Assessing the Vulnerability of Alaska's Coastal Habitats to Accelerating Sea-level Rise Using the SLAMM Model: A Case Study for Cook Inlet

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Includes:

Summary Report

Appendix A: A White Paper on Data Requirements and Data Inventory for Alaska SLAMM Analyses

Appendix B: SLAMM Analysis of Kenai Peninsula and Anchorage, AK

Summary Report Table Of Contents

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EXECUTIVE SUMMARY

Assessing the Vulnerability of Alaska's Coastal Habitats to Accelerating Sea-level Rise Using the SLAMM Model: A Case Study for Cook Inlet serves as National Wildlife Federation's final report required under its cooperative funding agreement (701818J719) with the U.S. Fish and Wildlife Service (USFWS) Region 7 Coastal Program.* This report increases our understanding of the vulnerability of Alaska's coastal systems to climate change and can help inform future coastal restoration, protection and adaptation measures.

The report appendices include a detailed account of the application of the Sea Level Affecting Marshes Model (SLAMM) in the Cook Inlet area. Also included is a white paper that provides an overview of Alaska data gaps and challenges to applying SLAMM in Alaska and suggestions for preliminary steps that should be taken to apply SLAMM with maximum effectiveness across the state.

Alaska is blessed with an amazing diversity of coastal habitats, from rocky cliffs and sandy beaches to tidal flats, marshes, and eelgrass beds. These habitats support hundreds of fish and wildlife species, including a majority of Alaska's threatened and endangered animals, and they are a linchpin for the state's economy, culture, and quality of life. Understanding the relative vulnerability of species, habitats, and/or ecosystems to the impacts of climate change is a necessary step in the development of meaningful strategies to reduce those risks. Collecting good, local data and modeling at a local level is an essential part of developing this understanding.

Over the past two years, National Wildlife Federation has worked with Warren Pinnacle Consulting, Inc, to investigate the potential impact of sea-level rise on coastal habitats in areas of Cook Inlet, Alaska. We used the SLAMM model, which simulates the dominant processes involved in wetland conversions and shoreline changes during long-term sea-level rise. While the SLAMM model has been successfully applied in a number of coastal areas across the U.S., this is the first time it has been used to study Alaska's coastal habitats. As a result, we considered this study a pilot project, and the results of the study are more significant for the lessons learned than for the specific impacts projected for the case study locations.

Ultimately, this study underscores the fact that Alaska poses unique challenges for sea-level rise modeling. The primary challenges are related to significant data gaps, especially the lack of high quality elevation data across the majority of the state, as well as the coarse quality of some other data inputs.

Despite the special limitations in data coverage, the areas that we modeled yielded interesting results. Most notably, the wetland habitat in the study region does not appear to be particularly vulnerable to sea-level rise and most impacts noted do not occur until after about a 1.5 meter rise in eustatic sea level (which some studies suggest may occur by 2100. See, for example, Vermeer and Rahmstorf, 2009). The primary reasons for the relatively low vulnerability among these habitats are two-fold: 1) on the basis of current trends, significant land uplift in the region is predicted over the next century, which counteracts the regional impact of sea-level rise; and 2) the area experiences relatively high tidal ranges, which are significantly less vulnerable to sea-level rise than are microtidal regimes because marshes extend over a much wider vertical range and any increase in sea-level rise relative to the overall tide range is much lower. Based on the challenges and results of this study, there are several recommendations for next steps:

1. Obtain baseline data: Significant investments should be made in filling key data gaps, particularly high resolution elevation data across coastal regions of the state. Other data gaps include regional uplift and tidal measurements. Newer and more detailed NWI data would also be useful. (See White Paper for more information)
2. To ensure that resources are spent most effectively, consideration should be given to conducting sea-level rise related studies and modeling in areas in Alaska where land uplift is limited or negative and where tidal ranges are moderate or low. The Yukon-Kuskokwim Delta region is one likely area.
3. All stakeholders in the region should push for sufficient funding for climate research, monitoring, and adaptation planning and implementation.

