Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0) to Caloosahatchee National Wildlife Refuge

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Introduction

Tidal marshes are among the most susceptible ecosystems to climate change, especially accelerated sea level rise (SLR). Sea level is predicted to increase by 30 cm to 100 cm by 2100 based on the International Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (Meehl et al. 2007). 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. A CCP is a document that provides a framework for guiding refuge management decisions. All refuges are required by law to complete a CCP by 2012.

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 Caloosahatchee National Wildlife Refuge.

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

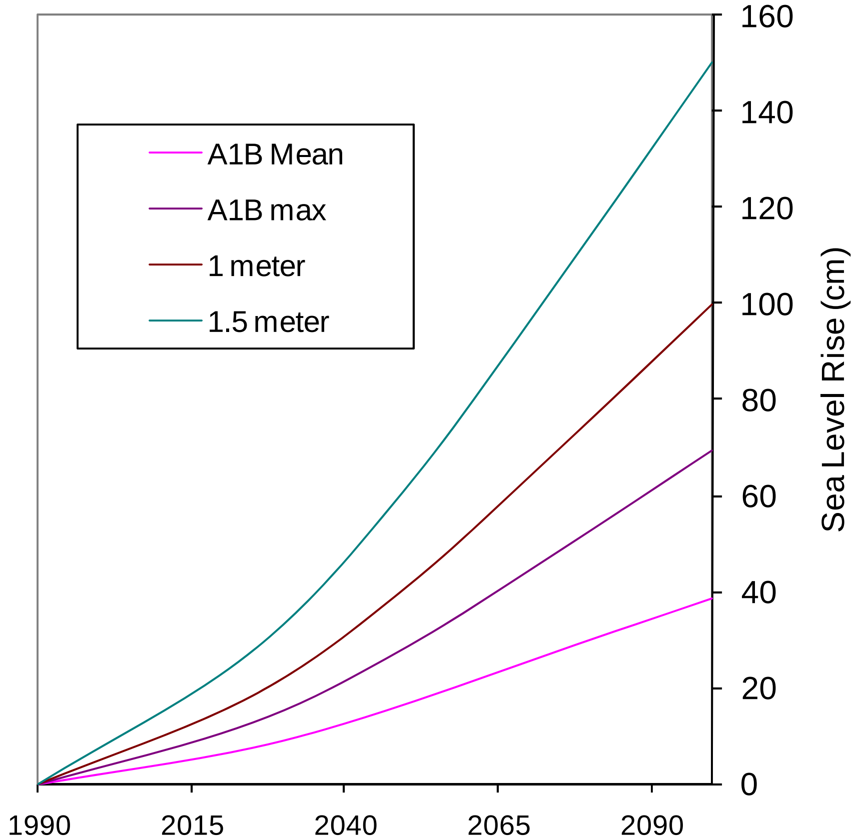
Sea-Level Rise Scenarios

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 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 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

No high-resolution LIDAR data were found for Caloosahatchee NWR so elevation data are based on the National Elevation Dataset (NED). An examination of the metadata of the NED indicates that the data were derived from a 1958 survey illustrated in the USGS topographic map shown below. The contour intervals resulting from this survey are five feet. The process of creating a digital elevation map (DEM) from a contour map does attempt to interpolate between contour lines but there is uncertainty in this process.

Figure 2: Caloosahatchee from USGS Topographical Map.

The National Wetlands Inventory for the Caloosahatchee National Wildlife Refuge is based on a photo date of 1999. This survey, when converted to 30 meter cells, suggests that the refuge is composed of approximately 8 acres of mangroves, and 0.9 acres of dry lands. Model predictions of effects due to sea level rise are run forward from 1999 as this was the date of the wetlands survey for this site.

The historic trend for Sea Level Rise was estimated at 2.4 mm/year based on the long-term tide gage at Fort Myers, Florida (NOAA station 8725520) using measurements since 1965. Other long term trends measurements within this vicinity include Naples FL (8725110) that registers at 2.02 mm/year (also since 1965).

The oceanic tide range was estimated at 0.40 meters using the closest NOAA station, Fort Myers, FL (8725520). The map vertical datum of NAVD88 was related to mean tide level using data gathered from that same Ft. Myers gage (8725520).

Parameters pertaining to non-mangrove marshes (i.e. accretion rates and erosion rates) are not relevant to this site as there were no marshes identified based on the National Wetlands Inventory, nor are any predicted to appear. Default values are therefore used, though the model will not be sensitive to those choices. Within SLAMM, mangrove accretion is set to 7mm/year based on Cahoon et al. (1999) a study that used field measurements from Rookery Bay, FL.

Tidal flat erosion rates were set to 0.5 horizontal meters per year based on the effects of wave action. This is a default model value that has been used in previous SLAMM applications to Florida. No site-specific studies of horizontal erosion rates were located for this analysis.

Modeled U.S. Fish and Wildlife Service refuge boundaries are based on Approved Acquisition Boundaries as received from Kimberly Eldridge, lead cartographer with U.S. Fish and Wildlife Service, and are current as of June, 2008. Paul Tritaik, the USFWS refuge manager for this refuge assisted in providing technical contacts and also indicated that he did not know of additional data-sets to assist in this analysis.

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.

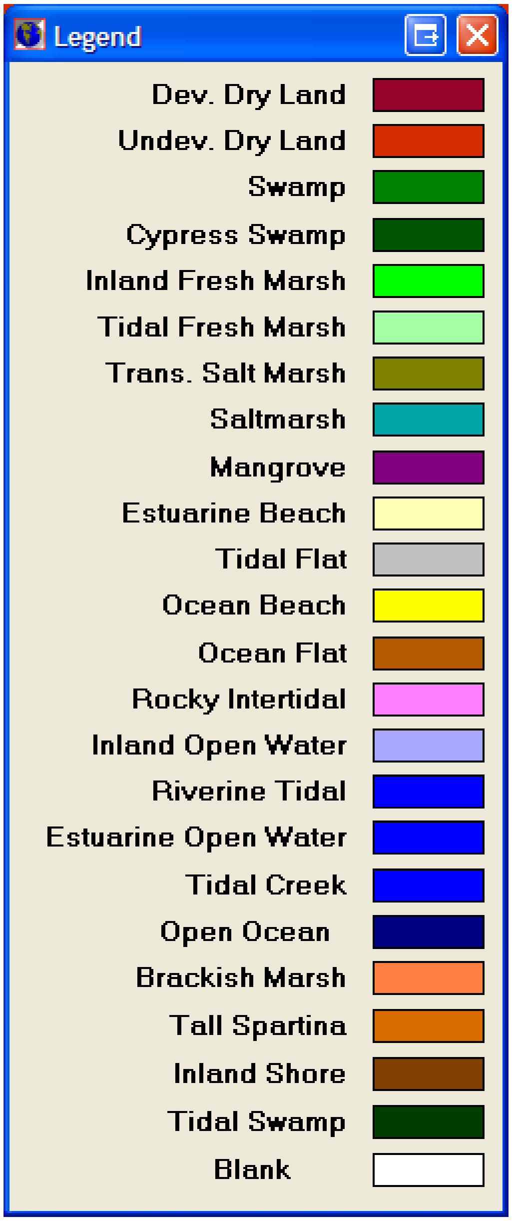
SLAMM INPUT PARAMETERS FOR CALOOSAHATCHEE

Site	**Caloosahatchee**
NED Source Date (yyyy)	1958
NWI_photo_date (yyyy)	1999
Direction_OffShore (N|S|E|W)	W
Historic_trend (mm/yr)	2.4
NAVD88_correction (MTL-NAVD88 in meters)	-0.127
Water Depth (m below MLW- N/A)	2
TideRangeOcean (meters: MHHW-MLLW)	0.401
TideRangeInland (meters)	0.401
Mean High Water Spring (m above MTL)	0.267
MHSW Inland (m above MTL)	0.267
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	3.9
Brackish March vert. accretion (mm/yr) Final	4.7
Tidal Fresh vertical accretion (mm/yr) Final	5.9
Beach/T.Flat Sedimentation Rate (mm/yr)	0.5
Frequency of Large Storms (yr/washover)	25
Use Elevation Preprocessor for Wetlands	TRUE

Results

Mangroves are assumed to have a high rate of vertical accretion. Mangrove accretion is set to 7mm/year based on Cahoon et al. (1999). Other studies of mangroves indicate similar accretion rates and therefore a fair degree of resiliency to sea level rise. Within this simulation, mangroves don't start to significantly lose ground until one meter of sea level rise is projected by 2100. Even in that case, only 13% of mangrove loss is predicted by 2100. However, under the scenario of 1.5 meters of sea level rise by 2100, nearly all mangroves are lost.

