Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Lewis and Clark 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 refuges. This analysis is designed to assist in the production of comprehensive conservation plans (CCPs) for each refuge along with other long-term management plans. This analysis is a summary of model runs produced by Ducks Unlimited (Warren Pinnacle Consulting, Inc. 2010).

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 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 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 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 the current simulations to test the SLAMM conceptual model. 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. If such a change is made, the change and the reason for it are fully documented.
- 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 Results and 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 in this report, SLAMM was also run assuming 1 meter and 1½ meters of eustatic sea level rise by the year 2100. The A1B- maximum scenario was scaled up to produce these bounding scenarios (Figure 1).

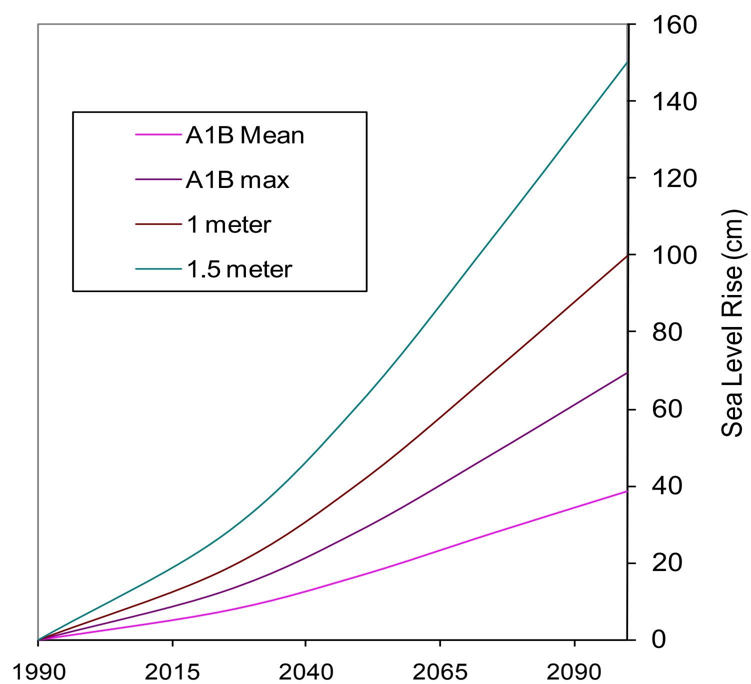


Figure 1. Summary of SLR Scenarios

Methods and Data Sources

This analysis is a summary of model runs produced by Ducks Unlimited (Warren Pinnacle Consulting, Inc. 2010).

The digital elevation map (DEM) used in this model simulation was derived from a combination of LiDAR and the USGS National Elevation Dataset (NED, Figure 2). The LiDAR was produced by the Puget Sound LiDAR Consortium in 1999, and was available as 6 foot bare-earth cells.

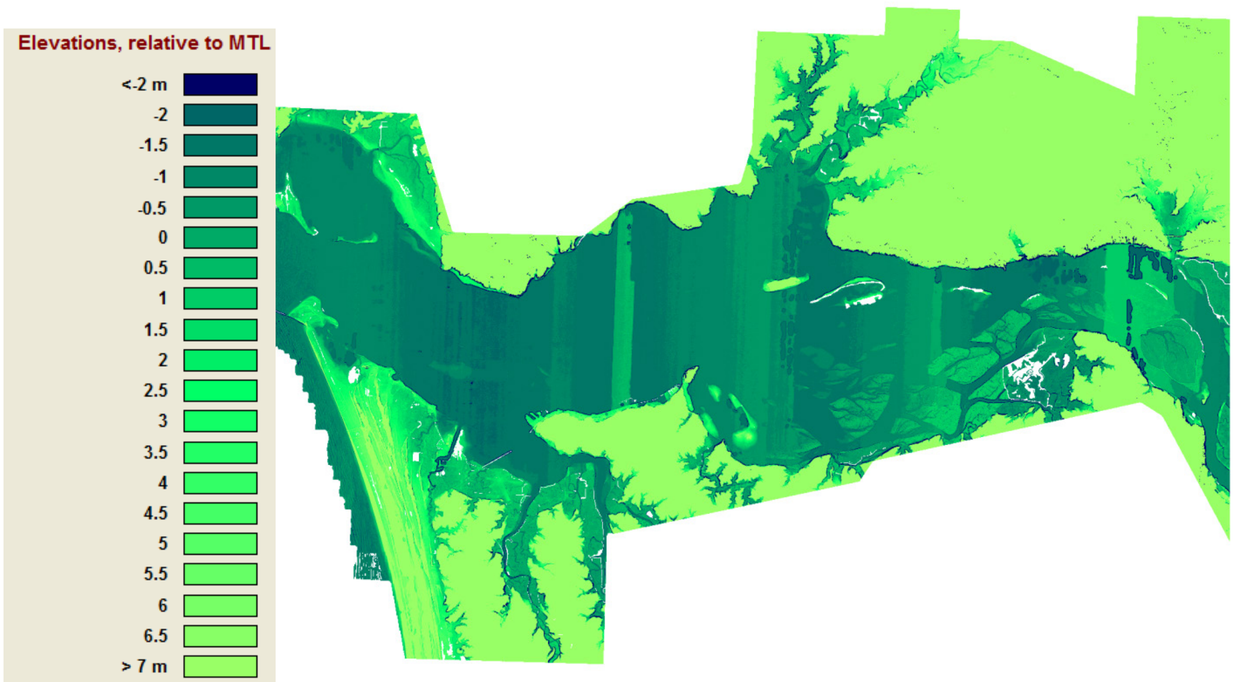


Figure 2. Elevation data for area of Lewis and Clark NWR area.

Land-cover categories within the modeling for Lower Columbia were derived from the National Wetlands Inventory (NWI). The NWI coverage for Lower Columbia was primarily based on 1981 photography.

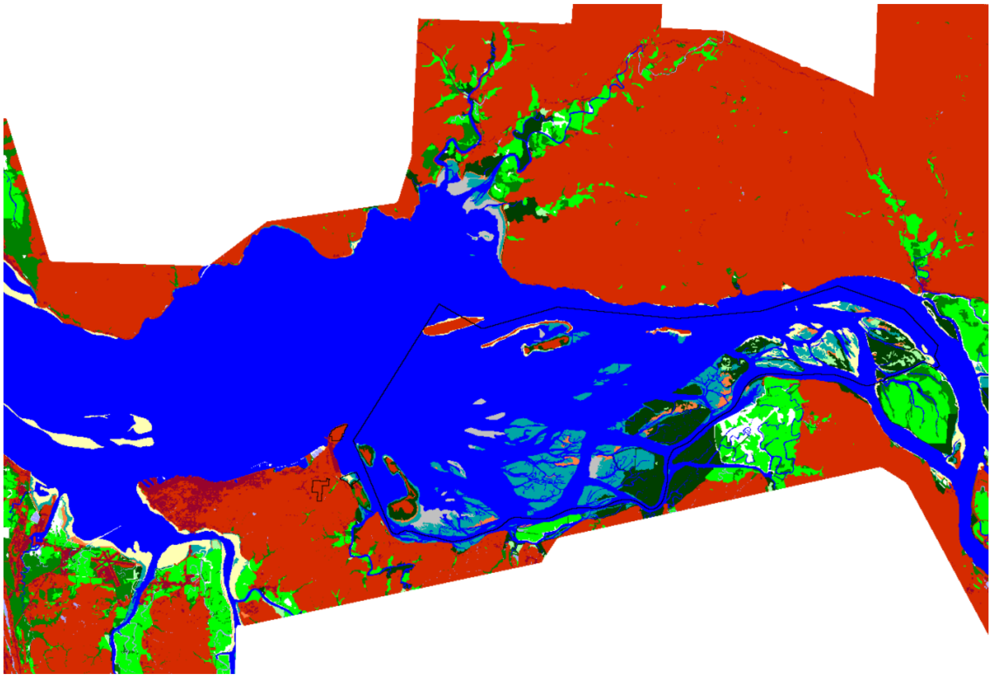


Figure 3. Wetland layer used for Lewis and Clark NWR. Refuge boundary in purple

The cell-size used for this analysis was 30 meter by 30 meter cells. Converting the NWI surveys to fit these cells and then converting to SLAMM cover categories suggests that the approximately 33,550 acre refuge was composed of the categories as shown in Table 1.

Table 1. Land cover categories and their abundance in the Lewis and Clark NWR study area according to the 1981 NWI layer.

Land cover type		Area (acres)	Percentage (%)
	Estuarine Open Water	24019	72
	Regularly Flooded Marsh	4047	12
	Tidal Swamp	2816	8
	Estuarine Beach	800	2
	Undeveloped Dry Land	721	2
	Tidal Flat	487	1
	Irregularly Flooded Marsh	418	1
	Tidal Fresh Marsh	244	1
	Total (incl. water)	**33553**	**100**

Wetlands in the study area protected by dikes were derived from a combination of data sources. Diked and impounded areas are listed within the National Wetland Inventory, but this coverage is often incomplete. An examination of USGS topographic maps was also undertaken. Finally, model results were used to see where saline inundation is immediately predicted. Local sources were contacted to determine if these areas are actually protected by dikes. This analysis was primarily performed by Kevin Petrik of Ducks Unlimited. The resulting location of lands protected by dikes, which are assumed to be protected from SLR, is shown in Figure 4.

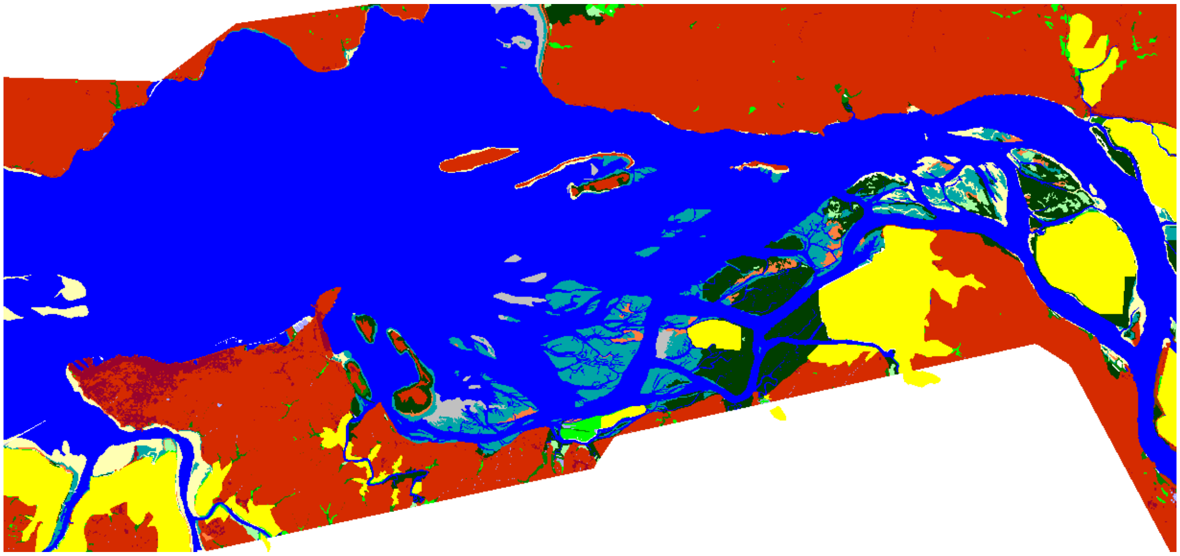


Figure 4. Primary locations of dikes (shown in yellow) within the study area

The historic SLR trend recorded at the nearby NOAA gauge station of Astoria, OR (ID 9439040) is on average -0.31 mm/yr. This negative rate is an outlier compared to other regional NOAA gauges (Toke Point 1.6mm/year, Seattle 2.06 mm/year, Garibaldi, 1.98 mm/year). Since the Astoria value is likely due to a localized uplift (Burgette et al. 2009; Canning 2007), a historic SLR rate of 2 mm/yr. was used in this model application, corresponding roughly to the average regional SLR trend. This value is also quite similar to the global average of SLR recorded for the last 100 years (approximately 1.7 mm/year, IPCC 2007a), and as a result, predicted local SLR will closely match future global scenarios. However, the potential for localized regions of uplift or subsidence are consequently ignored within this analysis.

The study area surrounding the refuge was divided into two subsites based on tide range values, as shown in Figure 5. The majority of the refuge is located in subsite 2, with only a small portion falling in subsite 1.

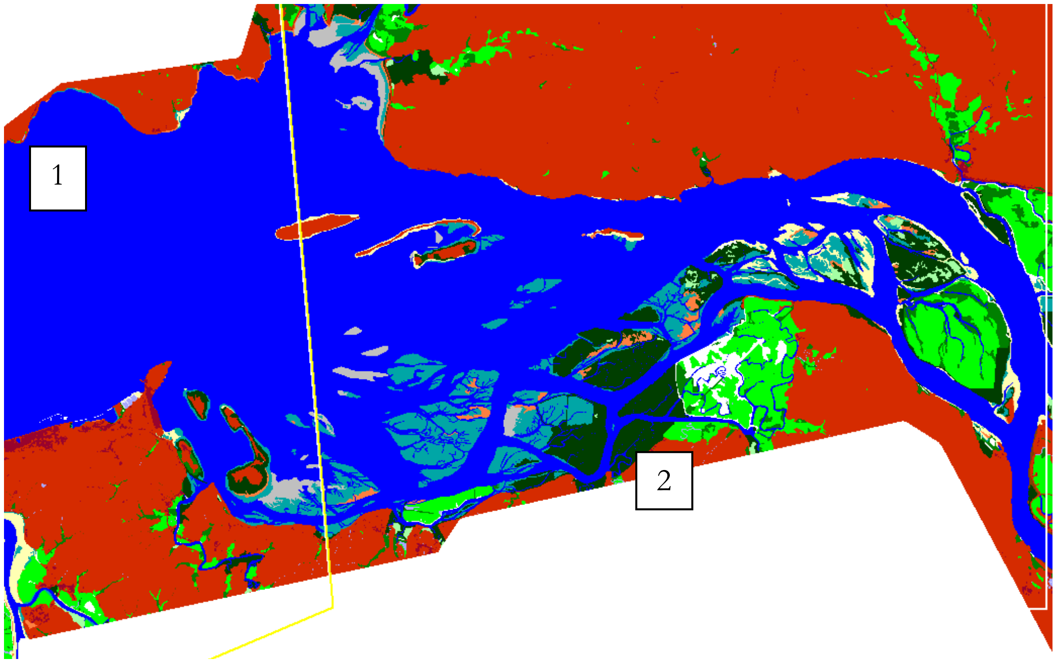


Figure 5. Input parameter subsites used

The tide range for Lower Columbia was applied in a spatially variable manner using several NOAA tide gauges (see Figure 6) (9440574, North Jetty, WA; 9440572, Jetty A, Columbia River, WA; 9439008, Fort Stephens, OR; 9439011, Hammond Nmfs Pier, OR; 9439026, Astoria, Youngs Bay, OR; 9440575, Knappton, WA; 9439040, Astoria, OR; 9440571, Altoona, Columbia River, WA; 9439069, Knappa, OR; 9440569, Skamokawa, WA; 9439099, Wauna, OR).

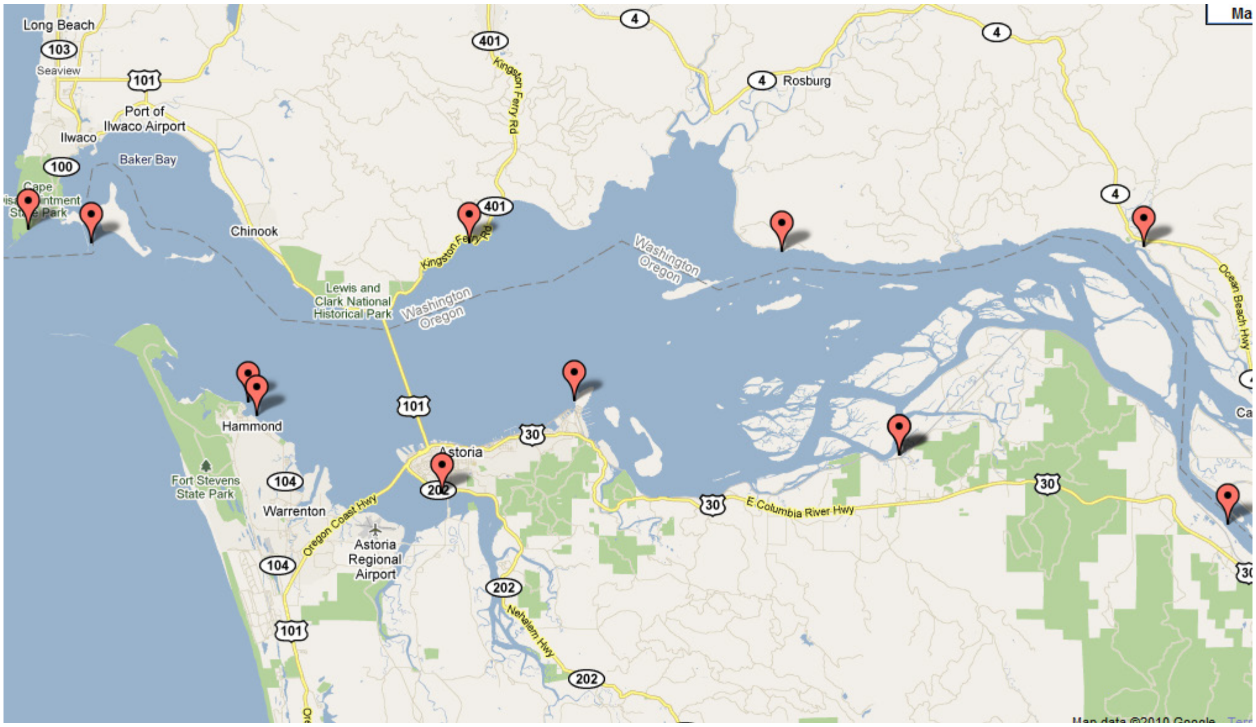


Figure 6. NOAA gauges in the Lower Columbia River

Salt marsh vertical accretion rates of 3.6 mm/year were from a regional average based on Thom (1992) who measured accretion rates of regularly-flooded (salt) marshes in the Pacific Northwest. . Model accretion rates for irregularly-flooded (brackish) marsh were set to 3.75 mm/yr and the tidal fresh marsh to 4 mm/yr, using SLAMM defaults in the absence of site-specific data. These values fall within the range of Pacific Northwest accretion measurements by Thom (1992). These rates also fall near the average values of a comprehensive literature review of accretion rates (Cahoon et al. 1999, 1995)

Erosion rates for the tidal flat were set to 0.2 meters/year, roughly based on a regional map of shoreline erosion (Keuler 1988). Erosion rates for marshes and swamps were set to SLAMM defaults of 2 meters/year and 1 meter/year, respectively. Horizontal erosion of marshes and swamps occurs only at the wetland-to-open-water interface and only when adequate open water (fetch) exists for wave setup.

Elevation data were converted to a mean tide level (MTL) basis using data available from NOAA tide gauges and the NOAA VDATUM software. MTL to NAVD88 elevation corrections were made on a cell-by-cell basis.

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. Based on a regional analysis of tidal data in the Puget Sound region, the "salt boundary" in SLAMM was set to 133% of MHHW (relative to

MTL), or 1.74 meters for input site 1 and 1.62 meters for input site 2. Lands above this elevation are assumed to be free of saline influence for the most part (e.g. dry lands, inland-fresh marsh, and swamps).

Table 2. Summary of SLAMM input parameters for Lewis and Clark NWR site

Parameter	SubSite 1	SubSite 2
NWI Photo Date (YYYY)	1981	1981
DEM Date (YYYY)	1999	1999
Direction Offshore [n,s,e,w]	West	West
Historic Trend (mm/yr)	2	2
MTL-NAVD88 (m)	Cell-by-cell	Cell-by-cell
GT Great Diurnal Tide Range (m)	2.62	2.44
Salt Elev. (m above MTL)	1.74	1.62
Marsh Erosion (horz. m /yr)	2	2
Swamp Erosion (horz. m /yr)	1	1
T.Flat Erosion (horz. m /yr)	0.2	0.2
Reg. Flood Marsh Accr (mm/yr)	3.6	3.6
Irreg. Flood Marsh Accr (mm/yr)	3.75	3.75
Tidal Fresh Marsh Accr (mm/yr)	4	4
Beach Sed. Rate (mm/yr)	0.5	0.5
Freq. Overwash (years)	0	0
Use Elev Pre-processor [True,False]	FALSE	FALSE

Results

This SLAMM application predicts Lewis and Clark NWR will be impacted by sea level rise, particularly at higher SLR scenarios.

Regularly-flooded marsh and tidal swamp are the dominant land cover types in the refuge. Simulations predict increasing tidal swamp loss with increasing SLR, culminating in 91% loss of this habitat type under the 2 m SLR scenario, as shown in Table 3. Tidal swamp and tidal fresh marsh exhibit a large increase in loss between the 1 m and 1.5 m SLR by 2100 scenarios. This increase corresponds to a large gain in irregularly-flooded marsh and tidal flat, as illustrated in Figure 7. These results suggest a threshold SLR exists for tidal swamp and tidal fresh marsh between 1 and 1.5 m of SLR by 2100. Below this threshold, tidal fresh marsh and tidal swamp are relatively resilient to SLR since they are located on a high marsh platform and, in the case of tidal fresh marsh, are subject to relatively high accretion rates (4 mm/yr for tidal fresh marsh). The maps presented in this section illustrate the changes predicted by SLAMM. The changes in the maps between 2075 and 2100 in the 1.5 m and 2 m SLR by 2100 scenarios indicate a major shift in land cover. In the 1.5 m scenario, for example, a large portion of tidal swamp is predicted to become irregularly-flooded marsh in the final 25 years of the simulation.