INTRODUCTION

The far-reaching impacts of climate change are ushering in a fundamental shift in natural resource management and conservation to help natural systems withstand and adapt to new climate conditions - a strategy called climate change adaptation. There has been growing attention to climate change adaptation planning across the country and in Alaska over the past few years.[1] For example, the Alaska Department of Fish and Game identified climate change as the primary challenge for fish and wildlife conservation in its 2006 Comprehensive Wildlife Conservation Strategy.[2] In addition, the U.S. Department of the Interior is working to build its capacity to address climate change in its relevant conservation and management efforts across the state. Given the multitude of stressors facing Alaska's natural systems, identifying and prioritizing meaningful climate change adaptation strategies is paramount. This requires not only a better understanding of the impacts, risks, and uncertainties associated with climate change, but also of the vulnerability of species, habitats, and ecosystems to these changes.*

* The Nature Conservancy's contribution to this report is gratefully acknowledged

* "Vulnerability" to climate change refers to the extent to which a species, habitat, or ecosystem is susceptible to harm from climate change impacts. More vulnerable species and systems are likely to experience greater impacts from climate change, while less vulnerable species and systems will be less affected or may even benefit.

This report highlights a recent effort to use the SLAMM model to assess the potential impacts of sea-level rise on coastal habitats in parts of Alaska's Cook Inlet, which is a critical habitat area for migratory birds and other fish and wildlife. In addition to summarizing model results, we focus on the key lessons learned and provide recommendations for next steps.

SEA-LEVEL RISE AND ALASKA

Sea-level rise due to a combination of thermal expansion of the oceans and rapidly melting glaciers and ice sheets is one of the most direct and certain consequences of global climate change. The average global ("eustatic"*) sea level rose about 7 inches over the 20th century, which was 10 times faster than the average rate of sea-level rise during the last 3,000 years.[3] Since 1990, sea level has been rising 3.4 mm/year, twice as fast as the average over the 20th century. In the coming decades, the rate of sea-level rise will continue to accelerate. While the range of projected sea-level rise varies across different studies, recent research suggests that, without significant reductions in global warming pollution, sea level could rise 75 to 190 cm (29.5 to 74.8 in.) by 2100.[4]

Given the critical importance of the coasts to America's ecology, economy, and way of life, understanding and addressing the current and future impacts of sea-level rise has already garnered considerable interest across the country. Much of this attention has focused on Atlantic and Gulf states, where the rate of relative sea-level rise is higher than other parts of the country due to a combination of rising eustatic sea levels and natural and human-influenced factors that are contributing to regional land subsidence. But other areas are vulnerable as well – including parts of Alaska.

Alaska has more than 44,000 miles of shoreline, which more than doubles the shoreline of the entire lower 48 states.[5] The Alaska coast consists of an incredible diversity of habitats, including coastal islands and sea cliffs, rocky intertidal zones, beaches and tidal flats, eelgrass beds, and tidal wetlands.[6] These habitats are home to a majority of Alaska's threatened and endangered animal species.[7] In addition to understanding sea-level rise impacts on fish and wildlife habitat, sea-level rise investigations are also important given that three quarters of Alaska's citizens live in coastal regions, which support 80% of the state's economic activity. Economic activity in Alaska's coastal zones includes world renowned fish and shellfish industries as well as a burgeoning recreation and tourism industry.[8]

MODELING THE IMPACTS OF SEA-LEVEL RISE: AN OVERVIEW

Numerous modeling and assessment tools exist to assist coastal managers and other stakeholders in assessing the vulnerability of coastal systems to climate change. Resources to identify potential impacts of sea-level rise exist at multiple levels of complexity. Some of the most straightforward tools are the so-called "bathtub" models, which assess which coastal areas are likely to be inundated under various sea level rise scenarios based on coastal elevation.

There are also more complex mathematical/statistical models that can identify in greater detail the physical and/or ecological responses of coastal systems to sea level rise, at various levels of detail and geographical scale. For example, the U.S. Geological Survey (USGS) has developed a Coastal Vulnerability Index (CVI) that uses a mathematical formula to determine the relative vulnerability of a coastal region to sea level rise based on six data variables (tidal range, wave height, coastal slope, historic shoreline change rates, geomorphology, and historical rates of relative sea-level change) (See http://woodshole.er.usgs.gov/project-pages/cvi/). CVI is a relative ranking of the likelihood that physical change will occur along the shoreline as sea level changes. Other models, such as the Sea Level Affecting Marshes Model (SLAMM) can help researchers identify potential impacts of sea-level rise on the composition as well as extent of coastal wetlands and other habitats under various scenarios of future sea-level rise (see Box 1 for more information about SLAMM). A similar model is the Kirwan marsh model, which couples sediment transport processes with vegetation biomass productivity.[9] These and other related models provide varying degrees of detail from local to regional landscape scales.

