

# Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0) to Wertheim NWR

Prepared For: Dr. Brian Czech, Conservation Biologist

U. S. Fish and Wildlife Service  
National Wildlife Refuge System  
Division of Natural Resources and Conservation Planning  
Conservation Biology Program  
4401 N. Fairfax Drive - MS 670  
Arlington, VA 22203

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Jonathan S. Clough & Evan C. Larson, Warren Pinnacle Consulting, Inc.  
PO Box 253, Warren VT, 05674  
(802)-496-3476

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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](http://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. Mause. 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 Wertheim 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).

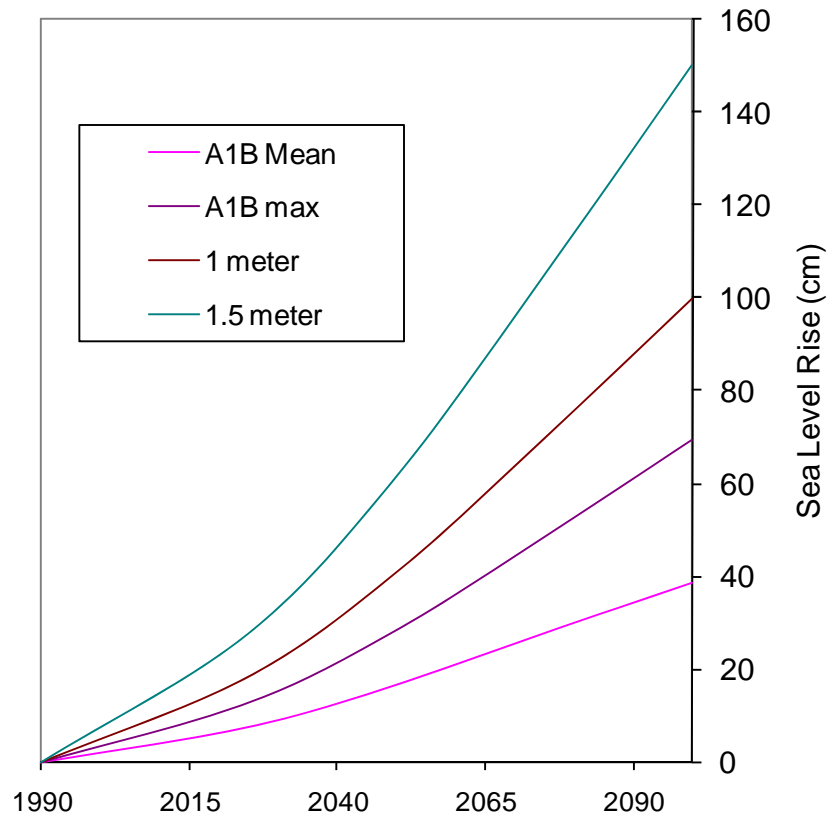
## ***Sea-Level Rise Scenarios***

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:

<b>Scenario</b>	<b>Eustatic SLR by 2025 (cm)</b>	<b>Eustatic SLR by 2050 (cm)</b>	<b>Eustatic SLR by 2075 (cm)</b>	<b>Eustatic SLR by 2100 (cm)</b>
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).

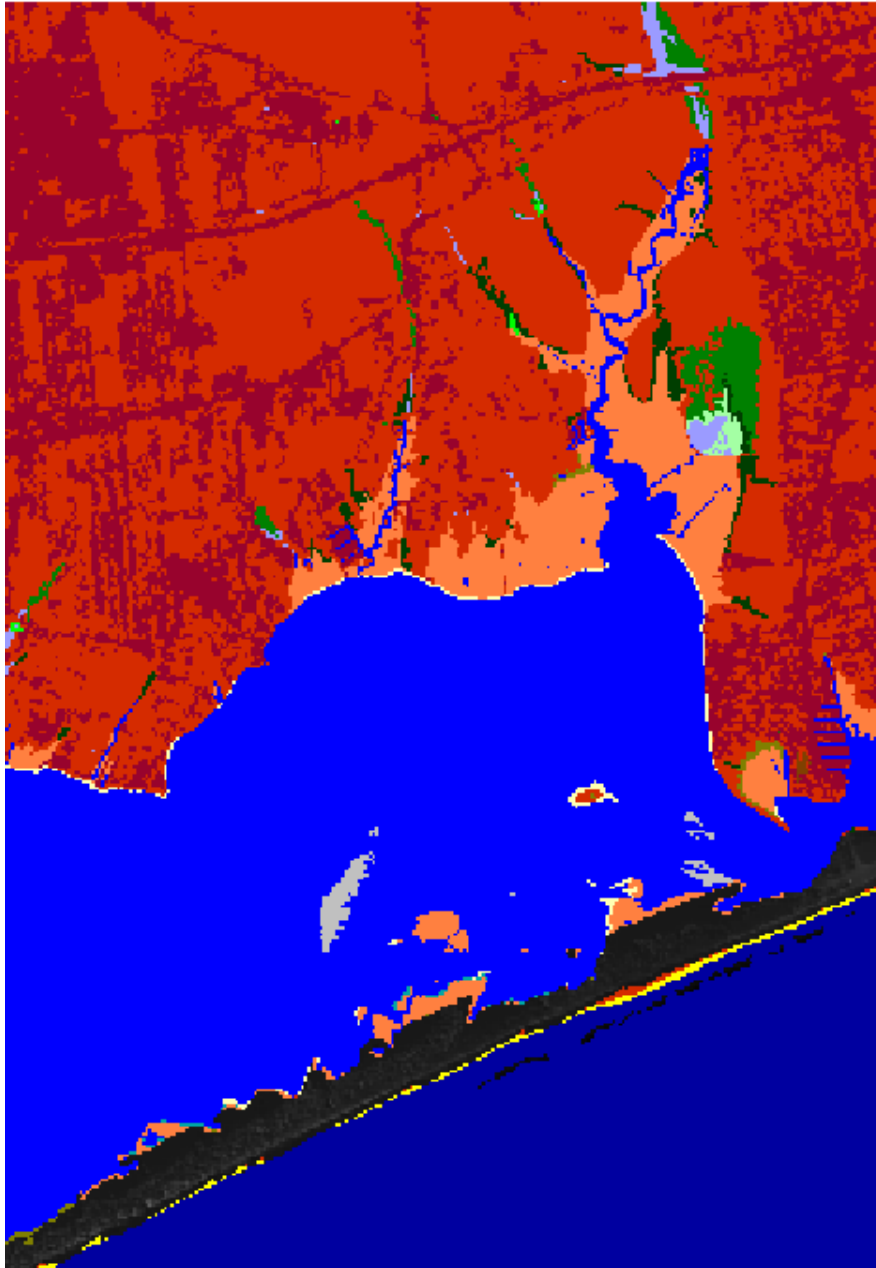
**Figure 1: Summary of SLR Scenarios Utilized**



## Methods and Data Sources

A limited set of LIDAR data was found for Wertheim NWR. The elevation data used are based on a combination of the LIDAR and National Elevation Data (NED).

NED metadata indicates that this digital elevation map (DEM) was derived from a 1956 survey; the LIDAR was derived from a 2005 flight date (Fig. 2a).



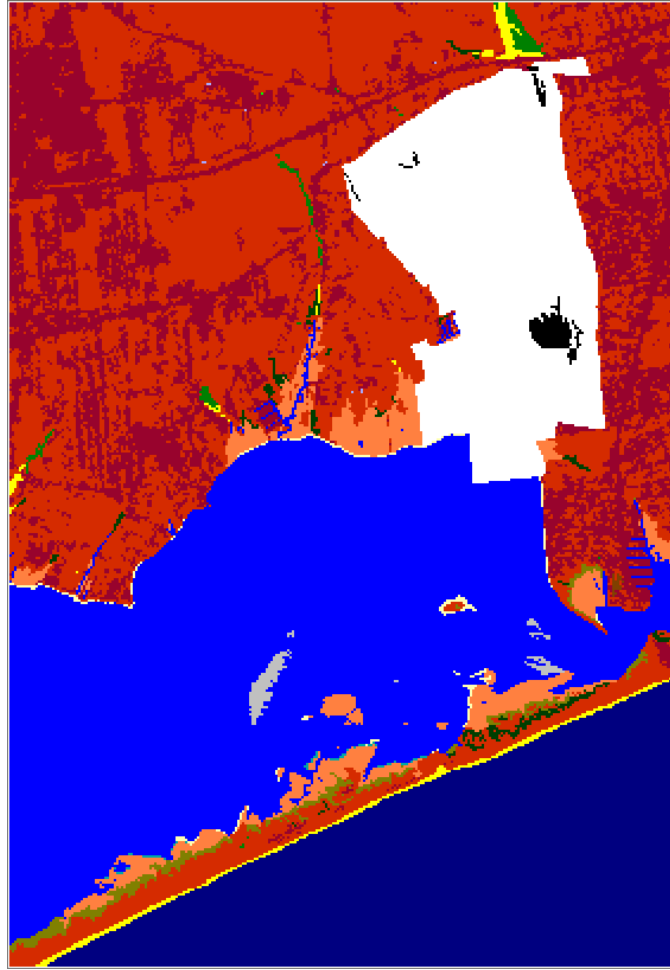
**Figure 2a: LIDAR elevation data (in Black) Over Study Area.**

The National Wetlands Inventory for Wertheim is based on a photo date of 1994. An examination of the NWI map overlaid on recent satellite photos indicates only minor changes in the Wertheim NWR wetland boundaries since that date.

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

Undeveloped Dry Land	50.0%
Brackish Marsh	23.4%
Estuarine Open Water	14.1%
Swamp	5.1%
Tidal Swamp	4.0%
Inland Open Water	1.4%
Tidal Fresh Marsh	1.0%
Developed Dry Land	0.4%
Estuarine Beach	0.3%
Trans. Salt Marsh	0.2%
Inland Fresh Marsh	0.2%

There are a number of diked and impounded wetlands in the region of the Wertheim NWR according to the National Wetlands Inventory (Fig. 2b). The SLAMM model assumes that these diked areas will not be subject to inundation. The small quantity of developed dry lands in the refuge (as defined by the National Land Cover Database from 2001) was assumed to be protected.

