Rhode Island
Shoreline Change Special Area Management Plan (SAMP)

Technical Report # 1

Title:

The Rhode Island Sea Level Affecting Marshes Model (SLAMM) Project

Summary Report

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Abstract/Executive Summary

Coastal wetlands, especially tidal marshes, are one of the most susceptible ecosystems to climate change and in particular accelerated sea level rise. A considerable percentage of coastal wetlands may be permanently lost by the end of this century unless upland areas directly abutting coastal wetlands are protected or otherwise set aside for the purpose of providing wetland migration in response to sea level rise (SLR). The problem facing Rhode Island and other coastal states is how best to quantify the response of coastal wetlands to sea level rise, identify affected upland areas that will likely be future coastal wetlands, and then use the information to develop and implement adaptive management strategies to protect and conserve these abutting upland areas and restore degraded wetlands.

Our project analyzed the potential impacts to coastal wetland ecosystems from sea level rise and the landward migration potential of coastal wetlands located within the 21 Rhode Island coastal municipalities. The main elements of the project included the Sea Level Affecting Marshes Model (SLAMM) version 6.1, the state 2011 LiDAR elevation data, and the 2010 digital Geographic Information System (GIS) National Wetland Inventory data set. Using 2011 elevation data provided an opportunity to assess future sea level rise scenarios along the Rhode Island shoreline and to depict inundation conditions and the response of wetlands under the selected SLR scenarios. The modeling effort used SLR projections of 1, 3 and 5 feet (above 1990 levels) to simulate short- and long-term impacts on coastal wetlands by the end of the century and to assess potential wetland migration pathways on both developed and undeveloped upland parcels.

The general results from our SLAMM simulations under all three SLR scenarios show a major change in land cover within the 21 coastal communities. In the near and long-term time frames, Rhode Island will face substantial loss of coastal wetlands and some freshwater wetlands in close proximity to the coast. Total statewide losses of existing coastal wetlands are projected to be 13%, 52% and 87% under 1, 3 and 5 feet SLR, respectively. Nevertheless, under the assumption that there will be successful marsh migration onto adjacent upland areas, the model is projecting that the state will have an overall net gain of coastal wetlands under all three SLR scenarios. Several communities, however, will experience an overall net loss of coastal wetlands under the 3 and 5 feet SLR scenarios.

Despite the SLAMM projections for potential new coastal wetland gains, existing development patterns greatly influences the outcomes. Our model was run in two different modes to obtain statistics of the impact that existing development have on the ability of coastal wetlands to migrate landward. In one mode SLAMM does not allow wetlands to migrate onto developed lands. We refer to this as “protected” development. In a second mode SLAMM allows wetlands to migrate onto developed areas (“unprotected” development) despite the highly altered upland condition including pavement, parking areas, etc. The utility of running the model in these two different modes allows a comparison as to how development will influence the overall ability of wetland migration and to show the potential for conservation and restoration efforts. The difference between these two model runs was significant with a fifteen (15) fold decrease in wetland migration acreage for protected development as compared to unprotected development (200 vs. 3000 acres) under the 5 foot SLR scenario.

The RI SLAMM project results will inform local municipalities, conservation organizations, and state agency decision-makers in developing adaptive management strategies to provide resiliency for critical coastal habitats and abutting upland areas necessary for the future success of migrating coastal wetlands. The project results will also assist in the adaptation and restoration planning efforts for coastal wetland ecosystems throughout the state.

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Introduction

Salt marshes are among the most productive habitats on the planet supporting numerous economic and environmental benefits such as nursery and forage for many marine fish and invertebrates, as well as nesting and migratory feeding sites for a number of bird species. Salt marshes help to keep coastal waters clean by filtering pollutants and sequestering nitrogen from nearby upland sources. In addition to these benefits, marshes help reduce the damage from coastal storms and erosion to shoreline infrastructure by absorbing wave energy. Unfortunately, much of these important habitats have already been lost due to filling and development by earlier generations unmindful to the damage and impacts on the marsh ecosystem. Present day marshes are now threatened by another stressor as rising seas advance upon our developed coastline. Under these circumstances, marshes will be squeezed between existing development and advancing seas and most likely will drown in place and disappear. Yet, if an unobstructed path is provided, there is the potential for these coastal wetland habitats to migrate landward with the rising sea levels. With the proper information and knowledge, local and state resource managers, planners and conservationists can take action to ensure that adjacent upland areas are available for these marshes to migrate landward and persist for future generations. This project is an effort to provide the data and knowledge to achieve the goal of preserving these important estuarine habitats.

As of 2010, coastal wetlands in Rhode Island comprised about 4,000 acres in and along Narragansett Bay and the coastal lagoons of the southern coastline. Going back to the early 1800’s Rhode Island had considerably more coastal wetland acreage before widespread destruction, filling and degradation of these wetlands occurred to support new development along the shoreline. As part of a research project on salt marsh losses in New England, Bromberg and Bertness (2005) calculated that Rhode Island lost approximately 1,831 hectares (4,524 acres) or 53% of salt marshes over the previous 200 years based on a study of historical maps. One of the more significant examples of salt marsh loss is the Great Salt Cove and associated wetlands in Providence where over many decades the cove was filled as new roads and buildings were constructed to support an ever expanding city. The downtown financial district near the confluence of the Woonasquatucket and Moshassuck Rivers rests largely on the remains of that earlier cove and its salt marshes. In addition, salt marshes were often filled with dredge spoils from navigation projects decades ago when the ecosystem values of these coastal wetlands were not well understood or appreciated.

The coastal wetlands of Rhode Island are now undergoing dramatic changes in vegetative composition and zonation primarily as a result of the impacts from sea level rise. The staff of the Narragansett Bay National Estuarine Research Reserve (NBNERR) and Save The Bay (STB) have been monitoring the impacts to coastal wetlands for over 10 years with consistent data showing that our salt marshes are not gaining sufficient elevation from sediment accretion and organic matter to keep up with observed rates of sea level rise. Other factors such as marsh compaction and subsidence also determine the overall elevation gain and loss on any particular marsh. Figure 1 shows typical degraded conditions that have been observed recently in RI salt marshes. Using Surface Elevation Tables (SETs) established at more than a dozen Rhode Island sites, NBNERR and STB researchers are collecting data and monitoring changes in marsh elevation. Although there are no long-term (greater than 20 years) marsh monitoring data from these SETs to support a statistically verifiable trend, the available data show that marshes have only been gaining elevation at a rate of about 1.5 mm/year averaged from several data sets going back to 1999 (Kenneth Raposa (NBNERR), pers. comm., January 20, 2015).

Figure 1. Typical degraded salt marsh conditions with sparse vegetation and standing water. Photo Credit: Wenley Ferguson, Save The Bay (Narrow River 2013)

The long-term rate of sea level rise at the Newport tide gauge averaged over the historic record 1930 to 2013, a period of 84 years, is 2.74 mm/year as shown in Figure 2. However, in review of the monthly mean NOAA tides data from 1993 through 2014 for both the Newport and Providence tide gauge stations show SLR trends over this period of about 4 mm/yr. The data are online at: http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8452660 for Newport and http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8454000 for Providence. These measurements are consistent with the satellite altimetry measured global SLR trend of 3.2 mm/yr for the same period of time as reported by the University of Colorado sea level research group at: http://sealevel.colorado.edu/.