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



Caloosahatchee
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

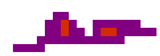
	Initial	2025	2050	2075	2100
Mangrove	8.0	8.0	8.0	8.0	8.0
Dry Land	0.9	0.9	0.9	0.9	0.9
Estuarine Open Water	0.0	0.0	0.0	0.0	0.0
Total (incl. water)	**8.9**	**8.9**	**8.9**	**8.9**	**8.9**

Caloosahatchee, Initial Condition

Caloosahatchee, 2025, Scenario A1B Mean

Caloosahatchee, 2050, Scenario A1B Mean

Caloosahatchee, 2075, Scenario A1B Mean



Caloosahatchee, 2100, Scenario A1B Mean

Caloosahatchee

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

Results in Acres

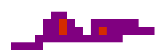
	Initial	2025	2050	2075	2100
Mangrove	8.0	8.0	8.0	8.0	8.3
Dry Land	0.9	0.9	0.9	0.9	0.6
Estuarine Open Water	0.0	0.0	0.0	0.0	0.0
Total (incl. water)	**8.9**	**8.9**	**8.9**	**8.9**	**8.9**

Caloosahatchee, Initial Condition

Caloosahatchee, 2025, Scenario A1B Maximum

Caloosahatchee, 2050, Scenario A1B Maximum

Caloosahatchee, 2075, Scenario A1B Maximum



Caloosahatchee, 2100, Scenario A1B Maximum

Caloosahatchee
1 Meter Eustatic SLR by 2100

Results in Acres

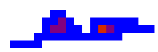
	Initial	2025	2050	2075	2100
Mangrove	8.0	8.0	8.0	8.3	1.1
Dry Land	0.9	0.9	0.9	0.6	0.2
Estuarine Open Water	0.0	0.0	0.0	0.0	7.6
Total (incl. water)	**8.9**	**8.9**	**8.9**	**8.9**	**8.9**

Caloosahatchee, Initial Condition, 1 meter

Caloosahatchee, 2025, 1 meter

Caloosahatchee, 2050, 1 meter

Caloosahatchee, 2075, 1 meter



Caloosahatchee, 2100, 1 meter

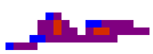
Caloosahatchee
1.5 Meters Eustatic SLR by 2100

Results in Acres

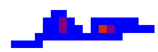
	Initial	2025	2050	2075	2100
Mangrove	8.0	8.0	6.7	0.7	0.5
Dry Land	0.9	0.9	0.8	0.2	0.0
Estuarine Open Water	0.0	0.0	1.4	8.0	8.4
Total (incl. water)	**8.9**	**8.9**	**8.9**	**8.9**	**8.9**

Caloosahatchee, Initial Condition, 1.5 meter

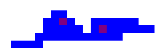
Caloosahatchee, 2025, 1.5 meter



Caloosahatchee, 2050, 1.5 meter



Caloosahatchee, 2075, 1.5 meter



Caloosahatchee, 2100, 1.5 meter

Discussion:

Dry land elevations at this site are high enough that dry land is lost only at the highest simulated rates of sea level rise, and then only by the year 2075. Mangroves are also predicted to be fairly resilient at this site. In fact, up to and including the 0.69 meters simulation of eustatic SLR the predicted changes at this site are quite minor indeed. At the 1-meter and 1½ meter simulation levels, though, most of the site is predicted to convert to open water.

According to these simulations, the primary dynamic affecting mangrove abundance at this site is the rate of mangrove accretion as compared to the rate of sea level rise. Because mangroves generally accrete at a high rate they are more resilient to sea level rise. However, once sea level rise exceeds mangrove accretion rates, all mangroves are predicted to quickly disappear. Precisely where this break-point exists is uncertain, especially because modeled mangrove accretion rates were based on regional, not site-specific measurements.

Elevation data are of relatively low quality at this site, based on five foot contour intervals. However, this uncertainty is probably less important than the uncertainty as to the rate of mangrove accretion in determining long-term mangrove viability.

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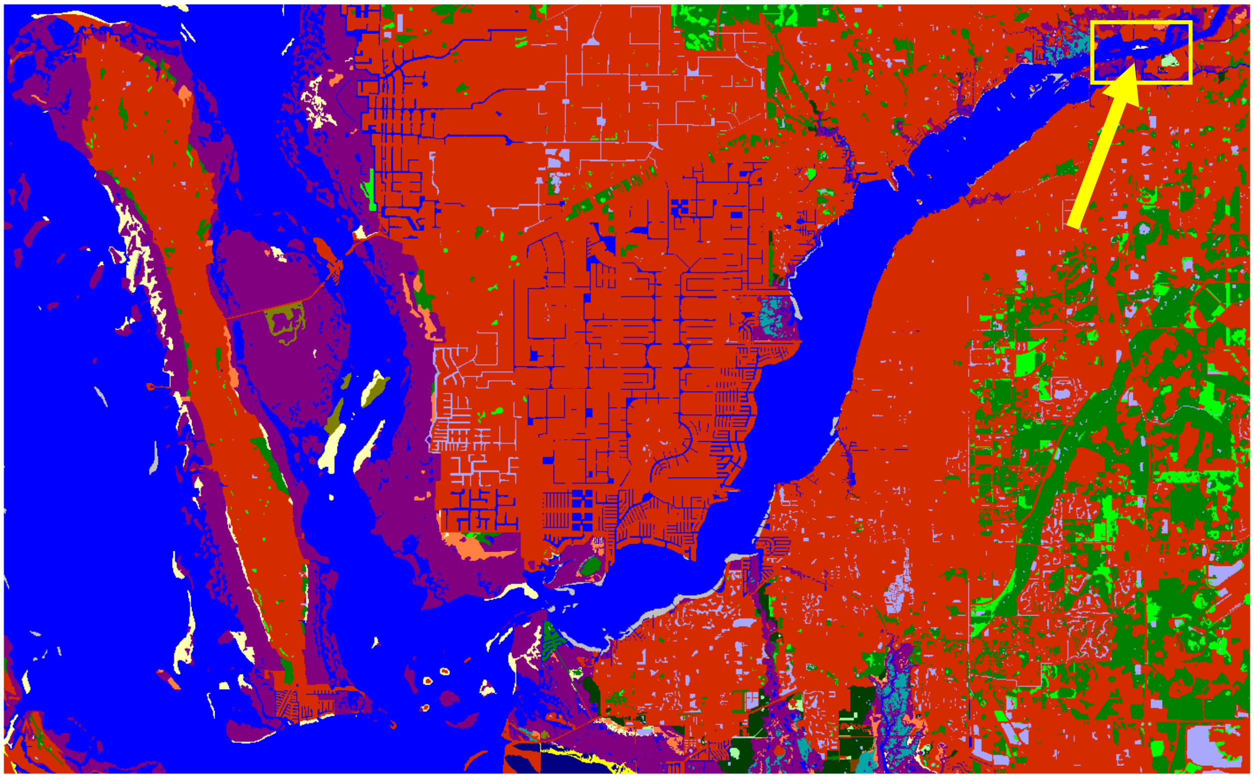
Appendix A: Contextual Results

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.

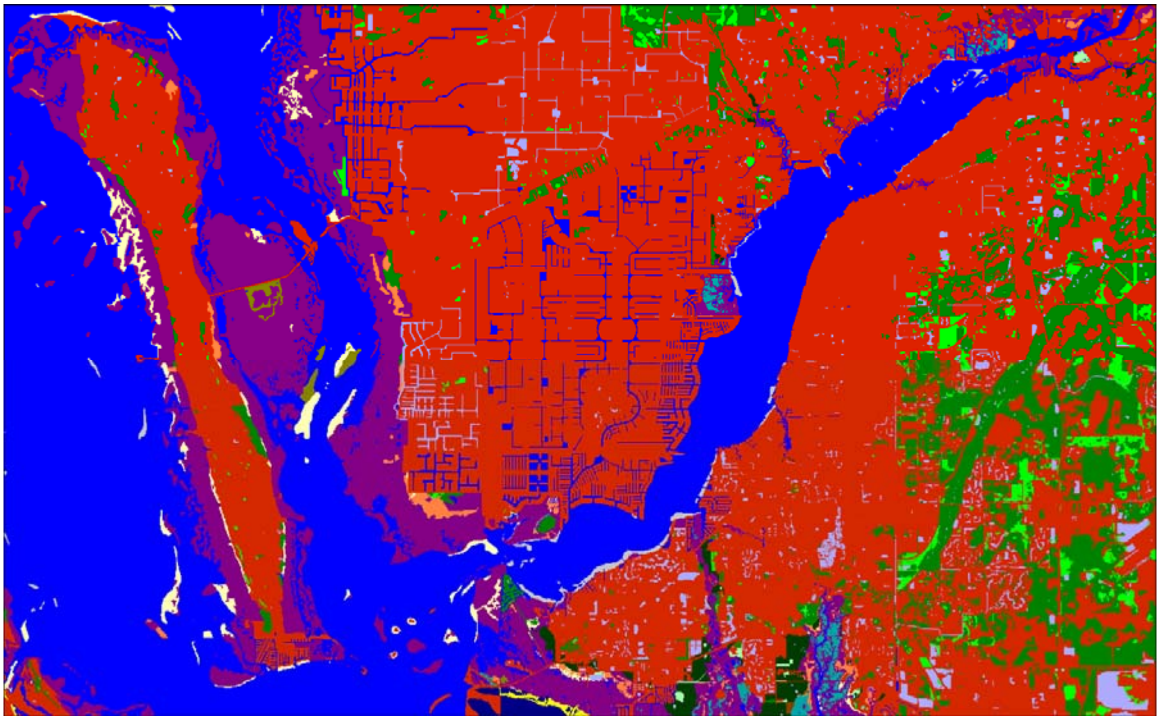
For this reason, an area larger than the boundaries of the USFWS refuge was modeled. These results maps are presented here with the following caveats:

- 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.

