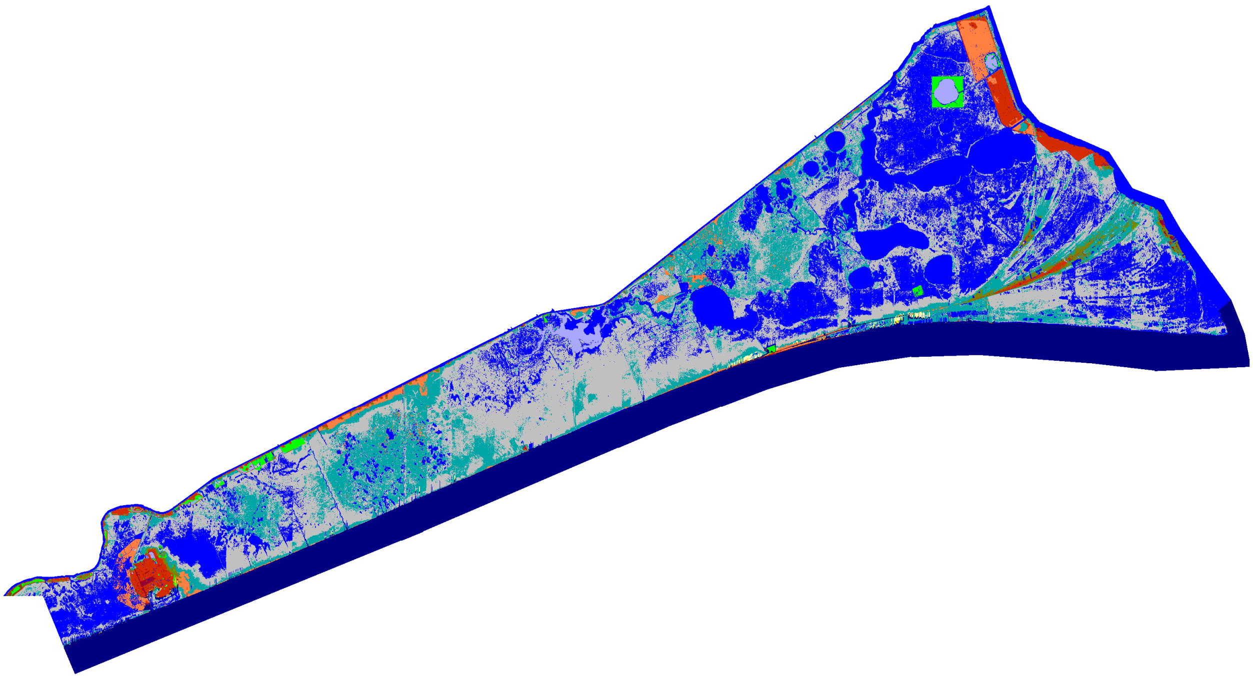
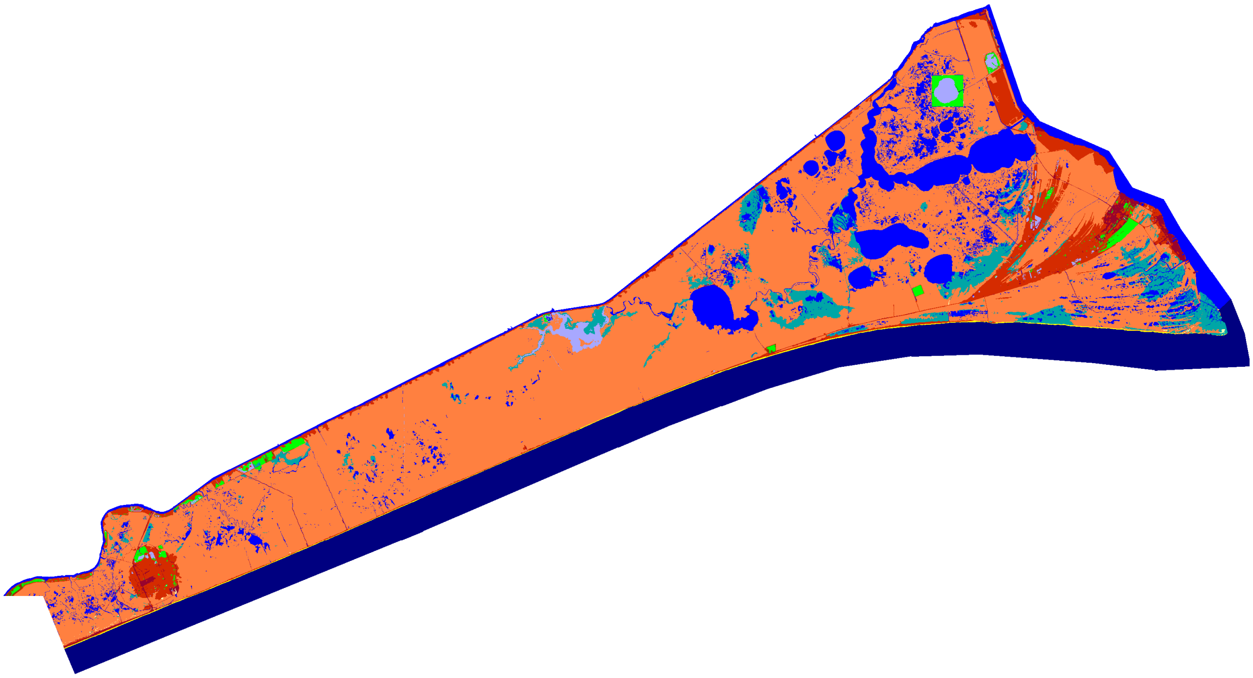
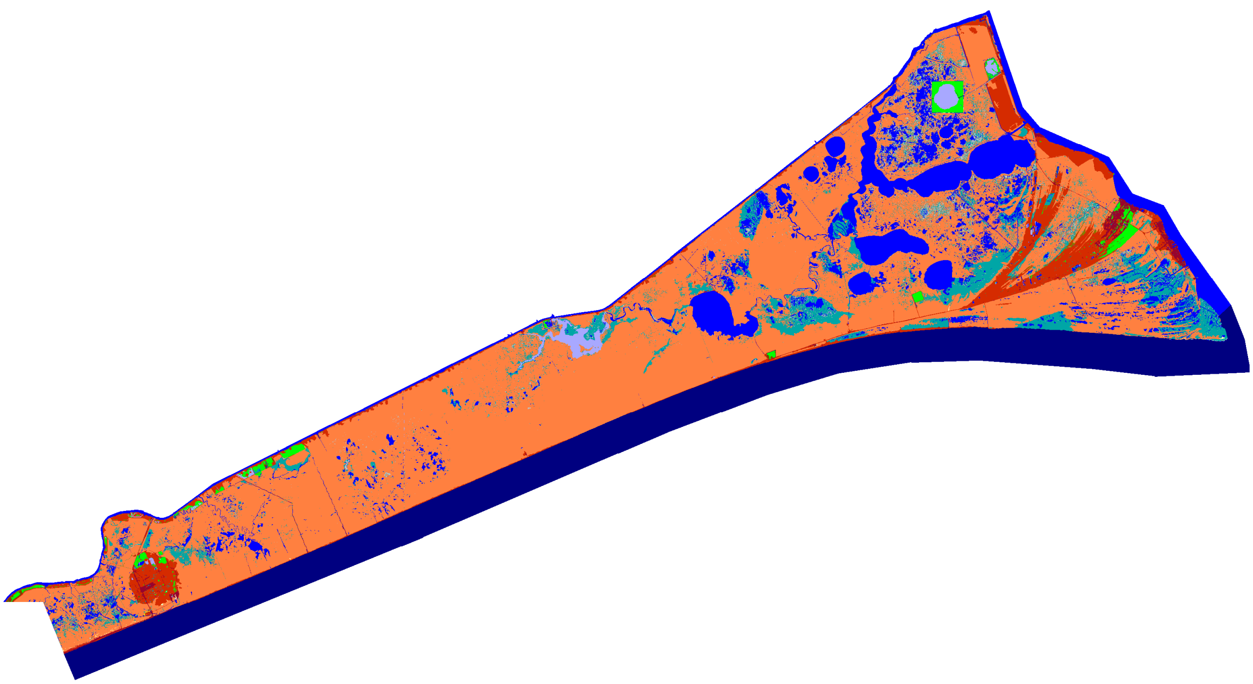


