Integrating SLAMM Results and Stakeholder Priorities to Define Marsh Adaptation Strategies

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Revised January 2019, corrected road totals on pages 39-42

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Integrating SLAMM Results and Stakeholder Priorities to Define Marsh Adaptation Strategies

Final Report

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Abstract

In 2014, the results of the application of the Sea Level Affecting Marshes Model (SLAMM) to Long Island, NY and NYC were delivered to NYSERDA (Agreement #28261). These model results have been well received by policymakers to date, but there have been requests for user friendly maps that assist in determining marsh migration pathways as opposed to locations of currently-existing marsh. Moreover, SLAMM-generated data sets can be integrated with GIS layers of assets to determine the probability of roads and buildings flooding; making these results a powerful communication tool and for marsh conservation as well as quantification of the potential infrastructure costs of accelerated sea-level rise (SLR). This builds on the existing SLAMM projects by updating elevation data, incorporating roads and critical infrastructure, including marsh collapse, and simulating the 10- and 100-year storm inundation heights to refine model predictions. The new model outputs were then used to develop the Dynamic Marsh Management Tool (DMMT), a decision-support tool that integrates SLAMM results with stakeholder values and other relevant metrics to provide a prioritized list of sites. Working with NYC Parks, the new SLAMM results and DMMT were also used to test the potential effects of management strategies to mitigate the predicted effects of accelerated SLR. The DMMT is a flexible tool for policymakers to design conservation and management goals. The tool can be applied wherever SLAMM results are available with minimum GIS processing. Ultimately, this work provides data and tools that have direct value in validating adaptation strategies to increase resilience to climate change in coastal New York State.

Keywords

New York State, Sea-Level Rise, Coastal Wetlands, Accretion, Sea-Level Affecting Marshes Model, SLAMM

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The following organizations were instrumental in helping us incorporate the best input data available, providing insight into local wetland issues, and giving valuable feedback to improve the modeling process:

New York City Parks
The Nature Conservancy
NYS Department of Environmental Conservation
New England Interstate Water Pollution Control Commission
NYS Department of State
Dewberry
NYC Planning
NYS Department of Transportation

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

DEC	New York State Department of Environmental Conservation
DEM	Digital Elevation Map
DMMT	Dynamic Marsh Management Tool
GIS	Geographic Information Systems
GT	Great Diurnal Tide Range
LiDAR	Light Detection and Ranging
NOAA	United States National Oceanic and Atmospheric Administration
NYSERDA	New York State Energy Research and Development Authority
RMSE	Root Mean Standard Error
SLAMM	Sea-level Affecting Marshes Model
SWEL	FEMA Stillwater Elevations
SLR	Sea-Level Rise

Summary

Conservation planning and management under climate change conditions, particularly sea-level rise (SLR), can be complicated by multiple policymaking goals and the wealth of divergent data sets available. For example, to plan for accelerating rates of SLR, coastal managers must consider not only existing tidal-flooding conditions, but also potential changes to tidal-flooding within marsh systems and adjacent developed upland before adopting one of many potential management strategies.

The goal of this project is to leverage a previous marsh-fate modeling application to create a decision support tool that allows stakeholders to plan adaptation strategies for marsh conservation and coastal community resiliency. To achieve this goal, three objectives were met:

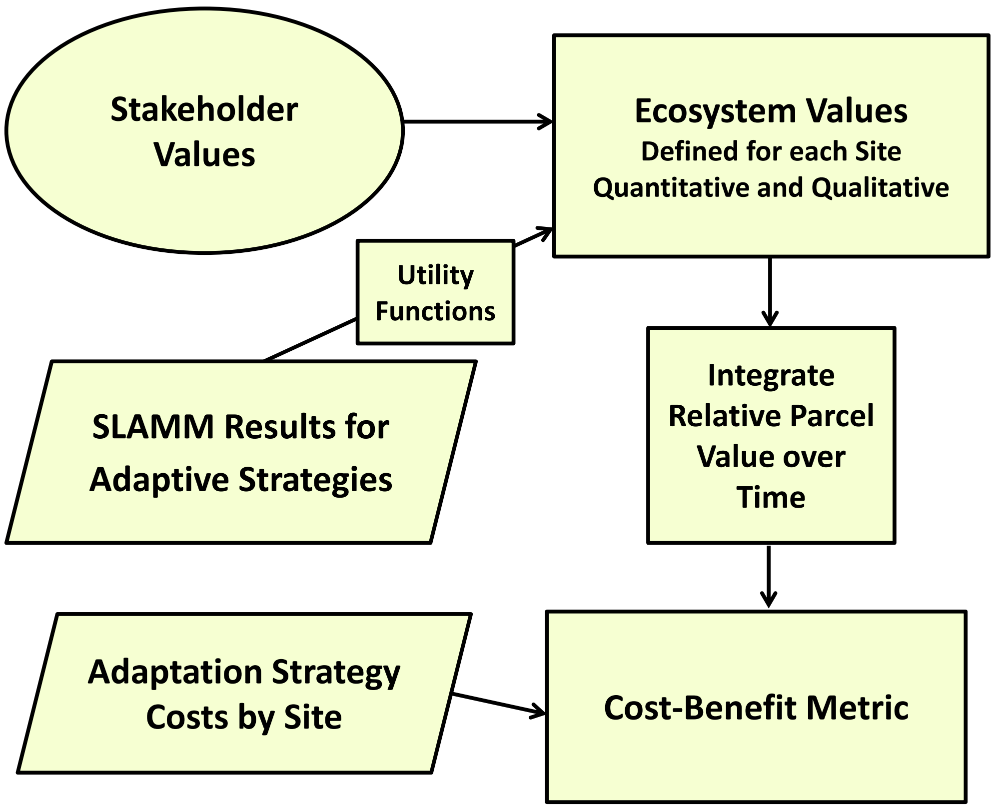
- The model was updated with the latest data, and the model was used to identify and characterize possible marsh migration pathways in response to increased sea level.
- The Dynamic Marsh Management Tool (DMMT) was developed. This tool accounts for environmental factors, socioeconomic factors, protection of developed areas, and SLAMM projections and their inherent uncertainty (Figure 1).
- Adaptation strategies were defined and modeled in collaboration with the NYC Parks and New York State Department of Environmental Conservation (DEC). Alternative management scenarios to enhance the adaptability of marshes and surrounding areas to accelerated sea-level rise were included within the DMMT framework.

Changes in tidal marsh area and habitat type in response to sea-level rise were modeled using SLAMM 6, a widely used wetland-fate model. Updates to the previous SLAMM model application included the following:

- Updates to elevation data that were of a higher quality than previous LiDAR data sets utilized.
- Updates to sea-level rise scenarios that match those released in 2016 by the New York State Governor's office.
- An updated model calibration using the latest tide-range, accretion, and elevation data.
- An accounting of the effects of combined storm-surge and SLR on roads, infrastructure, and dry lands.
- A marsh-collapse component that takes into account a potential loss of marsh elevation capital that occurs when marshes convert from one type to another.

- The addition of roads and infrastructure data to estimate the effects that infrastructure has on marsh-inundation pathways and that storm surge and SLR are likely to have on the infrastructure itself.
- Improvement in characterizing water-flow pathways through a “hydro-enforcement” process that takes into account culvert locations.

Figure 1. General Schematic for the Dynamic Marsh Management Tool



SLAMM model results were produced in both “deterministic” and “uncertainty-analysis” modes. Deterministic model runs are single runs for each individual SLR scenario and have single best estimates used for all model parameters. Uncertainty-analysis runs are hundreds of model runs that take into account model, data, and future SLR uncertainty. Model parameters are represented by uncertainty distributions.

The SLAMM modeling update produced dozens of new data products. New data include future wetland maps under individual SLR scenarios, maps that show likelihood of future marsh migration footprints, shapefiles of roads and railroads that show precisely where the roads are predicted to be inundated (down to 5-meter segments), and graphs showing how many km of roads will be flooded under SLR and SLR-plus-storm-surge scenarios. For Google Earth users, marsh fate and marsh-migration pathways may be plotted directly.

However, given that decision-makers are usually already inundated with information, and model results in particular, the team set out to integrate all of these data sets into a decision-support tool. First, the project simulated actions that can be taken by policymakers and estimated the costs of each action. The adaptation strategies that were modeled (as defined by project stakeholders) are as follows:

- **Protect dry land** by armoring shoreline and allowing no marsh migration.
- **Acquisition/transfer of parcels** to allow marsh migration in undeveloped dry land.
- **Acquisition/transfer of parcels and restoration** is same as the previous strategy but includes allowing marsh migration in developed dry land.
- **Restoration of marsh edges to 1970s marsh footprints—**SLAMM assumes that viable marshes will be restored in all wetland areas found in 1974 maps.
- **Thin-layer deposition** strategy considers the deposition of 20 cm of dredge material on low marsh to add elevation capital.

Each of these adaptation strategies was modeled in "uncertainty-analysis" mode so model and data uncertainty could be incorporated into the decision-making process.

Work continued with stakeholders to define unique marsh parcels to examine how they fare under different SLR and adaptation-strategy combinations. Stakeholder groups also developed an "ecosystem services list" to define what services wetlands provide that are valued by stakeholders. Literature and experts were referenced to define "utility functions." Utility functions are the relationship between ecosystem services and marsh quantity, marsh types, or other geometric metrics. Finally, stakeholders, spatial data, and expert feedback helped quantify each site's specific strengths and weaknesses for each identified ecosystem service. Essentially, it was ascertained "which sites currently offer specific services based on their location and health of the ecosystems."

To reduce data, uncertainty-analysis results were collapsed using the economic “expected value” calculation. The cost of each adaptation strategy was estimated for each site. The final result is a cost-benefit metric that defines wetland benefits per dollar for each site and each adaptation strategy.

Three case studies were completed in the coastal New York study area. These case studies do not reflect a completed set of decisions using the DMMT tool but can provide insights on which marsh management actions might be most useful and cost effective given the SLR and cost assumptions within the model. Prior to using the model to guide decisions, further research is advised, particularly on costs. The preliminary results presented in this document, however, can be useful in defining which costs need to be more accurately estimated. The DMMT also provides an interface to easily evaluate the effects that updated costs will have on optimal decision making.

One notable result from these three case studies was that thin-layer deposition was not usually found to be a cost-effective strategy when looking at benefits aggregated through the year 2100. The primary reason for this is the feedback between marsh elevation, inundation frequency, and the marsh elevation-change rate, which is included in the SLAMM model (and most other marsh-fate models). When marsh lands increase in elevation due to thin-layer deposition they trap sediment less effectively. Over a decadal time scale the marsh surface of an elevation-augmented marsh and a no-action marsh are predicted to equilibrate.

Another notable case-study result is that allowing marsh migration can provide the most overall benefits over the next 80 plus years. Dry lands that become regularly inundated and contain new marshes have high elevations relative to other marshes and are less vulnerable to future SLR. However, allowing for marsh migration is not always cost effective depending on the assumed cost of land or easement purchase. Marsh restoration provides immediate ecosystem benefits, making it cost effective in some locations. However, restored marsh can be vulnerable to future SLR.

The power of the DMMT is that it is capable of estimating which adaptation strategy will be most effective on a site-by-site basis, given model and data uncertainty. These estimates can then be refined by better pinning down cost estimates or refining the assumptions in and simulations of adaptation strategies.

Ultimately the success of the tool will depend on stakeholders learning to use the tool to test different sets of inputs and to understand the potential long-term effects of their actions. Extensive training materials to get individuals up to speed on the software are available on the project website (http://warrenpinnacle.com/prof/SLAMM/NYSERDA2015).

1 Background

Effective conservation planning and management in coastal communities is complicated by multiple and often competing objectives. Changes in climatic and ecological conditions and development footprints further complicate meeting these objectives. For example, accelerating rates of sea-level rise (SLR) require coastal managers to consider not only existing tidal-flooding conditions, but also potential changes to tidal flooding within marsh systems and adjacent developed upland before adopting management strategies involving the restoration or redirection of tidal flow.

In 2013 and 2014, the New York State Energy Research and Development Authority (NYSERDA) funded a marsh-habitat migration study for the entirety of coastal New York City and Long Island (J. Clough, Polaczyk, and Propato 2016; J. S. Clough, Polaczyk, and Propato, Marco 2014). That project used the Sea Level Affecting Marshes Model (SLAMM) to identify potential responses of New York's coastal marshes and adjacent upland areas to anticipated increases in mean-tidewater-level elevations as a result of accelerated sea-level rise.

The goal of the newer project was to leverage the previous SLAMM application to create a decision support tool that allows stakeholders to plan adaptation strategies for marsh conservation and coastal community resiliency. To achieve this goal three objectives were met:

- Identify and characterize possible marsh migration pathways in response to increased sea level. Marshes may survive gradual increases in sea level by migrating inland and upland. Therefore, identifying marsh migration zones is critical when planning for appropriate adaptation strategies. Policymakers requested further spatial analysis to better identify and characterize these potential marsh migration areas. To complete this goal SLAMM was updated to include roads as possible boundaries to marsh migration. Not only were roads used to refine marsh migration areas, but inundation data for roads were derived. In addition, point locations of critical infrastructure were included to provide inundation frequency data for those as well. Other improvements to the previous SLAMM application included incorporating new LiDAR data, simulating two storm surge scenarios (the 10- and 100-year storms) when added to accelerated SLR and the inclusion of marsh collapse data.

- Development of the Dynamic Marsh Management Tool (DMMT). Conservation planning and management under climate change conditions, particularly sea-level rise, can be complicated by the wealth of divergent data sets available and multiple policymaking goals. In this phase of the project a DMMT was created to assist policymakers in planning and prioritizing coastal marsh areas and evaluate effectiveness of adaptation and conservation strategies. This tool accounts for environmental factors, socioeconomic factors, protection of developed areas, and SLAMM projections and their inherent uncertainty.
- Assess adaptation strategies in collaboration with the NYC Parks and the DEC. Alternative management scenarios to enhance the adaptability of marshes and surrounding areas to accelerated sea-level rise were developed and simulated.

The current study used the previous project as a starting point with the goal of refining SLAMM projections and to use spatial analysis for identifying and characterizing potential marsh migration pathways. The geographic areas here considered are New York City and Nassau and Westchester counties. SLAMM simulations were updated to include the following:

- Accounting for road effects on marsh migration
- New LiDAR data where available
- Where necessary, improvements of modeled spatial hydraulic connectivity by detailed hydrologic enforcement of elevation data
- Marsh collapse that may occur during marsh transition
- Effects of storm surge inundation on infrastructure

In addition to providing data for environmental adaptation, the results of this study can benefit policymakers in the transportation, infrastructure, drinking water, and electrical utility sectors through:

- Identification and characterization of the effect of increased sea-level on tidal flooding of roads and critical infrastructure.
- Assessment of the combined effects of storm surge and SLR on infrastructure. Infrastructure risk was investigated given these additive effects.

This information has been output by SLAMM and can be leveraged by the DOT as well as other agencies.

The main deliverables of this project are SLAMM land cover prediction maps, land and infrastructure inundation maps, land cover projections maps under various possible adaptation strategies and the Dynamic Marsh Management Tool. The general model setup, input parameter and data selection were described in the report of the previous project and downloadable at http://www.nyserda.ny.gov/-/media/Files/Publications/Research/Environmental/SLAMM-report.pdf. The current report presents the updated methodologies included in these new simulations, new data inputs and amendments, summarizes the primary project results as well as the DMMT example parcel evaluations in New York City and

Nassau County. All results and data are available to be shared with those most likely to use it to develop plans at the local, regional and state-wide level in a way that clearly and readily transfers the information to key tidal marsh and infrastructure managers.

1.1 Model Summary

Changes in tidal marsh area and habitat type in response to sea-level rise were modeled using SLAMM 6. SLAMM is widely recognized as an effective model to study and predict wetland response to long-term sea-level rise (Mcleod et al. 2010) and has been applied in every coastal U.S. state (Czech 2015; Galbraith et al. 2002; Glick, Clough, and Nunley 2007; National Wildlife Federation and Florida Wildlife Federation 2006; Park et al. 1991; Park, Lee, and Canning 1993; Titus et al. 1991).

The latest SLAMM capabilities being used in this project are summarized below. A detailed description of the general model processes, underlying assumptions, and equations can be found in the SLAMM 6.7 Technical Documentation (available at http://warrenpinnacle.com/prof/SLAMM6/).

Recently SLAMM has been updated to include infrastructure and marsh collapse. The new infrastructure code allows for the input of multiple point shapefiles representing the locations of critical infrastructure. Road and railroad input is required to be a line shapefile, which is then divided into 5 m segments by SLAMM to characterize inundation on a segment-by-segment basis. Inundation for five inundation elevations (designated as “H1” to “H5”) above Mean Tide Level can be modeled. In the current model application, the “H1” inundation was set to the 30-day inundation height, H2 to the 60-day inundation height, H3 to the 90-day inundation height, H4 to the 10-year storm surge height, and H5 to the 100-year storm surge height. SLAMM outputs inundation results for each type of infrastructure as GIS database attributes associated with each line or point shape.

Another SLAMM model update is the accounting for marsh collapse, a process that represents the loss of elevation capital a marsh may undergo when transitioning from one marsh type to another. Through a collaboration with Dr. David Burdick at the University of New Hampshire, data were obtained to characterize this elevation loss that may occur when irregularly-flooded marsh is converted to regularly-flooded marsh and when regularly-flooded marsh is converted to tidal flat.

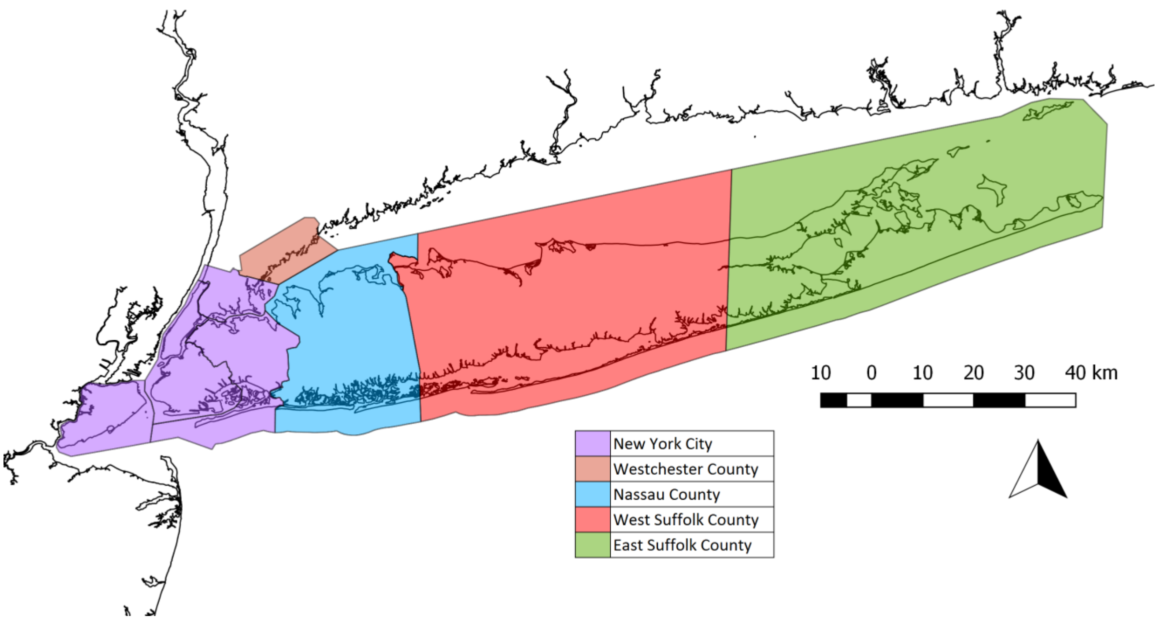
2 Methods

This section summarizes data used and SLAMM implementation approaches with particular focus on new data and model updates with respect to previous project simulations. For more detailed information on the input data and methods used in the previous SLAMM application to New York, see the previous NYSERDA Report (nyserda.ny.gov/-/media/Files/Publications/Research/Environmental/SLAMM%20report.pdf).

2.1 Study Area

The project study area comprises five individual SLAMM projects covering New York City, the north and south shores of Nassau and Suffolk Counties, and the Long Island shores of Westchester County, as shown in Figure 2.

Figure 2. Project study area broken into five individual SLAMM projects



2.2 Spatial Data

SLAMM is a raster-based model, meaning that input cells are equally sized squares arranged in a grid, like graph paper or a computer-based image. This section describes these critical data sources and the steps used to process the data for use in SLAMM. Data types reviewed here include elevation, wetland land cover, impervious land cover, dikes, and impoundments.

2.2.1 Elevation Data

Compared to the previous project, some study areas have more recent elevation data available listed in Table 1, in particular NYC elevations are derived from 2014 USGS Post-Sandy LiDAR data; Nassau and Westchester elevations are a combination of 2011–2012 DEC Coastal LiDAR data and 2012 USACE Post-Sandy LiDAR data.

These LiDAR data were combined and hydro-enforced (see Section 2.9.4 for more details) to create 5-meter resolution Digital Elevation Model (DEM) maps for each study area.

Table 1. Sources of NY LiDAR

Data Layer Name (Covered Area)	Nominal point spacing (*) (m)	Vertical Accuracy – RMSE (cm)	Download Source Site
2014 USGS CMGP LiDAR: Post Sandy (New York City)	0.7	5.3	NOAA Digital Coast
2012 USACE NCMP LiDAR: Post-Sandy (NJ & NY)	1	10	NOAA Digital Coast
2011–2012 DEC Coastal LiDAR	1	9	NOAA Digital Coast
2014 USGS CMGP LiDAR: Post Sandy (Suffolk)	0.7	11	NOAA Digital Coast
2014 NOAA NGS Topobathy Lidar: Connecticut	N/A	12	NOAA Digital Coast
2014 NOAA Topobathy DEM: Post-Sandy (SC to NY)	1	13	NOAA Digital Coast

(*) Average point spacing of a LiDAR dataset typically acquired in a zig-zag pattern with variable point spacing along-track and cross-track.

2.2.2 Slope Layer

Accurate slopes of the marsh surface are an important SLAMM consideration as they are used in the calculation of the fraction of a wetland that is lost (transferred to the next class). Slope rasters were derived from the hydro-enforced DEMs using QGIS terrain models tool to create slope with output values in degrees.

2.2.3 Elevation transformation, Land Coverage, Dikes and Impoundments, and Percent Impervious

The layers to convert elevation data from the North American Vertical Datum of 1988 (NAVD88) vertical datum to mean tide level were identical to the previous project (Clough et al., 2014) and were derived from NOAA's VDATUM modeling product version 3.2 (National Ocean Service, U.S. Department of Commerce, and National Oceanic and Atmospheric Administration, 2013).

The initial land cover layers are also the same as the ones used in previous project and were derived from the DEC (Personal Communication: Heaviland 2013), the National Wetland Inventory (U. S. Fish and Wildlife Service, 2004), data provided by the Department of Parks and Recreation, New York City (Personal Communication: Diegel 2013), and data provided by the National Park Service (Personal Communication: Christiano 2013).

The dike and impoundment layers have not changed from the previous model application. Similarly, "percent impervious" layers were taken from the previous project without any modification.

2.3 Model Timesteps

SLAMM simulations were run from the date of the initial wetland cover layer to 2100 with model-solution time steps of 2025, 2040, 2055, 2070, 2085, and 2100. Maps and numerical data were output for the years 2025, 2055, 2085, and 2100.

2.4 Sea-Level Rise Scenarios

On January 1, 2016 the New York Governor's office released a new set of SLR scenarios for planning purposes reported in Table 2. These scenarios are similar to those in the ClimAID report and used in previous SLAMM simulations, as shown in Figure 3. An important difference is that new scenarios vary depending on the geographic area. New York City and Long Island have different expected rates of accelerated SLR, which diverge most noticeably in the 2080 to 2100 period, with the NYC area expected to have a slightly higher SLR over the next century.

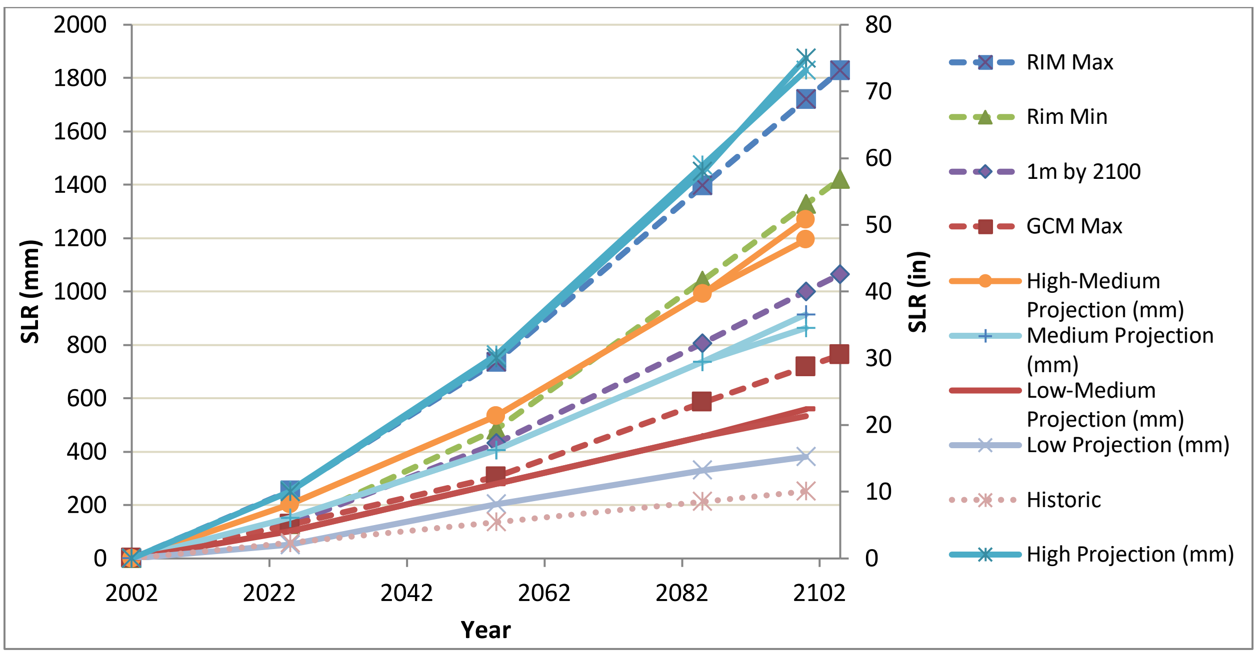
In this study the NYC SLR scenarios were applied to the NYC and Westchester Study areas and the Long Island scenarios to Nassau County.

Table 2. Sea Level Rise Scenarios applied

New York City and Lower Hudson Region/Long Island					
Time Interval	Low Projection (mm)	Low-Medium Projection (mm)	Medium Projection (mm)	High-Medium Projection (mm)	High Projection (mm)
2002	0	0	0	0	0
2025	51	102	152	203	254
2055	203	279	406	533	762
2085	330	457	737	991	1473
2100	381	559/533	914/864	1270/1194	1905/1829

Figure 3. New and older accelerated SLR scenarios used in SLAMM simulations.

Dashed lines indicate the ClimAID scenarios run in the previous project.



According to NOAA gauges, historic sea-level rise trends along the coastlines of the study area range from 2.5 mm/yr. at Kings Point to 2.84 mm/yr. at The Battery and 4.35 mm/yr. at Bergen Point.

2.5 Inundation Elevations

2.5.1 Tide Ranges

For most areas, the general tidal regimes and their spatial variability remained the same as the ones identified for the previous project. The one exception to this rule was Great South Bay in Suffolk where the great diurnal tide range (GT) and salt elevation were set to 0.42 m (from 0.32 m in previous simulations) to reflect newly available NOAA gauge data.

2.5.2 Salt Elevation

The salt elevation parameter in SLAMM defines the boundary between coastal wetlands and dry lands (including non-tidal wetlands). These inundation parameters were obtained from daily water level data as described in Clough et al. (2014), and generally were not modified from the previous project. Again, the one exception to this rule comes in Great South Bay in Suffolk County where salt elevation was increased to 0.45 m (from 0.27 m) following the relationship between GT and salt elevation derived and reported on previously (Clough et al. 2014).

2.5.3 30-day, 60-day, and 90-days inundation frequency

Different inundation heights were considered to investigate the exposure of land and infrastructure to inundation.

As discussed in more detail in the previous NYSERDA Report (Clough et al., 2014), the salt elevations are estimated as the 30-day inundation heights (elevations that are statistically inundated once every 30 days) and these were determined using daily inundation data from the several tide gauge stations along the coast of New York. One example that describes this statistic: if one year of data were available, the 30-day height would be the height that flooded for 12 days within that year (the 96.7 percentile daily-maximum water height). Based on many SLAMM model applications, and by analyzing land cover information and elevation data, the 30-day inundation height is closely correlated with the wetland to dryland boundary.

The 60- and 90-day periods were calculated in a similar way. Figure 4 and Figure 5 show the relationship between these inundation heights. Essentially, the 60- and 90-day inundation heights are 4 and 5 cm higher than the 30-day inundation heights.

Figure 4. 30-day vs. 60-day inundation height conversion

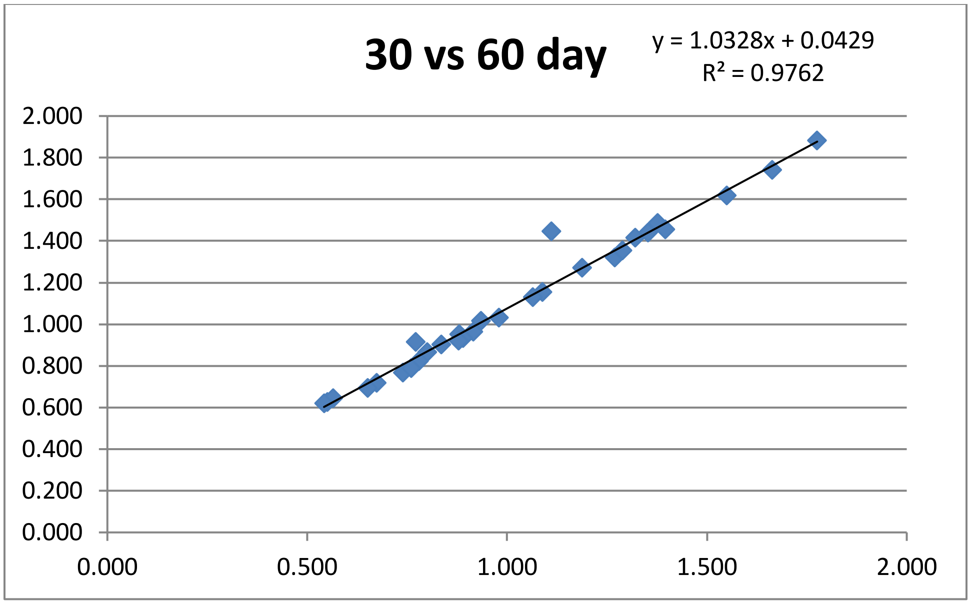
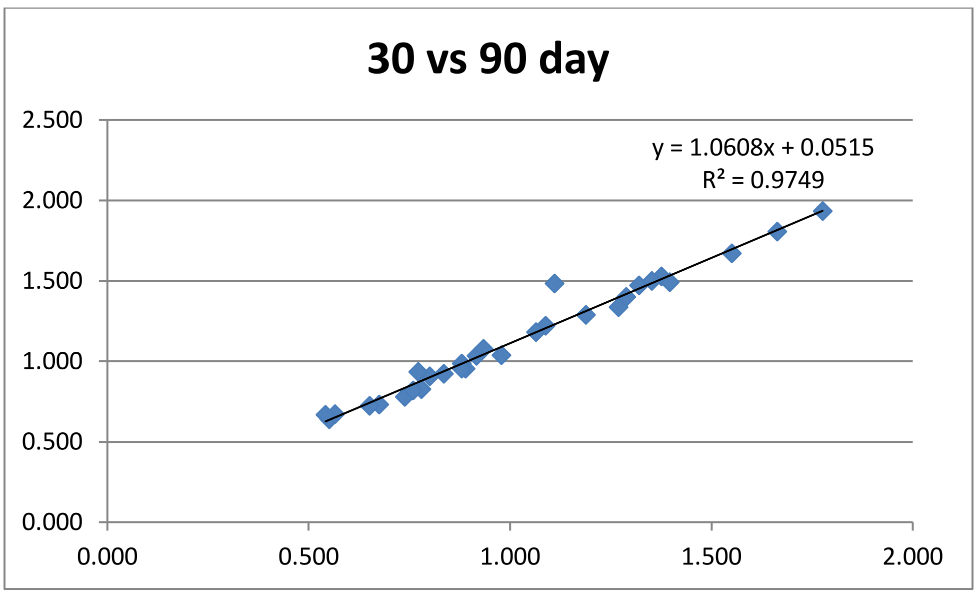


Figure 5. 30-day vs. 90-day inundation height conversion

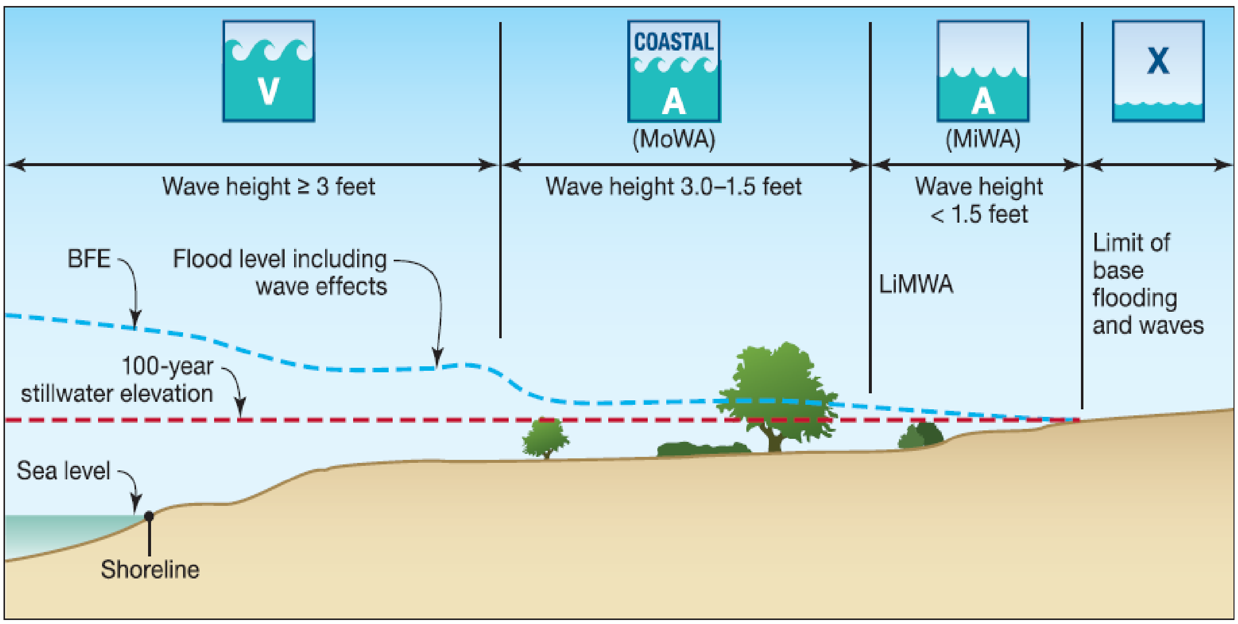


2.5.4 Storm Surge

Updated SLAMM simulations incorporated two storm surge inundation heights in order to predict the extent of infrastructure flooding under combined sea-level rise and storm surge conditions. The 10% and 1% FEMA Stillwater Elevations (SWEL) were used, corresponding to 10-year and 100-year return periods, respectively. The "Stillwater Elevation" is the elevation of the water due to the combined effects of the astronomic tides and storm surge on the water surface (Federal Emergency Management Agency 2013). SWEL data cover the entire FEMA coastal flooding hazard area up to the limit of base flooding and waves, similar to the base flood elevation (BFE) and shown in Figure 6.

Figure 6. FEMA Coastal Hazard Zones with SWEL for Reference

Source: Federal Emergency Management Agency 2011



In Nassau, Westchester, and Suffolk Counties, this project used storm-surge estimates prepared by Dewberry Consultants, LCC for NYSERDA (2016). These data included SWEL data layers where 12, 18, 24, 36, and 48 inches of SLR were added. Wave setup was included in the 100-year storm maps but not in those for the 10-year storm. As an example of the 100-year storm estimate, it has been estimated that Hurricane Sandy's peak water level corresponded to a 103-year return period at the Battery in Lower Manhattan (Lopeman, Deodatis, and Franco 2015). When SLAMM predicted SLR heights fell between the SLRs considered in the Dewbury project, linear interpolation was used to estimate the SWEL height at each location. A cell was assumed to be inundated if its bare-earth elevation was lower than the SWEL layer height.

The Dewberry project area did not include New York City, but FEMA SWEL layers were available. This meant that flood maps including SLR were not available. Inundation maps were obtained by adding the projected change in future sea levels to current SWEL water elevations and then comparing these elevations (SLR + current SWL) to the cell elevations.

2.6 Accretion and Erosion Rates

For New York City, Westchester County, and Nassau County study areas, accretion rates and their modeled response to SLR (when applicable) have not been changed from previous NYSERDA project (Figure 7). Mechanistic modeling was used to estimate the response of regularly flooded marsh elevations to different sea-levels. The effects of uncertainty in this relationship were also explored in the uncertainty analysis.

For Suffolk County, updated SET elevation-change data were available from The Nature Conservancy (Starke 2017). In several cases, higher elevation changes estimated using short-term data were replaced with somewhat-lower elevation changes measured in the longer term. This resulted in modifications to the accretion-feedback model used for regularly flooded and irregularly flooded marshes in Suffolk County.

The updated regularly flooded accretion model for Suffolk County is presented against observed data in Figure 7 (blue line compared with blue circles). The full set of accretion data used for regularly flooded marsh is presented in Table 3. Elevation-change data, from SET tables, are shown in bold. To determine whether measurements were made in regularly flooded vs. irregularly flooded marsh, the SLAMM land-cover classification was used at the site of the SET data or the accretion measurement. Additionally, marshes that occur above 120% of mean higher high water (MHHW) were assumed to be irregularly flooded marshes.

Elevation-change data from SET tables are the best data source for changes in elevation over time as a function of marsh type and elevation. However, plotting accretion measurements measured with pb210 against SET-derived data did not show a significant difference or bias. Two SET table measurements at Great Gun marsh were removed from the data set as they produced negative numbers (-1.5 and -4 mm/year). According to the data source (Roman, C.T. et al. 2007), those SET tables “may not be representative of the larger Great Gun marsh because the SET monitoring may have occurred in a portion of marsh where a natural marsh drainage was forming.”

Table 3. Updated regularly flooded marsh accretion data

Location	Elev. Change or Accr. (mm/yr)	Std. Dev. of measure (mm/yr)	Elev. (m, NAVD88 from LiDAR)	GT (m)	Method	Source	Where applied
Caumsett Park	4.1	3.3	-0.291	2.42	210 Pb	Cochran et al. (1998)	North
Shelter Island	3	2.7	0.322	0.87	210 Pb	Cochran et al.	Bays
JB- Big Egg	3.8	0.3	0.150	1.79	210 Pb	Kolker (2005)	South
HB- Smith D	1.4	0.1	0.707	1.34	210 Pb	Kolker (2005)	South
HB- Smith B	3.3	0.4	0.668	1.34	210 Pb	Kolker (2005)	South
HB- Hewlett	5	1.2	0.245	1.34	210 Pb	Kolker (2005)	South
JB- East High	2.8	0.4	0.450	1.79	210 Pb	Kolker (2005)	South
Nissequogue-B	4	0.3	0.268	2.42	210 Pb	Kolker (2005)	North
Bass Creek	**4.26**	**0.3**	**0.168**	**0.87**	**SET**	**Starke TNC (2017)**	**Bays**
Cedar Beach	**2.49**	**0.4**	**0.157**	**0.87**	**SET**	**Starke TNC (2017)**	**Bays**
Hubbard Creek	**2.57**	**0.7**	**0.344**	**0.87**	**SET**	**Starke TNC (2017)**	**Bays**
Mashomack Point	**3.47**	**0.1**	**-0.120**	**0.87**	**SET**	**Starke TNC (2017)**	**Bays**

Figure 7. Regularly flooded marsh accretion models plotted against available data

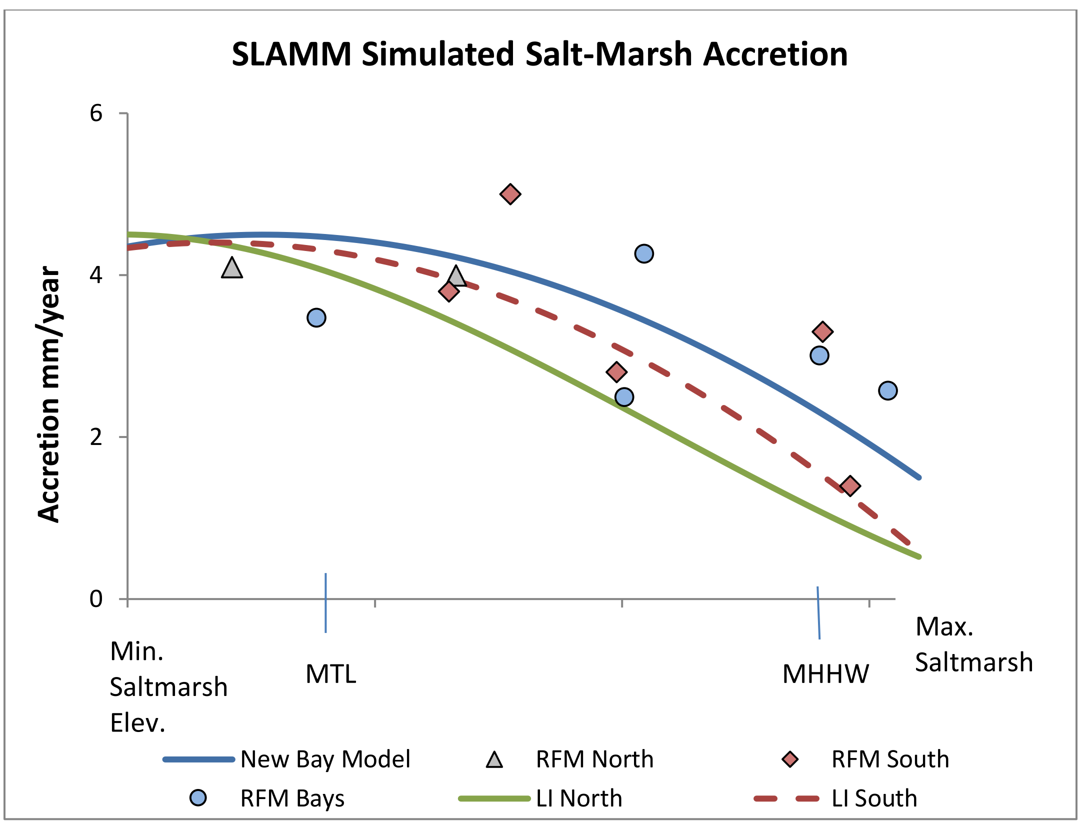


Table 4. Updated irregularly flooded marsh accretion data

Location	Elev. Change or Accr. (mm/yr)	Std. Dev. of measure	Elev. (m, NAVD88 from LiDAR)	GT (m)	Method	Source	Where applied
Flax Pond, (LI, NY)	2.1	0.4	0.918	2.2	210 Pb	Cochran et al. (1998)	North
Flax Pond, (LI, NY)	3.6	1.1	0.918	2.2	historical record	Flessa et al. (1977)	North
JB- JoCo Marsh	4.4	0.3	0.968	1.86	210 Pb	Kolker (2005)	South
CR- B	2.7	0.3	0.393	0.42	210 Pb	Kolker (2005)	South
CR- A	3.3	0.3	0.347	0.42	210 Pb	Kolker (2005)	South
Hubbard- A	2.3	0.2	0.457	0.87	210 Pb	Kolker (2005)	Bays
Hubbard- G	3	0.3	0.496	0.87	210 Pb	Kolker (2005)	Bays
Accobonac	**2.53**	**0.3**	**0.437**	**0.87**	**SET**	**Starke TNC (2017)**	**Bays**
Indian Island	**2.01**	**0.7**	**0.312**	**0.87**	**SET**	**Starke TNC (2017)**	**Bays**
Indian Island	**2.5**	**0.2**	**0.312**	**0.87**	**SET**	**Starke TNC (2017)**	**Bays**
Pine Neck	**3.17**	**1.5**	**0.472**	**0.87**	**SET**	**Starke TNC (2017)**	**South**
Pine Neck	**2.77**	**0.4**	**0.472**	**0.87**	**SET**	**Starke TNC (2017)**	**South**
Smith Point	**7.2**	**0.4**	**0.294**	**0.42**	**SET**	**Starke TNC (2017)**	**South**
Wellington-Wertheim	**4.4**	**0.5**	**0.333**	**0.42**	**SET**	**Starke TNC (2017)**	**South**
Watch Hill 1	**2.17**	**0.32**	**0.368**	**0.42**	**SET**	**Roman et al. 2007**	**South**
Watch Hill 2	**1.62**	**0.32**	**0.430**	**0.42**	**SET**	**Roman et al. 2007**	**South**
Watch Hill 3	**2.53**	**0.32**	**0.386**	**0.42**	**SET**	**Roman et al. 2007**	**South**
Hospital Point 3	**3.24**	**0.36**	**0.290**	**0.42**	**SET**	**Roman et al. 2007**	**South**
Hospital Point 2	**1.78**	**0.36**	**0.269**	**0.42**	**SET**	**Roman et al. 2007**	**South**
Hospital Point 1	**1.14**	**0.36**	**0.277**	**0.42**	**SET**	**Roman et al. 2007**	**South**
Great Gun 3	**2.41**	**0.32**	**0.261**	**0.77**	**SET**	**Roman et al. 2007**	**South**

Figure 8. Irregularly flooded marsh accretion model plotted against available data

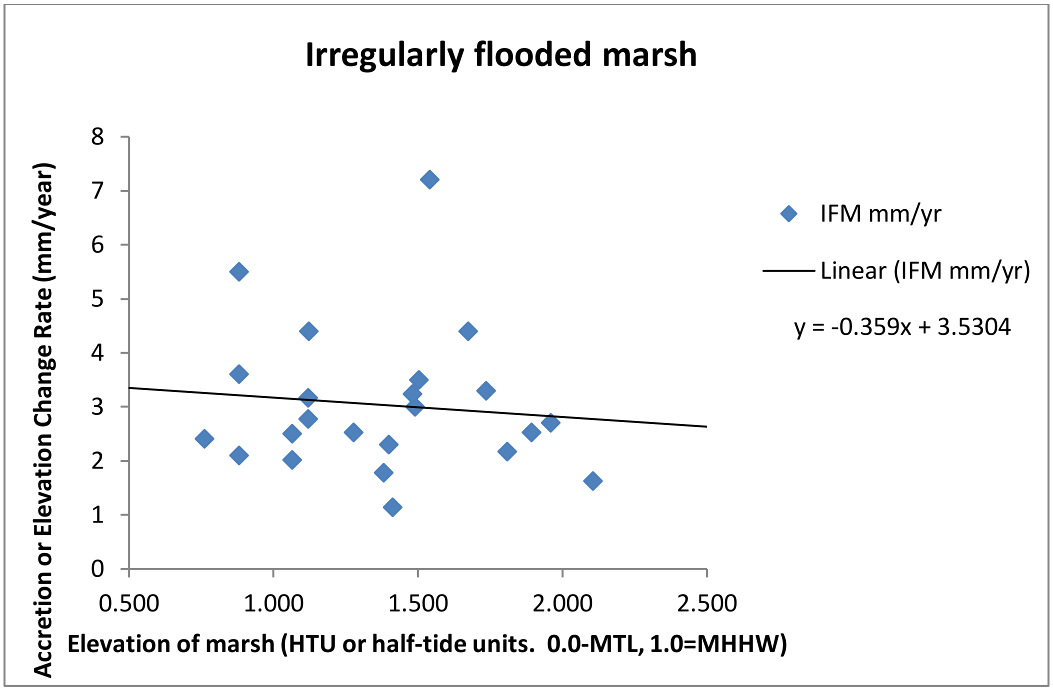


Figure 8 shows regularly flooded marsh accretion rates as a function of the marsh elevations within the tidal frame. As in the previous project, a strong feedback between high-marsh elevations and elevation-change rates is not present in the data. A linear regression shows a small negative correlation. (The relationship between marsh elevation and accretion rates is generally more pronounced in low marsh platforms because their regular flooding leads to more inorganic sediment deposition at lower elevations.)