Table 3. Predicted Loss of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise. *Negative values indicate gains.*

Land cover category	Simulated SLR by 2100				
	0.39 m	0.69 m	1 m	1.5 m	2 m
Regularly Flooded Marsh	34	44	60	74	59
Tidal Swamp	6	9	18	66	91
Estuarine Beach	12	25	47	57	62
Undeveloped Dry Land	20	22	25	32	38
Tidal Flat	-243	-271	-282	-352	-252
Irregularly Flooded Marsh	26	46	29	-194	-126
Tidal Fresh Marsh	1	2	6	64	98
Swamp	30	31	32	34	36

Loss of regularly-flooded marsh is predicted to reach a maximum of 75% under the 1.5 m of SLR by 2100 scenario. Under the 2 m scenario, however, the predicted loss of regularly-flooded marsh is 62%. A similar trend is noted for tidal flat and irregularly-flooded marsh, which both exhibit maximum gains under the 1.5 m SLR scenario (gains are represented by negative values in Table 3). These predictions result from increase in tidal swamp loss. In the SLAMM model, tidal swamp is converted to irregularly-flooded marsh and irregularly-flooded marsh is converted to regularly-flooded marsh due to increased inundation. Figure 7shows that illustrates that decreases in Tidal swamp and tidal fresh marsh relate to increases in irregularly-flooded marsh, while decreases in irregularly-flooded marsh correspond to increases in regularly-flooded marsh.

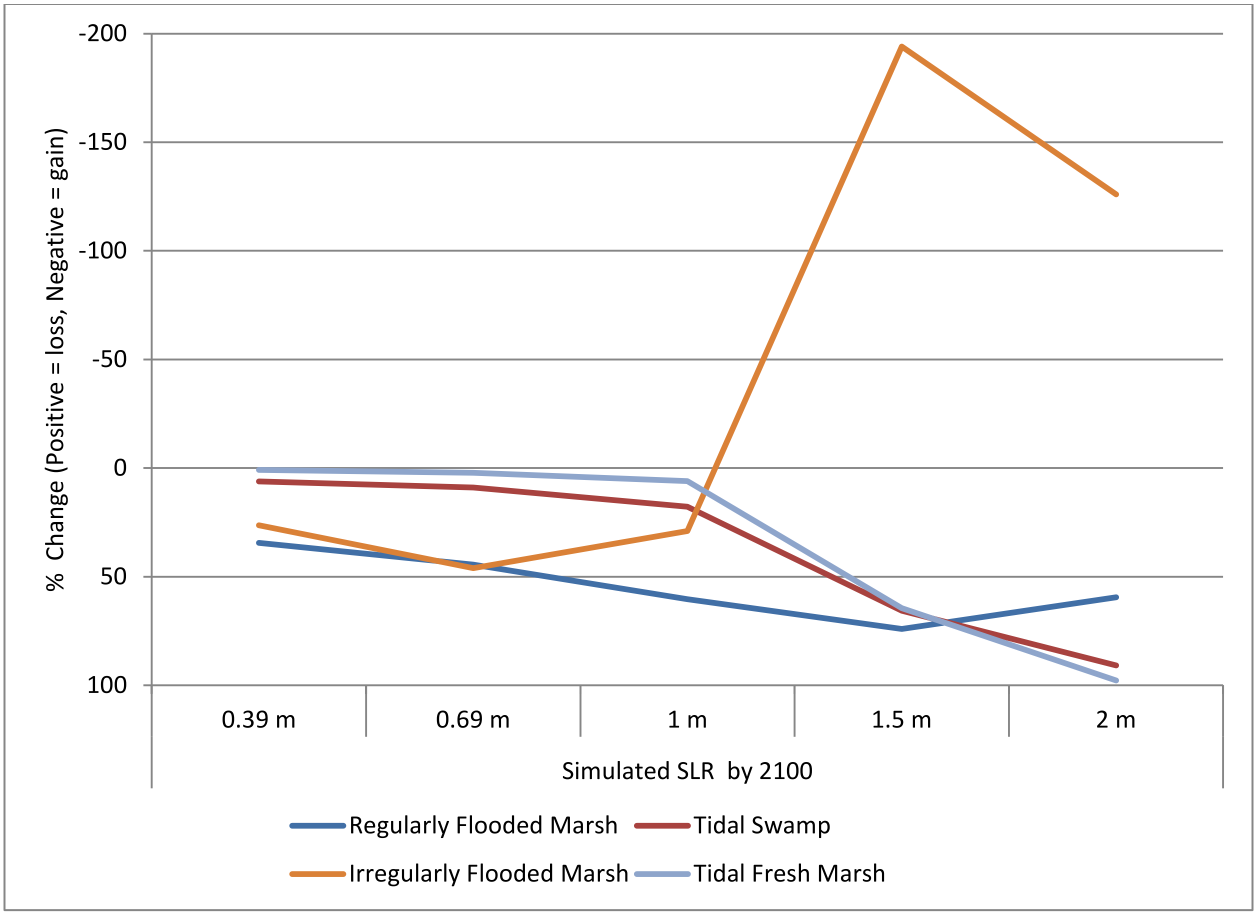


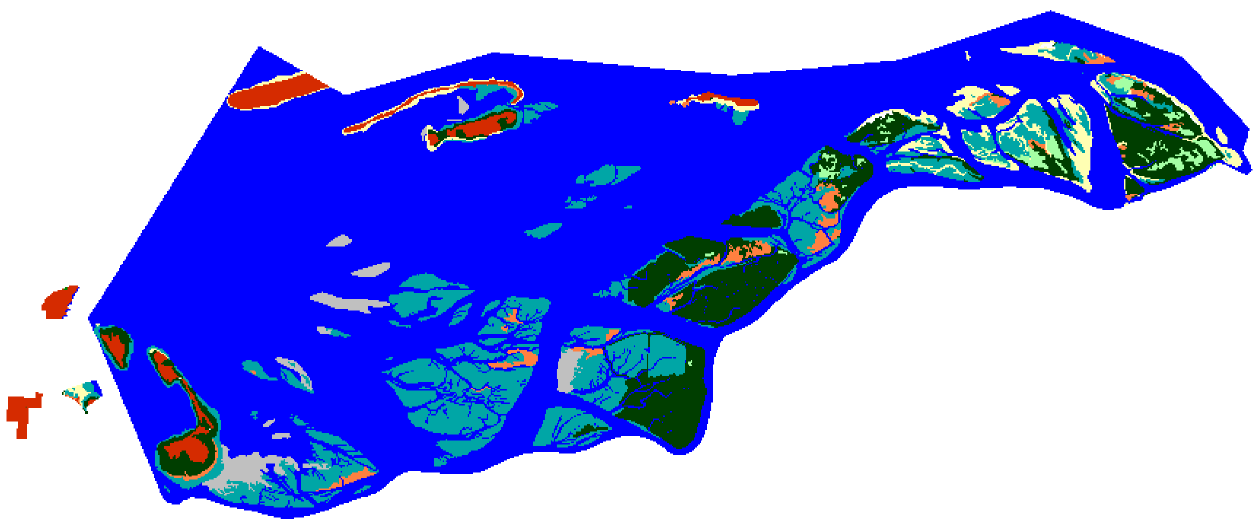
Figure 7. Percent change by 2100 for selected wetland categories.

Estuarine beach makes up a small portion of the refuge area but represents an important habitat type. SLAMM predicts nearly half of the estuarine beach in the initial wetland layer will be lost under the 1 m of SLR by 2100 scenario.

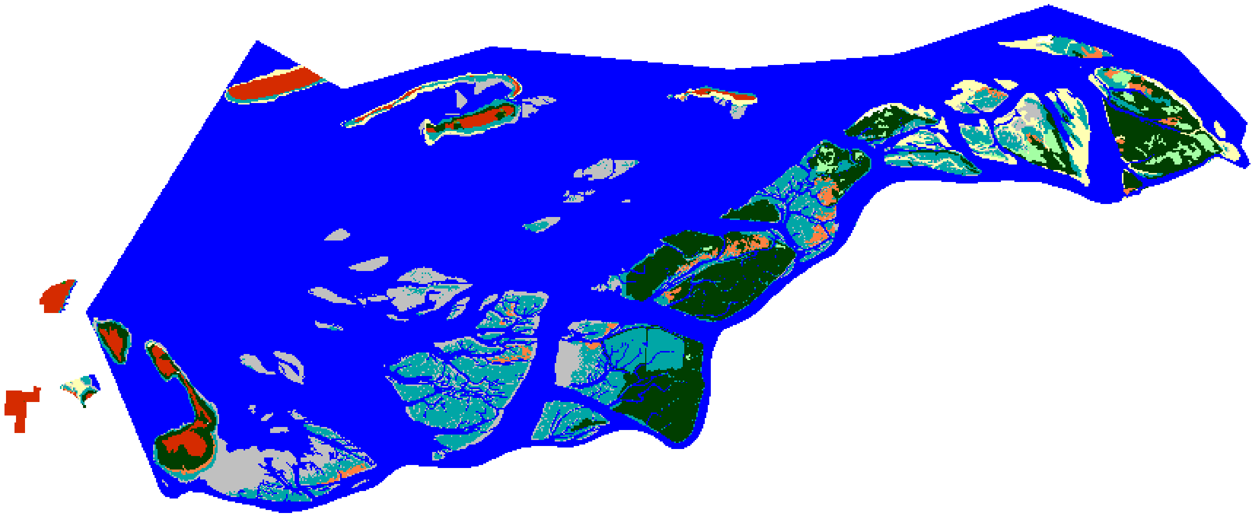
Lewis and Clark NWR
IPCC Scenario A1B-Mean, 0.39 m SLR eustatic by 2100

Results in Acres

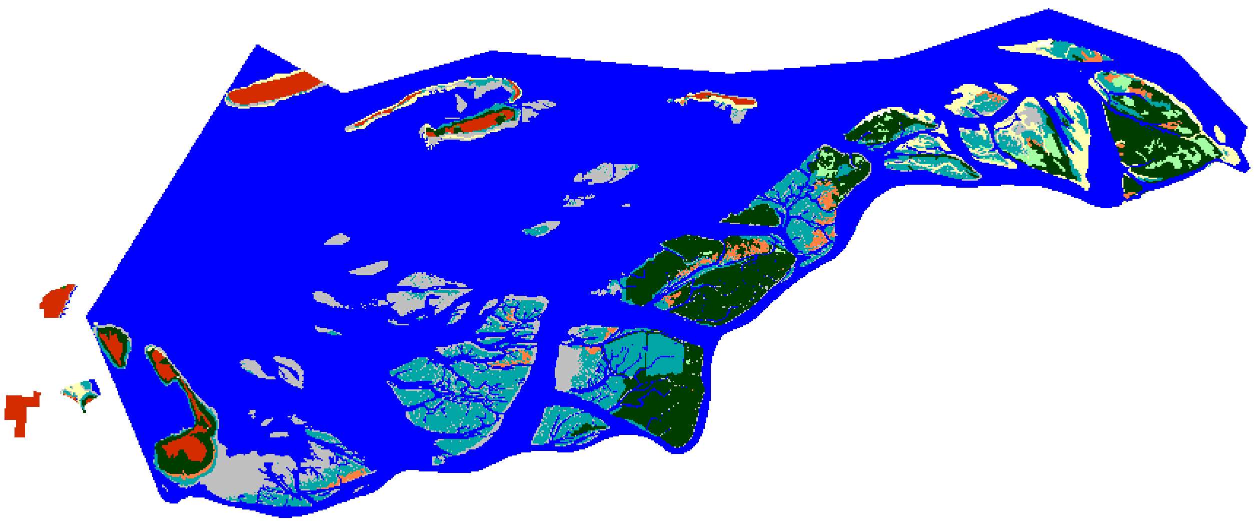
		Initial	2025	2050	2075	2100
	Estuarine Open Water	24019	24248	24373	24562	24723
	Regularly Flooded Marsh	4047	2849	2668	2674	2652
	Tidal Swamp	2816	2686	2677	2664	2644
	Estuarine Beach	800	781	764	740	706
	Undeveloped Dry Land	721	594	590	584	578
	Tidal Flat	487	1842	1922	1767	1669
	Irregularly Flooded Marsh	418	292	298	295	308
	Tidal Fresh Marsh	244	242	242	242	242
	Swamp	1	1	1	1	1
	Transitional Salt Marsh	0	18	20	24	30
	Total (incl. water)	**33553**	**33553**	**33553**	**33553**	**33553**



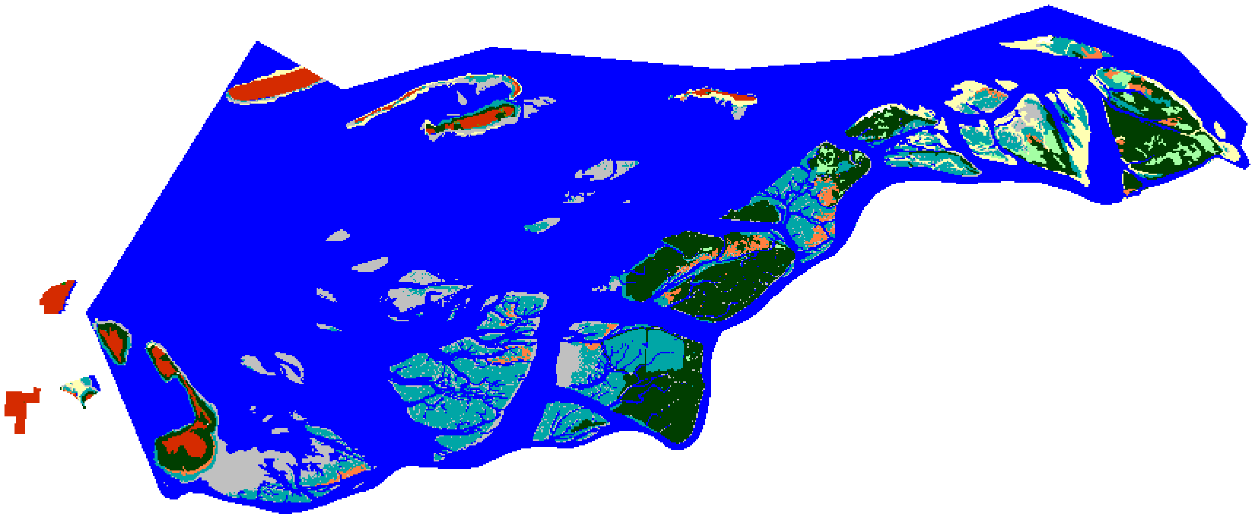
Lewis and Clark NWR, Initial Condition



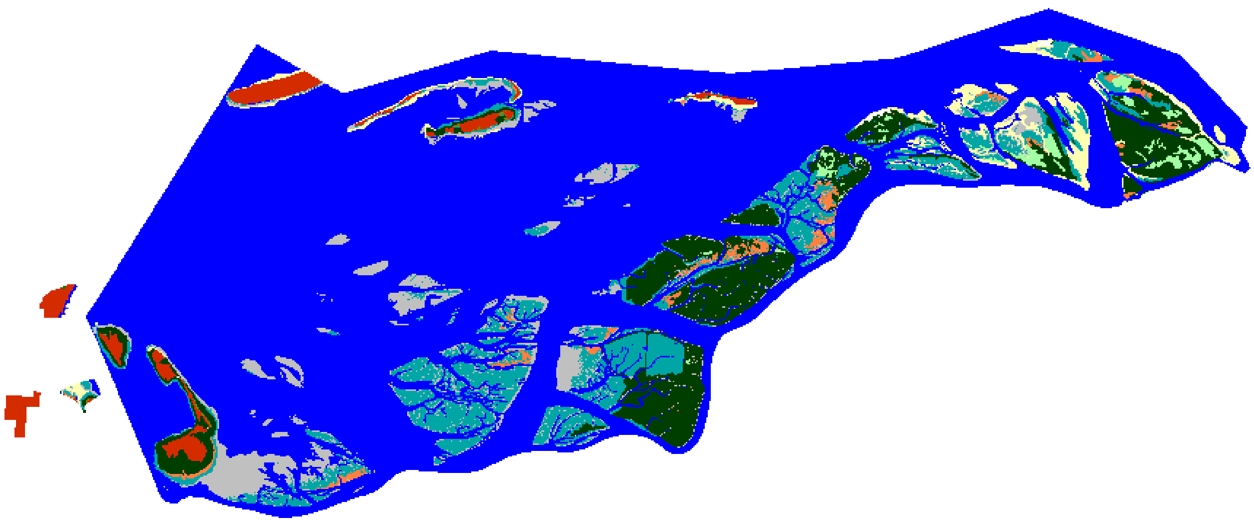
Lewis and Clark NWR, 2025, Scenario A1B Mean



Lewis and Clark NWR, 2050, Scenario A1B Mean



Lewis and Clark NWR, 2075, Scenario A1B Mean

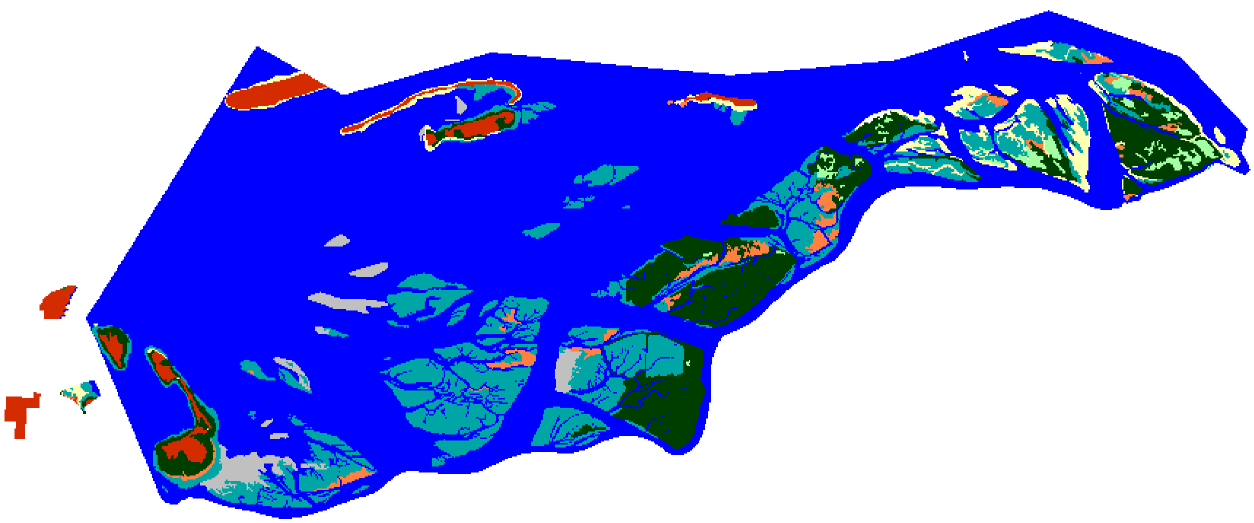


Lewis and Clark NWR, 2100, Scenario A1B Mean

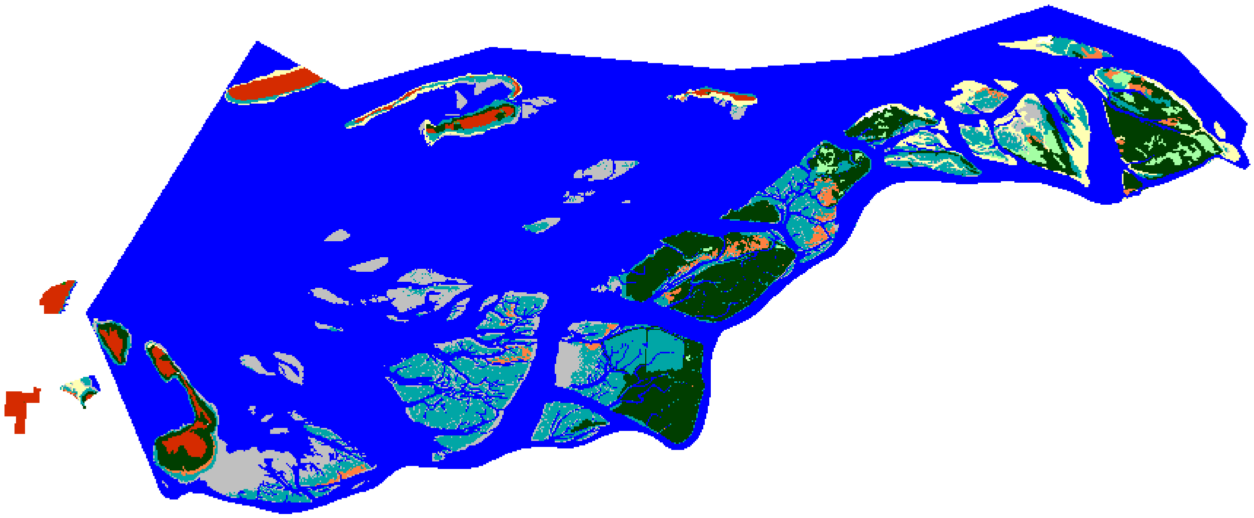
Lewis and Clark NWR
IPCC Scenario A1B-Max, 0.69 m SLR eustatic by 2100