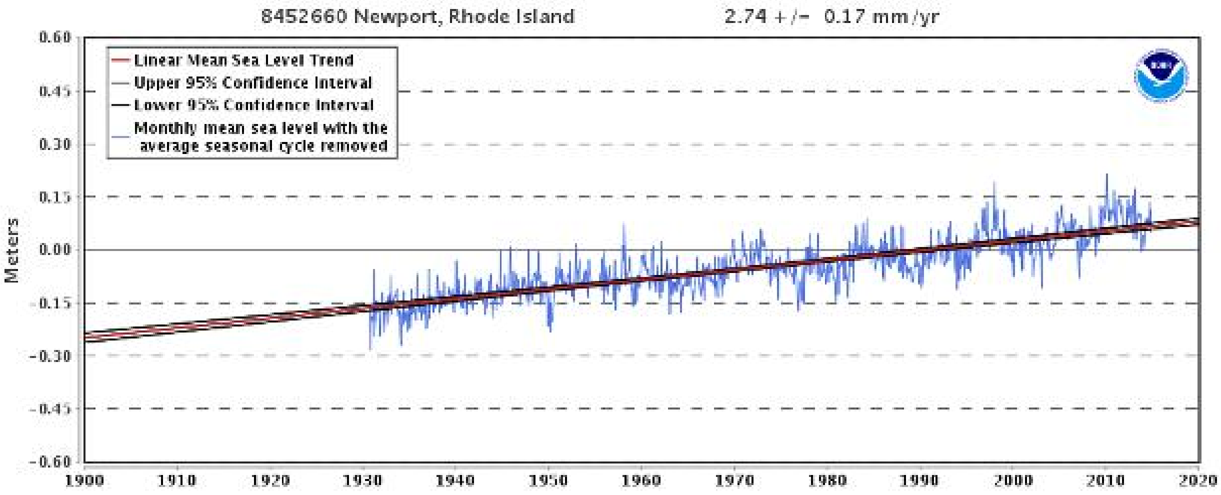

Figure 2. Historic sea level rise trend at Newport, RI

Source: http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8452660

Importantly, SLR along the North American Atlantic coast has accelerated over the last several decades as noted by Boon (2012). During the period 1970-2009, Sallenger et al. (2012) calculated a SLR rate of 3.80 mm/yr for this region. This trend is expected to continue into the end of this century as the relative rate (taking into account land subsidence) of SLR accelerates as shown in Figure 3 from projections by both the U.S. Army Corps of Engineers (ACOE) and NOAA for the Newport tide station.

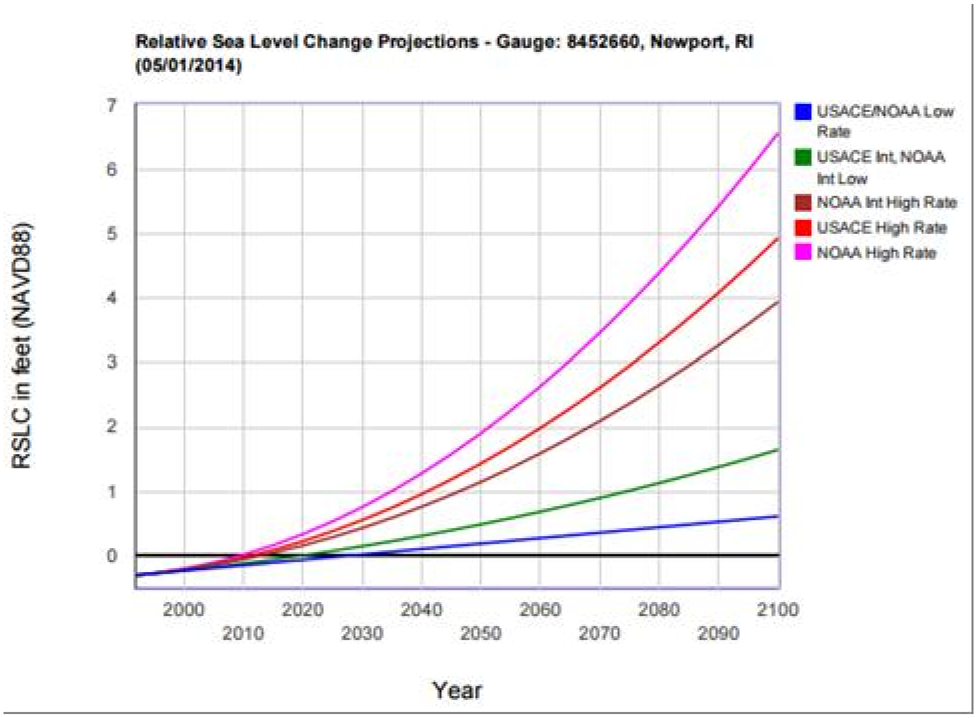

Figure 3. Projected sea level rise curves for Newport, RI

It's clear from both the local marsh elevation data and ongoing regional SLR trends that our marshes are not gaining elevation fast enough on an annual basis to keep pace with the present rates of SLR. Given these facts and the more frequent inundation that has been observed on the high marshes (zones dominated by Spartina patens and Distichlis spicata) it's not surprising that marsh deterioration is becoming more widespread. Based on the data and observations it's reasonable to assume that salt marsh deterioration will continue into the future. Salt marshes support numerous bird species that depend on salt marsh habitat for foraging and nesting, in particular the Saltmarsh Sparrow, Seaside Sparrow and Nelson's Sparrow (RIDEM 2015). The Saltmarsh Sparrow is reported in the current State Wildlife Action Plan as being a species of greatest conservation need in that it could become extinct within the years 2050-2070 due to the expected loss of salt marsh habitat (Id.). Additionally, our Rhode Island estuarine marsh habitats (brackish wetlands and salt marshes) support 14 rare flora species; 2 of which are globally rare and 12 that are regionally rare (New England Wild Flower Society, 2015). Sea level rise and other climate change factors will continue to exert compounding ecological factors on these particular habitats that will likely lead to a decline in the estuarine marsh habitat where these threatened bird species and rare plant and are found.

In 2011 the Rhode Island Coastal Resources Management Council, the University of Rhode Island (URI), URI Coastal Resources Center/RI Sea Grant and The Nature Conservancy and other partners completed a pilot project in the Town of North Kingstown to assess the impacts of sea level rise on town infrastructure, commercial and residential properties, and coastal wetlands. See: http://seagrant.gso.uri.edu/projects-2/north-kingstown-coastal-resilience/. As part of the project, the Sea levels Affecting Marshes Model (SLAMM) was used to model the response of existing coastal wetlands to SLR scenarios of 1, 3 and 5 feet by 2100. These SLR scenarios were used in the model largely because the CRMC had adopted in January 2008 a new Section 145 for climate change in its coastal program that projected sea levels of 3 to 5 feet above current levels (at that time) by the end of the century based on a range of projections supported by the latest peer-reviewed science and research.

The results of the North Kingstown pilot project provided the foundation for further analysis to evaluate the response of coastal wetlands to SLR in all 21 Rhode Island coastal municipalities. The project team was assembled in the fall of 2012 and commenced work to assemble the necessary data, run the model and conduct outreach with the 21 coastal municipalities to gain their input on draft SLAMM maps for their respective communities. The community outreach was invaluable in gaining local insight to the issues facing each community and their concerns regarding future sea levels and migrating coastal wetlands. The statewide SLAMM maps and Geographic Information System (GIS) data for the 21 coastal communities are the result of the RI SLAMM project using the best available information to model the most likely response of coastal wetlands to SLR and depict the locations of future salt marsh habitat under 1, 3 and 5 foot SLR conditions. The Sea Level Affecting Marshes Model (Version 6.1) was used with the most current wetland (National Wetlands Inventory 2010) and elevation (USGS 2011) data to produce the maps and GIS data layers.