Because some of the SET tables in Suffolk County with high elevation-change rates were modified and now have lower observations, the overall estimate of elevation change for the new models is slightly lower. The new irregularly flooded marsh accretion rate estimates range from approximately 3 to 3.5 mm/year whereas the previous application had estimates ranging from approximately 4 to 4.2 mm/year. The variability and uncertainty in these modeled accretion rates were considered in the uncertainty-analysis component of this project. Erosion rate parameters were not changed from the values defined in the previous project.

2.7 Marsh Collapse

Recently, SLAMM has been updated to account for the loss of elevation capital that occurs when irregularly flooded marsh is converted to regularly flooded marsh and when regularly flooded marsh is converted to tidal flat. Changes in pore-water salinity are known to cause changes in bacterial composition and this can result in rapid decomposition of underground biomass (Portnoy 1999). In addition, marsh collapse has been observed in marsh systems when the above land-cover conversions occur (DeLaune, Nyman, and Patrick Jr 1994).

Land-cover projections for this project include an implementation of this new model feature. Marsh-loss transitions include corresponding elevation losses based on data collected by Dr. David Burdick and his team at the University of New Hampshire (Burdick and Vincent 2015; Vincent, Burdick, and Dionne 2013). These data, collected in marshes in New Hampshire and Massachusetts, are summarized in Table 5. Marsh Collapse Data. The weighted-average elevation losses were applied across the study areas and the standard deviation was used within the uncertainty analysis.

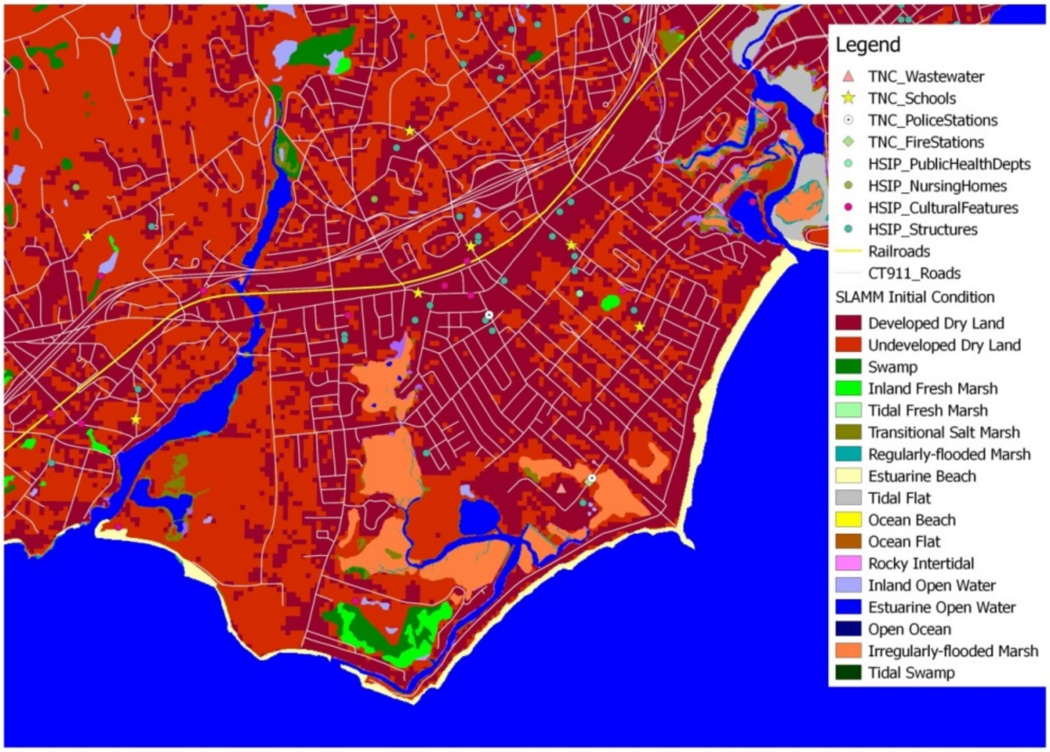
Table 5. Marsh Collapse Data

Transition Type	N	Weighted Average Elevation Loss (m)	Average Standard Deviation (m)
Irregularly flooded Marsh to Regularly flooded	70	0.07	0.02
Regularly flooded Marsh to Tidal Flat	31	0.19	0.07

2.8 Infrastructure Data

The addition of infrastructure to the SLAMM simulations was another improvement to model projections completed in this project. Roads, railroads, and point locations of critical infrastructure were added to simulations. An example map is presented in Figure 9.

Figure 9. SLAMM land cover and infrastructure data example



As discussed Section 2.8.1.1, detailed elevations of roads and railroads were incorporated into the DEM in order to better account for the effects of this infrastructure on water flows and hydraulic connectivity, as well as to predict the approximate frequency of flooding of these resources given increased flooding due to a higher sea level.

2.8.5 Roads and Railroads

Data on roads were obtained both from the NYS GIS Clearinghouse and the DOT. The Clearinghouse data (Street Segment Public Data) include more roads than the “RoadwayInventory” data provided by the DOT. However, the RoadwayInventory data are more detailed and include road class. In order to use all the details included in each of these datasets, the two shapefiles were merged using QGIS.

The NYS Railroad Lines dataset from DOT was downloaded through the NYSGIS Clearinghouse. This data layer represents active railroad lines in the state of New York. NYC subway lines were not included in this study. The Railroad Line data were cross-referenced with a spatial data layer representing tunnels obtained from Mark Landgraf at DOT. Railroad lines in tunnels were removed from the dataset for analysis.

Road and railroad files were reviewed for accuracy prior to input into SLAMM. However, due to the number of roads and railroads within the study area and it was not possible to review each one against satellite imagery. The data reported in the inundation of roads and railroads results section should be interpreted carefully with this uncertainty in mind.

2.8.5.1 Road and railroad elevations

The study area elevation layers were originally averaged at 5 m resolution. Averaging data at this resolution may not be precise enough to accurately represent road and railroad centerline elevations. Roads and railroads are often located on raised topography that can act as barrier to water flow. With a cell-size resolution of 5 m, the lower areas on the sides of the road would be included in the cell's average-elevation calculation.

To better represent road and railroad elevations, several steps of data manipulation were necessary:

- A one meter horizontal-resolution elevation layer covering the entire study area was created from the LiDAR data described in Section 2.2.1 that were downloaded at their native resolution.
- The infrastructure files with all the road and railroads lines were clipped to the study area extent, and a 1 m buffer was added on both side of each transportation center line.
- Road and railroad elevations were extracted by selecting all elevations within the 2 m wide buffered lines. These elevations were then resampled at 5 m resolutions and assigned to each road and railroad line as broken down into 5 m segments.

To model the impacts on water connectivity, the project DEM was modified using higher road-center elevations in those cells where roads and railroads are present.

2.8.6 Culverts

The DOT "large culverts" dataset was obtained from the NYSGIS Clearinghouse, reviewed, and added to the SLAMM simulation. This step enhanced the hydrologic enforcement completed in the previous SLAMM study. To include large culverts, the DEM of the project was examined considering the large-culvert locations. When a culvert was present and was not already represented in the DEM, its location was first reviewed via aerial and street-view photography in Google Maps to understand the culvert's configuration. Next a connection between the low-lying areas was added to the DEM to represent the culvert. In practice this was achieved by modifying the DEM with a line of low elevation cells that would cut through the bridge or road that had impeded the water flow.

2.8.7 Critical Infrastructure

Fifteen different infrastructure data inputs were incorporated in the SLAMM simulation. These data were obtained from three different sources.

From the National Oceanic and Atmospheric Administration's Digital Coast Data Registry:

- CERCLA site locations. Represents sites designated by the Comprehensive Environmental Response Compensation and Liability Act, also known as Superfund sites. Published in 2014.
- Coastal Energy Facilities (USEPA dataset)
- USACE Coastal Projects

From the New York State Global Information Systems Clearinghouse:

- Bridges (November 2014)
- Dams
- Railroads Passenger Stations
- SPDES

From The Nature Conservancy:

- Airports
- Electric Power Facilities
- Fire Stations
- Medical Facilities
- Police Stations
- Potable Water Facilities
- Schools
- Wastewater Facilities

Several other data sets were reviewed for inclusion but were not used due to data sharing restrictions. Electrical transmission line data could not be obtained due to the data-release policies that specify transmission line data may only be distributed to other NYS agencies with which the NYS Office of Information Technology Services has a data sharing agreement (Lasch 2015). Similarly, the cultural landmarks data were not available in a form that allowed further distribution of the dataset. Finally, while drinking water treatment plant data were obtained, the locations of potable water storage tanks were not available.

Infrastructure data were received as "point data" meaning that each piece of infrastructure is represented by a single latitude and longitude location. This location may or may not represent the most vulnerable part of the infrastructure to flood waters. The model assumes that when coastal water reaches the bare-earth DEM cell at the point's location the specified infrastructure will be subject to flooding. While this method lacks some precision, it does give an overall accounting of the relative vulnerability of infrastructure to tidal flooding and storm surge under SLR.

2.9 Model calibration

To test the consistency of key SLAMM modeling inputs, such as current land cover, elevations, tide ranges and hydraulic connectivity, SLAMM is run at "time zero" in which tides are applied to the study area, but no sea-level rise, accretion, or erosion are considered. Because of DEM and land cover uncertainty, local factors such as variability in the water table, and simplifications within the SLAMM conceptual model, some cells may initially be below their lowest allowable elevation land cover category and are immediately converted by the model to a different land cover category.

When time-zero results have significant land-cover changes additional investigation is required to determine if the current land cover of a particular area is better represented by time-zero conversion results rather than the initial wetland layer. If not, it may be necessary to calibrate data layers and model inputs to the actual observed conditions. The general rule of thumb is that if 95% of a major land cover category (one covering ≥ 5% of the study area) is not converted at time zero, then the model set-up is considered acceptable. However, land coverage conversion maps at time zero are always reviewed to identify any initial problems, and to make necessary adjustments to correct them. Model projections are reported from time-zero forward so that the projected land cover changes due only to SLR and not due to initial model and data inaccuracies.

Most of the model calibration was carried out in previous project with satisfactory results. The incorporation of new input data layers did not require calibration except for some tide ranges in the southern portion of Suffolk County. In fact, new tidal data were available for Great South Bay bringing the GT = 0.42 m (from previous GT=0.32 m) and setting the SE = 0.45 m (from previous SE=0.27 m) according to the GT vs. SE relationship and inundation analysis. This tidal adjustment is expected to somewhat increase the resiliency of the current marsh in Great South Bay.

2.9.8 Hydrologic Enforcement

Hydrologic enforcement refers to the process of correcting LiDAR land-surface elevations by modifying the elevations of artificial impediments, such as road fills or railroad grades, to simulate how man-made drainage structures, such as culverts or bridges, allow continuous downslope water flow (Poppenga et al. 2014). Without hydro-enforcement, downslope flow would be functionally dammed by the raised topography, creating false pooling on the upstream side (Poppenga et al. 2014) and tidal flow would be impeded from inundating upstream areas. Examples of model inconsistencies due to lack of hydrologic enforcement would be if an area classified as a tidal marsh does not get inundated because a bridge or culvert has not been hydro-enforced in the DEM. Similarly, areas identified as dry land could be regularly inundated because a tidal gate has not been properly accounted for.

Once initial model set up was completed, consistency between modeled inundation areas with land covers and elevations was closely analyzed. GIS analysis of SLAMM water-inundation maps allowed the team to identify areas that were either inundated too frequently or not frequently enough. If water flow pathways did not accurately replicate current hydraulic conditions on the ground, the combined DEMs were edited by Warren Pinnacle Consulting by removing all elevation of impediments that were identified (e.g., adding missing culverts and/or removing bridges from the DEM). This was achieved in practice by adding a line of low elevation cells that would cut through the bridge or road that had impeded the water flow.

2.9.9 New York City Model Calibration

Several changes were made to the three SLAMM project areas for this effort. By including recent LiDAR data covering the study area, there was an increased agreement between land cover input data and time-zero model land cover. In particular, the new model has fewer dry land cells reclassified as wet (flooded developed or transitional marsh) and fewer regularly-flooded marsh cells reclassified as tidal flat. Table 6 presents the new calibration data for the NYC area.

Table 6. NYC Initial Condition and Changes at Time Zero

Initial conditions vs. Time Zero					
Land cover type		Initial Coverage (acres)	Time Zero - 2008 (acres)	Change (acres)	% Change
	Developed Dry Land	123,973	123,874	-99	-0.1
	Estuarine Open Water	74,529	74,702	173	0.2
	Undeveloped Dry Land	60,499	59,995	-504	-0.8
	Open Ocean	32,650	32,665	15	0.0
	Irreg.-Flooded Marsh	2,073	2,025	-47	-2.3
	Tidal Flat	1,883	1,859	-24	-1.3
	Regularly-Flooded Marsh	1,567	1,561	-6	-0.4
	Inland Open Water	1,014	968	-46	-4.5
	Ocean Beach	738	727	-12	-1.6
	Swamp	549	546	-2	-0.4
	Estuarine Beach	463	448	-16	-3.4
	Inland Fresh Marsh	421	421	0	0.0
	Tidal Swamp	76	71	-5	-6.0
	Trans. Salt Marsh	75	559	484	645.0
	Tidal Fresh Marsh	31	20	-10	-33.6
	Riverine Tidal	13	13	0	0.0
	Inland Shore	2	2	0	0.0
	Flooded Dev. Dry Land	0	99	99	NA
	Total (incl. water)	**300,556**	**300,556**	**0**	**0.0**

2.9.10 Nassau Model Calibration

Similar to the NYC study area, LiDAR updates in the Nassau County study area improved the model calibration. Table 7 presents new calibration data for Nassau coastal area. Some notable ways these results differ from the previous calibration are that there is a lower initial loss of dryland due to the more precise elevation data and similarly, less irregularly flooded marsh area is reclassified as regularly flooded.

Table 7. Nassau Initial Condition and Changes at Time Zero

Initial conditions vs. Time Zero					
Land cover type		Initial Coverage (acres)	Time Zero - 2008 (acres)	Chang e (acres)	% Change
	Estuarine Open Water	61,477	61,639	161	0.0
	Open Ocean	40,363	40,364	0	0.0
	Undeveloped Dry Land	36,198	35,951	-247	0.0
	Developed Dry Land	27,581	27,551	-30	0.0
	Irreg.-Flooded Marsh	7,821	7,093	-728	-0.1
	Inland Open Water	1,261	1,252	-9	0.0
	Tidal Flat	987	926	-61	-0.1
	Swamp	900	897	-3	0.0
	Ocean Beach	854	862	8	0.0
	Estuarine Beach	714	689	-25	0.0
	Regularly-Flooded Marsh	713	1,390	677	0.9
	Inland-Fresh Marsh	224	220	-4	0.0
	Trans. Salt Marsh	221	452	231	1.0
	Inland Shore	36	36	0	0.0
	Tidal-Fresh Marsh	22	21	-1	0.0
	Tidal Swamp	12	12	-1	-0.1
	Flooded Developed Dry Land	0	30	30	NA
	Total (incl. water)	**179,386**	**179,386**	**0**	**0.0**

2.9.11 Westchester Model Calibration

The LiDAR data used in the Westchester project area were unchanged from the previous model application and therefore only small differences were noted between the two model calibrations (these minimal variations are due to the improved accounting of road elevations). Table 8 presents the new calibration data for the Westchester area.

Table 8. Westchester Initial Condition and Changes at Time Zero

Initial conditions vs. Time Zero					
Land cover type		**Initial Coverage (acres)**	**Time Zero - 2003 (acres)**	**Change (acres)**	**% Change**
	Estuarine Open Water	15,708	15,714	6	0.0
	Developed Dry Land	8,686	8,654	-32	-0.4
	Undeveloped Dry Land	7,453	7,359	-94	-1.3
	Inland Open Water	172	173	1	0.7
	Estuarine Beach	76	76	0	-0.6
	Swamp	72	72	0	0.0
	Irreg.-Flooded Marsh	69	66	-3	-4.2
	Rocky Intertidal	59	59	0	0.0
	Regularly-Flooded Marsh	58	60	2	3.0
	Inland Fresh Marsh	31	31	0	-0.6
	Tidal Flat	31	27	-4	-13.9
	Tidal Swamp	3	3	0	-5.6
	Riverine Tidal	1	1	0	-0.6
	Tidal Fresh Marsh	1	1	0	0.0
	Trans. Salt Marsh	0	93	93	NA
	Flooded Dev. Dry Land	0	32	32	NA
	Total (incl. water)	**32,420**	**32,420**	**0**	**0.0**

2.9.12 Suffolk County Model Calibration

Elevation data covering Suffolk County were also updated with newly available LiDAR. Elevations for these study areas primarily used the 2014 USGS CMGP Lidar: Post Sandy (Long Island, NY), but other LiDAR sources included 2014 NOAA data[1] and 2011–2012 DEC Coastal Lidar data. These alternative data sources were used to provide elevations in coastal areas not covered by the primary LiDAR source. The new elevation data provided a strong model calibration—error statistics were similar to the previous

1 2014 NGS Topobathy Lidar Post Sandy (SC to NY).

SLAMM application at this location. Some irregularly flooded marsh cells were reclassified as regularly flooded marsh because of low-elevation data relative to tides, and some cells at the water edges of undeveloped dry land were predicted to be converted to transitional marsh. Table 9 and Table 10 present the new calibration data for Suffolk County. As was the case for the other sites, these immediate predicted changes were assumed to represent the initial condition for model projections.

Table 9. Suffolk West Initial Condition and Changes at Time Zero

		Initial	2004	Area Change (Acres)	% Change
	Estuarine Open Water	156,973	157,201	228	0.0
	Open Ocean	76,977	77,093	116	0.0
	Undeveloped Dry Land	70,397	69,895	-502	0.0
	Developed Dry Land	24,394	24,356	-38	0.0
	Irreg.-Flooded Marsh	7,540	6,978	-562	-0.1
	Swamp	4,648	4,610	-38	0.0
	Inland Open Water	2,490	2,486	-4	0.0
	Regularly-Flooded Marsh	1,490	1,830	340	0.2
	Estuarine Beach	1,608	1,523	-86	-0.1
	Ocean Beach	1,071	1,044	-27	0.0
	Trans. Salt Marsh	461	877	416	0.9
	Tidal Flat	385	520	134	0.3
	Inland-Fresh Marsh	435	434	-1	0.0
	Tidal Swamp	432	418	-14	0.0
	Inland Shore	48	48	0	0.0
	Tidal-Fresh Marsh	41	40	0	0.0
	Flooded Developed Dry Land	0	38	38	NA
	Rocky Intertidal	1	1	0	0.0
	Total (incl. water)	**349,392**	**349,392**	0	0.0

Table 10. Suffolk East Initial Condition and Changes at Time Zero

		Initial	2010	Area change (Acres)	% change
	Open Ocean	229,238	229,383	144	0.0
	Estuarine Open Water	179,642	179,786	144	0.0
	Undeveloped Dry Land	143,421	142,667	-754	0.0
	Developed Dry Land	25,146	25,117	-29	0.0
	Irreg. Flooded Marsh	4,848	4,392	-456	-0.1
	Swamp	2,365	2,362	-2	0.0
	Inland Open Water	1,988	1,982	-6	0.0
	Ocean Beach	1,975	1,939	-36	0.0
	Estuarine Beach	1,831	1,762	-68	0.0
	Trans. Salt Marsh	281	930	649	2.3
	Regularly Flooded Marsh	194	674	480	2.5
	Inland-Fresh Marsh	456	443	-14	0.0
	Tidal Swamp	307	287	-20	-0.1
	Tidal Flat	181	135	-46	-0.3
	Tidal-Fresh Marsh	100	97	-3	0.0
	Rocky Intertidal	62	50	-12	-0.2
	Flooded Developed Dry Land	0	29	29	NA
	Inland Shore	1	1	0	0.0
	Ocean Flat	1	1	0	0.0
	Total (incl. water)	**592,036**	**592,036**	0	0.0

2.10 Modeling Adaptation Strategies

Several adaptation strategies were modeled to quantify their potential benefits under sea-level rise conditions. The strategies considered were as follows:

- **Protect dry land at all costs** by armoring shoreline and allow no marsh migration. This strategy is modeled in SLAMM by selecting the built-in option of "Protect all dry land". With this option no marsh transgression into dry land occurs.
- **Acquisition/transfer of parcels** to allow marsh migration in undeveloped dry land. This approach is the general base SLAMM simulation setup option
- **Acquisition/transfer of parcels and restoration** is similar to the previous strategy but includes allowing marsh migration in developed dry land. SLAMM has the option for marsh conversion when developed dry land starts to get regularly inundated.

- **Restoration of marsh edges to 1970's marsh footprints** (New York City and Nassau County only) was implemented by modifying land cover to 1974 wetland maps for areas that today are open water or tidal flat. In addition, elevations for these new marsh areas were updated to mean tide level.
- **Thin-layer deposition** considers the deposition of dredge material on low marsh to add elevation capital. To mimic this practice, the elevation layer was modified by adding 20 cm to the elevations of low marsh areas that were within 60 m distance from open water or dry land, which was the assumed distance that could be reached by a high-pressure sprayer from a barge or a truck. In reality, the elevation added by dredge material deposition is not uniform. The uncertainty analysis includes elevation uncertainties that also cover these restored areas. In addition, the area modeled as reachable may be overestimated since not all open waters are navigable or dry land reachable by truck.

2.11 Uncertainty Analysis Setup

The base analyses (non-uncertainty-analysis runs, also called the "deterministic" model) consider a range of different possible SLR scenarios, but other model uncertainties such as variability in measured input parameters and spatial-data errors were not accounted for.

All site-specific data required by SLAMM, such as the spatial distribution of elevations, wetland coverages, tidal ranges, accretion and erosion rates, local sea-level rise and subsidence rates, may be affected by uncertainties that can propagate into the predicted outputs. The propagation of input-parameter uncertainty into model predictions cannot be derived analytically due to the non-linear spatiotemporal relationships that govern wetland conversion. The Monte Carlo uncertainty analysis module within SLAMM uses efficient Latin-Hypercube sampling of the input parameters (McKay, Beckman, and Conover 1979). This module generates hundreds of prediction results that are then assembled into probability distributions of estimated wetland coverages. This module enhances the value of the results by providing confidence intervals, worst- and best-case scenarios, likelihoods of wetland conversion, and other statistical indicators useful to better characterize possible future outcomes and assist decision making. In addition, simplified maps showing the likelihood of wetland coverage in each location were produced for this project.

For each of the model input parameters, an uncertainty distribution was derived based on available site-specific data. Moreover, mechanistic considerations regarding the proper distributional family and the feasible bounds of the variable were considered. Distributions were derived reflecting the potential for measurement errors, uncertainty within measured central tendencies, and professional judgment (Firestone et al. 1997).

Because SLAMM calculates equilibrium effects of SLR based on relatively large time-steps, long-term erosion rates, accretion rates, and SLR rates were used to drive model predictions. Therefore, the uncertainty distributions described in the following section are based on long-term measurements rather than incorporating short-term variability within measurements. Cell-by-cell spatial variability has been considered for elevation data, but most of the input parameters have uncertainty distributions that vary on a subsite basis.

One important limitation that should be considered when interpreting these results is that the uncertainties of the general conceptual model in describing system behaviors are not taken into account (model framework uncertainty, Gaber et al. 2008). For example, within this uncertainty analysis, the flow chart of marsh succession is fixed. Low marshes must initially pass through a tidal flat category before becoming open water rather than directly converting to open water under any circumstance.

The next sections discuss each of the model's input parameters that are affected by uncertainties, and how they were handled within the uncertainty analysis for this project.

2.11.1 SLR by 2100

The SLR uncertainty distribution was not changed from the previous project, as it was found to be consistent with the January 2016 New York Governor's office SLR scenarios (Table 2). Sea level was assumed to vary between 0.35 m and 2.35 m by 2100 with a most-likely value of approximately 1 m. This distribution was derived by considering the recent NYC Panel on Climate Change (NPCC2) report (Rosenzweig and Solecki 2013) and the ClimAID report (Rosenzweig et al. 2011).

2.11.2 Digital Elevation Map Uncertainty

Spatial elevation uncertainty was accounted for in the same manner as the previous project by applying to each cell a normal spatially correlated random field of elevation uncertainty with standard deviation equal to the Root Mean Squared Error (RMSE) of the LiDAR data sources and ranging from 5 cm for NYC to 10 cm for Nassau and Westchester counties. In addition, these spatial variabilities were spatially correlated with p-value of 0.2495. For Suffolk County, the RMSE of the updated LiDAR data ranged from 11-12 cm (see Table 1) so a value of 12 cm was utilized for conservatism (to ensure that elevation-data uncertainty is adequately accounted for).

2.11.3 Vertical Datum Correction

The uncertainty associated with the VDATUM correction was not modified from the previous project. NOAA characterizes the "maximum cumulative uncertainty" for each location in the documentation of the model (National Oceanic and Atmospheric Association 2010). Like the DEM uncertainty, the vertical datum correction uncertainty was also applied via spatially variable auto-correlated maps. The RMSE for the datum correction was set to 10 cm for the entire study area with the assumption of strong spatial auto-correlation (p-value of 0.2495) applied.

2.11.4 Great Diurnal Tide Range

Tide-range variabilities determined in the previous project from available historical data were applied here. For Suffolk County, the maximum tidal amplitudes for muted-tidal areas on the south shore behind barrier islands were allowed to increase to the oceanic tide, thus modeling possible changes in tides due to breaches that may occur in the future.

2.11.5 Salt Elevation

As in previous project, uncertainty distributions for all salt elevations were modeled as Gaussian distributions with a standard deviation equal to 9 cm and correlated to the GT sampled in each model realization through the linear relationship described in Clough et al. (2014).

2.11.6 Erosion

Marsh erosion was modeled using a uniform distribution ranging from 0 m/yr to 2.0 m/yr. Swamp and Tidal Flat erosion uncertainty were assigned to normal distributions ranging between 0 m/yr and 2.0 m/yr with most likely rates varying spatially and equal to the values used in the base analysis. These distributions are the same as the ones used in the previous project.

2.11.7 Accretion

The accretion-rate response curve distributions determined in previous project were used here.

2.11.8 Marsh Collapse

Marsh-collapse uncertainty was estimated using the standard deviation data summarized in Table 5, and assuming a normal distribution for both irregularly and regularly flooded marsh collapse.

3 Deterministic projections

In the following subsections, deterministic model results are presented individually for each of the three modeled study areas for predicted land cover changes and inundation of infrastructure.

3.1 Land-cover projections

Tables of land-cover acreage at each time step for each SLR scenario simulated are included, as well as summary tables showing the percentage loss and acreage gain for selected land-cover types. It is important to note that changes presented in the summary tables are compared to the time-zero results and therefore represent projected land-cover changes as a result of sea-level rise excluding any land-cover change that occurs when the model is calibrated to initial-condition data.

3.1.1 New York City

Table 11 summarizes the results of the deterministic model simulations. Tables of results by year for each SLR scenario run may be found in Appendix A of this document.

These results show that the habitat types most vulnerable to accelerated SLR are high marshes (irregularly flooded) followed by estuarine beaches. One interesting difference between the two model applications is that flooded developed dry land is predicted to be more vulnerable than observed in the previous SLAMM simulations, likely due to updates in the elevation data used. However, a direct comparison is not possible as different SLR scenarios were run in each study. Figure 10 shows a detail map of New York City deterministic model results (for year 2085) under the medium and high SLR scenarios as compared to the current condition.

Figure 10. NYC Deterministic results

Current coverage (top) Medium SLR in 2085 (middle) High SLR in 2085 (bottom)

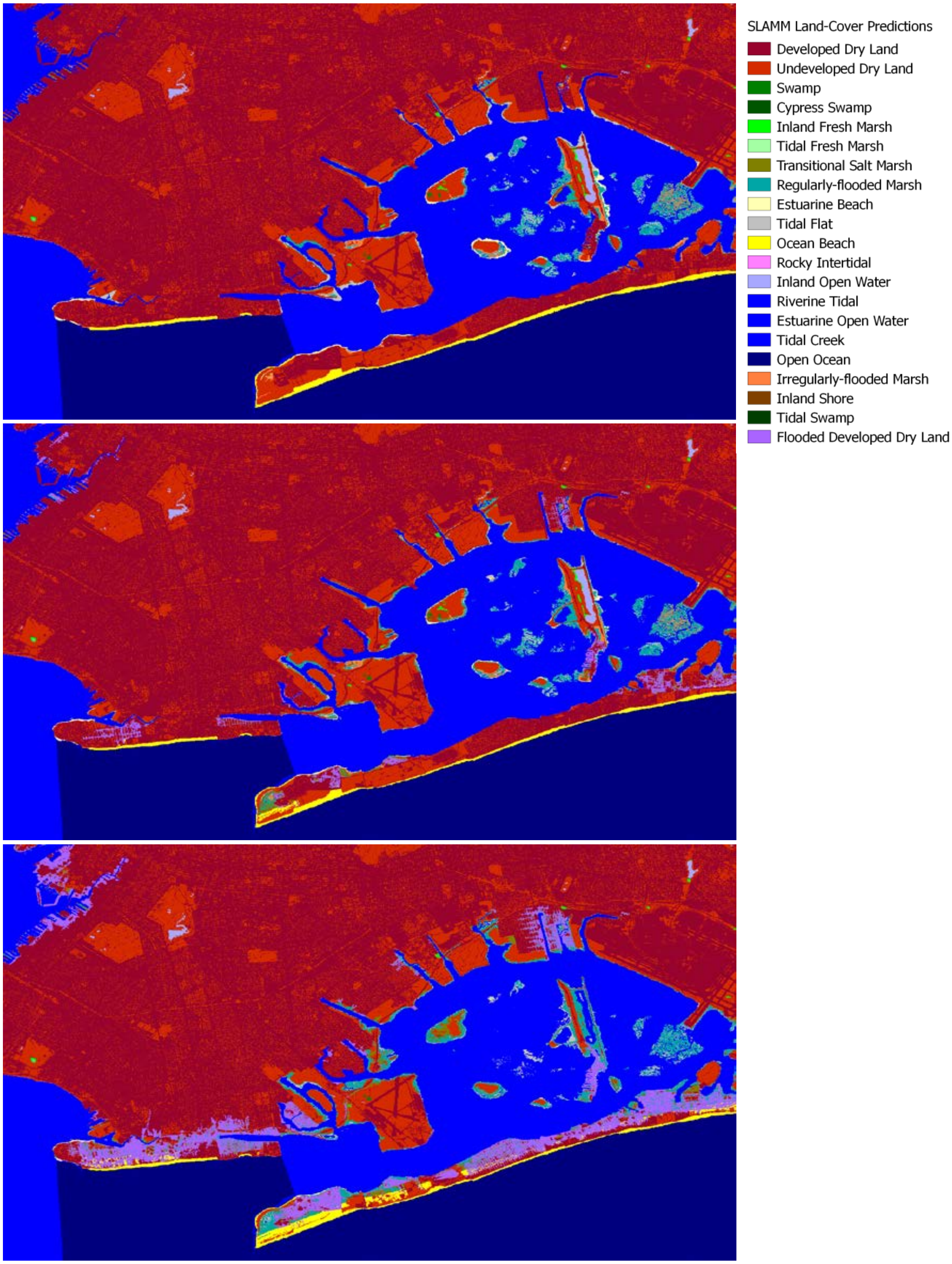


Table 11. NYC Land cover change summary

Positive indicates a gain, negative is a loss

Land cover category	Initial coverage 2008 (acres)	Percentage land cover change from 2008 to 2100 for different SLR scenarios (%)				
		NYC Low	NYC Low-Medium	NYC Medium	NYC High-Medium	NYC High
Developed Dry Land	123,874	0	0	-2	-4	-9
Estuarine Open Water	74,702	1	2	2	3	5
Undeveloped Dry Land	59,995	-1	-2	-4	-6	-11
Irreg.-Flooded Marsh	2,025	0	-2	-27	-67	-86
Tidal Flat	1,859	-39	-47	-57	-56	5
Regularly-Flooded Marsh	1,561	18	30	100	195	209
Ocean Beach	727	-19	-17	-3	18	46
Trans. Salt Marsh	559	25	74	128	146	268
Swamp	546	-1	-2	-7	-11	-26
Estuarine Beach	448	-27	-35	-48	-55	-64
Inland Fresh Marsh	421	0	-3	-11	-14	-54
Flooded Dev. Dry Land	99	164	465	1,978	4,404	10,059
Tidal Swamp	71	-8	-14	-32	-58	-80
Tidal Fresh Marsh	20	0	-4	-16	-23	-50

3.1.2 Nassau County

Table 12 summarizes the deterministic results for Nassau County. Tables of results by year for each SLR scenario run may be found in Appendix A of this document. Like the results of the previous study, these simulations show irregularly flooded marsh is vulnerable to accelerated SLR in the medium to high scenarios. This loss could be balanced by the gain of regularly flooded marsh that peaks under the medium SLR scenario, as illustrated in Table 12. Figure 11 shows a detail of Nassau County model results. This figure illustrates how high marsh (orange) can be converted to low marsh (light blue) and open water as SLR increases.

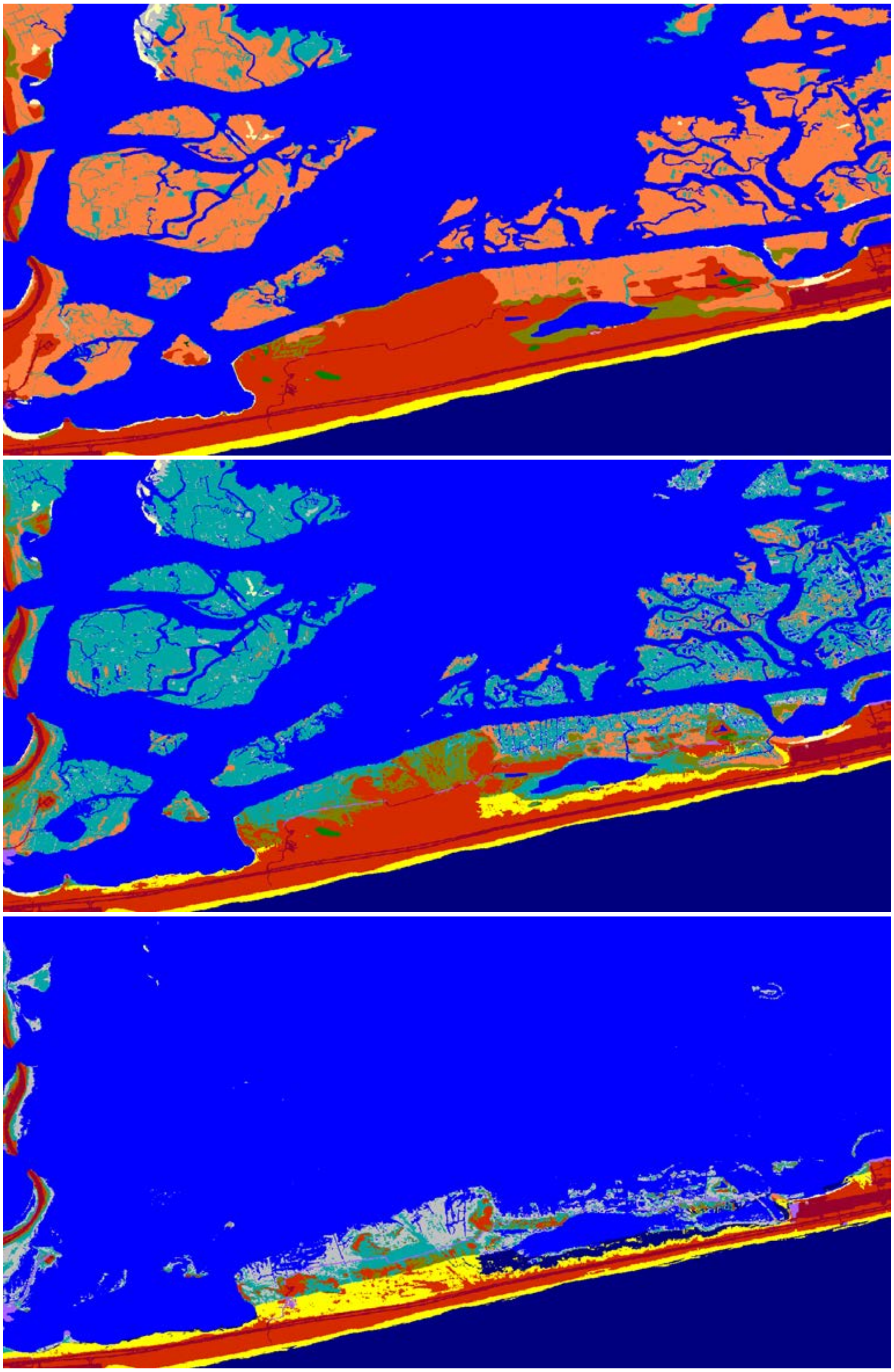
Table 12. Nassau Land cover change summary

Positive indicates a gain, negative is a loss

Land cover category	Initial Coverage 2004 (acres)	Percentage Land cover change from 2004 to 2100 for different SLR scenarios (%)				
		Long Island Low	Long Island Low-Medium	Long Island Medium	Long Island High-Medium	Long Island High
Estuarine Open Water	61,639	1	2	4	8	17
Open Ocean	40,364	1	1	1	1	1
Undeveloped Dry Land	35,951	-1	-2	-6	-12	-23
Developed Dry Land	27,551	-1	-2	-6	-11	-24
Irreg.-Flooded Marsh	7,093	0	-6	-83	-96	-99
Regularly-Flooded Marsh	1,390	1	31	426	329	221
Inland Open Water	1,252	0	-3	-8	-10	-14
Tidal Flat	926	-52	-60	-34	76	51
Swamp	897	0	-1	-3	-8	-12
Ocean Beach	862	-23	-19	-11	2	26
Estuarine Beach	689	-27	-34	-48	-60	-73
Trans. Salt Marsh	452	46	116	188	222	360
Inland-Fresh Marsh	220	-6	-9	-37	-55	-60
Inland Shore	36	0	0	0	0	0
Flooded Developed Dry Land	30	627	1,702	5,191	10,298	22,251
Tidal-Fresh Marsh	21	0	-1	-14	-26	-70
Tidal Swamp	12	-10	-34	-63	-83	-98

Figure 11. Nassau Detail of Deterministic Results, South Oyster Bay

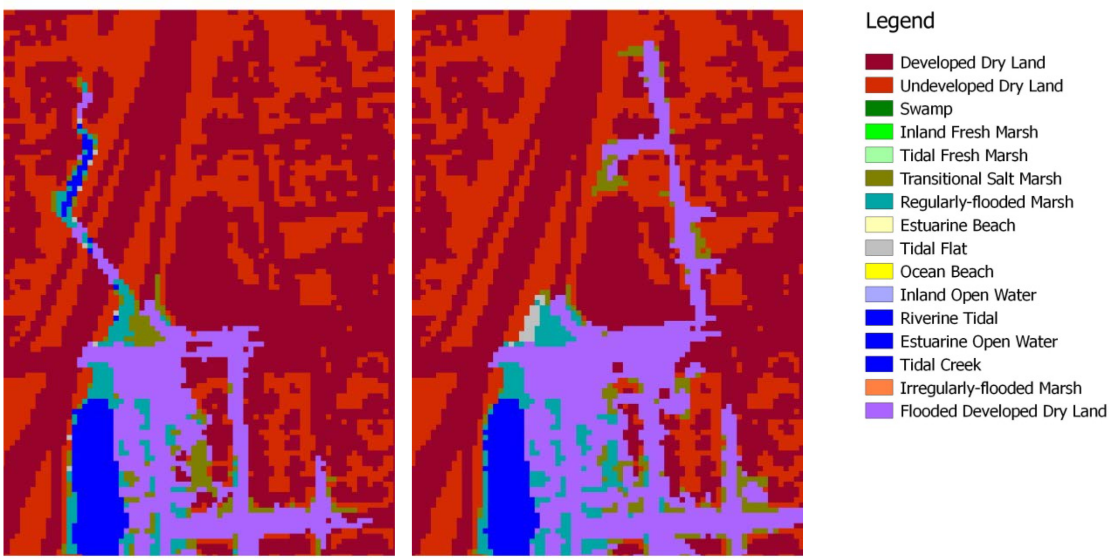
Current coverage (top), Medium SLR in 2085 (middle), and High SLR in 2085 (bottom)



Overall the results of the new simulations predict increased inundation as compared to the simulations results of the previous NYSERDA SLAMM project. This increased inundation is primarily a result of improved LiDAR elevation data that were incorporated into the updated simulations. However, there are also small areas where roads data have shown the limitations that infrastructure pose to marsh migration. Figure 12 illustrates an area in Nassau County where these differences are evident. On the left, the older simulation results show migration over a road, but in the new simulations shown on the right, marsh migration is constrained by the road.

Figure 12. The original simulation results for Nassau County

Simulation results are at 1m of SLR by 2100 (left) compared to results of the new SLAMM project under the same SLR scenario with roads included (right).



3.1.3 Westchester County

Table 13 presents the results of the deterministic simulations for Westchester County. Currently the Westchester County study area contains limited marsh habitats. However, as SLR increases, more frequent inundation of dry lands is predicted to convert some dry lands to transitional marsh (a high marsh category composed of recently flooded dry lands), with a peak under the Medium SLR scenario.

Table 13. Westchester Land cover change summary

Positive indicates a gain, negative is a loss

Land cover category	Initial coverage -2003 (acres)	Percentage land cover change from 2003 to 2100 for different SLR scenarios				
		NYC Low	NYC Low-Medium	NYC Medium	NYC High-Medium	NYC High
Estuarine Open Water	15,714	0%	0%	0%	1%	1%
Developed Dry Land	8,654	0%	-1%	-2%	-4%	-6%
Undeveloped Dry Land	7,359	-2%	-3%	-4%	-6%	-8%
Trans. Salt Marsh	93	18%	54%	116%	114%	78%
Estuarine Beach	76	-3%	-4%	-14%	-19%	-33%
Swamp	72	0%	0%	-3%	-4%	-8%
Regularly Flooded Marsh	60	168%	191%	259%	481%	795%
Rocky Intertidal	59	0%	-2%	-27%	-38%	-49%
Flooded Dev. Dry Land	32	131%	237%	517%	953%	1560%
Inland Fresh Marsh	31	-2%	-2%	-6%	-10%	-13%
Tidal Flat	27	-45%	-36%	17%	33%	54%
Tidal Swamp	3	-8%	-12%	-26%	-52%	-83%
Riverine Tidal	1	-2%	-3%	-4%	-7%	-8%
Tidal Fresh Marsh	1	0%	0%	0%	-5%	-18%

3.1.4 Suffolk County

Tables 14 and 15 present the results of the deterministic simulations for Suffolk County. Tables of results by year for each SLR scenario run are in Appendix A. Although SLR scenarios vary from previous simulations, results show a similar general trend with irregularly flooded marsh vulnerable to accelerated SLR in the medium to high scenarios. This loss could be balanced by the gain of regularly flooded marsh and dry land converting to transitional marsh, both peaking under the low-medium and medium SLR scenarios.

