Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0) to Seal Beach NWR

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Introduction

Tidal marshes are among the most susceptible ecosystems to climate change, especially accelerated sea level rise (SLR). The International 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 could be 50 to 140 cm. Pfeffer et al. (2008) suggests that 200 cm by 2100 is at the upper end of plausible scenarios due to physical limitations on glaciological conditions. Rising sea level may result in tidal marsh submergence (Moorhead and Brinson 1995) and habitat migration as salt marshes transgress landward and replace tidal freshwater and brackish 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 most Region 4 refuges. This analysis is designed to assist in the production of comprehensive conservation plans (CCPs) for each refuge along with other long-term management plans.

Model Summary

Changes in tidal marsh area and habitat type in response to sea-level rise were modeled using the Sea Level Affecting Marshes Model (SLAMM 5.0) 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, J.K., R.A. Park, and P.W. Mausel. 1992; Park, R.A., J.K. Lee, and D. Canning 1993; Galbraith, H., R. Jones, R.A. Park, J.S. Clough, S. Herrod-Julius, B. Harrington, and G. Page. 2002; National Wildlife Federation et al., 2006; Glick, Clough, et al. 2007; Craft et al., 2009.

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

- **Inundation:** The rise of water levels and the salt boundary are tracked by reducing elevations of each cell as sea levels rise, thus keeping mean tide level (MTL) constant at zero. The effects on each cell are calculated based on the minimum elevation and slope of that cell.
- **Erosion:** Erosion is triggered based on a threshold of maximum fetch and the proximity of the marsh to estuarine water or open ocean. When these conditions are met, horizontal erosion occurs at a rate based on site-specific data.
- **Overwash:** Barrier islands of under 500 meters width are assumed to undergo overwash during each 25-year time-step due to 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.

SLAMM Version 5.0 is the latest version of the SLAMM Model, developed in 2006/2007 and based on SLAMM 4.0. SLAMM 5.0 provides the following refinements:

- The capability to simulate fixed levels of sea-level rise by 2100 in case IPCC estimates of sea-level rise prove to be too conservative;
- Additional model categories such as "Inland Shore," "Irregularly Flooded (Brackish) Marsh," and "Tidal Swamp."
- *Optional.* In a defined estuary, salt marsh, brackish marsh, and tidal fresh marsh can migrate based on changes in salinity, using a simple though geographically-realistic salt wedge model. This optional model was not used when creating results for Seal Beach NWR.

Model results presented in this report were produced using SLAMM version 5.0.1 which was released in early 2008 based on only minor refinements to the original SLAMM 5.0 model. Specifically, the accretion rates for swamps were modified based on additional literature review. For a thorough accounting of SLAMM model processes and the underlying assumptions and equations, please see the SLAMM 5.0.1 technical documentation (Clough and Park, 2008). 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).

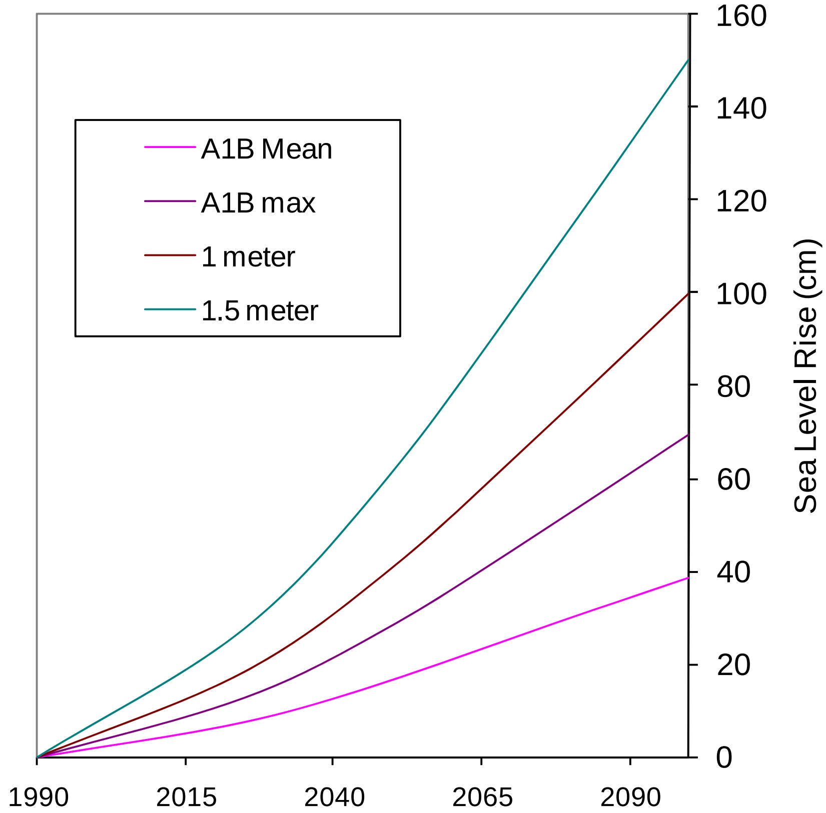
Sea-Level Rise Scenarios

The primary set of eustatic (global) sea level rise scenarios used within SLAMM was derived from the work of the Intergovernmental Panel on Climate Change (IPCC 2001). SLAMM 5 was run using the following IPCC and fixed-rate scenarios:

Scenario	Eustatic SLR by 2025 (cm)	Eustatic SLR by 2050 (cm)	Eustatic SLR by 2075 (cm)	Eustatic SLR by 2100 (cm)
A1B Mean	8	17	28	39
A1B Max	14	30	49	69
1 meter	13	28	48	100
1.5 meter	18	41	70	150

Recent 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 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 might be 50 to 140 cm. To allow for flexibility when interpreting the results, SLAMM was also run assuming 1 meter, 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 Utilized



Methods and Data Sources

A limited set of LIDAR data was found for Seal Beach NWR. The elevation data used are based on a combination of the LIDAR and ifSAR.

An examination of the ifSAR metadata indicates that this digital elevation map (DEM) was derived from flights in 2003 survey illustrated within the map in Figure 2a. An examination of the LIDAR metadata indicates that it was derived from a 1998 flight date (Fig. 2a, 2b).

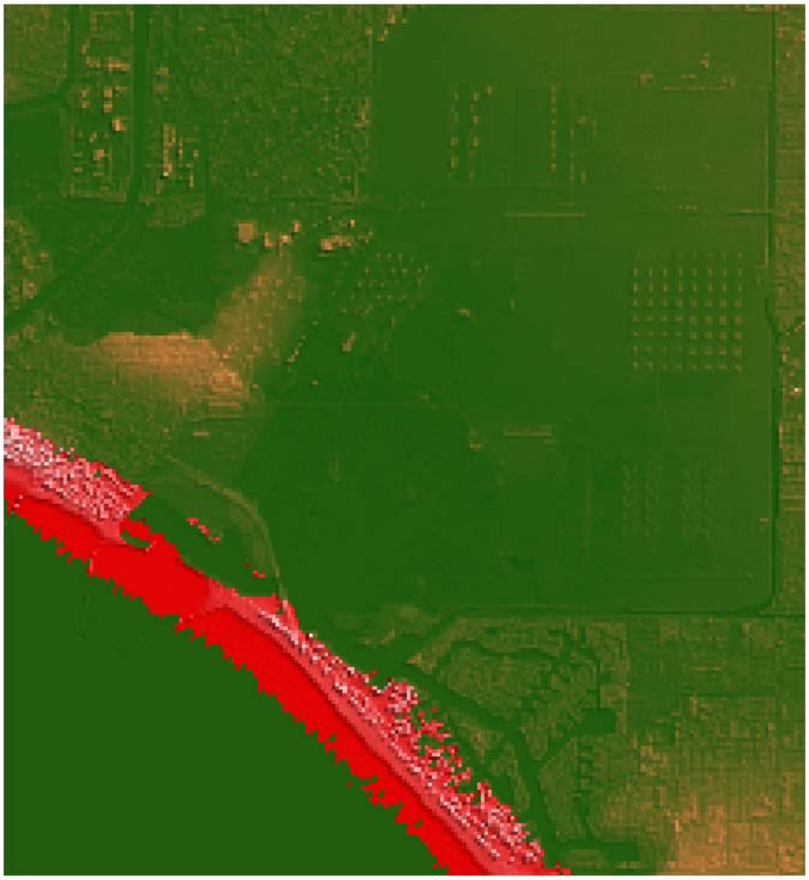


Figure 2a: Seal Beach LIDAR Coverage (in Red) over ifSAR Elevation Map.

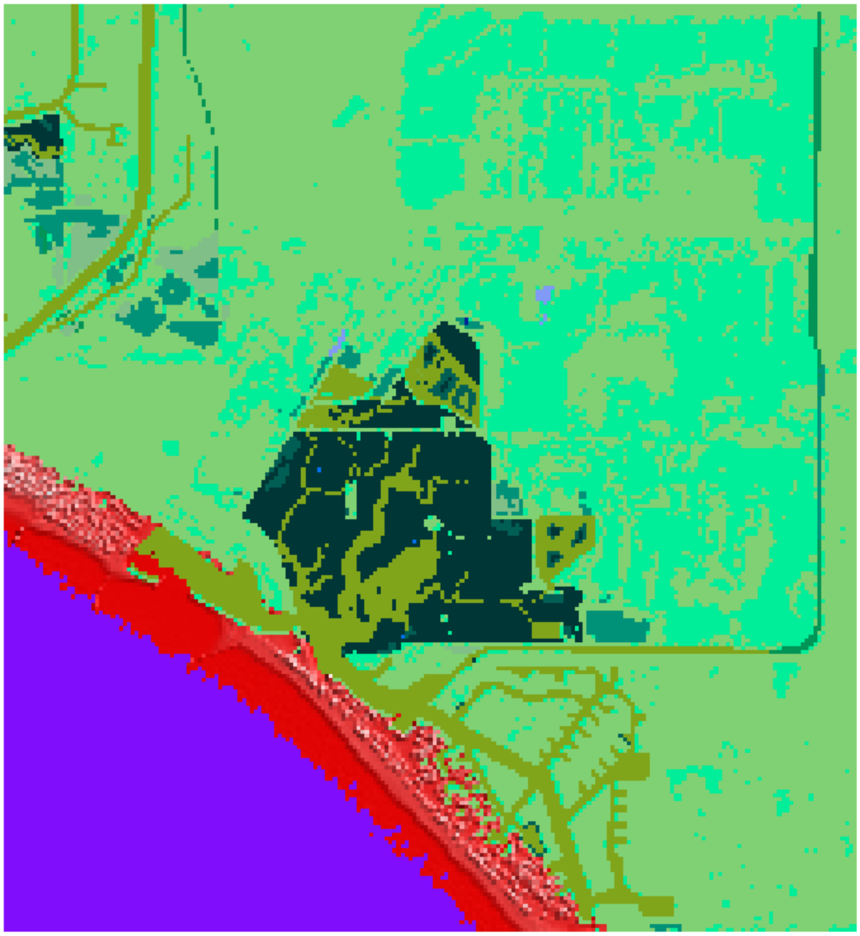


Figure 2b: Seal Beach LIDAR Coverage (in Red) Over NWI Map.

The National Wetlands Inventory for Seal Beach is based on a photo date of 2005. An examination of the NWI map overlaid on recent satellite photos indicates insignificant changes in the Seal Beach NWR wetland boundaries since that date.

Converting the NWI survey into 30 meter cells indicates that the approximately nine hundred sixty acre refuge (approved acquisition boundary including water) is composed of the categories as shown below:

Saltmarsh	56.0%
Estuarine Open Water	26.3%
Developed Dry Land	4.9%
Brackish Marsh	4.8%
Ocean Flat	3.8%
Undeveloped Dry Land	3.2%
Tidal Creek	0.8%
Inland Fresh Marsh	0.3%

Note that the NWI coverage maps tend to represent habitat type at low tide (e.g. wetlands that are flooded at high tide are not classified as open water). However, due to the 30 meter resolution of this study, tidal creeks of less than 30 meter in width are likely omitted.

Based on communication with Kirk Gilligan, the Seal Beach Refuge manager, no portion of this refuge was assumed to be diked or impounded, despite several areas being characterized as such in the NWI map. Kirk writes: "For the purposes of the report, it would be more valuable to me to make the assumption that tidal flow is unrestricted in these areas (since we don't have accurate measurements of how much the tide is or will be restricted)."

The historic trend for sea level rise was estimated at 1.5 mm/year using the average of the three closest stations (9410660, Los Angeles California; 9410580, Newport Beach California; 9410840, Santa Monica California). There are no long-term sea level trend data available for the gage at Long Beach CA. The measured rate can be considered roughly equal to the global average for the last 100 years (approximately 1.5 mm/year).

The tide range at this site was estimated at 1.67 meters using the average of the four closest NOAA oceanic gages (9410660, Los Angeles California; 9410580, Newport Beach California; 9410680, Long Beach, Terminal Island California; 9410650, Cabrillo Beach California). The USGS topographical map for this region suggests an approximate tidal range of four feet (1.22 meters).