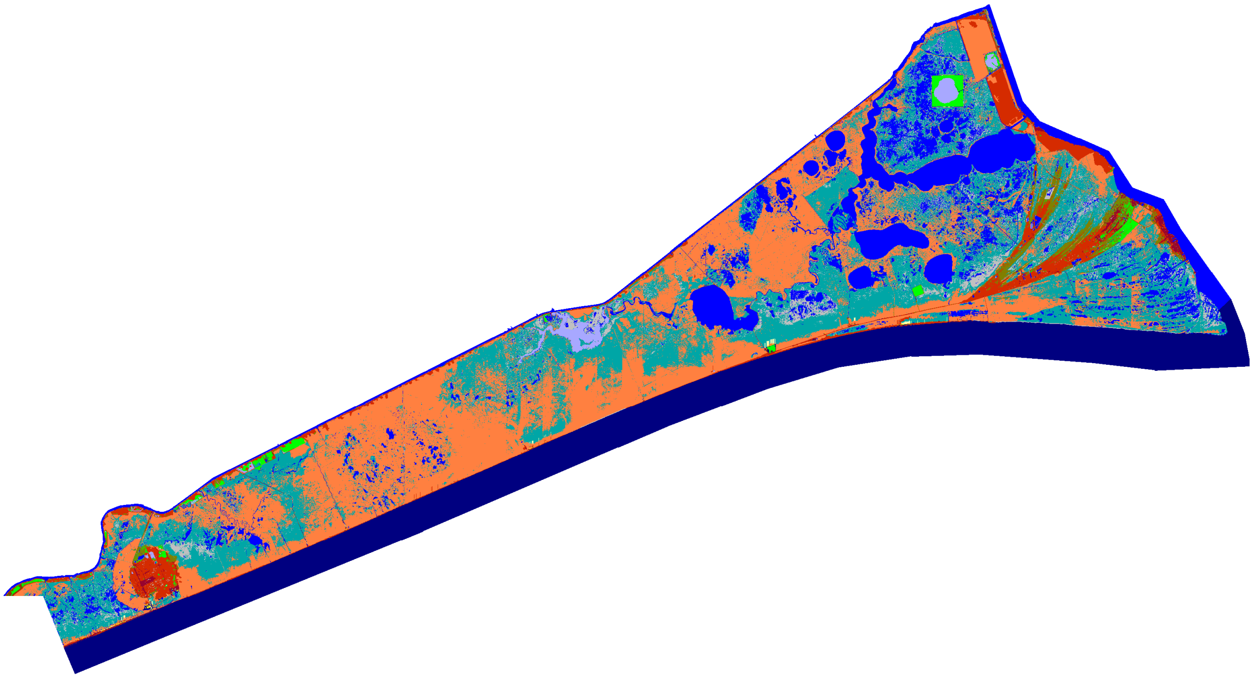
Texas Point Context, 2100, 1.5 m



Texas Point Context, Initial Condition