Results in Acres

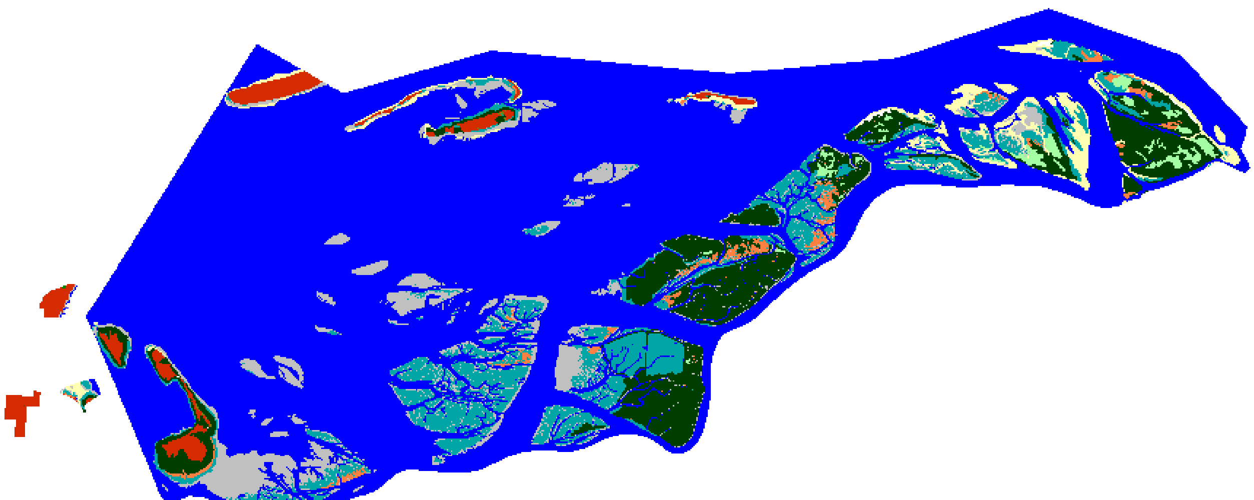
		Initial	2025	2050	2075	2100
	Estuarine Open Water	24019	24289	24508	24836	25265
	Regularly Flooded Marsh	4047	2848	2576	2440	2252
	Tidal Swamp	2816	2679	2659	2623	2564
	Estuarine Beach	800	773	740	669	600
	Undeveloped Dry Land	721	592	584	573	560
	Tidal Flat	487	1812	1930	1883	1808
	Irregularly Flooded Marsh	418	298	292	257	226
	Tidal Fresh Marsh	244	242	241	241	239
	Swamp	1	1	1	1	1
	Transitional Salt Marsh	0	19	22	30	39
	Total (incl. water)	**33553**	**33553**	**33553**	**33553**	**33553**



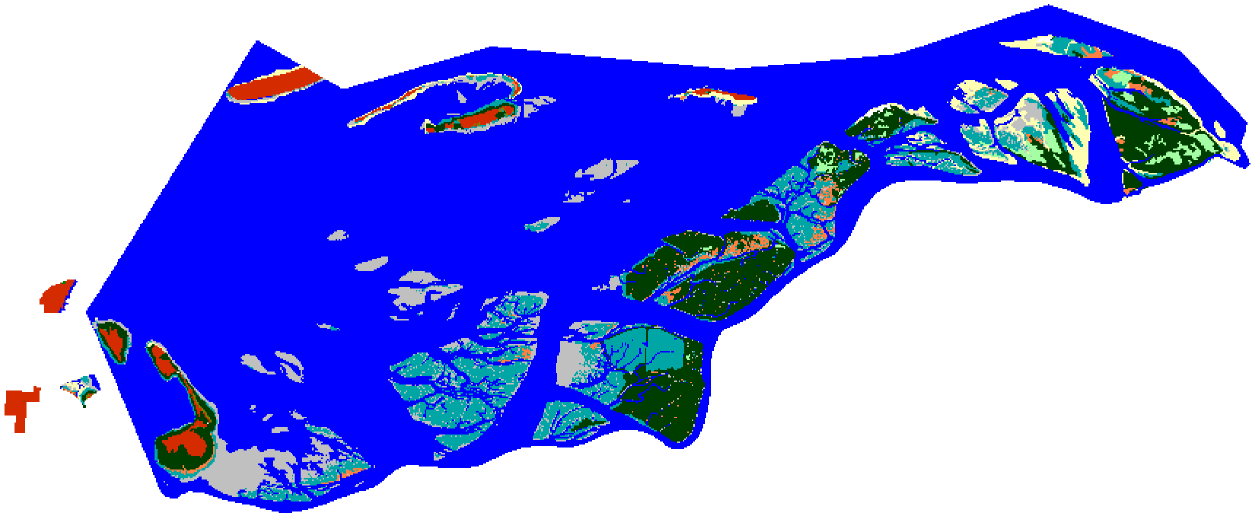
Lewis and Clark NWR, Initial Condition



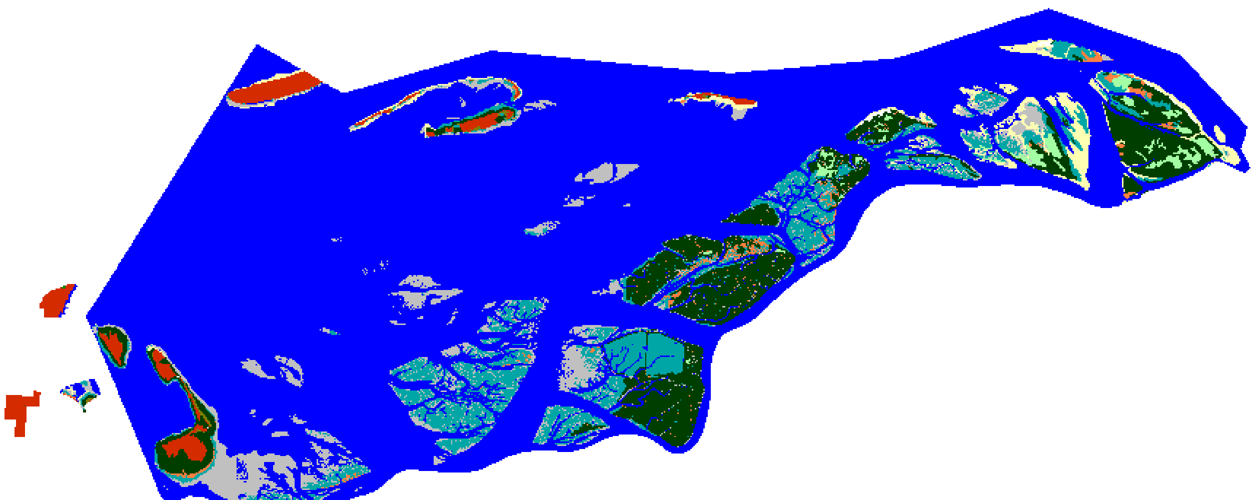
Lewis and Clark NWR, 2025, Scenario A1B Max



Lewis and Clark NWR, 2050, Scenario A1B Max



Lewis and Clark NWR, 2075, Scenario A1B Max

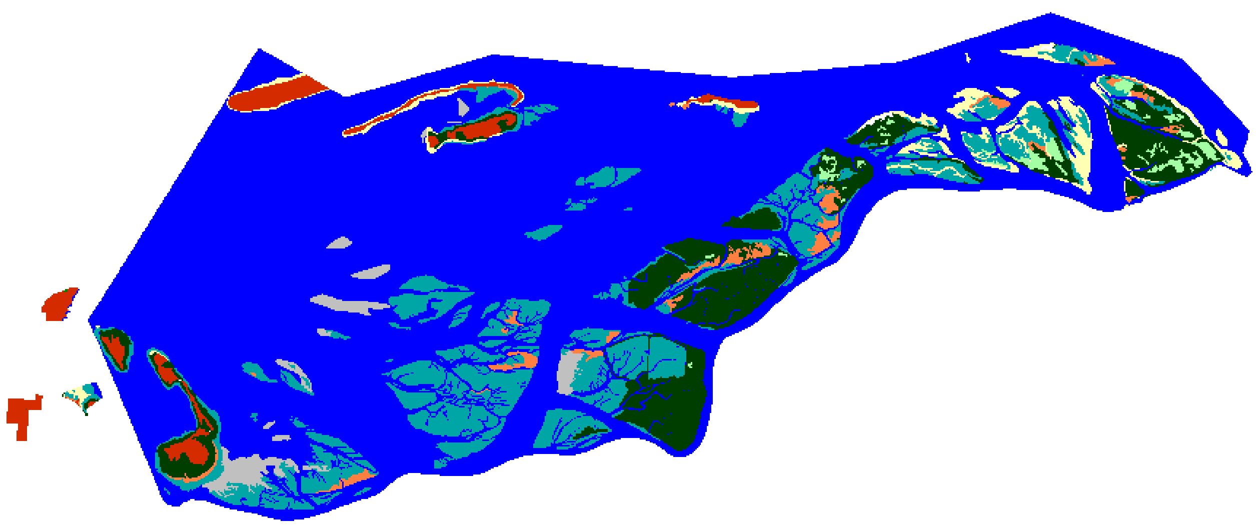


Lewis and Clark NWR, 2100, Scenario A1B Max

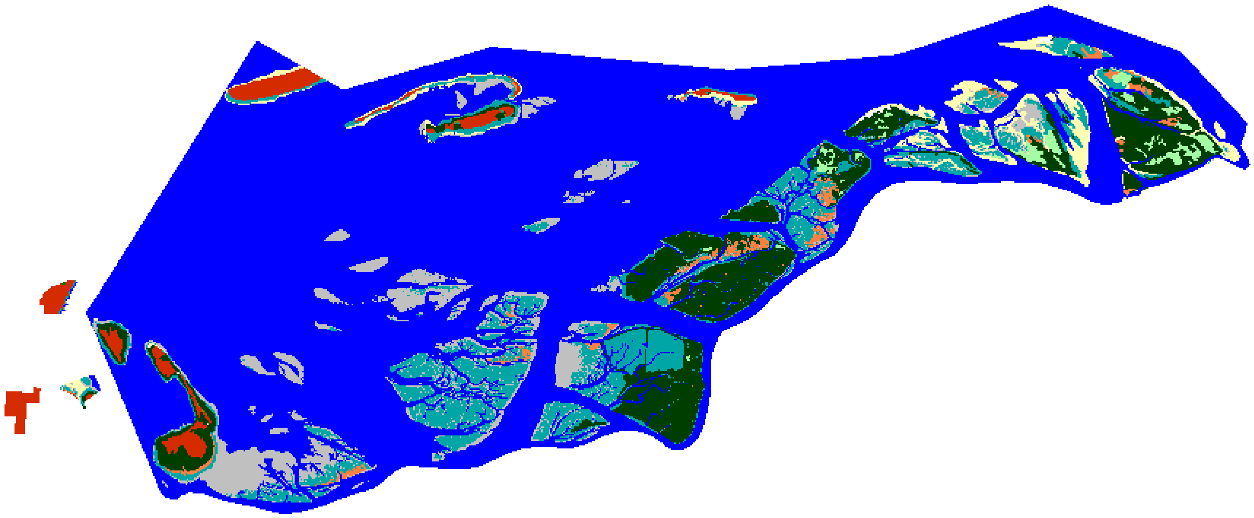
Lewis and Clark NWR
1 m eustatic SLR by 2100

Results in Acres

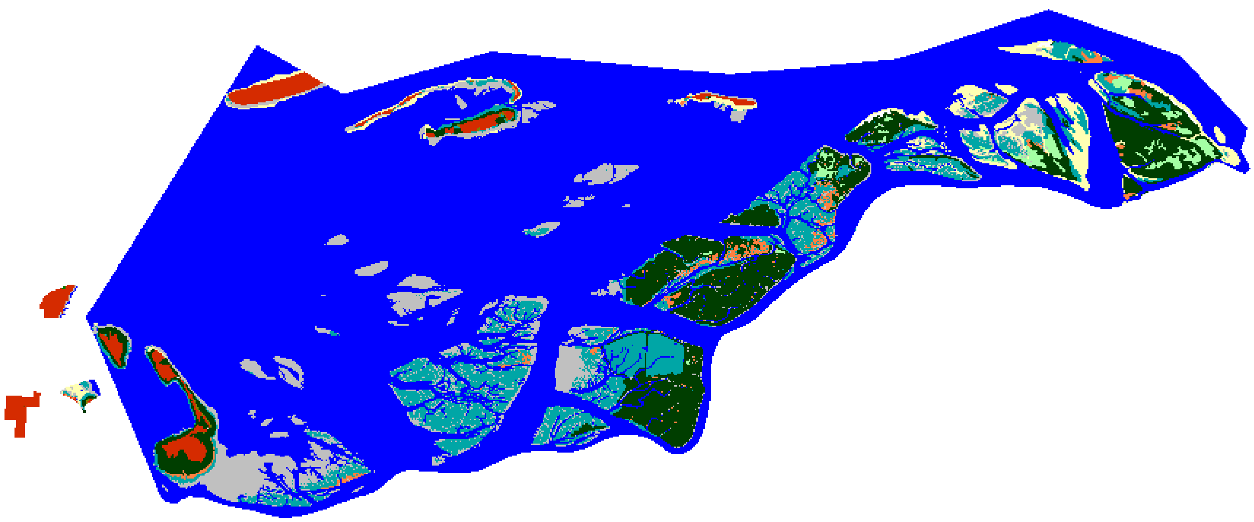
		Initial	2025	2050	2075	2100
	Estuarine Open Water	24019	24344	24661	25265	26242
	Regularly Flooded Marsh	4047	2781	2421	2114	1603
	Tidal Swamp	2816	2672	2635	2561	2315
	Estuarine Beach	800	762	697	597	422
	Undeveloped Dry Land	721	589	578	560	537
	Tidal Flat	487	1853	2034	1989	1861
	Irregularly Flooded Marsh	418	291	261	194	297
	Tidal Fresh Marsh	244	241	240	237	229
	Swamp	1	1	1	1	1
	Transitional Salt Marsh	0	20	25	35	47
	Total (incl. water)	**33553**	**33553**	**33553**	**33553**	**33553**



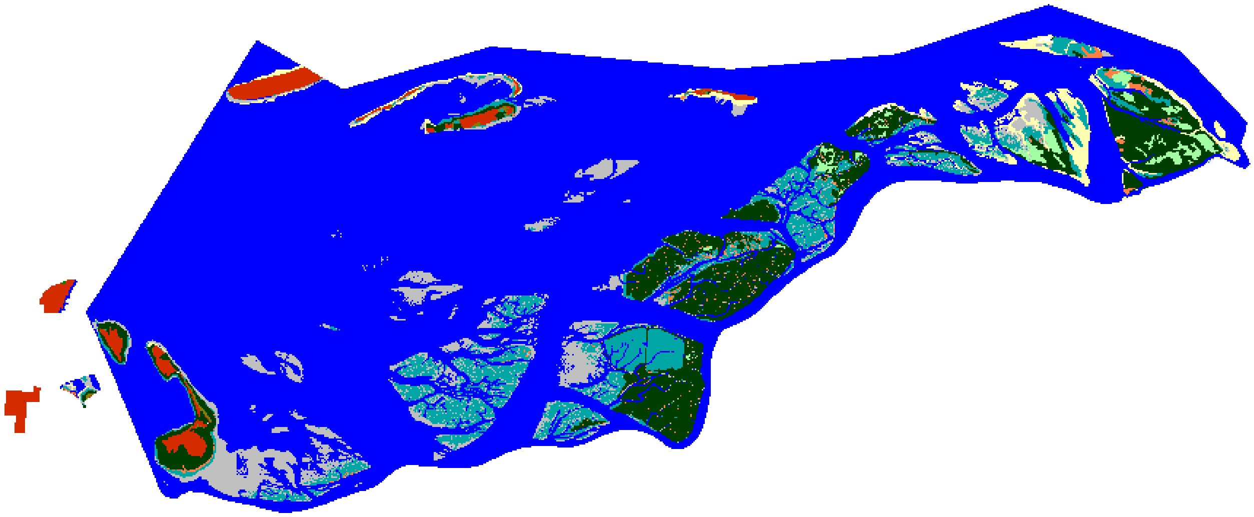
Lewis and Clark NWR, Initial Condition



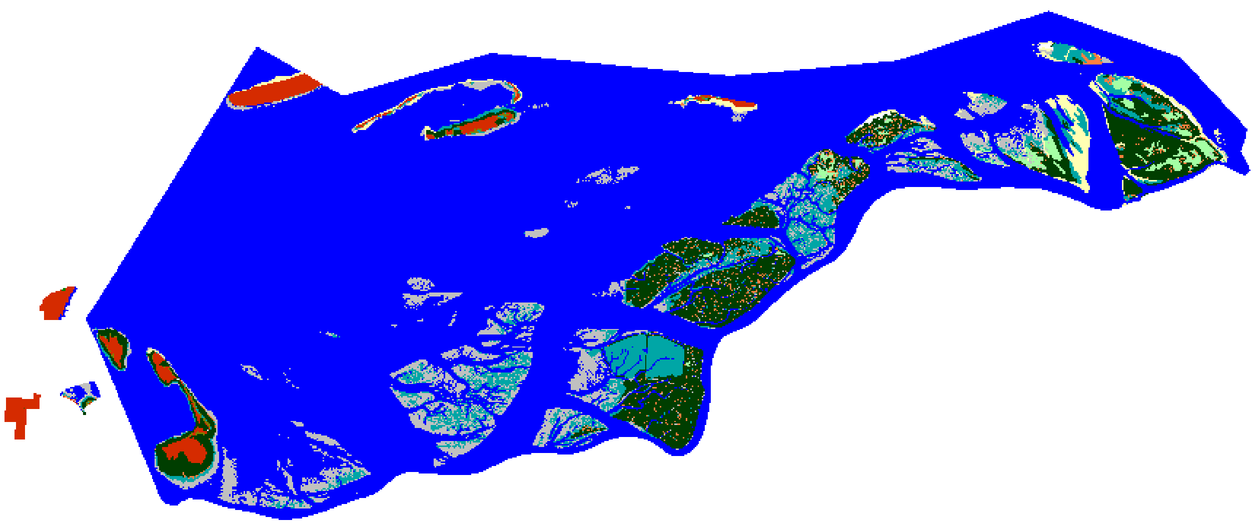
Lewis and Clark NWR, 2025, Scenario 1 Meter



Lewis and Clark NWR, 2050, Scenario 1 Meter



Lewis and Clark NWR, 2075, Scenario 1 Meter

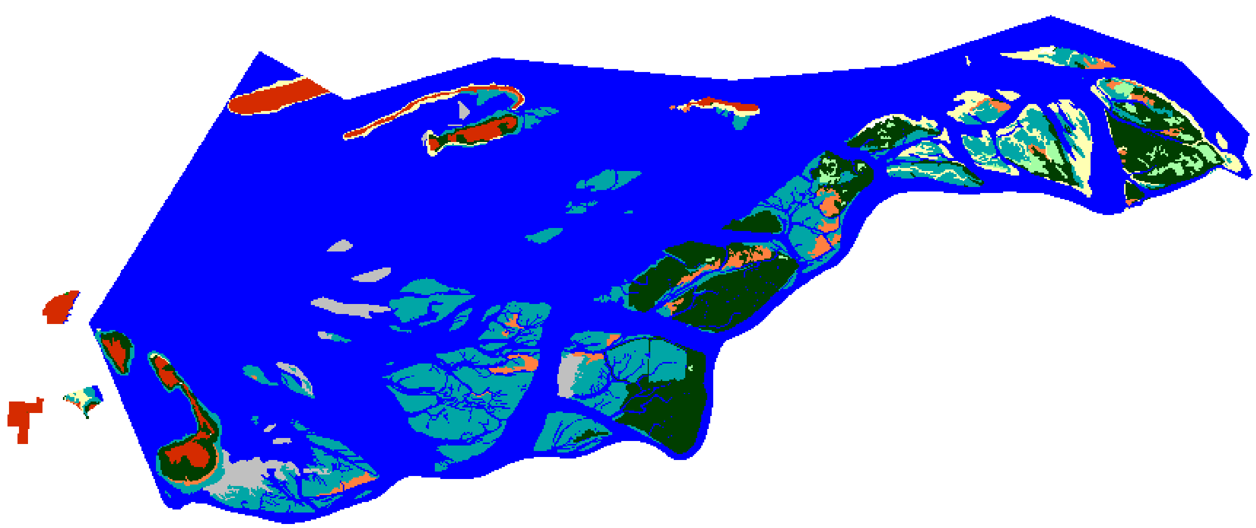


Lewis and Clark NWR, 2100, Scenario 1 Meter

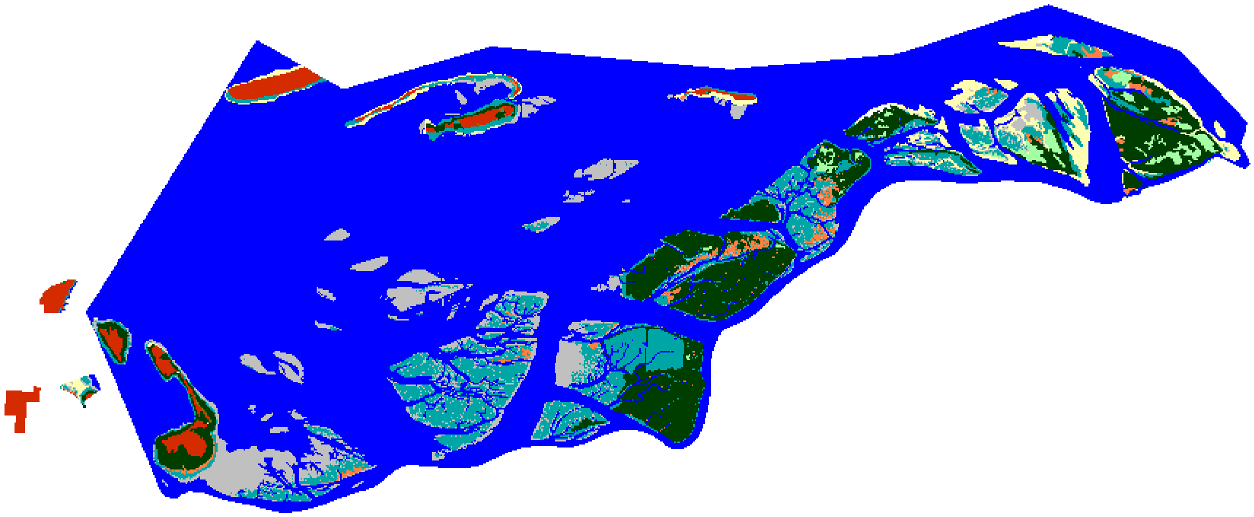
Lewis and Clark NWR
1.5 m eustatic SLR by 2100