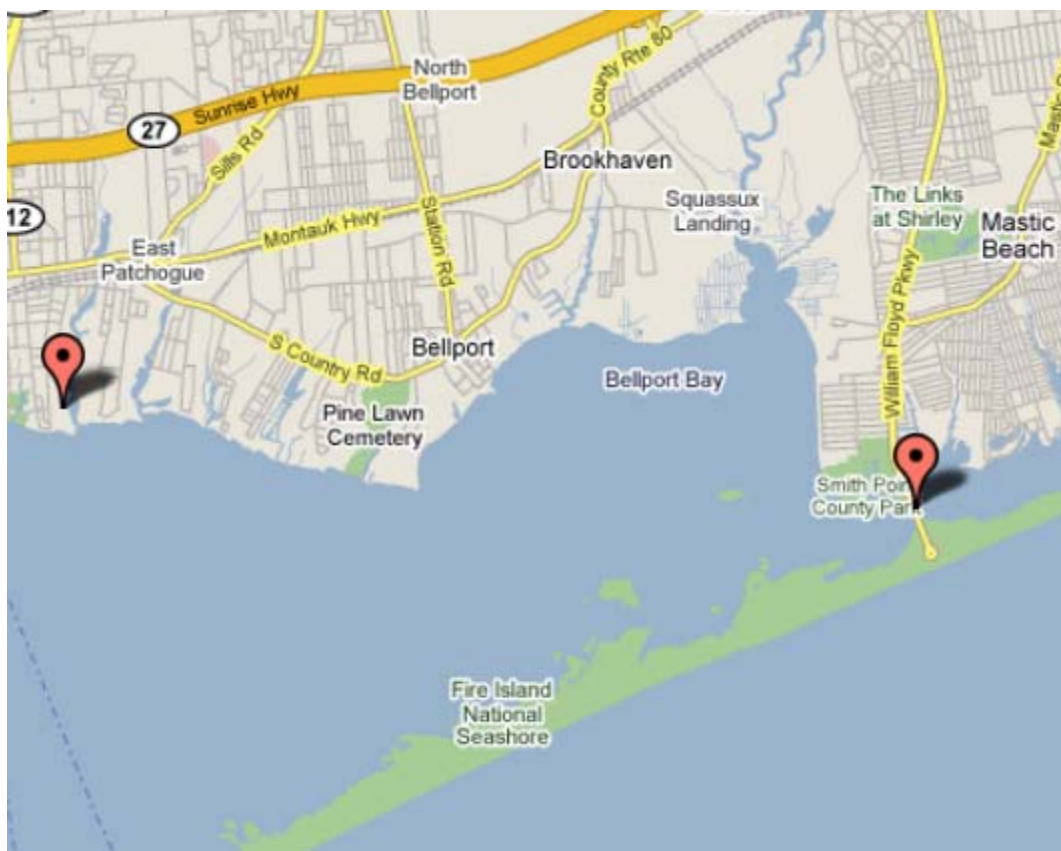


**Figure 2b: Wertheim Refuge in White; Diked Regions in Black**

The historic trend for sea level rise was estimated at 2.87 mm/year (Cashin Associates, 2006). NOAA gages on Long Island all estimate the long term sea level rise at between 2.3 and 3 mm/year. The rate of sea level rise on Long Island may be considered slightly higher than the global average for the last 100 years (approximately 1.5-2.0 mm/year).

The tidal range for the Wertheim NWR is estimated at 0.432 meters (Fig. 3) using tidal data from two local sites (Patchogue, 8514322; Smith Point Bridge, Narrow Bay, 8513825). The tidal range south of Fire Island is estimated at 1.67 meters using tidal data from South Long Island ocean gages.





**Figure 3: NOAA Gages Relevant to the Study Area.**

Accretion rates in salt and Irregularly Flooded marshes were set to 2.9 mm/year. This is the mean of measured accretion values from Wertheim NWR (McLetchie, 2006; R.A. Orson, 1998).

Modeled U.S. Fish and Wildlife Service refuge boundaries for New York are based on Approved Acquisition Boundaries as published on the FWS National Wildlife Refuge Data and Metadata website.

The cell-size used for this analysis was 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 WERTHEIM

<b>Description</b>	<b>Wertheim</b>	<b>Wertheim LIDAR</b>	<b>Wertheim Ocean</b>
DEM Source Date (yyyy)	1956	2005	1956
NWI_photo_date (yyyy)	1994	1994	1994
Direction_OffShore (N S E W)	S	S	S
Historic_trend (mm/yr)	2.87	2.87	2.87
NAVD88_correction (MTL-NAVD88 in meters)	-0.056	-0.056	-0.056
<i>Water Depth (m below MLW- N/A)</i>	2	2	2
TideRangeOcean (meters: MHHW-MLLW)	0.432	1.67	1.67
TideRangeInland (meters)	0.432	1.67	1.67
Mean High Water Spring (m above MTL)	0.287	1.111	1.111
MHSW Inland (m above MTL)	0.287	1.111	1.111
Marsh Erosion (horz meters/year)	1.8	1.8	1.8
Swamp Erosion (horz meters/year)	1	1	1
TFlat Erosion (horz meters/year) [from 0.5]	0.5	0.5	0.5
Salt marsh vertical accretion (mm/yr)	2.9	2.9	2.9
Irreg. Flooded March vert. accretion (mm/yr)	2.9	2.9	2.9
Tidal Fresh vertical accretion (mm/yr)	5.9	5.9	5.9
Beach/T.Flat Sedimentation Rate (mm/yr)	0.5	0.5	0.5
Frequency of Large Storms (yr/washover)	35	35	35
Use Elevation Preprocessor for Wetlands	TRUE	FALSE	FALSE

## Results

Wertheim NWR is predicted to be susceptible to the effects of all sea level rise scenarios run. Loss of irregularly flooded marsh – which constitutes roughly one quarter of this NWR – is predicted to be severe in all scenarios. Swamp and tidal swamps are predicted to be extensively lost only under scenarios of 1 meter or higher.

<b>SLR by 2100 (m)</b>	<b>0.39</b>	<b>0.69</b>	<b>1</b>	<b>1.5</b>
Undeveloped Dry Land	0%	4%	12%	18%
Irregularly Flooded Marsh	100%	98%	91%	99%
Swamp	-2%	8%	50%	69%
Tidal Swamp	2%	13%	62%	70%
Tidal Fresh Marsh	0%	0%	0%	0%

**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:

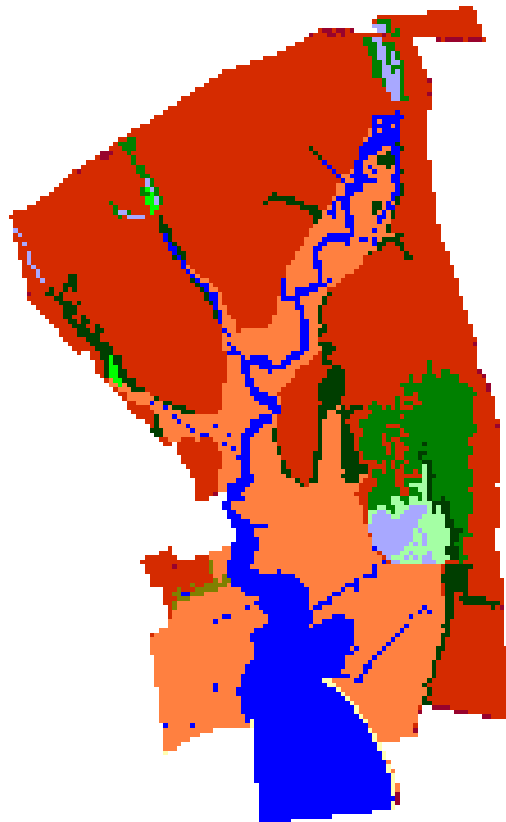


Wertheim NWR

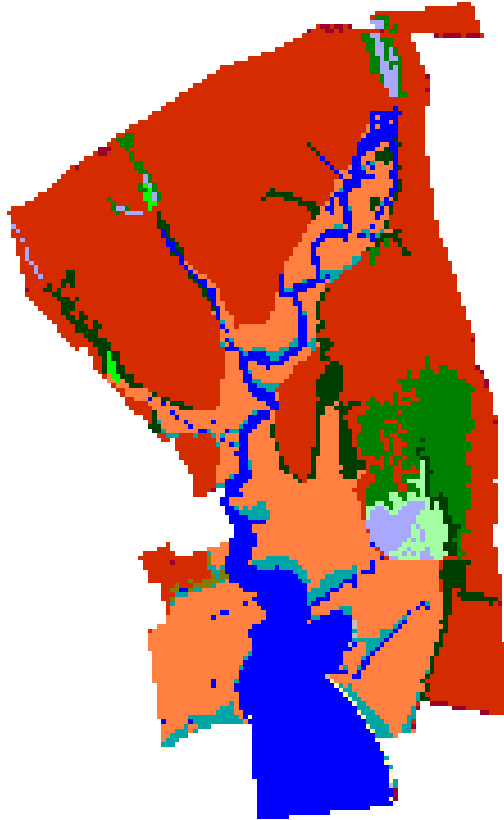
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

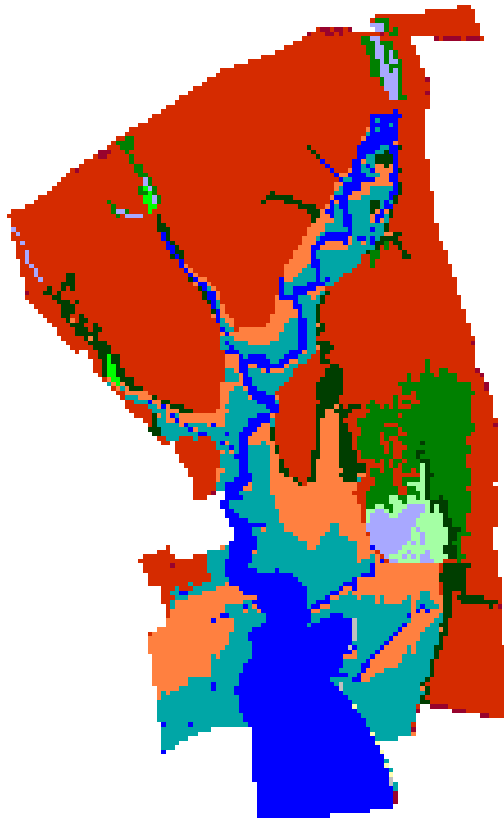
	Initial	2025	2050	2075	2100
Dry Land	1347.0	1345.3	1344.6	1343.6	1342.5
Irregularly Flooded Marsh	631.2	559.1	265.1	58.3	2.0
Estuarine Open Water	379.0	380.8	384.0	412.2	441.6
Swamp	138.1	139.8	140.3	140.9	141.0
Tidal Swamp	106.7	106.3	105.5	104.6	104.1
Inland Open Water	36.9	36.9	36.9	36.9	36.9
Tidal Fresh Marsh	26.7	26.7	26.7	26.7	26.7
Developed Dry Land	11.1	11.1	11.1	11.1	11.1
Estuarine Beach	6.9	4.1	1.6	0.4	1.0
Trans. Salt Marsh	6.4	4.8	0.1	0.2	0.3
Inland Fresh Marsh	4.4	4.4	4.4	4.4	4.4
Saltmarsh	0.0	73.4	372.1	411.2	139.3
Tidal Flat	0.0	1.9	2.0	144.0	443.5
<b>Total (incl. water)</b>	<b>2694.5</b>	<b>2694.5</b>	<b>2694.5</b>	<b>2694.5</b>	<b>2694.5</b>