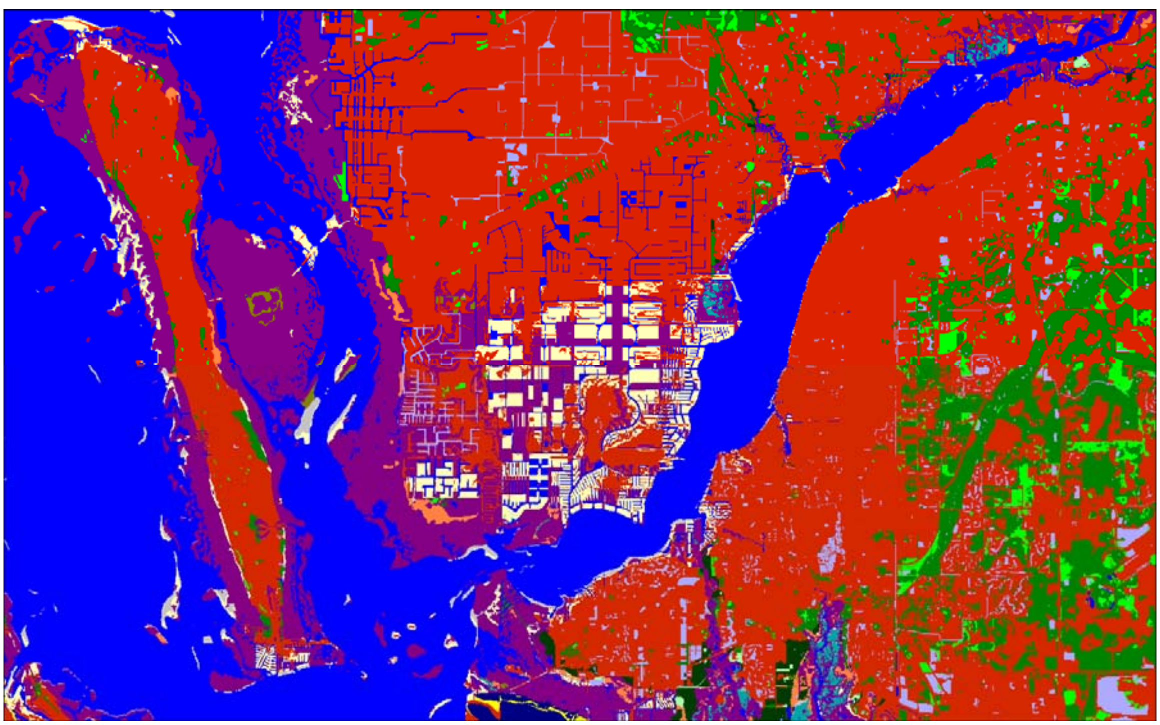


The approved acquisition Boundary for Caloosahatchee NWR is a small mangrove island shown here in white and indicated by the yellow arrow above.

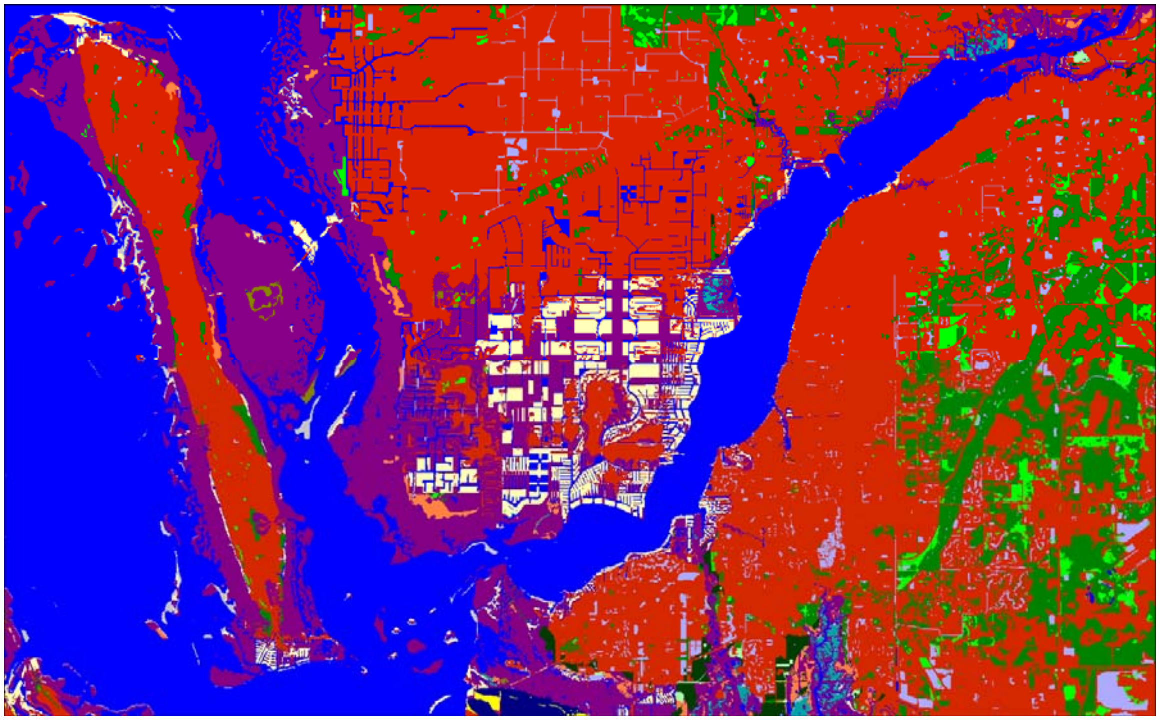
Close-up of rectangle above



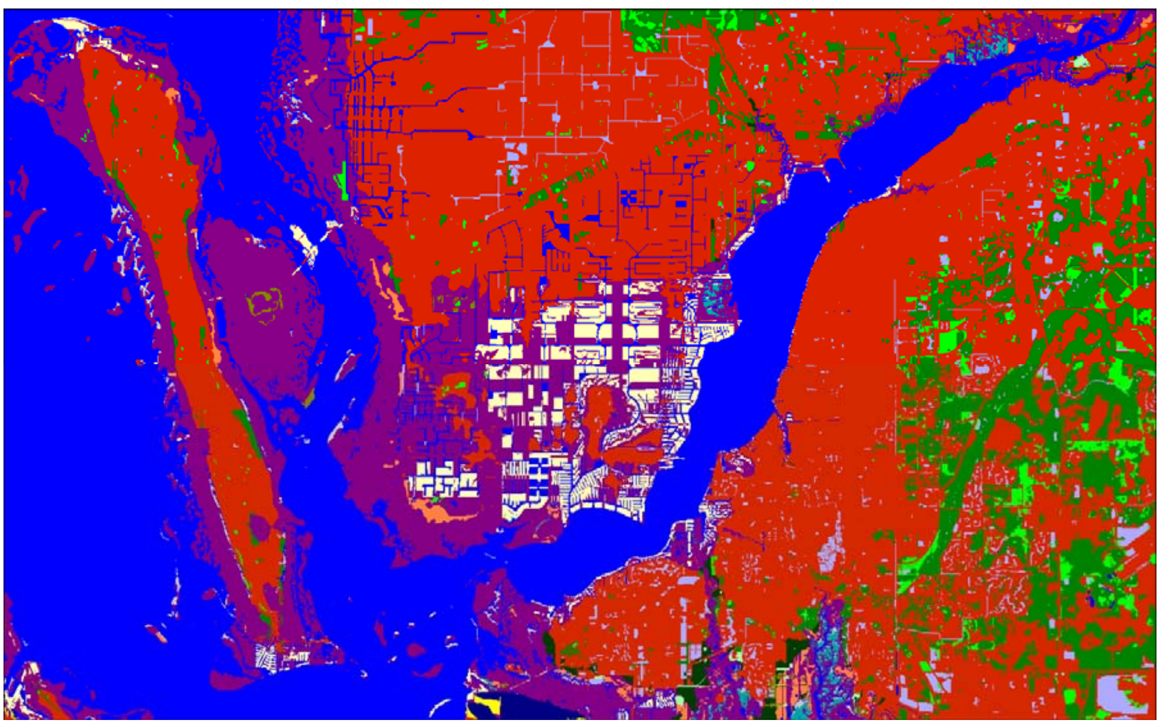
Caloosahatchee Context, Initial Condition