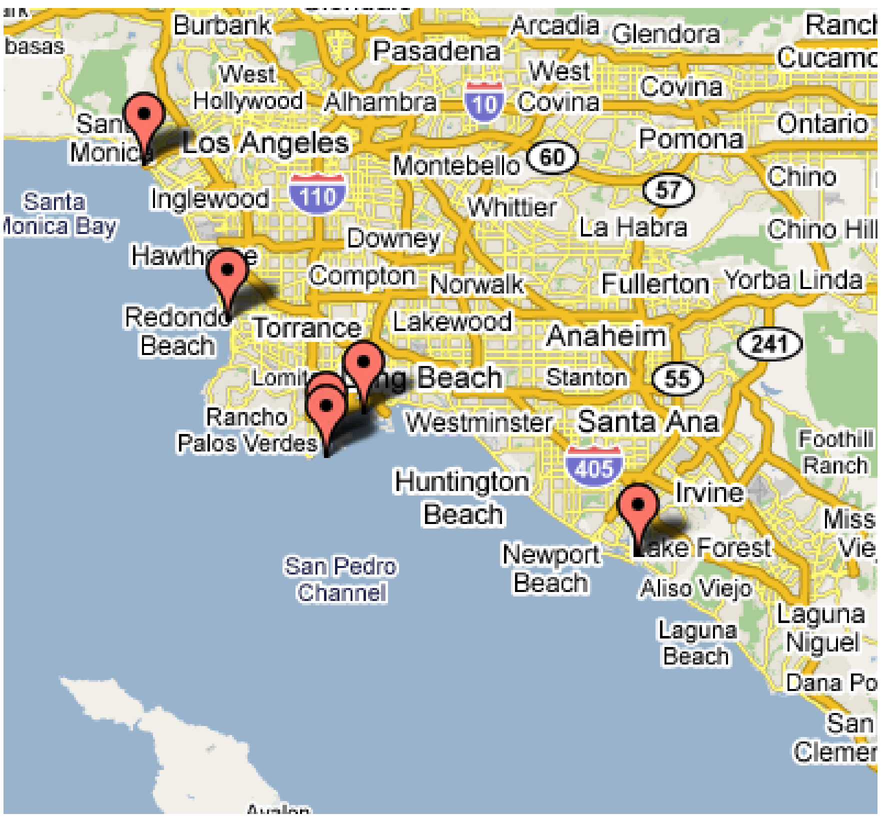


Figure 3: NOAA Gages Relevant to the Study Area.

Kirk Gilligan, the Seal Beach Refuge manager wrote: "*Since Seal Beach NWR does not have any freshwater input to the system, the only accretion would come from dying plant matter. There has also historically been subsidence of the land here up to .5 feet from the extraction of water and oil from beneath the Refuge. So, it's probably more likely that the accretion rate would be close to 0.*" Measured salt marsh accretion rates generally range from roughly 1.5 to 7 mm/year (Reed et al, 2008). By choosing 2 mm/year we selected the low end of measured accretion rates for salt marsh but continued to account for biogenic production and the possibility that increased sea level rise will deliver additional sediment to the Seal Beach refuge.

Modeled U.S. Fish and Wildlife Service refuge boundaries are based on Approved Acquisition Boundaries as published on the FWS National Wildlife Refuge Data and Metadata website, and are current as of October 2008 according to Valerie Howard, Realty Cartographer for Region 8.

The cell-size used for this analysis was 30 meter by 30 meter cells. However, the SLAMM model does track partial conversion of cells based on elevation and slope. (Note that since the LIDAR data produce a more accurate DEM, only the elevations of wetlands classes lying outside of the LIDAR data were overwritten as a function of the local tidal range using the SLAMM elevation pre-processor.)

SUMMARY OF SLAMM INPUT PARAMETERS FOR SEAL BEACH

Description	Seal Beach
DEM Source Date (yyyy)	2003
NWI_photo_date (yyyy)	2005
Direction_OffShore (N|S|E|W)	W
Historic_trend (mm/yr)	1.5
NAVD88_correction (MTL-NAVD88 in meters)	0.798
Water Depth (m below MLW- N/A)	2
TideRangeOcean (meters: MHHW-MLLW)	1.67
TideRangeInland (meters)	1.67
Mean High Water Spring (m above MTL)	1.111
MHSW Inland (m above MTL)	1.111
Marsh Erosion (horz meters/year)	1.8
Swamp Erosion (horz meters/year)	1
TFlat Erosion (horz meters/year) [from 0.5]	0.5
Salt marsh vertical accretion (mm/yr) Final	2.0
Brackish March vert. accretion (mm/yr) Final	2.0
Tidal Fresh vertical accretion (mm/yr) Final	4.0
Beach/T.Flat Sedimentation Rate (mm/yr)	0.5
Frequency of Large Storms (yr/washover)	25
Use Elevation Preprocessor for Wetlands	TRUE

Results

Seal Beach NWR is predicted to have differing degrees of vulnerability depending on the scenario of sea level rise analyzed. Under the 0.39 meters by 2100 scenario, only one quarter of marshes are predicted to be lost. This number increases to two thirds under a 0.69 meter scenario and nearly one hundred percent loss is predicted under scenarios of greater than one meter.

The small quantity of undeveloped dry land is predicted to be vulnerable under all scenarios run. Developed dry land is assumed to be maintained and protected in this analysis.

SLR by 2100 (m)	0.39	0.69	1	1.5
Saltmarsh	24%	68%	84%	97%
Developed Dry Land	0%	0%	0%	0%
Brackish Marsh	26%	68%	100%	100%
Ocean Flat	49%	86%	100%	100%
Undeveloped Dry Land	73%	94%	96%	98%

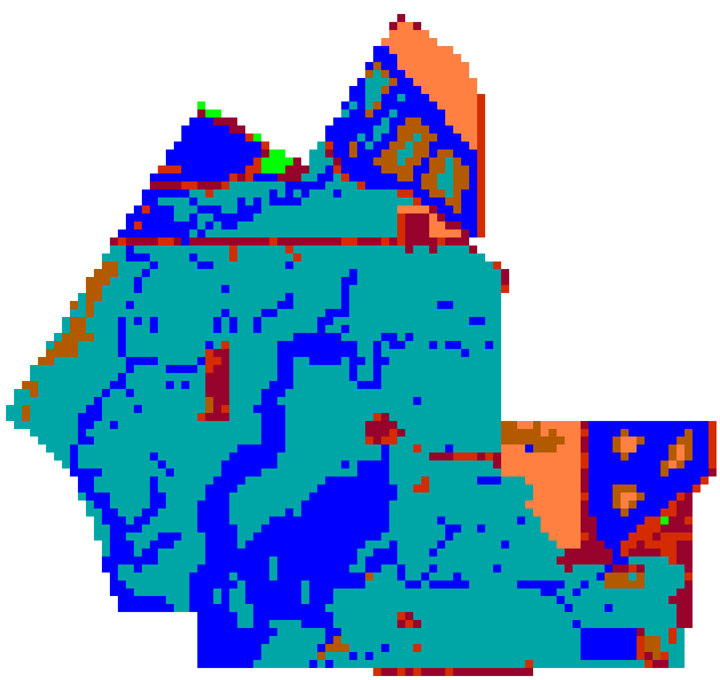
Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

Maps of SLAMM input and output to follow will use the following legend:

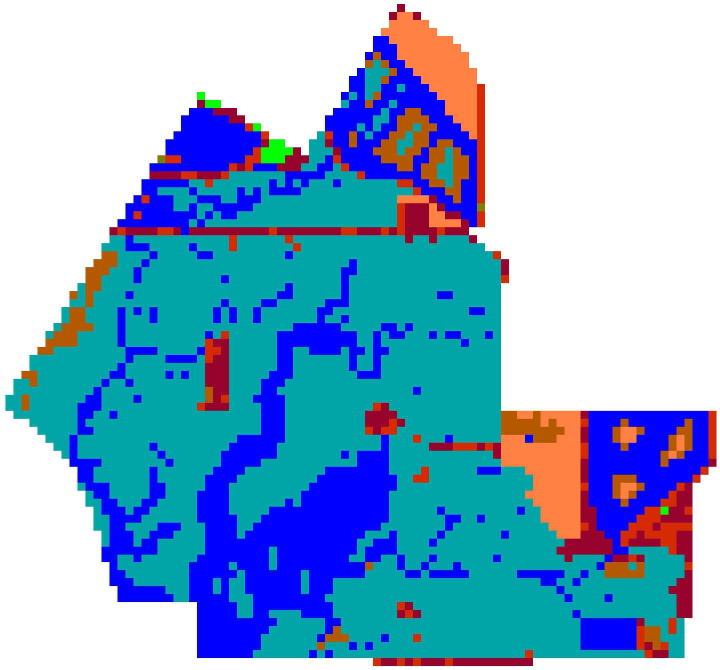
Seal Beach NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

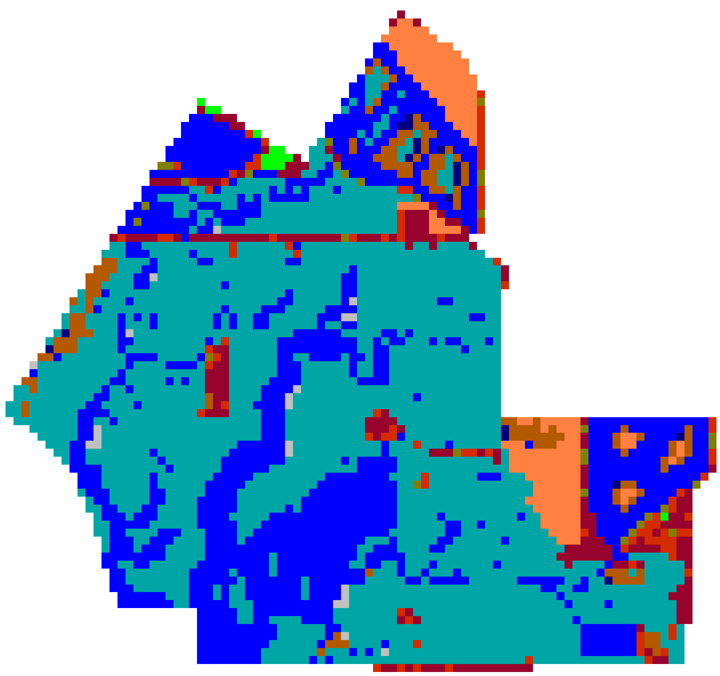
	Initial	2025	2050	2075	2100
Saltmarsh	537.5	536.1	514.5	469.5	409.5
Estuarine Open Water	252.2	253.8	267.3	288.1	290.2
Developed Dry Land	46.7	46.7	46.7	46.7	46.7
Brackish Marsh	45.8	45.7	44.4	39.8	34.1
Ocean Flat	36.3	34.7	30.6	24.8	18.3
Undeveloped Dry Land	30.2	27.5	21.6	13.2	8.2
Tidal Creek	7.3	7.3	7.3	7.3	7.3
Inland Fresh Marsh	3.1	3.1	3.1	3.1	3.1
Tidal Flat	0.0	0.0	9.4	39.2	88.6
Open Ocean	0.0	1.6	5.6	11.7	35.2
Trans. Salt Marsh	0.0	2.7	8.7	15.2	17.3
Ocean Beach	0.0	0.0	0.0	0.4	0.6
Estuarine Beach	0.0	0.0	0.0	0.0	0.1
Total (incl. water)	**959.2**	**959.2**	**959.2**	**959.2**	**959.2**



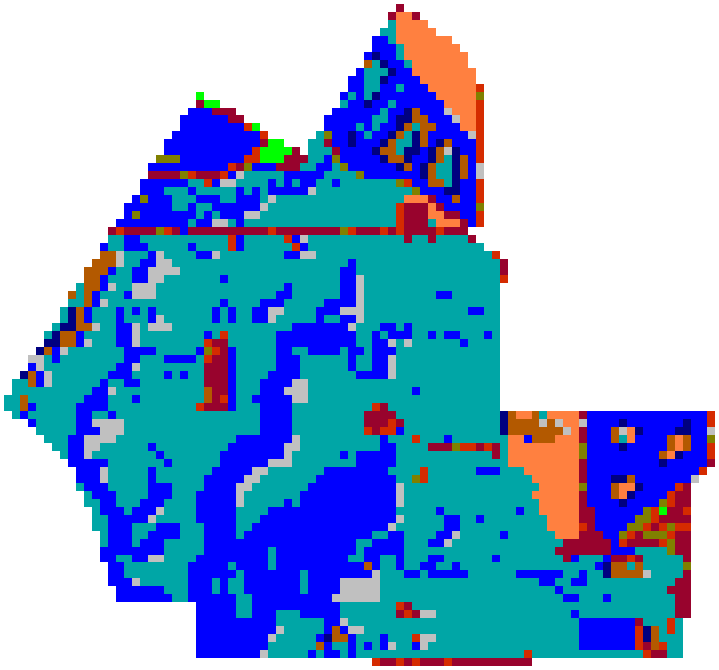
Seal Beach NWR, Initial Condition



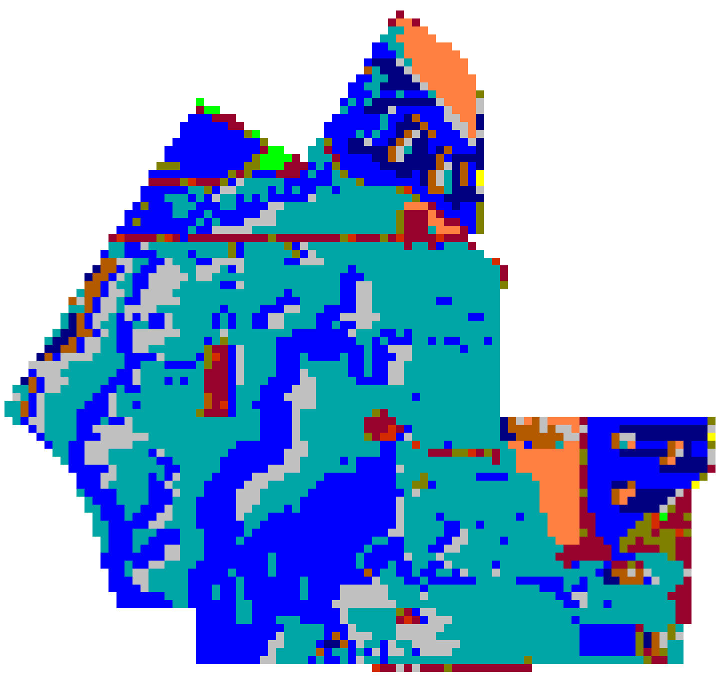
Seal Beach NWR, 2025, Scenario A1B Mean Protect Developed Dry Land