Results in Acres

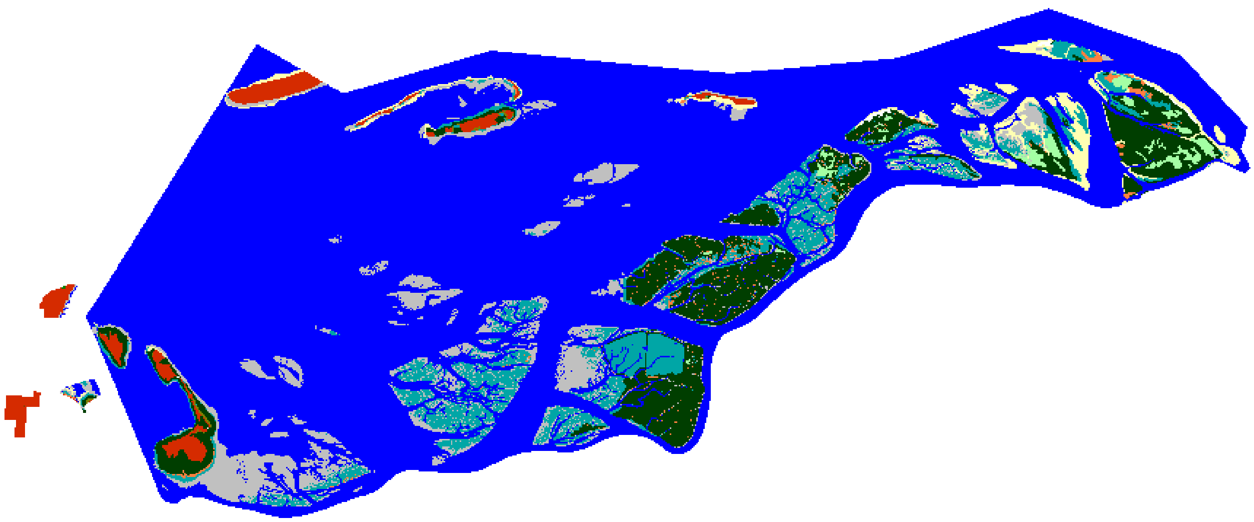
		Initial	2025	2050	2075	2100
	Estuarine Open Water	24019	24455	24962	26361	27124
	Regularly Flooded Marsh	4047	2669	2108	1268	1055
	Tidal Swamp	2816	2657	2582	2185	966
	Estuarine Beach	800	743	634	405	344
	Undeveloped Dry Land	721	585	566	534	488
	Tidal Flat	487	1909	2234	2114	2200
	Irregularly Flooded Marsh	418	271	200	424	1230
	Tidal Fresh Marsh	244	241	236	219	87
	Swamp	1	1	1	1	1
	Transitional Salt Marsh	0	22	29	42	58
	Total (incl. water)	**33553**	**33553**	**33553**	**33553**	**33553**



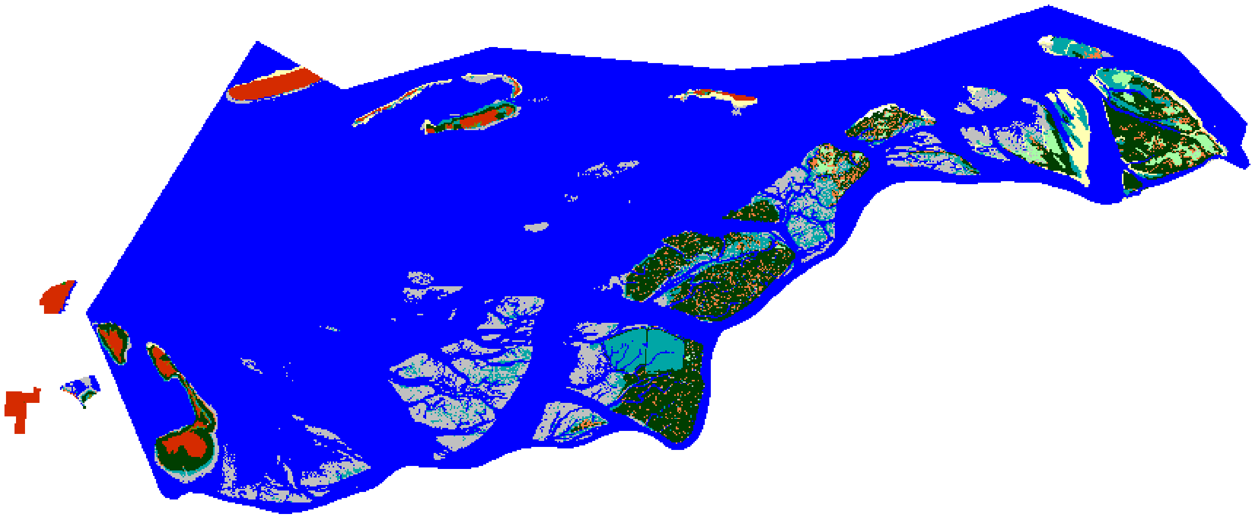
Lewis and Clark NWR, Initial Condition



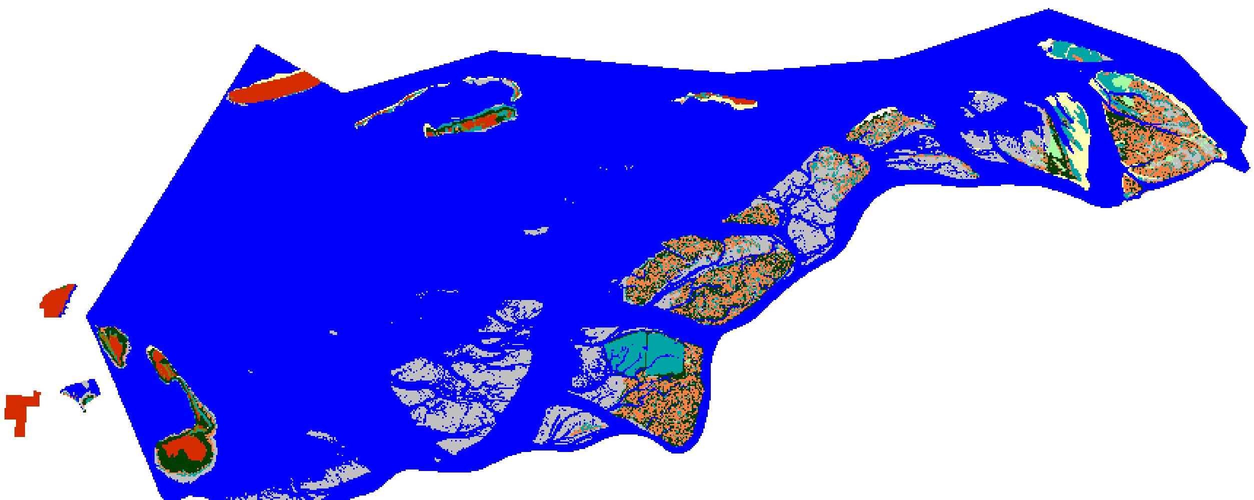
Lewis and Clark NWR, 2025, Scenario 1.5 Meters



Lewis and Clark NWR, 2050, Scenario 1.5 Meters



Lewis and Clark NWR, 2075, Scenario 1.5 Meters

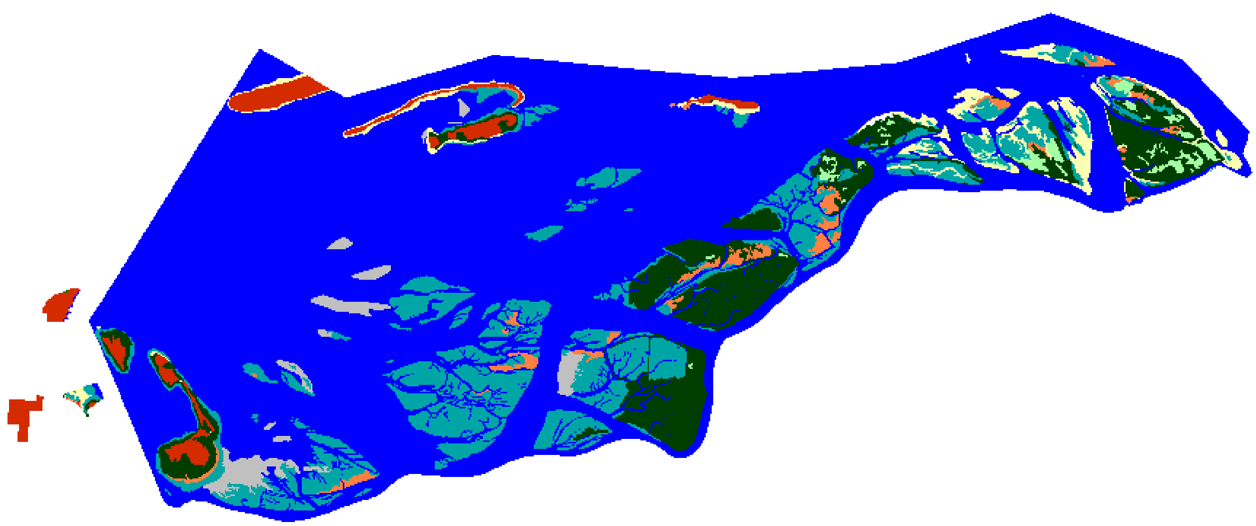


Lewis and Clark NWR, 2100, Scenario 1.5 Meters

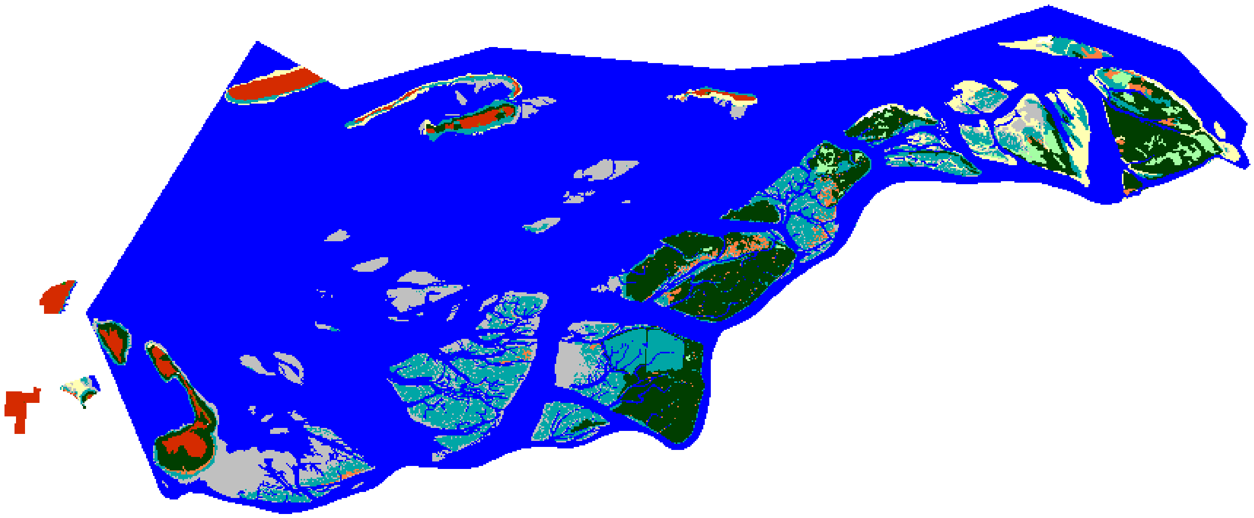
Lewis and Clark NWR
2 m eustatic SLR by 2100

Results in Acres

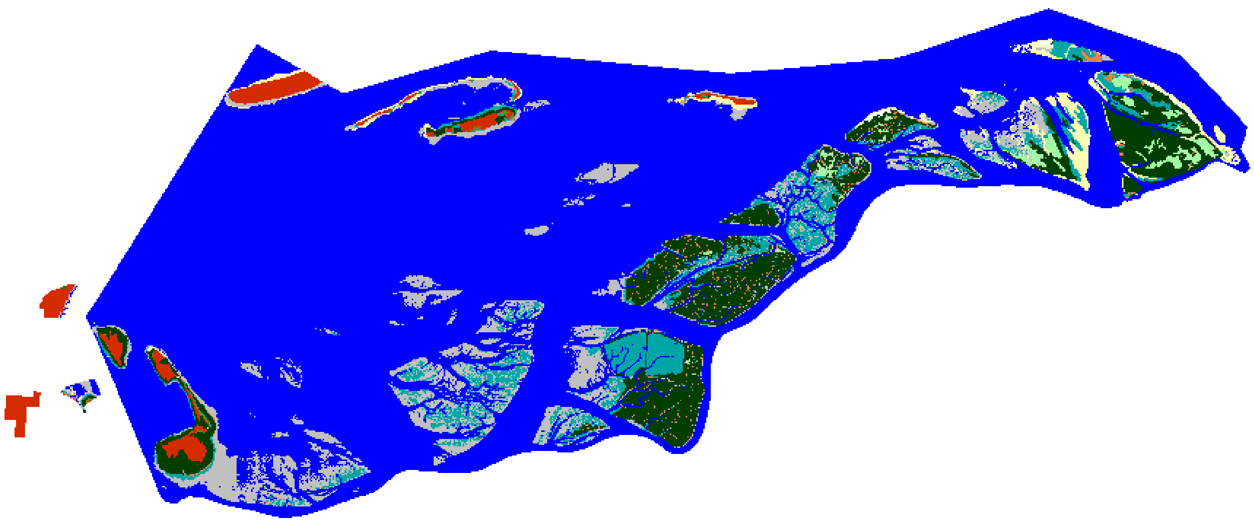
		Initial	2025	2050	2075	2100
	Estuarine Open Water	24019	24563	25538	26918	28118
	Regularly-flooded Marsh	4047	2469	1602	793	1601
	Tidal Swamp	2816	2640	2484	1203	258
	Estuarine Beach	800	714	522	357	302
	Undeveloped Dry Land	528	480	466	436	400
	Tidal Flat	487	1995	2292	2240	1693
	Irregularly-flooded Marsh	418	249	211	1290	945
	Tidal Fresh Marsh	244	239	229	91	5
	Swamp	1	1	1	1	1
	Transitional Salt Marsh	0	11	15	32	37
	Total (incl. water)	**33360**	**33360**	**33360**	**33360**	**33360**



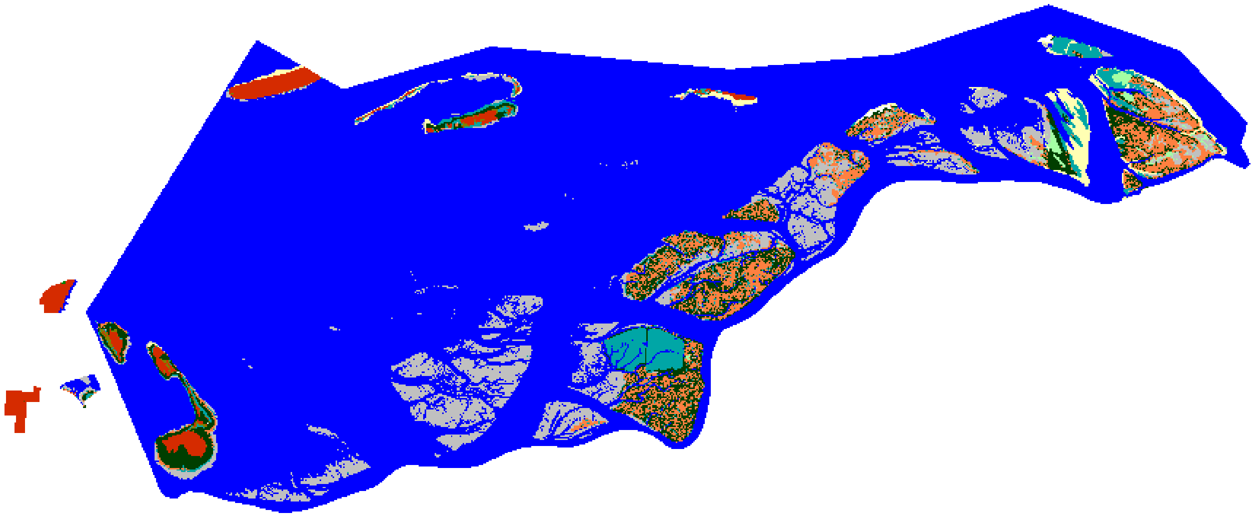
Lewis and Clark NWR, Initial Condition



Lewis and Clark NWR, 2025, Scenario 2 Meters



Lewis and Clark NWR, 2050, Scenario 2 Meters



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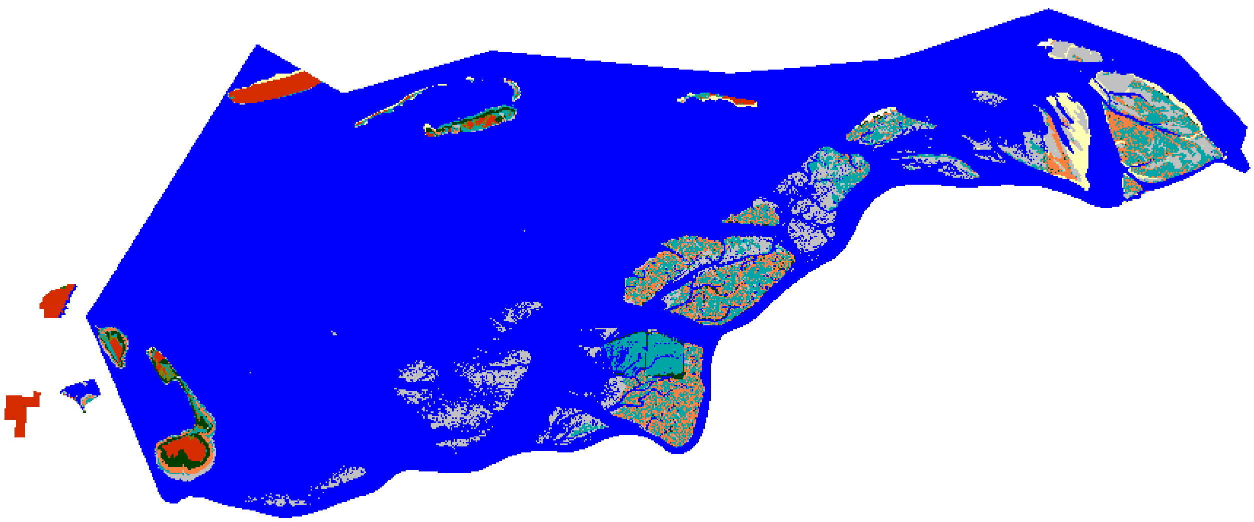

Lewis and Clark NWR, 2100, Scenario 2 Meters

Conclusions

Model results for Lewis and Clark NWR indicate that it is vulnerable to sea level rise, particularly at or above SLR scenarios of 1 m by 2100. Simulations suggest a maximum loss of regularly-flooded marsh, the dominant wetland type in the refuge, under the "1.5 m SLR by 2100" scenario, which also corresponds to maximum gains observed in the tidal flat category. Tidal swamp and tidal fresh marsh are also predicted to be widely lost at SLR rates of 1.5 m by 2100 and above. This result highlights the severe changes in wetland richness predicted by SLAMM given scenarios above 1 m SLR by 2100.