Table 14. Suffolk West Land cover change summary

Positive indicates a gain, negative is a loss

Land cover category	Acres in 2004	Percentage Land cover change from 2004 to 2100 for different SLR scenarios				
		Long Island Low	Long Island Low-Medium	Long Island Medium	Long Island High-Medium	Long Island High
Estuarine Open Water	157,201	0	1	5	6	9
Open Ocean	77,093	0	0	1	1	2
Undeveloped Dry Land	69,895	-2	-3	-6	-10	-15
Developed Dry Land	24,356	-2	-4	-8	-13	-20
Irreg. Flooded Marsh	6,978	-4	-36	-86	-95	-98
Swamp	4,610	-4	-6	-11	-15	-20
Inland Open Water	2,486	0	-1	-4	-6	-9
Regularly Flooded Marsh	1,830	28	168	132	126	113
Estuarine Beach	1,523	-21	-31	-43	-50	-63
Ocean Beach	1,044	-19	-10	9	14	9
Trans. Salt Marsh	877	90	139	132	113	119
Tidal Flat	520	-22	-31	155	221	445
Inland-Fresh Marsh	434	-2	-5	-16	-21	-30
Tidal Swamp	418	-13	-31	-63	-82	-92
Inland Shore	48	0	0	0	0	0
Tidal-Fresh Marsh	40	0	0	-14	-44	-48
Flooded Developed Dry Land	38	1,267	2,425	5,330	8,238	12,676
Rocky Intertidal	1	-5	-8	-20	-32	-56

Table 15. Suffolk East Land cover change summary

Positive indicates a gain, negative is a loss

Land cover category	Acres in 2010	Percentage Land cover change from 2010 to 2100 for different SLR scenarios				
		Long Island Low	Long Island Low-Medium	Long Island Medium	Long Island High-Medium	Long Island High
Open Ocean	229,378	0	0	0	0	1
Estuarine Open Water	179,775	0	1	1	3	6
Undeveloped Dry Land	142,732	-1	-2	-3	-5	-9
Developed Dry Land	25,120	-1	-1	-3	-6	-10
Irreg. Flooded Marsh	4,459	-4	-21	-76	-90	-97
Swamp	2,363	-1	-3	-8	-13	-30
Inland Open Water	1,983	0	-3	-9	-17	-22
Ocean Beach	1,937	-19	-17	-12	-12	-9
Estuarine Beach	1,769	-28	-36	-54	-68	-86
Trans. Salt Marsh	873	93	135	169	158	191
Regularly Flooded Marsh	602	101	280	764	668	497
Inland-Fresh Marsh	443	-12	-15	-29	-47	-69
Tidal Swamp	290	-13	-27	-53	-73	-90
Tidal Flat	136	-64	-37	282	961	2,201
Tidal-Fresh Marsh	97	0	-2	-25	-57	-86
Rocky Intertidal	50	-19	-42	-77	-91	-97
Flooded Developed Dry Land	26	533	1,022	2,615	4,336	7,555
Inland Shore	1	0	0	0	0	0
Ocean Flat	1	0	0	-6	-40	-78

4 Results: Roads and Infrastructure

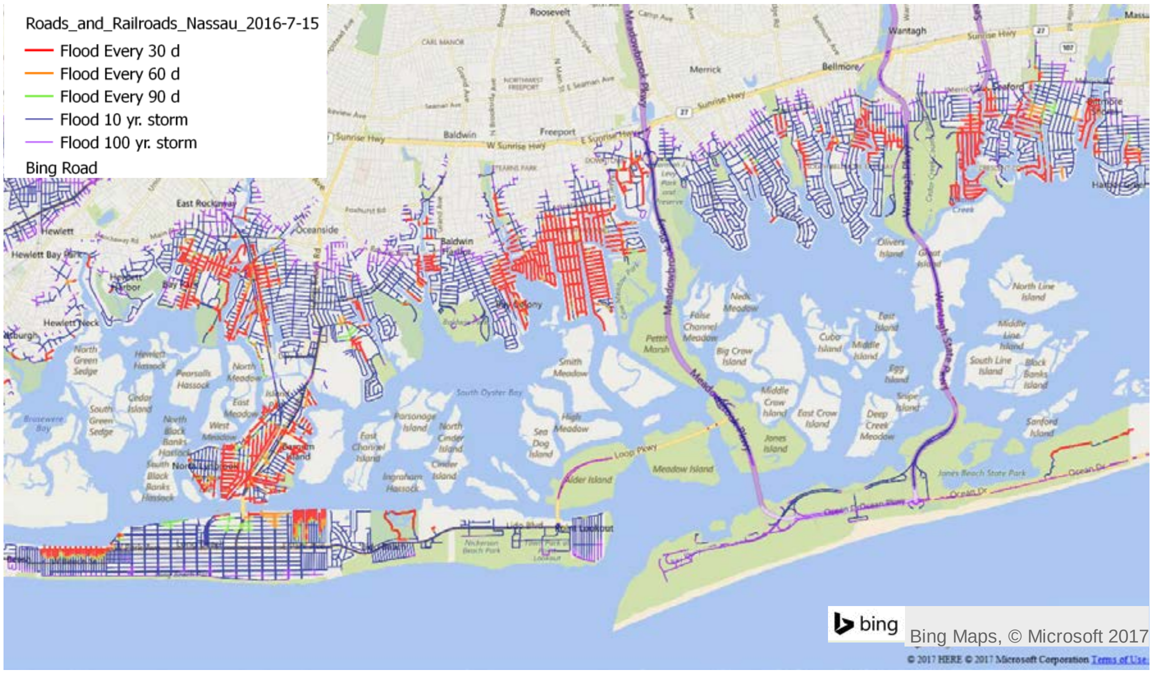
4.1 Roads and Railroad Results

One important and detailed output from the SLAMM infrastructure component is the fate of road segments throughout the study area. As described in more details in Section 2.8.1, road shape files are clipped to each 5 m by 5 m raster cell while road elevations are assigned to the corresponding cell. Then, the fate of that approximately 5-m road segment is tracked individually from the rest of the road line. This enables the model to predict partial flooding of individual roads and retain a shape file output. For each short road segment, a database of vulnerability under combined SLR and storm surge is available for each SLR scenario run and for each year of the simulation. This enables precise mapping of road vulnerability (Figure 13, for example). The full set of GIS model results for all study areas is available at the project website (http://warrenpinnacle.com/prof/SLAMM/NYSERDA2015).

Figure 13. Road sections vulnerable to monthly flooding

The map displays 10-year and 100-year storms, in southern Nassau County by 2085 under the medium SLR scenario.

Source: Microsoft Bing Maps screen shot(s) reprinted with permission from Microsoft Corporation.)

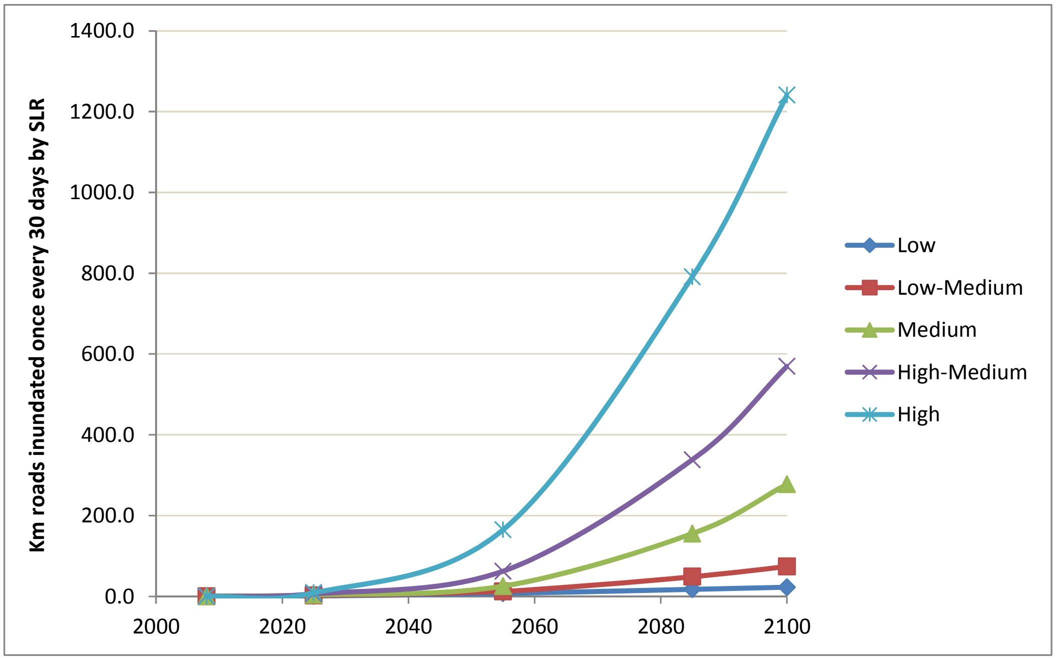


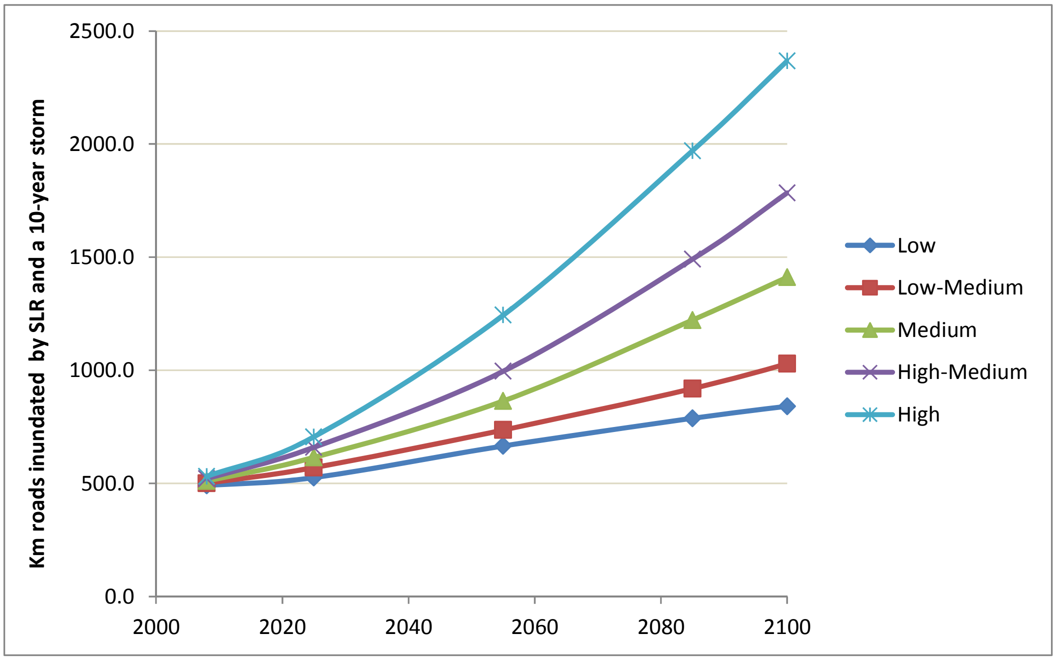
Because bridges are removed from the “bare-earth” elevation layer, and due to data inaccuracies, some roads were predicted to be regularly inundated at the start of the simulation.   These sites were removed from maps and road-flooding statistics.

In addition to maps, SLAMM calculates flooding statistics for each study area that can give a picture of relative vulnerability. Figure 14 shows how SLR alone and SLR added to a 10-year storm can affect overall road vulnerability in the NYC study area. The top graph indicates that under a medium SLR scenario over 155 km (over 95 miles) of city roads are predicted to be flooded every thirty days by 2085. Using the GIS component, the specific road segments subject to flooding can then be identified and proper remedial measures can be undertaken.

Figure 14. Total kilometers of roads and railroads subject to monthly flooding

The graph shows total kilometers under SLR alone (top) and subject to 10-year storms (bottom) in New York City.



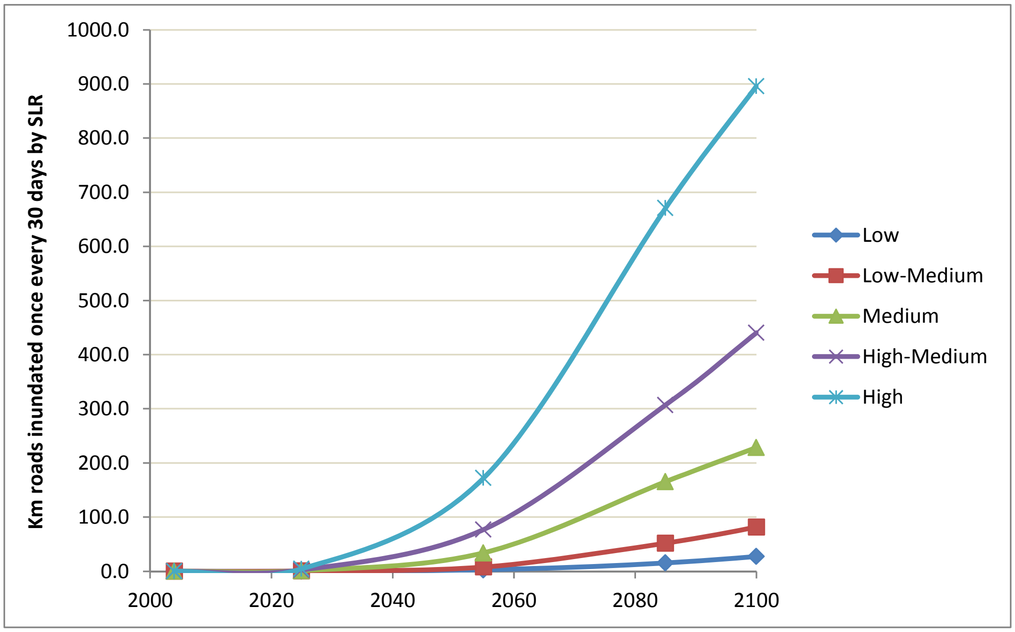


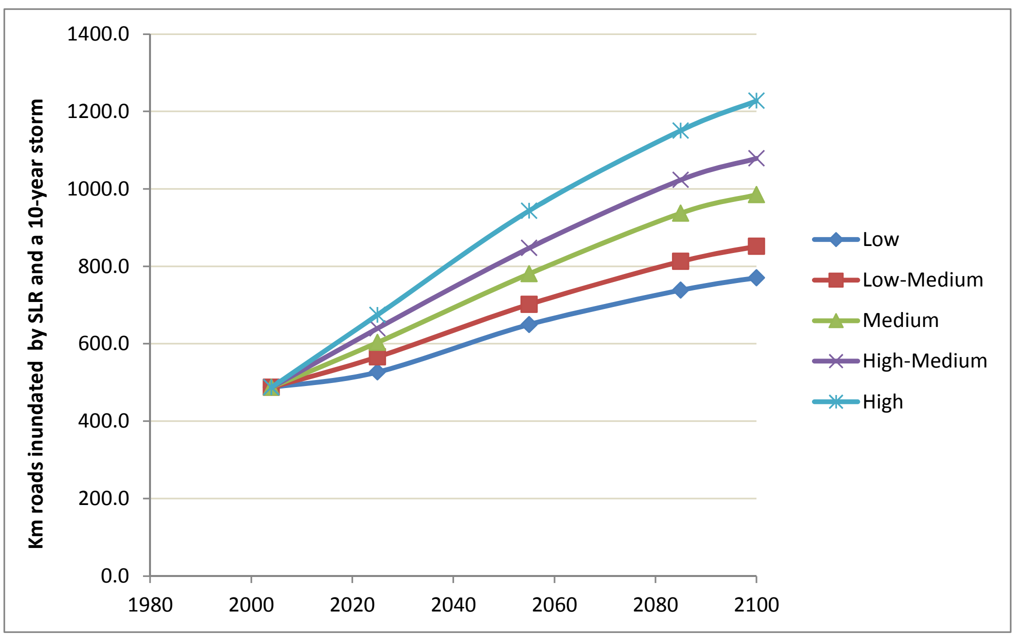
Under the medium SLR scenario in 2085 the bottom part of Figure 14 indicates that roads subject to flood impacts from a 10-year storm jump to over 1200 km in length (from approximately 500 km currently).

Nassau County has less mileage of immediately at-risk roads with nearly 500 km currently subject to a 10-year storm. This jumps to approximately 1000 km in 2085 under the medium SLR scenario (Figure 15).

Figure 15. Total kilometers of roads subject to monthly flooding in Nassau County

The graph shows total kilometers under SLR alone (top) and subject to 10-year storms (bottom)





Examining the relative vulnerability of the four counties studied, New York City has the highest mileage of roads that will be subject to regular flooding under SLR, with up to 1250 km of roads flooded under the highest SLR modeled (Figure 16).

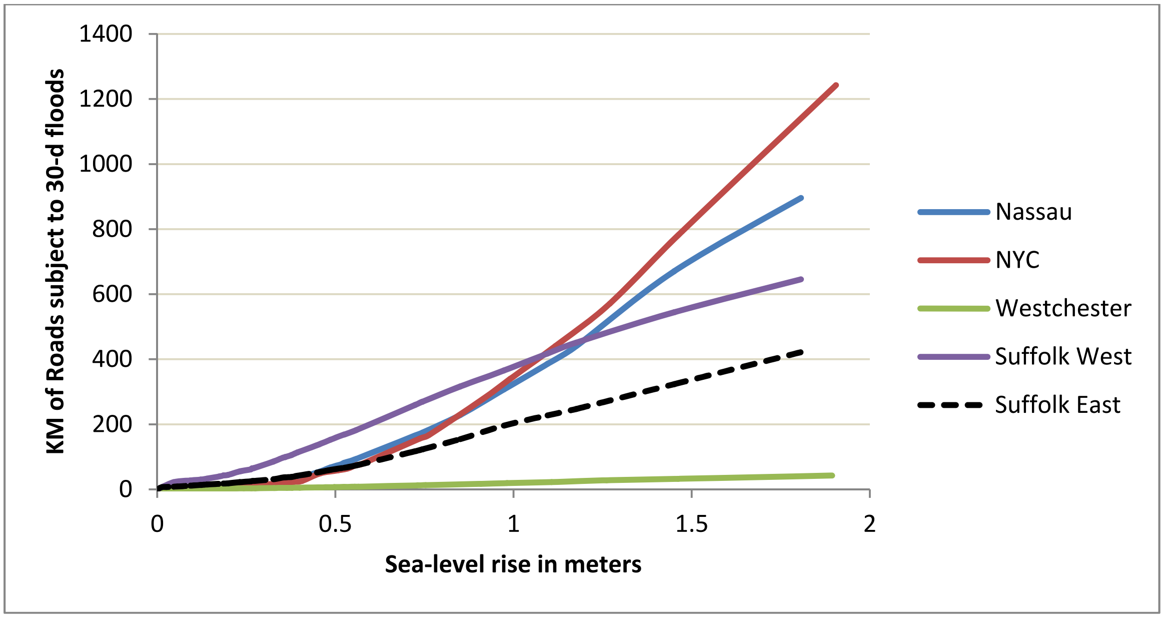


Figure 16. Kilometers of roads and railroads subject to 30-day floods in the project's study areas

4.2 Infrastructure Results

Projections of inundation frequency for point infrastructure within the study area were estimated. As described in Section 2.8.3, point infrastructure is assumed to be inundated when coastal water reaches the bare-earth DEM cell at the point's location.

Infrastructure facilities affected by SLR were those predicted to become periodically flooded at least once every 30, 60, or 90 days and also to future inundation risks for 10% and 1% storm surges (10-year and 100-year storms) under SLR scenarios. These results are summarized in point shapefiles showing the location of flooded infrastructures and with attributes the predicted inundation vulnerability risks under all SLR and storm surge scenarios.

Due to uncertainty in characterizing large facilities as having a "single-point" location, some facilities were already predicted to be regularly inundated at the start of the simulation. These sites were not included in SLR and storm-surge statistics. In addition, outputs were quality assured by a thorough visual review of output maps and data files. Duplicates were removed to ensure accurate accounting.

The results of these analyses uncover areas of vulnerability as well as resilience. In this section for infrastructure, regular flooding is defined as flooded more than four times each year. Examples of results are as follows:

- Only one of the 10 **CERCLA** sites analyzed was predicted to be inundated under any SLR/ storm surge scenario.
- Under the four lowest SLR scenarios 17% of **railroad stations** are predicted to regularly flood due to SLR alone; with storm surge and high SLR more than 21% of railroad stations are predicted to be subject to flooding during storm events.
- SLR alone is predicted to regularly flood 40% of the 10 **airports** studied; with SLR and storm surge by 2100, 60% of the airports are predicted to experience flooding during storm events (10 and 100 year).
- SLR alone could lead to regular flooding in up to 13% of **fire stations** (12 facilities) by 2100. SLR and storm surge could affect 22% of fire stations studied (20 facilities).
- SLR alone could flood seven of the 87 **medical facilities** studied (8%) by 2100. A 10-year storm combined with storm surge could flood nine of medical facilities (10%) by 2100 under the 10-year storm and 16 medical facilities studied (18%) given a 100-year storm
- SLR alone could lead to flooding in 14 of the 195 **police stations** examined (7%) by 2100. SLR and storm surge could flood 26 police stations studied (13%) by 2100 under the 10-year storm, and 37 police stations (19%) with the 100-year storm.
- Of the nine **potable water** facilities in the study area, four are predicted to be susceptible to SLR alone, but six of these facilities would be subject to the combination of SLR and storm surge.
- SLR alone can affect 19 of 76 **wastewater facilities** in the study area. Adding a 10-year storm surge increases that number to 34 facilities, and a 100-year storm increases that number to 45 facilities (59% of facilities studied).
- **SPDES** (State Pollution Elimination Discharge Permit) facilities include wastewater treatment plants, power generation stations, petroleum terminals, and industrial facilities. (Some of these facilities overlap with other infrastructure categories presented here.) Under the three lowest SLR scenarios, less than 10% of SPDES facilities are predicted to regularly flood due to SLR alone. Under the highest SLR scenario, 69 of 225 analyzed facilities are predicted to regularly flood (31%). With storm surge and high SLR 122 SPDES sites (54%) are predicted to be flooded during storm events.

Results for Coastal Energy Facilities and Schools are presented in detail in the following sections. Shapefiles for all infrastructure results are available on the project website (http://warrenpinnacle.com/prof/SLAMM/NYSERDA2015).

4.3 Coastal Energy Facilities

More than half of the 46 Coast Energy Facilities considered in this analysis are predicted to be vulnerable to the combination of SLR and storm surge. 59% of energy facilities (27 facilities) are predicted to flood in 2100 given a high rate of SLR and the 100-year-storm. These facilities are mainly operated by the New York Power Authority, Con-Ed, and local electricity-generating stations.

Under the three lowest SLR scenarios only one facility is predicted to regularly flood due to SLR alone. However, four facilities would flood in 2100 given this low rate of SLR and a 10-year-storm. Due to imprecision in their "single-point" locations, NRG Arthur Kill Operations Inc., the New York Power Authority facility in Queens, and the Montauk power plant operated by Long Island Power Authority were already predicted to be regularly inundated. These facilities were removed from maps and figures here.

Figure 17. Coastal Energy Facilities inundation annual frequency, flooding frequency, and SLR

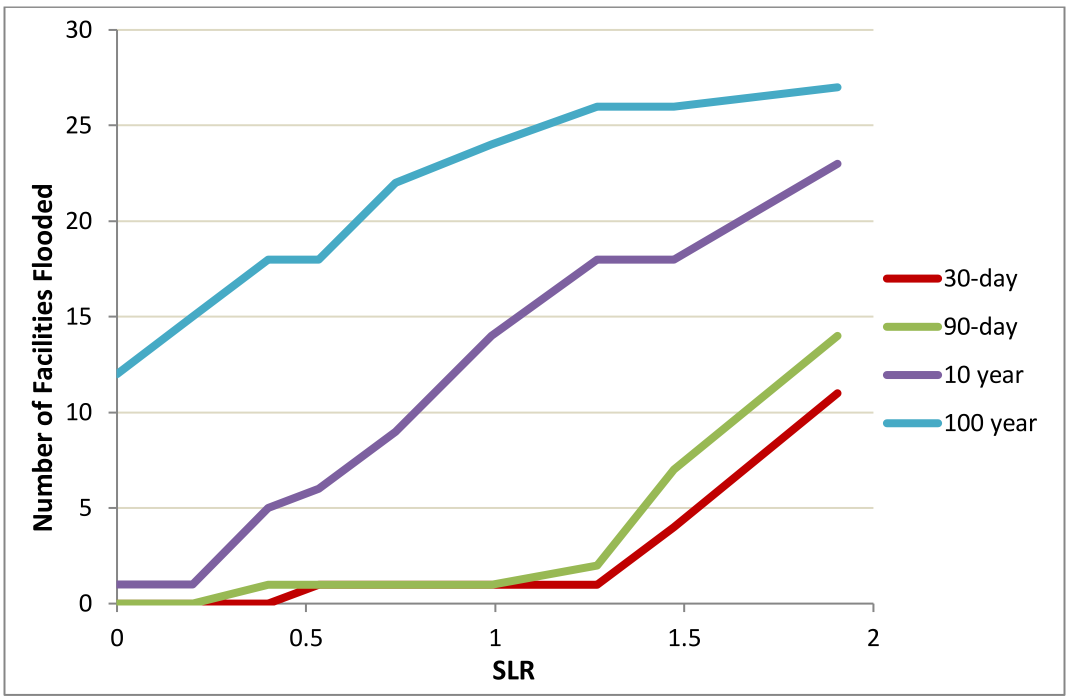
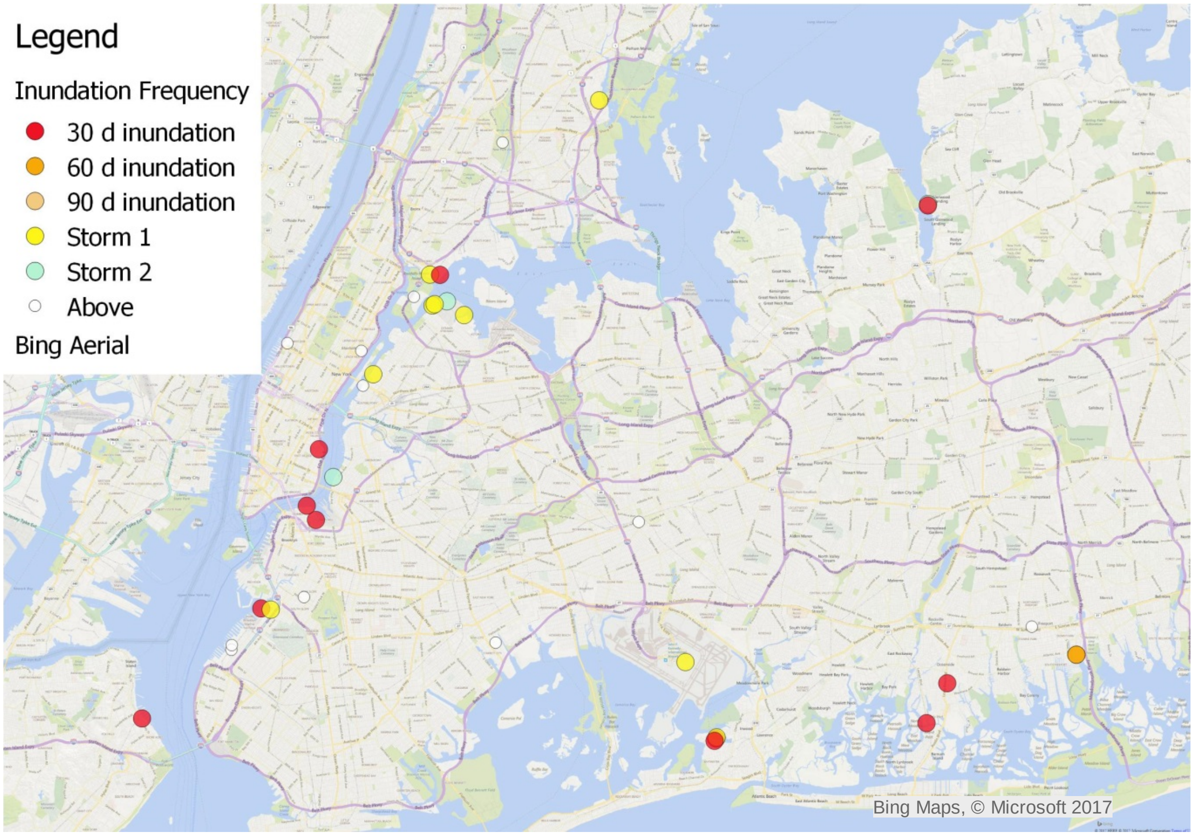


Figure 18 illustrates the locations and inundation frequencies of the coastal energy facilities within the project area given the High SLR scenario at 2100. Full GIS shapefile outputs for this project are available at the project website (http://warrenpinnacle.com/prof/SLAMM/NYSERDA2015).

Figure 18. Coastal Energy Facilities inundation frequencies at 2100, High SLR Scenario

Source: *Microsoft Bing Maps screen shot(s) reprinted with permission from Microsoft Corporation.*



4.4 Schools

Schools often serve as emergency shelters in addition to their primary function, increasing the importance of understanding their resilience or vulnerability to SLR and storm surge. According to SLAMM analysis, which included 2,485 schools throughout the study area, a maximum of 4.9% of schools are predicted to be affected by regular flooding under the High SLR scenario at 2100. When storm surge is considered, up to 15% of schools (363 facilities) are predicted to be subject to flooding in 2100 given a 100-year-storm. Figure 19 illustrates these results for each scenario and time step broken down by SLR and the two storm surge scenarios studied. Figure 20 shows that geographically, school impacts are predicted to be most intense in the Nassau County and New York City study areas. Figure 21 zooms in on these counties to show the location and inundation frequencies of some of the facilities predicted to be affected by flooding at 2085 under the Medium SLR scenario and Figure 23 shows this detail at 2100 under the High SLR scenario.

Figure 19. School-inundation frequency by year, flooding frequency, and SLR

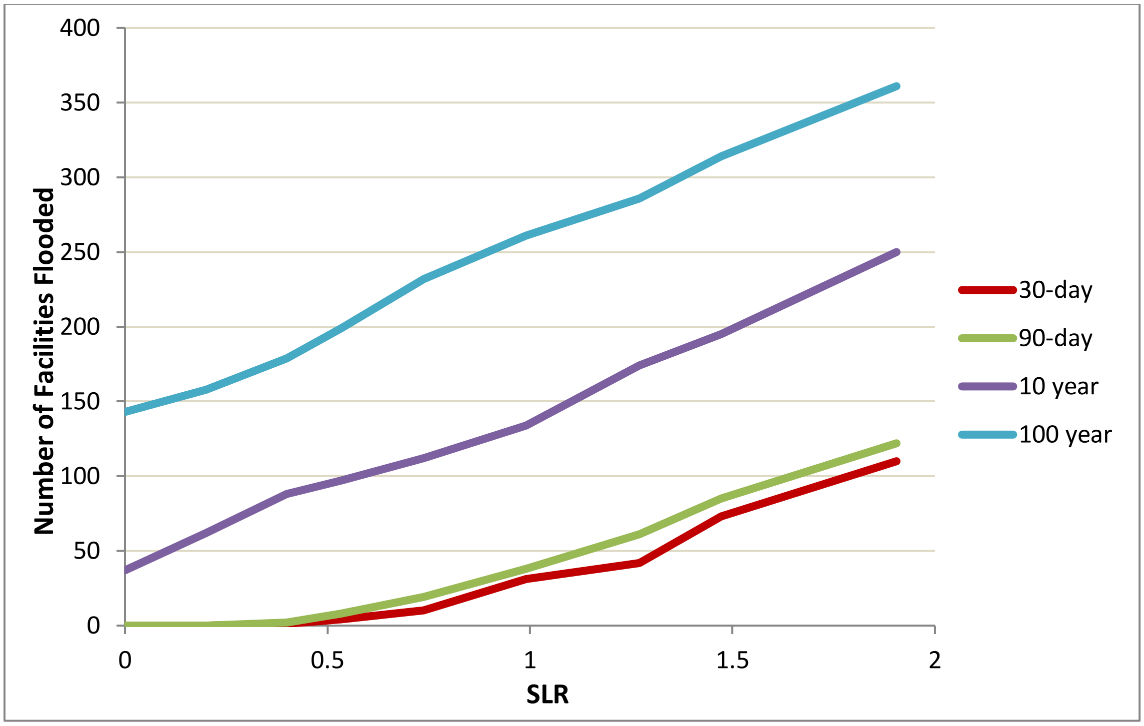


Figure 20. School inundation frequencies at 2100, High SLR Scenario

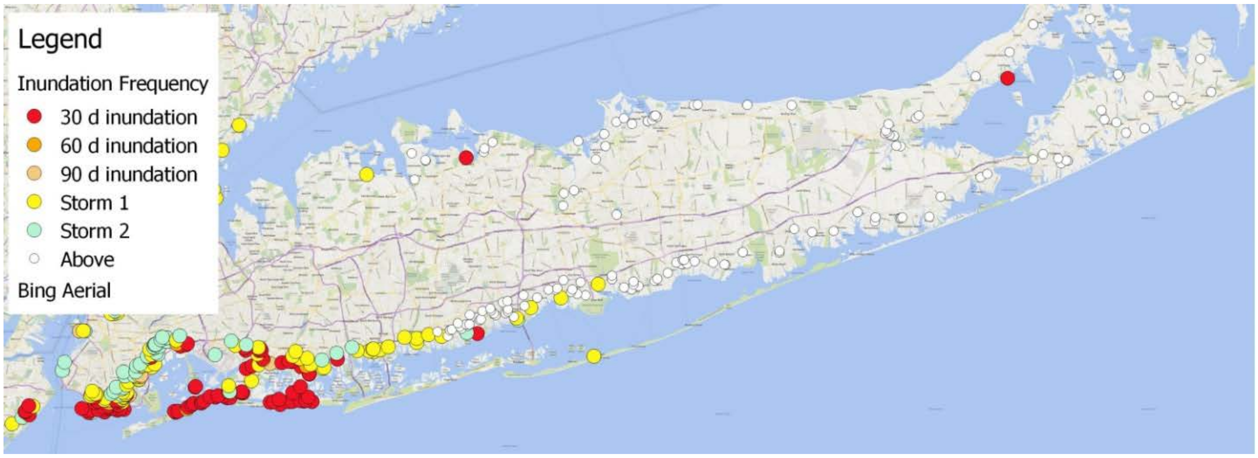


Figure 21. School inundation frequencies at 2085, Eastern Study Area, Medium SLR Scenario

For clarity, facilities that are not predicted to be inundated are omitted

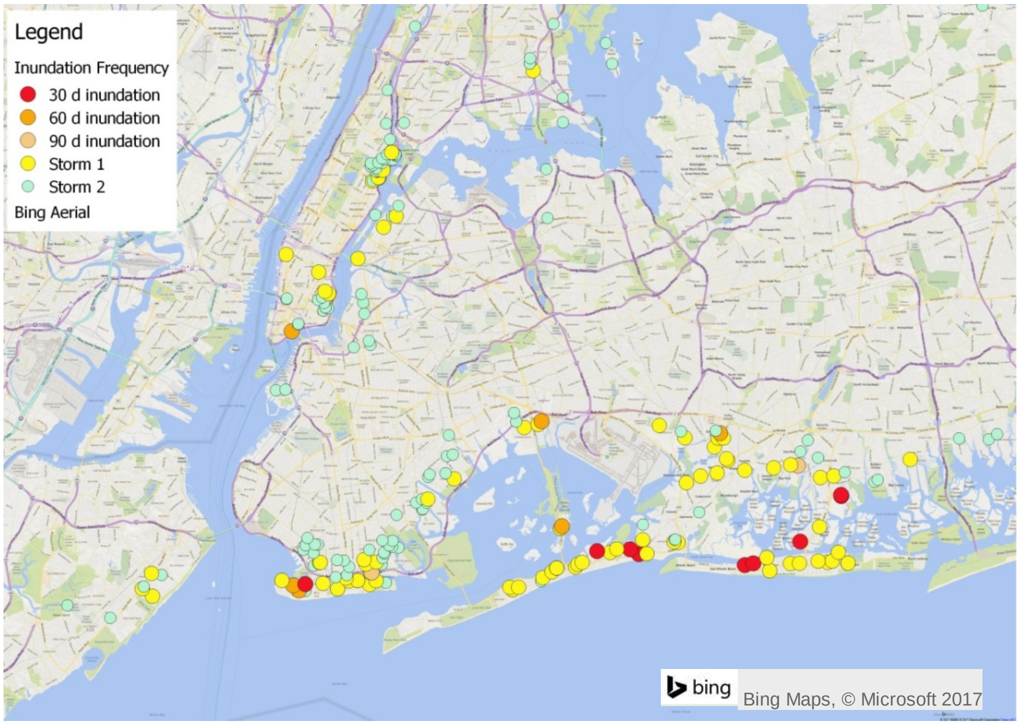
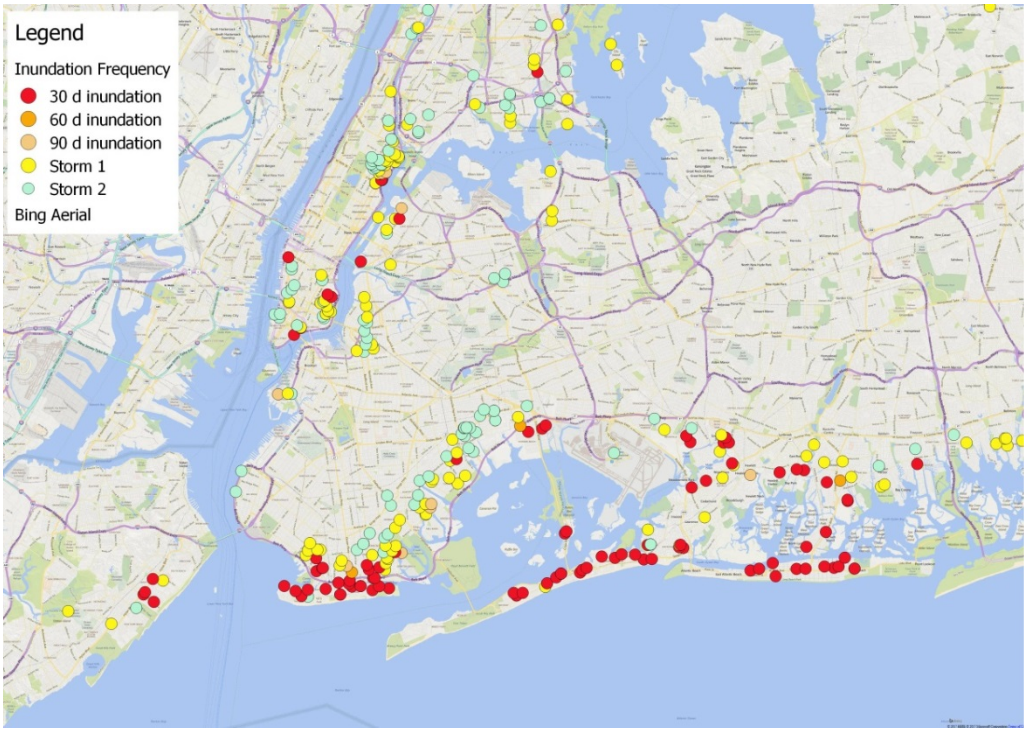


Figure 22. School inundation frequencies at 2100, Eastern Study Area, High SLR Scenario

For clarity, facilities that are not predicted to be inundated are omitted.



5 Results: Uncertainty Modeling

5.1 Overview

For each study area, 200 uncertainty iterations were run, sampling from all input distributions simultaneously. As the number of Monte Carlo simulations increases, the confidence of statistical estimates, such as mean, moments, and percentiles, also increases. However, given the 5-meter cell size and large study area for this application, it was not possible to expand the number of analyses run. Therefore, the calculation of land-cover confidence intervals takes into account the number of iterations run and widens these confidence intervals based on this number.[2]

It is worth noting that the results presented here represent uncertainty in all model parameters and driving variables including sea-level rise. While the model is sensitive to many parameters (Chu-Agor et al. 2010), sea-level rise is often the most important driver of model uncertainty. When presenting time series of confidence intervals in this report, deterministic results are plotted for each of the four SLR scenarios. These four deterministic results help to add context of how much the overall uncertainty interval is driven by future SLR as opposed to other parameter choices.

5.2 Confidence Intervals

For non-Suffolk County study areas, confidence-interval results by study area did not change materially from the previous uncertainty estimation reported in Clough et al. (2014). This remains true despite the addition to the model of the marsh-collapse algorithm, the updated Digital Elevation Maps, and the explicit addition of road centerline elevations. Overall, in terms of total acreage predictions, the primary factor that the model remains most sensitive to is the rate of sea-level rise. The secondary factor that causes the most sensitivity is tide range and the capability of the model to increase elevation due to accretion to keep up with the rising water levels.

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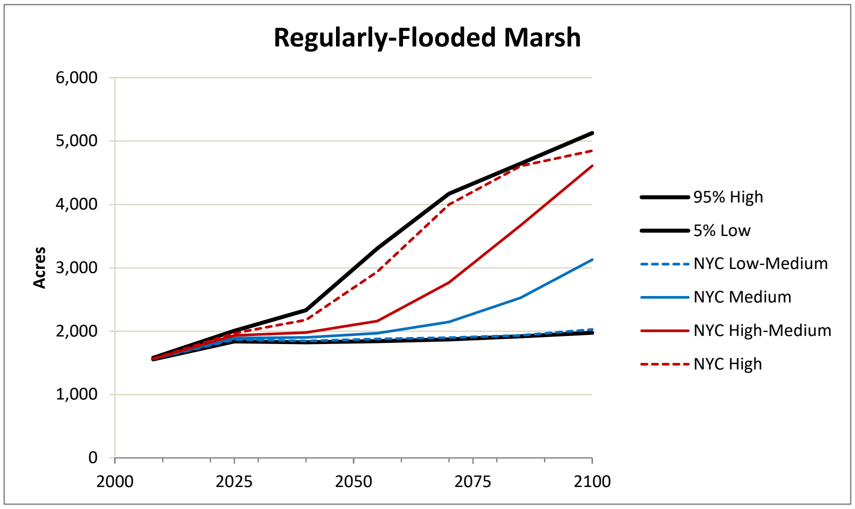
[2] Using non-parametric statistical methods, without requiring assumptions regarding the underlying statistical distribution, the confidence interval of each percentile can be calculated using the properties of binomial distributions (Walsh 1962). To be conservative, in the graphs presented herein the 5th percentile curve is reported by its lowest 5% confidence boundary, while the 95th percentile curve by its highest 95% confidence boundary.

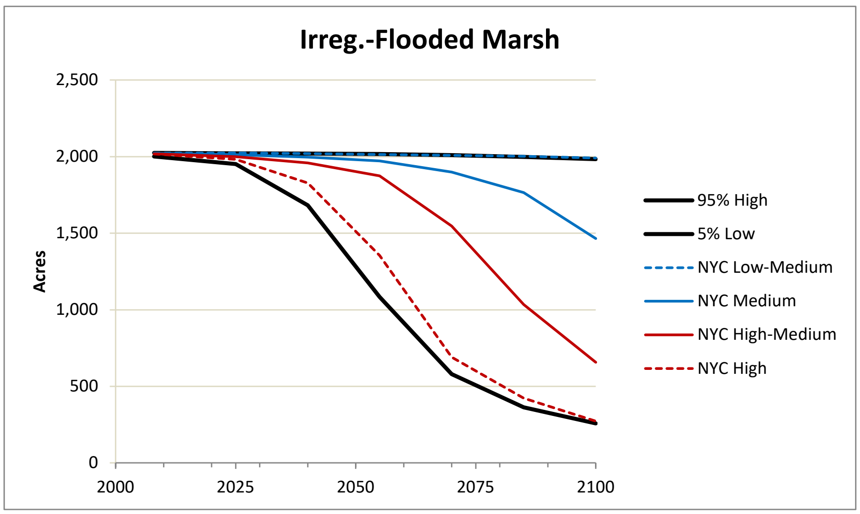
For Suffolk County, confidence interval results were similar but not identical to the previous report. The uncertainty analysis proved to be somewhat sensitive to the increase in maximum tidal amplitudes for muted-tidal areas on the south shore behind barrier islands. (Due to the possibility of these islands breaching and restoring non-muted tidal ranges, the oceanic tide in the possible tide ranges for these locations are included.) This resulted in a higher confidence interval for regularly flooded marsh and a lower confidence interval for irregularly flooded marsh at time zero (Figure 24)

As most confidence-interval results are similar to the previous report, these graphs are not exhaustively reproduced in this document. Additional confidence interval images are in Appendix A as well as in the 2014 report (Clough et al.).