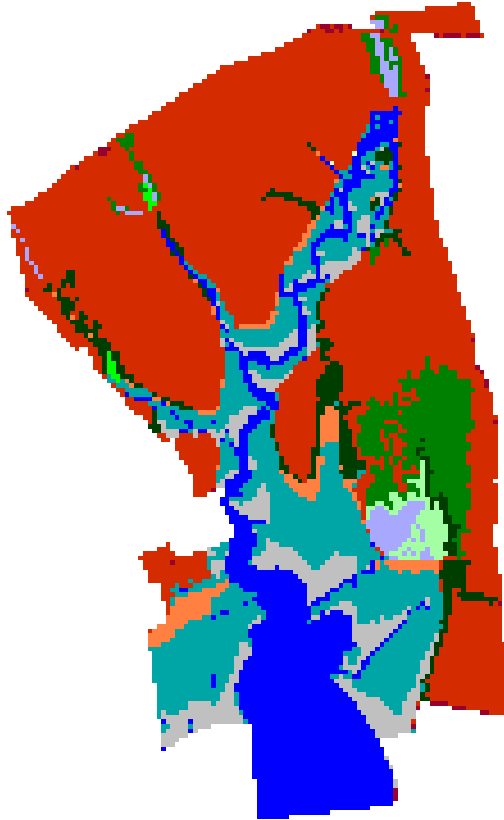
Wertheim NWR, Initial Condition



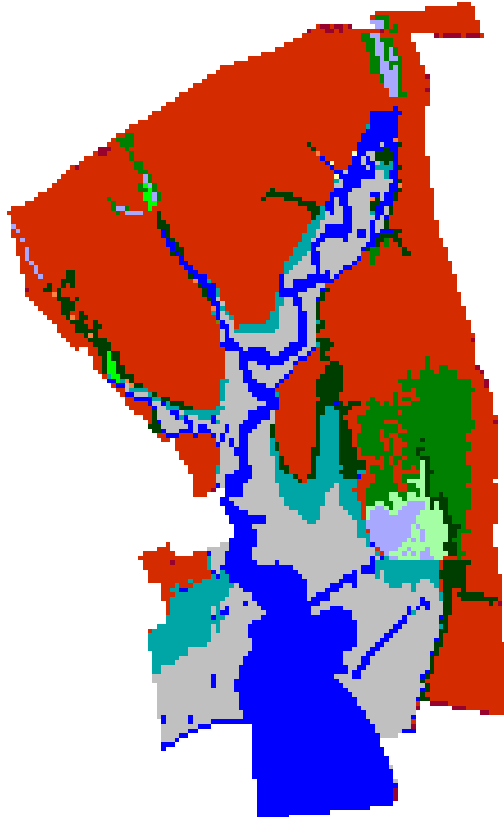
Wertheim NWR, 2025, Scenario A1B Mean Protect Developed Dry Land



Wertheim NWR, 2050, Scenario A1B Mean Protect Developed Dry Land



Wertheim NWR, 2075, Scenario A1B Mean Protect Developed Dry Land



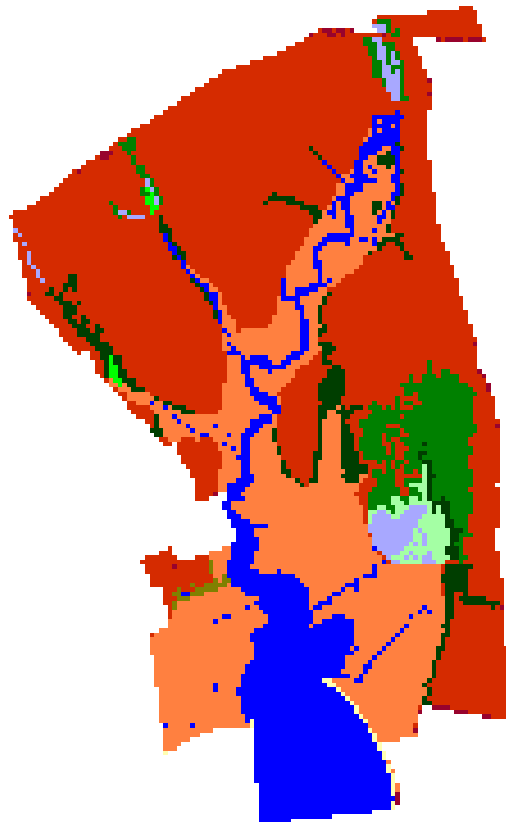
Wertheim NWR, 2100, Scenario A1B Mean Protect Developed Dry Land

Wertheim NWR

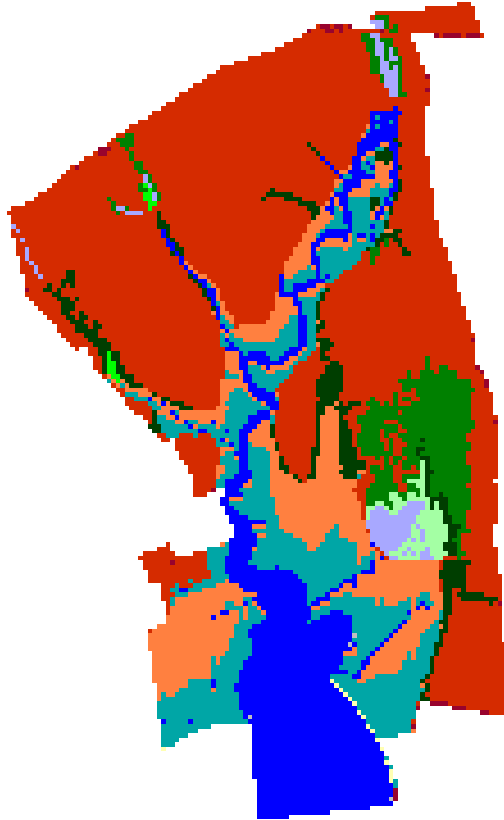
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

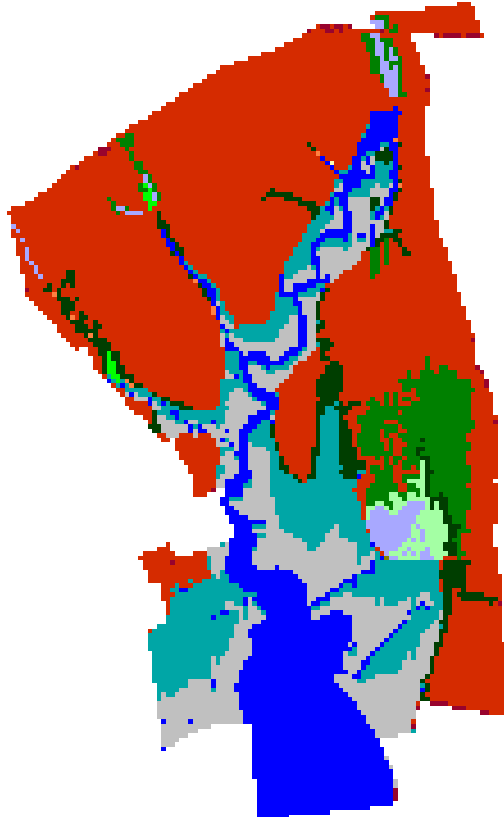
	Initial	2025	2050	2075	2100
Dry Land	1347.0	1344.3	1341.8	1338.5	1288.6
Irregularly Flooded Marsh	631.2	300.3	2.2	1.2	10.4
Estuarine Open Water	379.0	382.6	414.2	746.1	1026.0
Swamp	138.1	140.7	142.8	144.6	126.7
Tidal Swamp	106.7	105.9	104.7	103.7	93.4
Inland Open Water	36.9	36.9	36.9	36.9	36.9
Tidal Fresh Marsh	26.7	26.7	26.7	26.7	26.7
Developed Dry Land	11.1	11.1	11.1	11.1	11.1
Estuarine Beach	6.9	2.8	0.3	1.1	14.1
Trans. Salt Marsh	6.4	0.5	0.2	0.6	54.1
Inland Fresh Marsh	4.4	4.4	4.4	4.3	4.2
Saltmarsh	0.0	337.3	305.6	2.2	1.7
Tidal Flat	0.0	0.9	303.6	277.3	0.7
<b>Total (incl. water)</b>	<b>2694.5</b>	<b>2694.5</b>	<b>2694.5</b>	<b>2694.5</b>	<b>2694.5</b>