Seal Beach NWR, 2050, Scenario A1B Mean Protect Developed Dry Land



Seal Beach NWR, 2075, Scenario A1B Mean Protect Developed Dry Land

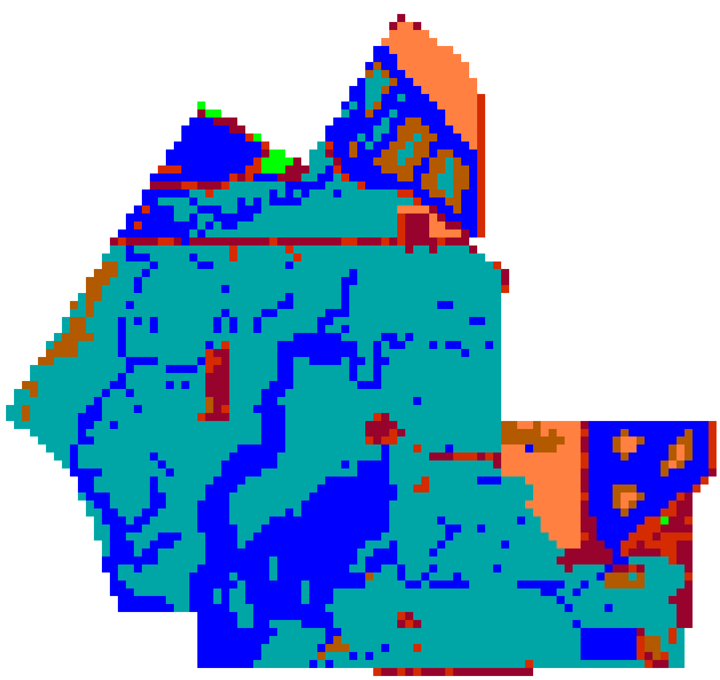


Seal Beach NWR, 2100, Scenario A1B Mean Protect Developed Dry Land

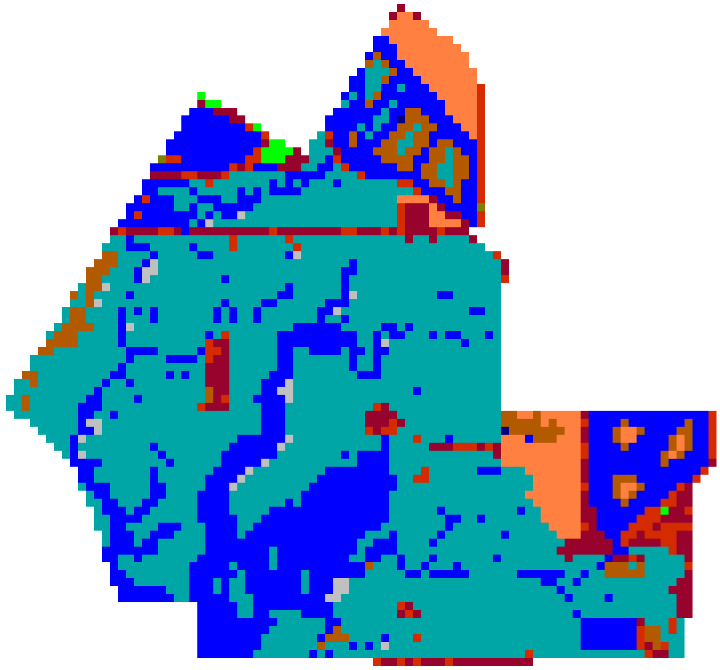
Seal Beach NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

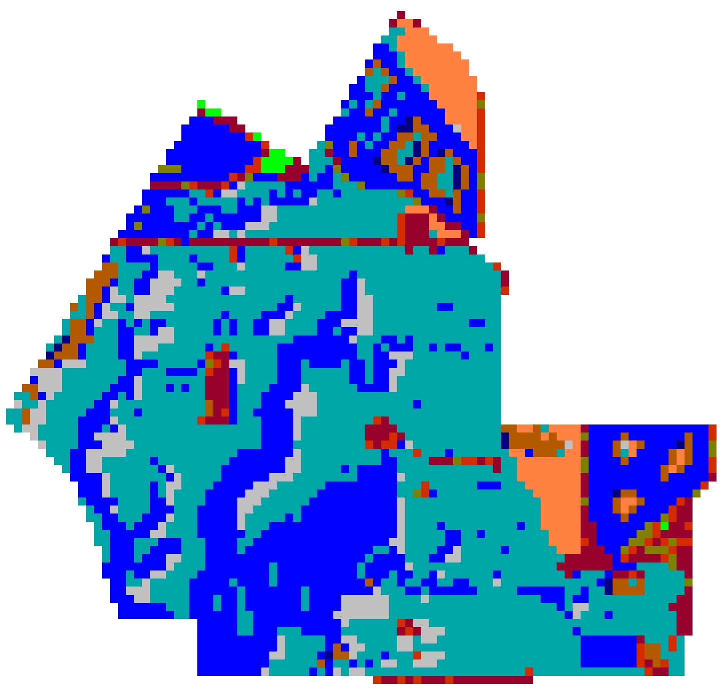
	Initial	2025	2050	2075	2100
Saltmarsh	537.5	520.9	443.3	305.2	172.9
Estuarine Open Water	252.2	262.6	287.4	314.2	318.4
Developed Dry Land	46.7	46.7	46.7	46.7	46.7
Brackish Marsh	45.8	44.8	38.5	27.5	14.7
Ocean Flat	36.3	33.2	25.1	12.6	5.2
Undeveloped Dry Land	30.2	25.7	14.4	4.9	1.8
Tidal Creek	7.3	7.3	7.3	7.3	7.3
Inland Fresh Marsh	3.1	3.1	3.0	2.2	1.3
Tidal Flat	0.0	7.3	66.3	193.4	322.8
Open Ocean	0.0	3.0	11.2	24.4	56.8
Trans. Salt Marsh	0.0	4.6	15.8	20.1	11.2
Ocean Beach	0.0	0.0	0.0	0.5	0.0
Estuarine Beach	0.0	0.0	0.0	0.0	0.1
Total (incl. water)	**959.2**	**959.2**	**959.2**	**959.2**	**959.2**



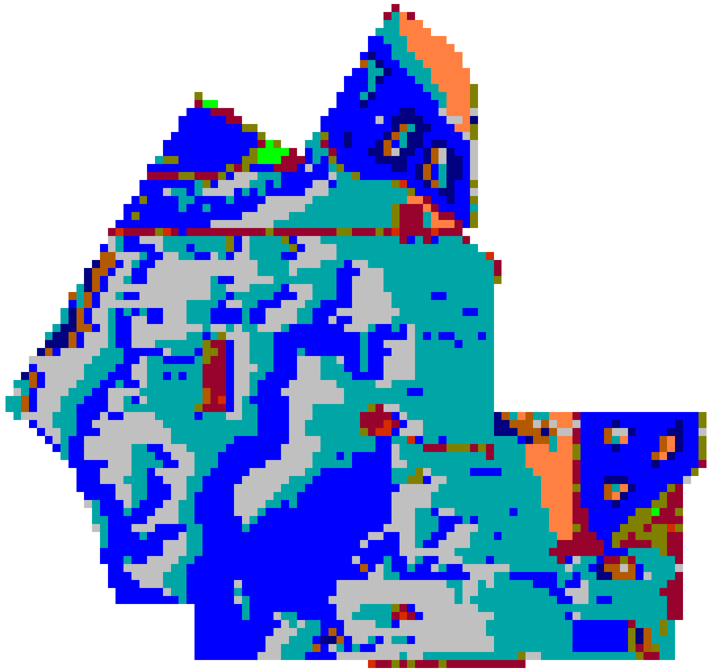
Seal Beach NWR, Initial Condition



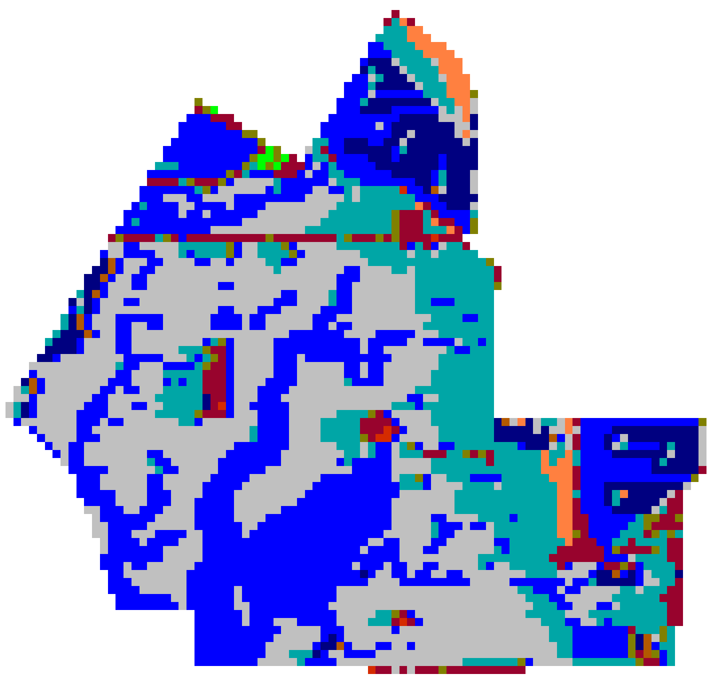
Seal Beach NWR, 2025, Scenario A1B Maximum Protect Developed Dry Land



Seal Beach NWR, 2050, Scenario A1B Maximum Protect Developed Dry Land



Seal Beach NWR, 2075, Scenario A1B Maximum Protect Developed Dry Land

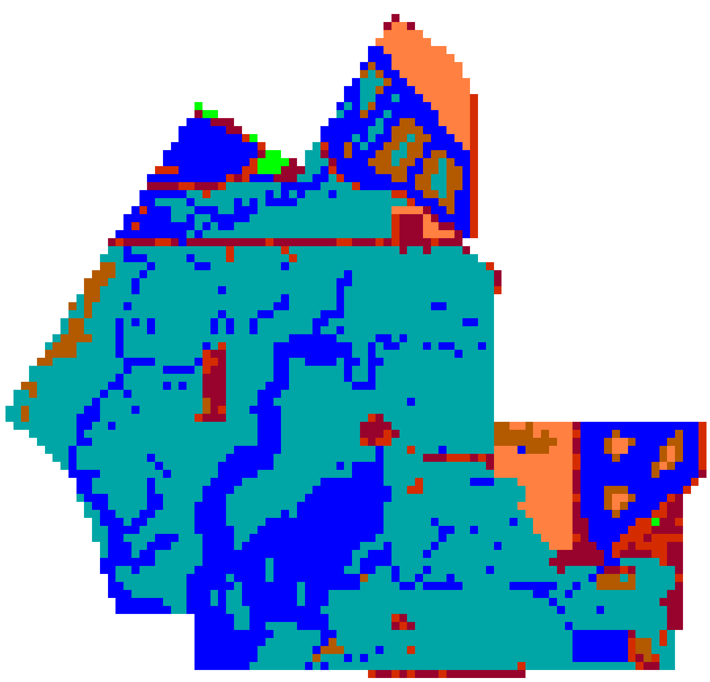


Seal Beach NWR, 2100, Scenario A1B Maximum Protect Developed Dry Land

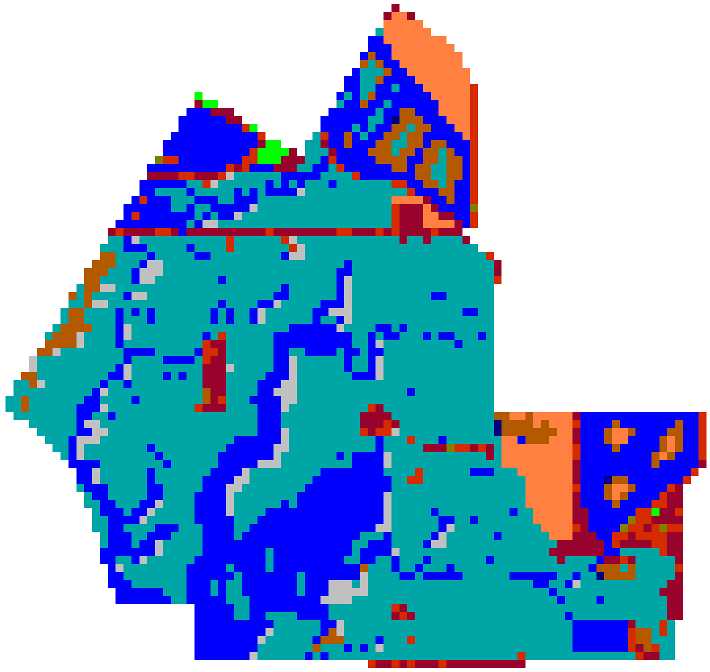
Seal Beach NWR
1 Meter Eustatic SLR by 2100

Results in Acres

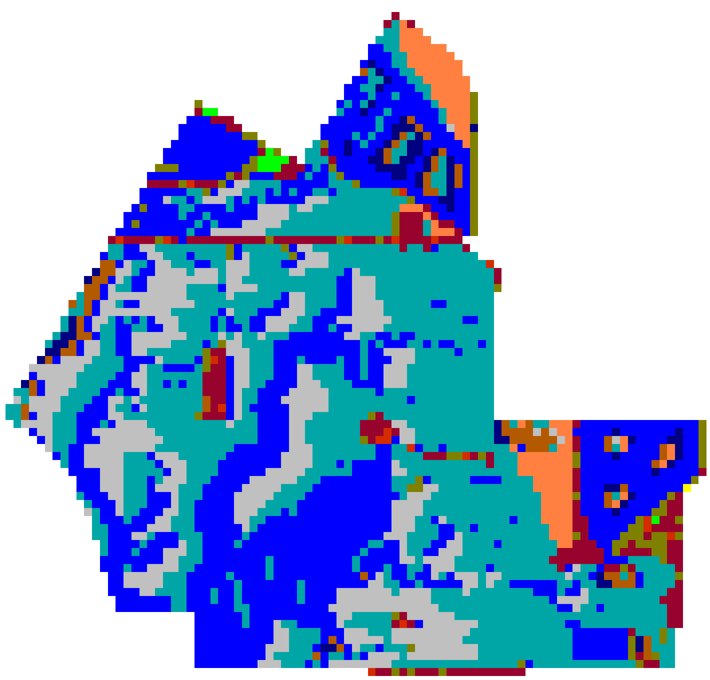
	Initial	2025	2050	2075	2100
Saltmarsh	537.5	501.6	352.3	158.1	86.9
Estuarine Open Water	252.2	266.5	296.2	306.4	325.5
Developed Dry Land	46.7	46.7	46.7	46.7	46.7
Brackish Marsh	45.8	43.5	31.7	12.9	0.0
Ocean Flat	36.3	31.5	18.3	5.5	0.1
Undeveloped Dry Land	30.2	23.6	9.3	1.8	1.2
Tidal Creek	7.3	7.3	7.3	7.3	7.3
Inland Fresh Marsh	3.1	3.1	2.3	0.9	0.5
Tidal Flat	0.0	24.0	155.9	358.0	419.9
Open Ocean	0.0	4.7	18.1	51.6	69.7
Trans. Salt Marsh	0.0	6.7	21.0	9.9	1.2
Ocean Beach	0.0	0.0	0.1	0.0	0.0
Estuarine Beach	0.0	0.0	0.0	0.2	0.1
Total (incl. water)	**959.2**	**959.2**	**959.2**	**959.2**	**959.2**