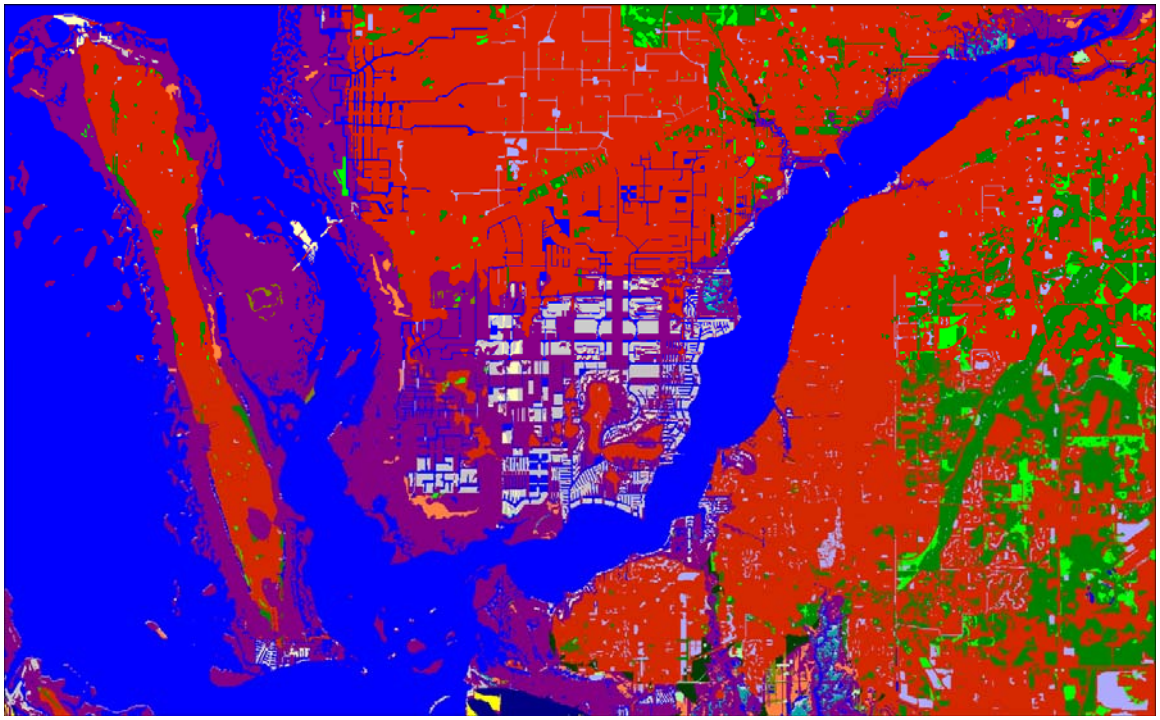
Caloosahatchee Simulation Context, 2025, Scenario A1B Mean



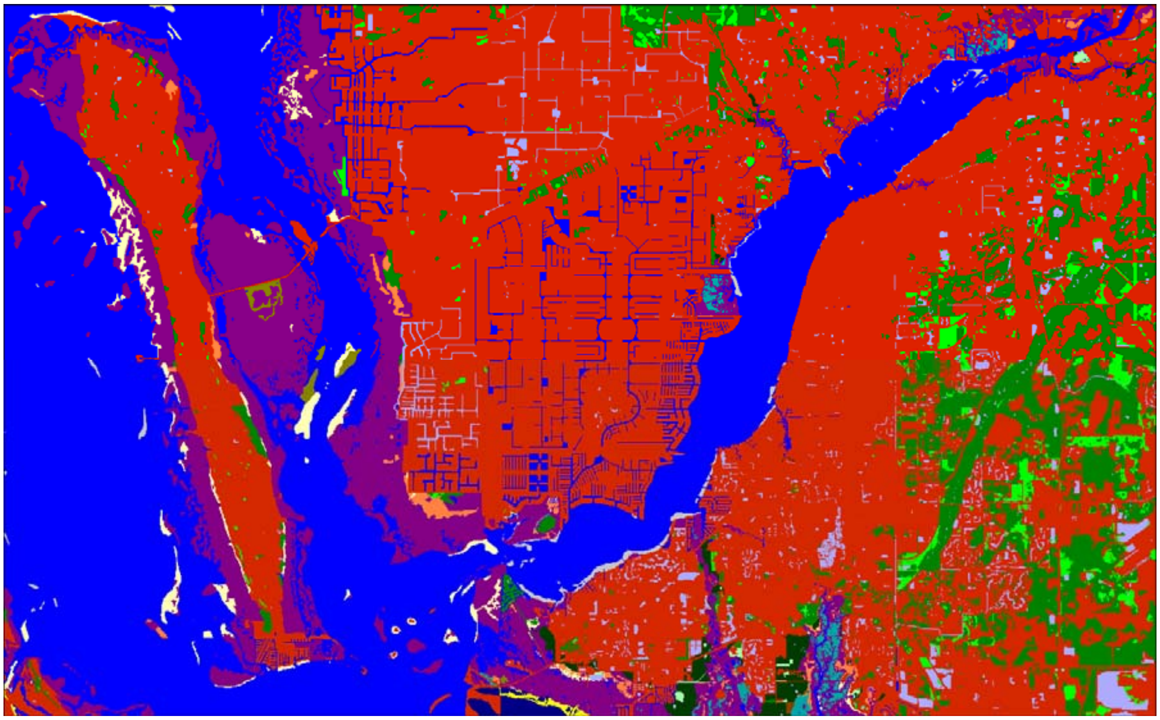
Caloosahatchee Simulation Context, 2050, Scenario A1B Mean



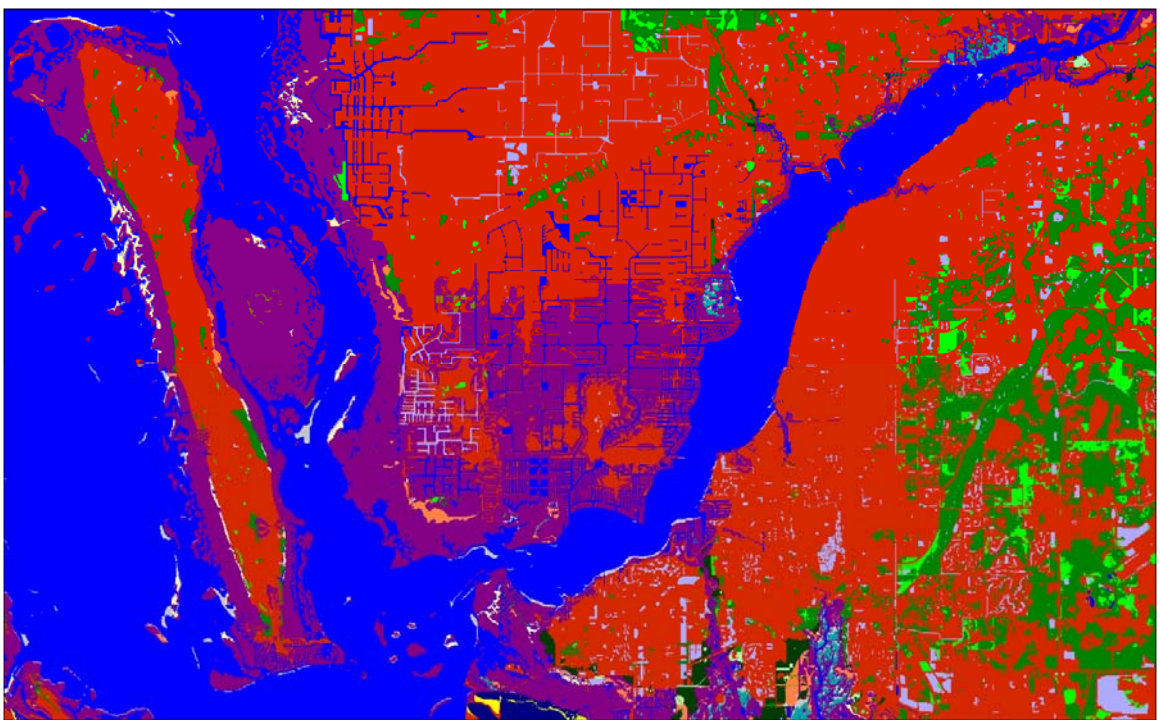
Caloosahatchee Simulation Context, 2075, Scenario A1B Mean