Wertheim NWR, Initial Condition

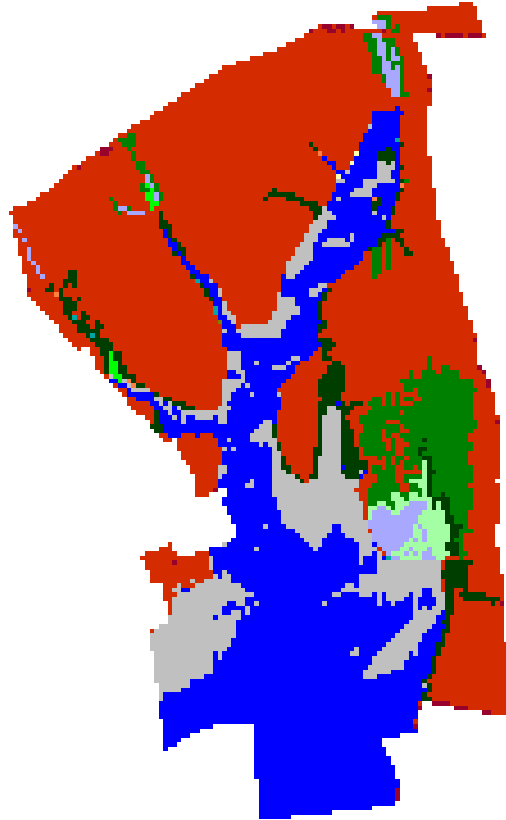


Wertheim NWR, 2025, Scenario A1B Maximum Protect Developed Dry Land

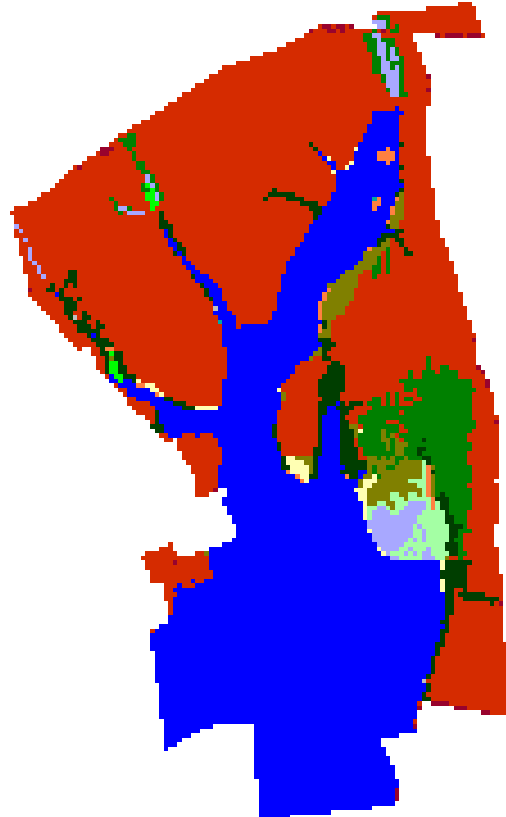


Wertheim NWR, 2050, Scenario A1B Maximum Protect Developed Dry Land





Wertheim NWR, 2075, Scenario A1B Maximum Protect Developed Dry Land



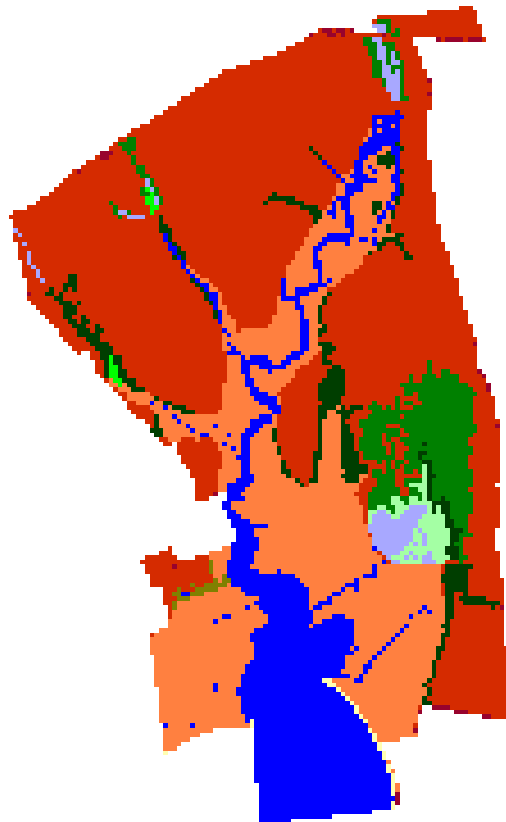
Wertheim NWR, 2100, Scenario A1B Maximum Protect Developed Dry Land

Wertheim NWR

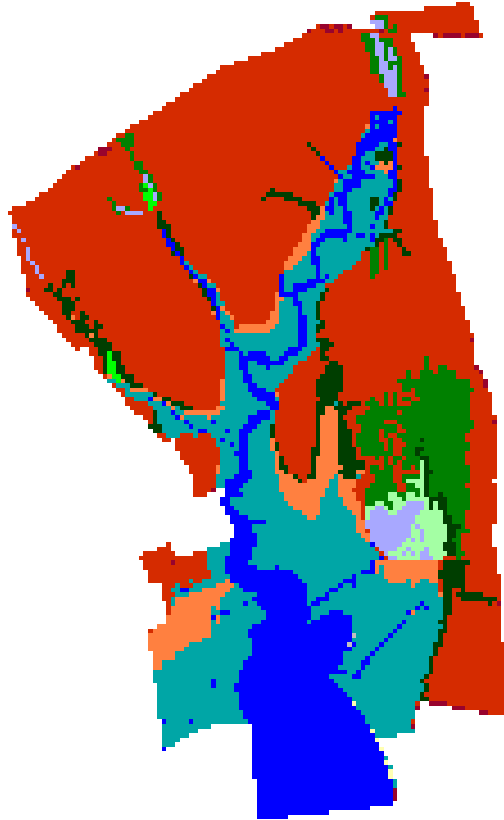
1 Meter Eustatic SLR by 2100

Results in Acres

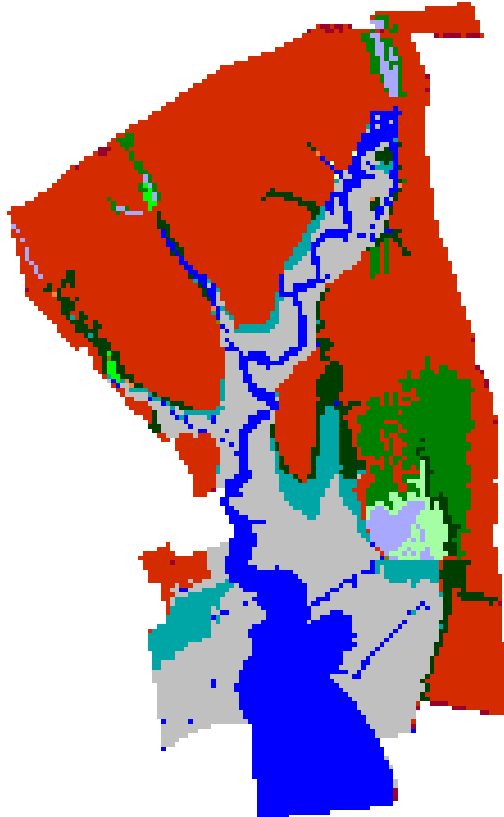
	Initial	2025	2050	2075	2100
Dry Land	1347.0	1341.9	1338.8	1314.3	1186.7
Irregularly Flooded Marsh	631.2	116.9	1.3	7.3	56.2
Estuarine Open Water	379.0	384.1	416.0	922.2	1031.8
Swamp	138.1	143.1	145.1	131.9	69.2
Tidal Swamp	106.7	105.5	104.2	96.8	40.3
Inland Open Water	36.9	36.9	36.9	36.9	36.9
Tidal Fresh Marsh	26.7	26.7	26.7	26.7	26.7
Developed Dry Land	11.1	11.1	11.1	11.1	11.1
Estuarine Beach	6.9	1.9	0.7	4.8	44.1
Trans. Salt Marsh	6.4	0.1	0.4	33.1	146.5
Inland Fresh Marsh	4.4	4.4	4.3	4.2	3.8
Tidal Flat	0.0	0.4	491.8	103.4	1.0
Saltmarsh	0.0	521.5	117.1	1.8	40.2
<b>Total (incl. water)</b>	<b>2694.5</b>	<b>2694.5</b>	<b>2694.5</b>	<b>2694.5</b>	<b>2694.5</b>



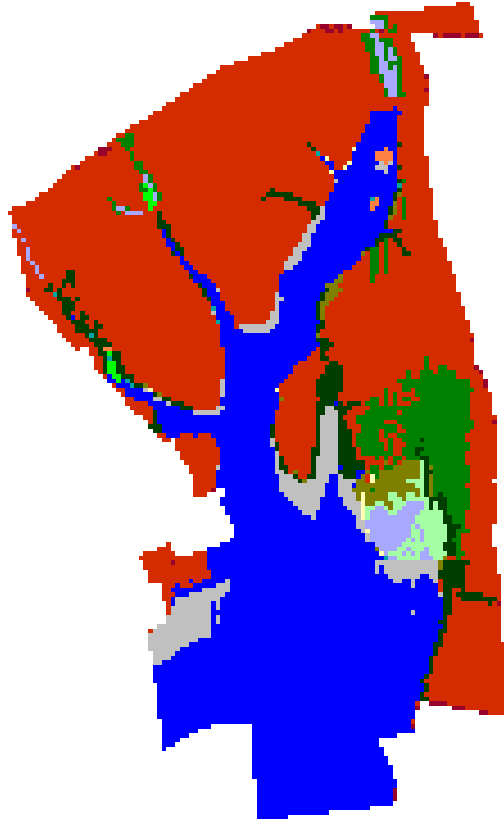
Wertheim NWR, Initial Condition



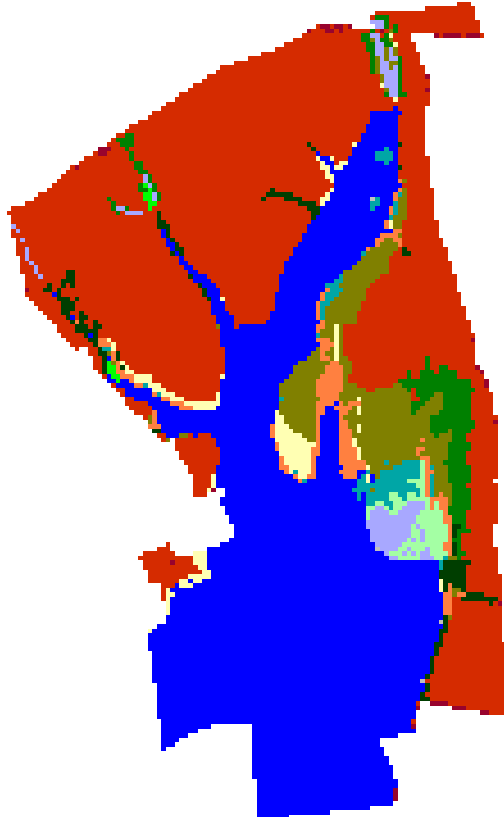
Wertheim NWR, 2025, 1 meter Protect Developed Dry Land