Figure 23. Confidence intervals for New York Study area

For low marsh (regularly flooded), high marsh (irregularly flooded), and transitional salt marsh (that includes recently flooded dry lands)





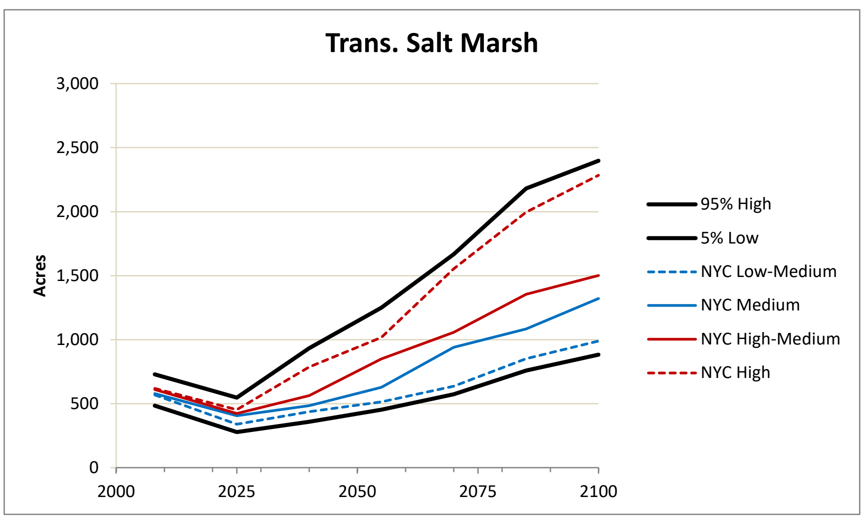
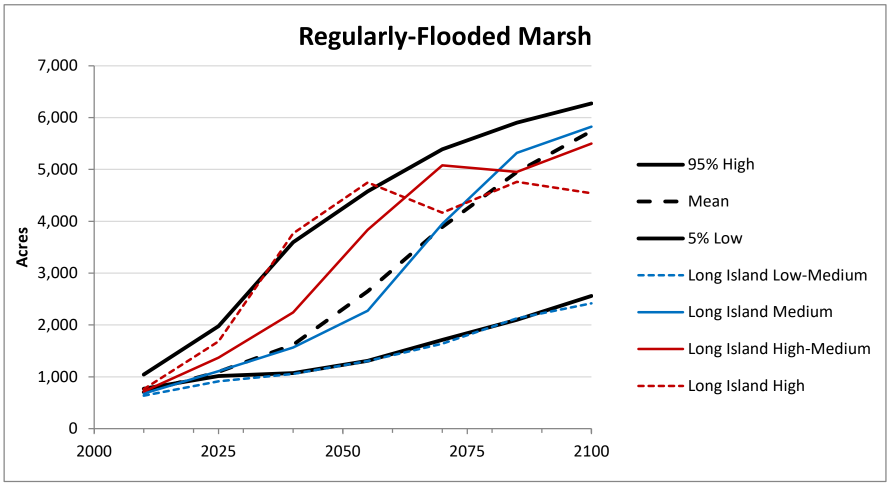
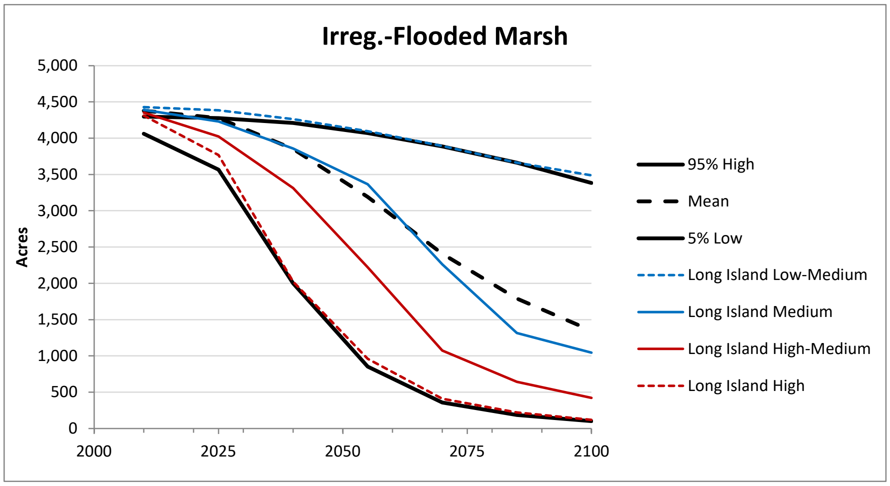
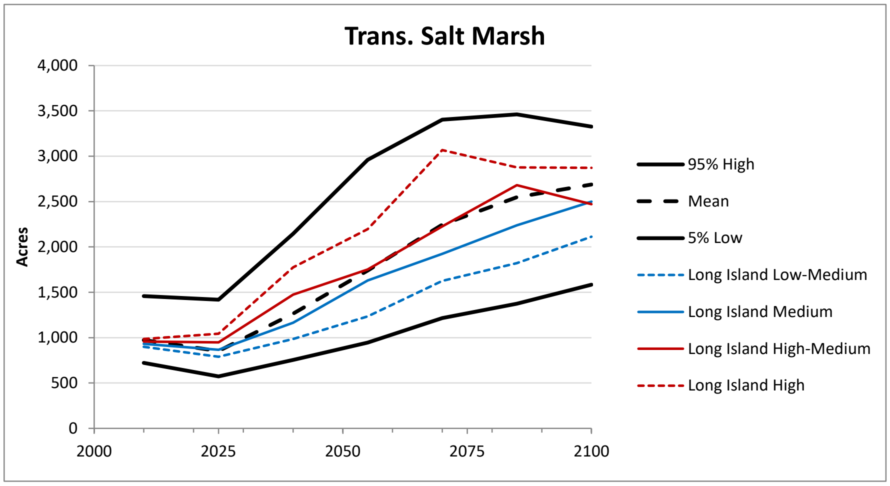


Figure 24. Confidence intervals for Suffolk East Study area

For low marsh (regularly flooded), high marsh (irregularly flooded), and transitional salt marsh (that includes recently flooded dry lands)







5.3 Uncertainty GIS Maps

Possibly the most useful form of uncertainty-analysis results are GIS maps in which uncertainty results are broken down on a cell-by-cell basis. There were ten such map types derived for this project:

- **Percent Likelihood of Habitat Change**: For each cell in the study area, the percent likelihood that this cell has changed category since the start of the simulation. ("habitatchange" suffix.)
- **Probability that the cell is a coastal marsh**: This map can assist in identifying potential locations for marsh migration. A coastal marsh is defined as a cell that is flooded by tidal waters, including low marsh (regularly flooded marsh), high marsh (irregularly flooded marsh), dry land recently converted to marsh (transitional marsh), and tidal-fresh marshes. (iscoastalmarsh" suffix.)
- **Probability that an existing marsh cell will remain a coastal marsh:** This category tracks the fate of currently existing coastal marsh. This is the same as the coastal-marsh probability, but does not include areas that were not coastal marshes at the simulation start time. ("existingmarsh" suffix.)
- **Probability that a cell that is not a coastal marsh will become a coastal marsh:** This category tracks the potential for marsh migration by identifying land that could be inhabited by coastal marsh in the future. This is the same as the coastal-marsh probability above, but exclusively includes areas that were not coastal marshes at the simulation start time. ("newcoastalmarsh" suffix)
- **Probability that a land category will have converted to open water:** Likelihood a cell that is not water at low tide (MLLW) will become open water at that tide at the map date. ("landtoopenwater" suffix)
- **Probability that the cell is below the salt elevation** (i.e., flooded once every 30 days): This map shows the possibility that each cell will be below the once every 30-day inundation height and connected to open water at the given time step. ("belowsaltev" suffix)
- **Probability that the cell is a beach** This category tracks the fate of existing and new beach cells—estuarine beach or ocean beach categories. ("isbeach" suffix)
- **Probability that developed land will become flooded:** The percent likelihood that a developed dry land cell will be regularly flooded at the map date. ("Isfloodeddev" suffix)
- **Probability that developed land will become flooded:** These maps track flooded developed land as above, but they exclude development that was flooded at time zero. For example, bridges appear flooded at time zero because their assigned bare-earth elevation is that of the water below. ("newfloodeddev" suffix)
- **Probability that cell is flooded every 30 days:** These maps delineate the line between regularly flooded lands and open water and locations that are tidally flooded less than once every 30 days. ("belowsaltelev" suffix)

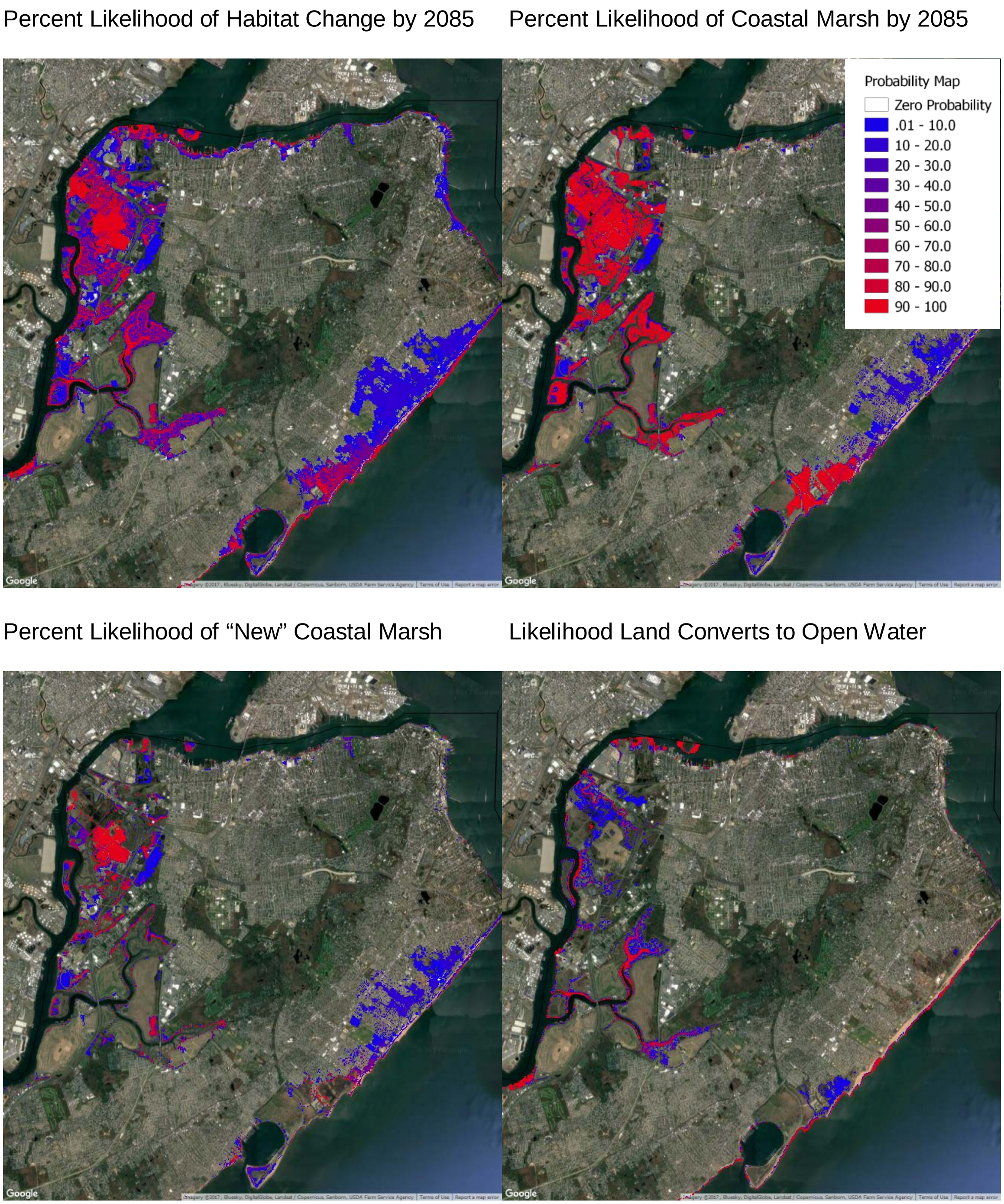
Figure 25 shows examples of four of these uncertainty maps for Staten Island, NY. All GIS uncertainty-map outputs and associated metadata for this project are available at the project website (http://warrenpinnacle.com/prof/SLAMM/NYSERDA2015).

The new coastal marsh maps provide a useful visualization of wetland migration pathways. These maps account for both the location of potential marsh habitation and the likelihood that these locations will contain marshes at multiple future dates. In this way, the most important regions for conservation or easements can be identified. Figure 26 is a detail map illustrating some examples of potential marsh-migration pathways in Nassau County.

Figure 25. Four examples of 2085 uncertainty maps from Staten Island Study Area

Red areas indicate high probabilities

Source: Satellite imagery from Google.

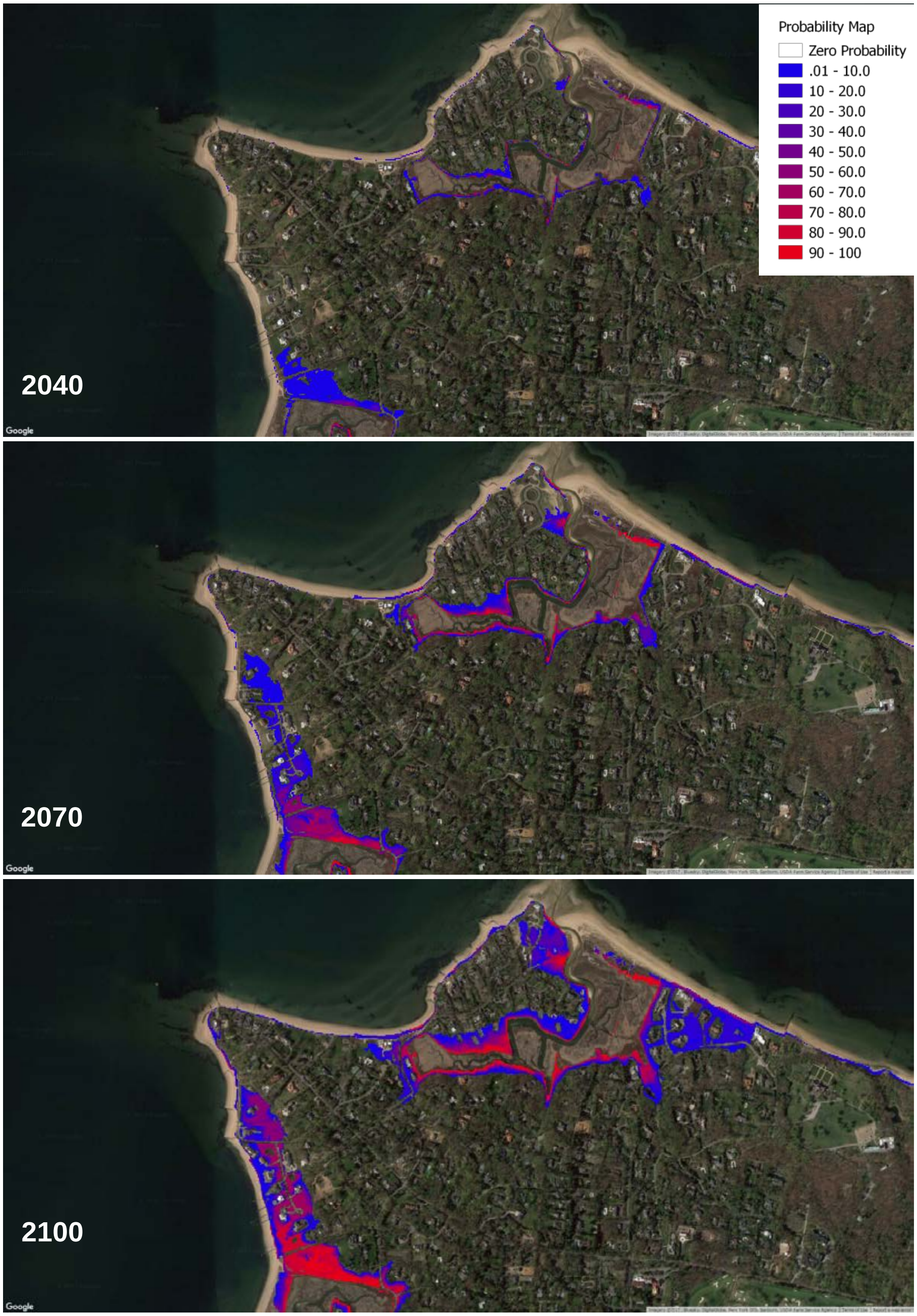


The probability maps in Figure 26 show the likelihood that a new marsh will migrate to the existing cell if that land is conserved or made available.

Figure 26. Example of potential marsh migration pathways at Sands Point in Nassau County

These probability maps show the likelihood that a “new marsh” will migrate to the existing cell if that land is conserved or made available.

Satellite imagery from Google.



6 SLAMM Google Earth Tool

For Google Earth users, a new data set has been created for this project that provides a user-friendly interface to illustrate the fate of current and potential-new marsh habitats. This tool allows users to zoom in on areas of interest without requiring GIS expertise.

Two layers are available on the tool, an “existing marsh” layer and a “new coastal marsh” layer. The existing marsh layer is designed to describe the fate of currently existing marsh in the future given uncertain SLR. Will the current marsh thrive or be permanently inundated by future water levels? The new coastal marsh layer is designed to describe locations where marsh may migrate in the future but does not exist now. This distinction is important for planning as dry lands may not be made available for marsh migration if they are private lands or have public uses. Barriers may be built, or fill could be added to prevent marsh migration.

Maps are shown as probabilities given uncertainty in future SLR and marsh sedimentation responses. A high probability of marsh existence means that a marsh is likely to exist given all these uncertainties. The SLAMM Google Earth Tool may be downloaded at the following URL: http://warrenpinnacle.com/prof/SLAMM/NYSERDA2015/GoogleEarth.html Once Google Earth is installed on a user’s machine, they may view the KML files available at the link above. A new list of data is then shown at the left of the Google Earth interface (Figure 27). This product is not yet compatible with the new browser-based "Earth for Chrome."

Rendered maps show the predicted fate of areas covered by marsh in 2008 (the date of the available initial land cover layer) and the potential location of new marshes given an uncertain future rate of SLR. The maps provide spatial information of the probability that an area covered by marsh in 2008 is still a marsh (probability maps for existing coastal marsh systems) and an area that was not in 2008 will become marsh (probability maps for potential new coastal marsh).

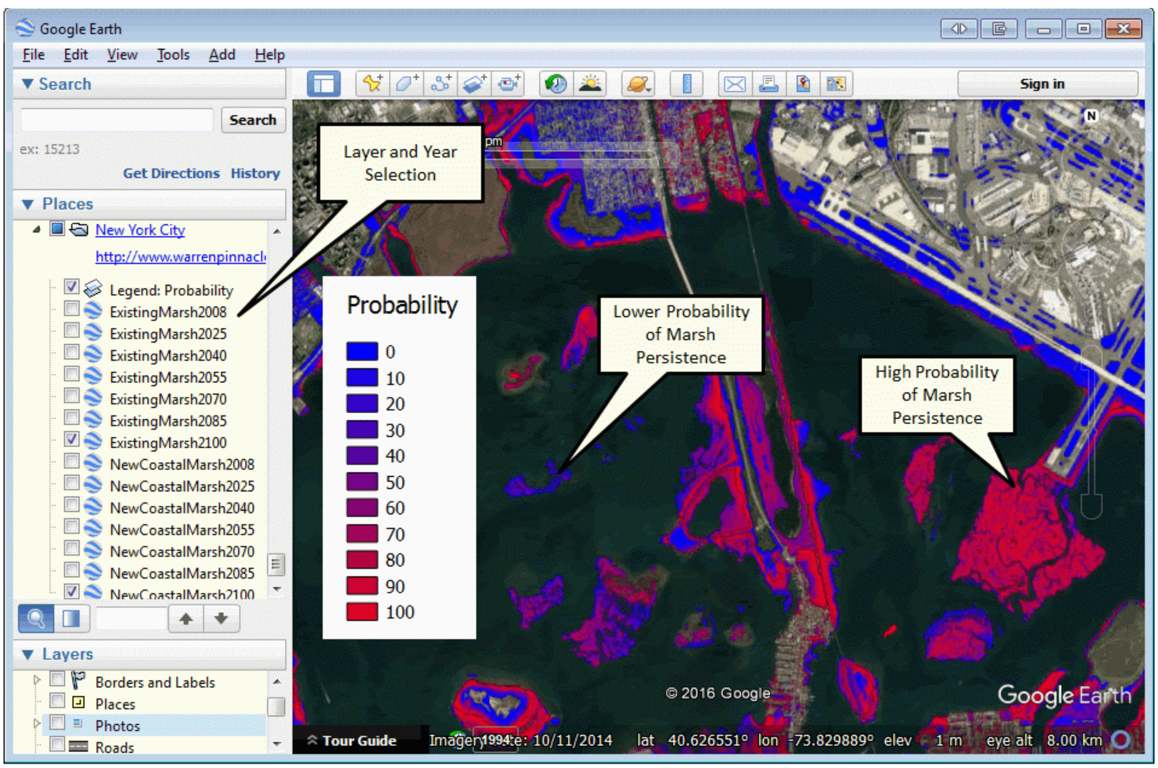
Probability maps were obtained by running the model for two hundred realizations with input parameters and SLR scenarios sampled from assigned uncertainty distributions that reflect measurement errors and/or lack of certainty (section 5 of this report). A high probability means that the marsh is not likely to be destroyed at that time despite uncertainty in SLR estimates and other input parameters. Low probability means the opposite.

Similarly, the model also looks at the potential migration of marshes under uncertain conditions. A high probability means new marshes are very likely to colonize the parcel in question and a low probability means the opposite. Zero percent probability is not visible (shown as transparency) such as on developed lands, high lands, or open waters.

Layers are labeled as "ExistingMarsh" and "NewCoastalMarsh" with relevant dates. An "existing marsh" layer with a date of 2025 would show the "probability that a marsh that exists on current wetland maps layers will continue to exist in the year 2025" A "new marsh" layer with a date of 2025 would show the "probability that this location will be a zone that new coastal marsh can migrate into." In other words, the “new marsh” layer can be used to define marsh migration pathways so that plans can potentially be made for land acquisition or protection.

Within these model results, SLAMM does not predict that marshes will inhabit currently-developed lands (within the accuracy of the development data layer used). Model results are available for 2008 (model prediction of current conditions also called "time zero") along with projections for 2025, 2040, 2055, 2070, 2085, and 2100.

Figure 27. Screen capture from the SLAMM Google Earth Tool



7 Results: Adaptation strategies

The uncertainty maps described in Section 5.3 were produced for each of the adaptation strategies considered (see Section 2.10 for the detailed description of the adaptation strategies). These uncertainty maps allow users to evaluate the potential benefits of each management strategy. An example of the use of these maps is presented here for the “Thorne Preserve and Gardiner County Park” in Suffolk County as shown in Figures 28, 29, and 30.

Figure 28. Thorne Preserve and Gardiner County Park area in Suffolk County

Source: Map data from Google

Figure 29 shows the current land cover of the area and SLAMM projections under the highest SLR scenario in 2100. These results suggest that a significant area has the potential to become regularly inundated by 2100. However, no information is provided on how likely this area is to become inundated or whether it will become a marsh rather than open water. A better knowledge of the likelihood of marsh establishment and persistence is required to evaluate the different marsh-conservation strategies. The probability maps for each different strategy can provide this information.

Figure 29. Current land cover

Maximum footprint of predicted areas to become regularly flooded marsh by 2100 (right)

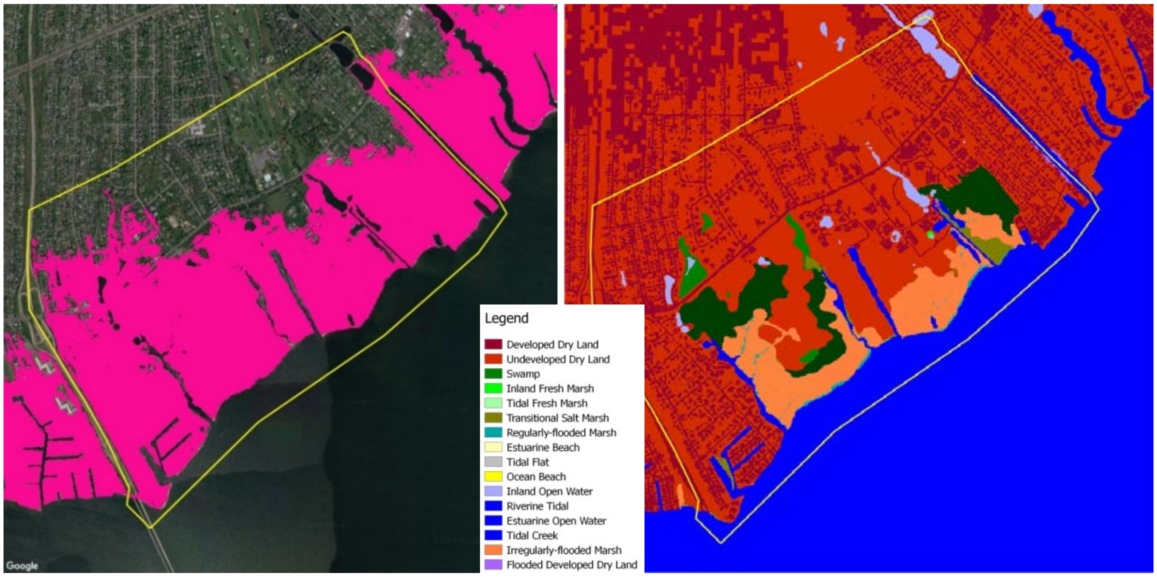


Figure 30-(A) is a probability map showing the likelihood of marsh presence at 2100. In this panel, marshes have been allowed to migrate to all dry land—undeveloped or developed. This is the strategy that provides the highest future marsh area. In panel 30a, one can see that marsh probability varies spatially, with the highest probability in the center of the parcel.

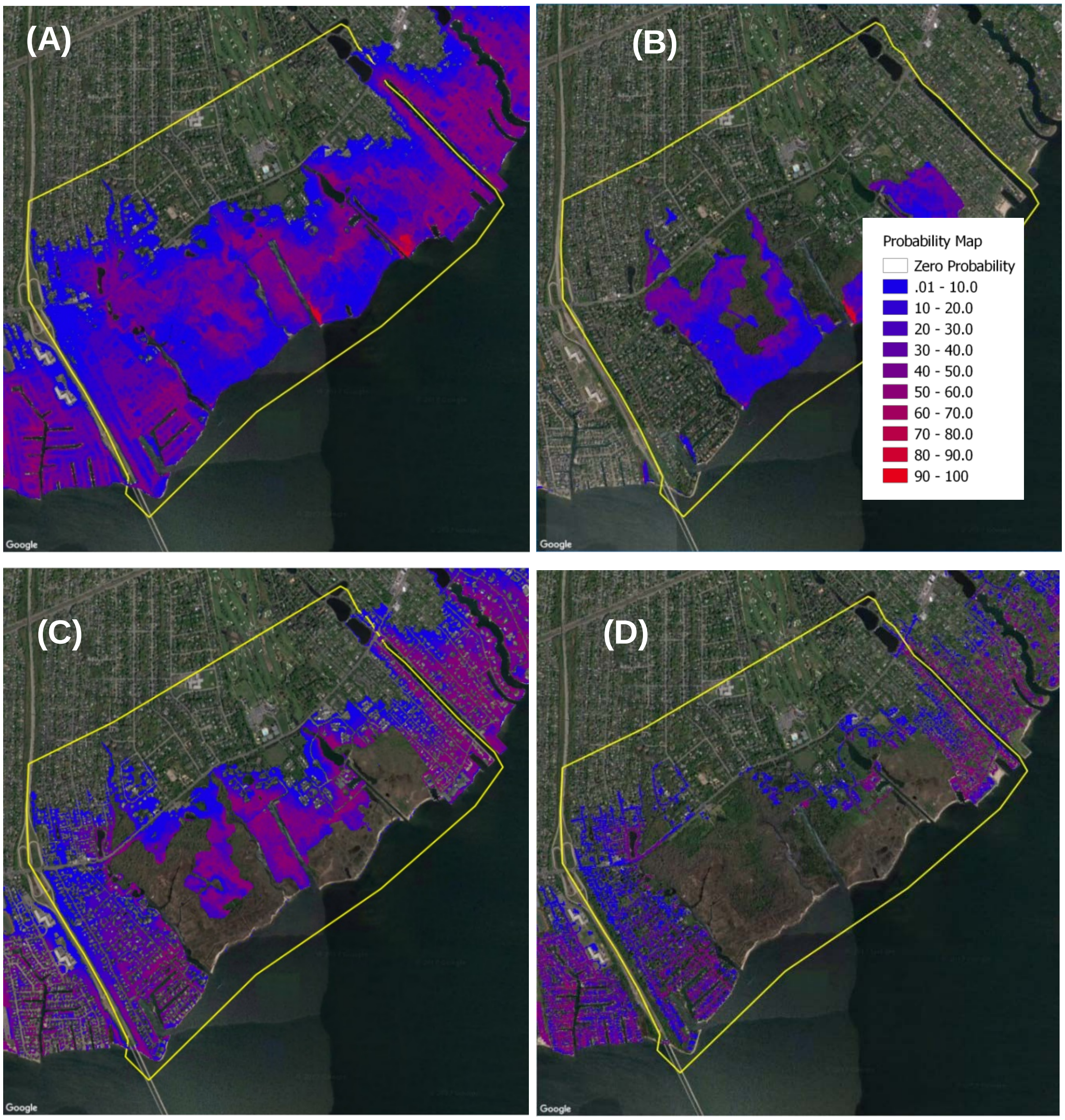
By looking at the other strategies, one can understand their different contributions to the projected marsh area and better evaluate each strategy's effect on overall marsh conservation. Figure 30b shows the projected fate of the current marsh footprint, obtained by running a strategy in which no marsh migration is allowed. It is evident that the current marsh footprint is likely to be significantly reduced, especially in the areas with proximity to open water. Therefore, if marsh is not allowed to migrate, significant losses of ecosystem services are likely to be experienced at this site.

Figures 30c and 30d provide the spatial probability of "new marsh" establishment when marsh is allowed to migrate to undeveloped and developed areas, respectively. Figure 30c shows that some dry areas have a great potential to accommodate marsh establishment if properly protected (in this example case, these areas may be already protected as they may be part of the preserve/park). Both figures also show that some developed residential areas around the preserve/park may have a high probability for marsh migration if this is allowed. In this case the costs to purchase such lands may be prohibitively expensive, but planners may wish to start considering these options. For example, one could use the maps shown in Figure 30 to identify and rank the residential parcels onto which marsh migration is most likely.

Thin-layer deposition and marsh restoration probability maps have also been produced, though they are not pictured here.

Figure 30. Probability maps for marsh establishment at 2100

All maps show the probability of a site's being a tidal marsh in 2100 under different adaptation scenarios: (A) Marsh migration to undeveloped and developed dry land; (B) No marsh migration (current marsh fate only); (C) Marsh migration to current undeveloped land; and (D) Marsh migration to current developed land. (Satellite imagery from Google).

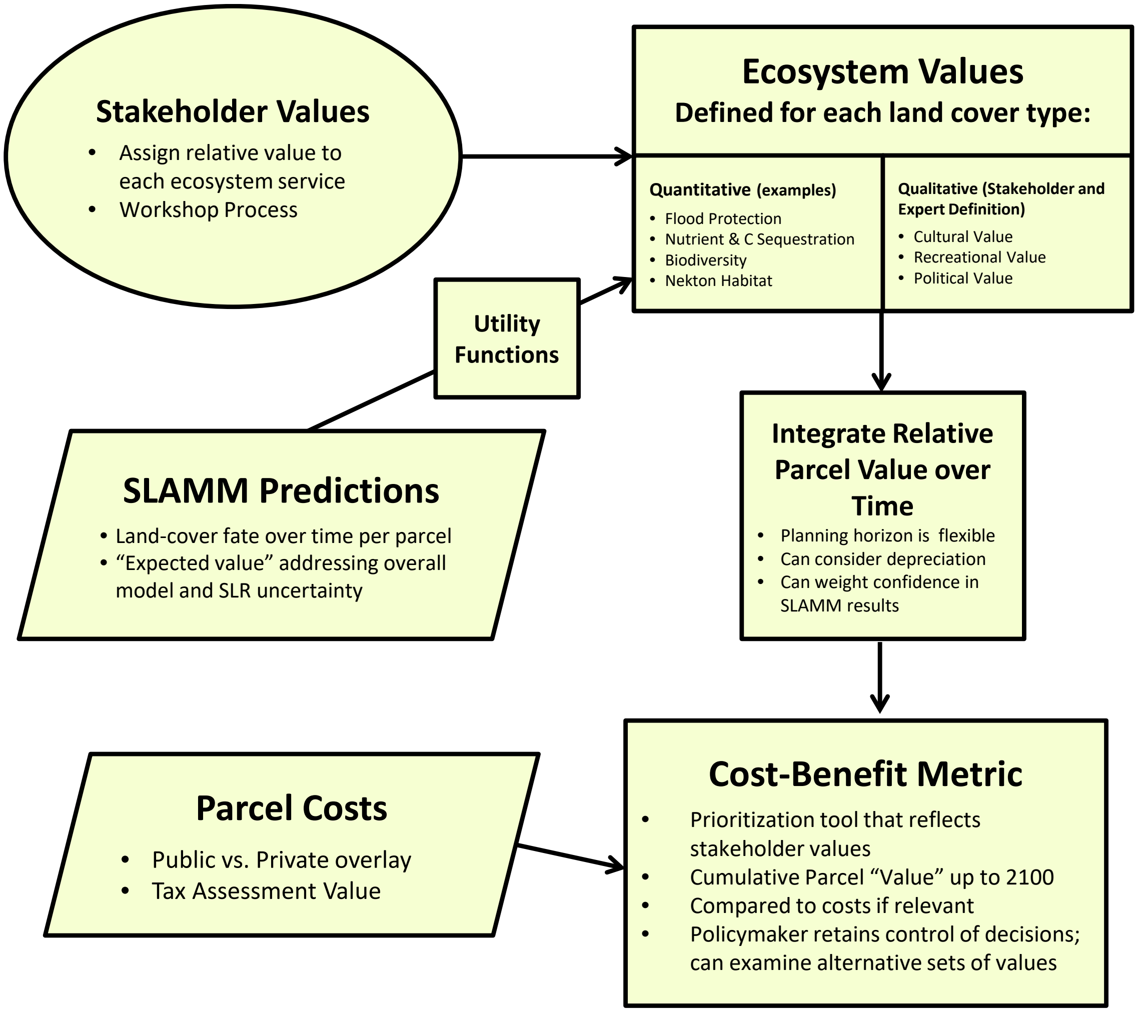


8 Dynamic Marsh Management Tool

Conservation planning and management under changing climate conditions, particularly sea level rise, can be complicated by the wealth of data available and multiple policymaking goals. Ideally, a manager could evaluate the relative benefits of adaptation strategies and maximize wetland benefits while considering uncertainty both in future sea-level rise, and dynamic marsh response. The DMMT is designed to consolidate the extensive data provided by SLAMM adaptation strategy runs, particularly those completed as uncertainty analyses. The DMMT integrates these model results over time along with the costs of adaptation strategies and stakeholder values that define the relative benefits of adaptation strategies (Figure 31).

Model results are combined with ecosystem-valuation assessments from stakeholders that define a set of relative “wetland benefits.” This approach was inspired by work produced by Catalysis Adaptation Partners LLC for the Maine Department of Agriculture, Conservation, and Forestry (Merrill and Colgan 2014). Stakeholders enumerate site specific wetland benefits that can include nature-centered benefits (such as nekton habitat preservation) and human-centered benefits (such as recreation and flood protection). Model results and stakeholder values are then linked together using utility functions that characterize the relationship between defined wetland benefits and geometric metrics such as “marsh type,” “marsh area,” “marsh edge,” and “marsh width.” Expected values for each site’s wetland benefits can then be projected into the future and compared to the estimated costs for each adaptation strategy. Estimates of optimal marsh-management strategies are produced by maximizing the “wetlands benefits per estimated costs.”

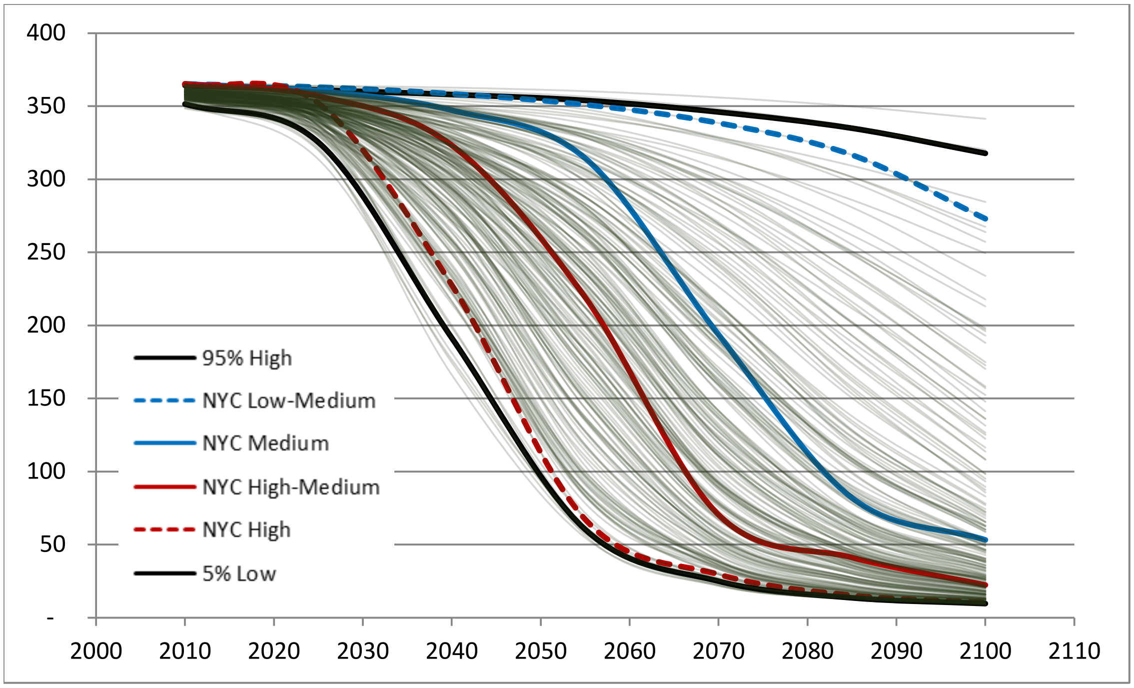
Figure 31. Detailed Schematic for the Dynamic Marsh Management Tool



Aggregating the hundreds of results provided by uncertainty analysis is completed using the economic concept of "expected value." An expected value provides an estimate of future value given a set of uncertain outcomes. It is calculated as the value of each occurrence multiplied by the probability of its occurrence. For example, Figure 32 shows a set of 200 uncertainty analysis runs, each assumed to have equal probability. The expected value of marsh acres would be the sum of marsh acres for each of these uncertainty-analysis runs divided by its likelihood of occurrence (one over the number of iterations run).

Figure 32. Example uncertainty-analysis results for high marsh plotted as light grey lines

Overall model confidence intervals are plotted in thick black lines and various SLR scenarios are shown as colors.



8.1 Stakeholder Input

To complete this project, a team of stakeholders and experts was convened to define and provide feedback on several topics. First, the team developed an "ecosystem services list." This list helps answer the question "what do we value about these wetlands?" The ecosystem services that were defined for this project were as follows:

- Nutrient sequestration (C, N, P)
- Recreation
    - Wetland
    - Natural services to under-served communities
    - Nekton habitat proximate to fishing areas
- Habitat
    - Nekton habitat
    - Habitat connectivity
    - Bird habitat

- Wave attenuation/Flood damage reduction
- Political/Cultural/Historic value
- General preservation of natural areas

A full description of these ecosystem services and how they were defined and interpreted for this project can be found in Appendix G of this document.

The second area in which stakeholders, literature, and experts provided insight was the definition of "utility functions." Utility functions are the relationship between "ecosystem services" and the quantity of marshes, marsh types, or other geometric metrics. Utility functions are discussed in more detail in section 8.3.1 below.

Then, stakeholders were polled about the relative value that they give to each of these ecosystem services. In other words, they were asked, "of the defined services, which do you currently value more than others?" This was done by providing a numeric percentage value to each service (normalized to 100% by the software). The tool can identify optimal actions given each individual user's ranking or an aggregate of all stakeholders polled can be utilized.

Finally, stakeholders poll results, spatial data, and expert feedback quantified the site-specific strengths and weaknesses for each site relative to each ecosystem service identified. Essentially, it was ascertained "which sites currently offer specific services based on their location and the health of the ecosystems." For example, a marsh that is not proximate to developed lands offers fewer wave attenuation benefits than one which is directly protecting valuable infrastructure. A marsh that is low density would be expected to sequester less carbon or nutrients than the same acreage of a thriving, higher-density marsh. A marsh that has a boardwalk and is next to a population center will offer more recreational and educational benefits than a marsh island that is difficult to access.

Taking these forms of stakeholder input into account, and using the SLAMM uncertainty analysis results, the model can then calculate a total "ecosystem services" utility for a site for each year and these benefits can be aggregated over a future planning horizon as well. These calculations provide the benefit side of a cost-benefit analysis for each potential adaptation strategy being considered.

8.2 Mathematical Details

8.2.1 Site Utility Calculation

The utility function is calculated such that the first-year utility for any particular site could be a maximum value of 100 (if each utility function was maximized). The utility function calculated is relative to other sites being examined in a given simulation but should not be compared from one DMMT implementation to the next.

$$\boldsymbol{Utility_{site,year}} = \sum_{u=1}^{n\,utils} \left(\sum_{s=1}^{n\,sims} \left(\frac{1}{n\,sims}\right) (\boldsymbol{Discount_{year}})(\boldsymbol{Utility}_{s,y,u,si})(\boldsymbol{SW}_{si\,norm})\,(\boldsymbol{ERR}_{u\,norm}) \right)$$

where:

$Utility_{site,year}$ = total utility calculated at a site in a given year (unitless);
n utils = number of utility functions;
n sims = number of uncertainty-analysis simulations;
$Discount_{year}$ = discount rate for year (unitless);
$Utility_{s,y,u,si}$ = the normalized utility function result for a given simulation, year, utility type, and year (unitless);
SW_{norm} = normalized site-specific weight for this utility (unitless);
$ERR_{u\,norm}$ = normalized ecosystem service relative rank for this utility (unitless).

$$Utility_{s,y,u,si} = \frac{Utility\,fn.}{UtilNorm_u}$$

where:

$Utility_{s,y,u,si}$ = the normalized utility function result for a given simulation, year, utility type, and year (unitless)
Utility fn. = interpolated result of user-defined utility function based on marsh quantity or geometric metric (for the given year at the given site)
$UtilNorm_u$ = normalization quantity (see equation below; defined to produce a maximum first-year utility sum of 100 for any site)

$$\boldsymbol{SW_{si\,norm} = 100 \left(\frac{SiteWeight}{\sum_{s2=1}^{n\,sites} SiteWeight_{s2}}\right)}$$

where:

$SW_{si\ norm}$ = normalized site-specific weight for this utility (0-100);
$SiteWeight_{si}$ = user input site weight for site in question

$$\boldsymbol{ERR_{u\ norm} = 100\left(\frac{ERR_u}{\sum_{u2=1}^{n\ utils} ERR_{u2}}\right)}$$

where:

$ERR_{u\ norm}$ = normalized ecosystem service relative rank for this utility (0-100)
ERR_u = user input ecosystem service relative rank for utility in question

$$\boldsymbol{UtilNorm_u = \sum_{s=1}^{n\ sims}\left(\frac{1}{n\ sims}\right)(Utility\ fn.)\left(\frac{SW_{si\ norm}}{100}\right)(ERR_{u\ norm})}$$

where:

$UtilNorm_u$ = normalization quantity defined to produce an average first-year total utility of 100 for any site. In this manner, the relative utility across sites in the current condition will reflect stakeholder "ecosystem service relative rank" valuations
n sims = number of uncertainty-analysis simulations
Utility fn. = interpolated result of user-defined utility function based on marsh quantity or geometric metric (for the given year at the given site)
$SW_{si\ norm}$ = normalized site-specific weight for this utility (0-100)
$ERR_{u\ norm}$ = normalized ecosystem service relative rank for this utility (0-100)

Because of the current-date normalization, ecosystem services relative ranks should be input based on the ***current-date*** relative value for the marsh systems being evaluated. In other words, "define the relative importance of the wetland benefits being offered by this suite of marshes now, and the tool will estimate the change in those benefits over time as a function of SLR and historic marsh loss rates.

8.2.2 Land Cover Loss Rates

Historical marsh loss rates not assumed to be from sea-level rise related factors may be projected into the future as well. This would mean marshes that are rapidly declining (for non-SLR related reasons) would be expected to continue this decline, whereas marshes that have been historically shown to be robust would continue that trend as well (prior to future SLR related losses).

To calculate the marsh-loss rate, this simple model first calculates land-cover loss rates due to SLR only based on SLAMM predictions. Next, these loss rates are modified by adding historic marsh loss rates. Although conceptually simple, the requirement to conserve overall land cover area requires the consideration of gains and losses for each land-cover class involved in the process.

8.2.2.1 General land cover changes due to SLR only

Undeveloped dry land: If $U(t_1)$ is the undeveloped land cover area at time t_1 and S_{UT} is the area loss to transitional marsh at time t_1, the general equation can be written as

$$\boldsymbol{U(t_2) = U(t_1) - S_{UT}(t_1)}$$

The last term is modeled as $S_{UT}(t_1) = R_{UT} * U(t_1)$ where R_{UT} is a loss rate, giving

$$\boldsymbol{U(t_2) = U(t_1) * (1 - R_{UT})}$$

Developed dry land (if allowed to convert to marsh) is very similar

$$\boldsymbol{D(t_2) = D(t_1) * (1 - R_{DT})}$$

Transitional Marsh

$$\boldsymbol{T(t_2) = T(t_1) + S_{UT}(t_1) + S_{DT}(t_1) - S_{TL}(t_1)}$$

where $S_{TL}(t_1)$ the area lost to regularly flooded marsh. Also, in this case, this loss is modeled as $S_{TL}(t_1) = R_{TL} * T(t_1)$ with R_{TL} the loss rate.

$$\boldsymbol{T(t_2) = T(t_1) * (1 - R_{TL}) + S_{UT}(t_1) + S_{DT}(t_1)}$$

Irregularly Flooded Marsh

$$\boldsymbol{I(t_2) = I(t_1) * (1 - R_{IL})}$$

Regularly Flooded Marsh

$$\boldsymbol{L(t_2) = L(t_1) + S_{TL}(t_1) + S_{IL}(t_1) - S_{LF}(t_1)}$$

where $S_{LF}(t_1)$ the area lost to open water. Also, in this case, this loss is modeled as

$S_{LF}(t_1) = R_{LF} * L(t_1)$ with R_{LF} the loss rate.

$$\boldsymbol{L(t_2) = L(t_1) * (1 - R_{LF}) + S_{TL}(t_1) + S_{IL}(t_1)}$$

Open Water

To maintain area cover balance, open water is calculated as a function of the change in all considered land-cover classes:

$$\boldsymbol{W(t_2) = W(t_1)} + \\ +[\boldsymbol{U(t_2) - U(t_1)}] + [\boldsymbol{D(t_2) - D(t_1)}] + [\boldsymbol{T(t_2) - T(t_1)}] + \\ +[\boldsymbol{I(t_2) - I(t_1)}] + [\boldsymbol{L(t_2) - L(t_1)}]$$

In this way, overall land-cover conservation is guaranteed despite potential model approximation errors and other land-cover change processes that are not considered.