Several sources of uncertainty are associated with these results.

- First, the wetland layer (used in the Ducks Unlimited analysis) dates back to 1981. It is probable that changes have occurred in the wetlands in the 30 years since this data layer was created.
- Second, the historic sea-level trend in this area is somewhat uncertain. The historic sea-level trend is used to estimate the amount of uplift or subsidence occurring within a site. The Astoria NOAA gauge, the closest gauge to the Lewis and Clark NWR, indicates significant uplift. However, the uplift observed at this gauge is likely to be extremely localized and likely is not representative of the overall SLR trend in the bay (Canning 2007). Therefore the rate applied in this model application was 2 mm/yr. The possibility of localized uplift zones adds uncertainty to the results presented in this analysis.
- Third, there is uncertainty in the results for tidal swamp and tidal fresh marsh. These wetland habitats may be more closely controlled by salinity rather than elevation. This SLAMM simulation did not include an explicit accounting of salinity on a cell-by-cell basis. Instead, the site-specific elevations of these categories relative to mean tide level was used as a surrogate for salinity and assumed to control habitat switching.

The contextual area surrounding Lewis and Clark NWR was studied by Ducks Unlimited (Warren Pinnacle Consulting, Inc. 2010). Spatial results for this study are presented in Appendix A.

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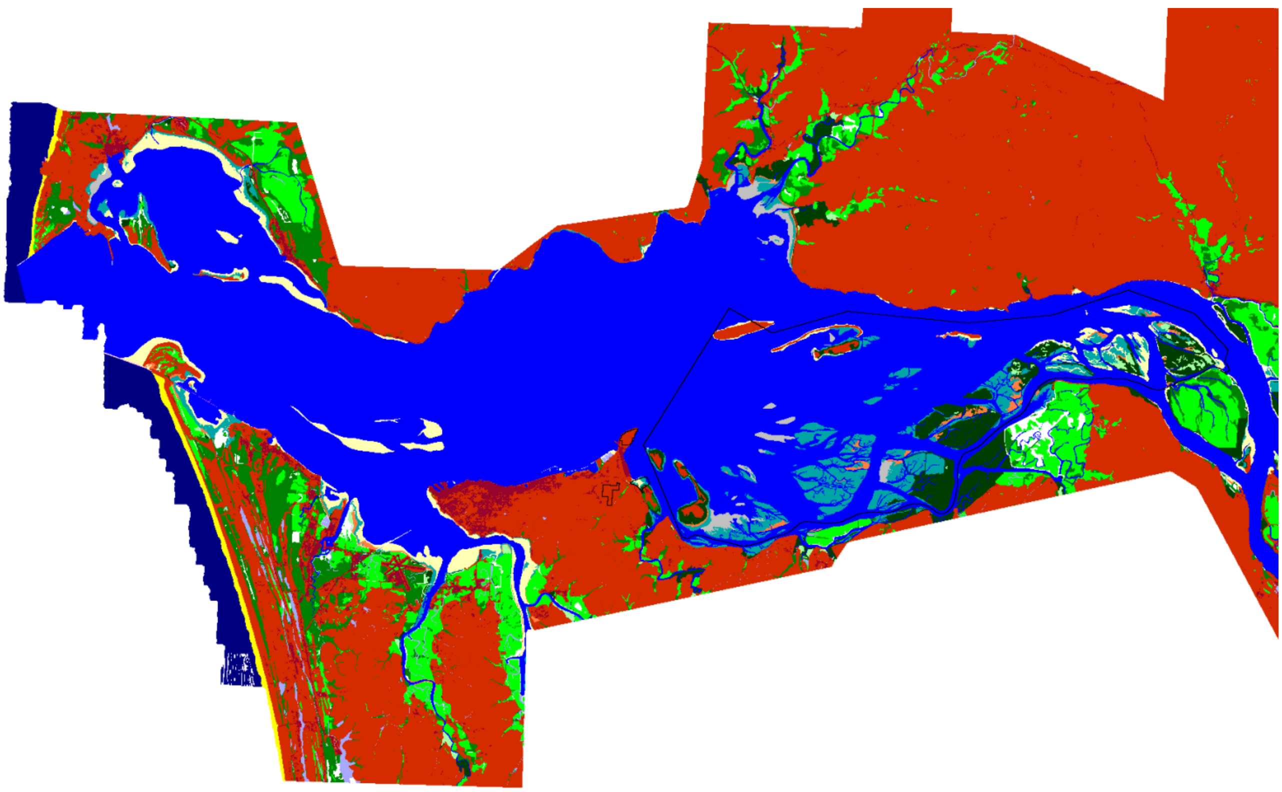
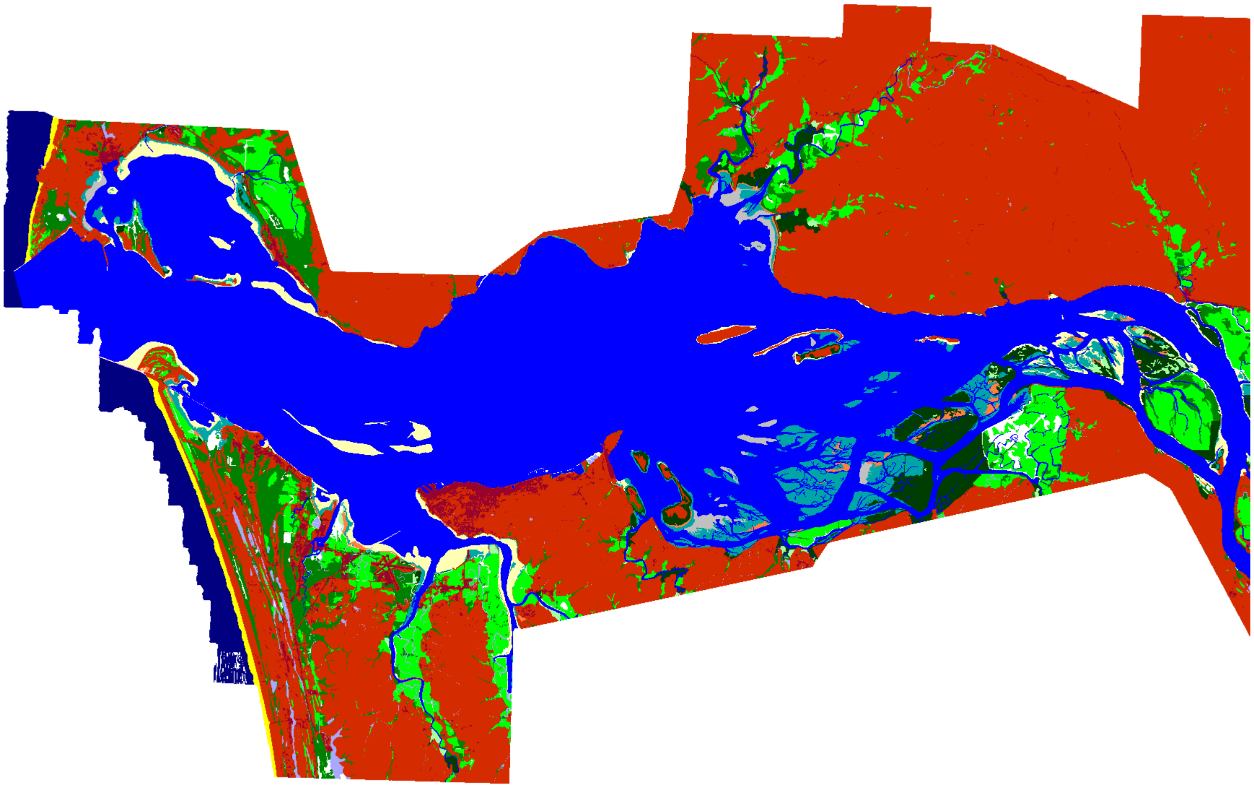
Appendix A: Contextual Results

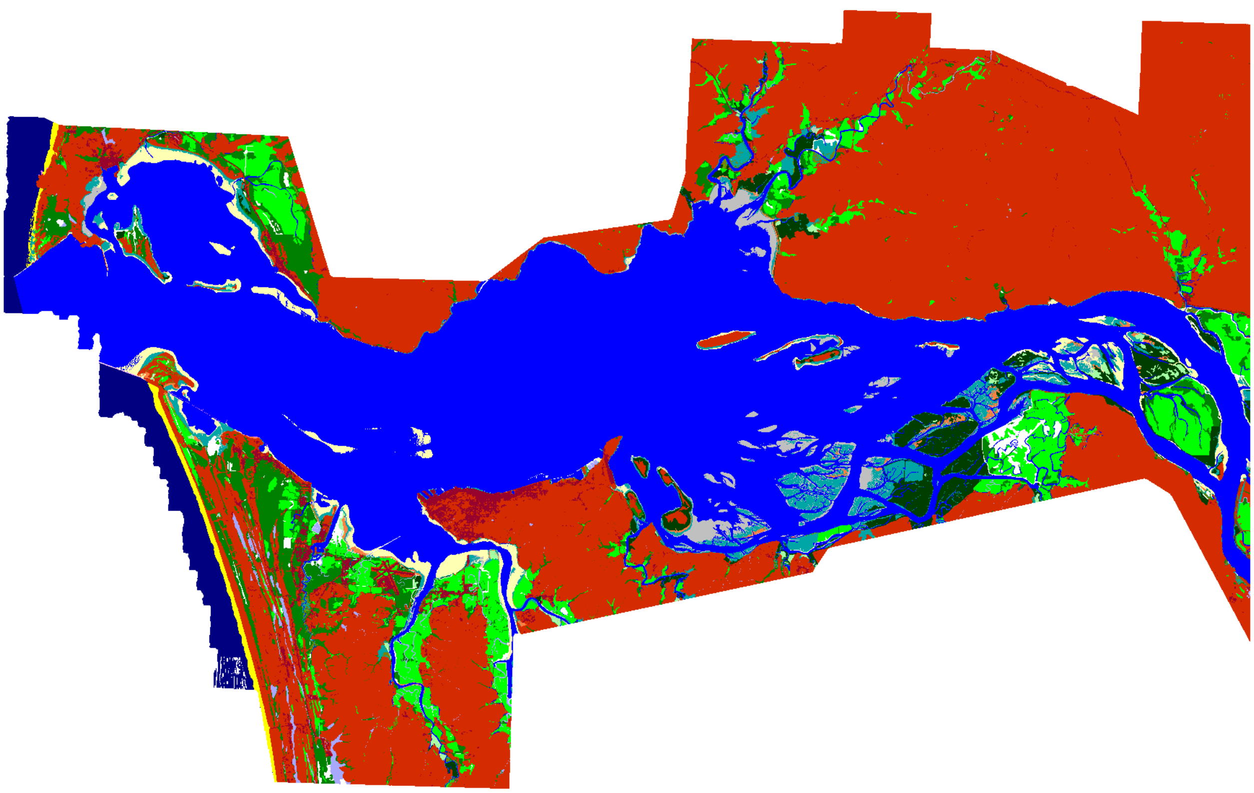
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated 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 area was funded by the National Wildlife Federation (Glick et al. 2007).

Lewis and Clark National Wildlife Refuge within simulation context (boundary outlined in black)

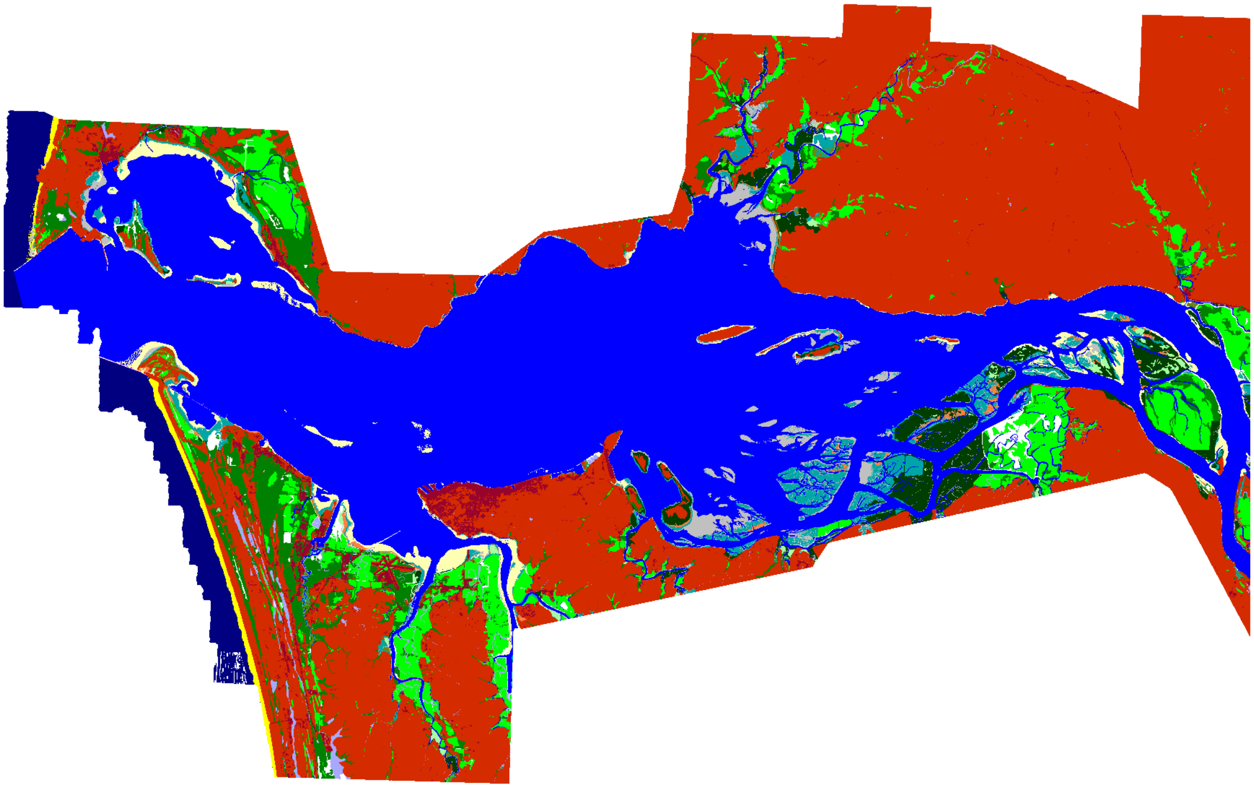




Lewis and Clark Context, Initial Condition



Lewis and Clark Context, 2025, Scenario A1B Mean



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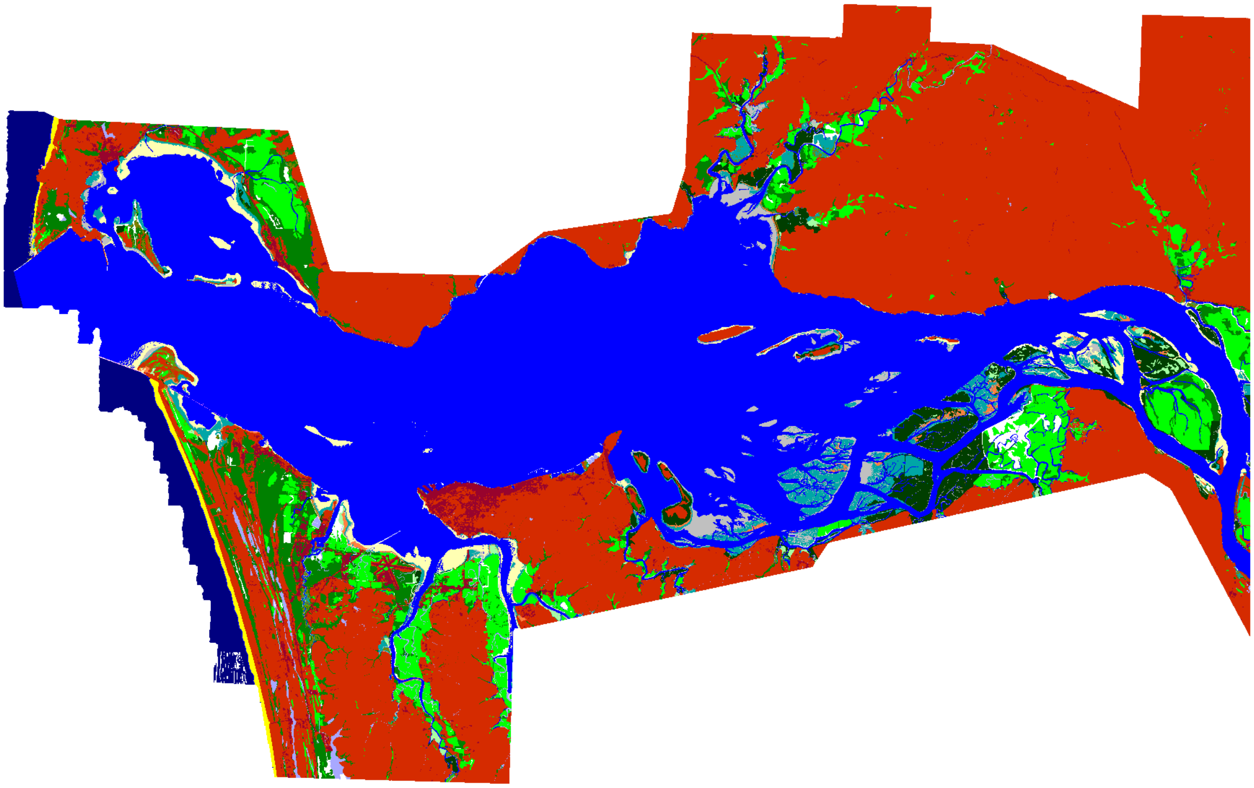