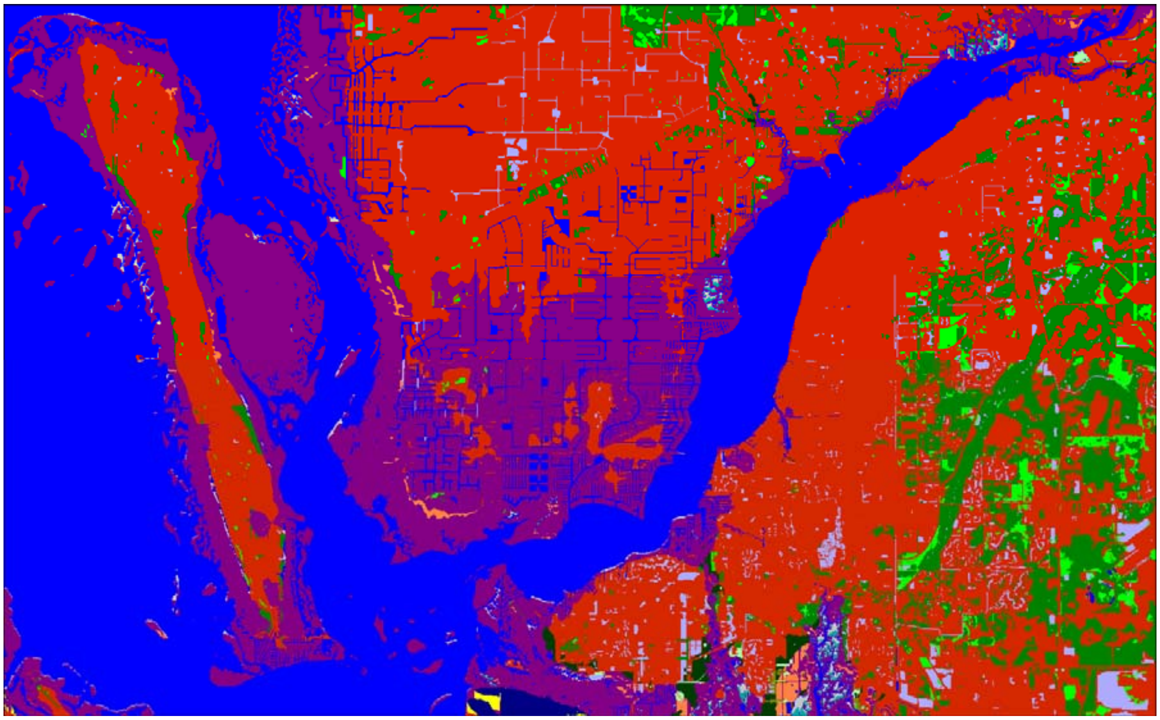
Caloosahatchee Simulation Context, 2100, Scenario A1B Mean



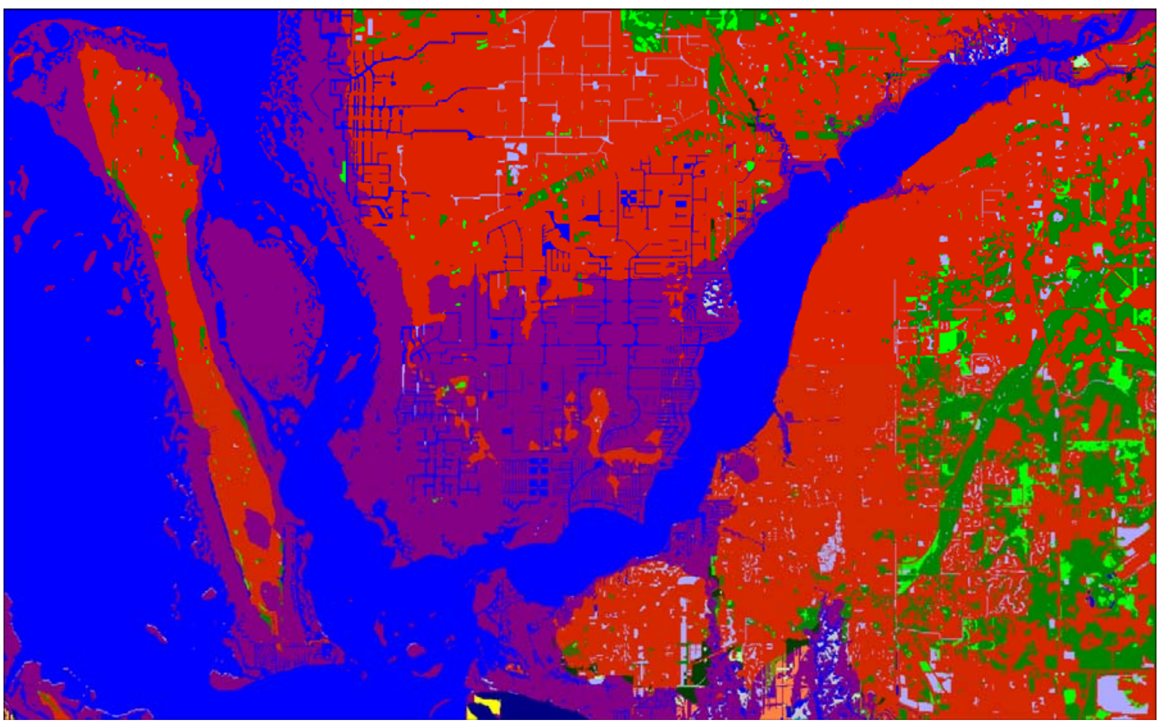
Caloosahatchee Simulation Context, Initial Condition



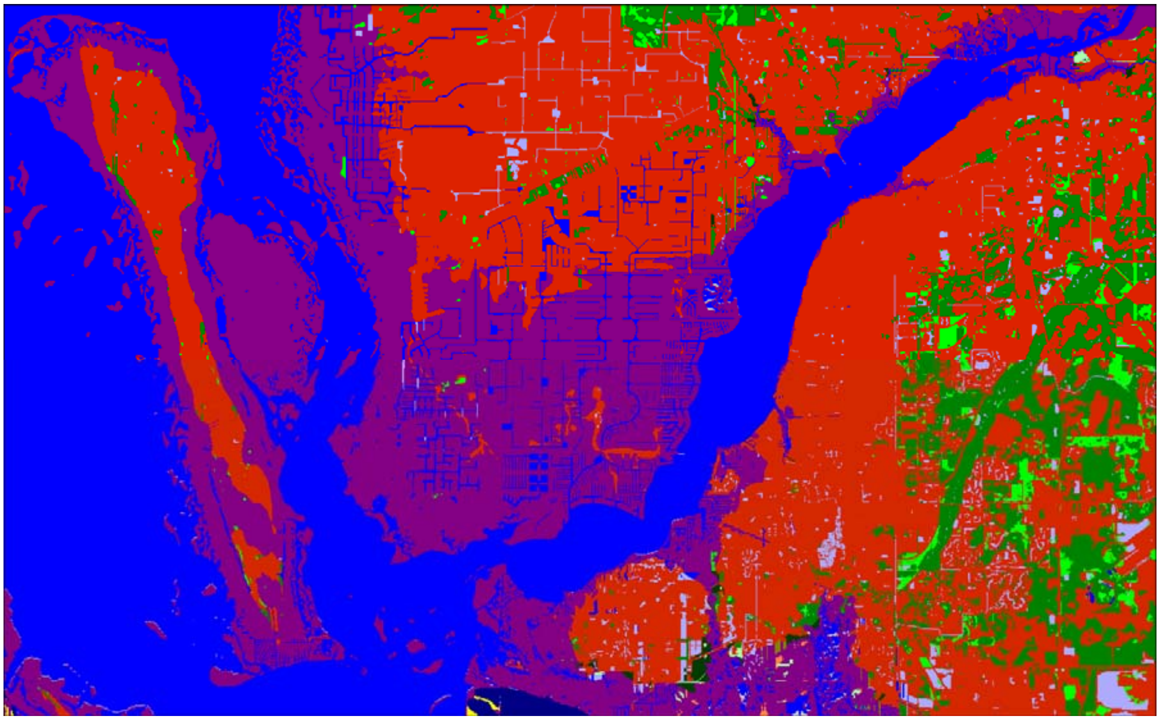
Caloosahatchee Simulation Context, 2025, Scenario A1B Maximum