8.2.2.2 Calculation of annual rate changes due to SLR

Assuming changes in marshes due to SLR are relatively slow, one can estimate loss/gain rates due to SLR on an annual scale, using SLAMM simulation projections at times t_1 and t_2 (generally 10–15 years apart).

Developed and undeveloped dry land loss rates

Assuming a constant annual loss rate and the model above, one obtains

$$\boldsymbol{R_{UT} = 1 -} \left[\frac{\boldsymbol{U(t_2)}}{\boldsymbol{U(t_1)}}\right]^{\frac{\boldsymbol{1}}{(t_2 - t_1)}} \qquad \boldsymbol{R_{DT} = 1 -} \left[\frac{\boldsymbol{D(t_2)}}{\boldsymbol{D(t_1)}}\right]^{\frac{\boldsymbol{1}}{(t_2 - t_1)}}$$

Where R_{UT} is the loss rate for undeveloped land and R_{DT} is the loss rate for developed lands.

Transitional marsh loss rates

For this land cover the calculation of annual loss rate due to conversion to regularly flooded marsh is complicated by the addition of new area previously classified as dry land. A simplifying assumption is that the annual land-cover change rate is constant between SLAMM simulation steps, given by " $\Delta T = [T(t_2) - T(t_1)]/(t_2 - t_1)$. From the state equation of transitional marsh, the annual loss rate estimate is:

$$\boldsymbol{R_{TL}(t+1) = 1 - \frac{T(t) + \Delta T - [S_{UT}(t) + S_{DT}(t)]}{T(t)}} \qquad \textbf{with} \qquad \boldsymbol{t_1 \leq t < t_2}$$

where R_{UT} is the loss rate for transitional marsh

Irregularly flooded marsh loss

For irregularly flooded marsh, the calculation of the annual loss rate is similar to that for dry land:

$$\boldsymbol{R_{IL} = 1 - \left[\frac{I(t_2)}{I(t_1)}\right]^{\frac{1}{(t_2 - t_1)}}}$$

where R_{UT} is the loss rate for irregularly flooded marsh.

Regularly-Flooded Marsh

The annual loss rate of regularly flooded marsh due to conversion to open water is similar to the estimate done for transitional flooded marsh:

$$\boldsymbol{R_{LF}(t+1) = 1 - \frac{L(t) + \Delta L - [S_{TL}(t) + S_{IL}(t)]}{L(t)}} \quad \textbf{with} \quad \begin{matrix} \boldsymbol{t_1 \le t < t_2} \\ \boldsymbol{\Delta L = [L(t_2) - L(t_1)]/(t_2 - t_1)} \end{matrix}$$

where R_{LF} is the loss rate for regularly flooded marsh.

8.2.3 Land cover changes including historic losses

Once the SLR land-cover loss rates have been estimated, a simple model can be produced to estimate the effects of historic marsh loss rates. For this model, an additional annual loss rate is included in the equations for transitional, irregularly and regularly flooded marsh. For example, if R_H is the historic loss rate, the regularly flooded marsh equation becomes

$$\boldsymbol{\tilde{L}(t_2) = \tilde{L}(t_1) * (1 - R_{LF} - R_H) + \tilde{S}_{TL}(t_1) + \tilde{S}_{IL}(t_1)}$$

All the area lost due to this historic loss rate is assumed to be converted to open water. Note that all the land-cover variables are now identified with a ~ because these quantities are in general different from the values due exclusively to SLR due to the cumulative effects of marsh historic losses on land cover predictions.

8.3 Ecosystem Services and Utility Functions

8.3.1 Utility Function Mathematical Details

Utility functions are defined to reflect the rate of change between a quantity of land-cover (or a geometric metric) and the benefits being supplied by the wetland. For example, the benefit from carbon sequestration can be considered a linear function of the amount of marshes that are sequestering carbon. If these marshes are twice as abundant, they can be assumed to have twice as much sequestration occurring.

The geometric metrics that are currently extracted from each defined marsh parcel are as follows:

- Predicted land-cover acreages for all SLAMM land-cover categories.
- The marsh to open water interface (meters). This is assumed to be proportional to nekton habitat.
- The non-fragmented area (unitless). This is defined to account for fragmentation for a site while also taking into account the size of the parcel being considered. Its mathematical definition is described below.
- The marsh width (meters). This is an accounting of the wave attenuation benefits that a marsh may provide.

Within the utility functions, the horizontal "*x* axis" is defined as the quantity of land cover or the geometric metric extracted from SLAMM uncertainty results, and the vertical "*y* axis" is defined as the quantity of wetland benefit being derived from that wetland or characteristic.

Utility functions are input in the Excel version of the tool as a curve on this *x/y* axis. The *x* axis may be defined as a single model category or can be a weighted average of several functions. For example, carbon sequestration is a function of tidal fresh marsh, irregularly flooded marsh (assumed to sequester carbon at 75% of tidal-fresh marsh) and regularly flooded marsh (assumed to sequester carbon at 32% of tidal-fresh marsh.) These initial ratios of nutrient sequestration were derived from the work of Loomis and Craft (2010).

The DMMT input is flexible with respect to the shape of utility functions, as well. Users can enter any number of *x* and *y* points and the model will interpolate between them.

To calculate the relative non-fragmented area of each marsh, a unitless "non-fragmented area" was defined. It is calculated as a function of the Edge Density function from the spatial FRAGSTATS pattern analysis program (McGarigal et al. 1994).

$$\boldsymbol{EdgeDensity} = \frac{\boldsymbol{Perimeter}}{\boldsymbol{WetlandArea}}$$

where:

Perimeter = marsh to open water interface in meters
WetlandArea = marsh area in m^2

The “non-fragmented” area is then defined as follows:

$$\boldsymbol{NonFrag} = \left(\frac{\boldsymbol{WetlandArea}}{\boldsymbol{10,000}}\right)\frac{\boldsymbol{0.8 - EdgeDensity}}{\boldsymbol{0.8 - 2\sqrt{\pi/WetlandArea}}}$$

where:

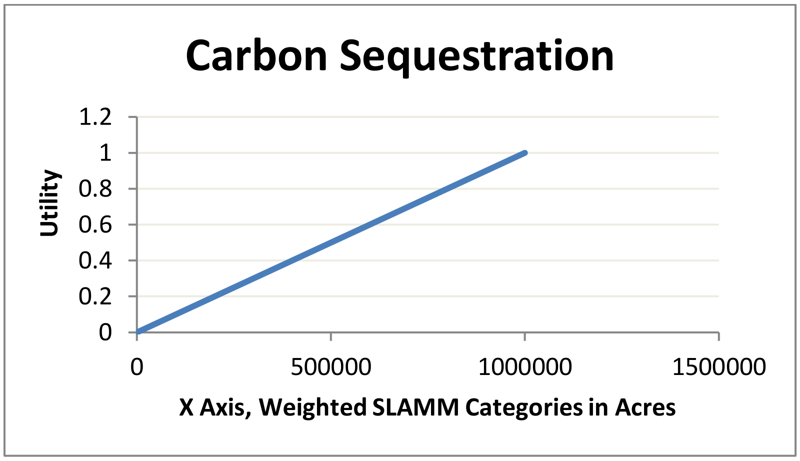
NonFrag	=	unitless non-fragmentation metric
10,000	=	square meters per hectare

All utility functions for this project were defined as linear and intersecting the origin. This means that when the *x* axis doubles, the *y* axis also doubles. When this is assumed, the definition of a utility function is simplified to be the determination of the appropriate metric (or weighted average) to place on the *x* axis. Some examples of utility functions that were defined for case studies follow.

8.3.1.1 Carbon Sequestration

The carbon sequestration *x* axis is composed of tidal fresh acres with a weight of 1.0, irregularly flooded marsh acres with a weight of 0.75 and salt marsh acres with a weight of 0.32 (Loomis and Craft 2010). The utility function is then a linear function (i.e., doubling the amount of marsh is assumed to double the quantity of carbon sequestration). The utility output is normalized to the current condition, so the scale of the *x* and *y* axis is not important in the definition of this, or any other utility function, so long as the *x* axis is not exceeded.

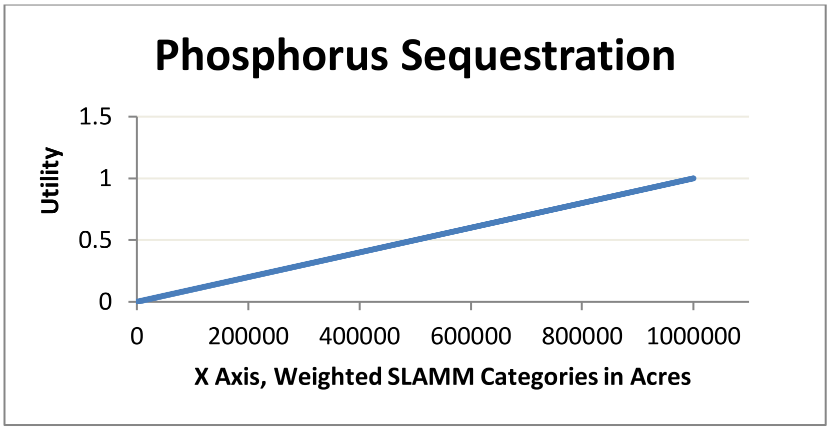
Figure 33. Defined utility function for carbon sequestration



8.3.1.2 Nutrient Sequestration

Similar to carbon sequestration, the x axis is composed of a weighted average of land-cover types depending on their capability to sequester nutrients. For nitrogen the weights were assigned as 1.0 for tidal-fresh marsh, 0.79 for irregularly-flooded marsh, and 0.29 for regularly-flooded marsh (Loomis and Craft 2010). For phosphorus, the weights were set to: 0.7 for tidal-fresh marsh, 1.0 for irregularly flooded marsh, and 0.30 for regularly flooded marsh. Site specific weights were used to estimate which marsh parcels are most important to nutrient sequestration due to their proximity to residential development or golf courses.

Figure 34. Defined utility function for phosphorus sequestration



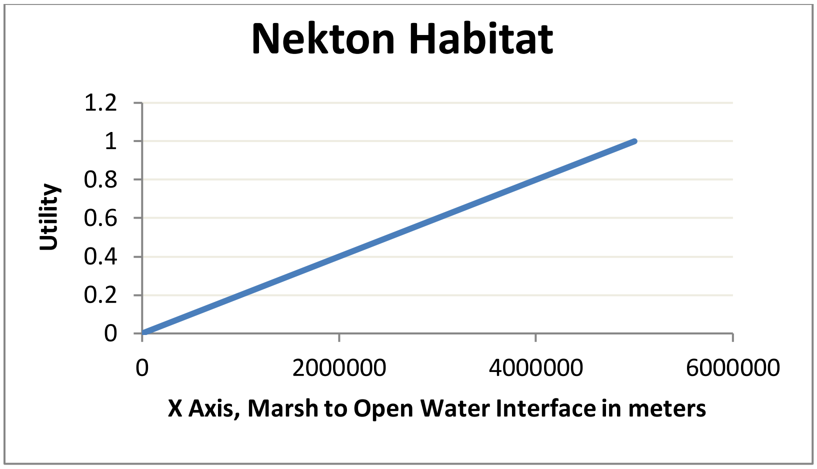
8.3.1.3 Marsh Land Recreation

The benefits of marsh land recreation are considered to be proportional to the amount of marsh land at a given site. Site-specific weights are important to represent proximity to populated areas and ease of access. Additionally, stakeholders suggested that irregularly flooded marsh (high marsh) is more important for bird watchers due to its importance as bird habitat. Therefore, high marshes were given a higher weight than regularly flooded marshes (1.0 vs. 0.25).

8.3.1.4 Nekton Habitat

Nekton habitat was assumed to be proportional to the marsh to open water interface that is extracted by SLAMM for each modeled site. This is because this interface is considered especially important habitat for nekton as compared to interior marsh (Peterson and Turner 1994).

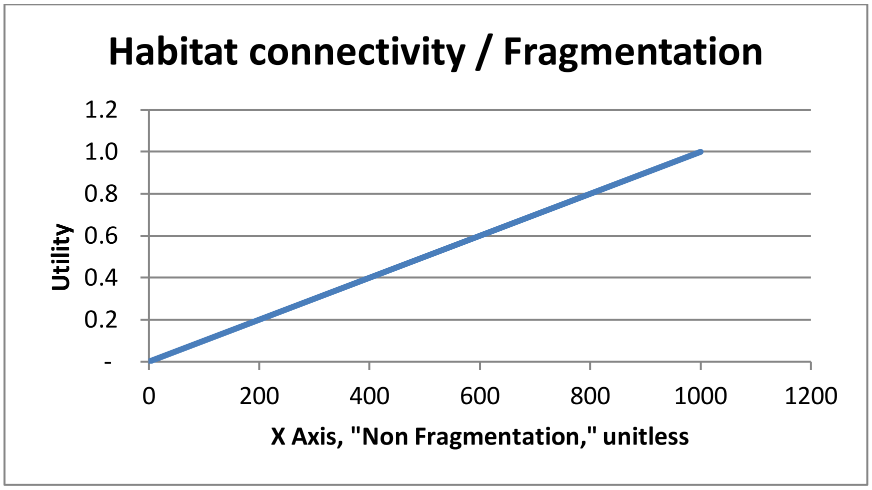
Figure 35. Defined utility function for nekton habitat



8.3.1.5 Habitat Connectivity and Lack of Fragmentation

Habitat connectivity was defined as a function of the non-fragmentation metric previously defined.

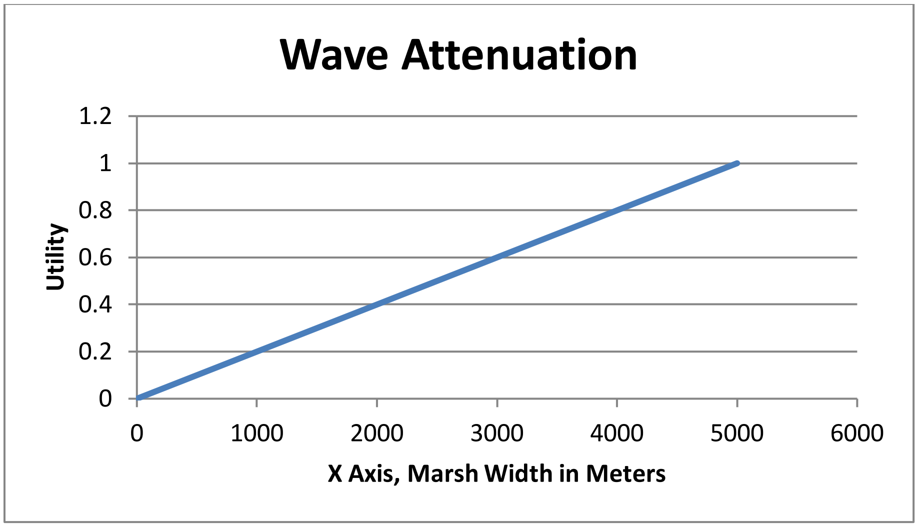
Figure 36. Defined utility function for habitat connectivity



8.3.1.6 Wave Attenuation

Wave attenuation was defined as a function of the marsh width adjacent to developed lands being protected. As a simple rule of thumb, the energy absorbed may be assumed proportional to the marsh width, though more complex models suggest a more complicated relationship to storm track, etc. (Wamsley et al. 2010). Site-specific weights are important to represent marsh proximity to development at risk of flooding.

Figure 37. Defined utility function for wave attenuation



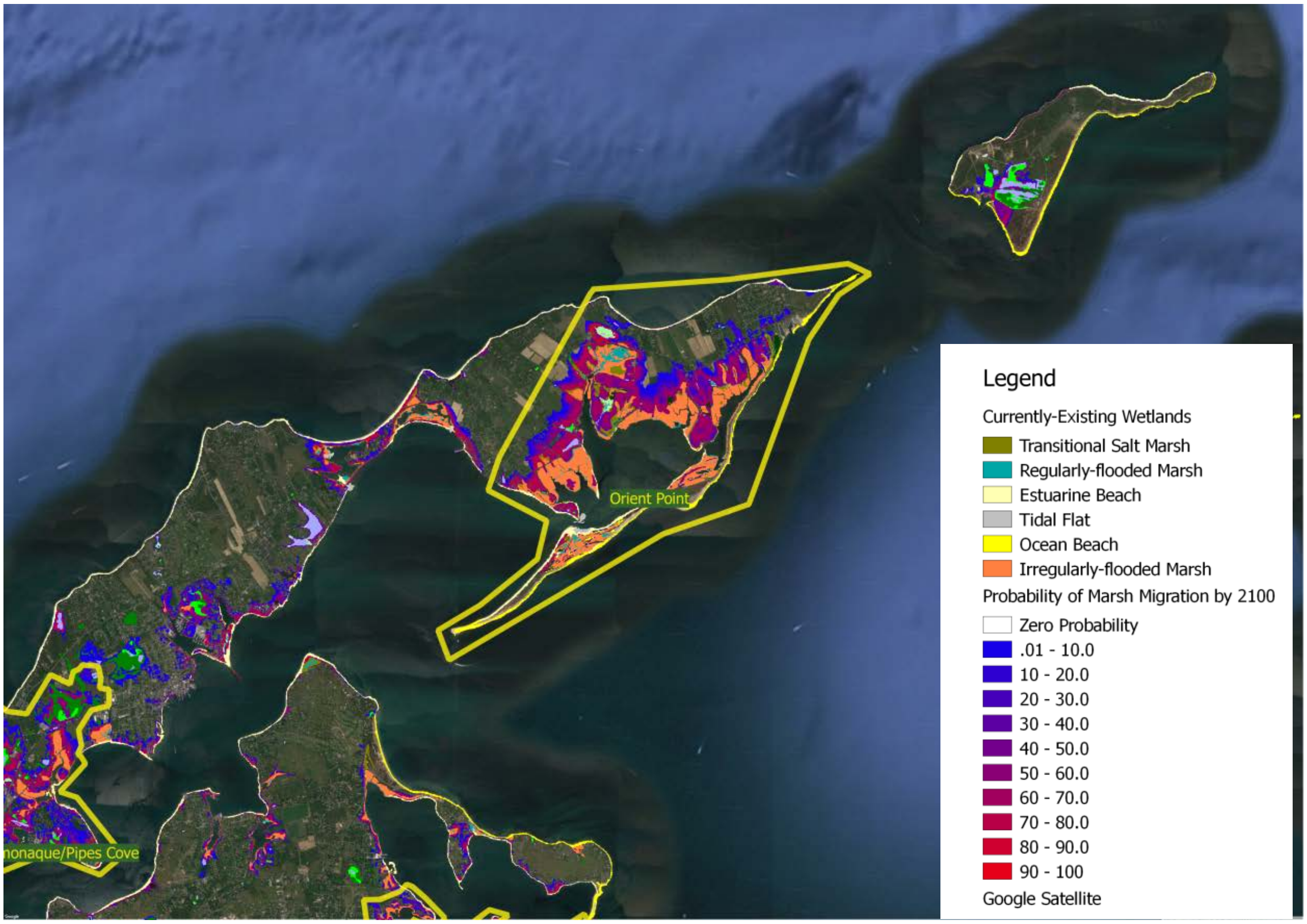
8.4 Selection of Sites

The DMMT allows users to break landscape-level model results into a set of defined marsh parcels so that the costs and benefits of adaptation strategies at each marsh system can be comparatively examined. For this project stakeholders defined sites that they were already managing and were identified by name. Stakeholder-provided shape files were then imported into SLAMM and adaptation-strategy uncertainty results were extracted for each defined site.

SLAMM results were also used to define the locations into which these existing marshes may migrate, and these zones were generally included in the defined marsh parcel (Figure 38). Appendices D-F present the sites selected in the New York City, Nassau, and Suffolk County study areas.

Figure 38. Defined marsh parcel for Orient Point in Suffolk County

Orange and teal colors show current marsh footprint and the blue to red gradient shows the likelihood that marsh will migrate into these lands by 2100.



8.5 Survey Administration

Along with two in-person meetings with stakeholders to gather the stakeholder input discussed in section 8.1, on-line surveys were utilized to gather relative values for ecosystem services and site-specific weights for the utility calculation. An example of such a survey is in Appendix C.

The team received strong feedback from users with regards to relative weights for ecosystem services; however, site specific weights were often left empty. Users cited their lack of site specific knowledge in many cases. For some ecosystem services, it can make sense to leave all site weights equal (such as carbon sequestration, in which one acre of a given marsh type may be assumed to sequester the same amount of carbon regardless of location). In other cases, site-specific weights are important (such as wave attenuation where some marshes are protecting infrastructure and other marshes are not.) Geographic data such as satellite imagery and GIS datasets can be used to provide this important detail in the tool.

An iterative Delphi survey process is another way to proceed to allow users to understand how their survey results affect the tool and record their preferences (Merrill and Colgan 2014). The Delphi method allows for multiple rounds of input from experts and stakeholders. Survey results (and the reason that they were chosen) are made transparent after each round.

8.6 Use of the DMMT

The DMMT is a Microsoft Excel-based tool with a Visual Basic computational engine. A complete User's Guide is available and can be found in Appendix B of this document. In addition, on the DMMT web page a tutorial has been produced to help users understand how to use the tool along with two video guides that show exactly where to click on the tool to answer the tutorial questions. In addition, a guide to add new SLAMM uncertainty-analysis results into the DMMT has been produced. All of these materials may be found on the project web page along with the DMMT spreadsheets and their underlying source code: http://warrenpinnacle.com/prof/SLAMM/NYSERDA2015/DMMT.html

The Excel platform allows for significant power and flexibility in terms of producing and customizing output graphics. One drawback to the Excel platform is that it is not "bullet proof" in terms of user input (in other words it is possible to enter a word where a number should be, and the model will not operate properly.) In addition, the tool relies on "pivot charts" to flexibly display model results and this is not supported in Excel for Macintosh operating systems.

A set of user tests was produced by Eastern Research Group, Inc. Based on feedback received from these tests, several important improvements were made to the model to maximize usability:

- A prominent status bar was added to clarify when the model is calculating.
- A success message was added after calculations were completed.
- Filtering options for charts and tables were made more prominent with call outs.
- Charts were combined into single Excel tabs to make them easier.
- The tool now defaults to opening on the instructions tab.
- A comparison function was added to allow users to compare new results to previous model results.
- Marsh-level terminology was clarified to increase understandability.

9 Case Study Results: Dynamic Marsh Management Tool

Three case studies were completed in the coastal New York study area. These case studies do not reflect a completed set of decisions using the DMMT tool but can provide insights on which marsh management actions might be most useful and cost effective given the cost and SLR assumptions within the model. All three case studies may be found on the DMMT web page: http://warrenpinnacle.com/prof/SLAMM/NYSERDA2015/DMMT.html

Prior to using the model to guide decisions, further research is advised, in particular on costs. These preliminary results, however, can be useful in defining which costs need to be more accurately estimated. The DMMT also provides an interface to evaluate the effects that costs will have on optimal decision making once estimates have been refined.

9.1 New York City

Six sites were selected for analysis in the New York City study area by NYC Parks and other stakeholders.

- Idlewild Inner and Outer
- Alley Creek, Queens
- Lemon Creek, Staten Island
- Pelham Bay Cove
- W.T. Davis
- Udall's Cove, Queens

Maps of these sites and additional descriptive details are in Appendix D.

Cost estimates of adaptation strategies were produced with the assistance of NYC Parks. Costs were aggregated across each defined wetland site. For migration onto adjacent land the marsh-migration footprint was determined using SLAMM uncertainty analyses. Next, this land was broken into four categories: “NYC Parks owned,” “other public land,” “private developed land,” and “private undeveloped land.” Undeveloped land owned by NYC Parks was assumed not to have an associated marsh-migration cost. For other categories, detailed high and low estimates of costs for land transfer, land acquisition, or purchase of land easements were developed (Table 16). For this case study, the mid-point estimate of costs between the high and low estimate was used.

To calculate the cost of thin-layer deposition, the total acres of regularly-flooded marsh available for thin-layer deposition at each site was calculated. This was then multiplied by a cost estimate per acre to apply 20 cm of dredge material onto each acre. The estimate of approximately $550,000 per acre was developed by NYC Parks and includes costs for stabilizing the construction entrance, erosion control materials, waterfowl barriers, sand placement, plug planting, permitting, and project management and engineering. The cost of marsh-edge restoration was estimated by NYC Parks to be $624,000 based on a similar set of calculations and estimates.

Table 16. Example of detailed cost estimates developed by NYC Parks

Acquisition, transfer, and easement cost estimates:

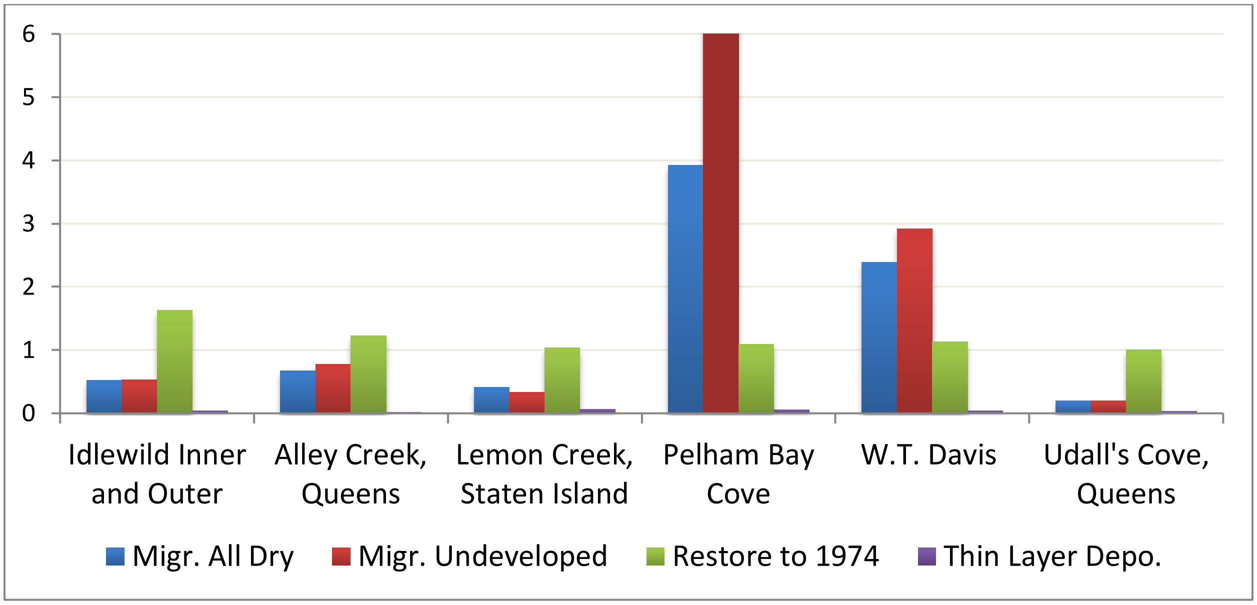
Acquisition or Easement on Private Property				
Item Description	**Unit**	**Quantify**	**High Cost**	**Low Cost**
Survey assumption from Capital	Acre	1	$ 4,000	$ 4,000
Guard rail	Linear Foot	500 / 150	$ 34,000	$ 10,200
Phase I Report	Each	1	$ 15,000	$ 15,000
Clean up debris	Lump sum	1	$1,800,000	$ 60,000
City Park Workers (CPW's) per year	Lump sum	1	$ 43,000	$ 3,000
Bobcat 300 with a grapple bucket	Lump sum	1	$ 85,000	$ 85,000
Uniform Land Use Review Procedure (ULURP)	Lump sum	1	$ 100,000	$ 50,000
Land Cost	Acre	1	$5,000,000	$1,000,000
TOTAL COST	**Acre**	**1**	**$7,081,000**	**$1,267,200**

Transfer or Easement High Cost				
Item Description	**Unit**	**Quantify**	**High Cost**	**Low Cost**
Survey assumption from Capital	Acre	1	$ 4,000	$ 4,000
Guard rail	Linear Foot	500 / 100	$ 34,000	$ 6,800
Phase I Report	Lump Sum	1	$ 15,000	$ 15,000
Clean up debris	Lump Sum	1	$1,800,000	$ 40,000
City Park Workers (CPW's) per year	Lump Sum	1	$ 43,000	N/A
Bobcat 300 with a grapple bucket	Lump Sum	1	$ 85,000	N/A
TOTAL COST	**Acre**	**1**	**$1,981,000**	**$ 65,800**

One intermediate product that can be produced with the DMMT is a graph that shows the acres of "persistent marsh" per million dollars spent. This graphic shows the number of acres of marsh that will persist in the study area through the year 2100 as compared to the "no action" scenario. A marsh that is predicted to persist for only 10 years will not be valueless but will have one-eighth the value of a marsh predicted to persist for the next 80 years.

Within this study area, the most cost-effective actions are to allow marsh migration in Pelham Bay and at W.T. Davis parcels (Figure 39). The high quantity of public and NYC-Parks owned lands at this site drive the low costs of this action. For other sites, marsh restoration becomes a cost effective alternative due to the higher land costs estimated at these locations.

Figure 39. Acres of "persistent marsh" per million dollars spent



One notable result from this case study (and most of the others), is that thin-layer deposition was not found to be a cost-effective strategy when looking at benefits aggregated through the year 2100. The primary reason for this is the feedback between marsh elevation, inundation frequency, and the marsh elevation-change rate, that was presented earlier in this document (Figure 7). When marsh lands increase in elevation they trap sediment less effectively. Over a decadal timescale, the marsh surface of an elevation-augmented marsh and a no-action marsh are predicted to equilibrate.

Another reason that thin-layer deposition is not predicted to be cost effective is that it has little effect under some of the SLR scenarios examined. Under low-SLR scenarios most regularly-flooded marshes are not predicted to be lost anyway, so there is no benefit to thin-layer deposition compared to the no-action scenario. Under the highest SLR scenarios, the regularly flooded marshes cannot keep up even with the initial 20 cm of sediment added to their surface. Again, there is little calculated benefit between the no-action and thin-layer deposition scenarios because the marsh is lost in either case.

It is important to note that this model application assumed a single application of 20 cm and tracked the effects over the next 85 years. Thin-layer deposition may have a very important role in keeping marshes viable in the short run and elevation capital may be supplemented by future applications. Additionally, this model did not try to optimize dredge placement to be cost effective. Instead, the model assumed that thin-layer deposition would occur on all regularly-flooded marshes that are accessible by barge or land.

While the “acres of persistent marsh” created by each action is an interesting metric, one central assumption within the DMMT, is that not all marsh acres have equal value to stakeholders. Based on marsh health, marsh type, and marsh location, different marshes provide differing degrees of ecosystem services. For this reason, a set of ecosystem services was defined by stakeholders (Appendix G) and stakeholders were surveyed to ascertain their relative ranking of ecosystem services and other site-specific considerations (Appendix C). The resulting ecosystem-service ranks are presented below in Table 17. Survey respondents indicated that habitat connectivity, flood protection, and nekton habitat have their highest priority, though if you combine nitrogen and phosphorus sequestration as “nutrient sequestration” that also ranks as a high priority to survey takers.

Table 17. Survey responses

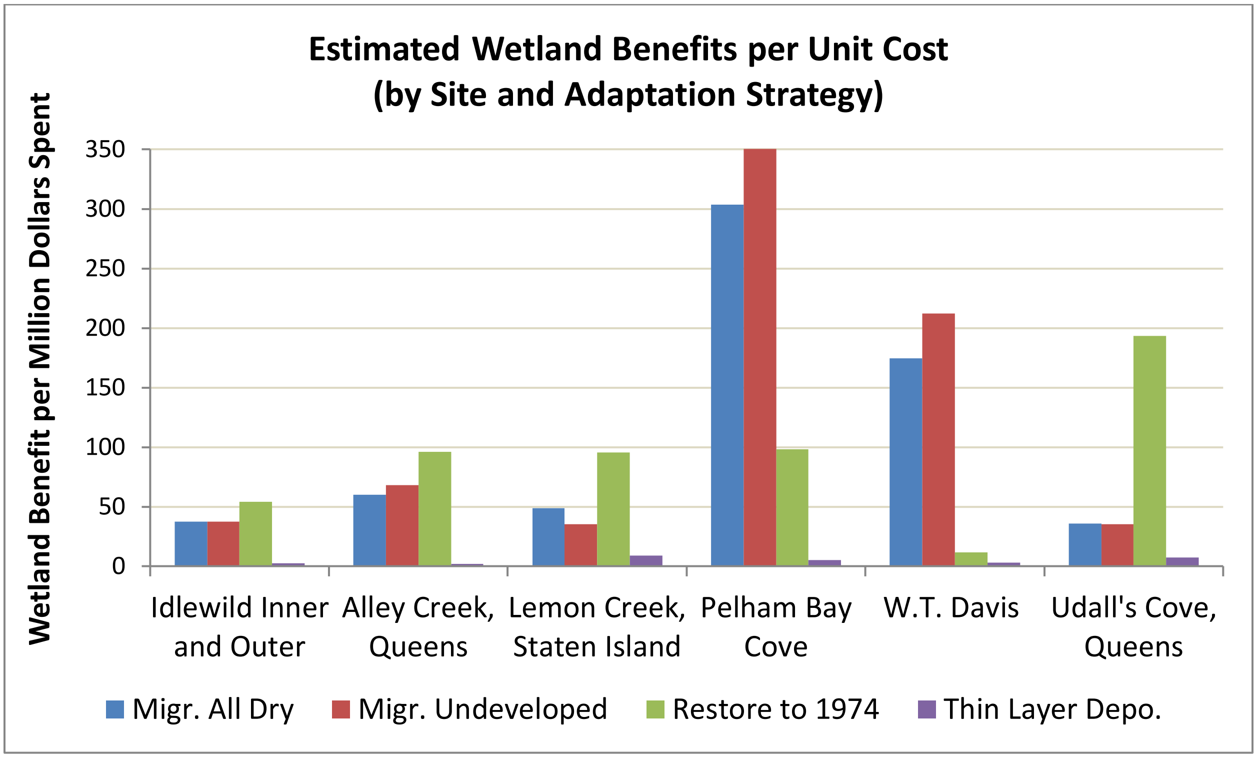
Survey asked participants to rank how important each of the following ecosystem services are to your decision-making process.

Answer Options	Response Average
Carbon Sequestration	7.7
Nitrogen Sequestration	8.3
Phosphorus Sequestration	7.6
Undeveloped dry land recreation utility	4.6
Marsh land recreation utility	4.6
Natural areas for underserved communities	8.2
Nekton habitat	13.8
Habitat connectivity/Fragmentation	18.0
Flood protection	14.2
Political/Cultural/Historic value	5.6
General preservation of natural areas	8.8

It is important to note that if an individual or an organization has different priorities than those listed in the survey , it is easy to go into the tool, change the rankings, and re-run the DMMT to see what impact this has on optimal decisions. Full instructions for how to do this and a tutorial are available on the DMMT webpage listed above.

When stakeholder preferences are incorporated into the DMMT, a different set of optimal management actions are predicted. Figure 49 is similar to Figure 39, but it graphs “wetland benefits” per million dollars spent as opposed to “persistent marsh acres.” The low cost of land at Pelham Bay Cove and W.T. Davis still makes marsh migration in those locations cost effective. However, marsh restoration at Udall’s Cove becomes much more competitive than before, and W.T. Davis is now the least cost-effective location for marsh restoration.

Figure 40. Wetland benefits predicted per million dollars spent



The reason for these predictions can be made clear by looking at the suite of additional figures available through the DMMT interface. For example, Figure 41 shows the components of each site's utility when aggregated over the study period (2016–2100). This figure suggests that while Udall's Cove, Queens has lower overall utility than the other sites examined (primarily due to its small size), it has larger-than-normal benefits in terms of "flood vulnerability reduction" due to the marsh location, the marsh width, and the infrastructure it is predicted to protect.

Figure 42 shows the predicted wetland utility for each site over time if no marsh migration is permitted. Note the average current (2016) utility for all sites is 100 wetland benefit units due to normalization. Predicted utilities for all sites drop over time, but especially at the two largest sites (Idlewild and W.T. Davis marshes). Figure 43 shows this same time series but for multiple adaptation strategies at a single site. Marsh restoration provides immediate wetland benefits at this site but drops down towards the no-action scenario ("no migration") by the end of the study period. Model results suggest that allowing marsh migration has the potential to provide continuous increases in wetland benefits. The wetland benefits predicted from a 20-cm thin layer deposition; however, are not significant when compared to the "no-action" scenario.

The DMMT tool is quite flexible in terms of graphing model results. All of the graphs produced here, and more are available by downloading the NYC version of the tool on the DMMT website.

Figure 41.Components of NYC site utility under restoration scenario

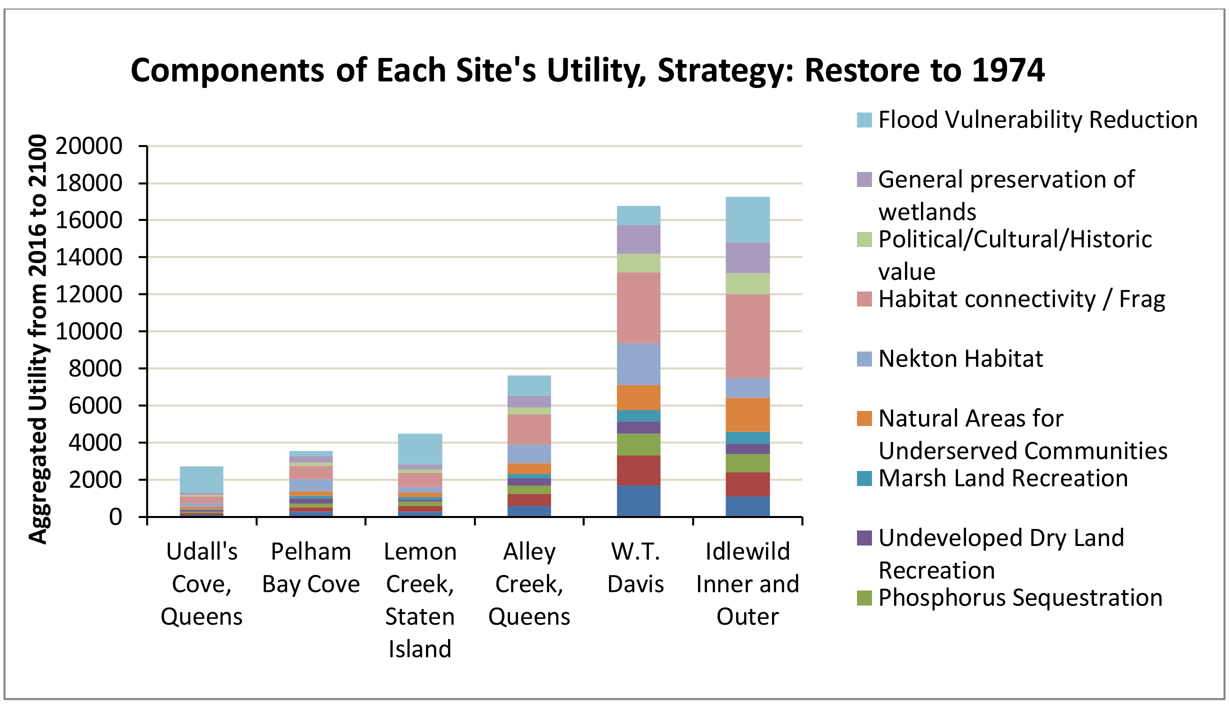


Figure 42. Time series of each NYC site's utility under no-action scenario

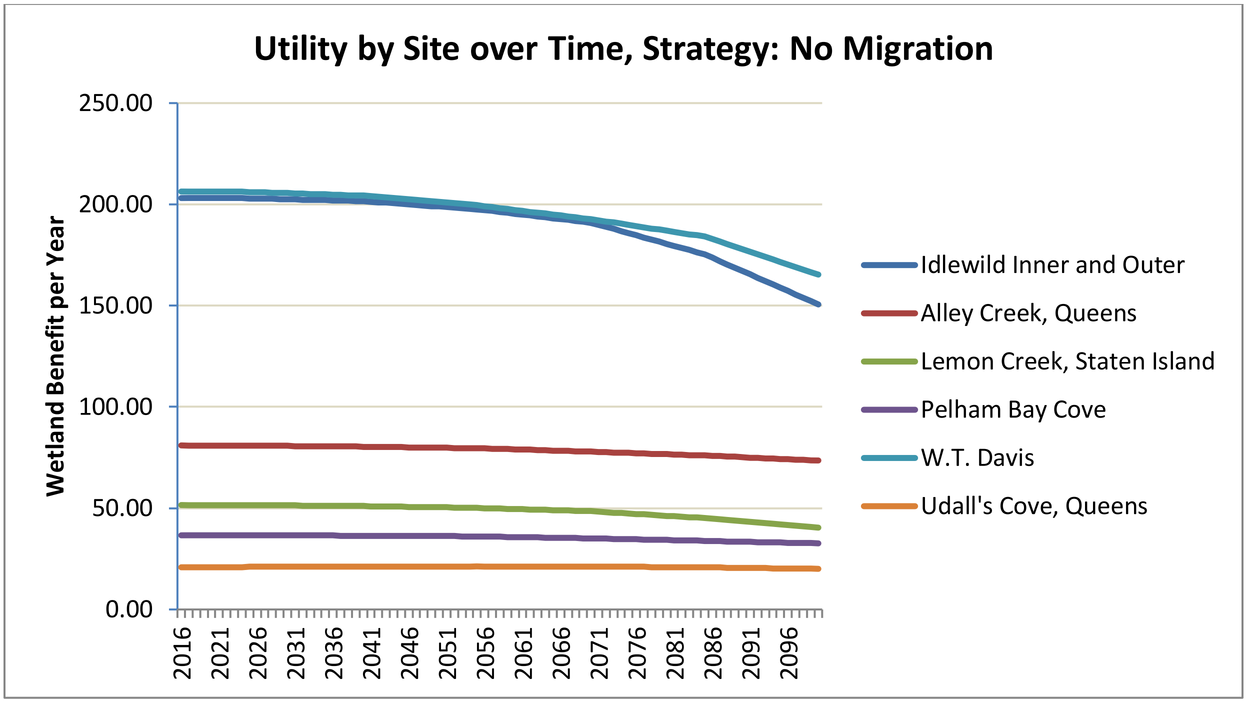
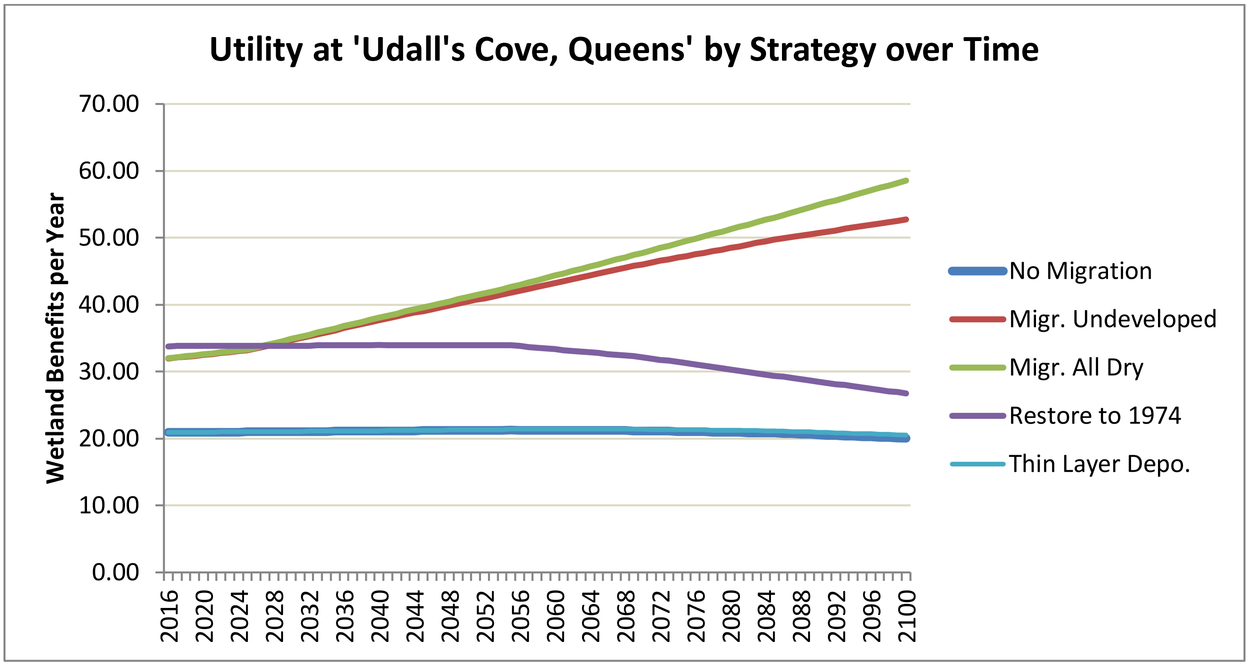


Figure 43. Time series of each adaptation strategy at Udall's Cove in Queens



9.2 Nassau County

Six sites were selected for analysis in the Nassau County study area by DEC staff and other stakeholders.

- Dosoris Pond/West Pond
- Lattingtown
- Hempstead Harbor
- Cuba Middle and East Island
- Marine Nature Study Area
- Seamans Neck Park

Maps of these sites and additional descriptive details are in Appendix E.

Cost estimates of adaptation strategies were estimated based on the costs produced by NYC Parks for New York City, and the same process to estimate costs was undertaken as described in the previous section. The survey in Appendix C was distributed to stakeholders and the resulting ecosystem-service ranks are presented below in Table 18. Survey respondents indicated that flood protection, habitat connectivity, and general preservation of natural areas (wetlands in this case) have their highest priority.