How to use the SLAMM maps and GIS data

There is an inherent uncertainty when using SLAMM and it is important to interpret these maps properly. The input data are excellent but imperfect and future rates of SLR have a degree of uncertainty. The model itself has limitations, as it's a mechanistic model, and does not attempt to model the flow of water nor does it track and account for the movement of sediment. The parameterization of the model also requires knowledge of the rate of processes such as accretion, sedimentation and erosion, which vary both spatially and through time.

Since the model does not include substrate data it treats all dry land the same and predicted changes are mainly driven by elevation data. This means that given equal elevations and flooding frequencies, all dry land within the model has the same probability of converting to wetland in increased sea level scenarios. Because of this, the model output shows a number of places along the coast that are modeled to support salt marsh where none is currently present. Though this is possible, it is more likely that the model is overestimating future marsh on the whole, as future salt marsh development may depend upon substrate type, seed sources or other factors.

There are two options provided in the model application. One prevents the migration of salt marsh upon currently developed land and is known as “Protected Development”. The other option, known as “Unprotected Development” allows for the establishment of marsh over paved or otherwise developed areas provided all other factors are favorable for marsh migration and development. This mode was used to show the complete picture of potential future salt marsh based on predicted tidal range on an idealized landscape. In reality many of the currently developed areas would obstruct marsh migration and not allow the conversion to marsh. Thus, the Unprotected Development mode results in a likely overestimation of the acreage of newly-created wetland. This model option, however, allows for a more complete understanding of existing impediments to marsh migration and identification of potential restoration sites. Nevertheless, these data should not be interpreted without other supporting data layers to describe current land use and land cover to gain a more complete picture of landscape factors that may influence marsh migration.

Special consideration is needed for the state’s many barrier systems. These barriers separate the coastal lagoons from the open ocean and are very dynamic systems due to their constant reshaping by waves and wind. The model’s overwash component simulates the erosion from the ocean side of the barriers and the deposition of sediment on the landward side based on a frequency of one major storm every five years. Expert opinion (Jon Boothroyd, pers. comm., April 12, 2013) is that the model fails to maintain the barriers that are predicted to persist and migrate landward. Due to this lower degree of confidence in this particular aspect of the model, coastal barrier systems have been obscured by a cross-hatch on the SLAMM maps to advise the user of the higher degree of uncertainty in the model output for these barrier areas.

Finally, the rate and extent of wetland loss depicted by the model is very likely an underestimation given the current status and condition of Rhode Island coastal wetlands. The 2010 NWI data used as the “starting point” (baseline condition) in this study provides classifications of wetland types, but no information as to whether a wetland is currently exhibiting signs of stress or degradation to SLR. Additionally, the NWI data do not account for changes in vegetation composition, vegetation die-off or weakened substrate as observed through the ongoing NBNERR Sentinel Site monitoring and the Rhode

Island Salt Marsh Assessment study. Coastal wetlands in more advanced stages of degradation may convert to open water habitat sooner or at lower SLR scenarios than our model projections imply.

Despite some limitations with the model the data still provide a valuable tool to locate those places that will continue to provide salt marsh habitat or may have the potential to provide salt marsh habitat in the future. As a rule of thumb, an area of salt marsh that is projected to migrate from an existing wetland is a much more likely scenario than a patch of marsh that is projected to appear in an area without any currently existing marsh. As long as the limitations are understood these model results can confidently be used to identify conservation priorities, aid in design of coastal wetland restoration projects and assist the state agencies and local municipalities, along with other stakeholders, in developing adaptation strategies to conserve coastal wetlands into the future.

Methods and Data Sources

The modeling for this project was done using the Sea Level Affecting Marshes Model (SLAMM) version 6.1. The model simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea level rise (Clough et al. 2010). Detailed information on SLAMM is available online here: http://www.warrenpinnacle.com/prof/SLAMM/.Model input data were processed using Environmental Systems Research Institute (ESRI) ArcMap® 10 Geographic Information System (GIS) software. Additionally, ArcMap® was used to combine and display the model outputs in map format. See: http://www.esri.com/.

The SLAMM model requires the input of a number of user defined parameters that describe the local physical environment. These can be applied simply to the entire study area or a number of user defined sub-sites can be created. For this state-wide model application 105 sub-sites were defined to better characterize the local conditions and parameters based on the locations of the many different salt marsh habitats along the south shore and up into Narragansett Bay. Figure 4 shows the extent of these sites.

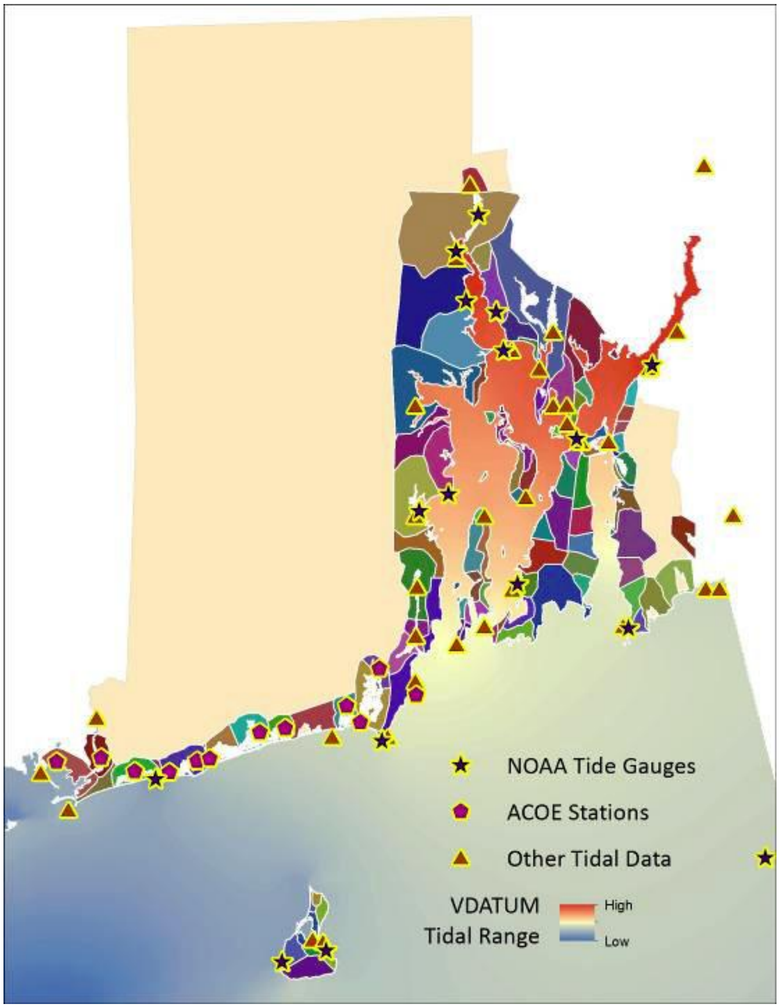

Figure 4. Map showing sub-sites and tidal stations for the RI SLAMM project. The model parameters and data sources are shown in Appendix 2 of this summary report.
Source: Kevin Ruddock, TNC 2014

Critical Wetlands

Early on in the development of this project we recognized the need to identify critical wetland areas that served as unique or rare habitat types, large marsh complexes, and those salt marshes that were critical habitat for the success of certain bird species (some of these are size dependent). We used 3 key attributes to define these wetland complexes. The National Audubon Society has identified and maintains an inventory of Important Bird Areas (IBA) throughout the United States and we were able to use their data for Rhode Island. See: http://netapp.audubon.org/IBA/State/US-RI. For this project we mapped those IBA that were primarily salt marshes, and we were of course particularly sensitive to identifying those marshes that support the Saltmarsh Sparrow, a threatened bird species in the state. All of these critical wetlands are shown in Figure 5.