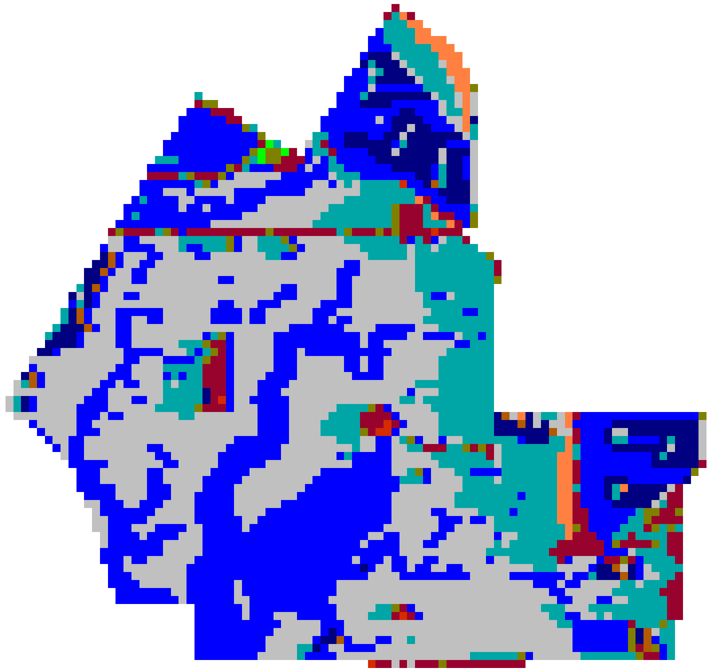
Seal Beach NWR, Initial Condition



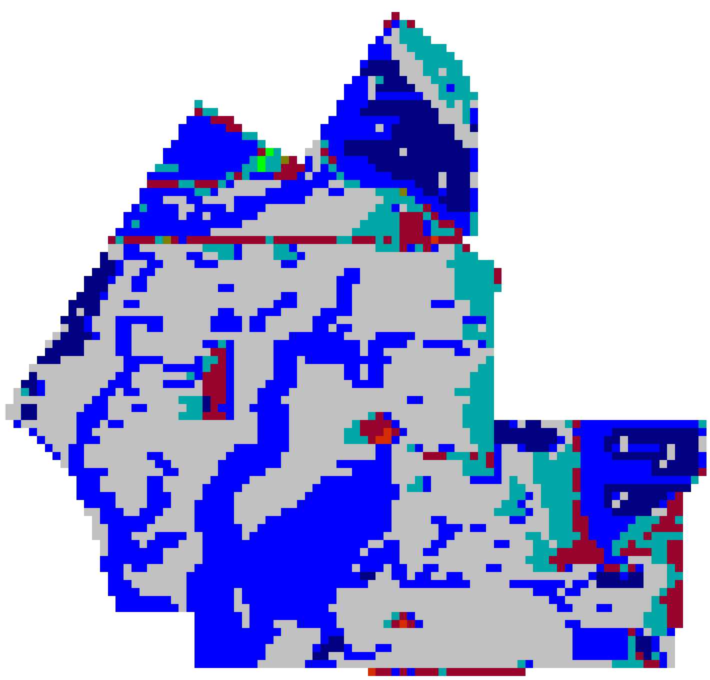
Seal Beach NWR, 2025, 1 meter Protect Developed Dry Land



Seal Beach NWR, 2050, 1 meter Protect Developed Dry Land



Seal Beach NWR, 2075, 1 meter Protect Developed Dry Land

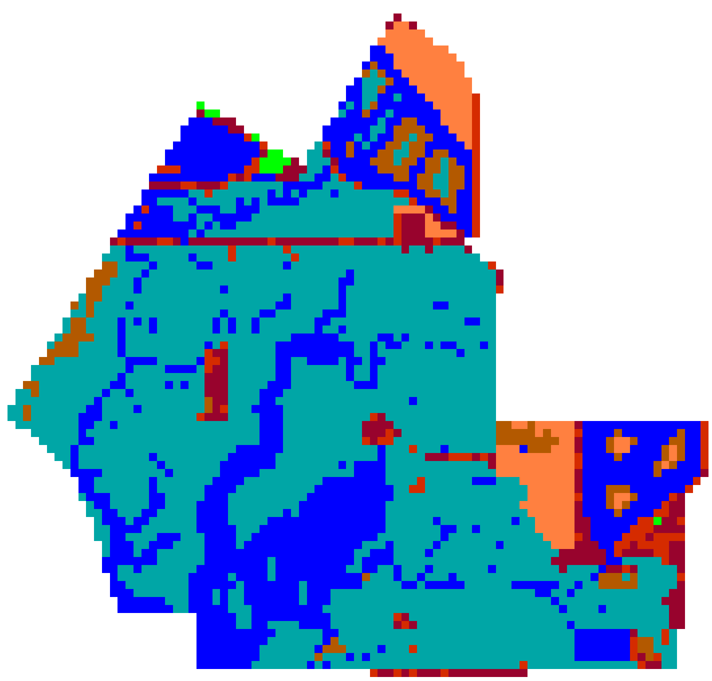


Seal Beach NWR, 2100, 1 meter Protect Developed Dry Land

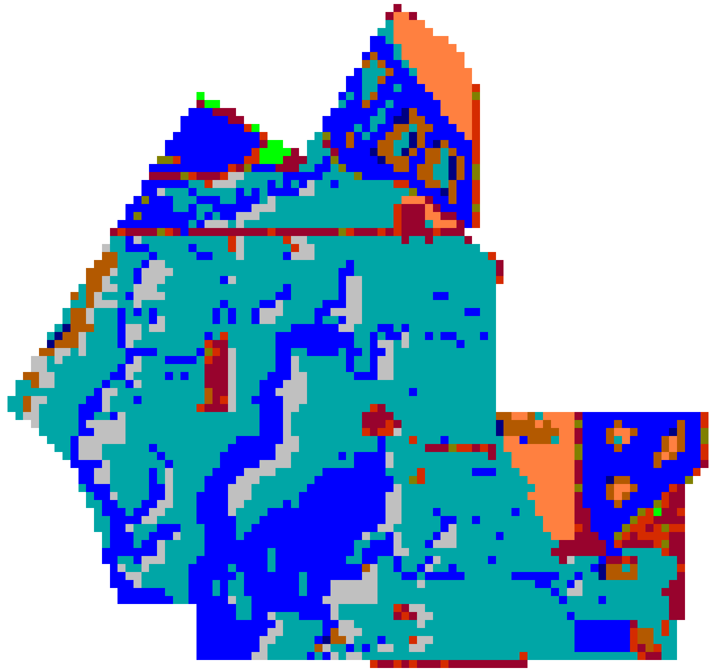
Seal Beach NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

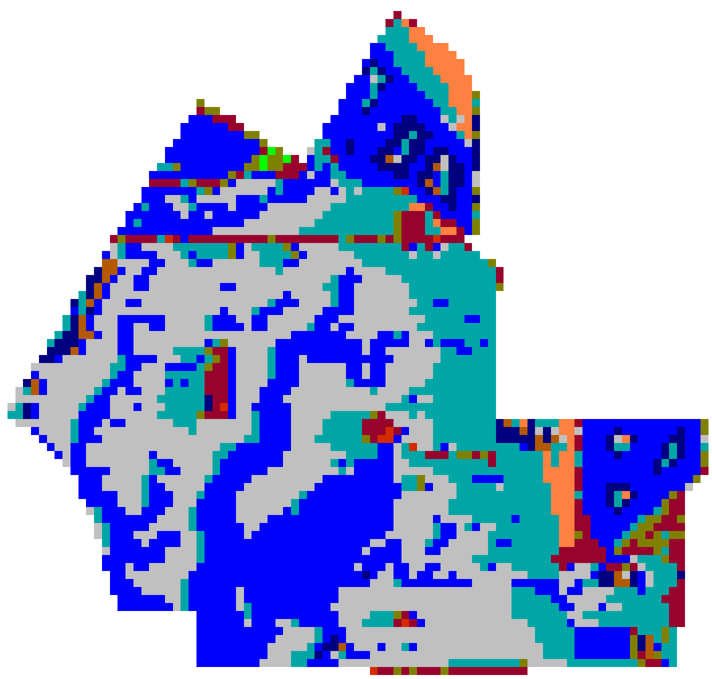
	Initial	2025	2050	2075	2100
Saltmarsh	537.5	462.2	205.6	73.9	18.6
Estuarine Open Water	252.2	272.0	303.9	315.7	630.5
Developed Dry Land	46.7	46.7	46.7	46.7	46.7
Brackish Marsh	45.8	40.4	20.0	0.0	0.0
Ocean Flat	36.3	28.6	9.2	0.1	0.0
Undeveloped Dry Land	30.2	19.7	2.5	1.2	0.7
Tidal Creek	7.3	7.3	7.3	7.3	7.3
Inland Fresh Marsh	3.1	2.9	1.1	0.4	0.0
Tidal Flat	0.0	60.9	317.0	447.1	178.5
Open Ocean	0.0	7.7	28.2	64.9	76.0
Trans. Salt Marsh	0.0	10.8	17.2	1.9	0.8
Ocean Beach	0.0	0.0	0.4	0.0	0.0
Estuarine Beach	0.0	0.0	0.1	0.1	0.0
Total (incl. water)	**959.2**	**959.2**	**959.2**	**959.2**	**959.2**



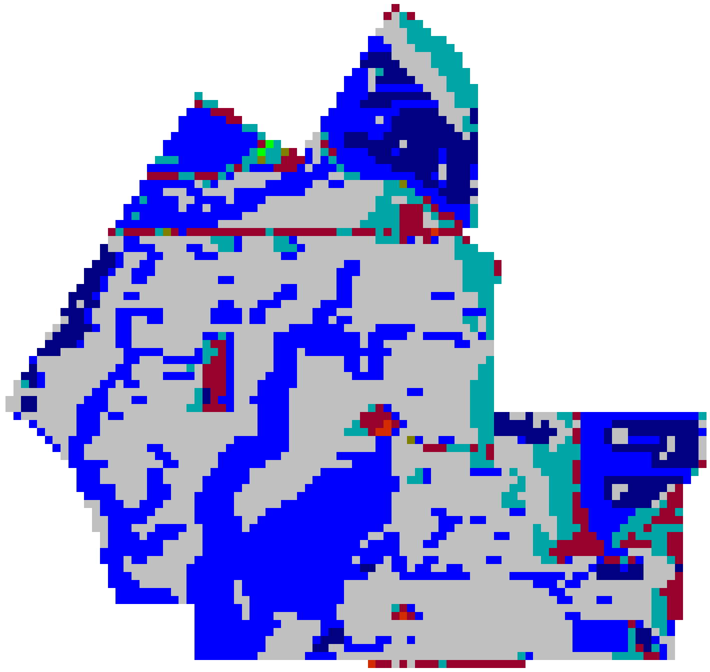
Seal Beach NWR, Initial Condition



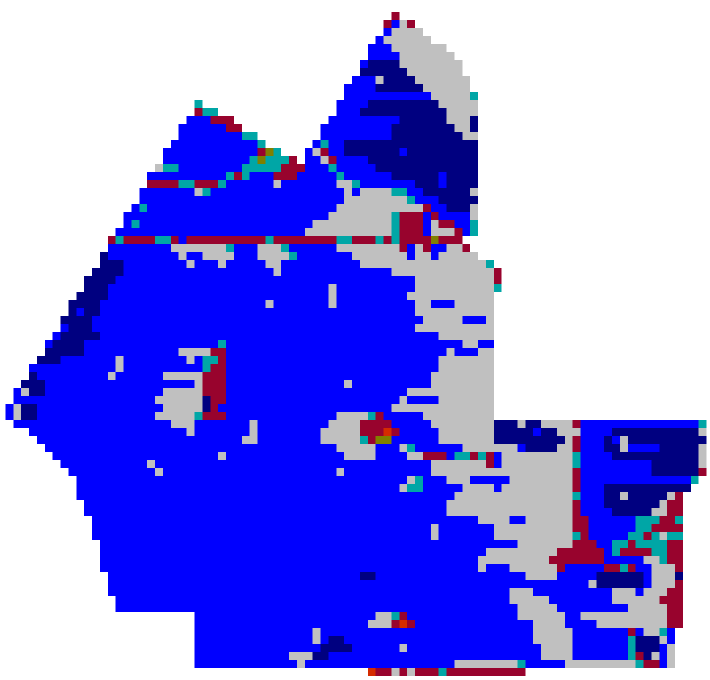
Seal Beach NWR, 2025, 1.5 meter Protect Developed Dry Land



Seal Beach NWR, 2050, 1.5 meter Protect Developed Dry Land



Seal Beach NWR, 2075, 1.5 meter Protect Developed Dry Land



Seal Beach NWR, 2100, 1.5 meter Protect Developed Dry Land

Discussion:

Model results indicate that Seal Beach NWR will be affected by sea level rise in all scenarios. In the most conservative sea level rise scenario of 0.39 meters the refuge is expected to lose roughly one quarter of its saltmarsh by 2100. Saltmarsh is nearly completely lost by 2100 in the most extreme scenario. Brackish marsh is completely lost by 2100 in the 1 meter scenario, but it only comprises roughly 5% of the refuge.