Wertheim NWR, 2050, 1 meter Protect Developed Dry Land



Wertheim NWR, 2075, 1 meter Protect Developed Dry Land



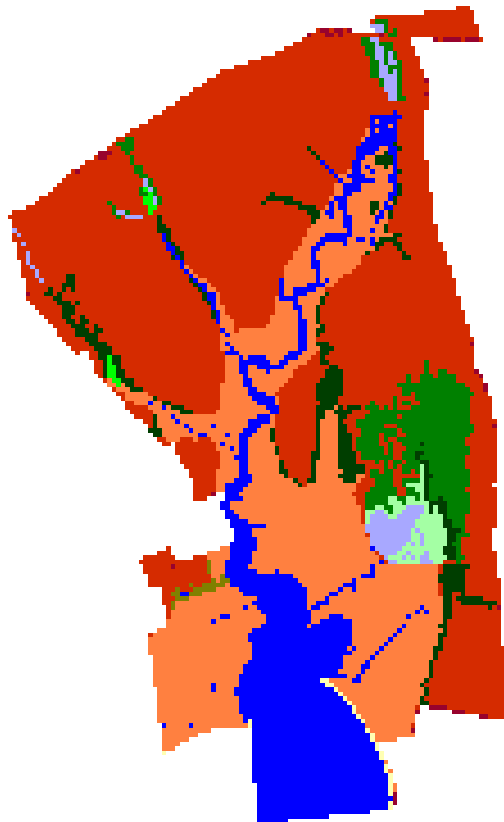
Wertheim NWR, 2100, 1 meter Protect Developed Dry Land

Wertheim NWR

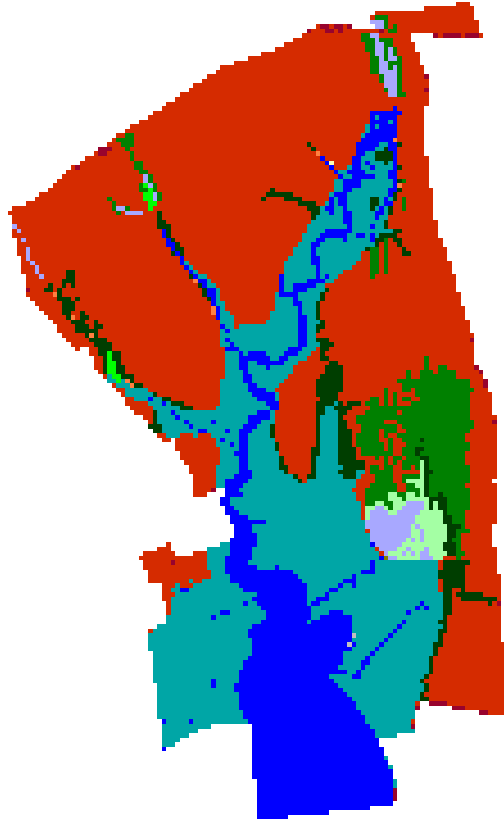
1.5 Meters Eustatic SLR by 2100

Results in Acres

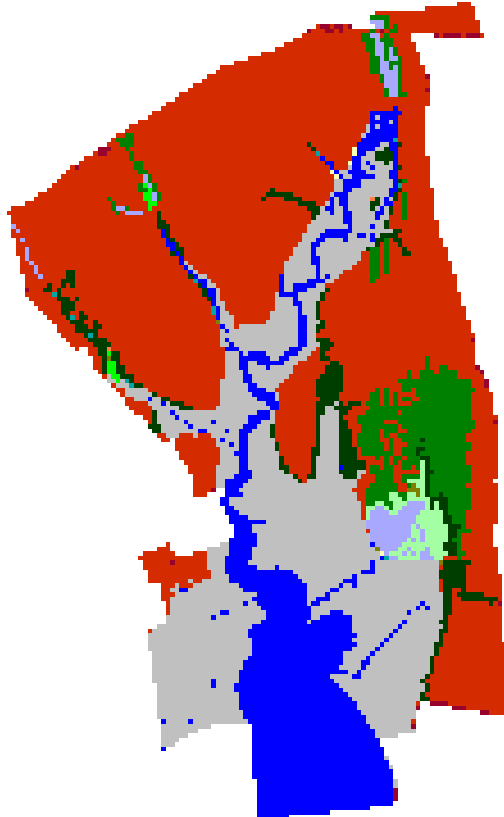
	Initial	2025	2050	2075	2100
Dry Land	1347.0	1339.7	1334.2	1183.4	1109.3
Irregularly Flooded Marsh	631.2	2.2	2.6	62.6	7.2
Estuarine Open Water	379.0	385.6	414.5	1026.5	1045.4
Swamp	138.1	145.2	146.7	71.5	43.1
Tidal Swamp	106.7	104.8	102.2	39.6	32.0
Inland Open Water	36.9	36.9	36.9	36.9	36.9
Tidal Fresh Marsh	26.7	26.7	26.7	26.7	26.7
Developed Dry Land	11.1	11.1	11.1	11.1	11.1
Estuarine Beach	6.9	0.5	1.6	15.5	35.6
Trans. Salt Marsh	6.4	0.2	2.5	211.1	67.3
Inland Fresh Marsh	4.4	4.4	4.2	3.5	3.2
Tidal Flat	0.0	0.4	608.9	1.0	5.6
Saltmarsh	0.0	637.0	2.4	5.1	271.1
<b>Total (incl. water)</b>	<b>2694.5</b>	<b>2694.5</b>	<b>2694.5</b>	<b>2694.5</b>	<b>2694.5</b>



Wertheim NWR, Initial Condition



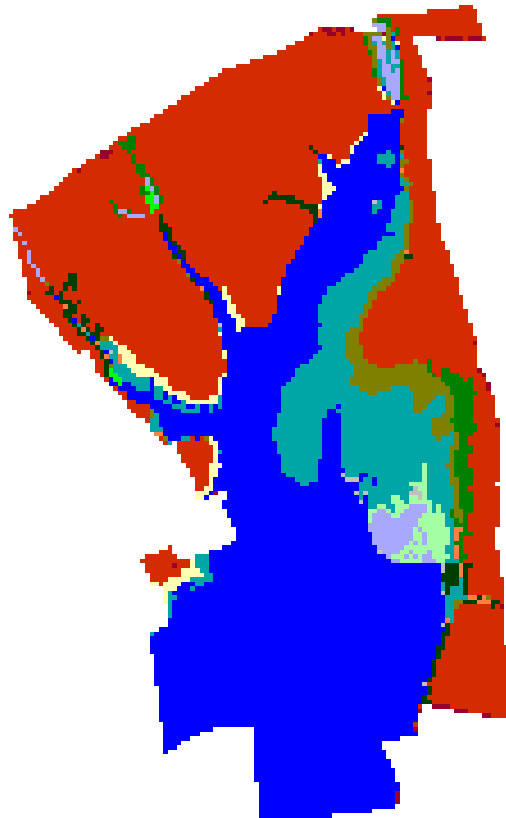
Wertheim NWR, 2025, 1.5 meter Protect Developed Dry Land



Wertheim NWR, 2050, 1.5 meter Protect Developed Dry Land



Wertheim NWR, 2075, 1.5 meter Protect Developed Dry Land



Wertheim NWR, 2100, 1.5 meter Protect Developed Dry Land

## **Discussion:**

Model results suggest that Wertheim NWR will be severely altered by sea level rise. Even in the most conservative scenario (0.39 meter eustatic by 2100) the refuge is expected to lose nearly all of its irregularly flooded marsh to tidal flats by 2100. This susceptibility to sea level rise is partially a result of the low tide range (0.432 meters) within Wertheim NWR.

As noted above, the elevation data for this site utilize both LIDAR and NED data. The LIDAR covers only the barrier island, the rest being NED that is more than 50 years old. None of the NWR is located on the barrier island, indicating that a future analysis would benefit from higher resolution elevation data.



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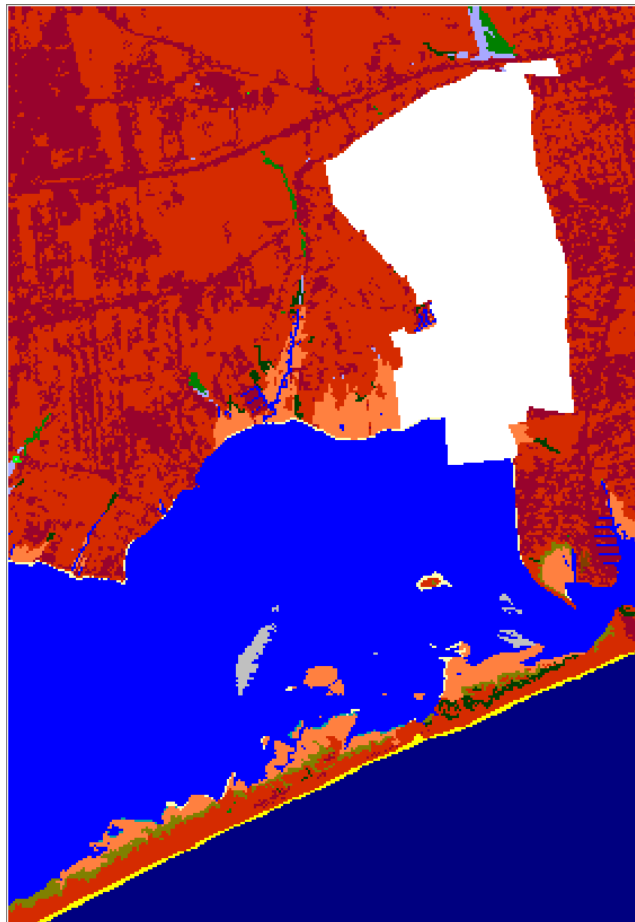
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## Appendix A: Contextual Results

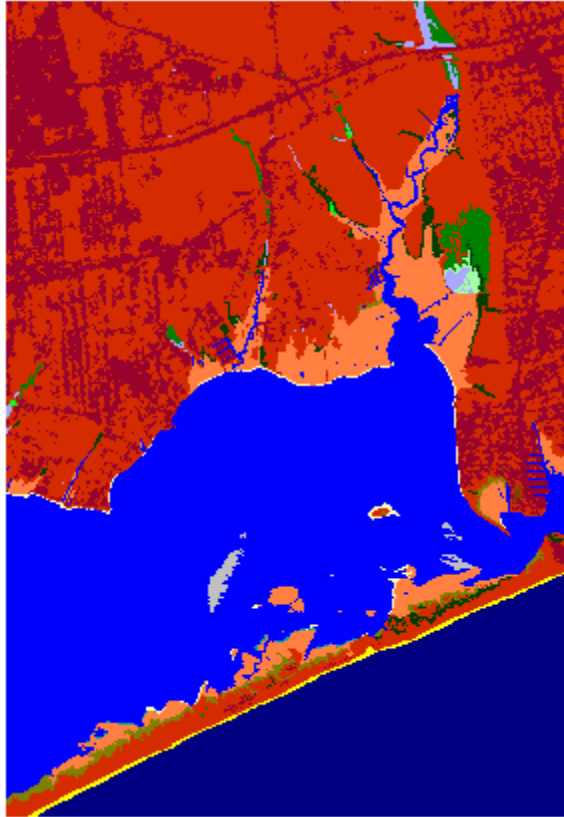
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