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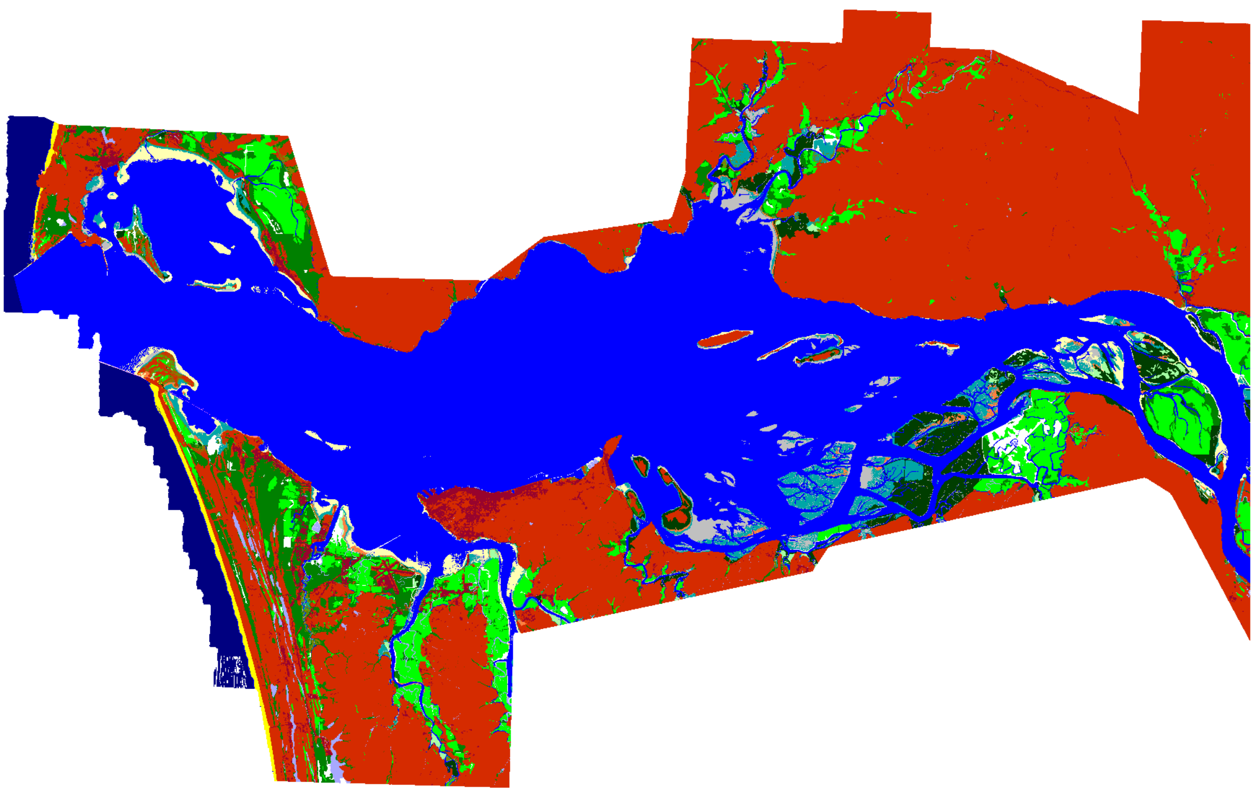
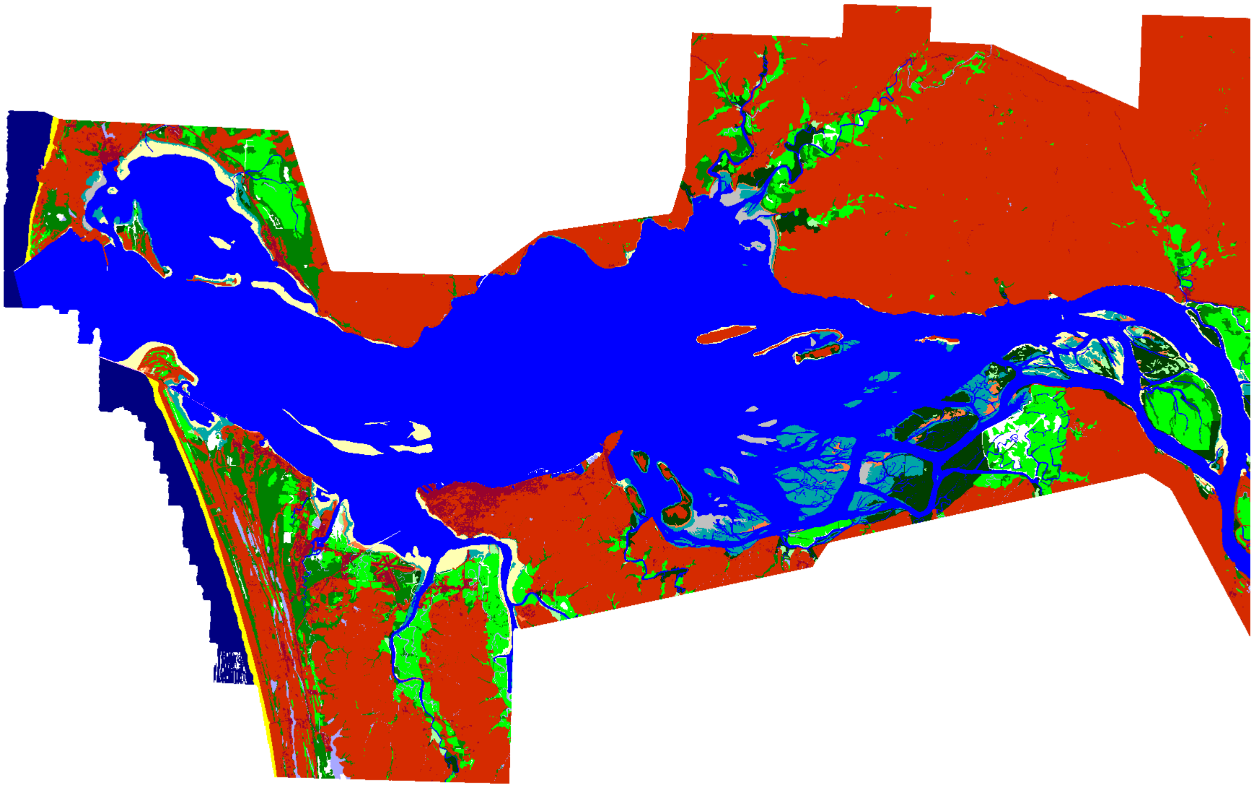
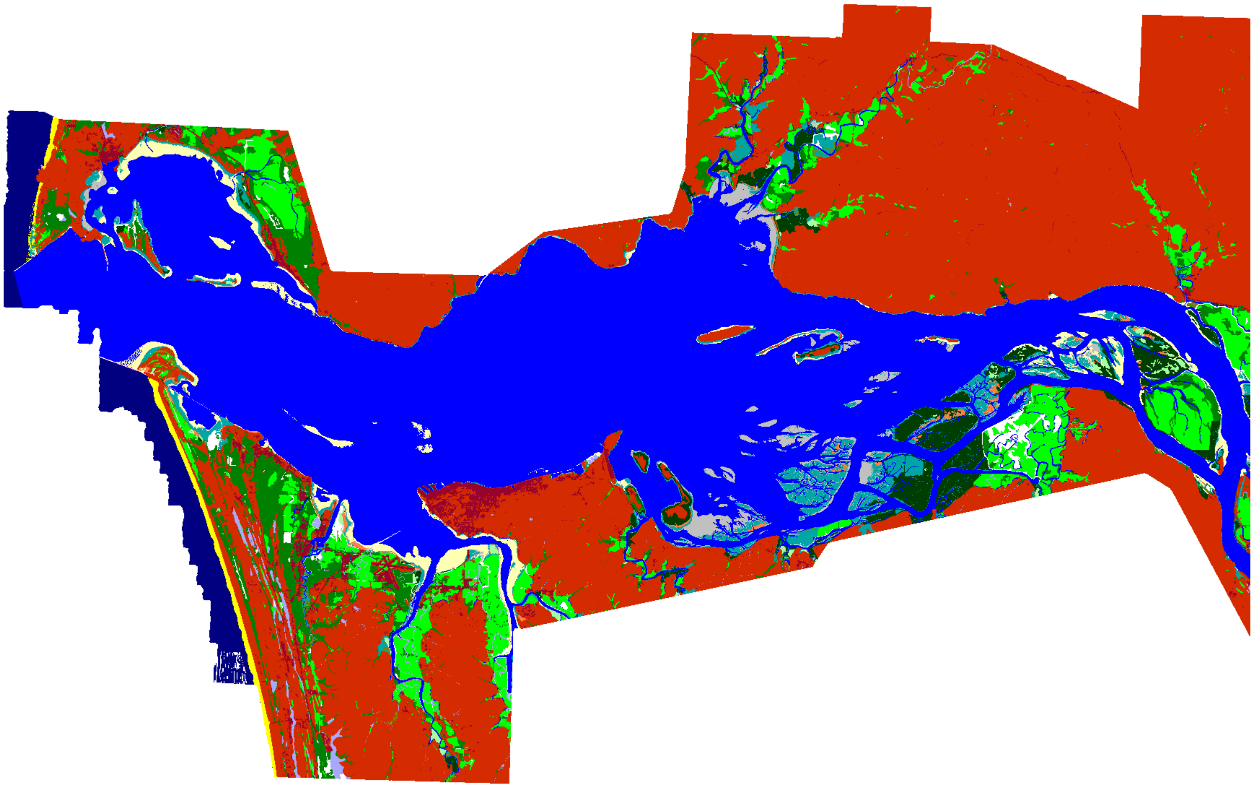


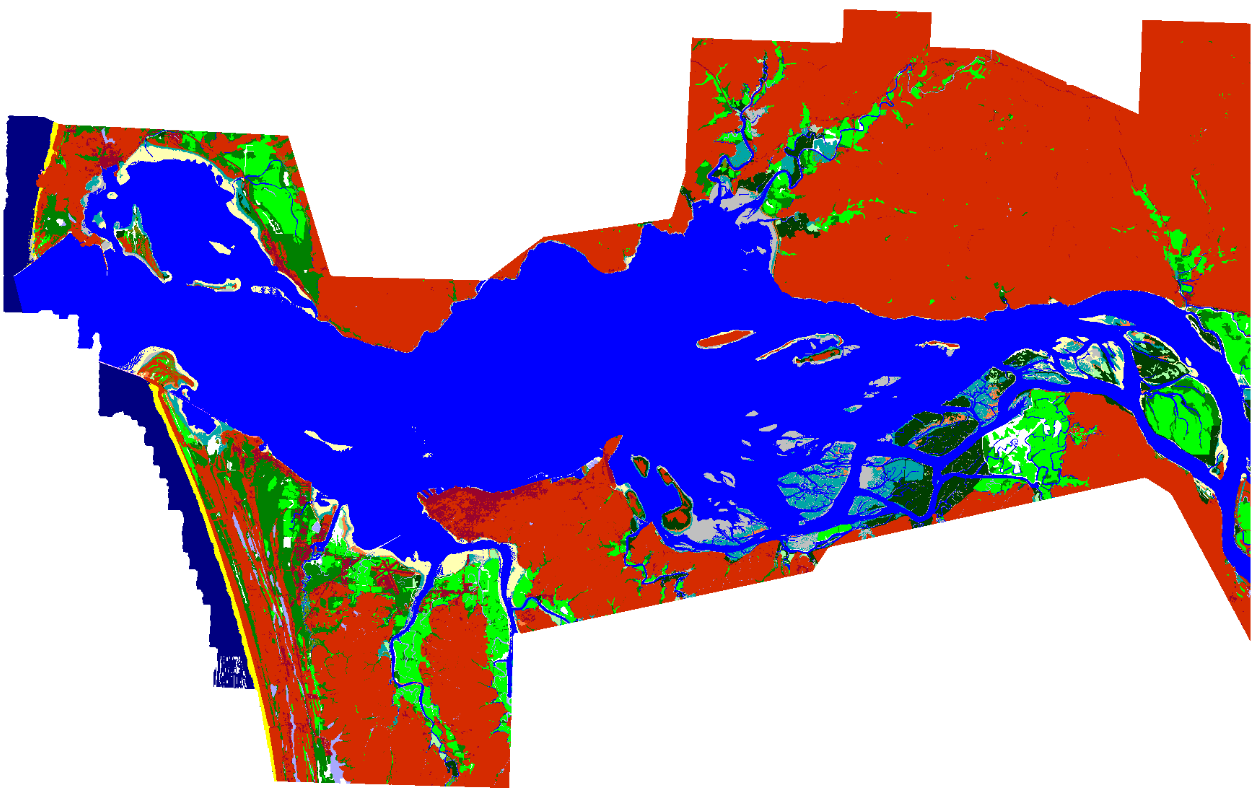
Lewis and Clark Context, 2100, Scenario A1B Mean



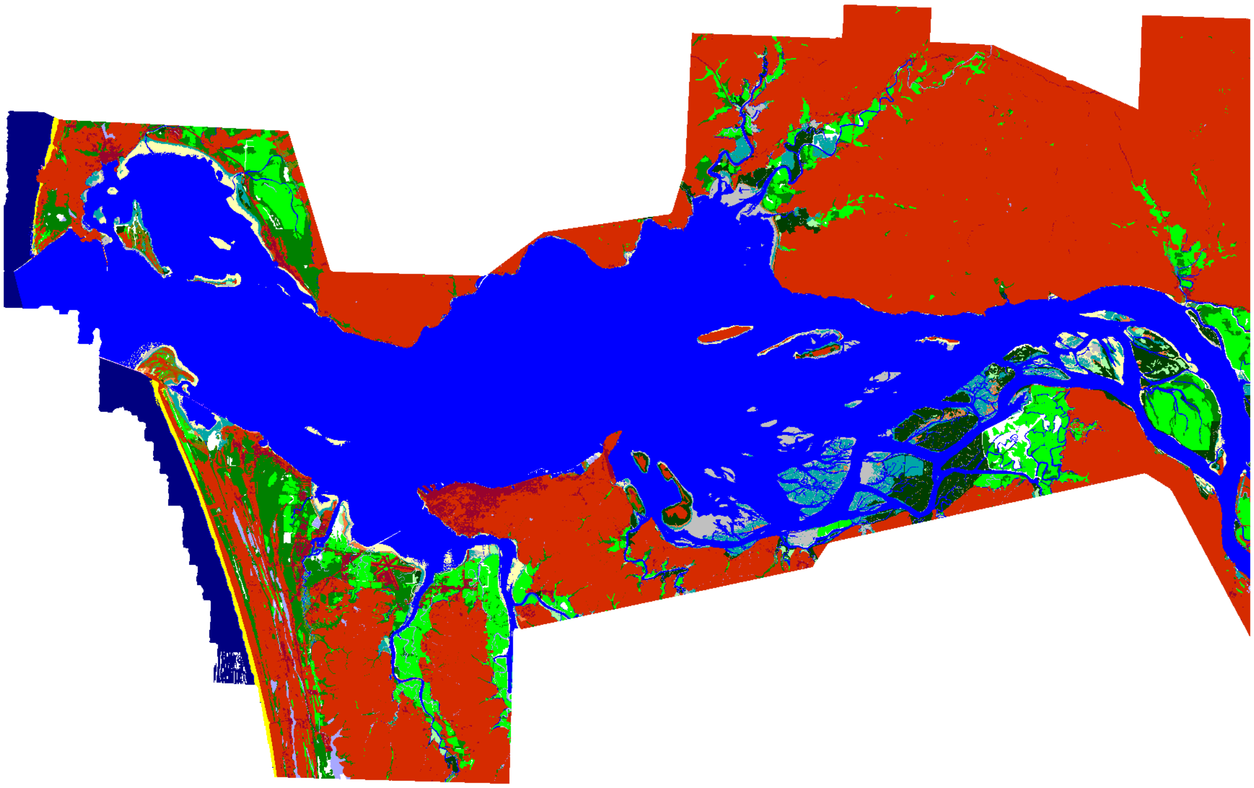
Lewis and Clark Context, Initial Condition



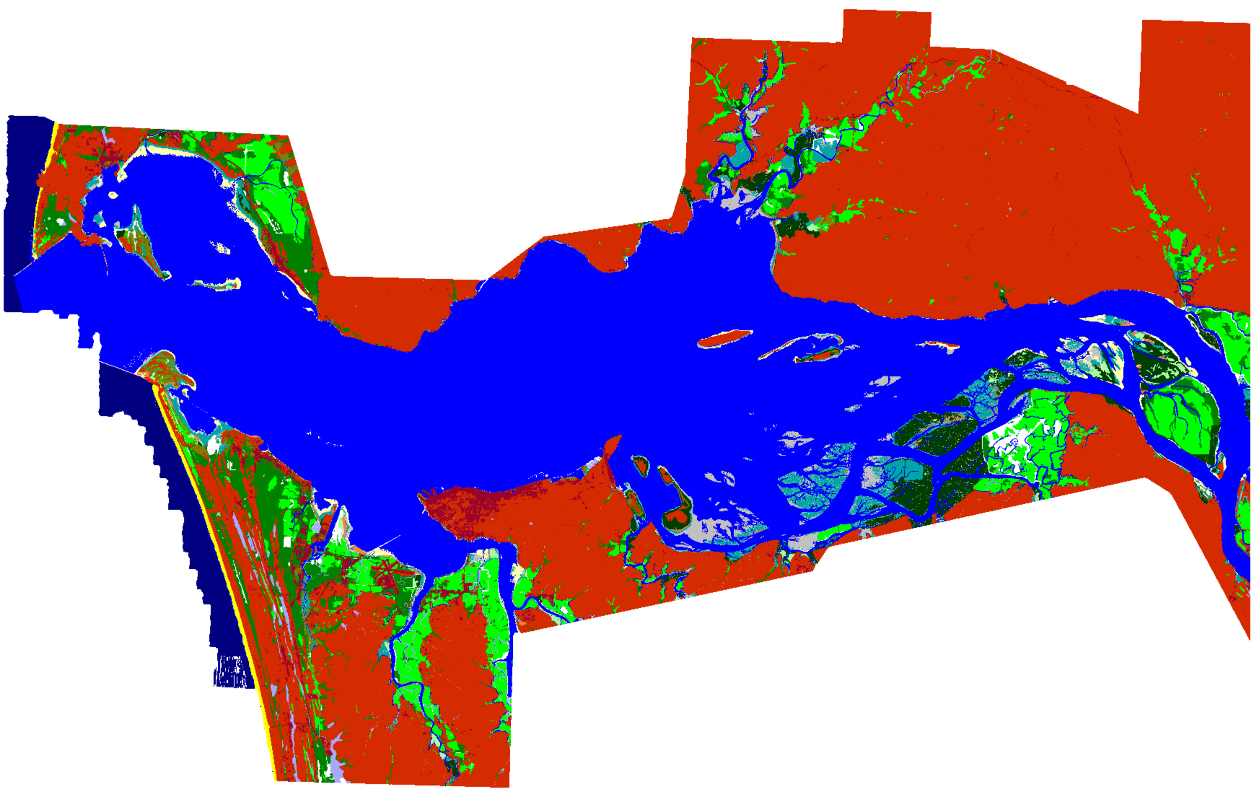
Lewis and Clark Context, 2025, Scenario A1B Maximum



Lewis and Clark Context, 2050, Scenario A1B Maximum



Lewis and Clark Context, 2075, Scenario A1B Maximum



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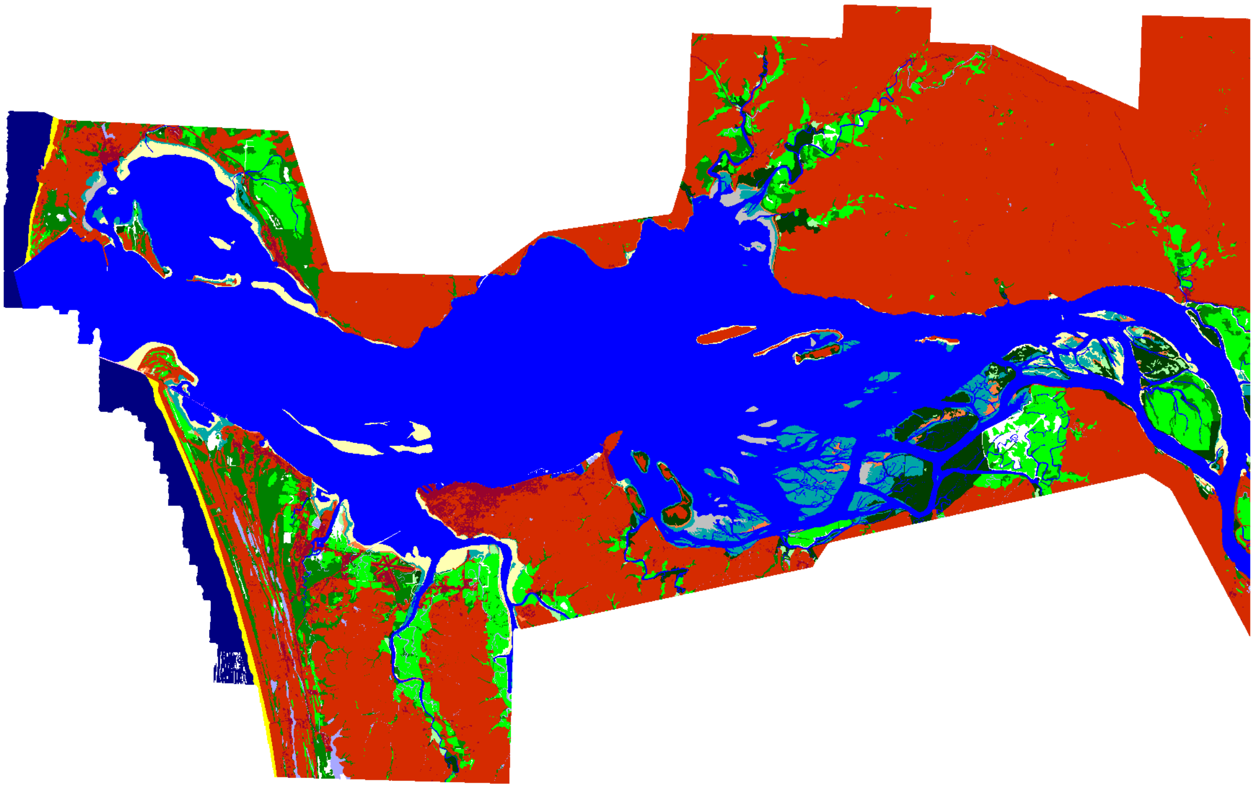