Accretion rates for wetlands are particularly subject to uncertainty in this analysis along with the potential for land subsidence due to oil and water removal from below the refuge. A relatively low accretion rate for marshes (2 mm/year) was chosen based on site-specific considerations but no site-specific measurements of accretion are currently available for this site.

As noted above, the elevation data for this site utilize both LIDAR and ifSAR data. However, none of the NWR site is covered by LIDAR, indicating that a future analysis could benefit from higher resolution elevation data.

References

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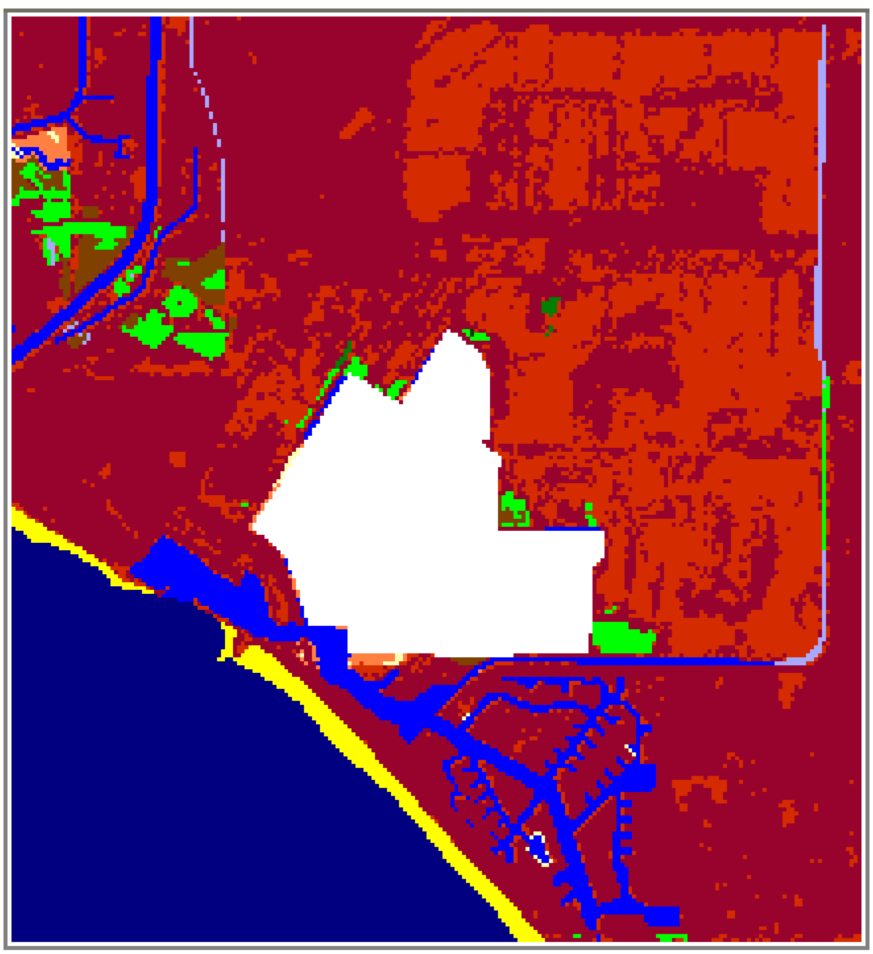
Appendix A: Contextual Results

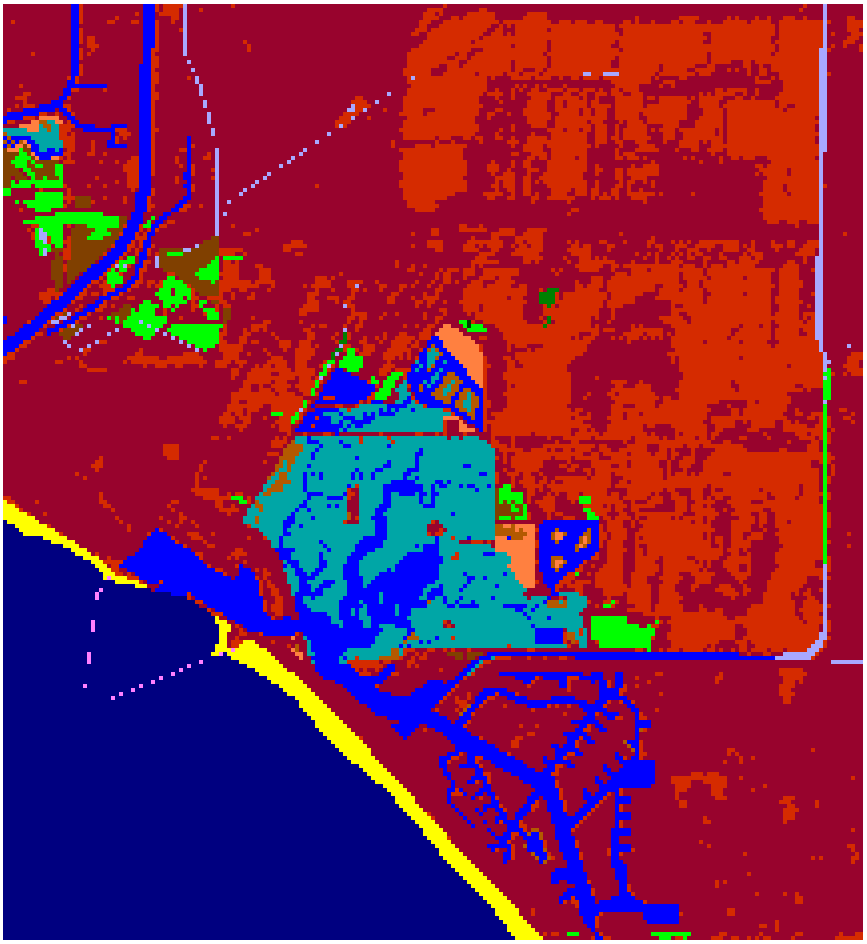
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

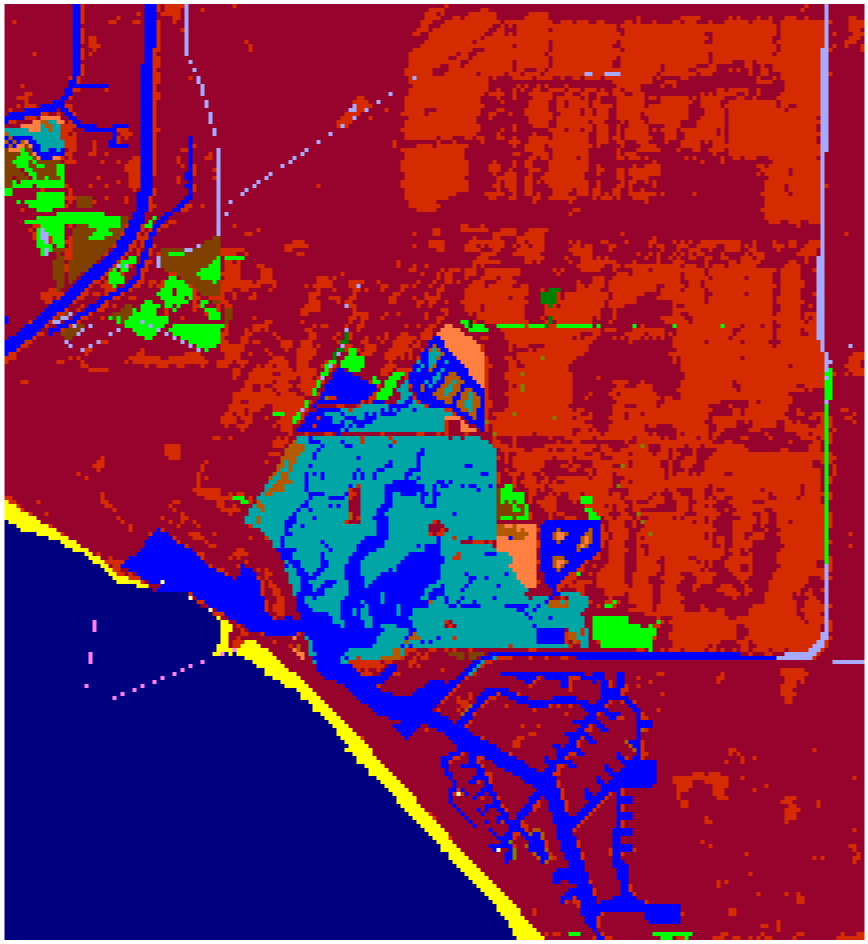
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



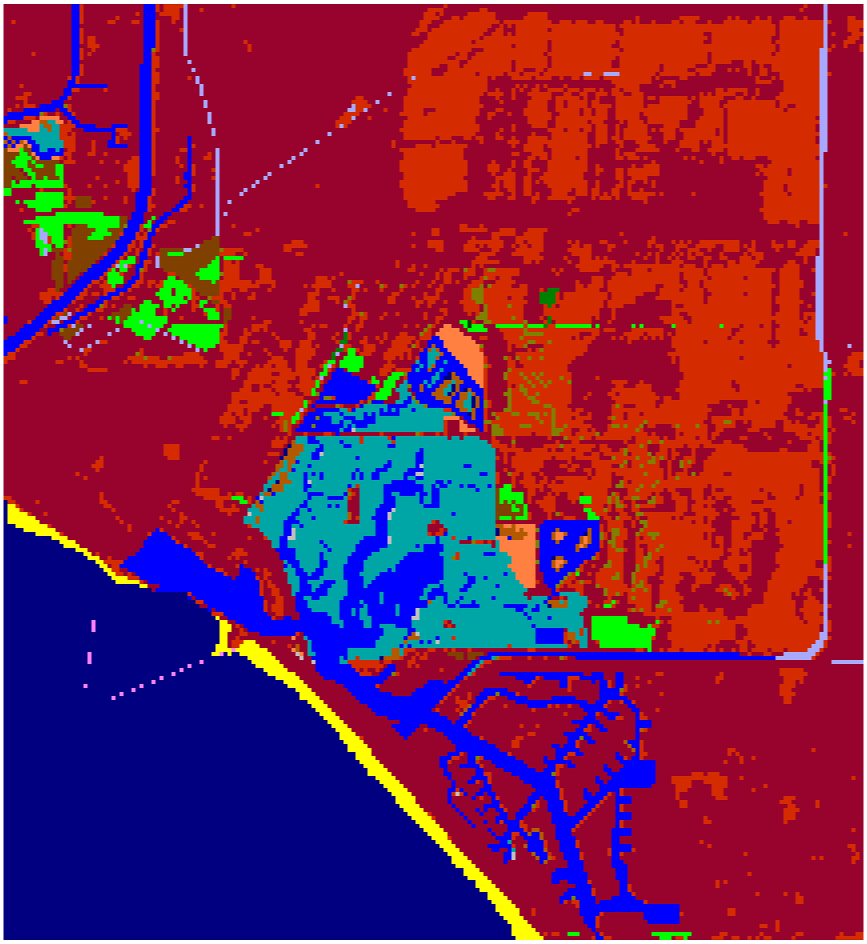
Location of Seal Beach National Wildlife Refuge (white areas) within simulation context