Finally, several multidisciplinary support tools have also been developed that can provide information on potential physical, ecological, and socio-economic impacts, typically at relatively large scales (e.g., the Dynamic Interactive Vulnerability Assessment Tool, or DIVA, at http://diva.demis.nl/).

All of the available modeling and assessment tools have their own pluses and minuses. For example, bathtub-type assessments are relatively straightforward and low cost, and they can provide an excellent overall sense of the vulnerability of a coastal area to inundation and storm surges. They can be particularly useful as a public education tool. However, they are of limited use for more detailed assessments of impacts to specific habitats, species, and ecosystems. Some of the more sophisticated models, on the other hand, can provide coastal managers with important and useful information about vulnerability of specific habitats or ecosystems at relatively fine scales and levels of detail. For example, they may provide a more accurate projection of impacts by incorporating factors that affect relative rates of sea-level rise. They may also enable incorporation of projected land use changes that would influence the ability of habitats to migrate upland in response to rising sea levels. However, highly detailed assessments can require extensive amounts of data and computer capabilities and can be more costly and time consuming. In all cases, the levels of uncertainty will depend on the resolution and quality of digital elevation data.

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* "Eustatic" sea-level rise refers to the changes in ocean volume due to thermal expansion and melting glaciers and ice sheets. At the localized level, the amount of relative sea-level rise can vary due to factors (both natural and human-influenced) that determine changes in vertical land elevation, such as land subsidence, sedimentation, and marsh accretion.

Box 1. About the Sea Level Affecting Marshes Model (SLAMM)

The SLAMM model, which has been in development for the past two decades, provides a highly accessible tool to assess how rising seas may impact coastal habitats. As with all models, SLAMM is not a crystal ball. It is not intended to forecast what will happen to the region's habitats in the future; rather, it is a tool to offer a picture of possible outcomes under a range of scenarios.

To do this, SLAMM integrates potential future scenarios of global sea-level rise with data inputs such as area-specific NOAA tidal data, detailed wetland information from the Fish and Wildlife Service National Wetlands Inventory, regional light-imaging detection and ranging (LiDAR) data, and USGS digital elevation maps to project potential habitat changes. One of the benefits of the SLAMM model is that it integrates multiple processes and datasets in an attempt to maximize realism. For example, it can assess the extent to which sea water inundation contributes to the conversion of one habitat type to another by looking at elevation, habitat type, slope, sedimentation and accretion, erosion, and the extent to which the affected area is protected by dikes or other structures.

In addition, SLAMM accounts for relative changes in sea level for each study site. Relative sea-level rise is calculated as the sum of the historic eustatic trend, the site specific rate of change of coastal elevation due to subsidence, changes in natural sediment loads, rates of marsh accretion, and the accelerated sea-level rise, depending on the future scenario chosen. Within SLAMM, there are five primary processes that affect wetland fate under different scenarios: inundation, erosion, overwash, saturation, and accretion.

The most recent version of SLAMM (6.0) has a number of upgrades from previous versions. In particular, the model is now able to incorporate dynamic feedbacks in marsh accretion, whereas previous versions assumed linear changes in accretion rates over time. That said, there are likely to be a number of dynamic geological and ecological changes that will not be captured through SLAMM. Furthermore, there are a number of additional impacts associated with climate change that are not incorporated into this model, such as altered hydrology and more-intense coastal storms, as well as additional anthropogenic stressors that will affect coastal habitats in the future. Certainly, all of these challenges will need to be addressed in coastal management decisions to the greatest extent possible. For detailed technical information about the SLAMM model, visit: http://www.warrenpinnacle.com/prof/SLAMM

CASE STUDY:

Modeling Sea-level Rise in Cook Inlet, Alaska (Kenai Peninsula and Anchorage)

In 2008, National Wildlife Federation (NWF) received funding from U.S. Fish and Wildlife Service (USFWS) to explore the possibility of piloting the SLAMM model within Cook Inlet, Alaska, which provides important habitat for numerous species of fish and wildlife.[10] Successive versions of the model have been used to estimate the impacts of sea-level rise on a number of coastal areas in the lower 48 states (Titus, et al., 1991; Lee, Park, and Mausel, 1992; Park, Lee, and Canning, 1993; Galbraith, et al., 2005; Glick and Clough, 2006; Glick, Clough, and Nunley, 2007; Glick, Clough, and Nunley, 2008; Craft, et al., 2009). In addition, the U.S. Fish and Wildlife Service has applied the SLAMM model at a number of its coastal wildlife refuges.