Texas Point Context, 2025, 2 m



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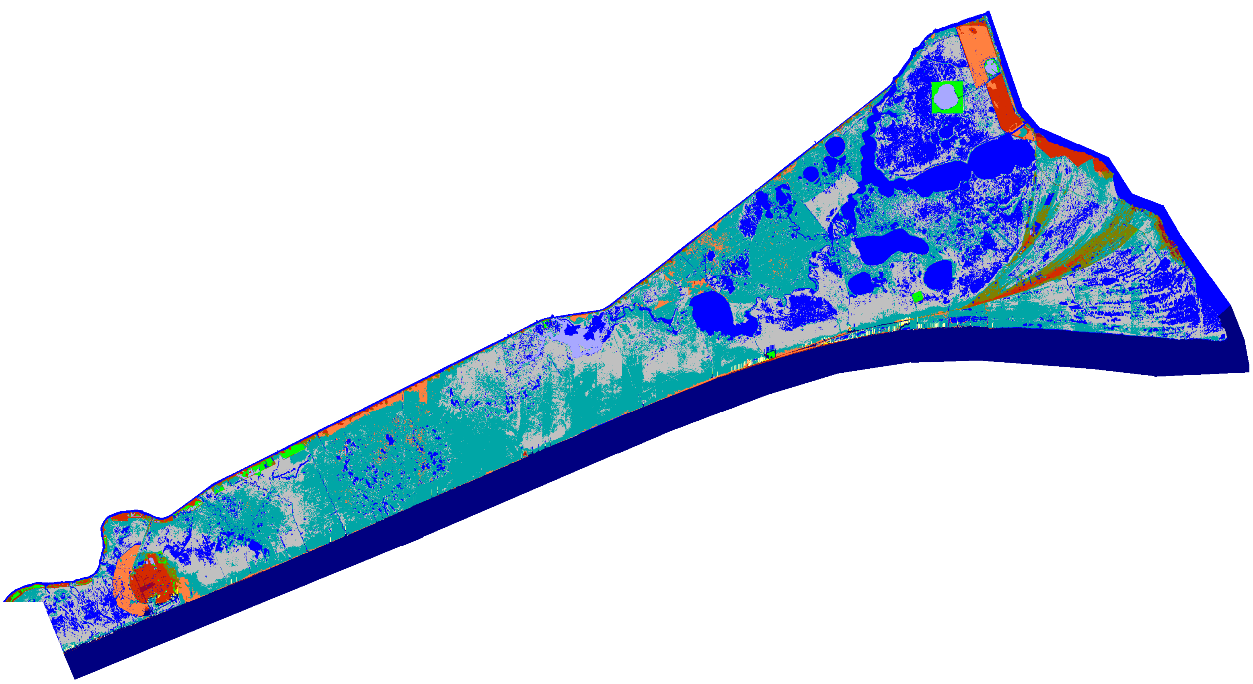