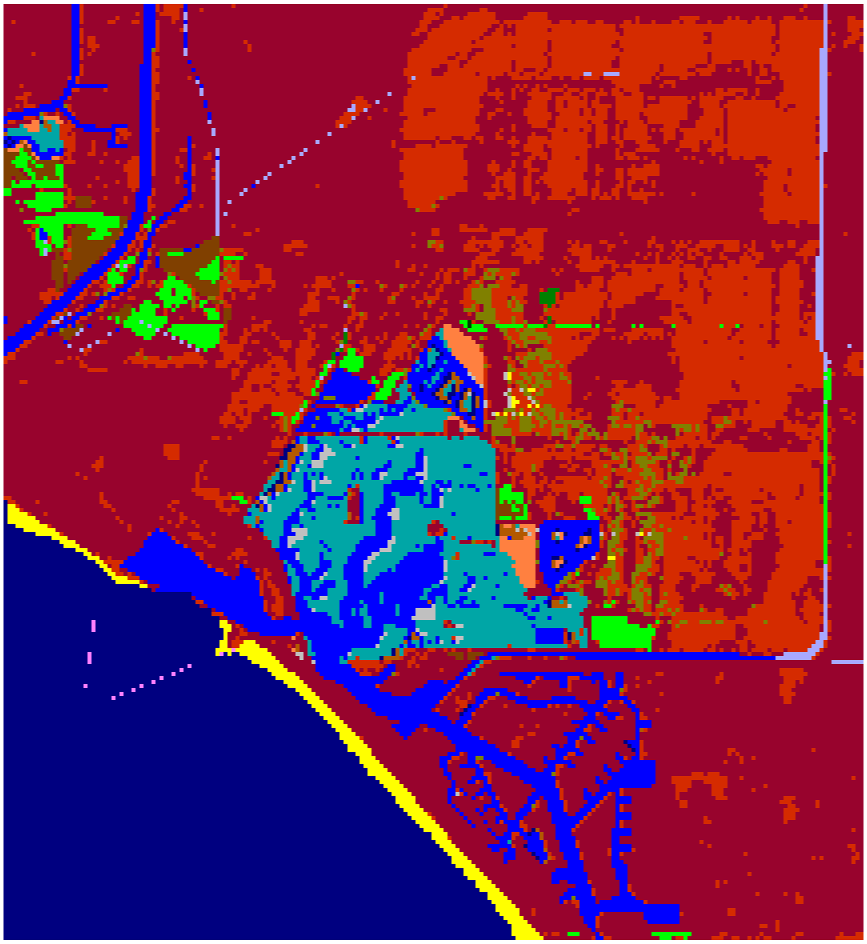
Seal Beach NWR, Initial Condition



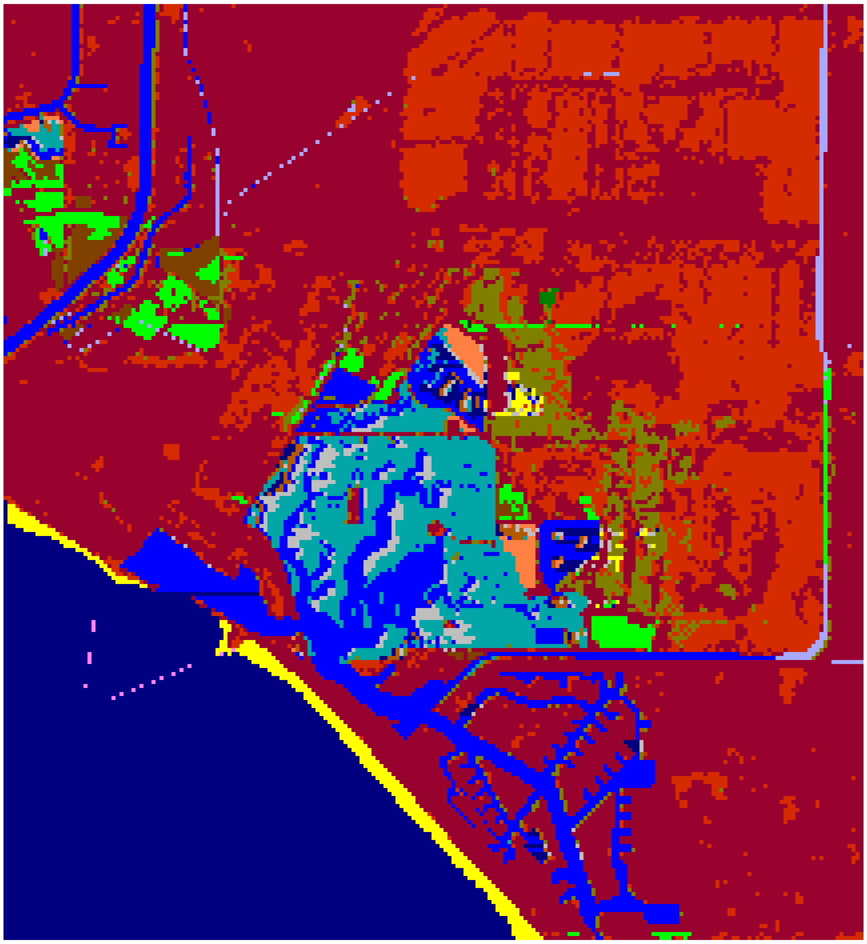
Seal Beach NWR, 2025, Scenario A1B Mean Protect Developed Dry Land



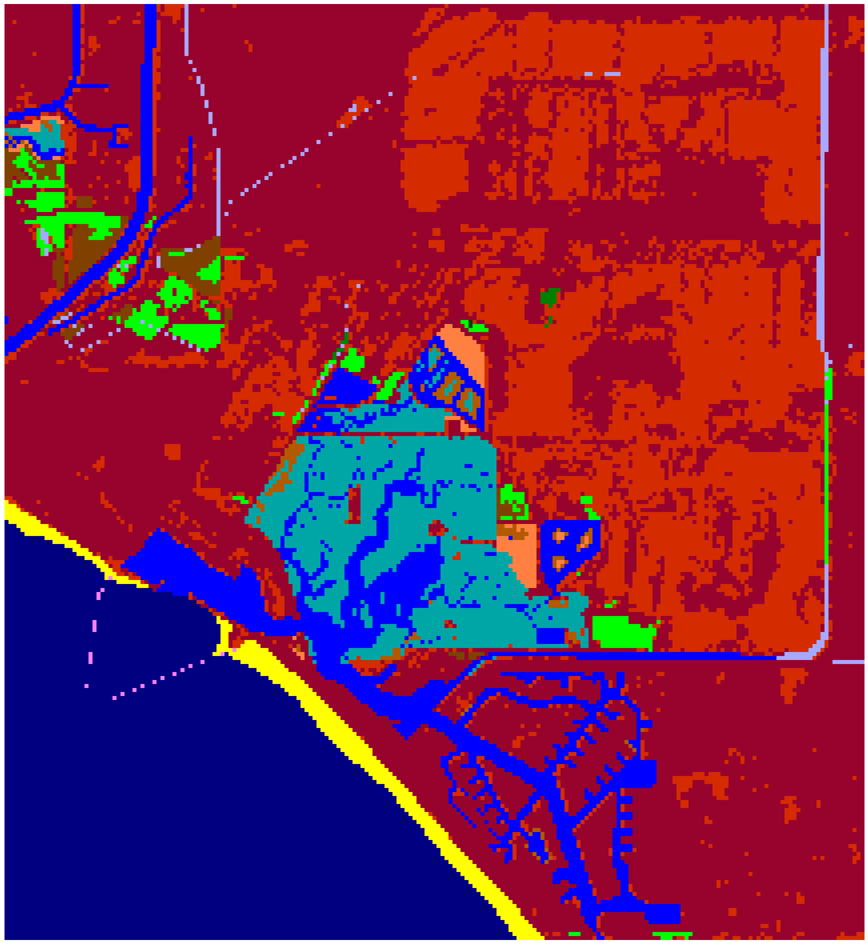
Seal Beach NWR, 2050, Scenario A1B Mean Protect Developed Dry Land



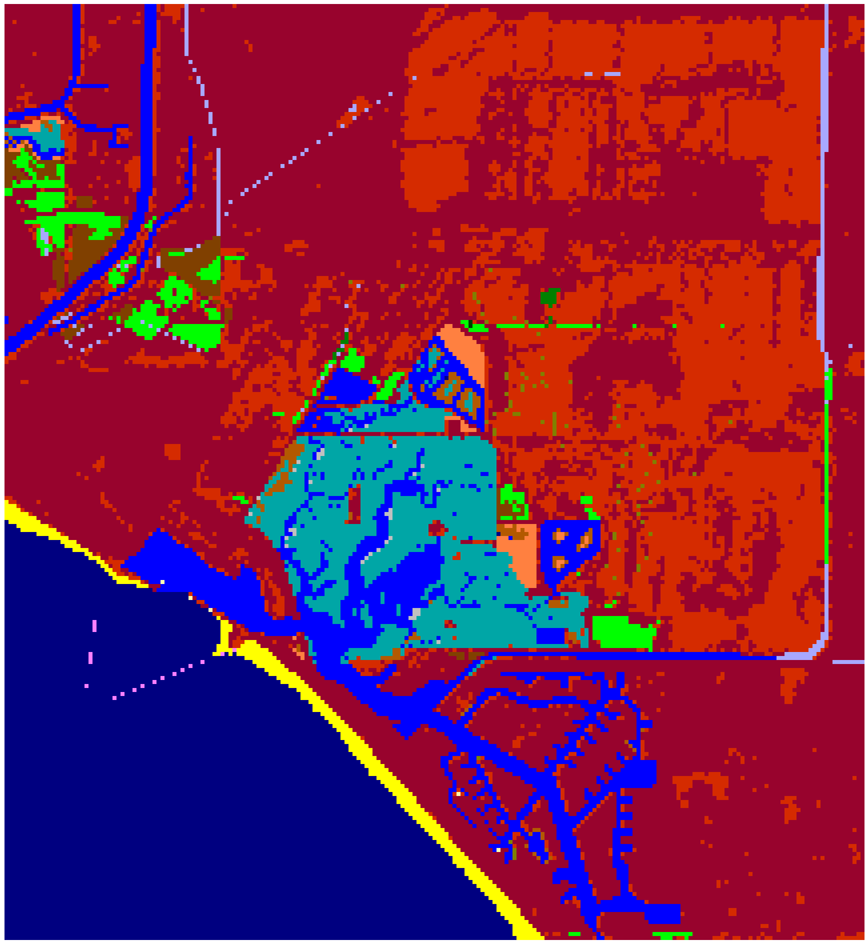
Seal Beach NWR, 2075, Scenario A1B Mean Protect Developed Dry Land



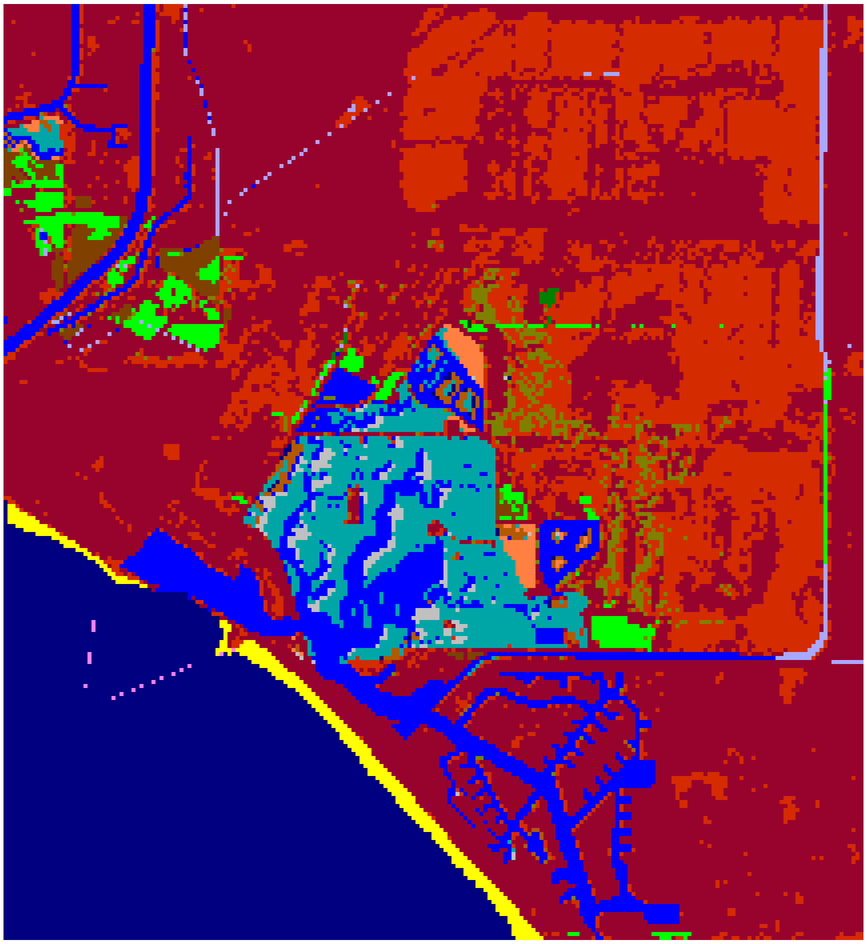
Seal Beach NWR, 2100, Scenario A1B Mean Protect Developed Dry Land



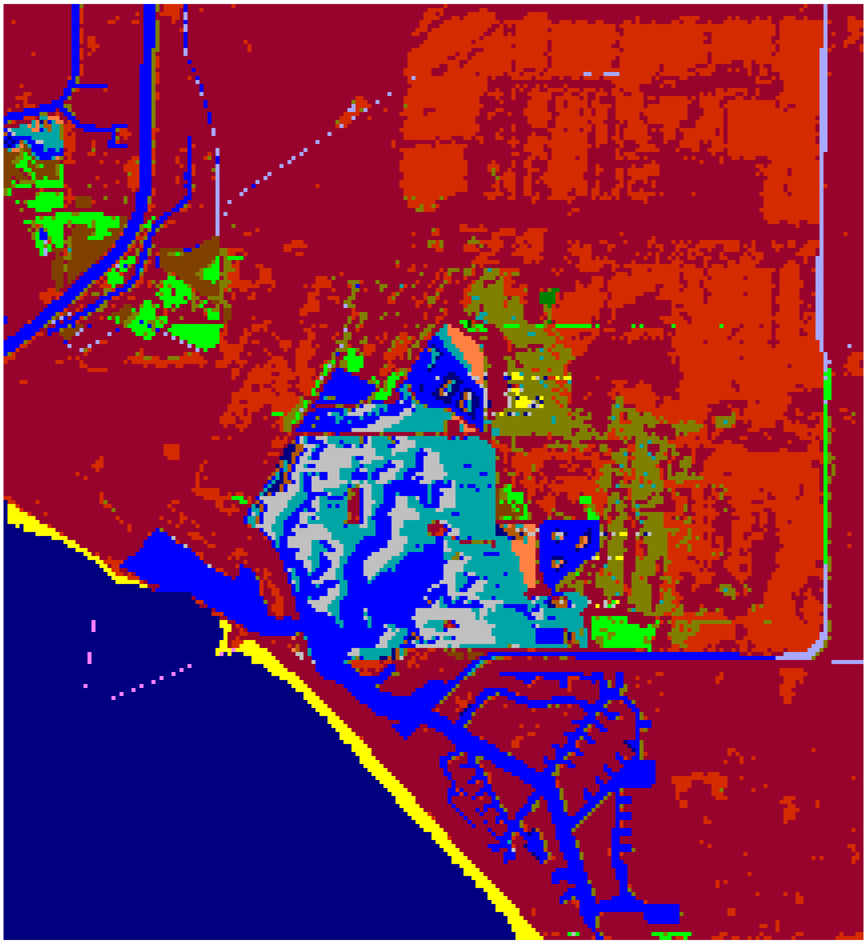
Seal Beach NWR, Initial Condition



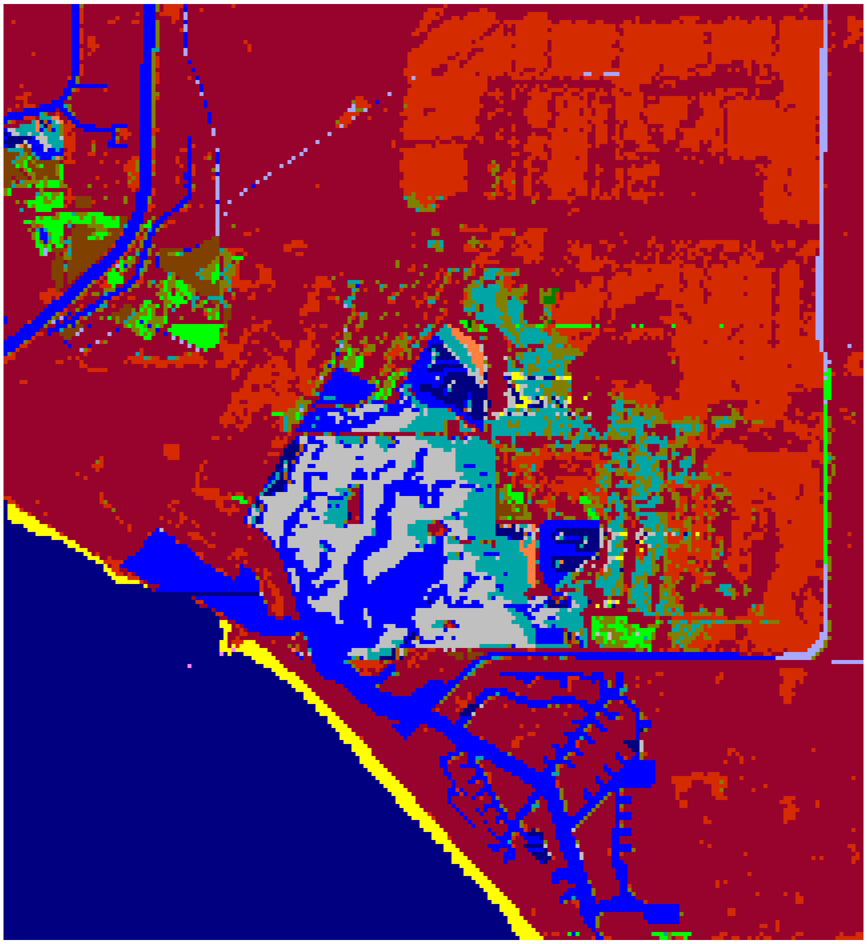
Seal Beach NWR, 2025, Scenario A1B Maximum Protect Developed Dry Land