This project represents the first time that SLAMM (or similar models) has been applied to assess the potential impacts of sea-level rise on Alaska's coast. It is intended to answer such questions as:

- Will SLAMM work in Alaska?
- Is Alaska different in some manner that renders the SLAMM conceptual model ineffectual?
- What are the data needs for SLAMM modeling in Alaska, and what is the current inventory of data?

Sea-level Rise Scenarios

For this study, SLAMM 6 was run using scenario A1B from the IPCC Special Report on Emissions Scenarios (SRES) – mean and maximum estimates.[11] The A1 scenario assumes that the future world includes very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. In particular, the A1B scenario assumes that energy sources will be balanced across all sources. Under the A1B scenario, the IPCC WGI Fourth Assessment Report (IPCC, 2007) suggests a likely range of 0.21 to 0.48 meters of sea-level rise by 2090-2099 "excluding future rapid dynamical changes in ice flow." The A1B-mean scenario that was run as a part of this project falls near the middle of this estimated range, predicting 0.40 meters of global sea-level rise by 2100. SLAMM was also run assuming 1 meter, 1½ meters, and 2 meters of eustatic sea-level rise by the year 2100 to accommodate the recent literature suggesting that the rate of sea-level rise is likely to be higher than the 2007 IPCC projections. [12,13,14]

Data Sources and Methodology

No matter how sophisticated or "realistic" a model might be, one of the primary factors determining the usefulness of the results is the quality of the data inputs. SLAMM is no exception.

Box 2. Key Data Requirements for SLAMM

Elevation Data. High vertical-resolution data is probably the most important SLAMM data requirement. Elevation data demarcates where salt water is predicted to penetrate and, when combined with tidal data, identifies the frequency of inundation for wetlands and marshes. Elevation data also helps determine the lower elevation range for beaches, wetlands, and tidal flats – the elevation at which point they are inundated too frequently and are predicted to convert to a different type of land-cover or open water. LiDAR data, as derived from laser pulses usually emitted from airplanes, is currently the "gold standard" for elevation data with vertical errors ranging from 4-20 cm. Currently, LiDAR data within Alaska is fairly limited in coverage.

Vertical Datum Considerations. Elevation data is generally provided with a vertical datum of NAVD88 or in some cases NGVD29. SLAMM requires that vertical data be converted to a tidal datum, specifically the mean tide level. Within much of the contiguous United States, such corrections may be derived from the NOAA VDATUM product. In Alaska, where VDATUM coverage is not available, these corrections must be derived from NOAA gages (Tidal Datums) or the National Geodetic Survey. In Alaska, gaps between tidal gages in the western portion of the state are especially large, making these conversions more troubling.

Land Cover Data. Land cover data for the SLAMM model is generally provided by the National Wetlands Inventory (NWI). Land covers are converted from the Cowardin Classification System into SLAMM land-cover categories. Coastal wetland data within Alaska are fairly complete, though there are occasional gaps.

Land Movement/Uplift. Due to the spatially-variable and high-magnitude effects of isostatic rebound within Alaska, accurate characterization of land uplift is of critical importance. One important source of land movement data within Alaska is the work of Dr. Jeffrey Freymueller, who conducted repeated GPS surveys covering the time period from 1992-2007 throughout the state.[15] Dr. Freymueller has noted that gaps between measuring stations in some regions, particularly western Alaska, are extremely large, making accurate land uplift estimates difficult in those areas.

Accretion Data. Within the SLAMM model, sea-level rise is offset by sedimentation or vertical accretion using average or site-specific values for each wetland category. Accretion rates are important model parameters. Depending on the rate at which they are vertically moving, wetlands may be much more resilient to or susceptible to sea-level rise. Wetlands accretion studies within Alaska appear to be extremely limited. Horizontal rates of marsh or tidal flat erosion are also quite useful for model setup. These data are somewhat more plentiful within Alaska and can be derived from shoreline change maps or direct studies of coastal erosion.