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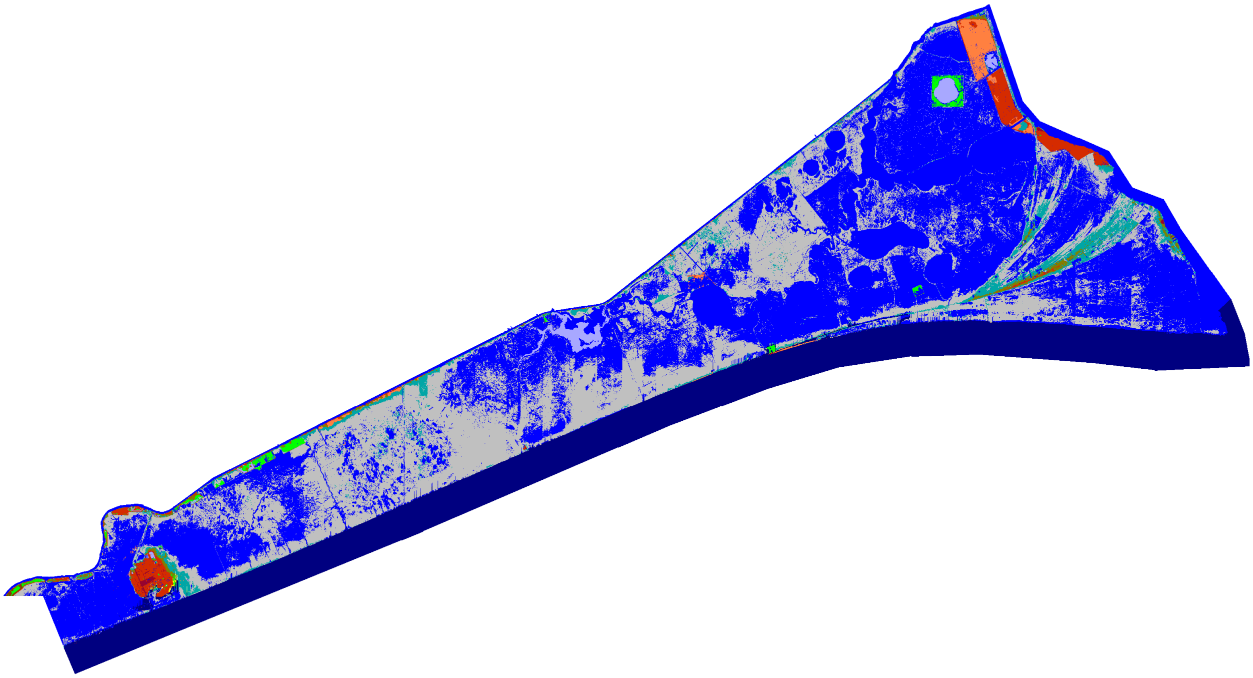

Texas Point Context, 2100, 2 m