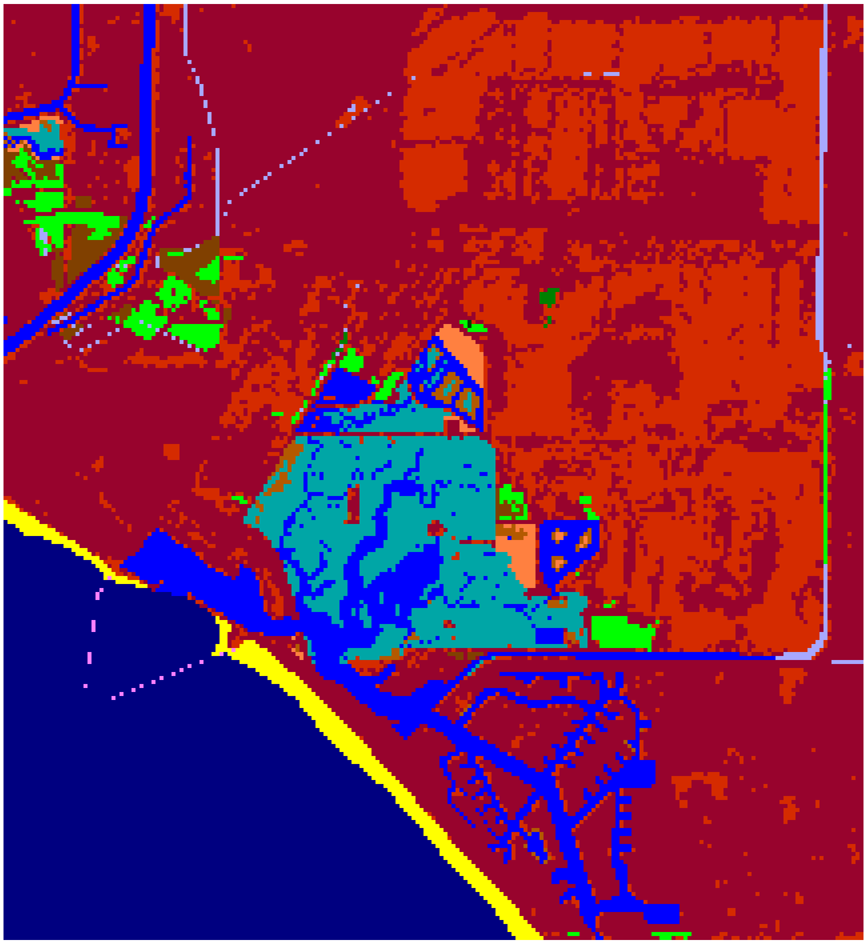
Seal Beach NWR, 2050, Scenario A1B Maximum Protect Developed Dry Land



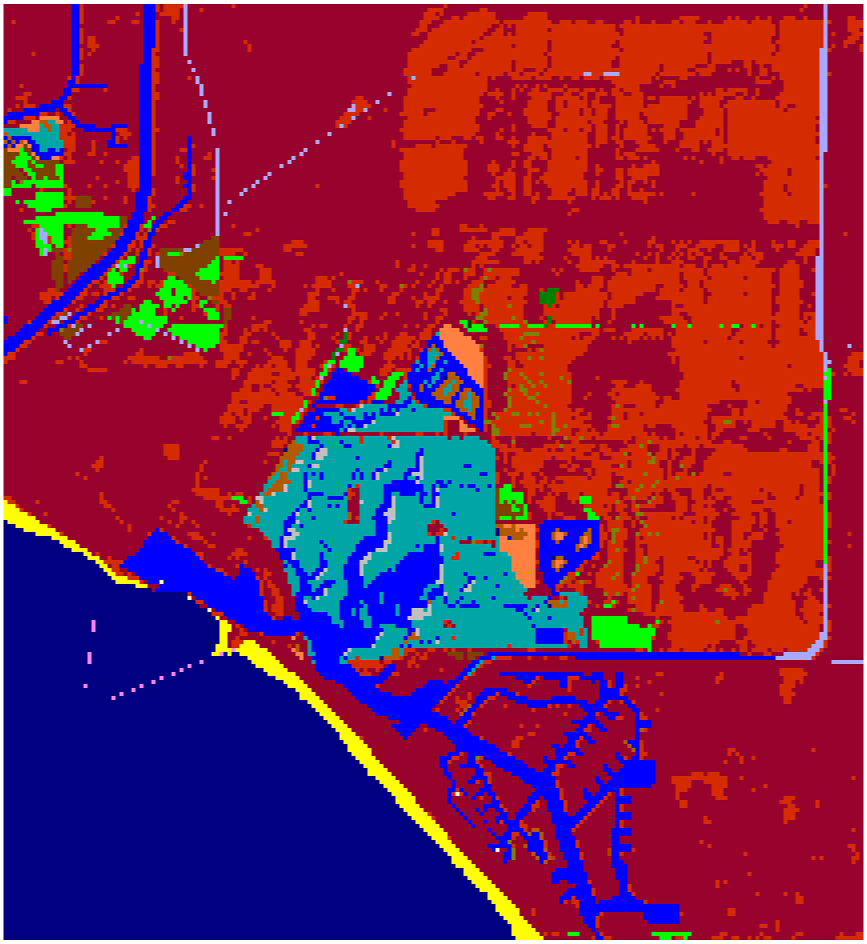
Seal Beach NWR, 2075, Scenario A1B Maximum Protect Developed Dry Land



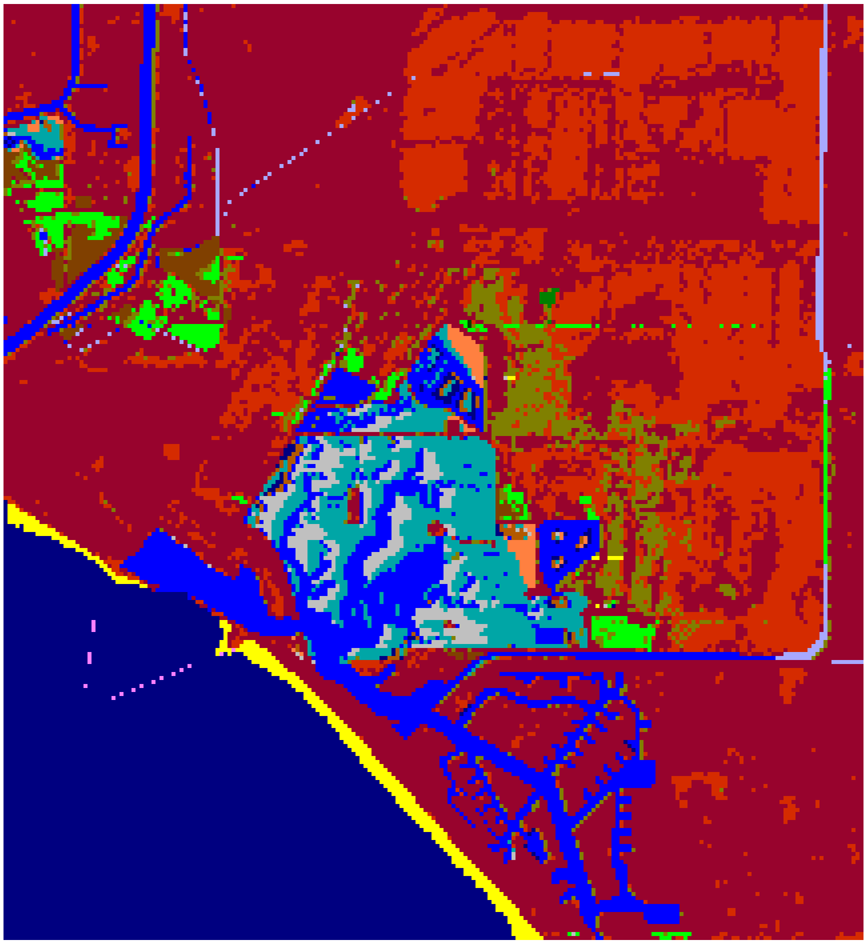
Seal Beach NWR, 2100, Scenario A1B Maximum Protect Developed Dry Land