Sea level fens were identified because they are very unique and rare in Rhode Island. In fact, there are only two known sites in the state. Sea level fens are an emergent wetland community that occupies the interface at the upper end of tidal marshes where there is an upland freshwater source, typically groundwater seepage. These habitats have a distinct species assemblage and are typically dominated by twig-rush (*Cladium*), bulrush (*Scirpus*) and spike-rush (*Elocharis*) in Rhode Island.

Most of the IBA wetlands are generally large marsh complexes that support particular bird species. We also identified other large coastal wetlands that were 25 acres and larger, as these wetlands serve important habitat functions and ecosystem services. Included within this category are marshes that although smaller than 25 acres were within 300 feet of other smaller marshes, and thus their combined acreage was 25 acres or more. These were considered as one unit for purposes of determining marshes of 25 acres or more. Some of these large existing marsh complexes will be lost under SLR scenarios of 3 or 5 feet. On the other hand, provided marsh migration is unobstructed and ideal conditions exist for the establishment of future wetlands under the same SLR scenarios, the SLAMM results show that several large marsh complexes of 25 acres or larger are likely to develop in the future. Accordingly, these future large marshes, which are identified on the SLAMM maps, are also shown in Figure 5.

Figure 5. Critical Wetland Areas for Rhode Island

Source: Kevin Ruddock, TNC 2014

SLAMM Results

Total statewide losses of existing coastal wetlands are predicted to be 13%, 52% and 87% under 1, 3 and 5 feet SLR, respectively. These are very significant losses when one considers that under the 5 feet SLR scenario the state could lose almost as much wetland as was lost by man-made alterations in the previous 200 years. While these losses may potentially be offset by projected gains from upland conversion to wetland in the future, there is uncertainty associated with the estimated wetland gains because much is unknown about the marsh migration process and the driving factors that create successful transition onto upland areas. Under the assumption that presently developed lands will block wetland migration (protected development mode) the model results show a net statewide increase of 38%, 19%, and 5% of new coastal wetlands for 1, 3, and 5 feet SLR, respectively. In contrast, allowing wetlands to migrate onto developed areas (unprotected development mode) results in net gains of 51%, 54% and 80% of new coastal wetland for the same SLR scenarios by the end of the century. Thus, existing development significantly impacts the ability of coastal wetlands to migrate with SLR and become established in upland areas.

Our baseline status of existing coastal wetlands was established using the National Wetlands Inventory 2010 data set for Rhode Island. For purposes of our study the data were segregated into three different wetland types representative of widely recognized wetland zones of irregularly flooded (high marsh), regularly flooded (low marsh) and transitional marsh/scrub shrub areas that abut the inland edges of the irregularly flooded high marsh. Table 1 breaks down the acreage of these coastal wetland habitats by municipality and statewide totals. The towns of Barrington, Charlestown, Narragansett, Portsmouth and South Kingstown have a combined total of 1,848 acres of existing coastal wetlands and represent almost 50% of the statewide total in just these five communities alone.

Tables 2 and 3 show the results of the SLAMM options for protected and unprotected development to understand the influence that current development patterns will have on the ability of coastal wetlands to migrate landward in the future with SLR. New marsh habitat is the acreage of coastal wetlands that are projected by SLAMM to develop under the selected SLR scenario. Persistent marsh is existing marsh that will continue to survive under the specified SLR elevation, while marsh habitat loss is the acreage that will drown in place or will not continue to persist at the specified SLR elevation.

Table 1. Initial status of coastal wetlands based on 2010 National Wetlands Inventory

City/Town	salt marsh (irregularly flooded)	salt marsh (regularly flooded)	transitional marsh/ scrub shrub	Grand Total
Barrington	31.9	327.5	5.6	365.1
Bristol	13.0	105.6	2.7	121.3
Charlestown	27.7	288.6	23.8	340.1
Cranston		2.9		2.9
East Greenwich	0.5			0.5
East Providence	11.1	65.6	3.5	80.3
Jamestown	3.8	117.9		121.7
Little Compton	116.2	43.6		159.9
Middletown		49.4		49.4
Narragansett	63.5	326.1	7.0	396.6
New Shoreham	14.8	55.9	0.9	71.6
Newport	3.7	17.0		20.7
North Kingstown	20.5	159.4	0.4	180.3
Portsmouth	46.7	384.0	4.2	434.9
Providence		4.2		4.2
South Kingstown	48.6	246.4	16.1	311.1
Tiverton	28.8	262.2		291.0
Warren	12.5	258.9	8.9	280.4
Warwick	28.1	211.9	0.5	240.5
Westerly	26.2	237.2	6.2	269.6
RI Total	**497.7**	**3,164.3**	**80.0**	**3,742.0**

Connecticut	8.2	95.8	1.0	105.0
Massachusetts	76.0	242.6	6.7	325.3
All State Total	**581.8**	**3,502.7**	**87.8**	**4,172.3**

Note: THE CT and MA coastal wetland areas are continuous and part of the RI coastal wetland complex. The RI Total is the result of “clipping” the GIS data set with the state line and is the total coastal wetland area specifically within the RI border.

Table 2. Salt marsh loss and gain in acres by City/Town under specified sea level rise- Protected

(Note: The SLAMM protected development option does not allow coastal wetlands to migrate onto current developed areas**.)**

	1 ft. Sea-Level Rise			**3 ft. Sea-Level Rise**			**5 ft. Sea-Level Rise**		
City/Town	**new marsh habitat**	**persistent marsh habitat**	**marsh habitat loss**	**new marsh habitat**	**persistent marsh habitat**	**marsh habitat loss**	**new marsh habitat**	**persistent marsh habitat**	**marsh habitat loss**
Barrington	164.6	349.5	33.8	327.9	308.8	74.5	428.0	35.7	347.6
Bristol	60.1	100.0	21.3	85.3	88.4	32.9	128.1	22.1	99.2
Charlestown	73.1	278.9	61.1	173.0	52.6	287.4	215.1	11.2	328.9
Cranston	0.5	2.5	0.3	12.0	1.9	0.9	45.3	0.6	2.3
East Greenwich	4.3	0.5	0.0	1.7	0.2	0.3	1.9	0.1	0.4
East Providence	54.9	59.4	3.8	82.9	55.2	8.0	117.2	8.6	54.6
Jamestown	81.1	107.5	14.3	67.9	56.0	65.8	98.4	5.7	116.0
Little Compton	55.5	134.7	24.8	82.2	87.0	72.5	143.0	63.3	96.2
Middletown	41.4	40.6	8.8	39.6	22.0	27.4	35.5	6.8	42.6
Narragansett	77.2	389.5	10.2	121.0	111.7	287.9	144.7	42.6	356.7
New Shoreham	120.7	68.0	3.6	109.6	22.1	49.6	97.4	10.2	61.4
Newport	76.4	12.9	7.9	77.9	4.9	15.8	124.3	1.4	19.3
North Kingstown	185.6	170.8	9.6	249.7	105.5	74.8	363.4	31.7	148.6
Pawtucket	7.9	0.0	0.0	6.6	0.0	0.0	9.6	0.0	0.0
Portsmouth	237.4	382.5	55.0	246.3	266.9	170.6	332.5	79.9	357.6
Providence	8.4	3.9	0.3	8.1	3.5	0.6	13.3	1.1	3.1
South Kingstown	78.8	276.9	35.0	124.1	79.4	232.5	194.0	30.9	280.9
Tiverton	134.3	256.1	35.1	190.3	125.3	166.0	234.2	17.1	274.2
Warren	109.4	250.9	29.3	249.2	217.3	62.9	327.1	37.8	242.4
Warwick	185.8	214.8	25.9	218.7	162.9	77.8	315.5	44.7	195.9
Westerly	89.4	240.4	29.1	136.2	62.0	207.6	111.6	18.4	251.2
RI Total	**1,846.9**	**3,340.4**	**409.2**	**2,610.2**	**1,833.6**	**1,915.8**	**3,480.0**	**469.8**	**3,279.2**

Table 3. Salt marsh loss and gain in acres by City/Town under specified sea level rise-Unprotected

(Note: The SLAMM unprotected development option allows coastal wetlands to migrate onto currently developed areas provided all other model parameters are favorable for marsh development.)