Tide Ranges. Tide ranges are generally gathered from NOAA gages and/or NOAA tide tables. Tide data is fairly plentiful within portions of Alaska but there are some regions in which gages are so far apart that long-distance interpolation could be required.

From the inception of this study, we determined that applying the SLAMM 6 model to a large percentage of Cook Inlet was not possible, primarily due to limitations in available elevation data. For the western shore of Cook Inlet and areas towards the mouth of the inlet, the best available elevation data were based on large contour intervals (up to 100 feet), and much of these data predated the Alaska earthquake of 1964, which significantly altered land levels in the region. Along the coast of the Gulf of Alaska, for example, average land levels rose about 6 feet, with as much as a 50-foot rise in some places.

Given these data limitations, we chose to apply the model to two sub-sites, the Kenai Peninsula and Anchorage, which comprise more than 545,000 hectares and 24,000 hectares respectively. To simplify data presentation and improve the resolution of maps within this report, the study areas were broken into several different output sites, including four sites for the Kenai region (Figure 2) and two sites for the Anchorage region (Figure 3).

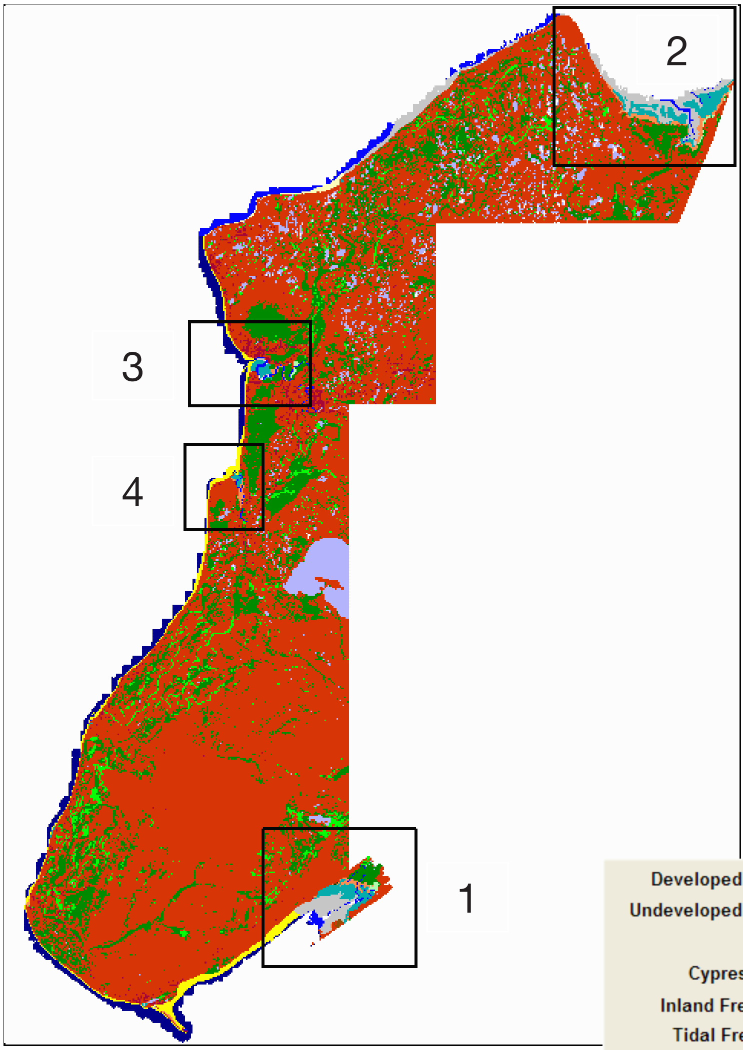


Figure 2: Kenai region output sites.