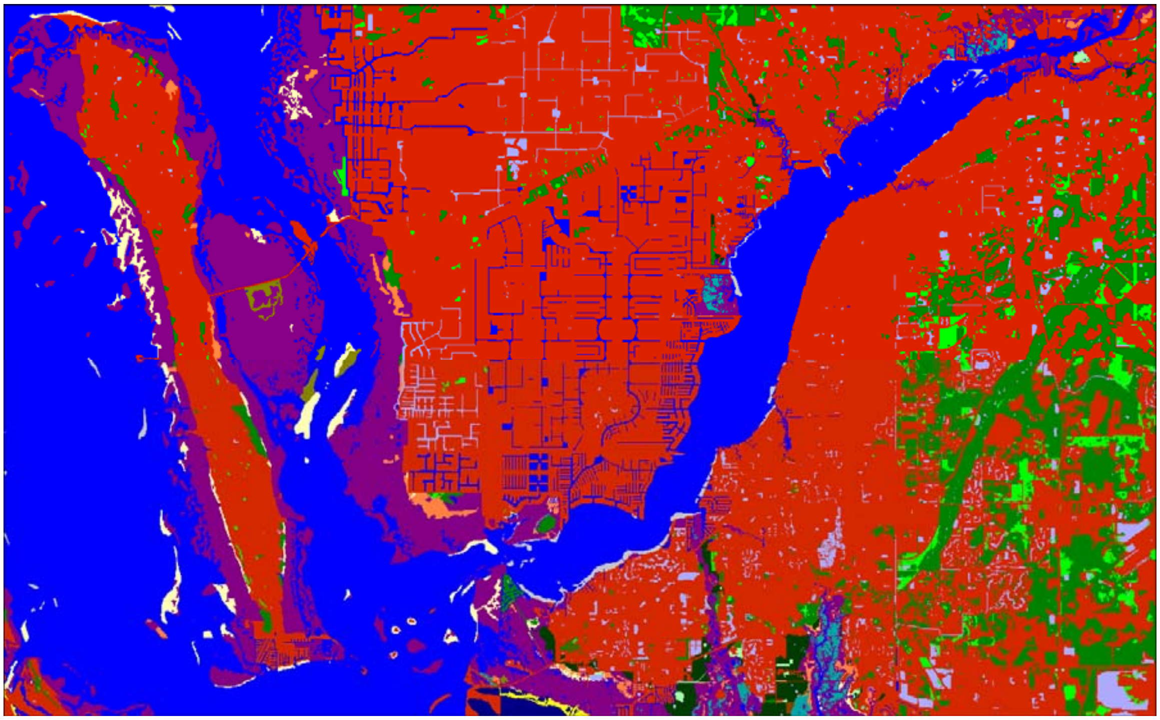
Caloosahatchee Simulation Context, 2050, Scenario A1B Maximum

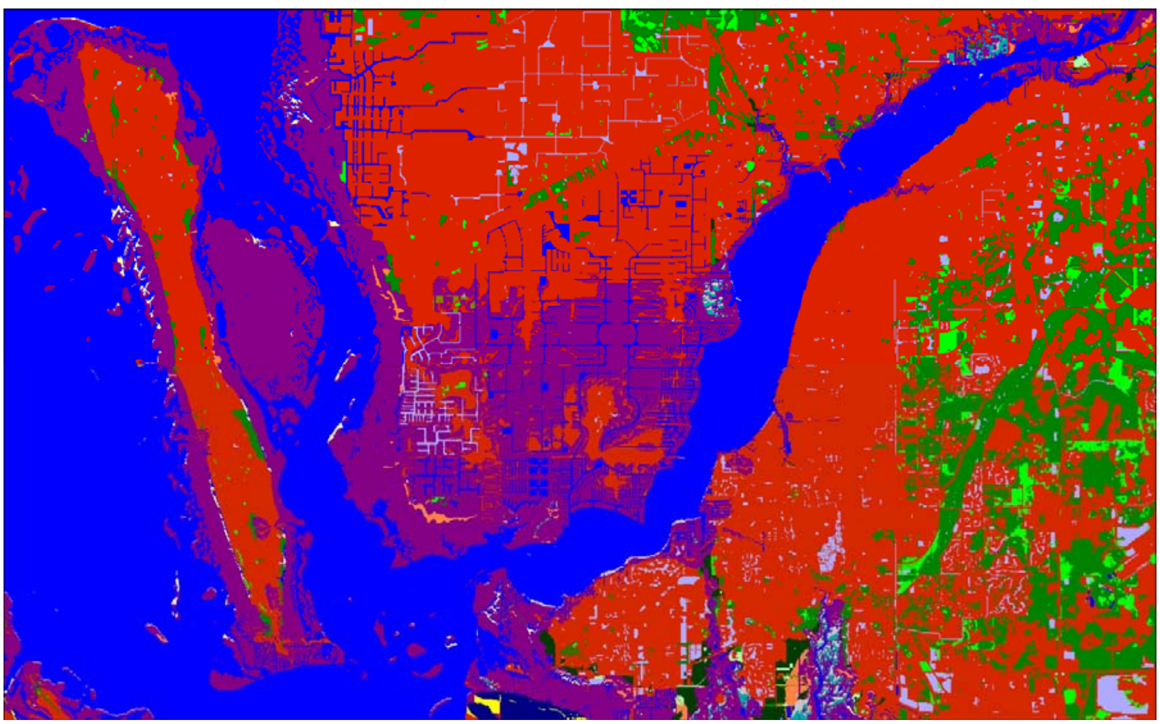


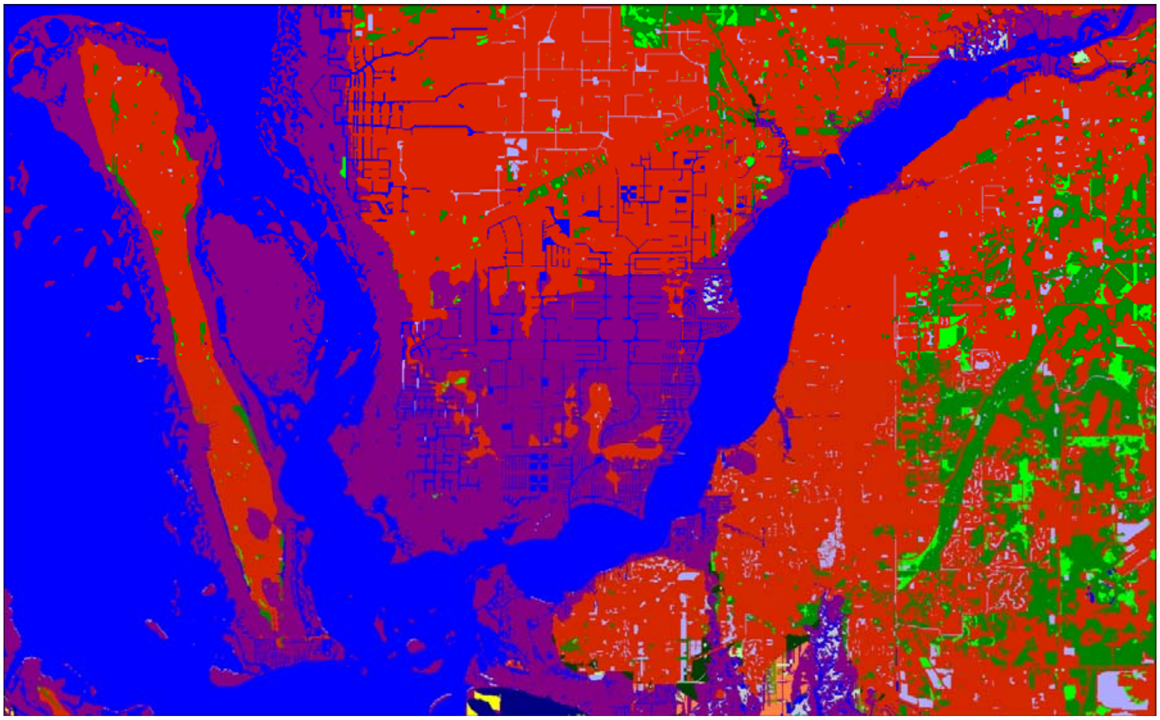
Caloosahatchee Simulation Context, 2075, Scenario A1B Maximum



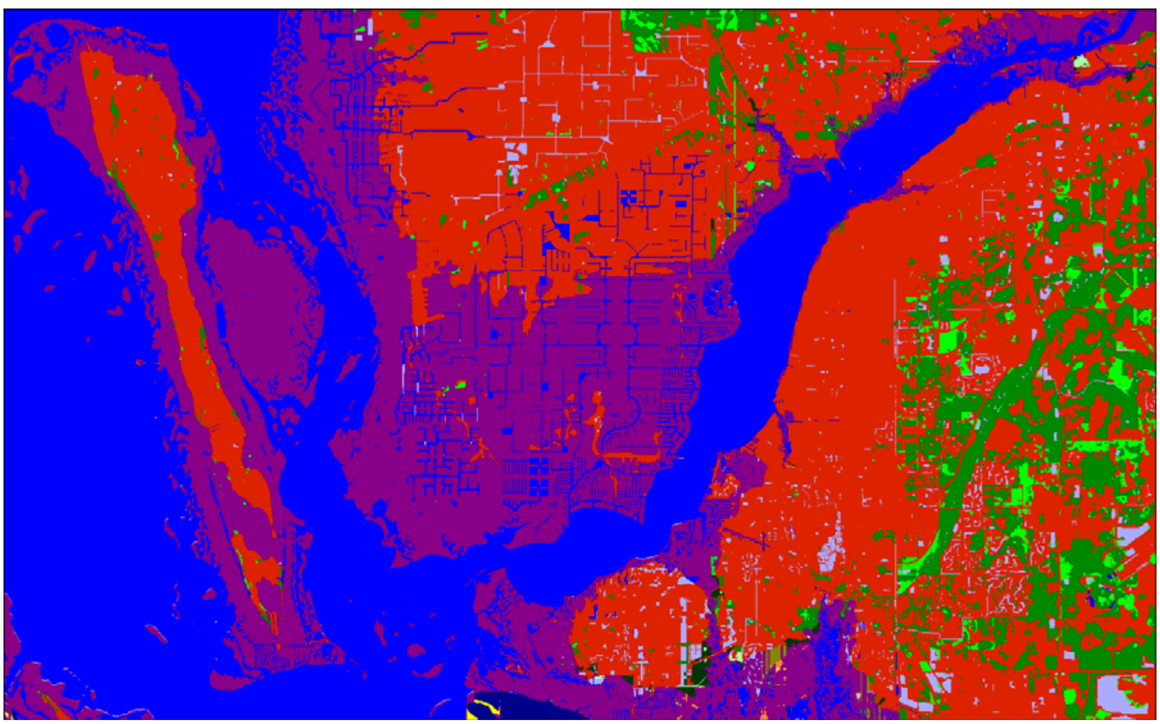
Caloosahatchee Simulation Context, 2100, Scenario A1B Maximum