	1 ft. Seal-Level Rise			3 ft. Sea-Level Rise			5 ft. Sea-Level Rise		
City/Town	**new marsh habitat**	**persistent marsh habitat**	**marsh habitat loss**	**new marsh habitat**	**persistent marsh habitat**	**marsh habitat loss**	**new marsh habitat**	**persistent marsh habitat**	**marsh habitat loss**
Barrington	240.7	349.5	33.8	493.2	308.8	74.5	743.2	35.7	347.6
Bristol	79.4	100.0	21.3	142.7	88.4	32.9	236.7	22.1	99.2
Charlestown	82.0	265.1	75.0	192.4	50.7	289.4	283.4	14.9	325.1
Cranston	6.2	2.5	0.3	21.2	1.9	0.9	79.0	0.6	2.3
East Greenwich	6.5	0.5	0.0	5.3	0.2	0.3	10.5	0.1	0.4
East Providence	88.4	59.4	3.8	138.7	55.2	8.0	228.7	8.6	54.6
Jamestown	91.3	107.5	14.3	83.6	55.9	65.8	137.8	5.7	116.1
Little Compton	59.0	134.7	24.8	92.7	87.0	72.5	163.2	63.3	96.2
Middletown	56.8	40.6	8.8	46.2	21.9	27.5	46.1	6.8	42.6
Narragansett	102.1	380.0	19.8	190.9	104.2	295.6	266.8	40.5	359.3
New Shoreham	148.4	68.0	3.7	155.8	22.0	49.7	161.7	10.2	61.5
Newport	107.9	12.8	7.9	217.9	4.9	15.8	415.9	1.6	19.2
North Kingstown	232.6	170.8	9.6	411.0	105.5	74.8	868.5	31.7	148.6
Pawtucket	9.1	0.0	0.0	7.8	0.0	0.0	14.3	0.0	0.0
Portsmouth	275.9	382.5	55.0	327.1	266.9	170.6	502.7	79.9	357.7
Providence	35.8	3.9	0.3	64.2	3.5	0.6	193.2	1.1	3.1
South Kingstown	101.6	253.4	58.5	166.9	59.2	252.7	243.4	27.7	284.2
Tiverton	151.2	256.1	35.1	221.8	125.3	166.0	288.7	17.1	274.2
Warren	150.1	250.9	29.3	362.0	217.3	62.9	511.0	37.8	242.4
Warwick	254.0	214.8	25.9	380.6	162.9	77.8	632.8	44.7	195.9
Westerly	112.7	224.4	45.1	237.0	54.0	215.6	250.1	18.4	251.2
RI Total	**2,391.6**	**3,277.4**	**472.1**	**3,959.2**	**1,795.7**	**1,953.9**	**6,277.6**	**468.3**	**3,281.3**

Importantly, the net overall change in coastal wetland acreage by community and statewide was significant. The SLAMM results for the protected mode (not allowing migration onto developed land) shows a net statewide increase of 1,438 acres, 695 acres and 201 acres, respectively, of new coastal wetlands for SLR of 1, 3, and 5 feet by the end of the century. This represents an increase of 38%, 19% and 5%, respectively, over existing coastal wetland acreage (baseline conditions). In contrast, our model results for unprotected development show a net statewide increase of 1,919 acres, 2,005 acres and 3,000 acres of new coastal wetland habitat for the same SLR scenarios if wetlands are able to migrate onto developed areas (unprotected mode). This represents an increase of 51%, 54% and 80%, respectively, over baseline conditions. Clearly, existing development along our shorelines will greatly impede the ability of coastal wetlands to migrate landward. For example, our results show that with one foot of SLR there is a 481 acre difference in marsh migration acreage where existing development blocks wetland migration as compared to allowing wetland migration to occur regardless of current development status. This difference grows to 2,800 acres under 5 feet of SLR. Although the model results show the state as a whole will see net overall gains of coastal wetlands under all SLR scenarios, the communities of Charlestown, Narragansett, South Kingstown and Westerly are projected by the model to see net losses under 3 and 5 feet of SLR as shown below in Table 4.

Table 4. Net change of coastal wetlands in acres by City/Town for both Protected and Unprotected development model runs

	Unprotected Development			**Protected Development**		
City/Town	**1 ft. SLR**	**3 ft. SLR**	**5 ft. SLR**	**1 ft. SLR**	**3 ft. SLR**	**5 ft. SLR**
Barrington	206.9	418.7	395.6	130.8	253.4	80.4
Bristol	58.1	109.8	137.5	38.8	52.4	28.9
Charlestown	7.0	-97.0	-41.7	12.0	-114.4	-113.8
Cranston	5.9	20.3	76.7	0.2	11.9	43.0
East Greenwich	6.5	5.0	10.4	4.3	1.4	1.5
East Providence	84.6	130.7	174.1	51.1	74.9	62.6
Jamestown	77.0	17.8	21.7	66.8	2.1	-17.6
Little Compton	34.2	20.2	67.0	30.7	9.7	46.8
Middletown	48.0	18.7	3.5	32.6	12.2	-7.1
Narragansett	82.3	-104.7	-92.5	67.2	-166.9	-212.0
New Shoreham	144.7	106.1	100.2	117.1	60.0	36.0
Newport	100.0	202.1	396.7	68.5	62.1	105.0
North Kingstown	223.0	336.2	719.9	176.0	174.9	214.8
Pawtucket	9.1	7.8	14.3	7.9	6.6	9.6
Portsmouth	220.9	156.5	145.0	182.4	75.7	-25.1
Providence	35.5	63.6	190.1	8.1	7.5	10.2
South Kingstown	43.1	-85.8	-40.8	43.8	-108.4	-86.9
Tiverton	116.1	55.8	14.5	99.2	24.3	-40.0
Warren	120.8	299.1	268.6	80.1	186.3	84.7
Warwick	228.1	302.8	436.9	159.9	140.9	119.6
Westerly	67.6	21.4	-1.1	60.3	-71.4	-139.6
Total	**1,919.4**	**2,005.1**	**2,996.6**	**1,437.8**	**695.2**	**201.0**

A cautionary note needs to be stated here as these results may be interpreted as being very positive in that the model predicts overall statewide net gains of coastal wetlands under all SLR scenarios despite present development patterns. What is not well understood is the future condition of new tidally influenced areas. It’s very likely that many upland areas inundated by SLR in the future may not result in the establishment of new salt marsh, despite SLAMM predictions otherwise. These upland areas may be converted to regularly-flooded tidal flats and may not establish salt marsh vegetation for long periods of time, if ever. Another uncertainty is the future rate of SLR. A very rapid acceleration in the coming decades, at a rate higher than anticipated by the model, may overwhelm accretion and elevation gains by new salt marsh. Accordingly, this will result in much smaller net gains of new coastal wetland acreage than presently predicted by these model results. Other uncertainties include nutrient pollution, stormwater discharge and other factors that negatively impact salt marshes. We also suspect that the NWI 2010 wetland data set for RI used in our analysis may overestimate the current acreage of existing salt marshes in that some of the areas interpreted as marsh may have converted to open water or deteriorated significantly since the time of aerial photo interpretation. This hypothesis is supported by a recent study by Watson et al. (in review) reporting Rhode Island salt marsh vegetation losses at 17.3% in comparing the 2011 with 1972 areal extent of salt marshes. Consequently, our SLAMM projections for “persistent” marsh may likely overestimate the acreage of marsh that is shown not to be submerged (and therefore persistent) under SLR scenarios of 1, 3, and 5 feet.