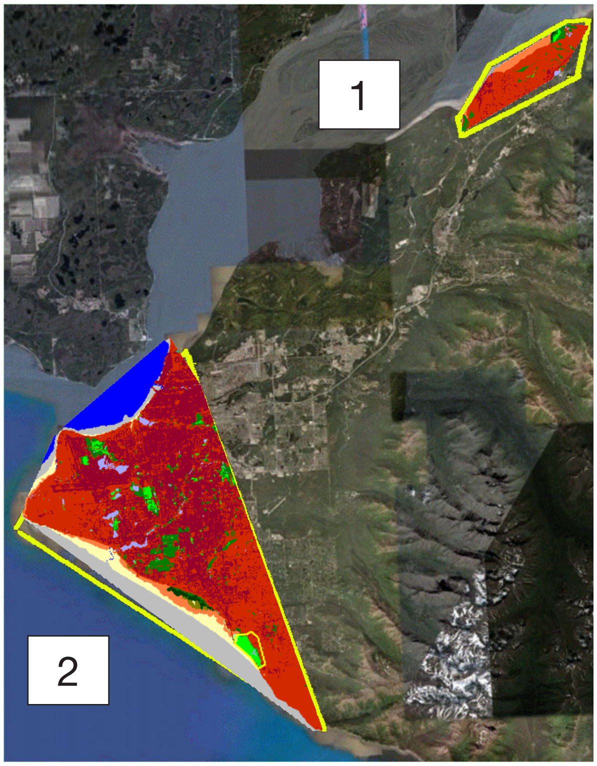
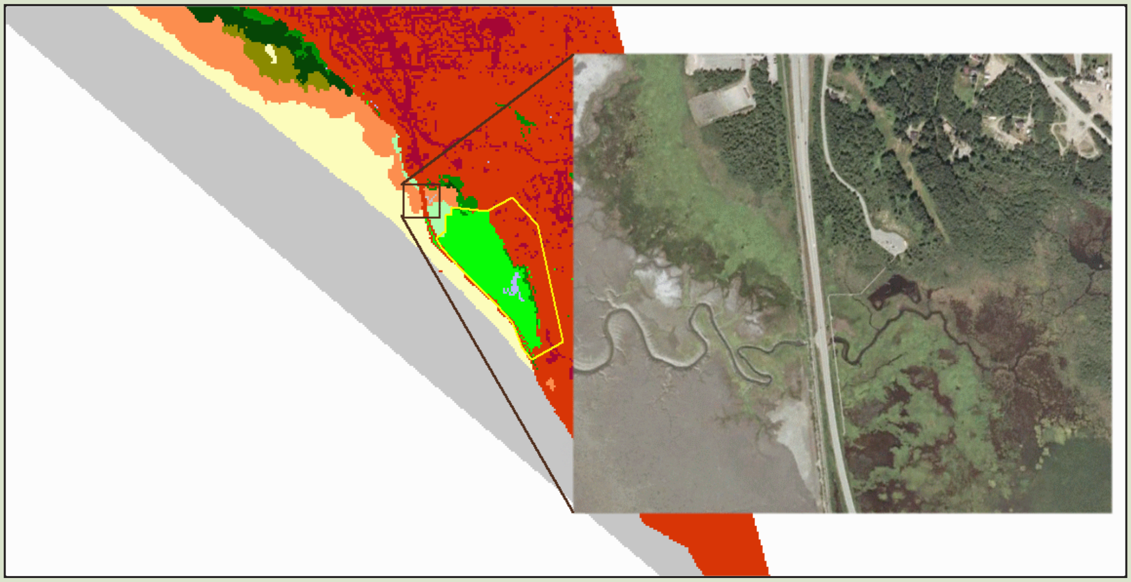


Figure 3: Anchorage region output sites. Potter March input site bordered in yellow (See Box 3).

Developed Dry Land	🟥	Estuarine Beach	🟨	Tidal Creek	🟦
Undeveloped Dry Land	🟥	Tidal Flat	⬜	Open Ocean	🟦
Swamp	🟩	Ocean Beach	🟨	Irreg. Flooded Marsh	🟧
Cypress Swamp	🟩	Ocean Flat	🟧	Inland Shore	🟫
Inland Fresh Marsh	🟩	Rocky Intertidal	🟪	Tidal Swamp	🟩
Tidal Fresh Marsh	🟩	Inland Open Water	🟪	Blank	⬜
Trans. Salt Marsh	🟫	Riverine Tidal	🟦	Vegetated Tidal Flat	🟩
Regularly Flooded Marsh	🟦	Estuarine Open Water	🟦	Backshore	🟨

Box 3. Ground-truthing for Localized Factors

Even where adequate input variables for the SLAMM model are available, it is possible that some discrete localized factors (such as the existence of dikes or other infrastructure) are not effectively captured in the land cover data or other relevant data sources. Accordingly, it is important to supplement modeling efforts such as this with expert knowledge of the study regions. For example, within the Anchorage study area, the Potter Marsh input site was estimated as having a reduced tide range (7 meters) due to the effects of culverts on water access. After model results initially suggested saline intrusion, a site visit confirmed that a lower tide range is present at this site due to the railroad embankment between Rabbit and Potter creeks that restricts tides and storm surges.