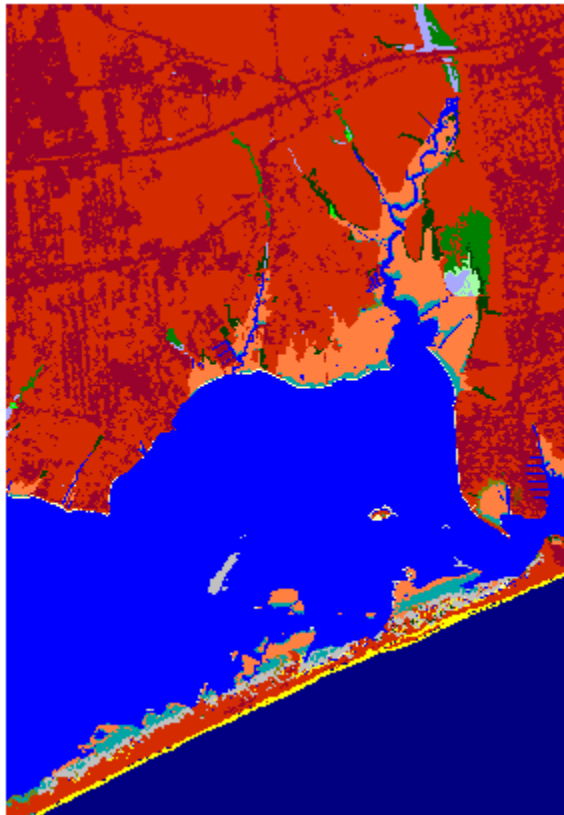
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



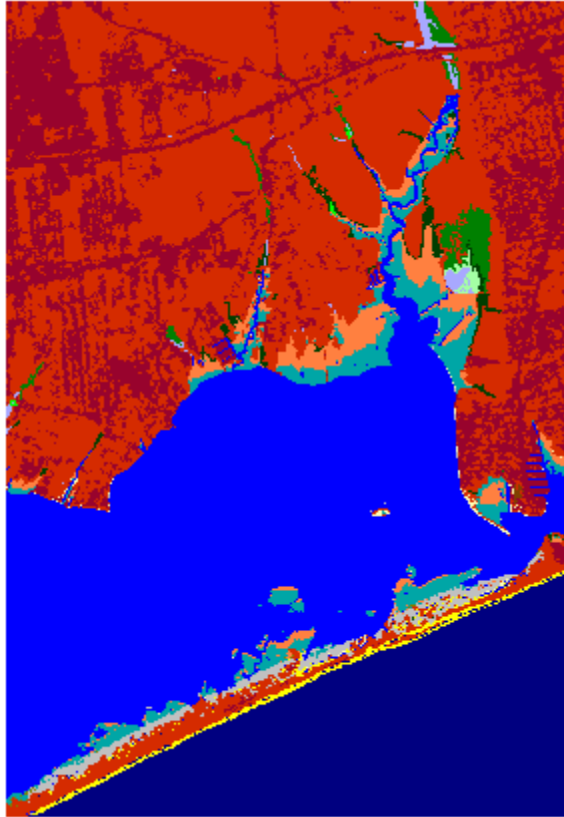
Location of Wertheim National Wildlife Refuge (white area) within simulation context



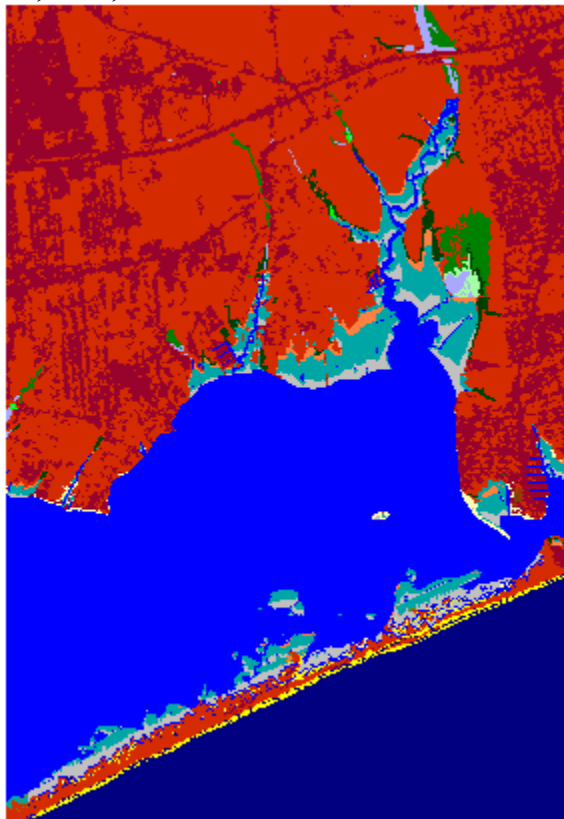
Wertheim NWR, Initial Condition



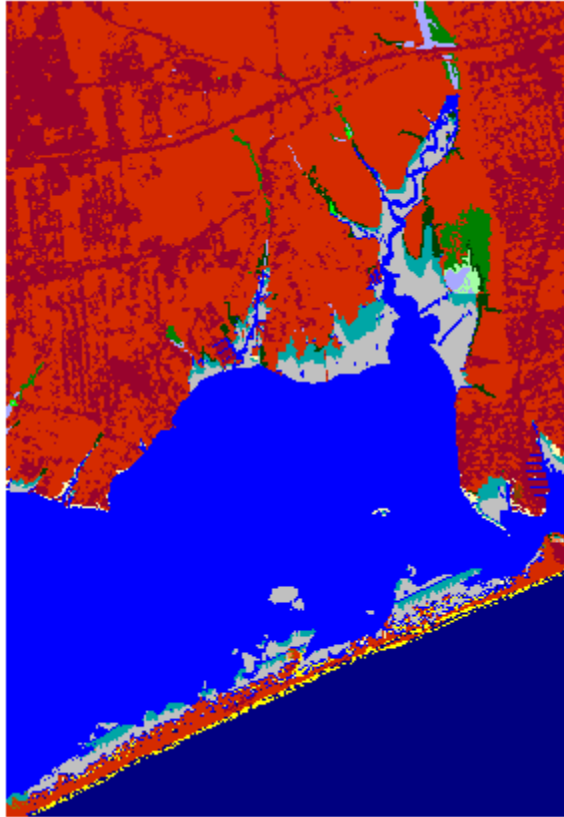
Wertheim NWR, 2025, Scenario A1B Mean Protect Developed Dry Land



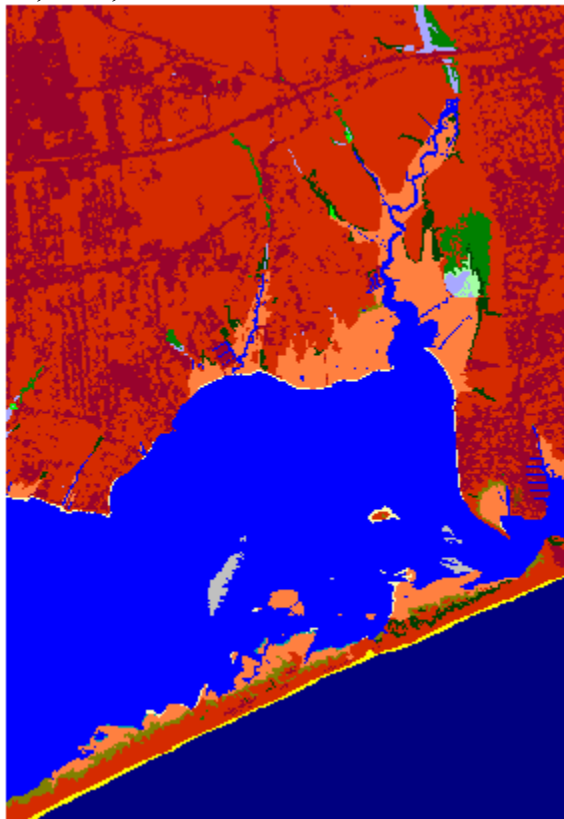
Wertheim NWR, 2050, Scenario A1B Mean Protect Developed Dry Land