The results from recent EPA, NBNERR and STB research and observations on RI salt marshes suggests that current salt marsh deterioration and fragmentation has been and continues to be largely driven by SLR, and it’s likely these salt marshes will continue to deteriorate and become unstable as tidal inundation increases in the future. We anticipate that existing marshes may be quickly submerged with increasing SLR, which would further reduce the marsh migration potential onto upland areas. Thus, we view these SLAMM results to be optimistic with respect to the projected gains in acreage of viable coastal wetlands through the end of this century. Given the uncertainties associated with new marsh development via marsh migration, it’s likely that we will see a period of overall net loss of salt marsh function as new marshes develop in tidally influenced areas.

In addition to the losses and gains for coastal wetlands statewide, as well as net overall changes, our SLAMM results show that some freshwater wetlands located near the shoreline at lower elevations will become submerged by tidal waters in the future. The model projects that these low lying freshwater wetlands will likely convert to coastal wetland habitat. Inundation by tidal waters will certainly negatively impact and alter vegetation that is not adapted to saline conditions. Once these affected freshwater wetland systems are regularly flooded by tidal waters the vegetation will die off and the area may likely convert to tidal flat habitat for some period of time before the eventual establishment of coastal wetland vegetation. Table 5 shows freshwater wetland losses of 204 acres, 635 acres and 1060 acres statewide with 1, 3 and 5 feet of SLR, respectively. Moreover, the largest percentages of freshwater wetland acreage losses as a result of SLR are attributable to the towns of Barrington, Charlestown, South Kingstown, Warren and Westerly. These five communities account for almost one-half of the total statewide losses of freshwater wetland ecosystems under the 5 feet of sea level rise scenario.

Table 5. Freshwater wetland losses in acres by City/Town under specified sea level rise scenario

City/Town	1 ft. SLR	3 ft. SLR	5 ft. SLR
Barrington	32.9	100.7	144.4
Bristol	5.9	18.3	31.3
Charlestown	7.0	41.3	97.1
Cranston		11.2	39.7
East Providence	2.8	31.0	43.5
Jamestown	5.6	12.7	19.4
Little Compton	12.1	23.1	47.0
Middletown	9.0	21.3	26.5
Narragansett	5.2	29.9	52.8
New Shoreham	26.3	30.0	33.9
Newport	5.0	34.8	57.4
North Kingstown	9.6	23.9	61.1
Portsmouth	7.7	15.6	23.2
South Kingstown	9.2	41.8	84.6
Tiverton	32.2	48.6	66.9
Warren	13.3	77.2	99.3
Warwick	4.3	23.9	56.7
Westerly	15.6	50.0	75.0
Total	**203.8**	**635.3**	**1059.7**

Note: There are no freshwater wetland losses for the communities of East Greenwich, Pawtucket and Providence as modeled.

Next Steps and Recommendations

Adoption of SLAMM maps

The primary task of the project was to develop SLAMM maps for all 21 Rhode Island coastal communities and facilitate their adoption as part of the RI Coastal Resources Management Program, essentially sanctioning the maps for use by local municipalities and state agencies. The CRMC issued public notice and proposed coastal program amendments to adopt the SLAMM maps on October 6, 2014. At a public hearing held on January 13, 2015 the CRMC adopted the amendments, which became effective on March 3, 2015 after filing with the office of the RI Secretary of State. See: http://www.crmc.ri.gov/regulations.html#adopted. The adoption of the SLAMM maps by the CRMC now officially endorses the use of these maps by local government and state agencies for vulnerability assessments, adaptation planning and coastal wetland restoration design purposes. Additionally, these maps may also inform land development permit decisions at both the local and state levels.

The CRMC is using the SLAMM map data to aid in the design of two coastal wetland restoration projects along the south coast as detailed below. The SLAMM maps are accessible from the CRMC web page in PDF format at: http://www.crmc.ri.gov/maps/maps_slamm.html. The maps can be viewed by clicking on the selected map panel on the index map or by selecting one of the 21 PDF files that cover each of the coastal communities. Additionally, the Geographic Information System (GIS) shape files and metadata have been uploaded to the RIGIS website (http://www.edc.uri.edu/rigis/spfdata/oceans/SLAMM15.zip) for use in GIS desktop software applications.

Design and planning for coastal wetland restoration projects

The SLAMM maps are being used to inform the planning and design for coastal wetland restoration and coastal resiliency projects in Rhode Island following a $7 million grant award from the U.S. Department of the Interior. The CRMC in partnership with the U.S. Fish & Wildlife Service, The Nature Conservancy and Save the Bay are nearing implementation of a project to restore some selected coastal wetlands within the Narrow River in Narragansett and South Kingstown. As part of this effort a pilot project will be conducted to evaluate the effectiveness of applying thin layer deposition (TLD) of sediment on the marsh surface to help the wetland gain elevation and stay ahead of persistent sea level rise. Following the TLD application and subsequent monitoring, if deemed successful, the method may be used on other vulnerable coastal wetlands where feasible and cost effective. Also as part of the Narrow River project the runnel (shallow ditching) method will be used on selected high marsh areas to drain standing water and eroding marsh edges will be secured using a combination of methods including coir logs and oyster shell bags to create so-called “living shorelines.” Coastal wetland restoration projects are also being planned with the help of SLAMM maps for Ninigret, Quonochontaug and Winnapaug Ponds. These sites may also be candidates for the TLD method if the pilot project in the Narrow River proves successful. Additionally, the SLAMM maps are helping in the design of a coastal wetland restoration project at Sachuest Point in Middletown.

The SLAMM maps are also being used to highlight areas where different land management techniques should be implemented to foster landward marsh migration. This information is especially valuable to land trusts, private property owners and municipalities. For example, a portion of a low lying active agricultural field adjacent to the Seapowet salt marsh in Tiverton is proposed to be planted with warm season grasses as part of a coastal adaptation project led by RIDEM and funded by the CRMC. This action will allow the advancement of marsh vegetation into the field as sea levels continue to rise.

Incorporation of SLAMM results and data into RI State Wildlife Action Plan

The RI Department of Environmental Management (DEM) is integrating SLAMM project results into the current update of the State Wildlife Action Plan (SWAP). The DEM plans to use the SLAMM results and revised SWAP to implement adaptive management strategies at state facilities/management areas under DEM ownership or control to conserve coastal wetlands and adapt to rising sea levels. The draft State Wildlife Action Plan is posted online at:

http://www.dem.ri.gov/programs/bnatres/fishwild/swap15.htm. The DEM Freshwater Wetlands staff also intends to use SLAMM project data to inform the state Freshwater Wetland Monitoring & Assessment Program concerning the future loss of wetland habitat, as projected by SLAMM for those freshwater wetlands near the coast that will be affected by sea level rise and tidal inundation.

Using SLAMM results and data to inform state and local decision-making

Based on key stakeholder input and analysis of SLAMM results, the Project Team developed an outline of “Opportunities & Challenges” together with adaptive management options on a representative SLAMM map for selected communities. The annotated maps depict sample adaptive management options that may be feasible and achievable for each selected area. The Project Team engaged key stakeholders over the 2-year project period through municipal meetings, workshops and stakeholder meetings. This provided input and feedback to validate SLAMM maps and to inform recommendations on coastal wetland adaptation strategies. The Project Team conducted two municipal workshops held on October 28 and 30, 2014. The workshops provided coastal municipal planners and other local officials with training on use of the SLAMM data and decision support tools, and recommendations to increase municipal capacity to proactively incorporate climate change adaptation policy for coastal wetlands in local comprehensive plans and zoning codes. In all, the Project Team directly engaged and communicated with over 300 people throughout the state, including state and local officials, land trusts, conservation organizations and other stakeholders during the two year project.