Caloosahatchee Simulation Context, Initial Condition

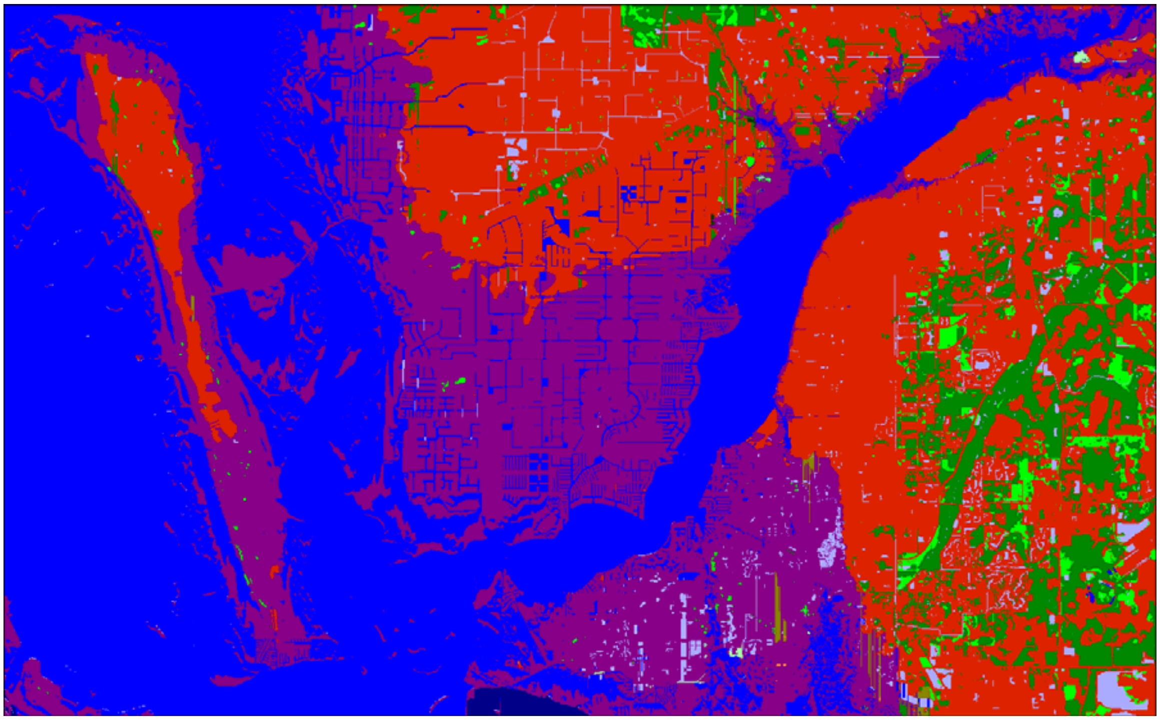

Caloosahatchee Simulation Context, 2025, 1 meter eustatic SLR by 2100



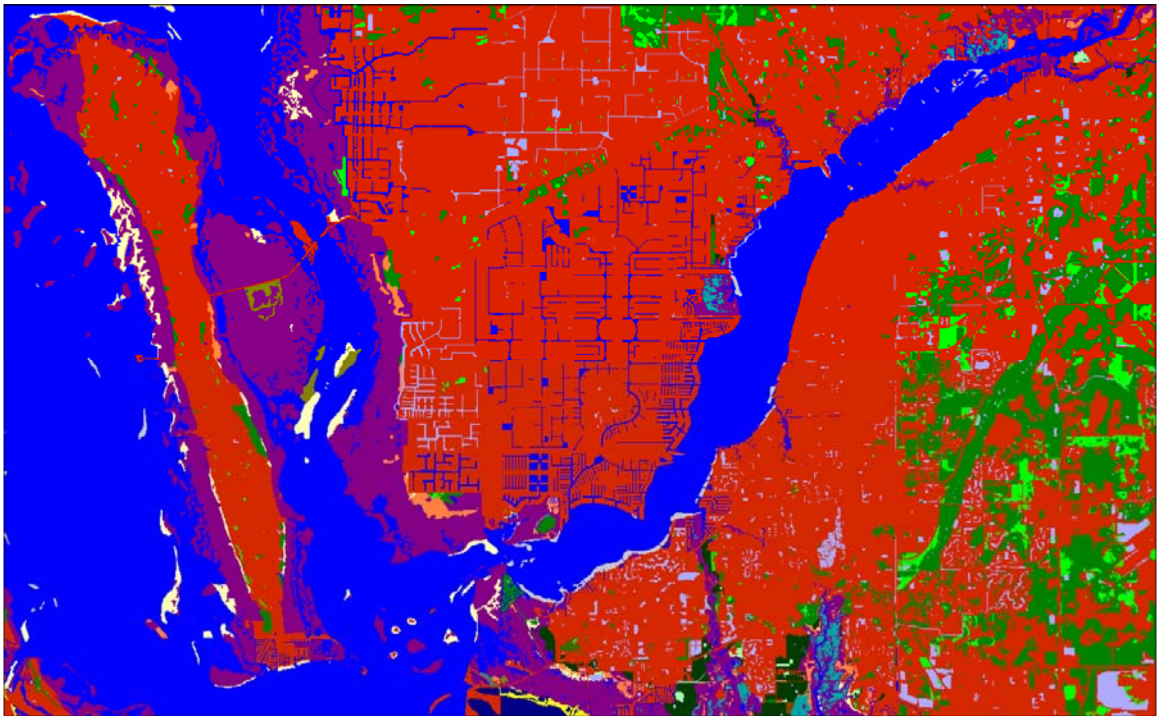
Caloosahatchee Simulation Context, 2050, 1 meter eustatic SLR by 2100



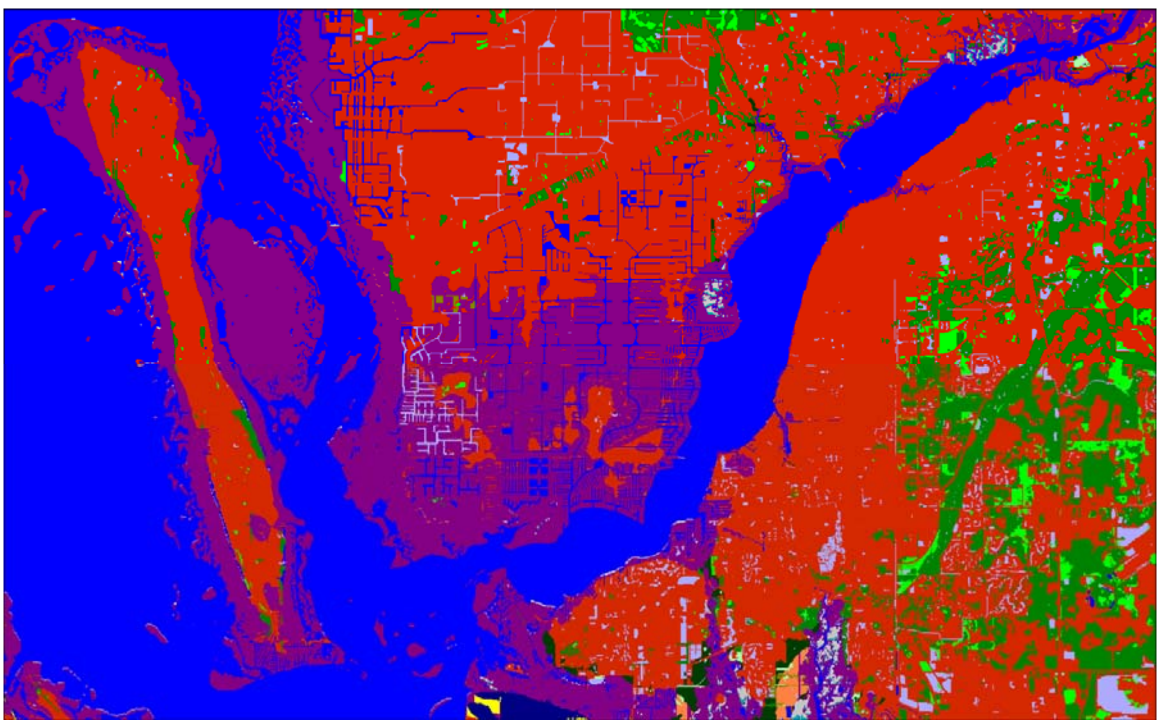
Caloosahatchee Simulation Context, 2075, 1 meter eustatic SLR by 2100