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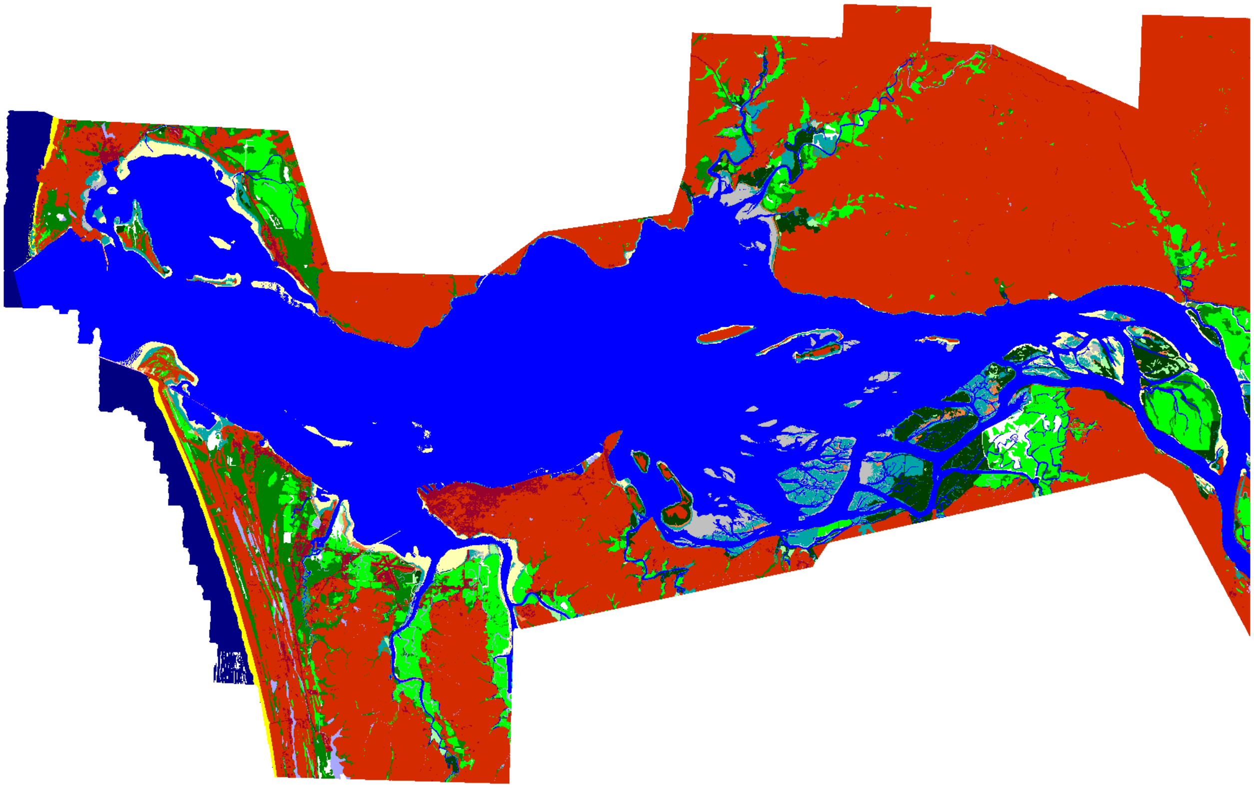
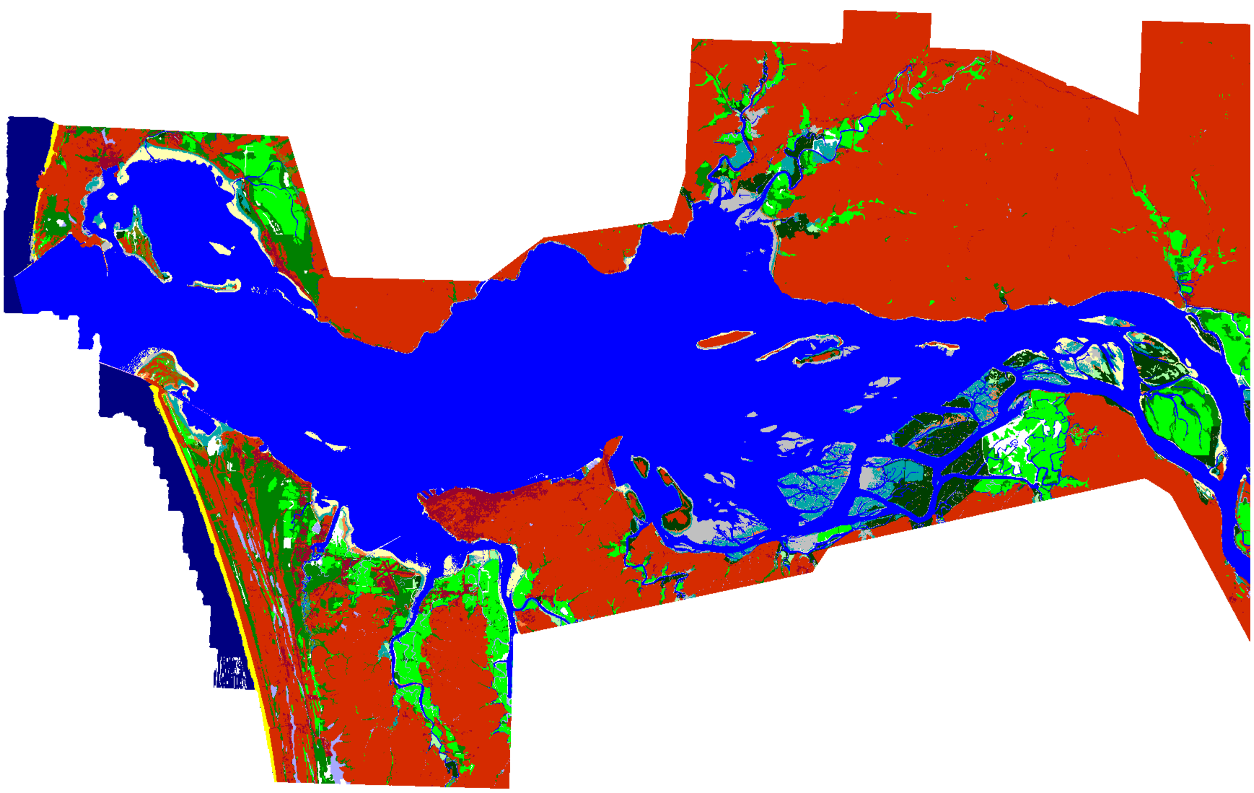


Lewis and Clark Context, 2025, 1 m



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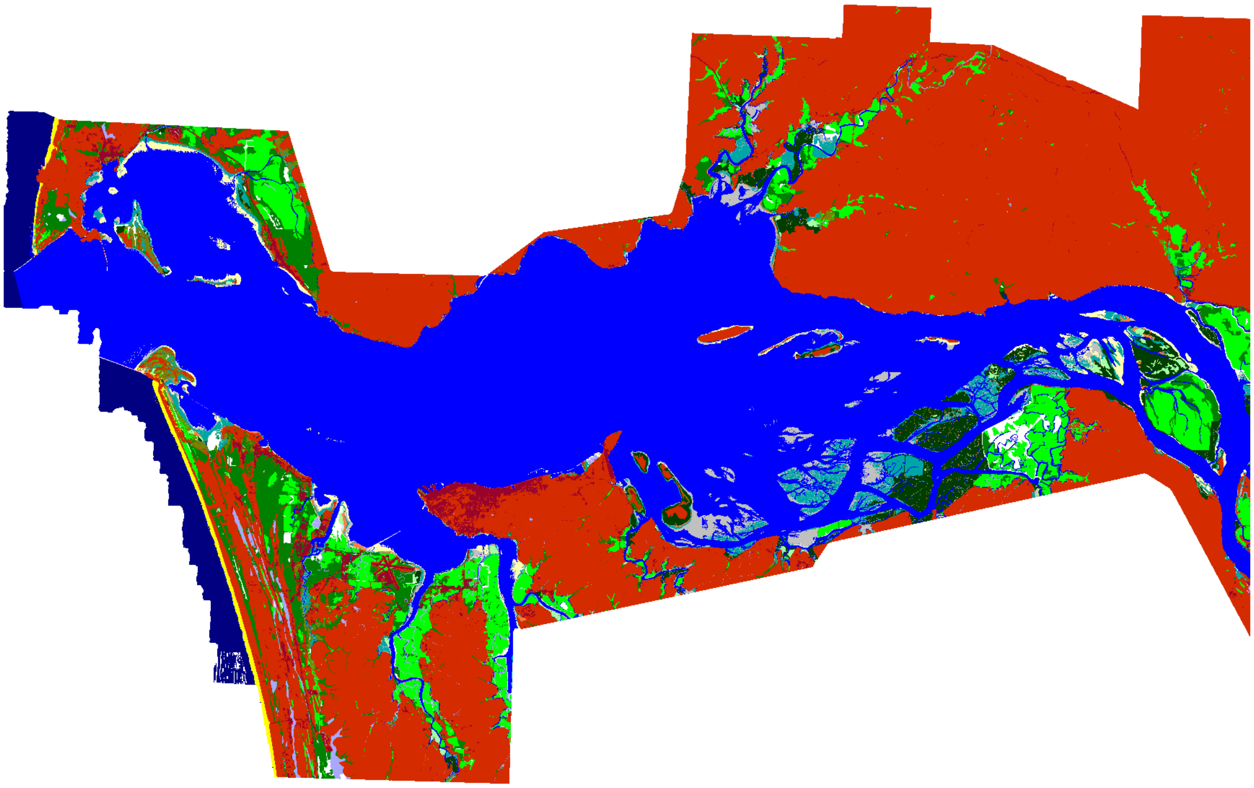

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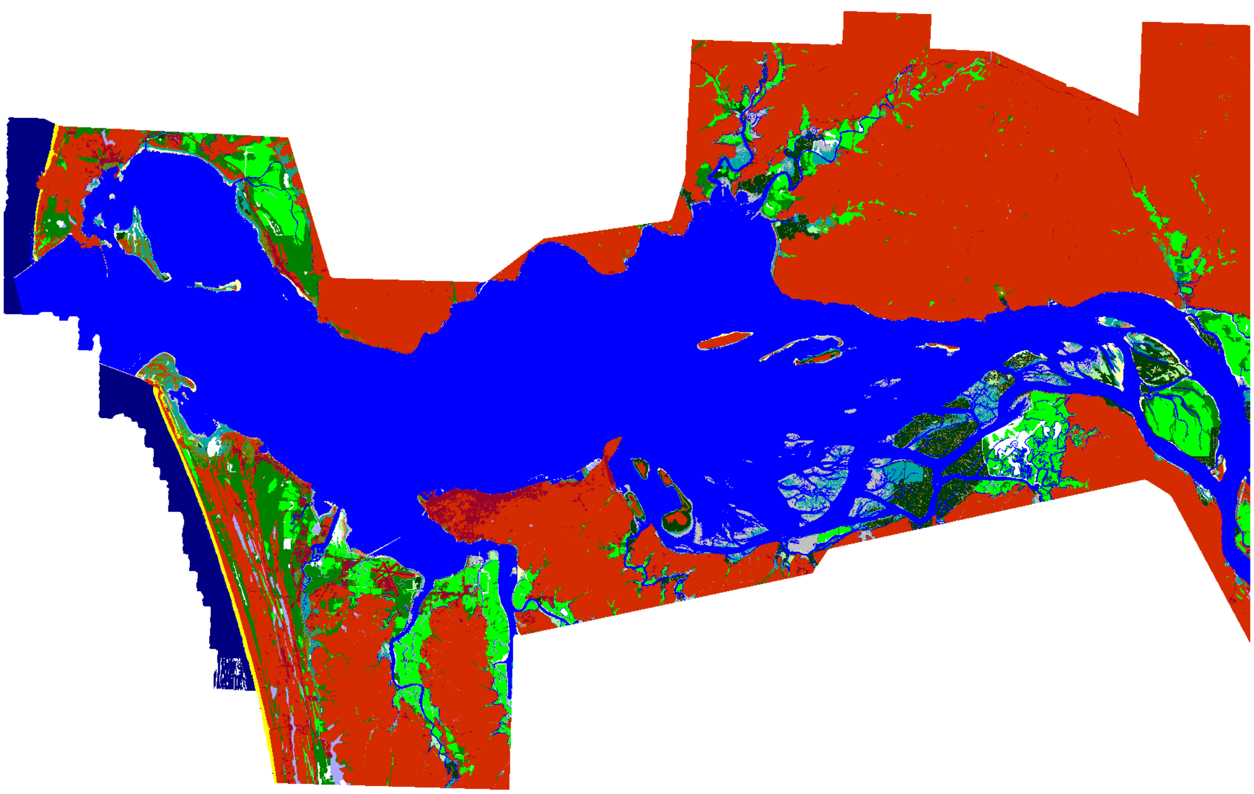
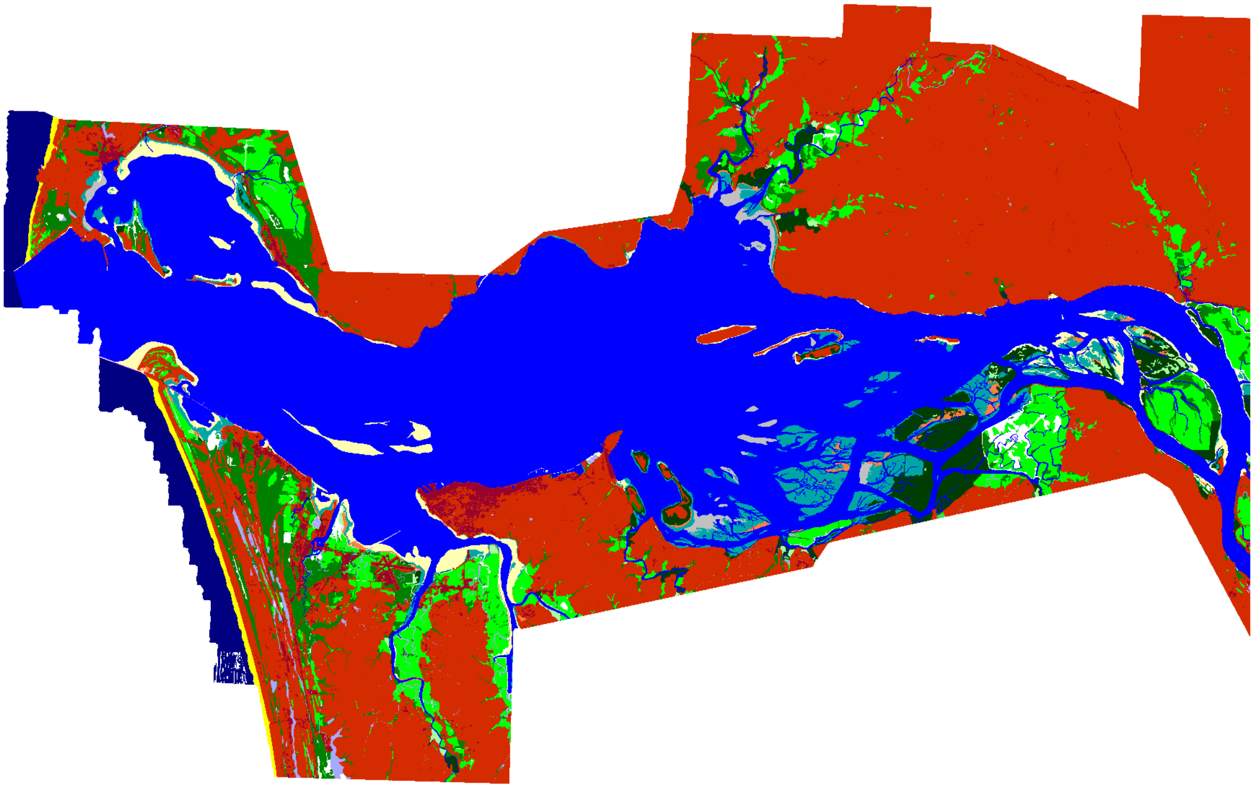


Lewis and Clark Context, 2100, 1 m



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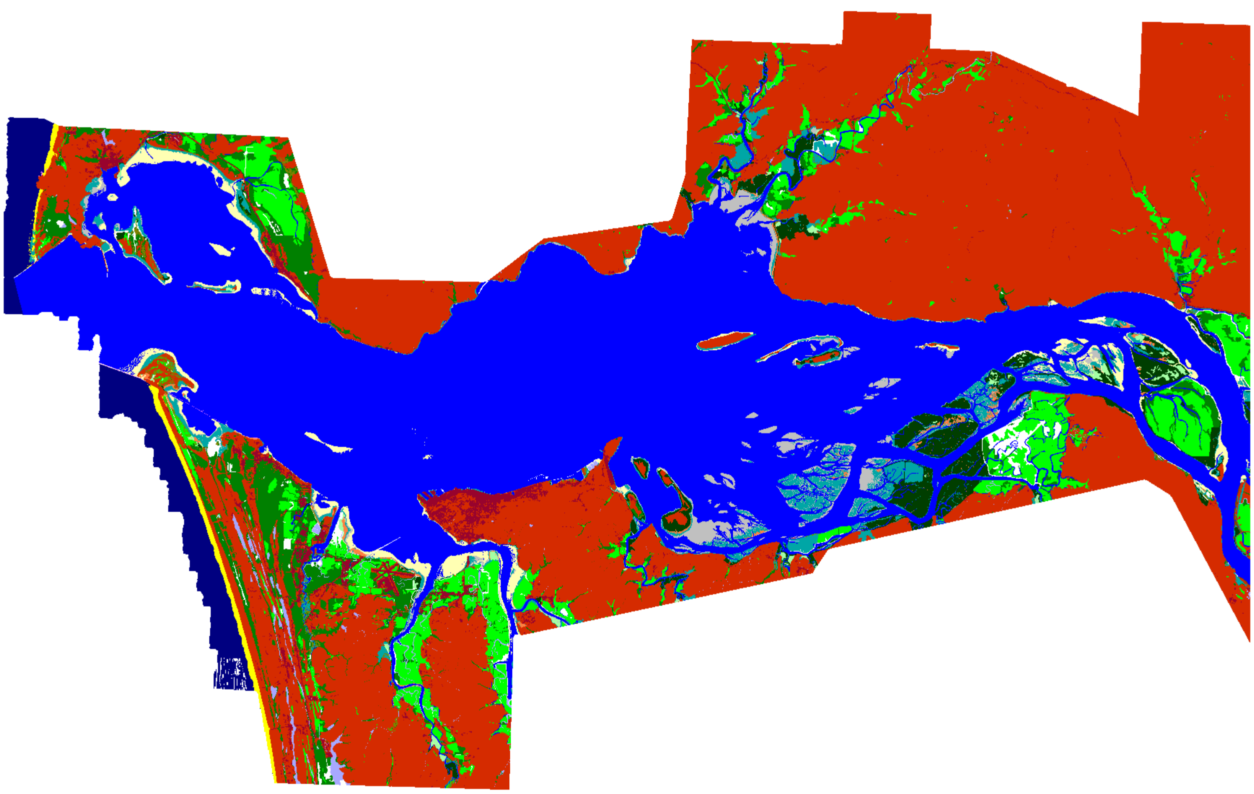
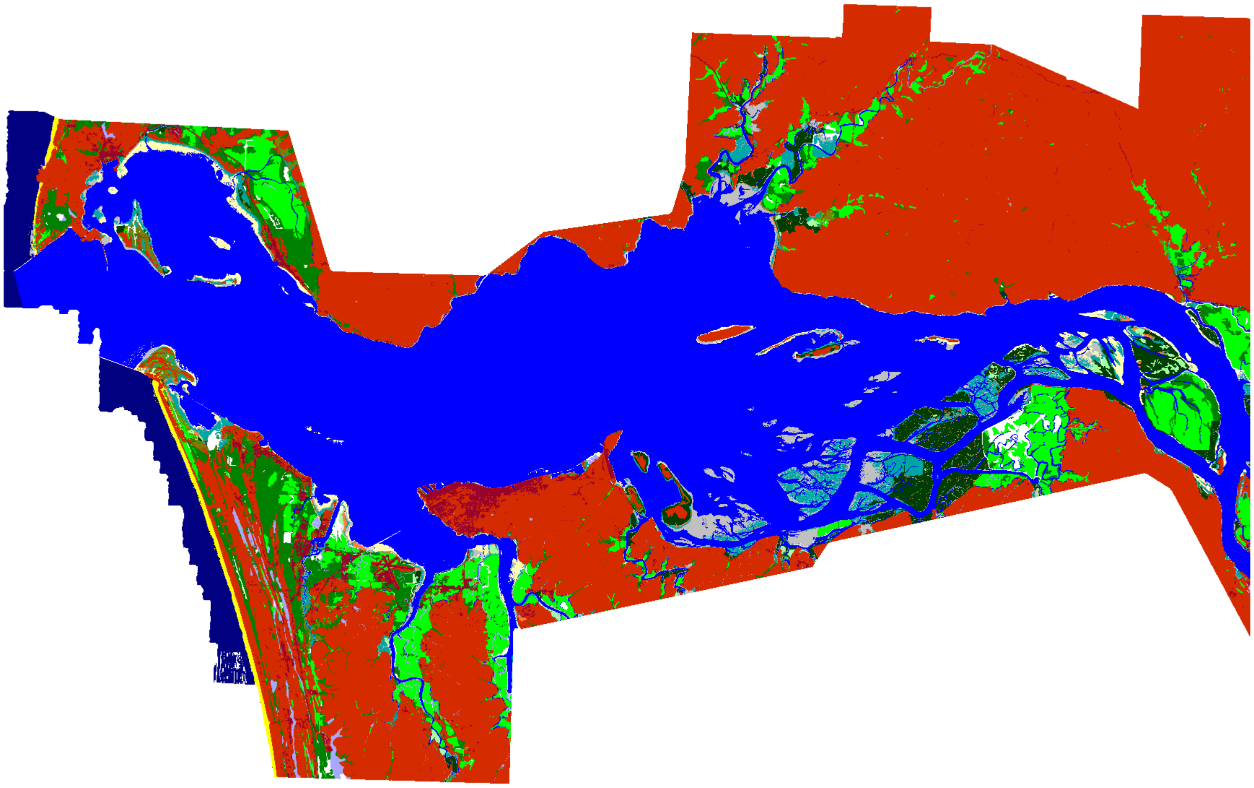