The Project team worked closely with the RI Statewide Planning Program staff to develop criteria and guidance for incorporating climate change and the RI SLAMM project results within a draft state guidance document for the preparation of local comprehensive plans. Each municipality is required by state law to update their comprehensive plans, which guide local land use and zoning ordinances, to address climate change and protection of natural resources by 2016. It is expected that each of the 21 RI coastal communities will reference SLAMM maps and insert data into their comprehensive plans as to how their community will address projected wetland loss, provide marsh migration pathways, and enhance conservation efforts to preserve coastal wetlands for the future.

Statewide Recommendations

1. Support needed field research into salt marsh migration to determine current migration rates and patterns, what affects those rates, and to test methods that can enhance marsh migration rates. These data will help to ground truth the SLAMM predictions and support further salt marsh adaptation efforts.
2. Implement statewide education and outreach with residents (including seasonal residents), municipal officials, business community, realtors, designers, engineers and other stakeholders on coastal wetland conservation issues. Use the CRMC Shoreline Change (Beach) Special Area Management Plan as the primary statewide education and training forum.
3. Use SLAMM maps to plan and design new or rebuilt transportation infrastructure, including raising roadways, building causeways, enlarging culverts beneath roadways, and relocating or modifying parking lots to promote coastal wetland migration.

4. Use SLAMM maps as part of the State Planning Council review process for major state capital projects and economic development planning.
5. Implement green infrastructure in state and local projects to manage stormwater in coastal areas that is thoughtfully designed around coastal wetland migration.
6. Require developers of state and local projects to review SLAMM results for project sites and incorporate design elements (e.g., building location, parking areas, etc.) based on the project design life (e.g., 20, 30, 50 years, etc.) to accommodate future coastal wetland locations and functionality where warranted.
7. Use SLAMM maps to design state and local redevelopment projects in areas abutting existing marsh complexes to provide for coastal wetland migration.
8. Consider implementing setbacks and buffers based on SLAMM coastal wetland migration projections to reserve targeted upland areas for future wetland migration pathways.
9. Establish funding mechanism for purchasing targeted upland areas to promote coastal wetland migration.
10. Consider the use of a rolling easement concept for new coastal development project permits based on SLAMM projections to help manage upland areas for coastal wetland migration in the future. A rolling easement concept could be embodied in permit language and determined by sea level rise threat and coastal wetland encroachment.
11. Discourage the use of hardened shoreline protection structures and encourage alternative shoreline protection methods that allow coastal wetland migration where feasible.

Recommendations for local communities to implement adaptive management strategies for conserving coastal wetlands

1. Engage planners, building officials, planning and zoning boards, public works, conservation commissions, land trusts and other local stakeholders to understand sea level rise impacts and the implications of SLAMM.
2. Incorporate SLAMM results including community specific maps and other information into new updated natural hazards section of municipal comprehensive plans consistent with requirements of R.I.G.L. § 45-22.2-6.
3. Consider SLAMM maps for 3 foot sea level rise (SLR) scenario as part of the local building permit review process.
4. Use SLAMM maps based on 5 foot SLR scenario for planning of major capital expenditures on local public infrastructure with long range (50+ years) design life.
5. Develop or update local conservation development ordinances to shift new construction and development projects away from SLAMM projected potential salt marsh areas.
6. Develop zoning overlay district with special use permit for high hazard areas that include storm surge inundation, sea level rise and SLAMM data to guide development away from these risky and highly vulnerable areas.

7. Review SLAMM maps in the local planning and review of local redevelopment projects in areas adjacent to salt marshes.
8. Include SLAMM results into other local long-range plans for waterfront development, natural resource and land conservation, and water resource planning efforts.
9. Use SLAMM maps to guide local wetland restoration projects.
10. Engage in outreach to residential and commercial property owners.
11. Use SLAMM maps to inform the purchase of affected upland parcels or obtain conservation easements to accommodate wetland migration onto adjacent upland areas.

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Appendix 1 – SLAMM Map Atlas and RIGIS Data

A statewide hyperlinked PDF index map for individual SLAMM map panels and complete PDF map sets for each coastal community are available on the CRMC website at:
http://www.crmc.ri.gov/maps/maps_slamm.html

SLAMM Geographic Information System (GIS) shape files are posted on the RIGIS website here: http://www.edc.uri.edu/rigis/data/data.aspx?ISO=oceans. Please review the associated metadata file to better understand the limitations and caveats when using the SLAMM shape files for analyses.

Appendix 2 – Model Parameters and Data Sources

The following information describes the model parameters and data sources used for the RI SLAMM project.

Parameter: *DEM date*
Value: 2011
This parameter is called DEM data as it refers to the date of the Digital Elevation Model (DEM) used to create the elevation and slope input grids. The SLAMM model is dependent on accurate elevation data and the best elevation data available for Rhode Island (2011 LiDAR) were used at the time of the model. A 5-meter cell size DEM was created by re-sampling the bare earth elevation data provided by the Northeast LiDAR Project
Source: http://www.edc.uri.edu/rigis/data/download/2011USGS/about.html.

Parameter: *Historic Sea level rise*
Value: 2.6 mm
This parameter is used to estimate subsidence or uplift by comparison with the global rate.

Source: Newport tide gauge, Newport, RI http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8452660

Parameter: *MTL – NAVD88*
Value range: -0.018m to -0.109m
This parameter is used to convert from a geodetic vertical datum, in this case NAVD88, to a datum that is relative to mean tide level (MTL). The adjustment is smallest in upper Narragansett Bay, particularly in Mount Hope Bay and the Seekonk River. The largest adjustments were needed toward the southwest coast of the state especially for Little Narragansett Bay in Westerly.

Source: NOAA tide gauges and VDATUM (http://vdatum.noaa.gov/)

Parameter: *NWI date*
Value: 2010
This parameter refers to the date of the wetland input data. The wetland data are an important model input representing the distribution of wetland habitats at the initial condition of the model. The attributes of the NWI were simplified to the SLAMM codes as described below.

Source data: U. S. Fish and Wildlife Service (USFWS). 2010. National Wetlands Inventory website. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. http://www.fws.gov/wetlands/.