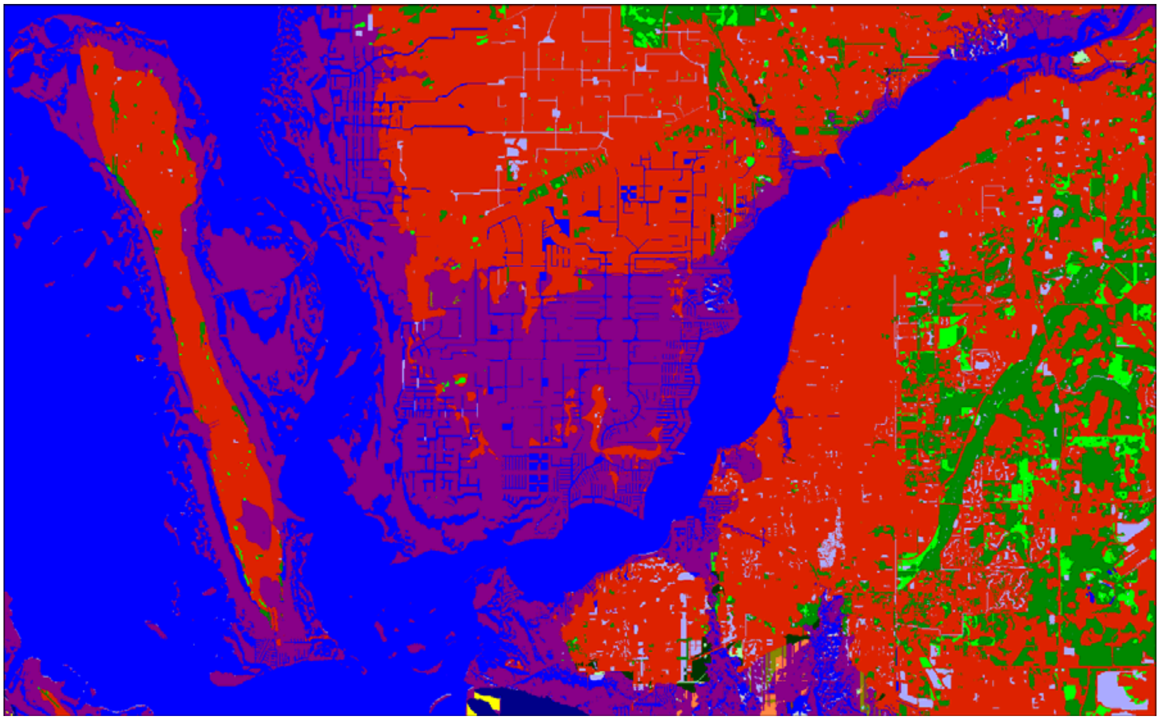
Caloosahatchee Simulation Context, 2100, 1 meter eustatic SLR by 2100



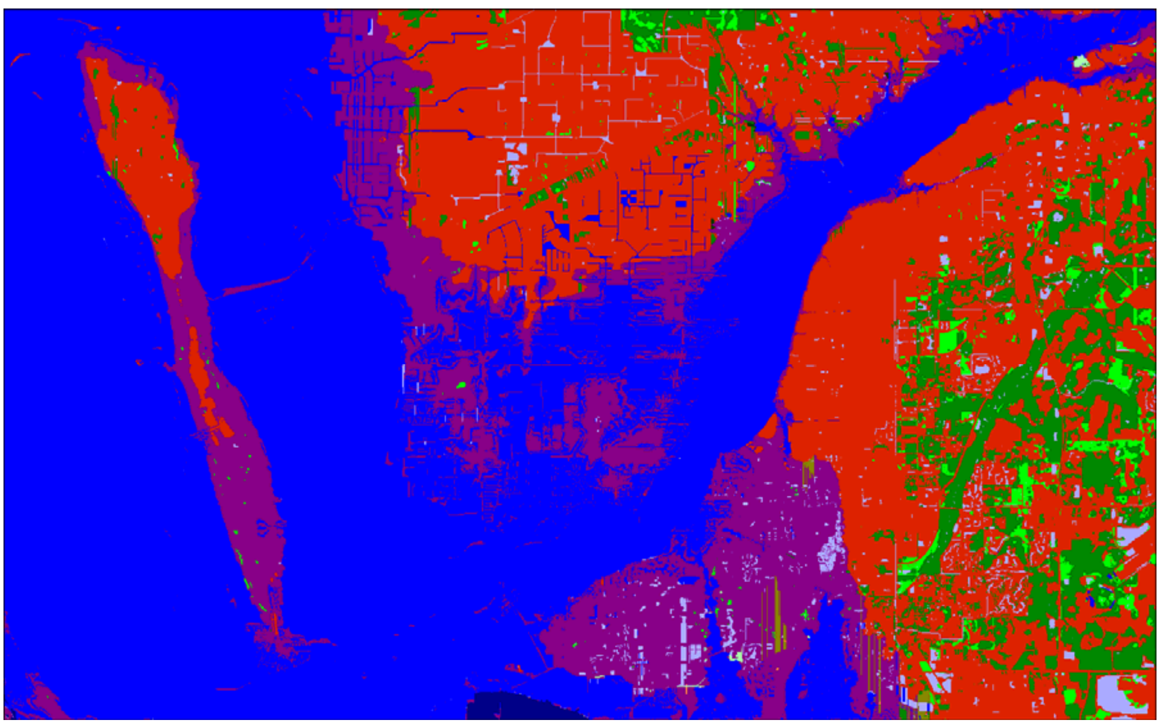
Caloosahatchee Simulation Context, Initial Condition



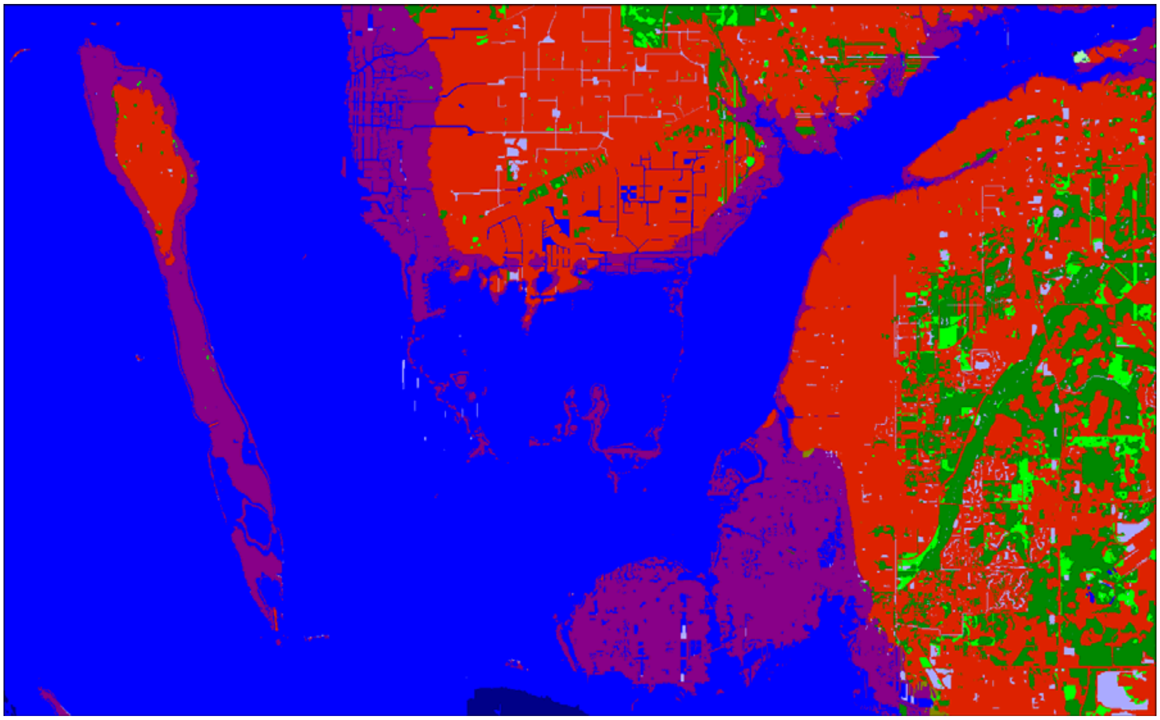
Caloosahatchee Simulation Context, 2025, 1.5 meters eustatic SLR by 2100



Caloosahatchee Simulation Context, 2050, 1.5 meters eustatic SLR by 2100



Caloosahatchee Simulation Context, 2075, 1.5 meters eustatic SLR by 2100



Caloosahatchee Simulation Context, 2100, 1.5 meters eustatic SLR by 2100