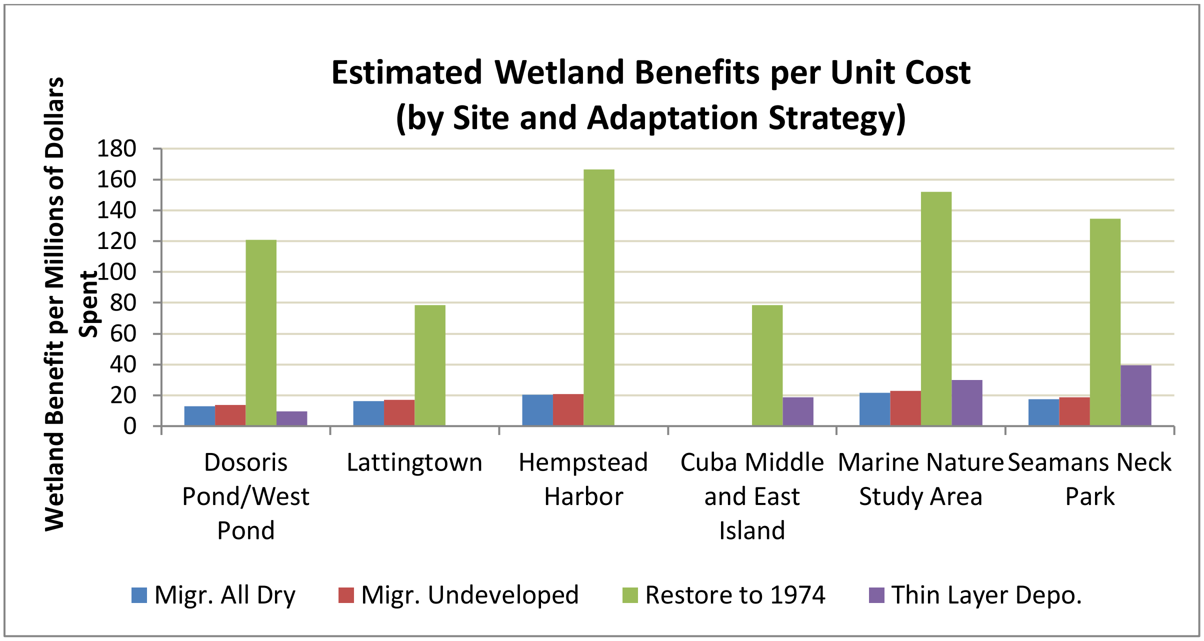
Table 18. Survey responses

Survey asked participants to provide the relative ranks for how important each of the following ecosystem services are to your decision-making process.

Answer Options	Response Average
Carbon Sequestration	7.2
Nitrogen Sequestration	7.2
Phosphorus Sequestration	7.2
Undeveloped dry land recreation utility	4.5
Marsh land recreation utility	9.1
Natural areas for underserved communities	9.1
Nekton habitat	9.1
Habitat connectivity/Fragmentation	12.7
Flood protection	14.5
Political/Cultural/Historic value	7.2
General preservation of natural areas	12.4

Figure 44 shows that the optimal management actions for Nassau County are predicted to be somewhat different than for the New York City area. However, rough assumptions were used about land costs. All lands for these areas were assumed to be private and NYC land costs were used for this analysis. Under these assumptions, marsh restoration becomes the most cost-effective option within this case study.

Figure 44. Wetland benefits per cost for Nassau County Case Study



Another interesting output from the DMMT is the "expected value" land cover for each defined wetland parcel, and under each adaptation strategy. Figure 45 shows that the marsh islands of "Cuba Middle and East Island" are predicted to lose acreage over time and that there is no dry land at this site for marshes to migrate onto. Figure 46 tells a different story about "Marine Nature Study Area." Total marsh area remains somewhat consistent due to migration onto non-tidal lands that are lost. There also is a significant conversion from transitional marsh (higher irregularly-flooded marshes) to salt marshes (regularly-flooded marshes). These graphs can be easily produced for all sites studied and all adaptation strategies using pull-down menus available in the DMMT interface.

Figure 45. Expected value land cover for Cuba Middle and East Island under uncertain SLR

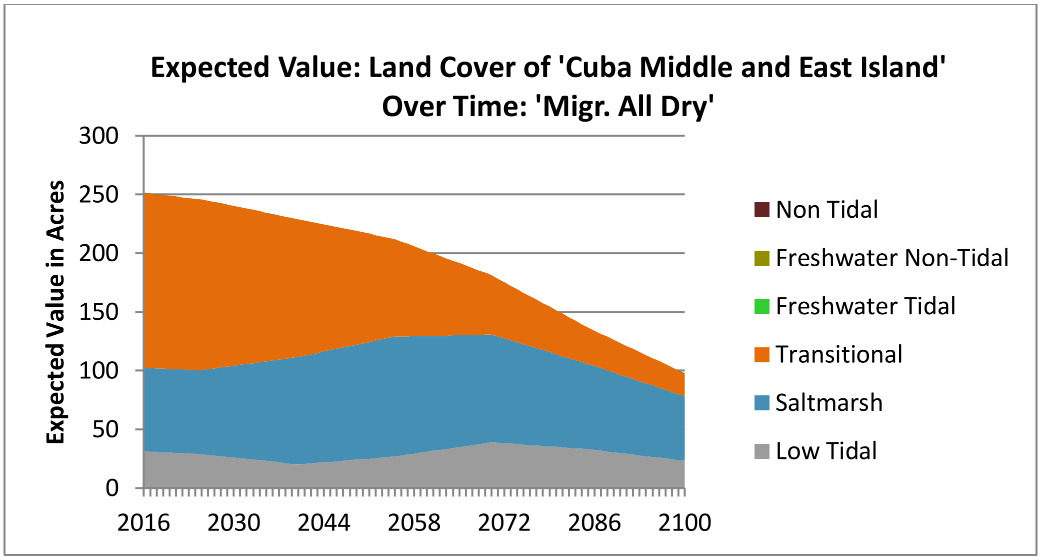
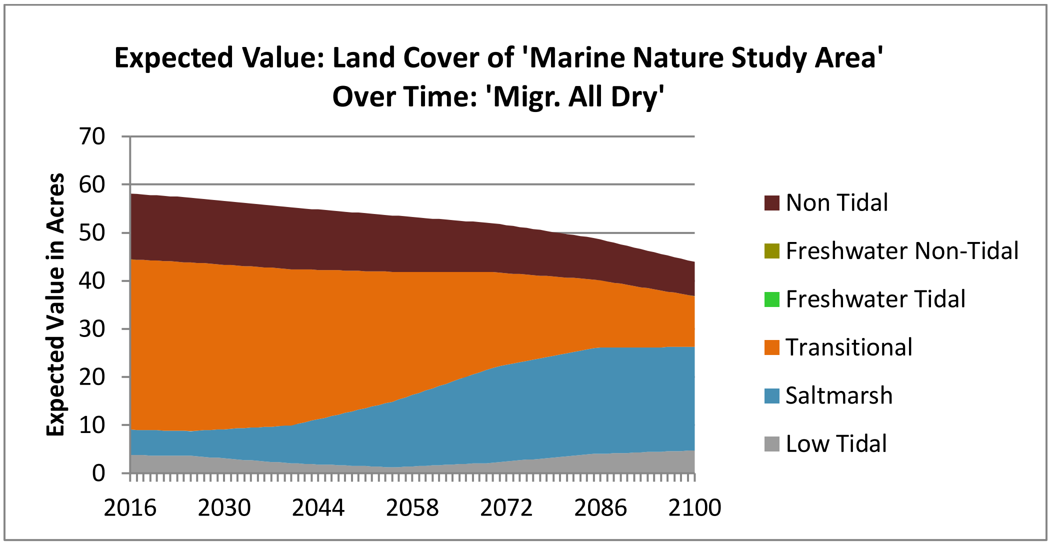
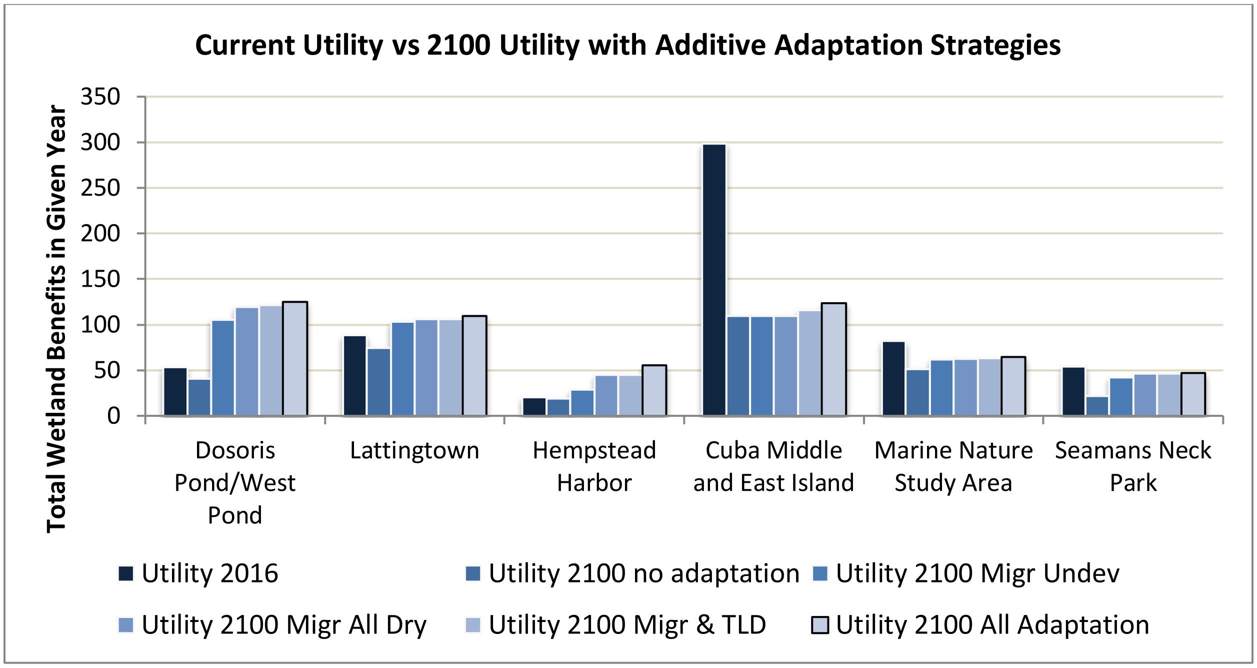


Figure 46. Expected value land cover for Marine Nature Study Area under uncertain SLR



Another graph within DMMT compares 2100 utilities (wetland benefits) against current utilities and then looks at the additive benefits of each adaptation strategy (Figure 47). The black bar to the left of each site shows the current wetland benefits being provided by the given marsh. The second bar shows the no-action predicted utility in the year 2100. The following bars show incremental benefits provided by adding multiple adaptation strategies to the previous bar. For example, the third bar shows the benefit of undeveloped dry-land migration and the fourth shows migration to all dry land. The fifth shows dry land migration as well as thin-layer deposition. The final bar shows all adaptation strategies combined including restoring marshes to their 1974 footprint.

Figure 47. Current vs. future wetland benefits and the impact of adaptation strategies



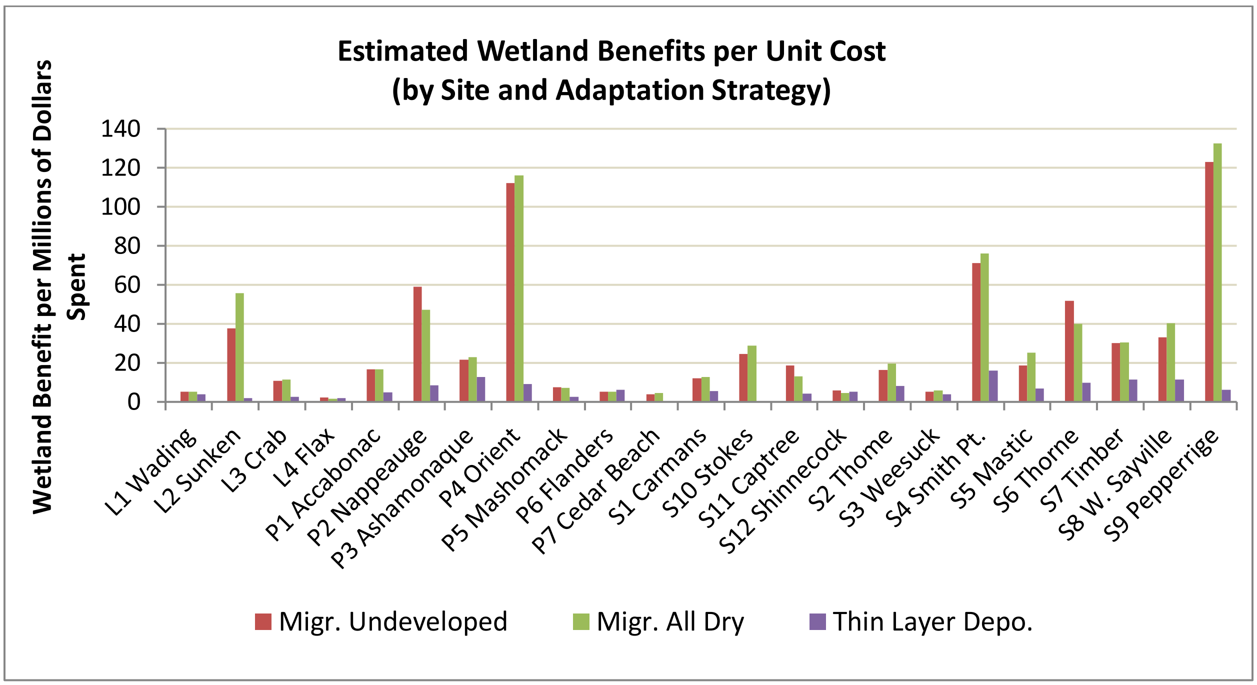
For Nassau County, Figure 47 shows that Cuba Middle and East Island has by far the most current utility but is also one of the sites most at risk for wetland losses by 2100. For Cuba Middle and East Island, tested adaptation strategies only had limited effectiveness as there is little or no available dry land for marsh migration. Therefore, marsh restoration to the 1974 boundary and thin-layer deposition are suggested to have minimal effectiveness. Alternatively, for the "Dosoris Pond" study area, marsh utilities are predicted to fall, but if marsh migration is allowed, total marsh area and total wetland benefits may increase by 2100. For Seamans Neck Park, the combination of all adaptation strategies could cause marsh wetland benefits to remain approximately the same by 2100.

9.3 Suffolk County

For the Suffolk County study area, stakeholder outreach was conducted in a series of meetings to define the study area to be considered, the adaptation strategies to be modeled, and the ecosystem services list to be used in the tool. As a result, the Suffolk County implementation of the DMMT differs from the other two sites as stakeholders decided to perform a "breadth" rather than "depth" analysis. As shown in Appendix F, twenty-three sites were included in the DMMT framework taken from all coastal regions in the county. Furthermore, stakeholders suggested that "restoration to the 1974 footprint" was not a relevant adaptation strategy for this location, so those simulations were not run. Some refinements were made to the ecosystem services list as shown in Appendix G. Specifically, "dry land recreation," and “general preservation of wetlands” were not included, and “bird habitat” and “nekton habitat proximate to fishing areas” were added to the list. Additional gathering of site-specific cost data required by the tool and stakeholder preferences is continuing to be conducted with The Nature Conservancy and DEC taking the lead on this data gathering and outreach.

Preliminary DMMT results are presented here (and on the DMMT website) using estimates for ecosystem-service rankings based on stakeholder-outreach meetings. Professional judgement, satellite imagery, and site-specific data were used to estimate strengths and weaknesses for each site and each ecosystem service. Rough estimates were utilized for costs of adaptation strategies. Figure 48 presents wetland benefits per unit cost and suggests that some sites have more potential benefits than others with respect to migration to dry lands. Differences in predicted benefits from thin-layer deposition are predicted on the basis of differing tide ranges and vulnerability of regularly flooded marshes throughout the study area.

Figure 48. Wetland Benefits per Unit Cost for Suffolk County



10 Conclusions

This study set out with multiple objectives.

- Re-run the New York State SLAMM model with the newest data and SLR scenarios
- Account for the effects of roads and infrastructure on marsh-migration pathways
- Examine the combined effects of SLR and flooding on roads and infrastructure
- Add a marsh collapse process to SLAMM results and examine the effect on model predictions
- Update the model's uncertainty analysis runs and produce maps that summarize results given model and data uncertainty

Some interesting lessons were learned from re-running the model in this manner. For example, the newest model predicts results quite similar to the previous model. However, somewhat more inland inundation of dry lands is predicted in the latest results due to the updated and improved elevation data. Another finding was that improving the accuracy of roads and infrastructure elevations (beyond the 5-meter cell size that is native to the project) did not have much effect on water inundation pathways. A third finding was that the marsh-collapse process did not significantly change marsh-fate projections. This is because predicted marsh accretion rates and accretion feedbacks are more important to model results than small differences (5-15cm) in marsh elevation capital.

The modeling steps listed above produced extensive new data sets that are publicly available. However, given that policy makers are generally already inundated with information and data, this study set out to move beyond data creation. To do this, the team worked with stakeholders to create a decision support tool. This process consisted of several steps:

- Define adaptation strategies with stakeholders and represent these actions within the SLAMM model
- Run adaptation strategies in uncertainty-analysis mode so that SLR, model, and data uncertainty are accounted for when making decisions
- Define a specific set of marsh parcels with stakeholders so actions at these sites can be compared
- Estimate costs of adaptation strategies for each named site
- Define, with stakeholders, which marsh ecosystem services are most important to them, and create a linkage between SLAMM model results and these ecosystem services
- Combine all the model runs, uncertainty analyses, adaptation strategies, costs, and stakeholder valuations into a single cost/benefit metric so that optimal decision-making can be estimated

The result of these steps is an Excel-based tool that calculates cost/benefit metrics and incorporates model uncertainty, data uncertainty, and SLR uncertainty. Interesting insights can be gained from the results of this tool. For example, because of the potential that marshes will undergo less vertical accretion following thin-layer deposition, thin-layer deposition to existing marshes may not be the most cost-effective adaptation strategy. On the other hand, as with all models there are simplifying assumptions, model results must be tested with different sets of cost assumptions and thin-layer deposition strategies to understand if this finding is general across these multiple sets of assumptions.

Ultimately the success of the tool will depend on stakeholders learning to use the tool to test different sets of inputs and to understand the potential long-term effects of their actions. Extensive training materials to get individuals up to speed on the software are available on the project website. (http://warrenpinnacle.com/prof/SLAMM/NYSERDA2015)

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Appendix A. Additional SLAMM Projection Results

Table A-1. NYC Low

		2008	2025	2055	2085	2100
	Developed Dry Land	123,874	123,868	123,823	123,751	123,711
	Estuarine Open Water	74,702	74,867	75,266	75,516	75,609
	Undeveloped Dry Land	59,995	59,946	59,753	59,589	59,493
	Open Ocean	32,665	32,685	32,744	32,795	32,820
	Irreg.-Flooded Marsh	2,025	2,026	2,028	2,030	2,030
	Tidal Flat	1,859	1,708	1,407	1,199	1,127
	Regularly-Flooded Marsh	1,561	1,848	1,833	1,847	1,847
	Inland Open Water	968	975	976	977	978
	Ocean Beach	727	707	651	611	589
	Trans. Salt Marsh	559	315	472	608	699
	Swamp	546	546	545	544	543
	Estuarine Beach	448	433	383	344	325
	Inland Fresh Marsh	421	421	421	420	420
	Flooded Dev. Dry Land	99	105	150	222	262
	Tidal Swamp	71	71	69	67	66
	Tidal Fresh Marsh	20	20	20	20	20
	Riverine Tidal	13	13	13	13	13
	Inland Shore	2	2	2	2	2
	Total (incl. water)	**300,556**	**300,556**	**300,556**	**300,556**	**300,556**

Table A-2. NYC Low-Medium

		2008	2025	2055	2085	2100
	Developed Dry Land	123,872	123,859	123,786	123,579	123,403
	Estuarine Open Water	74,720	74,945	75,384	75,697	75,965
	Undeveloped Dry Land	59,985	59,901	59,653	59,257	59,007
	Open Ocean	32,666	32,690	32,752	32,805	32,832
	Irreg.-Flooded Marsh	2,023	2,024	2,014	2,002	1,990
	Tidal Flat	1,844	1,646	1,328	1,087	977
	Regularly-Flooded Marsh	1,562	1,869	1,877	1,934	2,030
	Inland Open Water	968	974	975	976	863
	Ocean Beach	726	703	651	610	606
	Trans. Salt Marsh	568	339	514	852	990
	Swamp	546	546	543	538	533
	Estuarine Beach	446	421	368	316	288
	Inland Fresh Marsh	421	421	421	409	406
	Flooded Dev. Dry Land	101	114	187	394	570
	Tidal Swamp	71	70	67	63	61
	Tidal Fresh Marsh	20	20	20	20	19
	Riverine Tidal	13	13	13	13	13
	Inland Shore	2	2	2	2	2
	Total (incl. water)	**300,556**	**300,556**	**300,556**	**300,556**	**300,556**

Table A-3. NYC Medium

		2008	2025	2055	2085	2100
	Developed Dry Land	123,871	123,847	123,694	122,746	121,844
	Estuarine Open Water	74,738	75,039	75,574	76,220	76,522
	Undeveloped Dry Land	59,975	59,811	59,441	58,500	57,817
	Open Ocean	32,667	32,697	32,763	32,822	32,854
	Irreg.-Flooded Marsh	2,021	2,013	1,972	1,766	1,466
	Tidal Flat	1,830	1,579	1,214	886	779
	Regularly-Flooded Marsh	1,564	1,891	1,970	2,528	3,131
	Inland Open Water	968	974	974	853	790
	Ocean Beach	725	697	647	652	706
	Trans. Salt Marsh	579	406	629	1,084	1,321
	Swamp	546	545	538	522	510
	Estuarine Beach	444	406	342	264	231
	Inland Fresh Marsh	421	421	420	400	376
	Flooded Dev. Dry Land	102	126	279	1,227	2,129
	Tidal Swamp	71	69	64	55	48
	Tidal Fresh Marsh	20	20	19	18	17
	Riverine Tidal	13	13	13	13	13
	Inland Shore	2	2	2	2	2
	Total (incl. water)	**300,556**	**300,556**	**300,556**	**300,556**	**300,556**

Table A-4. NYC High-Medium

	2008	2025	2055	2085	2100
Developed Dry Land	123,868	123,826	123,476	121,340	119,247
Estuarine Open Water	74,756	75,121	75,767	76,632	77,096
Undeveloped Dry Land	59,942	59,752	59,071	57,517	56,340
Open Ocean	32,668	32,705	32,772	32,847	32,882
Irreg.-Flooded Marsh	2,019	2,000	1,874	1,035	658
Tidal Flat	1,817	1,523	1,115	822	806
Regularly-Flooded Marsh	1,565	1,935	2,162	3,669	4,611
Inland Open Water	968	973	970	788	734
Ocean Beach	724	689	655	742	853
Trans. Salt Marsh	611	424	849	1,354	1,501
Swamp	546	544	531	504	487
Estuarine Beach	441	394	316	229	196
Inland Fresh Marsh	421	421	407	371	360
Flooded Dev. Dry Land	105	147	497	2,633	4,726
Tidal Swamp	71	68	60	42	30
Tidal Fresh Marsh	20	19	18	16	15
Riverine Tidal	13	13	13	13	13
Inland Shore	2	2	2	2	2
Total (incl. water)	**300,556**	**300,556**	**300,556**	**300,556**	**300,556**

Table A-5. NYC High

		2008	2025	2055	2085	2100
	Developed Dry Land	123,866	123,803	122,653	117,297	113,133
	Estuarine Open Water	74,775	75,198	76,232	77,547	78,745
	Undeveloped Dry Land	59,933	59,688	58,439	55,276	53,047
	Open Ocean	32,670	32,714	32,795	32,896	32,943
	Irreg.-Flooded Marsh	2,016	1,982	1,355	423	273
	Tidal Flat	1,802	1,471	994	1,268	1,885
	Regularly-Flooded Marsh	1,567	1,970	2,941	4,607	4,848
	Inland Open Water	968	973	852	724	710
	Ocean Beach	723	687	680	935	1,052
	Trans. Salt Marsh	620	453	1,018	1,996	2,284
	Swamp	546	542	517	436	405
	Estuarine Beach	438	383	276	190	158
	Inland Fresh Marsh	421	421	399	234	194
	Flooded Dev. Dry Land	107	171	1,320	6,677	10,840
	Tidal Swamp	70	67	53	23	14
	Tidal Fresh Marsh	20	19	17	14	10
	Riverine Tidal	13	13	13	13	13
	Inland Shore	2	2	2	2	2
	Total (incl. water)	**300,556**	**300,556**	**300,556**	**300,556**	**300,556**

Table A-6. Nassau Low

		2004	2025	2055	2085	2100
	Estuarine Open Water	61,639	61,805	62,189	62,404	62,477
	Open Ocean	40,364	40,403	40,477	40,546	40,578
	Undeveloped Dry Land	35,951	35,930	35,819	35,653	35,549
	Developed Dry Land	27,551	27,547	27,520	27,432	27,363
	Irreg.-Flooded Marsh	7,093	7,093	7,093	7,093	7,094
	Regularly-Flooded Marsh	1,390	1,433	1,393	1,405	1,411
	Inland Open Water	1,252	1,251	1,255	1,255	1,252
	Tidal Flat	926	902	643	490	443
	Swamp	897	897	896	895	895
	Ocean Beach	862	824	753	693	666
	Estuarine Beach	689	658	586	527	505
	Trans. Salt Marsh	452	320	415	565	660
	Inland-Fresh Marsh	220	220	216	211	206
	Inland Shore	36	36	36	36	36
	Flooded Developed Dry Land	30	34	61	148	217
	Tidal-Fresh Marsh	21	21	21	21	21
	Tidal Swamp	12	12	11	11	10
	Total (incl. water)	**179,386**	**179,386**	**179,386**	**179,386**	**179,386**

Table A-7. Nassau Low-Medium

		2004	2025	2055	2085	2100
	Estuarine Open Water	61,639	61,866	62,330	62,659	62,783
	Open Ocean	40,364	40,404	40,484	40,555	40,590
	Undeveloped Dry Land	35,951	35,893	35,731	35,353	35,080
	Developed Dry Land	27,551	27,542	27,485	27,223	27,042
	Irreg.-Flooded Marsh	7,093	7,082	6,928	6,728	6,669
	Regularly-Flooded Marsh	1,390	1,430	1,522	1,736	1,818
	Inland Open Water	1,252	1,250	1,253	1,233	1,215
	Tidal Flat	926	879	596	427	368
	Swamp	897	897	895	893	891
	Ocean Beach	862	824	748	707	697
	Estuarine Beach	689	649	562	483	452
	Trans. Salt Marsh	452	345	473	761	976
	Inland-Fresh Marsh	220	218	214	203	200
	Inland Shore	36	36	36	36	36
	Flooded Developed Dry Land	30	39	96	358	539
	Tidal-Fresh Marsh	21	21	21	21	21
	Tidal Swamp	12	11	11	9	8
	Total (incl. water)	**179,386**	**179,386**	**179,386**	**179,386**	**179,386**

Table A-8. Nassau Medium

		2004	2025	2055	2085	2100
	Estuarine Open Water	61,639	61,933	62,592	63,319	63,805
	Open Ocean	40,364	40,407	40,492	40,572	40,611
	Undeveloped Dry Land	35,951	35,858	35,486	34,181	33,616
	Developed Dry Land	27,551	27,535	27,330	26,456	25,998
	Irreg.-Flooded Marsh	7,093	6,943	6,306	2,209	1,200
	Regularly-Flooded Marsh	1,390	1,540	2,084	6,247	7,314
	Inland Open Water	1,252	1,250	1,245	1,170	1,155
	Tidal Flat	926	868	553	617	608
	Swamp	897	896	893	875	868
	Ocean Beach	862	822	759	764	767
	Estuarine Beach	689	638	517	397	362
	Trans. Salt Marsh	452	364	609	1,219	1,302
	Inland-Fresh Marsh	220	218	203	175	138
	Inland Shore	36	36	36	36	36
	Flooded Developed Dry Land	30	46	251	1,125	1,583
	Tidal-Fresh Marsh	21	21	21	19	18
	Tidal Swamp	12	11	9	5	4
	Total (incl. water)	**179,386**	**179,386**	**179,386**	**179,386**	**179,386**

Table A-9. Nassau Medium-High

		2004	2025	2055	2085	2100
	Estuarine Open Water	61,639	62,002	62,895	64,511	66,770
	Open Ocean	40,364	40,417	40,503	40,597	40,663
	Undeveloped Dry Land	35,951	35,820	35,095	32,908	31,740
	Developed Dry Land	27,551	27,523	27,069	25,470	24,469
	Irreg.-Flooded Marsh	7,093	6,768	4,253	528	319
	Regularly-Flooded Marsh	1,390	1,685	4,069	6,370	5,963
	Inland Open Water	1,252	1,248	1,216	1,142	1,129
	Tidal Flat	926	863	579	2,155	1,628
	Swamp	897	896	889	852	827
	Ocean Beach	862	813	781	852	879
	Estuarine Beach	689	624	476	328	277
	Trans. Salt Marsh	452	385	789	1,399	1,456
	Inland-Fresh Marsh	220	216	199	106	100
	Inland Shore	36	36	36	36	36
	Flooded Developed Dry Land	30	58	512	2,111	3,112
	Tidal-Fresh Marsh	21	21	20	16	16
	Tidal Swamp	12	11	7	3	2
	Total (incl. water)	**179,386**	**179,386**	**179,386**	**179,386**	**179,386**

Table A-10. Nassau High

		2004	2025	2055	2085	2100
	Estuarine Open Water	61,639	62,072	63,477	68,971	71,909
	Open Ocean	40,364	40,422	40,520	40,708	40,836
	Undeveloped Dry Land	35,951	35,768	34,100	30,093	27,803
	Developed Dry Land	27,551	27,507	26,408	22,903	20,892
	Irreg.-Flooded Marsh	7,093	6,539	757	104	51
	Regularly-Flooded Marsh	1,390	1,879	6,837	3,747	4,460
	Inland Open Water	1,252	1,248	1,166	1,110	1,080
	Tidal Flat	926	866	1,376	2,876	1,396
	Swamp	897	895	871	807	788
	Ocean Beach	862	809	820	959	1,083
	Estuarine Beach	689	609	411	225	188
	Trans. Salt Marsh	452	414	1,241	2,062	2,081
	Inland-Fresh Marsh	220	215	173	93	87
	Inland Shore	36	36	36	36	36
	Flooded Developed Dry Land	30	74	1,173	4,678	6,689
	Tidal-Fresh Marsh	21	21	17	12	6
	Tidal Swamp	12	11	5	1	0
	Total (incl. water)	**179,386**	**179,386**	**179,386**	**179,386**	**179,386**

Table A-11. Westchester Low

		Initial	2003	2025	2055	2085	2100
	Estuarine Open Water	15,708	15,714	15,721	15,734	15,740	15,744
	Developed Dry Land	8,686	8,654	8,651	8,638	8,618	8,611
	Undeveloped Dry Land	7,453	7,359	7,354	7,327	7,238	7,228
	Inland Open Water	172	173	173	173	173	171
	Estuarine Beach	76	76	75	74	74	73
	Swamp	72	72	72	72	72	72
	Irreg.-Flooded Marsh	69	66	66	66	65	65
	Rocky Intertidal	59	59	59	59	59	59
	Regularly-Flooded Marsh	58	60	107	99	105	161
	Inland Fresh Marsh	31	31	31	31	31	31
	Tidal Flat	31	27	20	21	16	15
	Tidal Swamp	3	3	3	3	3	3
	Riverine Tidal	1	1	1	1	1	1
	Tidal Fresh Marsh	1	1	1	1	1	1
	Trans. Salt Marsh	0	93	51	74	156	111
	Flooded Dev. Dry Land	0	32	35	48	68	74
	Total (incl. water)	**32,420**	**32,420**	**32,420**	**32,420**	**32,420**	**32,420**

Table A-12. Westchester Low-Medium

		Initial	2003	2025	2055	2085	2100
	Estuarine Open Water	15,708	15,714	15,721	15,735	15,745	15,752
	Developed Dry Land	8,686	8,653	8,647	8,629	8,599	8,577
	Undeveloped Dry Land	7,453	7,359	7,348	7,313	7,208	7,173
	Inland Open Water	172	173	173	173	171	171
	Estuarine Beach	76	76	75	74	74	73
	Swamp	72	72	72	72	72	72
	Irreg.-Flooded Marsh	69	66	66	65	65	65
	Rocky Intertidal	59	59	59	59	59	58
	Regularly-Flooded Marsh	58	60	110	105	170	175
	Inland Fresh Marsh	31	31	31	31	31	31
	Tidal Flat	31	27	20	22	18	17
	Tidal Swamp	3	3	3	3	3	3
	Riverine Tidal	1	1	1	1	1	1
	Tidal Fresh Marsh	1	1	1	1	1	1
	Trans. Salt Marsh	0	94	55	79	117	144
	Flooded Dev. Dry Land	0	32	39	56	87	109
	Total (incl. water)	**32,420**	**32,420**	**32,420**	**32,420**	**32,420**	**32,420**

Table A-13. Westchester Medium

		Initial	2003	2025	2055	2085	2100
	Estuarine Open Water	15,708	15,714	15,721	15,738	15,774	15,790
	Developed Dry Land	8,686	8,653	8,643	8,607	8,535	8,486
	Undeveloped Dry Land	7,453	7,359	7,340	7,222	7,116	7,053
	Inland Open Water	172	173	173	173	170	170
	Estuarine Beach	76	76	75	74	68	65
	Swamp	72	72	72	72	70	70
	Irreg.-Flooded Marsh	69	66	65	65	63	61
	Rocky Intertidal	59	59	59	59	49	43
	Regularly-Flooded Marsh	58	60	113	115	189	215
	Inland Fresh Marsh	31	31	31	31	31	29
	Tidal Flat	31	27	21	25	28	31
	Tidal Swamp	3	3	3	3	3	2
	Riverine Tidal	1	1	1	1	1	1
	Tidal Fresh Marsh	1	1	1	1	1	1
	Trans. Salt Marsh	0	94	59	157	173	203
	Flooded Dev. Dry Land	0	32	43	79	151	200
	Total (incl. water)	**32,420**	**32,420**	**32,420**	**32,420**	**32,420**	**32,420**

TableA-14. Westchester Medium-High

		Initial	2003	2025	2055	2085	2100
	Estuarine Open Water	15,708	15,714	15,722	15,746	15,796	15,823
	Developed Dry Land	8,686	8,653	8,638	8,583	8,460	8,343
	Undeveloped Dry Land	7,453	7,358	7,327	7,180	7,026	6,930
	Inland Open Water	172	173	173	171	170	169
	Estuarine Beach	76	76	75	74	64	61
	Swamp	72	72	72	72	70	69
	Irreg.-Flooded Marsh	69	66	65	64	55	30
	Rocky Intertidal	59	59	59	58	41	37
	Regularly-Flooded Marsh	58	60	116	182	240	348
	Inland Fresh Marsh	31	31	31	31	29	28
	Tidal Flat	31	27	21	26	37	36
	Tidal Swamp	3	3	3	3	2	2
	Riverine Tidal	1	1	1	1	1	1
	Tidal Fresh Marsh	1	1	1	1	1	1
	Trans. Salt Marsh	0	94	69	127	202	201
	Flooded Dev. Dry Land	0	33	48	103	226	343
	Total (incl. water)	**32,420**	**32,420**	**32,420**	**32,420**	**32,420**	**32,420**

TableA-15. Westchester High

		Initial	2003	2025	2055	2085	2100
	Estuarine Open Water	15,708	15,714	15,722	15,773	15,847	15,891
	Developed Dry Land	8,686	8,653	8,632	8,528	8,277	8,143
	Undeveloped Dry Land	7,453	7,358	7,318	7,107	6,867	6,742
	Inland Open Water	172	173	173	170	169	169
	Estuarine Beach	76	76	75	68	59	51
	Swamp	72	72	72	70	68	66
	Irreg.-Flooded Marsh	69	66	65	61	19	10
	Rocky Intertidal	59	59	59	47	34	30
	Regularly-Flooded Marsh	58	60	120	212	420	537
	Inland Fresh Marsh	31	31	31	30	28	27
	Tidal Flat	31	27	22	27	38	41
	Tidal Swamp	3	3	3	3	1	1
	Riverine Tidal	1	1	1	1	1	1
	Tidal Fresh Marsh	1	1	1	1	1	1
	Trans. Salt Marsh	0	94	73	165	183	168
	Flooded Dev. Dry Land	0	33	54	157	408	542
	Total (incl. water)	**32,420**	**32,420**	**32,420**	**32,420**	**32,420**	**32,420**

Table A-16. Suffolk West Long Island Low

		Initial	2004	2025	2055	2085	2100
	Estuarine Open Water	156,973	157,201	157,300	157,628	157,810	157,899
	Open Ocean	76,977	77,093	77,197	77,316	77,404	77,435
	Undeveloped Dry Land	70,397	69,895	69,836	69,509	69,007	68,729
	Developed Dry Land	24,394	24,356	24,343	24,238	24,006	23,876
	Irreg.-Flooded Marsh	7,540	6,978	6,973	6,852	6,694	6,698
	Swamp	4,648	4,610	4,606	4,540	4,453	4,428
	Inland Open Water	2,490	2,486	2,486	2,481	2,480	2,476
	Regularly-Flooded Marsh	1,490	1,830	1,951	2,064	2,309	2,338
	Estuarine Beach	1,608	1,523	1,474	1,361	1,250	1,200
	Ocean Beach	1,071	1,044	944	861	832	841
	Trans. Salt Marsh	461	877	692	984	1,435	1,670
	Tidal Flat	385	520	599	478	432	405
	Inland-Fresh Marsh	435	434	434	432	428	425
	Tidal Swamp	432	418	416	401	375	363
	Inland Shore	48	48	48	48	48	48
	Tidal-Fresh Marsh	41	40	40	40	40	40
	Flooded Developed Dry Land	-	38	50	156	388	518
	Rocky Intertidal	1	1	1	1	1	1
	Total (incl. water)	**349,392**	**349,392**	**349,392**	**349,392**	**349,392**	**349,392**

Table A-17. Suffolk West Long Island Low-Medium

		Initial	2004	2025	2055	2085	2100
	Estuarine Open Water	156,973	157,201	157,331	157,746	158,139	158,357
	Open Ocean	76,977	77,093	77,202	77,329	77,431	77,472
	Undeveloped Dry Land	70,397	69,895	69,752	69,237	68,288	67,788
	Developed Dry Land	24,394	24,356	24,322	24,121	23,678	23,436
	Irreg.-Flooded Marsh	7,540	6,978	6,880	6,292	5,068	4,487
	Swamp	4,648	4,610	4,584	4,467	4,350	4,313
	Inland Open Water	2,490	2,486	2,484	2,479	2,458	2,450
	Regularly-Flooded Marsh	1,490	1,830	2,046	2,634	4,119	4,901
	Estuarine Beach	1,608	1,523	1,458	1,322	1,135	1,050
	Ocean Beach	1,071	1,044	949	878	904	935
	Trans. Salt Marsh	461	877	760	1,210	1,843	2,097
	Tidal Flat	385	520	617	504	436	356
	Inland-Fresh Marsh	435	434	434	429	417	415
	Tidal Swamp	432	418	412	382	321	288
	Inland Shore	48	48	48	48	48	48
	Tidal-Fresh Marsh	41	40	40	40	40	40
	Flooded Developed Dry Land	-	38	72	273	716	957
	Rocky Intertidal	1	1	1	1	1	1
	Total (incl. water)	**349,392**	**349,392**	**349,392**	**349,392**	**349,392**	**349,392**

Table A-18. Suffolk West Long Island Medium

		Initial	2004	2025	2055	2085	2100
	Estuarine Open Water	156,973	157,201	157,370	158,060	161,245	164,348
	Open Ocean	76,977	77,093	77,209	77,353	77,497	77,587
	Undeveloped Dry Land	70,397	69,895	69,649	68,608	66,307	65,390
	Developed Dry Land	24,394	24,356	24,296	23,833	22,766	22,335
	Irreg.-Flooded Marsh	7,540	6,978	6,583	4,176	1,295	958
	Swamp	4,648	4,610	4,541	4,355	4,177	4,097
	Inland Open Water	2,490	2,486	2,481	2,471	2,430	2,399
	Regularly-Flooded Marsh	1,490	1,830	2,316	4,539	4,218	4,240
	Estuarine Beach	1,608	1,523	1,440	1,225	942	874
	Ocean Beach	1,071	1,044	952	942	1,103	1,137
	Trans. Salt Marsh	461	877	859	1,532	1,998	2,039
	Tidal Flat	385	520	669	890	3,133	1,327
	Inland-Fresh Marsh	435	434	434	423	377	365
	Tidal Swamp	432	418	406	333	190	154
	Inland Shore	48	48	48	48	48	48
	Tidal-Fresh Marsh	41	40	40	40	36	35
	Flooded Developed Dry Land	0	38	97	561	1,627	2,059
	Rocky Intertidal	1	1	1	1	1	1
	Total (incl. water)	**349,392**	**349,392**	**349,392**	**349,392**	**349,392**	**349,392**

Table A-19. Suffolk West Long Island High-Medium

		Initial	2004	2025	2055	2085	2100
	Estuarine Open Water	156,973	157,201	157,410	158,997	165,152	167,395
	Open Ocean	76,977	77,093	77,218	77,377	77,639	77,859
	Undeveloped Dry Land	70,397	69,895	69,528	67,832	64,481	63,026
	Developed Dry Land	24,394	24,356	24,252	23,463	21,920	21,232
	Irreg.-Flooded Marsh	7,540	6,978	6,130	2,128	532	341
	Swamp	4,648	4,610	4,500	4,277	4,023	3,919
	Inland Open Water	2,490	2,486	2,479	2,454	2,380	2,349
	Regularly-Flooded Marsh	1,490	1,830	2,743	5,021	4,052	4,140
	Estuarine Beach	1,608	1,523	1,417	1,100	842	757
	Ocean Beach	1,071	1,044	957	1,025	1,213	1,189
	Trans. Salt Marsh	461	877	961	1,682	1,951	1,867
	Tidal Flat	385	520	736	2,338	2,186	1,668
	Inland-Fresh Marsh	435	434	434	414	358	341
	Tidal Swamp	432	418	396	266	115	77
	Inland Shore	48	48	48	48	48	48
	Tidal-Fresh Marsh	41	40	40	38	26	22
	Flooded Developed Dry Land	0	38	142	931	2,474	3,161
	Rocky Intertidal	1	1	1	1	1	1
	Total (incl. water)	**349,392**	**349,392**	**349,392**	**349,392**	**349,392**	**349,392**

Table A-20. Suffolk West Long Island High

			Initial	2004	2025	2055	2085	2100
	Estuarine Open Water	156,973	157,201	157,457	160,698	168,112	170,571	
	Open Ocean	76,977	77,093	77,228	77,431	78,114	78,480	
	Undeveloped Dry Land	70,397	69,895	69,372	66,185	61,178	59,125	
	Developed Dry Land	24,394	24,356	24,184	22,704	20,422	19,550	
	Irreg.-Flooded Marsh	7,540	6,978	5,470	907	204	137	
	Swamp	4,648	4,610	4,456	4,140	3,795	3,672	
	Inland Open Water	2,490	2,486	2,477	2,428	2,319	2,255	
	Regularly-Flooded Marsh	1,490	1,830	3,369	3,796	4,365	3,890	
	Estuarine Beach	1,608	1,523	1,392	969	682	569	
	Ocean Beach	1,071	1,044	963	1,185	1,202	1,137	
	Trans. Salt Marsh	461	877	1,087	2,024	2,246	1,925	
	Tidal Flat	385	520	823	4,608	2,329	2,832	
	Inland-Fresh Marsh	435	434	430	375	335	305	
	Tidal Swamp	432	418	384	173	48	32	
	Inland Shore	48	48	48	48	48	48	
	Tidal-Fresh Marsh	41	40	40	30	21	21	
	Flooded Developed Dry Land	0	38	209	1,689	3,972	4,844	
	Rocky Intertidal	1	1	1	1	0	0	
	Total (incl. water)	**349,392**	**349,392**	**349,392**	**349,392**	**349,392**	**349,392**	

Table A-21. Suffolk East Long Island Low

		Initial	2010	2025	2055	2085	2100
	Open Ocean	229,238	229,378	229,477	229,689	229,846	229,903
	Estuarine Open Water	179,642	179,775	179,846	180,134	180,366	180,460
	Undeveloped Dry Land	143,421	142,732	142,655	142,173	141,594	141,332
	Developed Dry Land	25,146	25,120	25,116	25,078	25,018	24,981
	Irreg.-Flooded Marsh	4,848	4,459	4,459	4,374	4,294	4,297
	Swamp	2,365	2,363	2,363	2,357	2,349	2,344
	Inland Open Water	1,988	1,983	1,983	1,986	1,983	1,976
	Ocean Beach	1,975	1,937	1,847	1,691	1,608	1,578
	Estuarine Beach	1,831	1,769	1,726	1,545	1,351	1,273
	Trans. Salt Marsh	281	873	711	1,064	1,518	1,687
	Regularly-Flooded Marsh	194	602	802	944	1,134	1,211
	Inland-Fresh Marsh	456	443	443	434	394	389
	Tidal Swamp	307	290	288	274	258	251
	Tidal Flat	181	136	142	78	51	48
	Tidal-Fresh Marsh	100	97	97	97	97	97
	Rocky Intertidal	62	50	49	47	44	40
	Flooded Developed Dry Land	0	26	31	68	129	165
	Inland Shore	1	1	1	1	1	1
	Ocean Flat	1	1	1	1	1	1
	Total (incl. water)	**592,036**	**592,036**	**592,036**	**592,036**	**592,036**	**592,036**

Table A-22. Suffolk East Long Island Low-Medium

		Initial	2010	2025	2055	2085	2100
	Open Ocean	229,238	229,380	229,483	229,711	229,901	229,976
	Estuarine Open Water	179,642	179,780	179,876	180,257	180,626	180,758
	Undeveloped Dry Land	143,421	142,703	142,528	141,853	140,866	140,389
	Developed Dry Land	25,146	25,119	25,106	25,045	24,913	24,836
	Irreg.-Flooded Marsh	4,848	4,427	4,385	4,098	3,661	3,489
	Swamp	2,365	2,363	2,361	2,351	2,304	2,299
	Inland Open Water	1,988	1,982	1,981	1,977	1,932	1,927
	Ocean Beach	1,975	1,938	1,853	1,714	1,627	1,603
	Estuarine Beach	1,831	1,766	1,710	1,482	1,223	1,122
	Trans. Salt Marsh	281	898	789	1,234	1,821	2,111
	Regularly-Flooded Marsh	194	636	911	1,305	2,125	2,416
	Inland-Fresh Marsh	456	443	436	428	384	377
	Tidal Swamp	307	289	284	262	229	212
	Tidal Flat	181	135	145	73	58	85
	Tidal-Fresh Marsh	100	97	97	97	95	95
	Rocky Intertidal	62	50	49	46	35	29
	Flooded Developed Dry Land	0	28	40	101	233	310
	Inland Shore	1	1	1	1	1	1
	Ocean Flat	1	1	1	1	1	1
	Total (incl. water)	**592,036**	**592,036**	**592,036**	**592,036**	**592,036**	**592,036**

Table A-23. Suffolk East Long Island Medium

		Initial	2010	2025	2055	2085	2100
	Open Ocean	229,238	229,383	229,490	229,751	230,030	230,148
	Estuarine Open Water	179,642	179,786	179,913	180,491	181,243	181,958
	Undeveloped Dry Land	143,421	142,667	142,377	141,166	138,912	137,852
	Developed Dry Land	25,146	25,117	25,094	24,962	24,557	24,347
	Irreg.-Flooded Marsh	4,848	4,392	4,231	3,365	1,315	1,043
	Swamp	2,365	2,362	2,359	2,307	2,243	2,184
	Inland Open Water	1,988	1,982	1,980	1,963	1,891	1,803
	Ocean Beach	1,975	1,939	1,866	1,741	1,710	1,709
	Estuarine Beach	1,831	1,762	1,689	1,357	961	818
	Trans. Salt Marsh	281	930	866	1,630	2,237	2,500
	Regularly-Flooded Marsh	194	674	1,109	2,273	5,318	5,826
	Inland-Fresh Marsh	456	443	435	385	339	312
	Tidal Swamp	307	287	278	236	160	136
	Tidal Flat	181	135	152	96	435	515
	Tidal-Fresh Marsh	100	97	96	88	77	73
	Rocky Intertidal	62	50	49	41	17	11
	Flooded Developed Dry Land	0	29	52	184	589	799
	Inland Shore	1	1	1	1	1	1
	Ocean Flat	1	1	1	1	1	1
	Total (incl. water)	**592,036**	**592,036**	**592,036**	**592,036**	**592,036**	**592,036**

Table A-24. Suffolk East Long Island Medium-High

		Initial	2010	2025	2055	2085	2100
	Open Ocean	229,238	229,385	229,500	229,805	230,165	230,359
	Estuarine Open Water	179,642	179,793	179,963	180,781	182,813	185,240
	Undeveloped Dry Land	143,421	142,635	142,211	140,432	136,780	135,143
	Developed Dry Land	25,146	25,114	25,082	24,846	24,095	23,731
	Irreg.-Flooded Marsh	4,848	4,353	4,023	2,222	642	422
	Swamp	2,365	2,362	2,356	2,293	2,100	2,053
	Inland Open Water	1,988	1,982	1,978	1,917	1,775	1,648
	Ocean Beach	1,975	1,940	1,873	1,767	1,780	1,713
	Estuarine Beach	1,831	1,758	1,661	1,233	743	571
	Trans. Salt Marsh	281	957	948	1,751	2,680	2,470
	Regularly-Flooded Marsh	194	715	1,370	3,836	4,952	5,498
	Inland-Fresh Marsh	456	443	434	375	261	234
	Tidal Swamp	307	286	271	200	110	78
	Tidal Flat	181	133	160	163	2,027	1,414
	Tidal-Fresh Marsh	100	96	93	81	51	42
	Rocky Intertidal	62	50	48	32	8	4
	Flooded Developed Dry Land	0	32	65	301	1,052	1,415
	Inland Shore	1	1	1	1	1	1
	Ocean Flat	1	1	1	1	1	1
	Total (incl. water)	**592,036**	**592,036**	**592,036**	**592,036**	**592,036**	**592,036**

Table A-25. Suffolk East Long Island High

		Initial	2010	2025	2055	2085	2100
	Open Ocean	229,238	229,387	229,512	229,905	230,531	231,007
	Estuarine Open Water	179,642	179,800	180,024	181,368	187,086	190,019
	Undeveloped Dry Land	143,421	142,603	142,019	138,795	132,779	129,923
	Developed Dry Land	25,146	25,112	25,063	24,533	23,212	22,547
	Irreg.-Flooded Marsh	4,848	4,311	3,767	960	220	119
	Swamp	2,365	2,362	2,350	2,237	1,875	1,649
	Inland Open Water	1,988	1,982	1,974	1,884	1,611	1,536
	Ocean Beach	1,975	1,940	1,889	1,843	1,907	1,761
	Estuarine Beach	1,831	1,753	1,620	1,018	421	244
	Trans. Salt Marsh	281	986	1,042	2,196	2,876	2,873
	Regularly-Flooded Marsh	194	761	1,684	4,748	4,760	4,542
	Inland-Fresh Marsh	456	441	430	335	215	136
	Tidal Swamp	307	285	263	149	46	30
	Tidal Flat	181	132	177	1,373	2,540	3,037
	Tidal-Fresh Marsh	100	96	89	59	20	13
	Rocky Intertidal	62	50	48	17	2	1
	Flooded Developed Dry Land	0	34	83	614	1,934	2,600
	Inland Shore	1	1	1	1	1	1
	Ocean Flat	1	1	1	1	0	0
	Total (incl. water)	**592,036**	**592,036**	**592,036**	**592,036**	**592,036**	**592,036**

Figure A-1. Confidence intervals for Westchester Study area

For low marsh (regularly flooded), an aggregated "Transitional" category (irregularly flooded marsh plus transitional marsh), and inland-fresh marsh habitats.