Wertheim NWR, 2075, Scenario A1B Mean Protect Developed Dry Land

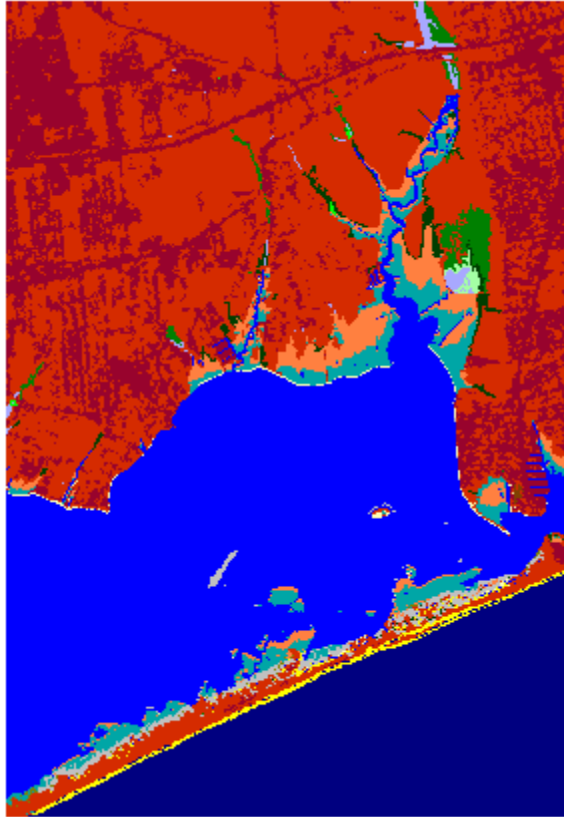


Wertheim NWR, 2100, Scenario A1B Mean Protect Developed Dry Land

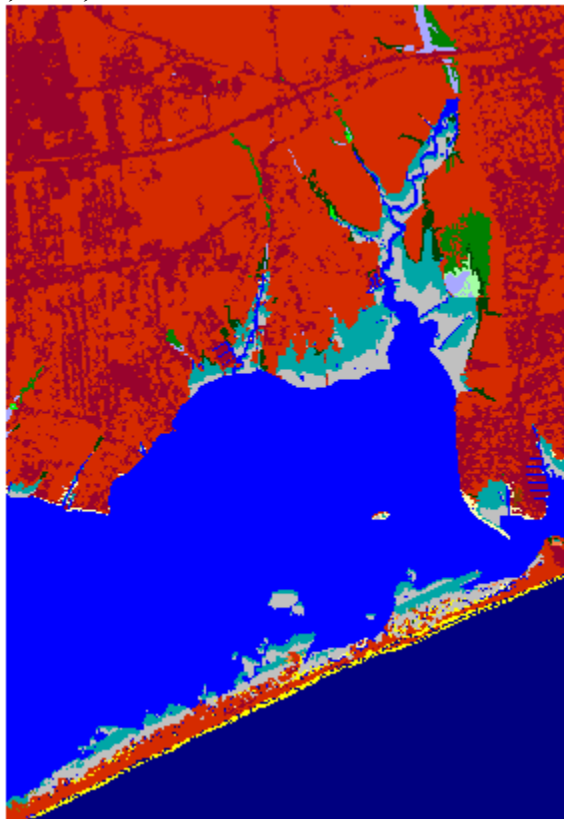


Wertheim NWR, Initial Condition

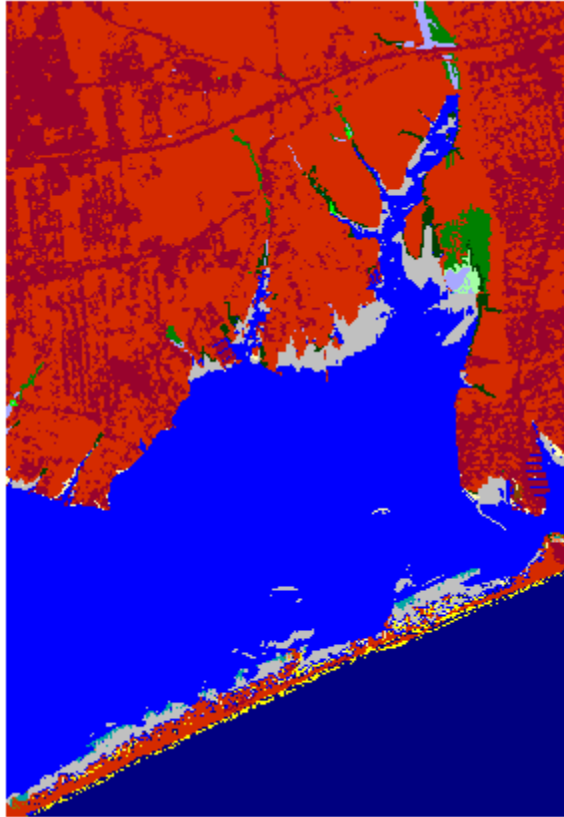




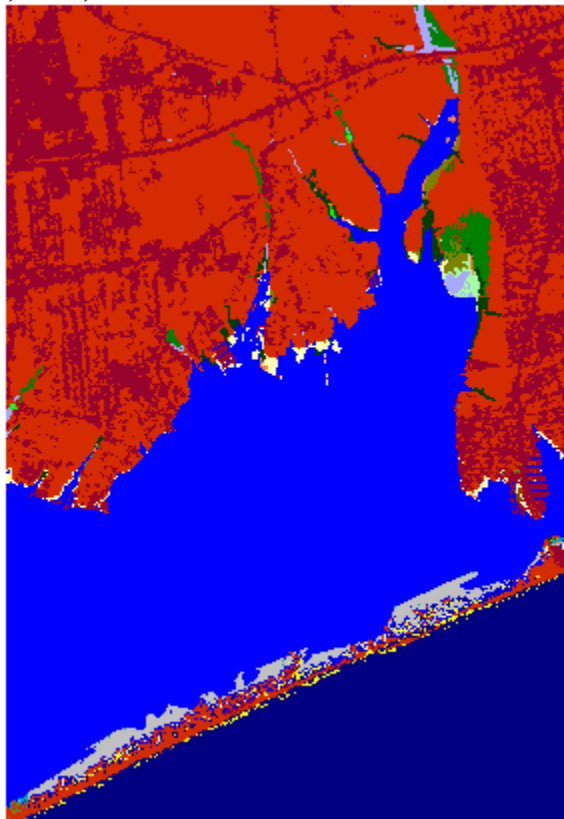
Wertheim NWR, 2025, Scenario A1B Maximum Protect Developed Dry Land



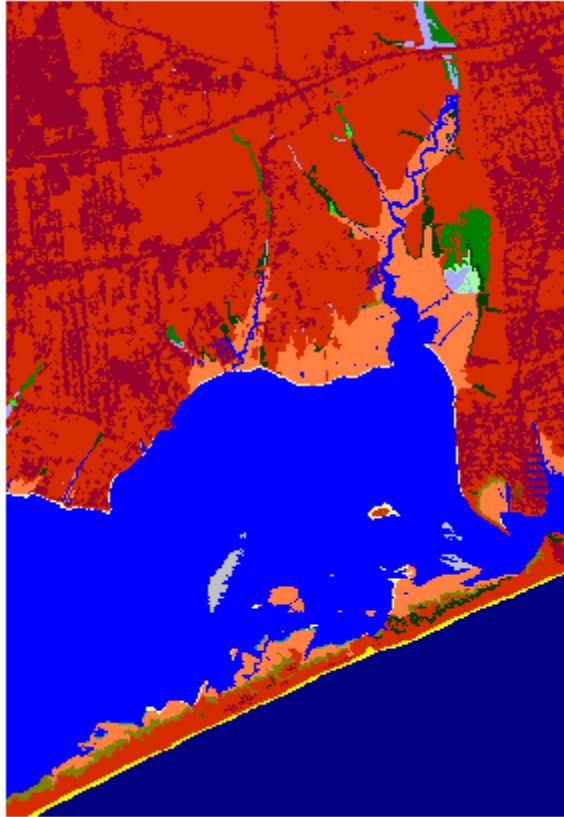
Wertheim NWR, 2050, Scenario A1B Maximum Protect Developed Dry Land



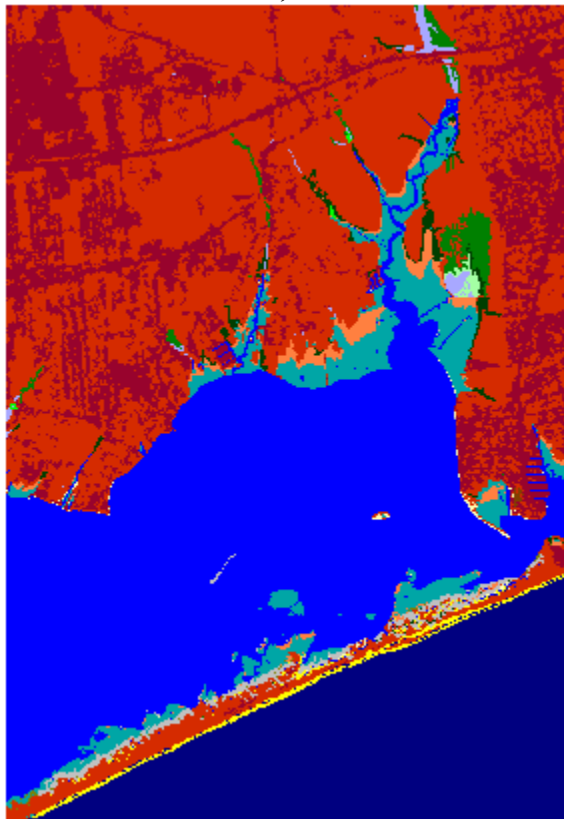
Wertheim NWR, 2075, Scenario A1B Maximum Protect Developed Dry Land



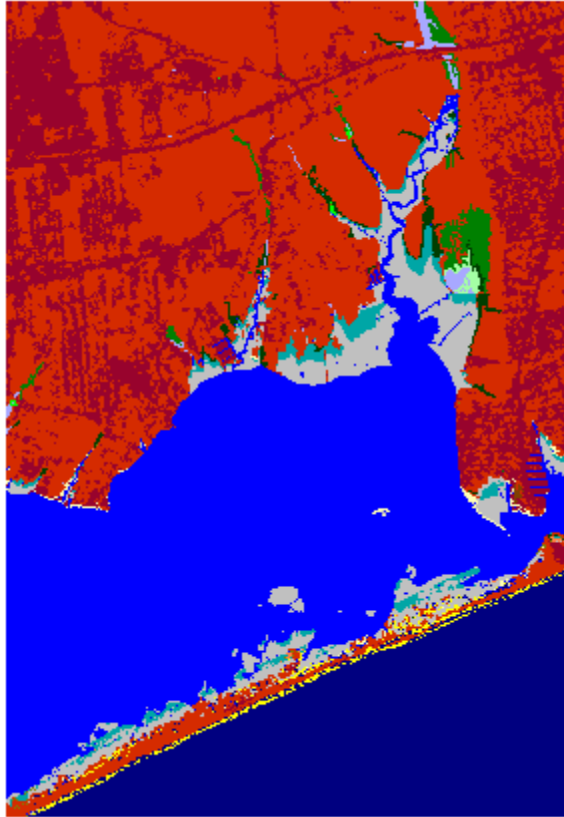
Wertheim NWR, 2100, Scenario A1B Maximum Protect Developed Dry Land