Lewis and Clark Context, 2025, 1.5 m



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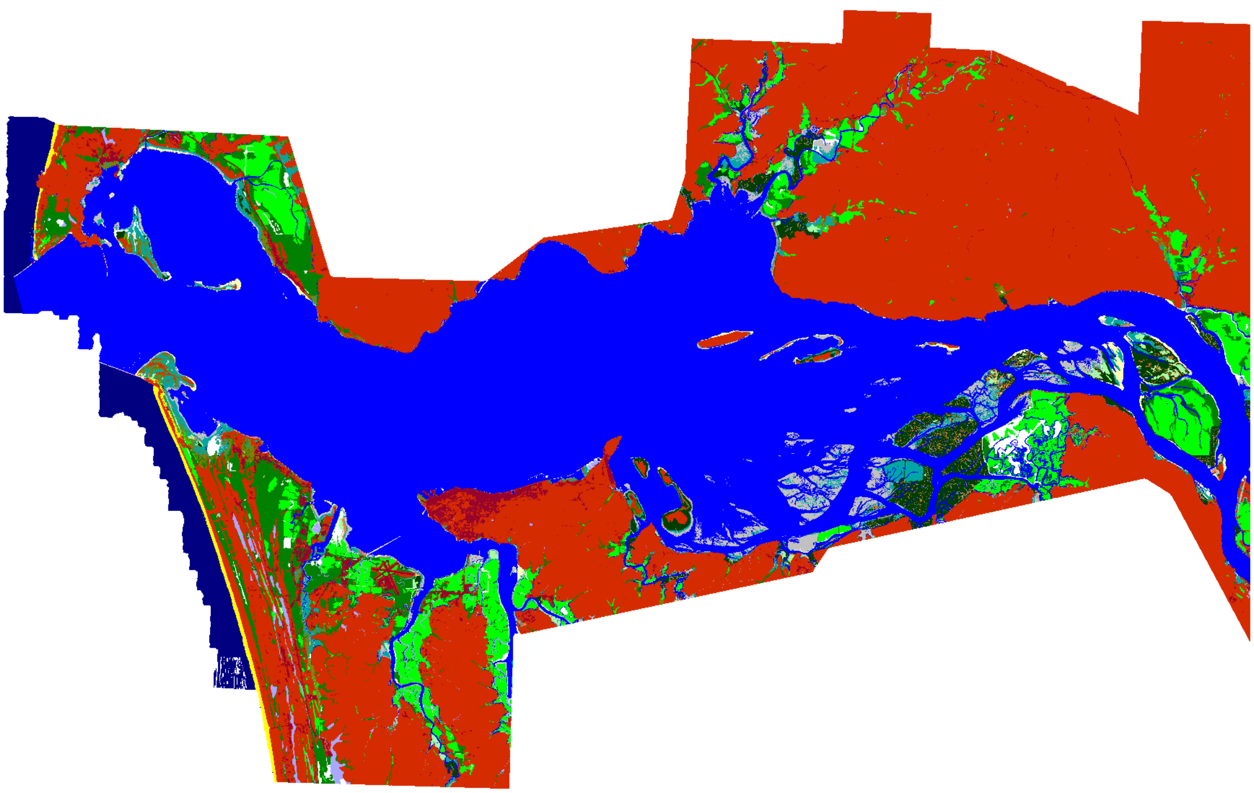

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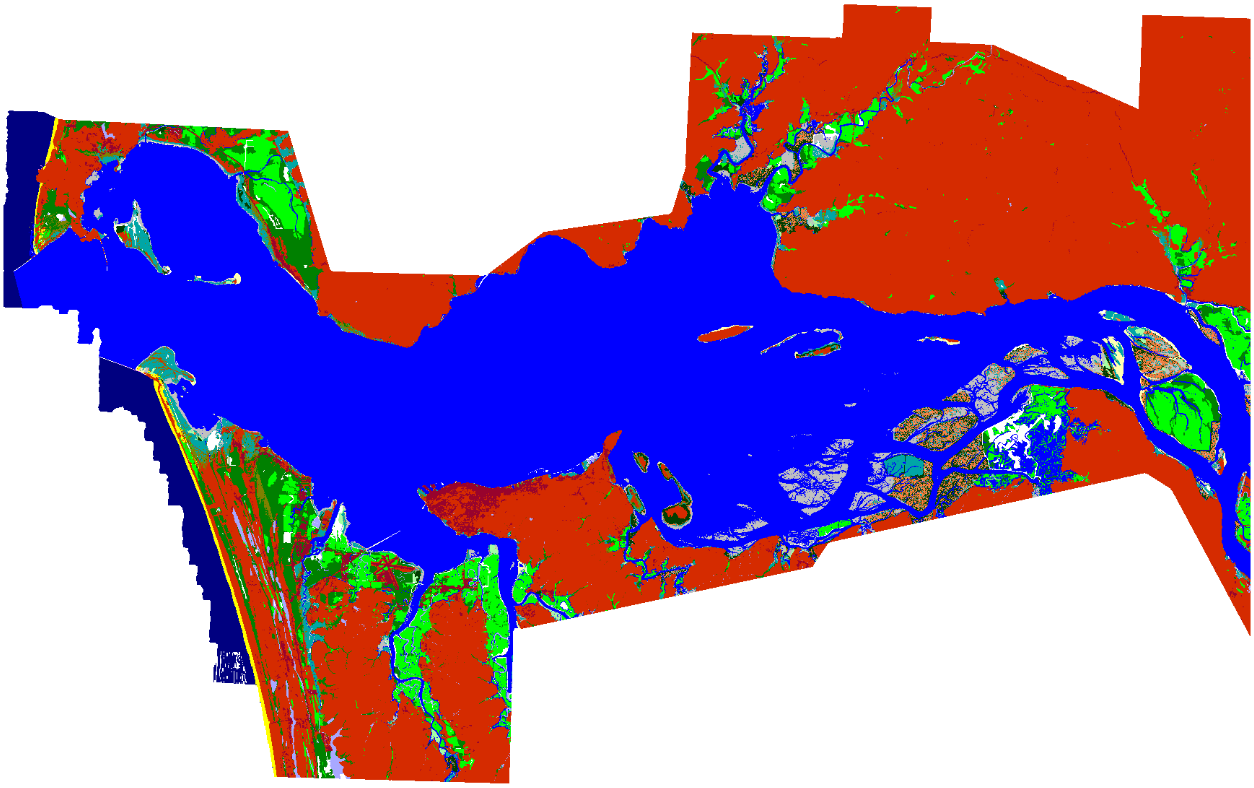

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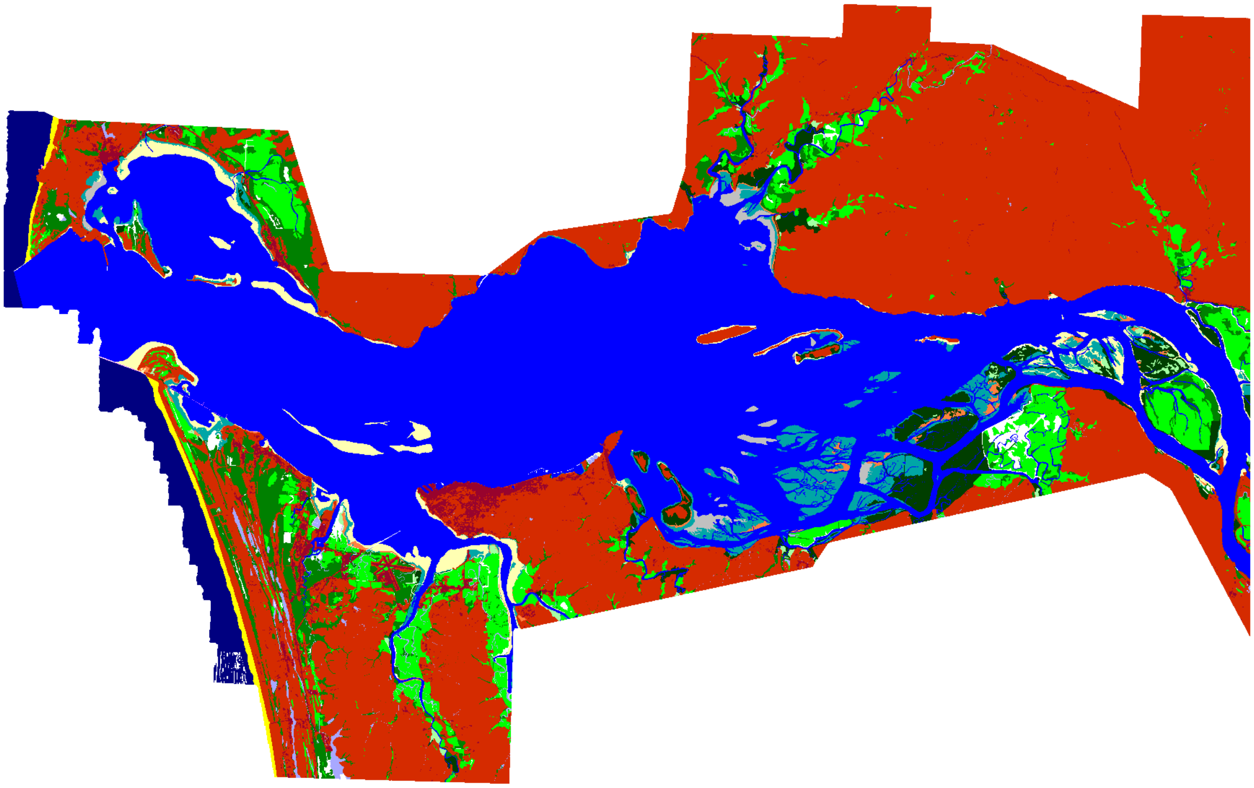

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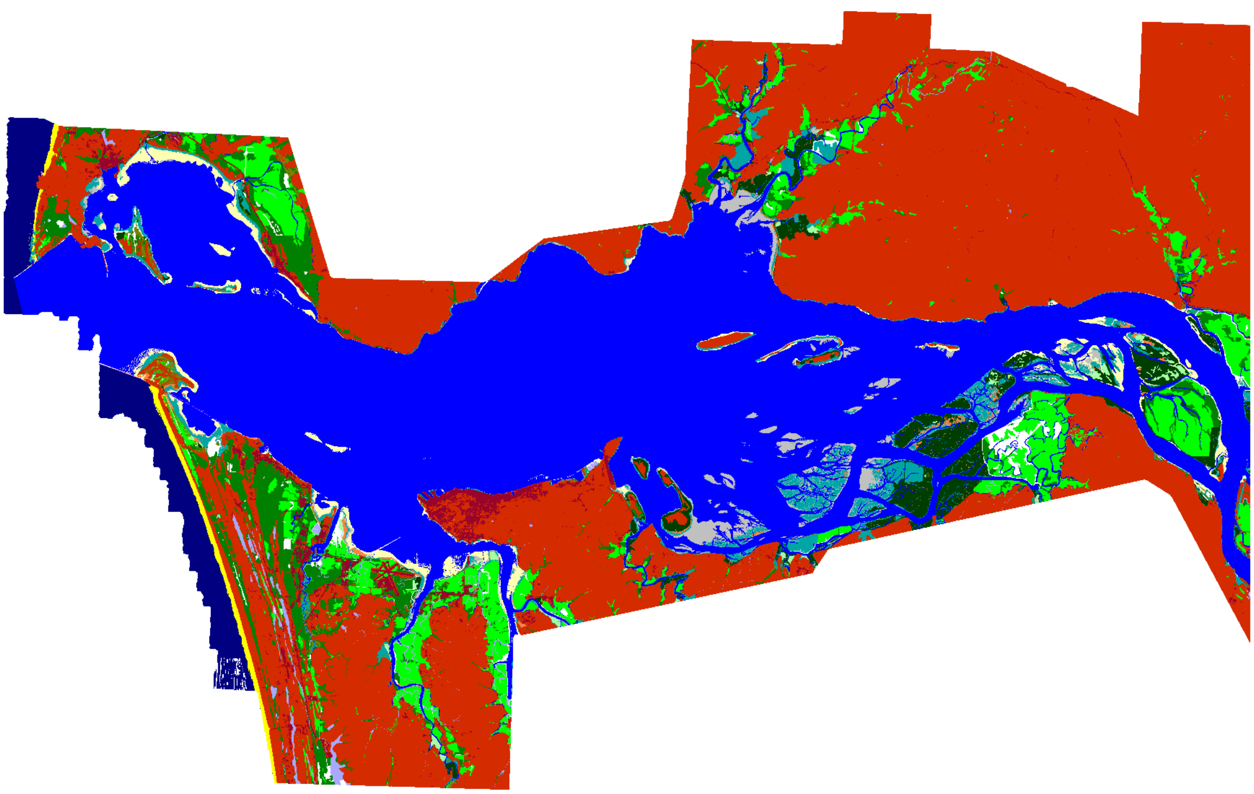
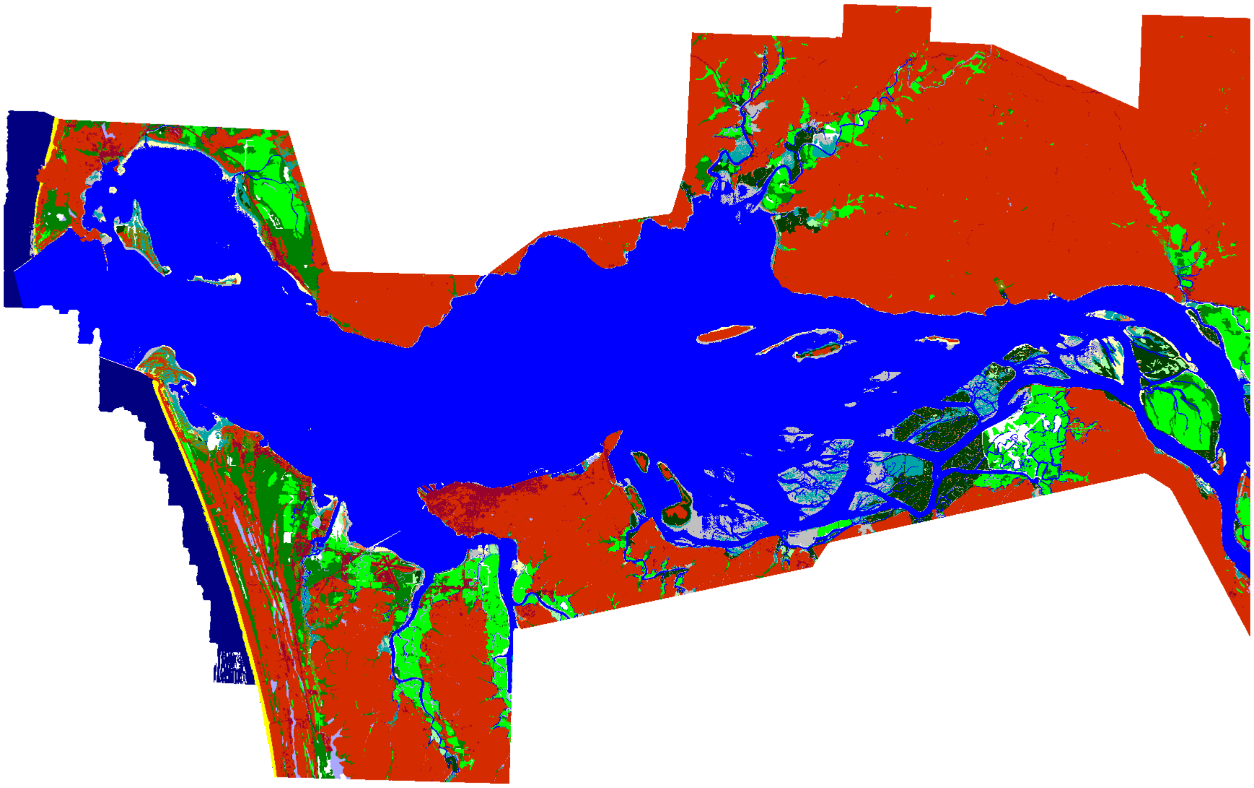


Lewis and Clark Context, 2025, 2 m



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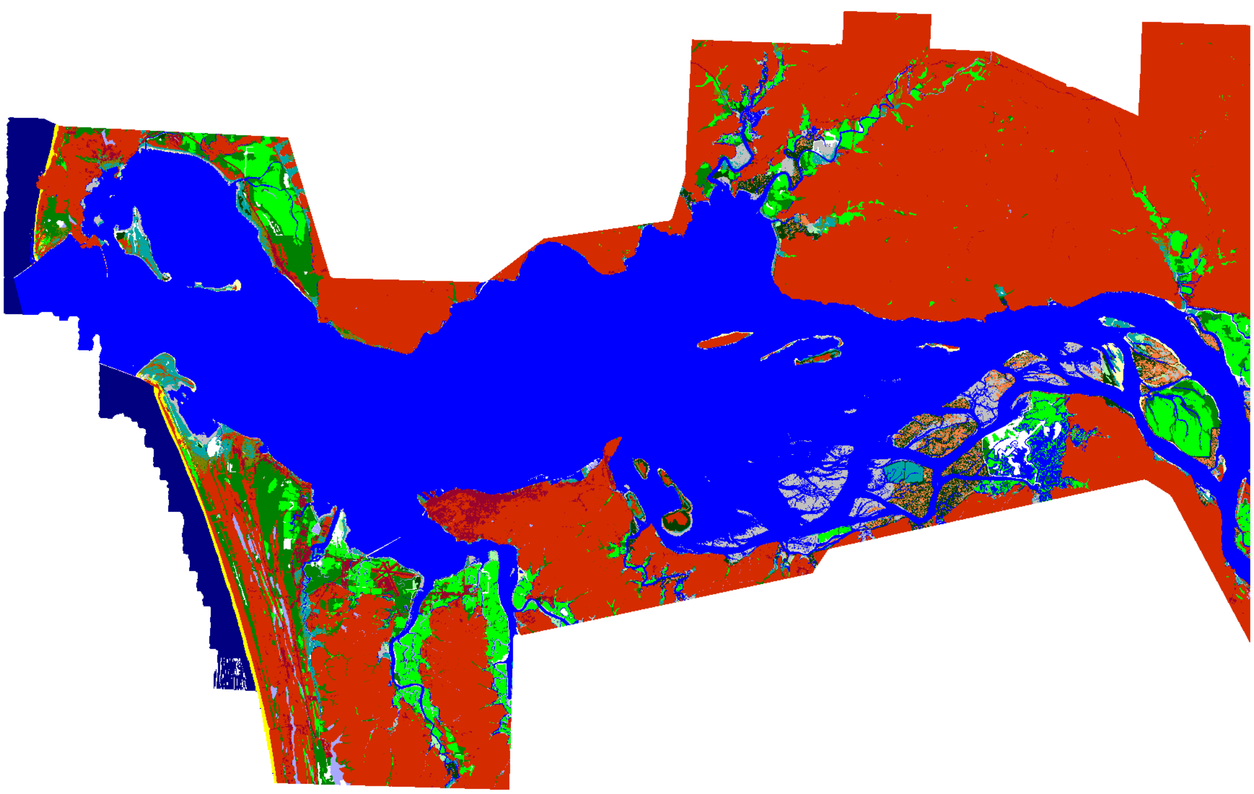

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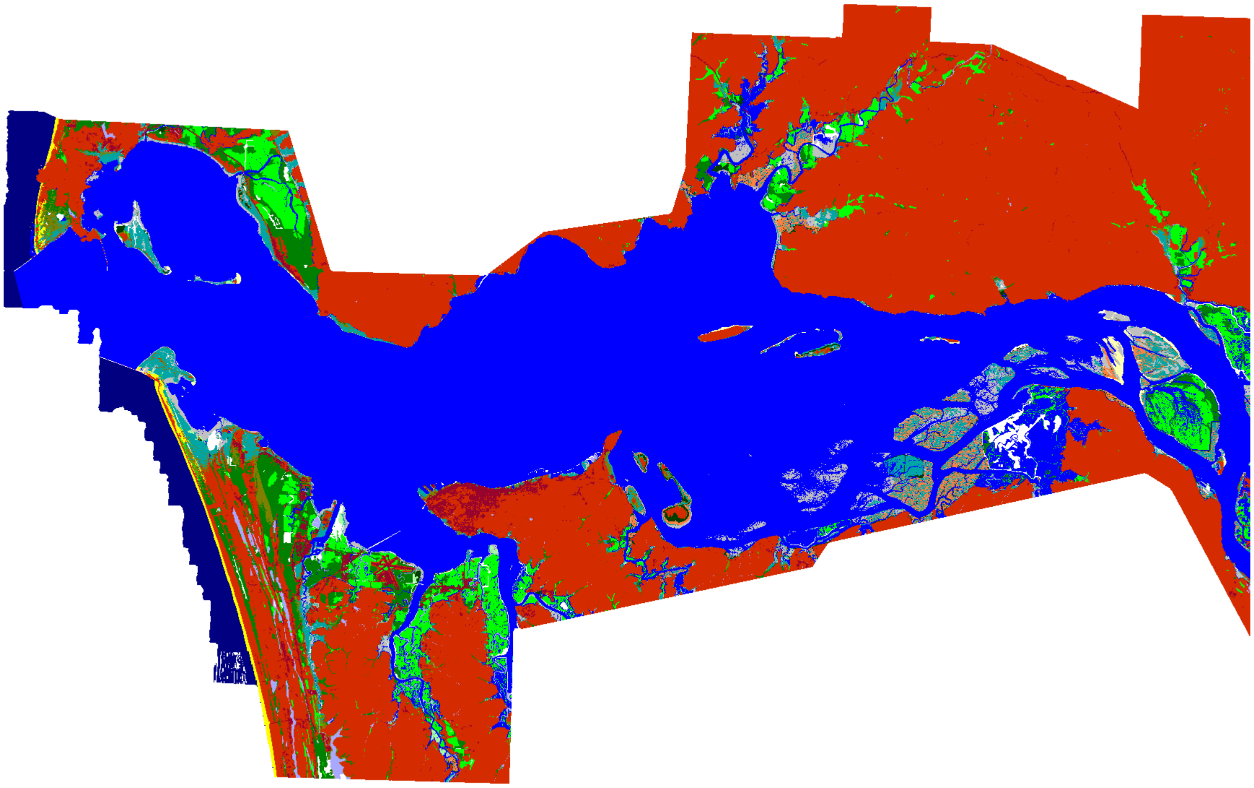

Lewis and Clark Context, 2100, 2 m