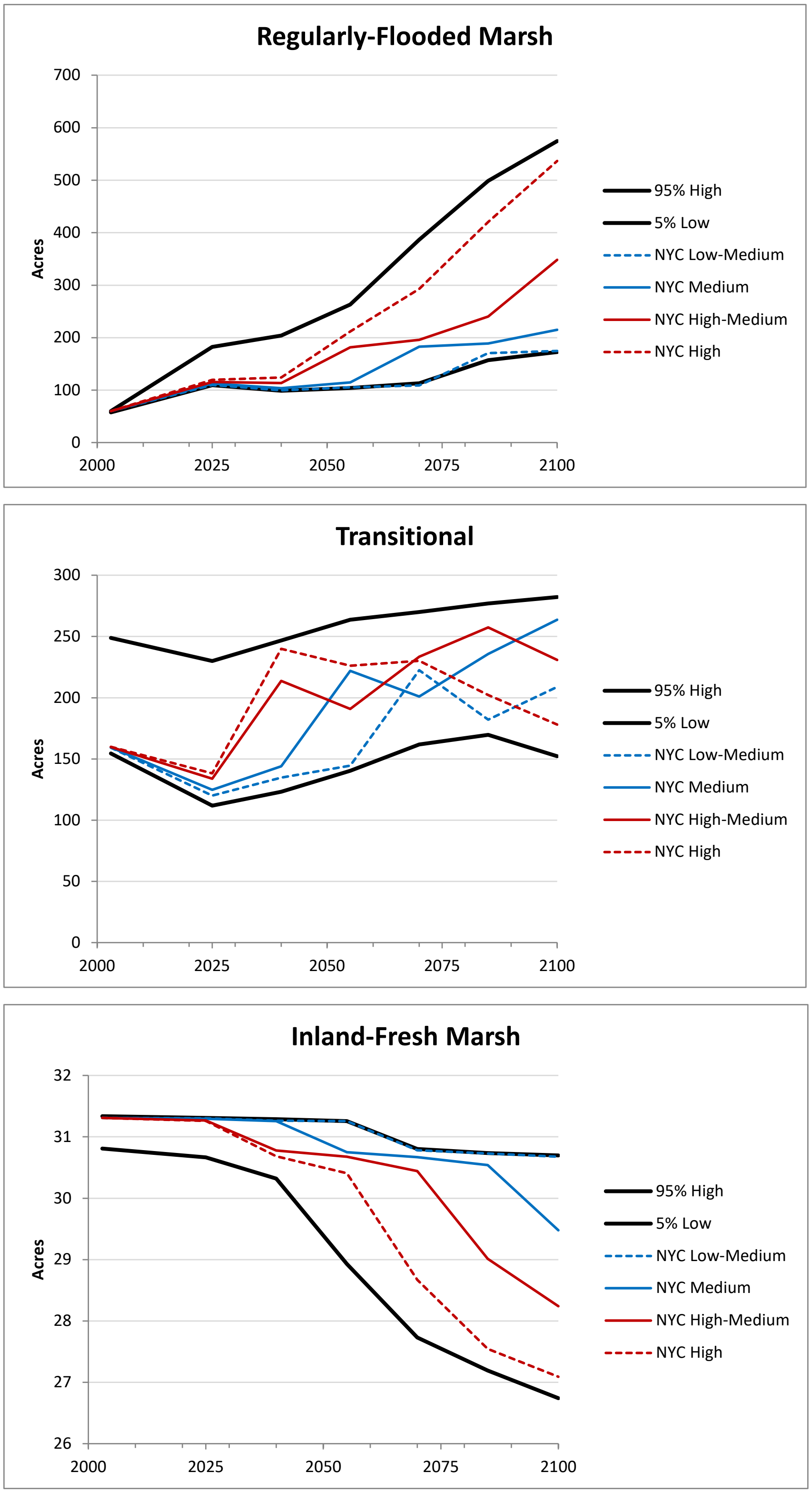
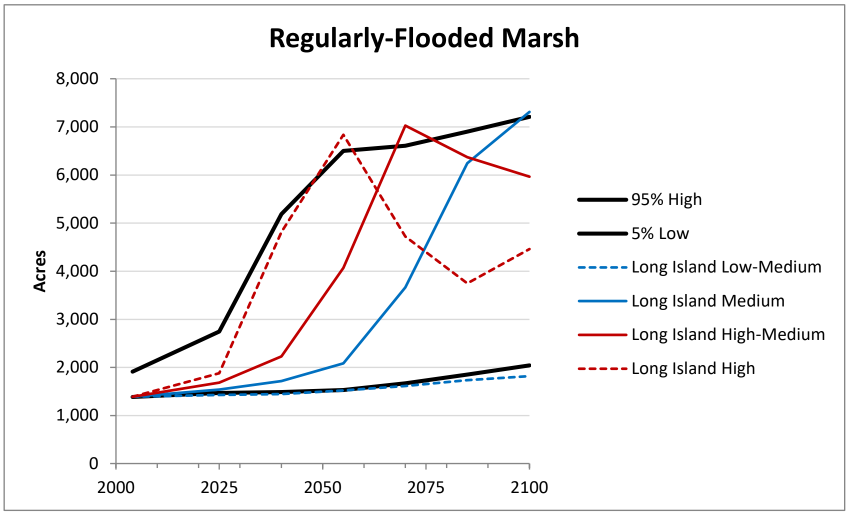
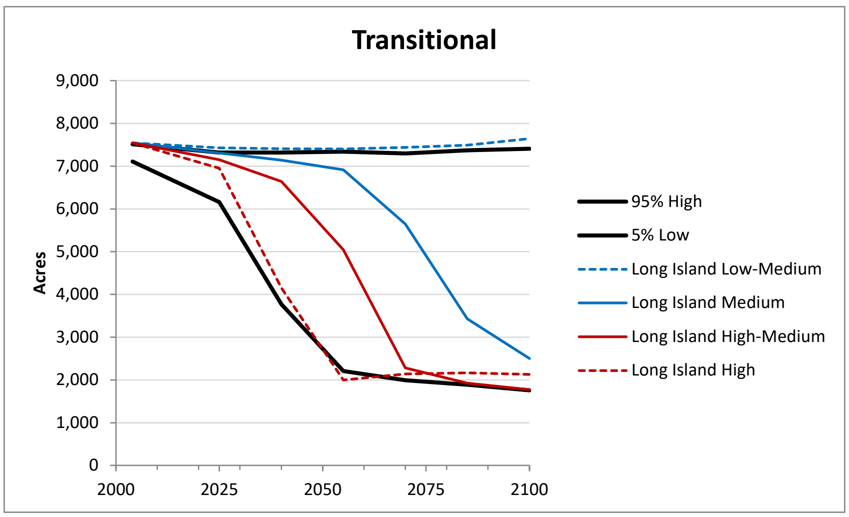


Figure A-2. Confidence intervals for Nassau Study area

For low marsh (regularly flooded), an aggregated “Transitional” category (irregularly flooded marsh plus transitional marsh), and developed dry lands.





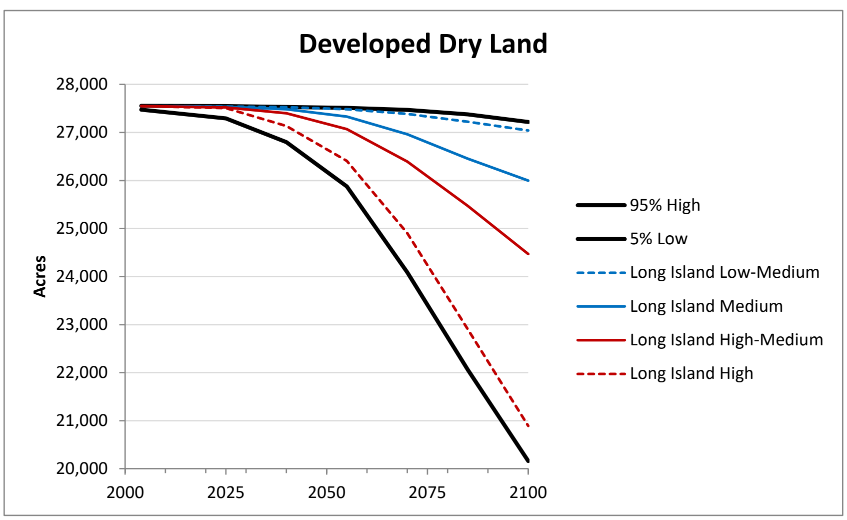
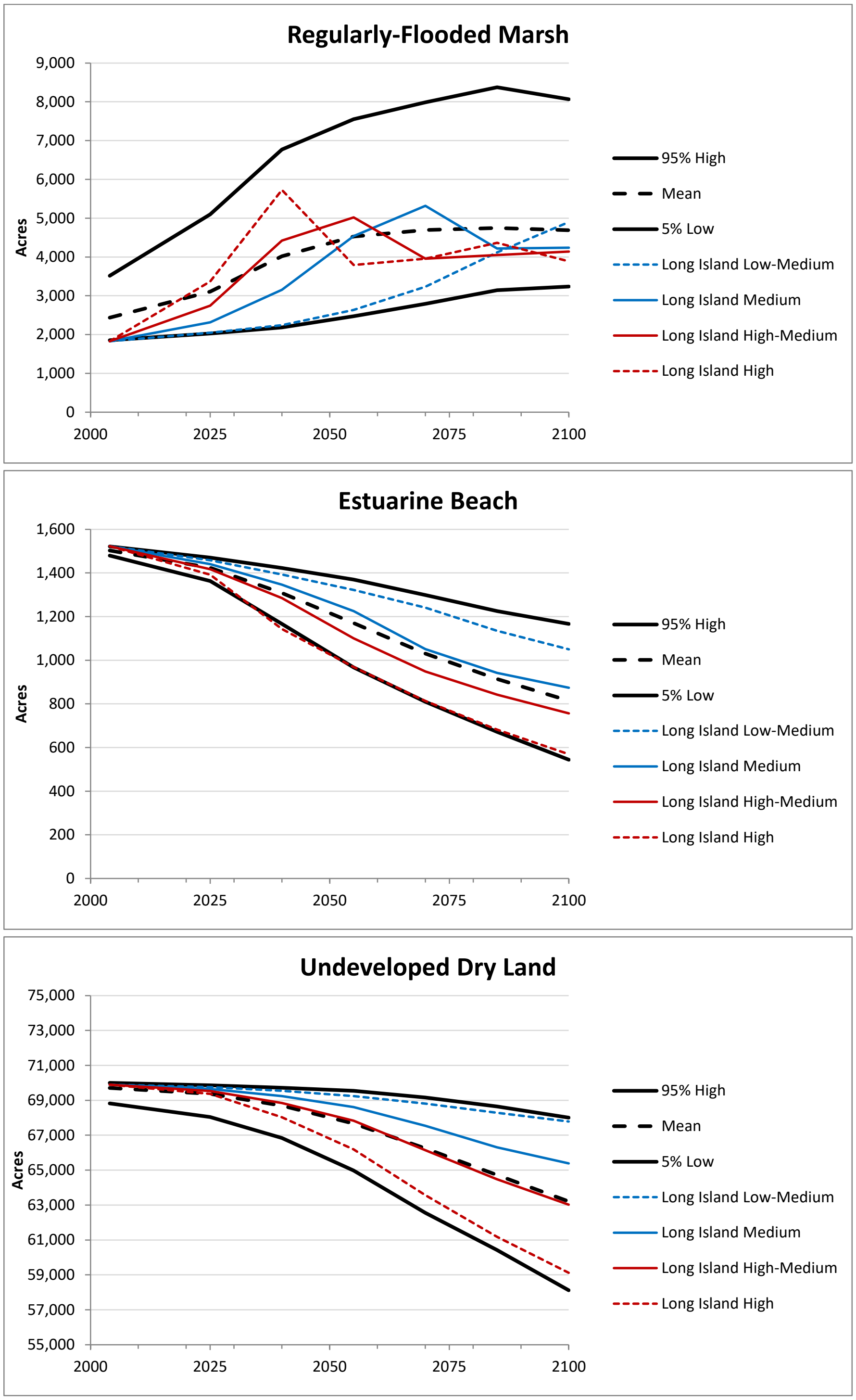


Figure A-3. Confidence intervals for Suffolk West Study area

For low marsh (regularly flooded marsh), estuarine beach, and undeveloped dry lands



Appendix B. DMMT Users Guide

The SLAMM Dynamic Marsh Management tool allows users to integrate complex SLAMM uncertainty-analysis results over time and to evaluate them on a land-parcel basis. The relative values of ecosystem services across multiple parcels may be evaluated given inputs about stakeholder values, alternative simulation scenarios, and uncertain future sea-level rise (SLR).

For background on the conceptual model behind the tool, please visit: http://warrenpinnacle.com/prof/SLAMM/NYSERDA2015/Description_Marsh_Management_Tool.pdf

This tool uses an Excel spreadsheet to store model inputs and outputs and uses Visual Basic to perform calculations based on modified user inputs. A basic understanding of Microsoft Excel is required to use this product.

This Users' guide is designed for the tool's end user that wishes to look at different scenarios and to modify the flexible assumptions about the relative values of various ecosystem services. Therefore, the guide assumes that the SLAMM model has already been run, that SLAMM model results have already been extracted on a parcel basis, and that results are properly stored in the "SLAMM Raw Data" and "Data Setup" tabs. To add new parcels or new sets of SLAMM results to the model is a task for advanced SLAMM users only. A separate reference sheet will be prepared to guide users through those tasks.

Getting Started

Moving through Excel tabs from left to right:

- The "**Instructions**" tab contains a link to this information.
- The "**Model Summary**" tab contains information about the sites and scenarios that are included within the model.
    - A "site" is a specific GIS parcel that can be evaluated using this tool. Its definition can be based on tax maps, or delineation of individual marsh systems, as two examples.
    - A "scenario" contains the results of a SLAMM simulation with a specific adaptation strategy explored. These results may be uncertainty runs or deterministic. Multiple adaptation scenarios may be included in the tool at one time to examine different assumptions, management scenarios, or SLR scenarios. In terms of costs and incremental benefits of adaptation strategies, the first scenario in the list is considered the "no action" scenario.

- Historic Percent Loss rates per year are also included for information in this tab. Historic marsh loss rates may be projected into the future and are considered additive to projected SLR losses. (In the NYC example, these rates were derived by comparing 1974 and 2008 wetland maps for each parcel. Marsh losses were assumed to predate significant acceleration in SLR in these sites.)
- The "**Model Inputs**" tab contains all other model inputs required to run the model "Beginning year" and "end year" may be set to vary the planning horizon
- The "**Ecosystem Relative Rank**" fields (horizontal across the top of the page) carry the results of the survey question asking, "Please provide the relative ranks for how important each of the following ecosystem services are to your decision-making process."

	Nutrient Sequestration			Recreation			Habitat		Other			
	Carbon Sequestration	Nitrogen Sequestration	Phosphorus Sequestration	Dry-land Recreation	Wetland Recreation	Natural services to under-served communities	Nekton habitat	Habitat fragmentation/ connectivity	Flood Vulnerability Reduction	Political/ Cultural/ Historic value	General preservation of natural areas	**Total Relative Rank**
Ecoservice Relative Rank	8.3	9.0	6.9	4.2	4.2	7.4	15.0	19.5	12.8	5.1	7.8	100

More information about the interpretation of the Ecosystem Relative Rank may be found in the Ecosystem Services Glossary document http://www.warrenpinnacle.com/prof/SLAMM/NYSERDA2015/Ecosystem_Service_Glossary.pdf

- Site-specific weights: The ecosystem benefits examined here have been related to the acreage predictions of land-cover types that come out of SLAMM simulations using "utility functions." However, these equations do not take into account quality of habitat, for example. (In one location with a higher marsh density, more carbon sequestration could be assumed to occur than another location with lower density.) For this reason, site-specific weights are provided for the user to add information about each site when available.

	Site-specific "Quality of Habitat," should not reflect the numbers of acres of a particular land-cover type							
Site 1	Idlewild Inner and Outer	20.33	23.67	35.00	7.67	6.67	7.67	6.00
Site 2	Alley Creek, Queens	30.33	32.00	47.50	6.67	6.33	7.33	9.00
Site 3	Lemon Creek, Staten Island	28.67	30.33	45.00	6.33	6.67	6.33	6.50
Site 4	Pelham Bay Cove	27.00	23.67	35.00	6.33	6.33	6.00	10.50
Site 5	W.T. Davis	33.67	30.33	45.00	6.33	6.33	6.67	11.00
Site 6	Udall's Cove, Queens	28.67	30.33	45.00	7.00	7.00	7.00	8.50

Site-specific weights are especially important for such categories as "recreation" in which the location and historic use of a marsh may be considered in providing weights. However, the size of the marsh should not be considered when providing weights.

- **"Discount Factors"** – Below the site-specific weights in the "Model Inputs" tab, a user may experiment with weighting current ecosystem services more than future ecosystem services using the "Discount Factors" inputs. The table of discount factors is used, but it can be populated using a discount rate using the formula and input in column H.

Discount Factors

Discount Rate: 0%

	Year	Discount Factor		
Timestep 1	2016	100.0%	2016	100.0%
Timestep 2	2020	100.0%	2020	100.0%
Timestep 3	2040	100.0%	2040	100.0%
Timestep 4	2050	100.0%	2050	100.0%
Timestep 5	2065	100.0%	2065	100.0%
Timestep 6	2075	100.0%	2075	100.0%
Timestep 7	2085	100.0%	2085	100.0%
Timestep 8	2100	100.0%	2100	100.0%
Timestep 9				
Timestep 10				

interpolates within up to 10 timesteps

Example discount rate calcuation that can be copied into the discount factors table to the left.

- Below the discount factors is the cost of each adaptation strategy by parcel (optional). These fields allow the user to put a price on each of the adaptation scenarios by parcel depending on land costs, the extent of land predicted converted, marsh-restoration costs, and thin-layer deposition costs, for example.

		Adaptation Strategy Costs (millions of dollars per parcel)				
		No Migration	Migr. Undeveloped	Migr. All Dry	Restore to 1974	Thin Layer Depo.
	Cost Details	no cost, existing marsh footprint	purchase undeveloped land or easement when required	purchase developed and undeveloped land when required	marsh restoration costs	thin layer deposition costs
Site 1	Idlewild Inner and Outer	N / A	57.12	67.33	20.66	31.66
Site 2	Alley Creek, Queens	N / A	41.56	50.74	9.87	8.65
Site 3	Lemon Creek, Staten Island	N / A	21.88	25.72	3.93	2.59
Site 4	Pelham Bay Cove	N / A	0.00	5.19	5.78	3.54
Site 5	W.T. Davis	N / A	10.83	13.60	21.25	6.01
Site 6	Udall's Cove, Queens	N / A	51.66	55.32	4.91	2.00
Site 7						
	Total Strategy Cost	**$ -**	**$ 183.05**	**$ 217.88**	**$ 66.40**	**$ 54.44**

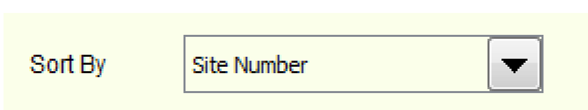
- At the bottom of the "Model Inputs tab" is a set of "marsh loss" fields. These fields allow the user to enter the historical marsh loss rates for each parcel. Given low historical SLR rates, these historical marsh loss rates are not assumed to be from sea-level rise related factors. If the user wishes to extrapolate these losses into the future and add them to SLR losses the "assume historical marsh loss rates continue" button may be checked. This would mean that marshes that are rapidly declining would be expected to continue this decline, whereas marshes that have been historically shown to be robust would continue that trend as well (prior to any sea-level rise related losses).

☐ Assume Historical Marsh Loss Rates Continue (Additive to SLR losses)

	Site Name	Historic Pct. Annual Marsh Loss (yr-1)
Site 1	Idlewild Inner and Outer	0.45%
Site 2	Alley Creek, Queens	0.66%
Site 3	Lemon Creek, Staten Island	0.53%
Site 4	Pelham Bay Cove	0.78%
Site 5	W.T. Davis	0.54%
Site 6	Udall's Cove, Queens	1.84%

- After all inputs have been edited, click "Calculate" to start the model calculation (or press <control><shift><R>). Note Excel will stop receiving inputs for a number of seconds, view the lower left of the Excel window to view model-run progress.

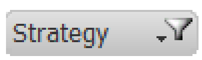
- The "**Survey Questions**" tab is provided for reference. It contains a summary of responses from stakeholders regarding the valuation of various ecosystem services.
  - NYSERDA survey information:
    https://www.surveymonkey.com/r/NYSERDA_SLAMM_NASSAU
    https://www.surveymonkey.com/r/NYSERDASLAMM_NYC
- The "**Model Outputs**" tab contains a basic summary of aggregated utilities calculated over the simulation period.
  - Benefits aggregated over the study period are presented by wetland-benefit type, by site, and by adaptation scenario run.
  - These may be automatically sorted using the "Sort by" pulldown box.

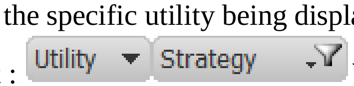


- o Wetland-service benefits are unitless but can be compared across sites and across adaptation strategies. However, these are relative benefits and therefore cannot be compared from one spreadsheet implementation to the next (Nassau County SLAMM runs vs. NYC for example).
- o To the right of the table of benefits are columns showing incremental benefits and costs.

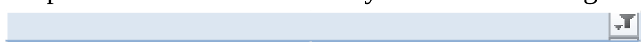
Site number	Site Name	Adaptation Scenario	Incremental Benefit	Cost of Strategy (millions)	Cost per Unit Benefit	Benefit per unit cost
Site 1	Idlewild Inner and Outer	Migr. Undeveloped	900.31	57.12	0.06	15.76
Site 2	Alley Creek, Queens	Migr. Undeveloped	1214.86	41.56	0.03	29.23
Site 3	Lemon Creek, Staten Island	Migr. Undeveloped	346.23	21.88	0.06	15.83
Site 4	Pelham Bay Cove	Migr. Undeveloped	616.94	0.00	0.00	N / A
Site 5	W.T. Davis	Migr. Undeveloped	956.59	10.83	0.01	88.35

The incremental benefit column shows how much the adaptation strategy has improved predicted wetland benefits against the "no-action" scenario (the "no-action" scenario is often labeled "no migration"). When this is combined with the cost of the adaptation strategy, the cost per unit benefit and benefit per unit cost may be calculated. Generally, a user would be most interested in the adaptation strategy that provides the highest benefit per unit cost.

- The "**Ecosystem Benefits**" tab contains additional pre-made charts that can be used to examine model results.
  - o Most of these tables have editable fields that allows the user to customize the graphic. For example a field that says: 

 will allow you to click on the icon on the right and select one of the adaptation strategies and change the graph accordingly.
  - o "**Components of Each Site's Utility**" shows the components of utility for each site in a stacked bar chart. ((Note: you can select which strategy is being examined using the "Strategy" pull-down box at the top of the chart. You can also edit which utilities are shown and which sites using the other pull-down boxes marked with  .)
  - o "**Utility by Site over Time**" shows how the ecosystem utilities of each site change over time given SLR effects, historical marsh loss, and the selected discount rate. (The default is to show the sum of all utilities. However, the specific utility being displayed may be edited along with the strategy at the upper left : 

)
  - o "**Utility at one Site by Strategy over Time**" shows how the ecosystem utilities of one site across all adaptation strategies modeled. (The site being displayed, and the utilities included, may be edited at the upper left).
  - o **"Expected Value Land-Cover Summary"** shows the predicted quantity of each wetland at each parcel over the simulation period. (Note: select which site and strategy you are viewing using the pulldown box at the top left.) The land cover selection originally shows only wetland types, but dry lands and open water may be selected using the land-cover pull down box at the right of the graph: 

- The **“Adaptation Strategy Benefits”** tab contains results showing the benefits and incremental benefits of each adaptation strategy.
    - **“Comparative Incremental Benefits of Adaptation Strategies”** shows the predicted incremental benefit of each adaptation strategy broken down by site. This gives the user an idea of the impact of each adaptation strategy against the others as well as the site-specific differences in adaptation strategy.
    - **“Incremental Benefits”** pie chart shows the incremental benefits of one adaptation strategy by site. The relative benefit to each site of each adaptation strategy may be displayed. The adaptation scenario chosen may be modified using the pull-down box at the upper left:
      
    - **“Current Utility vs. 2100 Utility”** is an interesting bar chart that displays the current wetland benefits as a black bar for each site followed by a set of predictions for 2100. The second bar shows the no-action scenario predicted utility in the year 2100. The following bars show incremental benefits provided by adding multiple adaptation strategies to the previous bar. For example, the third bar shows the benefit of undeveloped-dry-land migration and the fourth shows migration to all dry land. The fifth shows dry land migration as well as thin-layer deposition. The final bar shows all adaptation strategies combined including restoring marshes to their 1974 footprint. The take home message: in some cases, additive adaptation strategies will allow a marsh to retain its current utility by 2100 and in other cases they may not.
    - **“Estimated Wetland Benefits per Unit Cost” chart** shows the wetland benefits each adaptation strategy by site as a function of that adaptation strategy cost for that site. Higher bars indicate that a particular adaptation strategy is predicted to be more cost effective at a particular site than lower bars.

- **The Utility Tabs**
    - These tabs describe the relationship between modeled wetland types and land covers or land-cover metrics produced by the model. They are editable for a more advanced user and guidance on editing them will be available soon.
    - Note to advanced users—the magnitude of the utility value does not matter—each of these are “relative utilities” and are then normalized by the model based on the ecosystem relative ranks. Therefore, an ecosystem “relative rank” for one ecosystem service that is twice as large as another means that the maximum utility for the first ecosystem service will be twice as high as the maximum utility for the second.

- **Other tabs to the right**
    - These tabs contain the raw model results and some intermediate inputs and are generally for the more advanced user only.

Appendix C. Decision-Support Surveys

Two surveys were shared as part of this project. Both focused on obtaining the ecosystem service values from stakeholders. The only way they differed were the geographic scope they were being applied to. Surveys were created and managed using the on-line “SurveyMonkey” tool.

The survey below was created to collect ecosystem service values for six parcels in the NYC area. A description of these parcels is presented in Appendix D. A nearly identical survey was circulated to obtain the same data for 10 sites in Nassau County. The only difference between the two was the sites listed under each valuation question. Nassau County sites are described in Appendix E.

The number of sites being considered in Suffolk County (23) were considered unwieldy for a survey such as the one presented here, so Suffolk County data were directly entered into the DMMT interface based on stakeholder input.

The surveys read as follows:

In this survey you will be asked to provide your opinions on the relative values of current and potential marsh migration areas in New York City. Depending on your familiarity with the study areas, this survey should take 20 to 40 minutes to complete. The survey can be started and finished later if you don't complete it all in one sitting.

Thank you for participating. Your feedback is critical to building the Dynamic Marsh Management Tool.

1. Please choose your sector

2. If you would like to receive a copy of your responses for your records, please enter your email address:

The "ecosystem service relative rank" represents the value that is given in the decision making process in comparison to other ecosystem services listed. If a user is mostly interested in recreation, for example, high weights could be given to those services and much lower (or zero) weights to nutrient sequestration.

The links below provide background information on the parcels being compared and the approach and terminology used throughout the survey.

Click here to download a guide to the New York City parcels

Click here for a glossary of ecosystem services and guide to assigning weights

The total rankings do not need to sum to 100, but they should be provided relative to one another. For example, if you rank one service as twice as important as another it should have double the value.

3. Please provide the relative ranks for how important each of the following ecosystem services are to your decision-making process.

Carbon Sequestration	
Nitrogen Sequestration	
Phosphorus Sequestration	
Undeveloped dry land recreation utility	
Marsh land recreation utility	
Natural areas for underserved communities	
Nekton habitat	
Habitat connectivity/Fragmentation	
Flood protection	
Political/Cultural/Historic value	
General preservation of natural areas	

The remainder for the survey will ask for you to provide weights for ecosystem benefits at each site.

Ecosystem benefits have all been related to the acreage predictions of land-cover types projected by SLAMM simulations. However, these equations do not take into account quality of habitat. Therefore, it is important to rate sites based on the quality, not the quantity of marsh.

For example, in one location with a higher marsh density, more carbon sequestration could be assumed to occur than another location with lower density. For this reason, site-specific weights are being asked for so users can add information about each site when available. These are especially important for such categories as "recreation" in which the location and historic use of a marsh may be considered in providing weights.

If no information is available for a specific ecosystem service, all sites may be weighted evenly. In this case, one acre of wetland will be assumed to provide the same amount of benefit across sites. Weights need not sum to 100 (they will be normalized later).

On this page we ask you to provide values for each site with regard to nutrient sequestration potential.

Tidal marshes are important for improving water quality. In particular they can sequester organic Carbon and nutrients that may otherwise lead to additional climate disruption or eutrophication of estuarine systems. The nutrient sequestration ecosystem services quantify the relative amount of organic Carbon, Nitrogen and Phosphorus that may be accumulated based on landcover types.

The weight assigned to each site should differentiate the quality of marsh with respect to nutrient sequestration, rather than the quantity. Therefore the size of the marsh should not be taken into account.

4. Between the sites being compared, what value would you assign each with regard to potential for Carbon Sequestration?

Site 1 - Idlewild	
Site 2 - Alley Creek	
Site 3 - Lemon Creek	
Site 4 - Pelham Bay Cove	
Site 5 - William T. Davis	
Site 6 - Udall's Cove	

5. Please explain the rationale for your Carbon Sequestration valuation choices

6. Between the sites being compared, what value would you assign each with regard to potential for Nitrogen Sequestration?

Site 1	
Site 2	
Site 3	
Site 4	
Site 5	
Site 6	

7. Please explain your rationale for your Nitrogen Sequestration valuation choices

8. Between the sites being compared, what value would you assign each with regard to potential for Phosphorus Sequestration?

Site 1	
Site 2	
Site 3	
Site 4	
Site 5	
Site 6	

9. Please explain the rationale for your Phosphorus Sequestration valuation choices

On this page we ask questions regarding the values of each site with regard to recreation. Recreation is divided into three categories: Dry land (trails, ball fields, open space, etc.), Wetland, and "Natural services to underserved communities." Each is described below.

Dry land. Dry land recreation is the current value of an area for recreation on dry land. This could include open fields, ball fields and courts, nature trails, etc. Historical sites on dry land are accounted for here.

Wetland. Wetland recreation describes the current value of an area for recreation in wetlands, which might include bird watching or the presence of boardwalk areas for nature observation and enjoyment.

Natural services to underserved communities. This ecosystem service combines the currently available areas and their proximity to underserved or at risk communities. This allows one to give priority to areas that are located in or near areas where few other natural areas exist for recreation.

As was the case in the previous page, please rank the quality of land cover per acre rather than the overall quantity of land cover.

10. Between the sites being compared, what value would you assign each with regard to potential for dry land recreation value?

Site 1 - Idlewild	
Site 2 - Alley Creek	
Site 3 - Lemon Creek	
Site 4 - Pelham Bay Cove	
Site 5 - William T. Davis	
Site 6 - Udall's Cove	

11. Please explain the rationale for your dry land recreation valuation choices

12. Between the sites being compared, what value would you assign each with regard to potential for wetland recreation value?

Site 1	
Site 2	
Site 3	
Site 4	
Site 5	
Site 6	

13. Please explain the rationale for your wetand recreation valuation choices

14. Between the sites being compared, what value would you assign each with regard to natural services to underserved communities?

Site 1	
Site 2	
Site 3	
Site 4	
Site 5	
Site 6	

15. Please explain the rationale for your natural services to underserved communities valuation choices

This page asks for your values regarding the parcels's values for supporting habitat.

Nekton habitat. Nekton are animals that are able to move independently of water currents and include bony fish and aquatic mammals, turtles, snakes, octopus, squid, and shrimp. In particular, nearshore nekton habitat is important for juvenile fish to ensure the maintenance of healthy fish population. Salt marsh edge vs. interior is considered especially important habitat (Peterson and Turner 1994). The weight assigned to this service is intended to represent the value of a particular parcel for supporting healthy nekton ecosystems.

Habitat connectivity. This service represents the degree of connectivity within a habitat by calculating the length of marsh edge per unit marsh area. Large marshes that are not fragmented have a low marsh edge density while narrow, fringing marshes, especially those that are fragmented and breaking apart, have a lot of edge.

Please remember to rank the quality of land cover per acre rather than the overall quantity of land cover.

16. Between the sites being compared, what value would you assign each with regard to potential for nekton habitat value?

Site 1 - Idlewild	
Site 2 - Alley Creek	
Site 3 - Lemon Creek	
Site 4 - Pelham Bay Cove	
Site 5 - William T. Davis	
Site 6 - Udall's Cove	

17. Please explain the rationale for your nekton habitat valuation choices

18. Between the sites being compared, what value would you assign each with regard to potential for habitat connectivity/fragmentation value?

Site 1	
Site 2	
Site 3	
Site 4	
Site 5	
Site 6	

19. Please explain the rationale for your habitat connectivity/fragmentation valuation choices

On this page we ask you to weight the sites based on the their ability to provide flood protection, their Political/Cultural/Historical value and the "General preservation of wetlands"

The **flood protection** benefit quantifies the capability of the marsh system to provide some level of protection against storm surges. Normally, this is done by estimating the amount of energy that a marsh system can absorb when storm water reaches the system. In this tool, the "width" of the marsh is used to differentiate between parcels. As a simple rule of thumb, the energy absorbed may be assumed proportional to the width, though more complex models suggest a more complicated relationship to storm track, etc. (Wamsley et al. 2010). The spatial weights assigned to the parcels should reflect the value of infrastructure and quantity of population protected. Site-specific weights could be estimated using available data or assigned by expertise knowledge.

The **Political/Cultural/Historic service** accounts for the value of maintaining existing marshes for other anthropocentric reasons not enumerated above. Site specific weighting is critical, or alternatively this ecosystem benefit may be assigned to an overall weight of zero.

The '**General preservation of wetlands' value** accounts for the coverage of all wetland cover types. It may be used to define the intrinsic value of wetlands outside of defined anthropocentric benefits, or to capture benefits that are not captured by the recreation, habitat, and nutrient sequestration categories.

Please remember to rank the quality of land cover per acre rather than the overall quantity of land cover.

20. Between the sites being compared, what value would you assign each with regard to potential for flood protection value?

Site 1 - Idlewild	
Site 2 - Alley Creek	
Site 3 - Lemon Creek	
Site 4 - Pelham Bay Cove	
Site 5 - William T. Davis	
Site 6 - Udall's Cove	

21. Please explain the rationale for your flood protection valuation choices

22. Between the sites being compared, what value would you assign each with regard to potential for Political/Cultural/Historic value?

Site 1 [ ]

Site 2 [ ]

Site 3 [ ]

Site 4 [ ]

Site 5 [ ]

Site 6 [ ]

23. Please explain the rationale for your Political/Cultural/Historic value choices

[ ]

24. Between the sites being compared, what value would you assign each with regard to potential for the general preservation of natural areas?

Site 1 [ ]

Site 2 [ ]

Site 3 [ ]

Site 4 [ ]

Site 5 [ ]

Site 6 [ ]

25. Please explain the rationale for your general preservation of natural areas valuation choices

[ ]

Appendix D. NYC Site Summaries

In conjunction with NYC Parks, the following six sites were analyzed in the pilot application of the DMMT.

Site 1: Idlewild Inner and Outer, Queens (Jamaica Bay)

Idlewild Park is located northeast of John F. Kennedy International Airport. The park's 160 acres contain freshwater and tidal wetlands, woodland, meadow, and grassland dune-scrub habitat. The park contains two meandering tributaries of Hook Creek, which feeds into Jamaica Bay. Much of the marsh habitat around Hook Creek is high quality and is managed for the protection of colonial wading birds, which breed locally on rookery islands. The marsh provides essential habitat for foraging by egrets, ibis, and herons, which make up 25% of the northeast Atlantic population.

A significant amount of the associated upland is filled historical wetland and restoration of the wetlands at Idlewild Park has been ongoing for nearly a decade. Several joint projects between Parks' Natural Resources Group (NRG) and the New York City Department of Environmental Protection have been completed including the restoration of 23 acres of woodland, wetland, meadow, and dune-scrub communities (1997 to 1999) and a 3-acre tidal wetland and shrubland/grassland restoration project (1999-2003). http://www.nycgovparks.org/greening/nature-preserves/site?FWID=32

Recent EPA project findings showed Idlewild Marsh had a lower condition, higher vulnerability, need for elevation increase, high priority for acquisition of adjacent property.

Figure D-1. Idlewild Marsh Parcel

Site 2: Alley Creek, Queens (Long Island Sound)

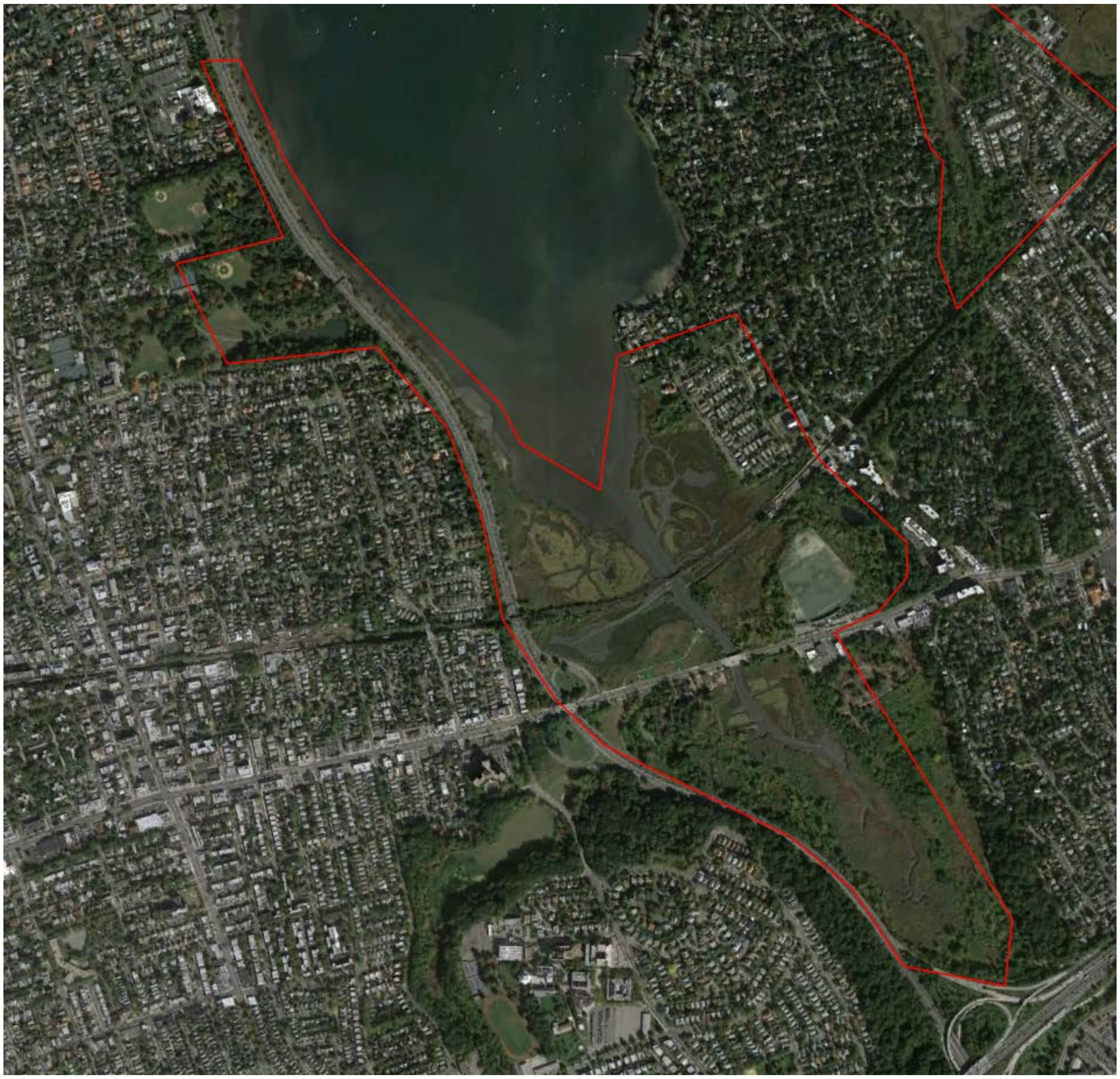
The Alley Creek Parcel includes Crocheron Park and areas adjacent to Alley Pond Park. It is also in close proximity to Udall's Cove (Site 6).