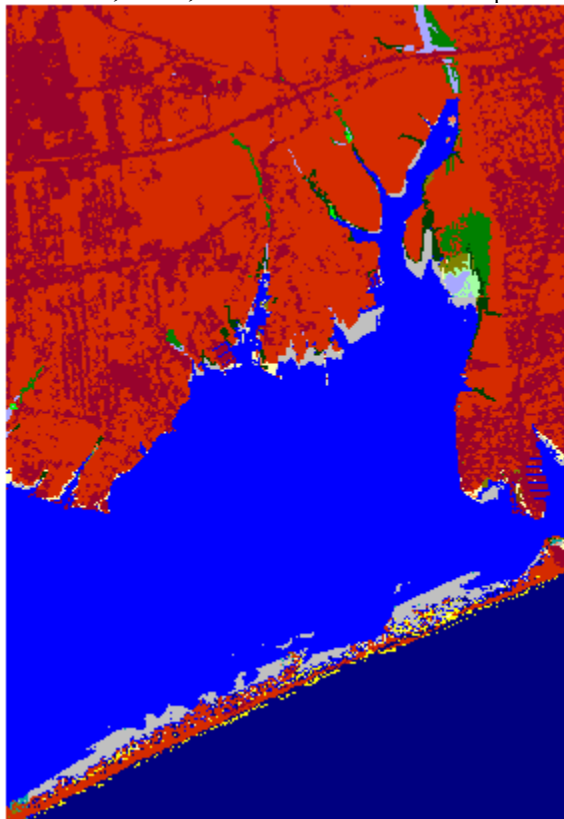
Wertheim NWR, Initial Condition



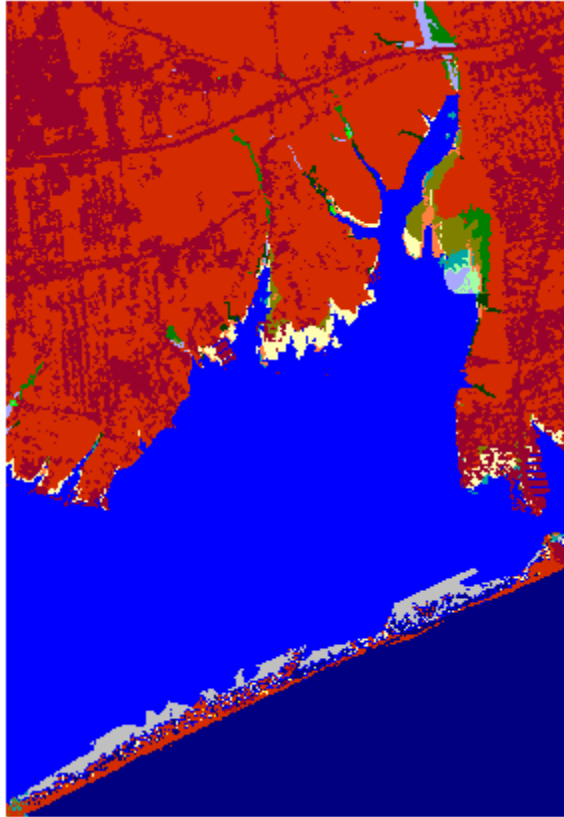
Wertheim NWR, 2025, 1 meter Protect Developed Dry Land



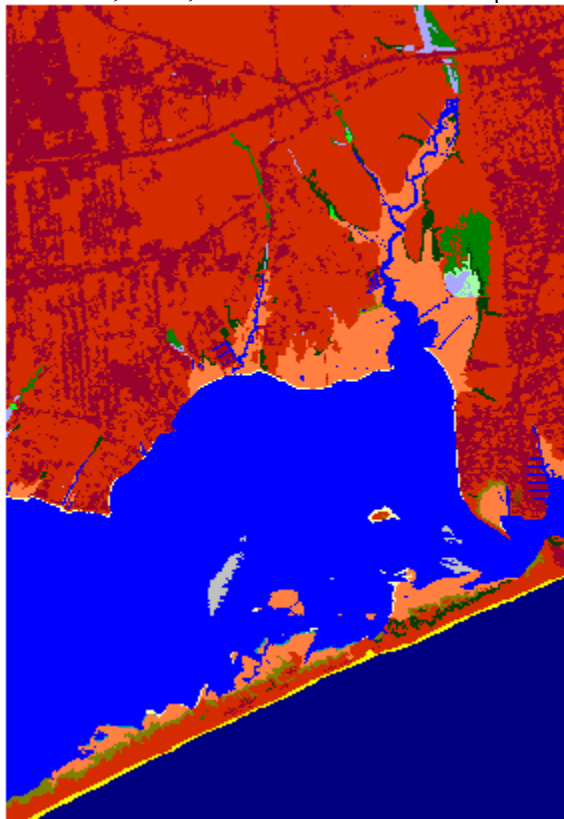
Wertheim NWR, 2050, 1 meter Protect Developed Dry Land



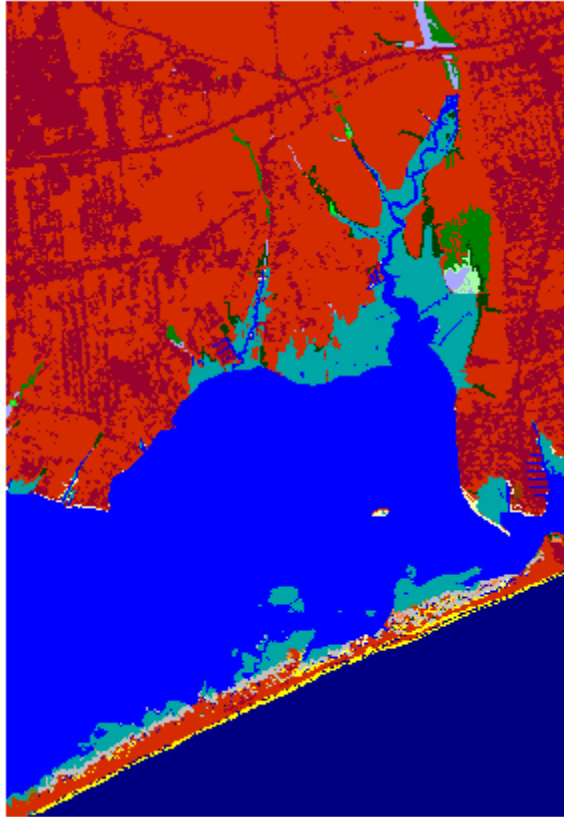
Wertheim NWR, 2075, 1 meter Protect Developed Dry Land



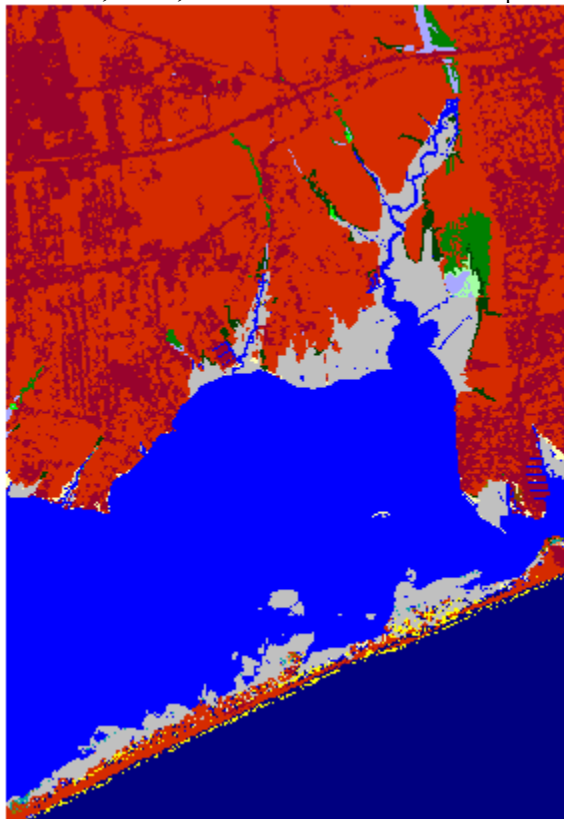
Wertheim NWR, 2100, 1 meter Protect Developed Dry Land



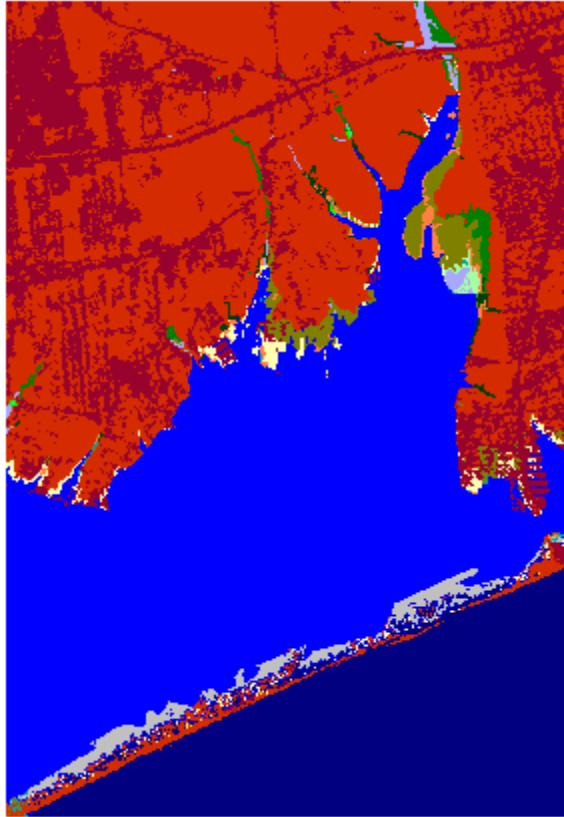
Wertheim NWR, Initial Condition



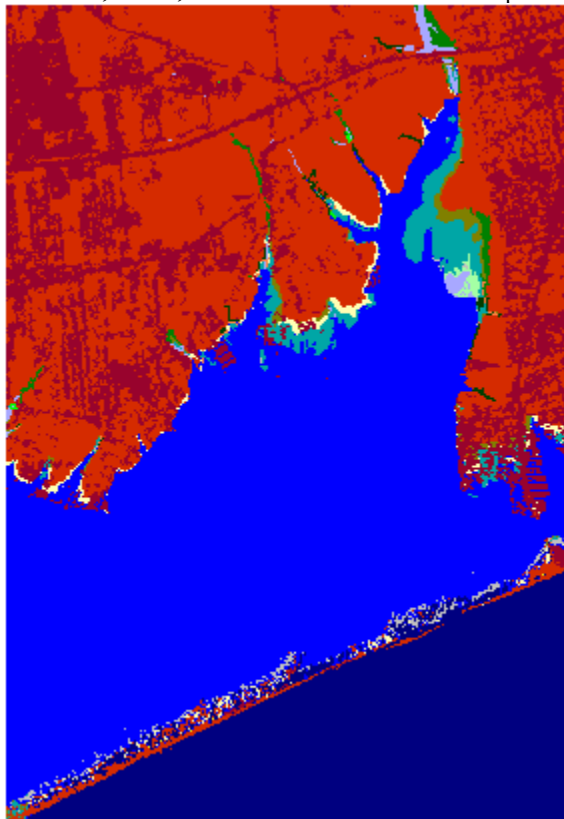
Wertheim NWR, 2025, 1.5 meter Protect Developed Dry Land



Wertheim NWR, 2050, 1.5 meter Protect Developed Dry Land



Wertheim NWR, 2075, 1.5 meter Protect Developed Dry Land



Wertheim NWR, 2100, 1.5 meter Protect Developed Dry Land