SLAMM category (code)	Source Data
	National Wetlands Inventory (NWI) unless otherwise specified
developed dry land (1)	Dry land areas were differentiated as developed based on RIGIS *Land Cover/Land Use for Rhode Island 2003/04.* Values in the 100 range were assigned to this category.
undeveloped dry land (2)	This category captures any land area not in the developed dry land or wetland categories.
Non-tidal swamp (3)	PFO/SS1B,PFO/SS1C,PFO/SS1E,PFO1,PFO1/4A,PFO1/4B,PFO1/4C,PFO1/4E,PFO1/4Ed,PFO1/4Eg,PFO1/SS1B,PFO1/SS1Bd,PFO1/SS1C,PFO1/SS1E,PFO1A,PFO1Ad,PFO1Ah,PFO1B,PFO1Bd,PFO1Bh,PFO1C,PFO1Cd,PFO1Ch,PFO1Cx,PFO1E,PFO1Ed,PFO1Eh,PFO1F,PFO1Fb,PFO1Fh,PFO4/1A,PFO4/1B,PFO4/1C,PFO4/1E,PFO4/1Eg,PFO4/SS1C,PFO4/SS1Eg,PFO4/SS3B,PFO4A,PFO4Ah,PFO4B,PFO4C,PFO4E,PFO4Eg,PFO5/EM1F,PFO5F,PFO5Fb,PFO5Fh,PFO5H,PFO5Hh,PSS1,PSS1/3B,PSS1/4A,PSS1/4B,PSS1/4C,PSS1/4Eg,PSS1/EM,PSS1/EM1A,PSS1/EM1B,PSS1/EM1Bd,PSS1/EM1C,PSS1/EM1Ch,PSS1/EM1E,PSS1/EM1Eh,PSS1/EM1F,PSS1/EM1Fh,PSS1/EME,PSS1/FO1B,PSS1/FO1C,PSS1/FO1E,PSS1/UBF,PSS1A,PSS1Ad,PSS1Ah,PSS1B,PSS1Bd,PSS1C,PSS1Cd,PSS1Ch,PSS1Cx,PSS1E,PSS1Ed,PSS1Eh,PSS1Ex,PSS1F,PSS1Fb,PSS1Fh,PSS1Fx,PSS3B,PSS3Ba,PSS4C,PSS4Eg
inland fresh marsh (5)	PEM,PEM1/5A,PEM1/5Ad,PEM1/5Ch,PEM1/5Cx,PEM1/5E,PEM1/5Ed,PEM1/5Ex,PEM1/SS1A,PEM1/SS1Ad,PEM1/SS1B,PEM1/SS1Bd,PEM1/SS1C,PEM1/SS1Ch,PEM1/SS1E,PEM1/SS1Eh,PEM1/SS1F,PEM1/SS1Fh,PEM1/SS3E,PEM1/UBF,PEM1/UBFh,PEM1/UBFx,PEM1A,PEM1Ad,PEM1Ah,PEM1Ax,PEM1B,PEM1Bd,PEM1C,PEM1Cd,PEM1Ch,PEM1Cx,PEM1E,PEM1Ed,PEM1Eh,PEM1F,PEM1Fb,PEM1Fd,PEM1Fh,PEM1Fx,PEM1Kx,PEM5/1E,PEM5/1Eh,PEM5/1Fx,PEM5/1Rd,PEM5/SS1E,PEM5A,PEM5Ad,PEM5B,PEM5C,PEM5Ch,PEM5E,PEM5Eh,PEM5Ex,PEMF,Pf,PUB/EM1F,PUB/EM1Fh,PUB/EM1Fx
Tidal fresh marsh (6)	PEM1/5R,PEM1R,PEM1Rd,PEM1Rh,PEM1S,PEM1T,PEM1Th,PEM5/1R,PEM5R,PEM5Rh
transitional marsh/scrub shrub (7)	E2SS1/EM1P,E2SS1/EM5P,E2SS1P,E2SS1P6,E2SS1Pd
saltmarsh (8)	E2EM,E2EM1/5P,E2EM1/AB1N,E2EM1/SS1P,E2EM1/SS1Ph,E2EM1/US3N,E2EM1N,E2EM1Nh,E2EM1P,E2EM1Pd,E2EM1Ph,E2EMd
estuarine beach (10)	E2US/AB1N,E2US1/2N,E2US1N,E2US1P,E2US2/1P,E2US2/EM1N,E2US2M6,E2US2Md,E2US2N,E2US2N6,E2US2Ns,E2US2P,E2US2P6,E2USN,E2USP
tidal flat (11)	E2AB3L,E2US,E2US1M,E2US2/AB1M,E2US2M,E2US3M,E2US3N,E2US3N6,E2US4M,M2AB1M,M2AB1N,M2ABL
ocean beach (12)	M2US1N,M2US1P,M2US2/1N,M2US2/1P,M2US2N,M2US2P,M2USN
ocean flat (13)	M2US,M2US2M
rocky intertidal (14)	E2AB1M,E2AB1N,E2EM5Pd,E2RF2N,E2RF2Nr,E2RS,E2RS1N,E2RS1P,E2RS2N,E2RS2Nr,E2RS2P,E2RS2Pr,E2RSP,M2RS,M2RS1N,M2RS1P,M2RS2N,M2RS2P,M2RS2Pr
inland open water (15)	L1UBH,L1UBHh,L1UBHx,L1UBV,L1UBVh,L2AB,PAB4H,PABFx,PABH,PABHh,PABHx,PUB,PUB/FO5Hh,PUB/SS5Hh,PUBF,PUBFb,PUBFh,PUBFx,PUBH,PUBHb,PUBHh,PUBHx,PUBKx,PUBV,PUBVh,PUBVx,R2ABH,R2UBH,R2UBHx
riverine tidal open water (16)	R1UBV
estuarine open water (17)	E1AB1L,E1AB1L6,E1AB3L,E1AB4L,E1ABL,E1ABL6,E1ABM,E1UB,E1UB/AB1L,E1UB4L,E1UBL,E1UBL4,E1UBL6,E1UBL6h,E1UBL6x,E1UBLh,E1UBLx
tidal creek (18)	E2SB2N
open ocean (19)	M1AB1L,M1AB3L,M1UB,M1UB1L,M1UBL,M1UBLx

irregularly flooded marsh (20)	E2EM1/5P6,E2EM1/5P6d,E2EM1/5Pd,E2EM1N6,E2EM1P6,E2EM1P6d,E2EM1P6h,E2EM5/1P,E2EM5/1P6,E2EM5/1Pd,E2EM5/SS1P,E2EM5/SS1P6,E2EM5P,E2EM5P6,E2EM5P6d,E2EM5P6h
inland shore (22)	L2USC,L2USCh,PUSAx,PUSC,PUSCh,PUSCx,PUSRd
tidal swamp (23)	PFO1/SS1S,PFO1R,PFO1Sd,PSS1/EM1R,PSS1/FO1R,PSS1R,PSS1Rd

Parameter: GT great diurnal tidal range
Value range: 0.13m to 1.48m
This parameter measures the vertical difference between mean lower low water (MLLW) and mean higher high water (MHHW) to capture the tidal range of a site. The range is lowest in lagoons and estuaries that have restricted connections to marine waters. The upper reach of the Pettaquamscutt (Narrow) River site has the lowest range. The highest range is found in the upper Narragansett Bay where the tidal range is amplified by the narrowing of the channel.
Source: NOAA tide gauges and VDATUM (http://vdatum.noaa.gov/)

Parameter: Salt Elevation
Value range: 0.114m to 1.30m
Salt elevation is described as "The elevation at which dry land and freshwater wetlands begin, often defined as the elevation that is inundated by salt water less than every thirty days." Since the salt height is directly related to the tidal range, the evaluation of key locations with a long time series of data was used to determine a factor of 0.88 to convert the tidal range data to salt elevation.
Source: NOAA tide gauges and VDATUM (http://vdatum.noaa.gov/)

Parameter: Erosion
Marsh value: 1.8m/yr
Swamp value: 1m/yr
Tidal flat value: 0.5/yr
This parameter determines the annual rate of horizontal erosion due to wave action. These values were taken from "Application of Sea-Level Affecting Marshes Model (SLAMM 5.0) to Rhode Island National Wildlife Refuge Complex", a SLAMM model run completed for Rhode Island's USFWS refuges.
Source: Kevin Ruddock, TNC

Parameter: Accretion Rates (all marsh types)
Value: 3.8mm/yr
This parameter describes the vertical growth in elevation of marshes due to the accumulation of organic and mineral sediment.
Source: NBNERR

Parameter: Beach Sedimentation Rate
Value: 0.5mm/yr
This is the SLAMM default value. Estimates of this value were difficult to find and sensitivity analyses showed minimal impact to model results.