Crocheron Park includes baseball fields, basketball courts, playgrounds and tennis courts, as well as restroom and restaurant facilities. http://www.nycgovparks.org/parks/crocheron-park/

Alley Pond Park offers glimpses into New York's geologic past, its colonial history, and its current conservation efforts. Because of its glacier-formed moraine, the park has numerous unique natural features, like its freshwater and saltwater wetlands, tidal flats, meadows, and forests, which create a diverse ecosystem and support abundant bird life. http://www.nycgovparks.org/parks/alley-pond-park/

EPA project findings showed Ally Creek mid-range condition, higher vulnerability, need for and proposed shore edge restoration project by NYC Parks.

Figure D-2. Alley Creek Parcel. The red in the upper-right corner is Site 6: Udall's Cove



Site 3: Lemon Creek, Staten Island (Raritan Bay)

Lemon Creek Park includes historic houses, marinas, eateries, and kayak and canoe launch sites. http://www.nycgovparks.org/parks/lemon-creek-park

EPA project findings showed lower condition marshes with higher vulnerability, a need for elevation increase and potential flooding of adjacent hard surfaces.

Figure D-3. Lemon Creek Parcel

Site 4: Pelham Bay Cove, Bronx (Long Island Sound)

Pelham Bay Cove is part of Pelham Bay Park, the City's largest park property. The parcel defined includes the Bartow-Pell Woods and Mansion Museum, and the Siwanoy Trail. http://www.nycgovparks.org/parks/pelham-bay-park

EPA project findings suggest this marsh has a higher condition, lower vulnerability, and flooding of adjacent hard surfaces.

Figure D-4. Pelham Bay Cove Parcel (outlined in red)

Site 5: William T. Davis, Staten Island (Arthur Kill)

William T. Davis Wildlife Refuge is part of Freshkills Park. Besides providing a green space for passive outdoor recreation, it also provides the surrounding community with water pollution filtration and a natural flood control system. Many birds make their homes in this park's marshes, including herons (Ardea), egrets (Egretta), ibis (Threskiornithinae), cormorants (Phalacrocorax), and gulls (Larus). On the ground and in the water, snapping turtles (Chelydra serpentina), fiddler crabs (Uca), and muskrats (Ondatra zibethica) can be seen throughout the site. http://www.nycgovparks.org/parks/freshkills-park/highlights/12298. EPA project findings: Higher condition, lower vulnerability, need for elevation increase and shore edge restoration.

Figure D-5. WT Davis Parcel

Site 6: Udall's Cove, Queens

This 30-acre inlet off of Little Neck Bay is an important preserve and habitat area for northeastern Queens. The preserve was formed in 1972 to save precious wetlands and forest from the increasing development. https://www.nycgovparks.org/greening/nature-preserves/site?FWID=33. Udall's cove is on the border with Nassau County and is contiguous with marshes in Great Neck Estate's Park (Part of the Nassau County prioritization effort).

EPA Project Findings: Moderate condition, higher vulnerability, and need for shore edge restoration.

Figure D-6. Udall's Cove Parcel

Alley Creek Parcel (Site 2) outline is noticeable to the Southwest.

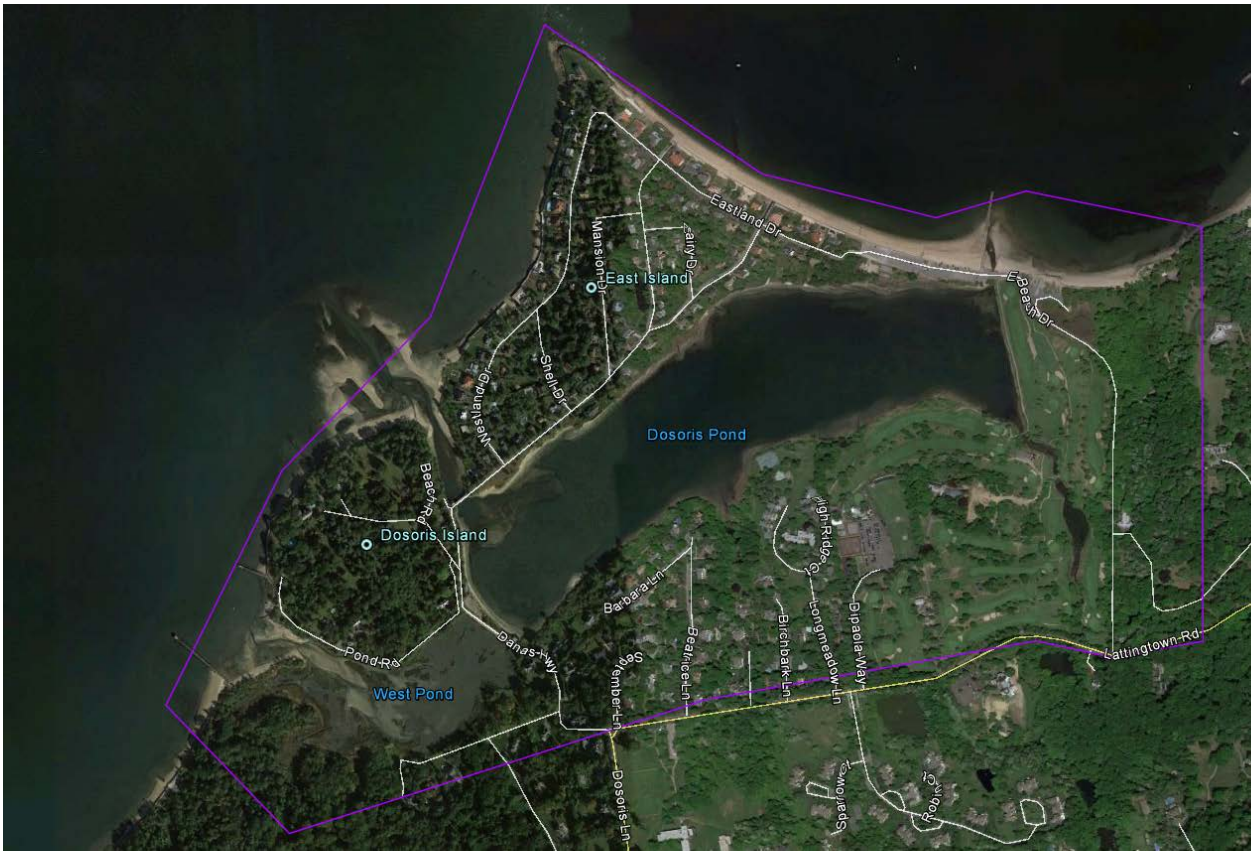
Appendix E. Nassau County Site Summaries

Working with DEC, the following 10 sites were included in the Nassau County pilot application of the DMMT.

Site1: Dosoris Pond/West Pond

Dosoris Pond is a lake near to East Island and East Beach. It is also close to West Pond and Welwyn Preserve County Park. The area is a hotspot for bird watching. Currently the only marsh occurs at West Pond, to the southwest of Dosoris Pond.

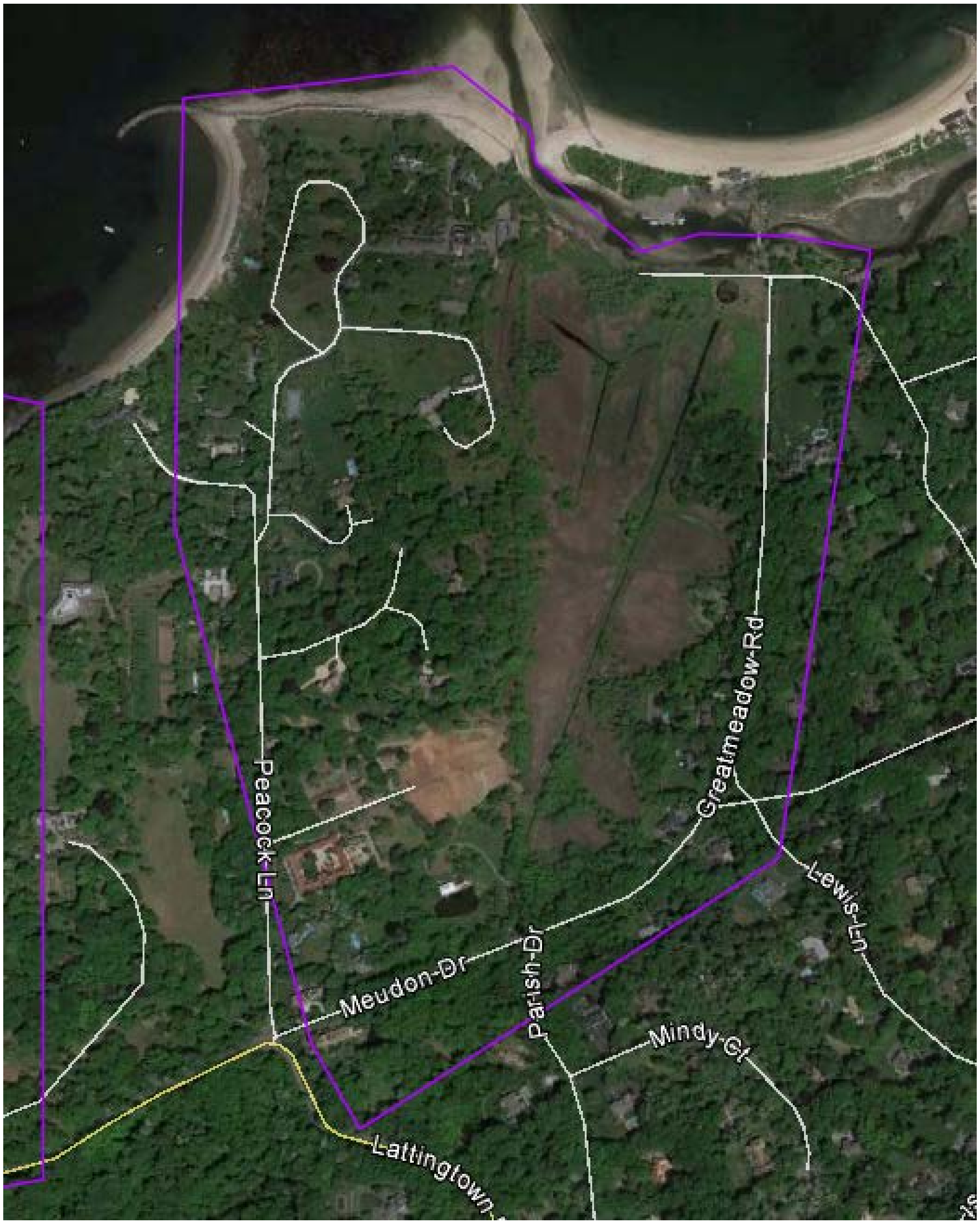
Figure E-7. Dosoris and West Ponds



Site 2: Lattingtown

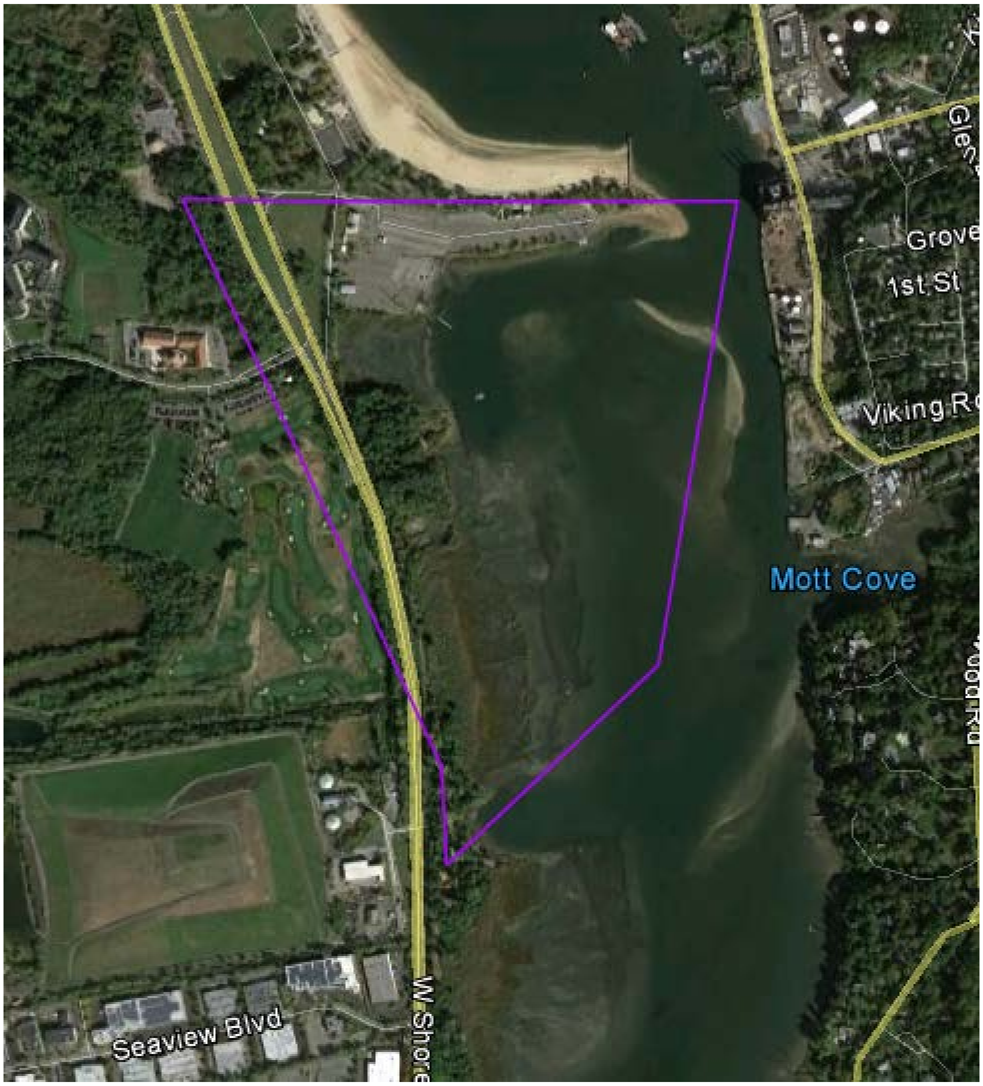
This natural area in Lattingtown is directly East of Dosoris Pond.

Figure E-8. Lattingtown Marsh



Site 3: Hempstead Harbor

Figure E-9. Hempstead Harbor



Site 4: Great Neck Estates Park

This site is on the border with NYC and only the Nassau County portion is included in this analysis at this time. Great Neck Estates Park is a members-only park with a kiddie pool with adjacent play facilities; seven tennis courts; marina and dock area; baseball and soccer fields; children's playground; and basketball and handball courts. http://www.vgne.com/parks.htm

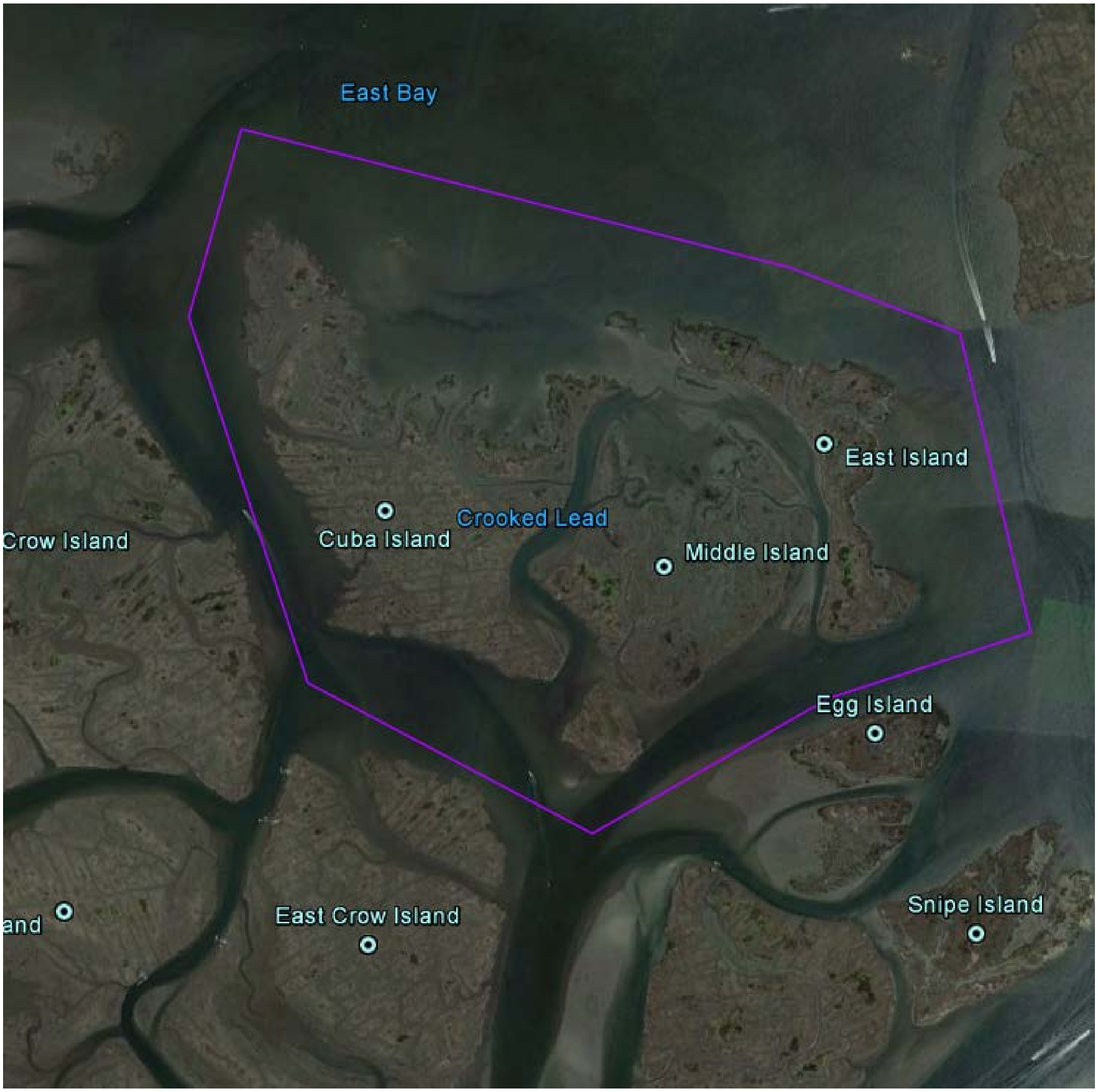
This site is contiguous with the Udall's Cove site in the NYC study area (marsh to the southwest).

Figure E-10. Great Neck Estates Park

Site 5: Cuba, Middle, and East Islands

These marsh islands between Meadowbrook /Wantagh parkway are uninhabited and currently composed of regularly flooded marsh and tidal flat.

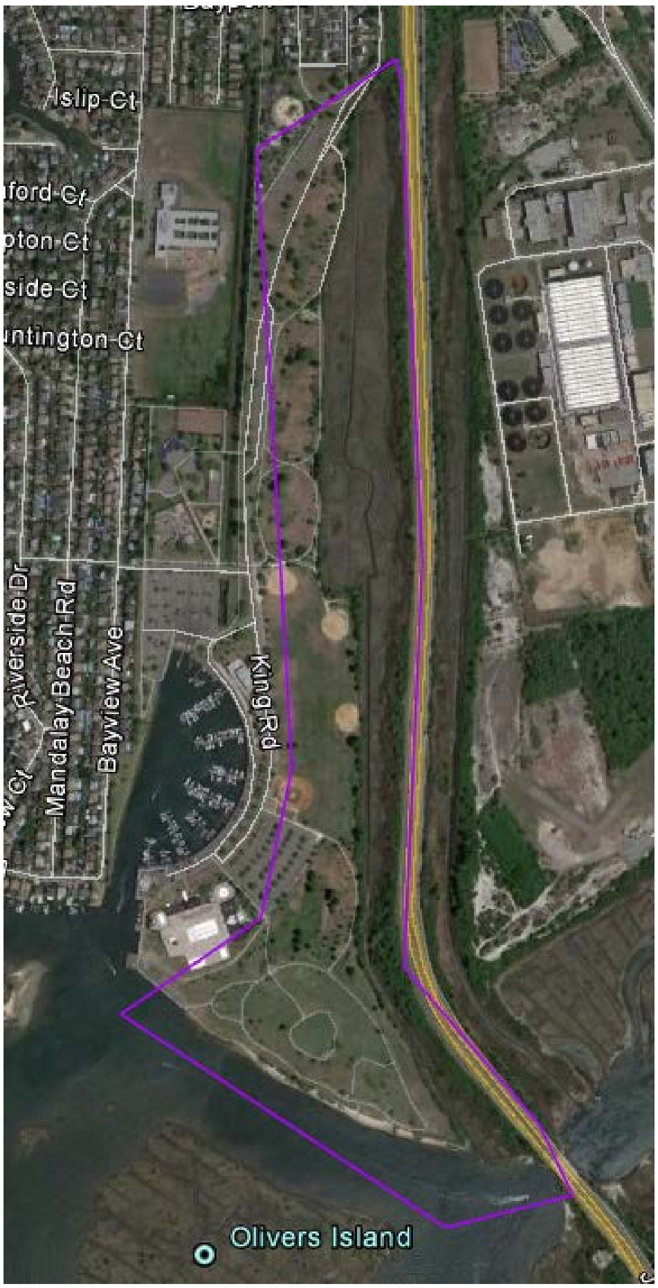
Figure E-11. Cuba, Middle and East Islands



Site 6: Wantagh Park

Wantagh Park is located in the Southeastern Nassau County and covers 111 acres. The park provides a waterfront location and numerous opportunities for recreation including a large swimming complex, tennis courts, softball fields, walking paths, a game area and bocce and horseshow courts. There are also boat slips and a fishing pier. https://www.nassaucountyny.gov/2805/Wantagh-Park

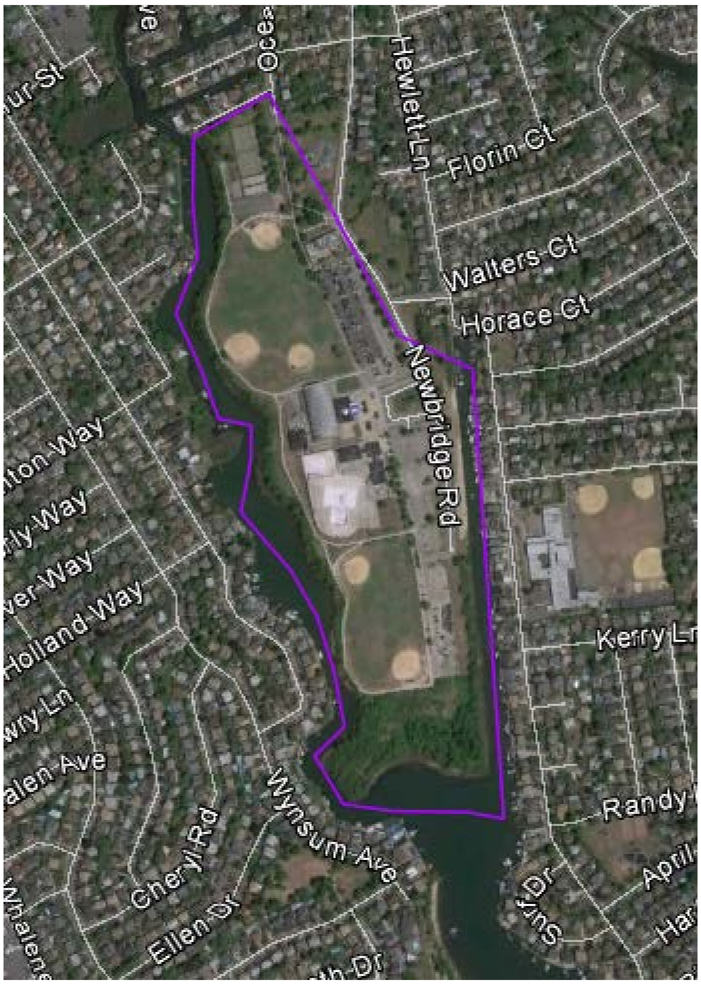
Figure E-12. Wantagh Park



Site 7: Newbridge Road Park

Located in the town of Hempstead, Newbridge Road Park includes basketball, handball, and tennis courts, softball, baseball, and multi-purpose fields, a playground, game tables, play equipment, outdoor pools, indoor ice rink, horseshoes, and a sitting area. http://www.toh.li/facilities/parks

Figure E-13. Newbridge Road Park



Site 8: Marine Nature Study Area

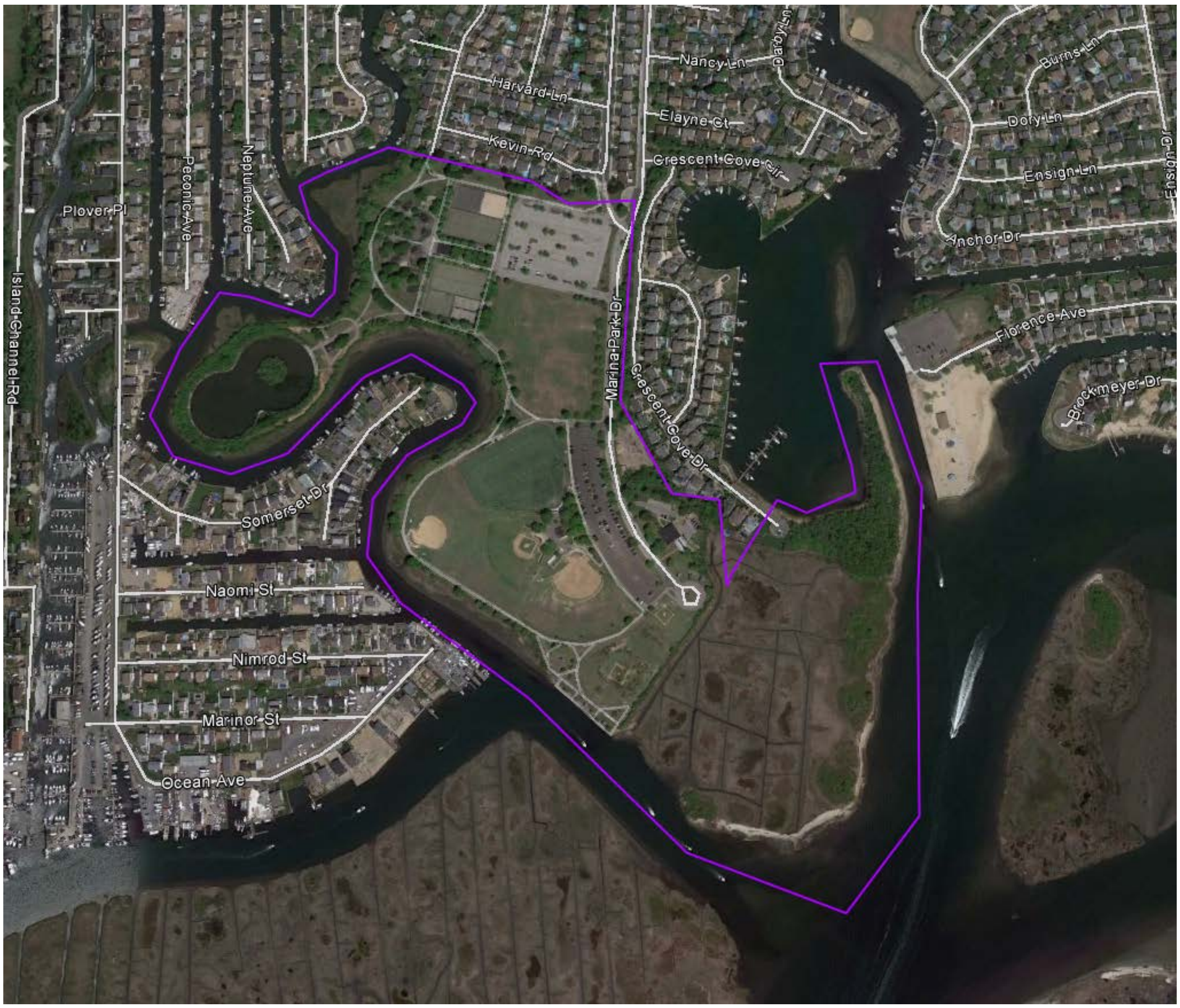
The Marine Nature Study Area is a 52-acre preserve located in Oceanside devoted to environmental education and natural history. This area provides an outdoor laboratory for elementary and secondary schools to study salt marsh ecology, marine conservation practices, earth science, and marine biology. The Area also provides opportunity for research in marsh ecology and management to local college students and opportunity for art and photographic studies.www.mnsa.info.

Figure E-14. Marine Nature Study Area

Site 9: Seaman's Neck Park Wetlands

Located in the Town of Hampstead, Seamen's Neck Park includes several recreations facilities as well as marshlands. The park offers courts and fields for basketball, handball, paddleball, tennis, volleyball, soccer, football, softball, and baseball as well as a playground, walking path, and a fishing pier.

Figure E-15. Seaman's Neck Park (parcel outlined in purple)



Site 10: Jones Beach State Park

Jones Beach State Park is made up of more than 2,400-acres of maritime environment on the south shore of Long Island. Jones Beach offers many activities to the 6 million visitors to the park each year among them are swimming in the ocean, strolling the boardwalk, fishing, playing miniature golf or learn about the marine environment at the Theodore Roosevelt Nature Center. http://nysparks.com/parks/jonesbeach/

Figure E-16. Jones Beach State Park

Appendix F. Suffolk County Site Summaries

For Suffolk County, stakeholders including Suffolk County government employees, The Nature Conservancy, and NY DEC were consulted to determine sites of interest across this vast county. A total of 23 sites were selected and the decision was made to look at results on a "breadth" rather than "depth" basis. In addition, for each site, stakeholders were provided a map of current wetland and future prospective wetland footprints as shown in Figures 70 and 71.

The full set of wetlands selected and all maps produced are available at the below URL: http://warrenpinnacle.com/prof/SLAMM/NYSERDA2015/Suffolk_Site_Details.pdf

Site list

Peconic Sites

P1 Accabonac Harbor
P2 Nappeaugue/Lazy Point
P3 Ashamonaque/Pipes Cove
P4 Orient Point
P5 Mashomack Preserve
P6 Flanders Bay/Hubbard County Park
P7 Cedar Beach - Southold

Southern Sites

S1 Carmans River/ Fire Place Creek
S2 Thorne Preserve
S3 Weesuck Creek/ Pine Neck Preserve
S4 Smith Point County Park-North
S5 Mastic Beach

Southern Sites (cont.)

S6 Thorne Preserve/Gardiner Co Park
S7 Timber Point
S8 West Sayville
S9 Pepperridge Hall
S10 Stokes/Pouges
S11 Captree Island
S12 Shinnecock Nation

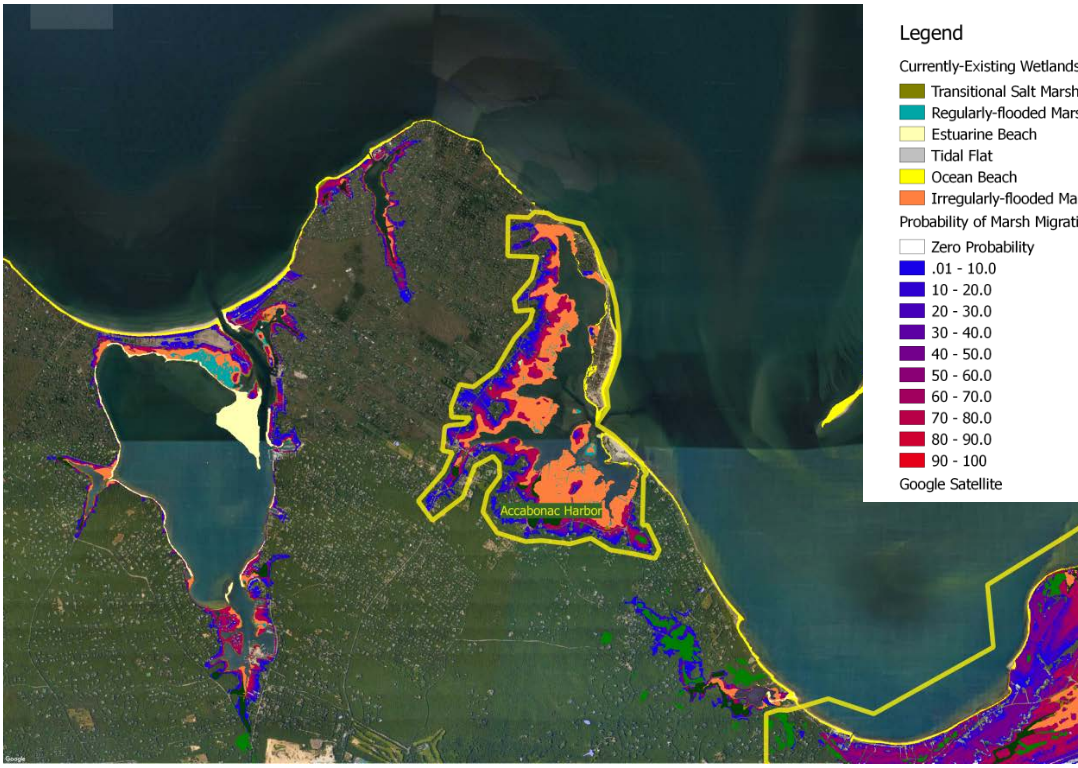
Long Island Sound Sites

L1 Wading River
L2 Sunken Meadow State Park
L3 Crab Meadow
L4 Flax Pond

Figure F-1. Western Portion of Suffolk County DMMT Study Area

Figure F-2. Eastern Portion of Suffolk County DMMT Study Area

Figure F-3. Site "P1," Accabonac Harbor: site outline, current, and future marshes



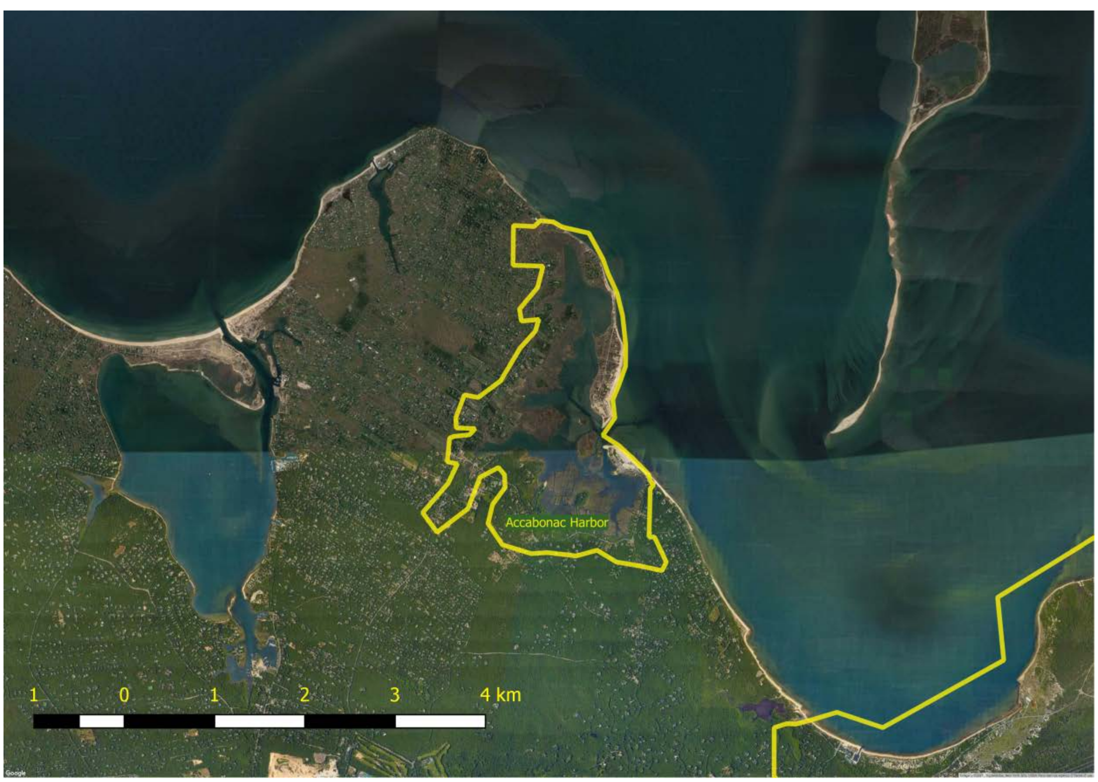
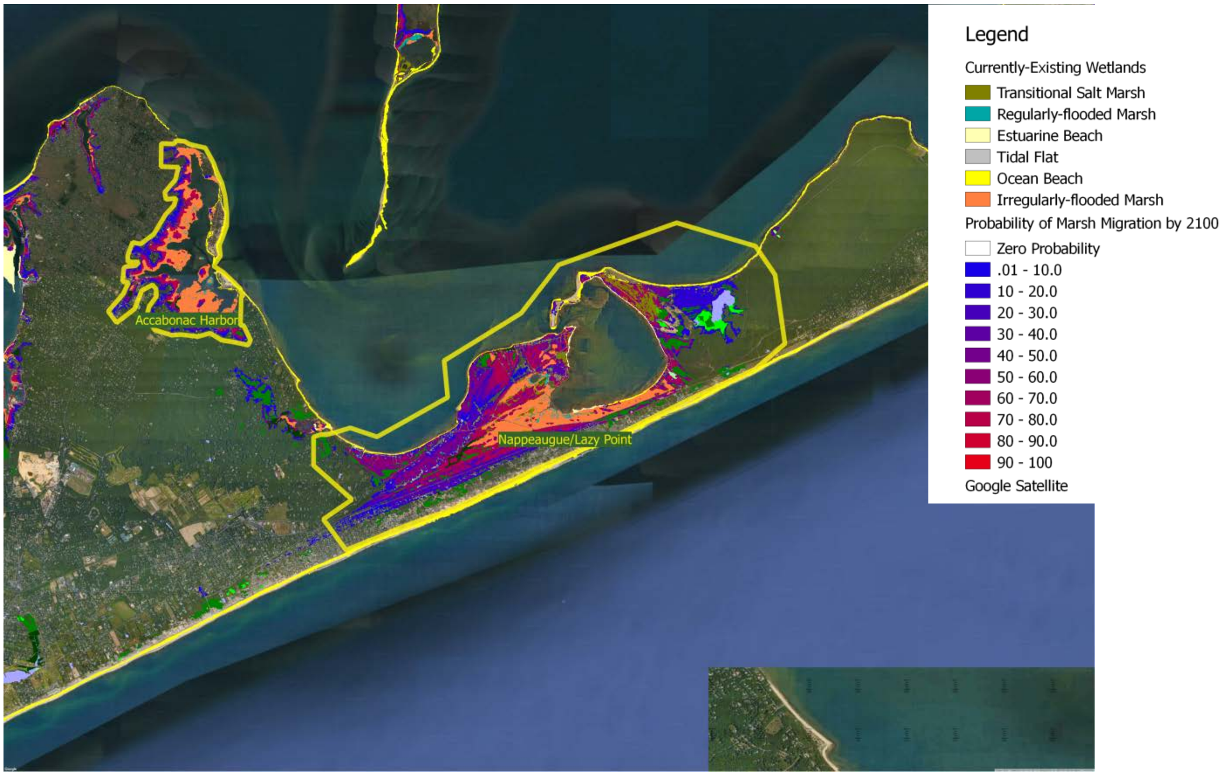


Figure F-4. Site "P2," Nappeaugue/Lazy Point: site outline, current, and future marshes



Appendix G. Ecosystem Services and Tool Glossary

Along with the corresponding site summary, each survey was circulated with a link to the Ecosystem Service Glossary to provide clarification and guidance on how to allocate weights to each site/service.

Ecosystem Service Glossary

Determining Site-specific Weights

The ecosystem benefits described above have all been related to the acreage predictions of land-cover types that come out of SLAMM simulations. However, these equations do not take into account quality of habitat, for example. (In one location with a higher marsh density, more carbon sequestration could be assumed to occur than at another location with lower density.) For this reason, site-specific weights are provided for the user to add information about each site when available. These are especially important for such categories as “recreation” in which the location and historic use of a marsh may be considered in providing weights.

If no information is available for a specific ecosystem service, all sites may be weighted evenly. In this case, one acre of wetland will be assumed to provide the same amount of benefit across sites.

Nutrient sequestration

Tidal marshes are important for improving water quality. In particular, they can sequester organic Carbon and nutrients that may otherwise lead to additional climate disruption or eutrophication of estuarine systems. The nutrient sequestration ecosystem services quantify the relative amount of organic carbon, nitrogen and phosphorus that may be accumulated based on landcover types. The ratios of nutrient sequestration were derived from the work of Loomis and Craft (2010). It is important to note that this work does not specifically account for methane emissions that may occur in freshwater wetlands.

The intention of the weight assigned to each nutrient is to represent how valuable the parcel may currently be for sequestration.

Recreation

Recreation is divided into three categories: Dry land (trails, ball fields, open space, etc.), Wetland, and "Natural services to underserved communities." Each is described.

Dry land. Dry land recreation is the current value of an area for recreation on dry land. This could include open fields, ball fields and courts, nature trails, etc. historical sites on dry land are accounted for here. *This was not included as an ecosystem service for the Suffolk County study area.*

Wetland. Wetland recreation describes the current value of an area for recreation in wetlands, which might include bird watching or the presence of boardwalk areas for nature observation and enjoyment.

Natural services to underserved communities. This ecosystem service combines the currently available areas and their proximity to underserved or at-risk communities. This allows one to give priority to areas that are located in or near areas where few other natural areas exist for recreation.

Nekton habitat (proximate to fishing areas). This ecosystem service was defined by Suffolk County stakeholders and was only modeled in that location. This considers food-web benefits of nekton habitat (defined in the following paragraph) on fishing populations near popular fishing areas.

Habitat

Nekton habitat. Nekton are animals that can move independently of water currents and include bony fish and aquatic mammals, turtles, snakes, octopus, squid, and shrimp. In particular, nearshore nekton habitat is important for juvenile fish to ensure the maintenance of healthy fish population. Salt marsh edge vs. interior is considered especially important habitat (Peterson and Turner 1994).

The weight assigned to this service is intended to represent the value of a particular parcel for supporting healthy nekton ecosystems.

Habitat connectivity. This service represents the degree of connectivity within a habitat by calculation the length of marsh edge per unit marsh area. Large marshes that are not fragmented have a low marsh edge density while narrow, fringing marshes, especially those that are fragmented and breaking apart, have a lot of edge.

Bird Habitat. High marsh habitat is especially important bird habitat for several species (Nicole Maher, Personal Communication) This utility benefits high marsh as a critical bird habitat.

Other Ecosystem Services

Wave Attenuation (also referred to as Flood protection)

This benefit quantifies the capability of the marsh system to provide some level of protection against storm surges. Normally, this is done by estimating the amount of energy that a marsh system can absorb when storm water reaches the system. In this tool, the “width” of the marsh is used to differentiate between parcels. As a simple rule of thumb, the energy absorbed may be assumed proportional to the width, though more complex models suggest a more complicated relationship to storm track, etc. (Wamsley et al. 2010). The spatial weights assigned to the parcels should reflect the value of infrastructure and quantity of population protected. Site-specific weights could be estimated using available data or assigned by expertise knowledge.

Political/Cultural/Historic value

This service accounts for the value of maintaining existing marshes to people for other reasons. Site specific weighting is critical, or alternatively this ecosystem benefit may be assigned to an overall weight of zero.

General preservation of wetlands

This utility accounts for the coverage of all wetland cover types. It may be used to define the intrinsic value of wetlands outside of defined anthropocentric benefits, or to capture benefits that are not captured by the recreation, habitat, and nutrient sequestration categories.

Weighting different utilities

The “ecosystem service relative rank” represents the value that is given in the decision-making process in comparison to other ecosystem services listed. If a user is mostly interested in recreation, for example, high weights could be given to those services and much lower (or zero) weights to nutrient sequestration.

Stakeholders should weight ecosystem services according to the level of importance for their decision. However, the spatial definition of the parcels to be examined also plays a role in this. A marsh-only parcel definition will not allow the user to assess dry-land recreation, for example. A marsh-only parcel definition will also not allow a user to assess the ecosystem services of marshes predicted to migrate beyond their existing footprints.

Appendix H. Infrastructure Data and sources

Infrastructure	Download Source/Provider	Peer-review status	Notes
Roads	DOT	DOT reviewed	
	NY GIS Clearinghouse		
Railroads	NY GIS Clearinghouse	Not specifically mentioned in metadata (from DOT, so likely reviewed)	
CERCLA site locations	NOAA Digital Coast	Published by NOAA's Ocean Service, Office for Coastal Management (OCM)*	None in Westchester
Coastal Energy Facilities	NOAA Digital Coast	Published by NOAA's Ocean Service, Office for Coastal Management (OCM)*	None in Westchester
USACE Coastal Projects	NOAA Digital Coast	Not specified	
Bridges (Nov2014)	NY GIS Clearinghouse	Not specified	
Dams	NY GIS Clearinghouse	Not specified	
Railroads Passenger Stations	NY GIS Clearinghouse	Not specified	
SPDES	NY GIS Clearinghouse	Not specified	
Airports	TNC	Not specified	None in Westchester and Nassau
Electric Power Facilities	TNC	Not specified	None in Westchester
Fire Stations	TNC	Not specified	
Medical Facilities	TNC	Not specified	
Police Stations	TNC	Not specified	
Potable Water Facilities	TNC	Not specified	None in Westchester and NYC
Schools	TNC	Not specified	
Wastewater Facilities	TNC	Not specified	

* "NOAA makes no warranties or representations regarding the availability, quality, accuracy, content, completeness or suitability for the user's needs of such information. The services, information, and data made available on the MarineCadastre.gov website are provided 'as is' without warranties of any kind. These data are intended for coastal and ocean use planning. Not for navigation."

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