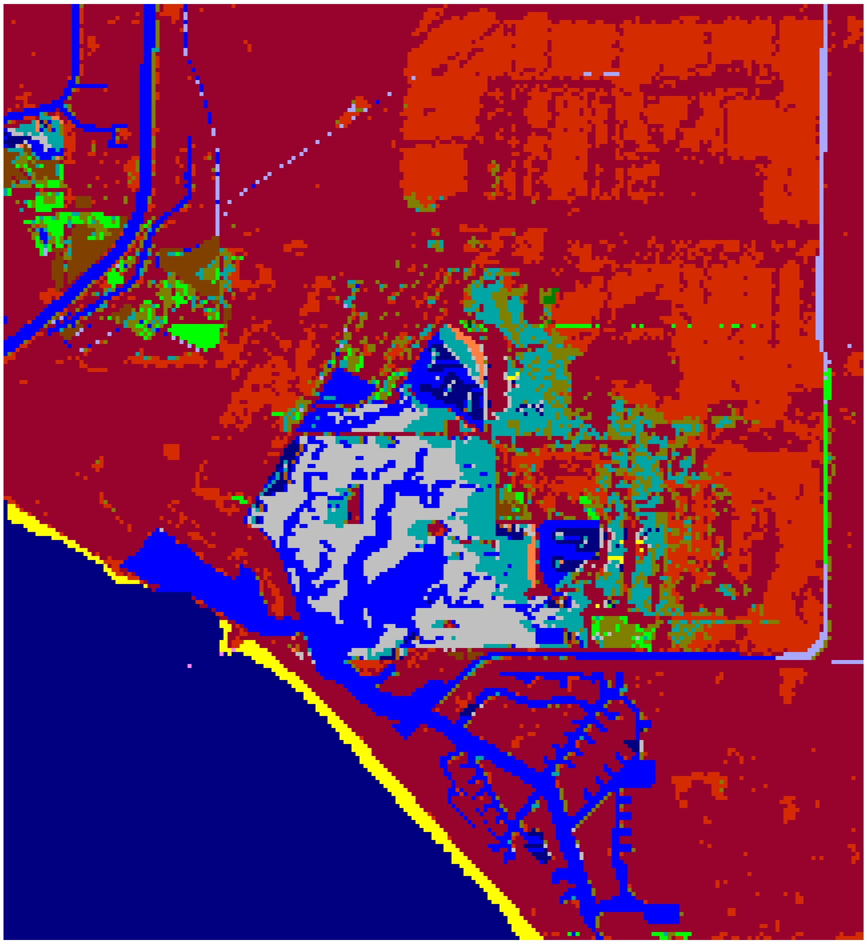
Seal Beach NWR, Initial Condition

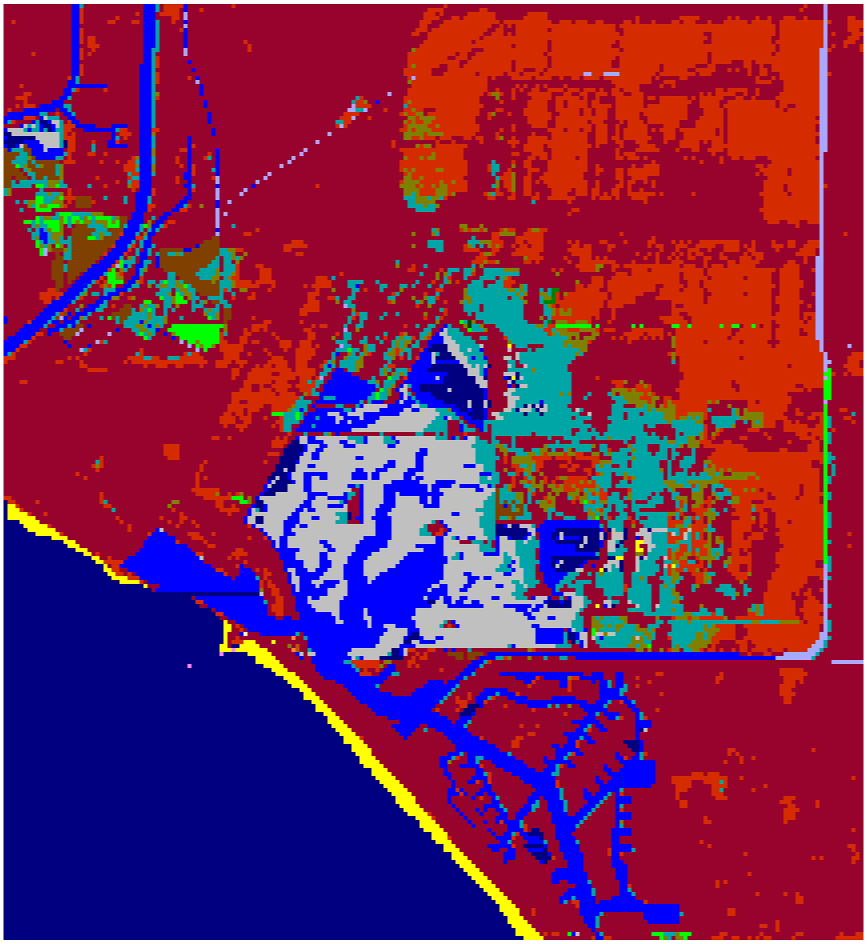


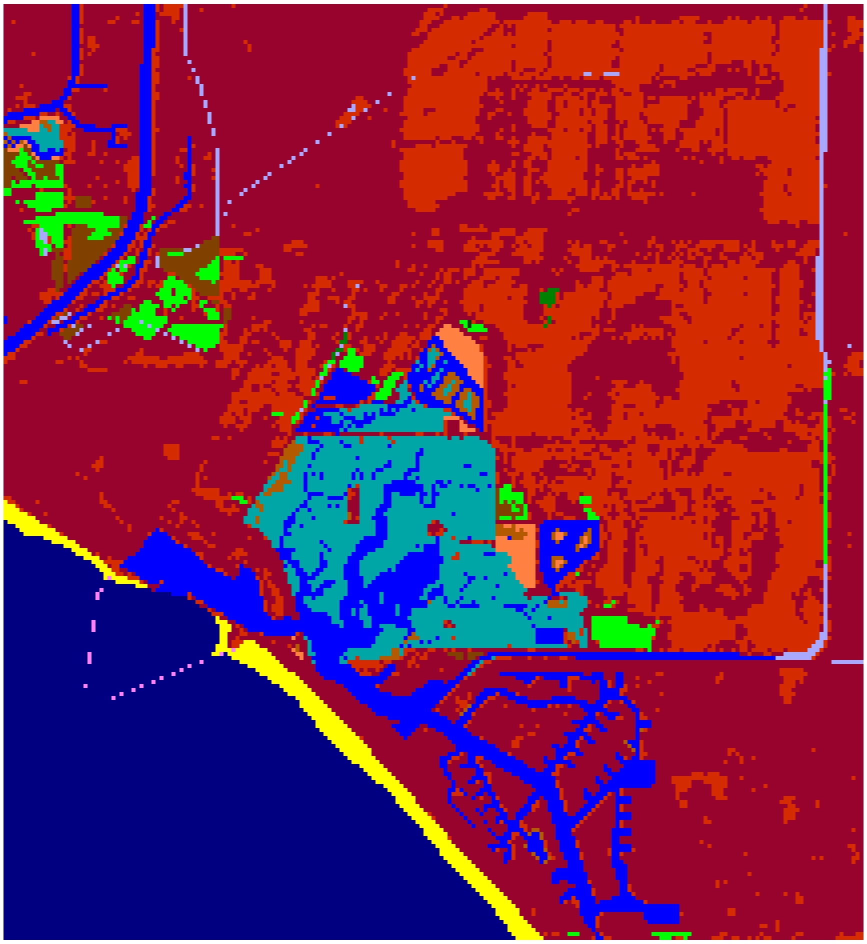
Seal Beach NWR, 2025, 1 meter Protect Developed Dry Land



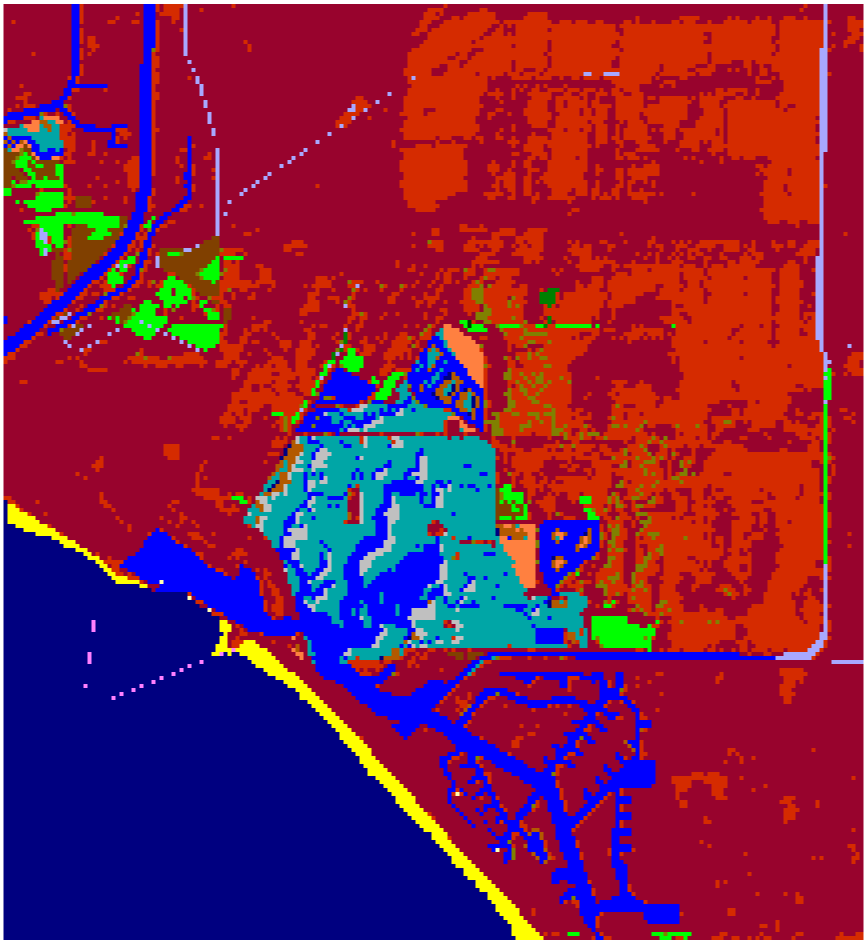
Seal Beach NWR, 2050, 1 meter Protect Developed Dry Land


Seal Beach NWR, 2075, 1 meter Protect Developed Dry Land

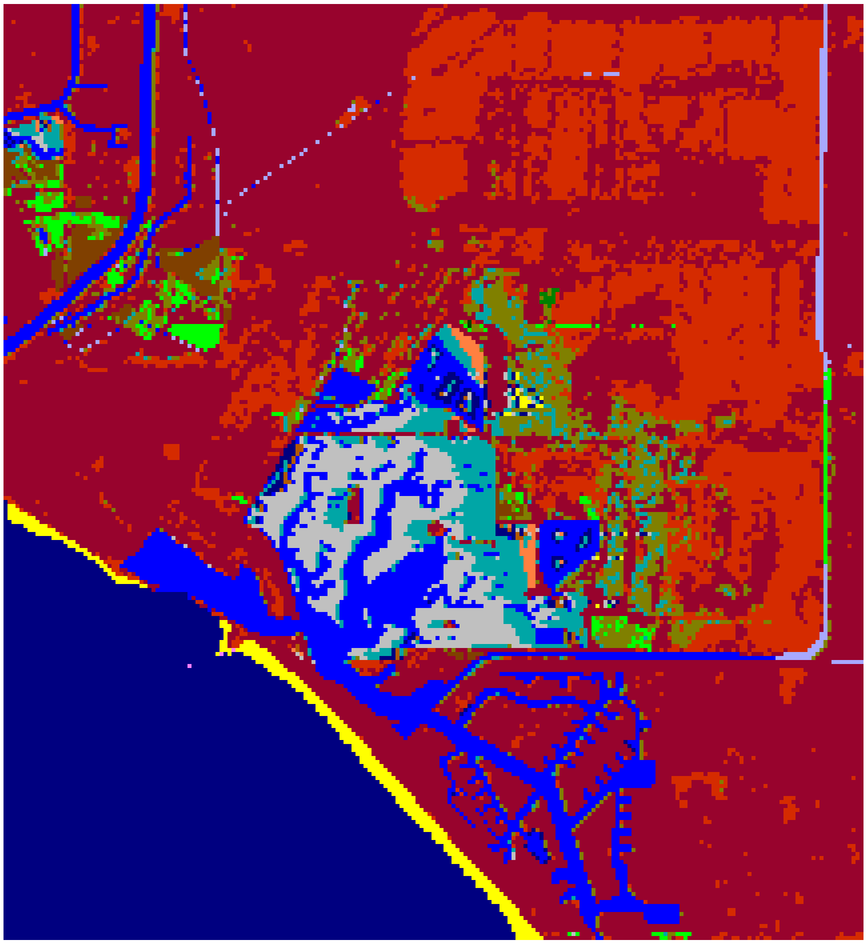

Seal Beach NWR, 2100, 1 meter Protect Developed Dry Land



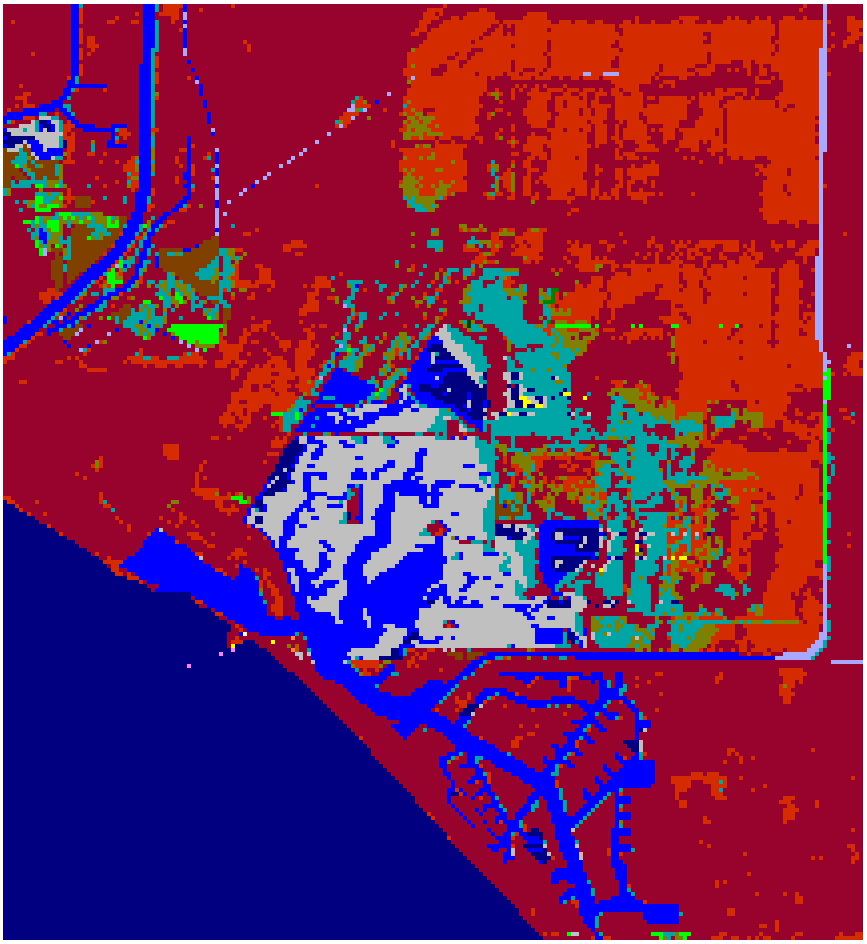
Seal Beach NWR, Initial Condition



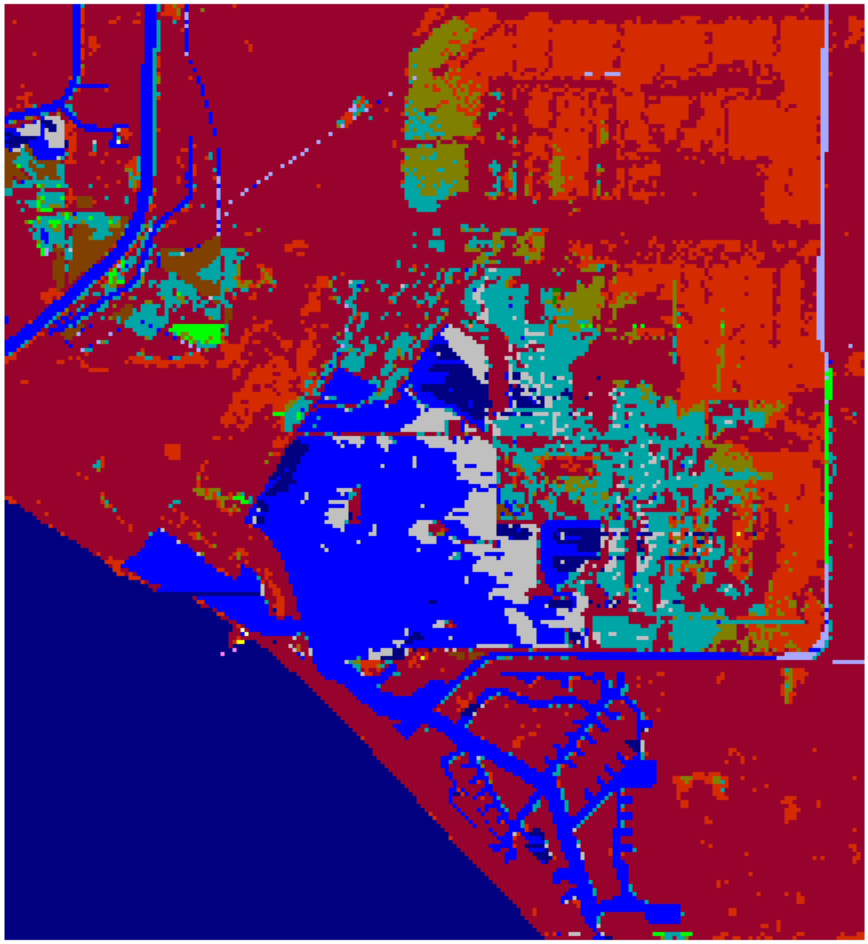
Seal Beach NWR, 2025, 1.5 meter Protect Developed Dry Land



Seal Beach NWR, 2050, 1.5 meter Protect Developed Dry Land



Seal Beach NWR, 2075, 1.5 meter Protect Developed Dry Land



Seal Beach NWR, 2100, 1.5 meter Protect Developed Dry Land