Tables 1 and 2 summarize the key input parameters for the Kenai site and the Anchorage site, respectively. A much more detailed description of the key data sources and assumptions used in identifying these and other relevant model parameters can be found in a technical companion to this report, SLAMM Analysis of Kenai Peninsula and Anchorage, AK (2009),[16] which is included in this report's appendices.

1. Table 1. SUMMARY OF SLAMM INPUT PARAMETERS FOR KENAI SITE

Parameter	Global	SubSite 1	SubSite 2	SubSite 3	SubSite 4	SubSite 5
Description	Kenai Alaska	Subsite Homer	Subsite 2	Near Anchorage	Subsite 4	Kenai River
NWI Photo Date (YYYY)	1977	1977	1977	1977	1977	1977
DEM Date (YYYY)	2007	2007	2007	2007	2007	2007
Direction Offshore (n,s,e,w)	West	West	West	North	North	West
Historic Trend (mm/yr)	Kriging	Kriging	Kriging	Kriging	Kriging	Kriging
MTL-VAVD88 (m)	1.21	1.4	1.31	1.47	1.4	1.21
GT Great Diurnal Tide Range (m)	6.267	5.583	5.85	8.889	7.5	5.953
Salt Elev. (m above MTL)	4.51	4	4.21	6.4	5.4	4.28
Marsh Erosion (horz. m/yr)	2	2	2	2	2	2
Swamp Erosion (horz. m/yr)	1	1	1	1	1	1
T. Flat Erosion (horz. m/yr)	1.75	1.75	1.75	1.75	1.75	1.75
Reg. Flood Marsh Accr (mm/yr)	3.6	3.6	3.6	3.6	3.6	3.6
Irreg. Flood Marsh Accr (mm/yr)	3.5	3.5	3.5	3.5	3.5	3.5
Tidal Fresh March Accr (mm/yr)	4	4	4	4	4	4
Beach Sed. Rate (mm/yr)	5	5	5	5	5	5
Freq. Overwash (years)	0	0	0	0	0	0
Use Elev Pre-processor [True, False]*	False	False	False	False	False	False

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* The elevation pre-processor is used to estimate wetland elevations as a function of tide range in areas with poor elevation data. As the study area in question is entirely covered with LiDAR, this tool was not used.

2. Table 2. SUMMARY OF SLAMM INPUT PARAMETERS FOR ANCHORAGE SITE

Description	Anchorage Alaska	Potter Marsh
NWI Photo Date (YYYY)	2002	2002
DEM Date (YYYY)	2006	2006
Direction Offshore (n,s,e,w)	West	West
Historic Trend (mm/yr)	Kriging	Kriging
MTL-VAVD88 (m)	-0.28	-0.28
GT Great Diurnal Tide Range (m)	8.9	7
Salt Elev. (m above MTL)	5.92	4.55
Marsh Erosion (horz. m/yr)	2	2
Swamp Erosion (horz. m/yr)	1	1
T. Flat Erosion (horz. m/yr)	1.75	1.75
Reg. Flood Marsh Accr (mm/yr)	3.6	3.6
Irreg. Flood Marsh Accr (mm/yr)	3.5	3.5
Tidal Fresh March Accr (mm/yr)	4	4
Beach Sed. Rate (mm/yr)	10	10
Freq. Overwash (years)	0	0
Use Elev Pre-processor [True, False]*	False	False

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* The elevation pre-processor is used to estimate wetland elevations as a function of tide range in areas with poor elevation data. As the study area in question is entirely covered with LiDAR, this tool was not used.

Model Results

Because predicted changes within the Alaska study area are relatively gradual, primarily due to uplift of land, maps of results in this report are shown as initial conditions followed by year 2100 predictions under different scenarios of sea-level rise. Predictions are shown ranging from 0.7 to 2.0 meters of eustatic sea-level rise by 2100. Results maps for all scenarios for years 2025, 2050, 2075, and 2100 are available upon request either in Microsoft Word or GIS Raster formats.

Kenai

Figure 4 shows the relative changes in habitat types over time for the overall Kenai study region. This site consists mostly of dry land, with swamp and inland fresh marsh being the second and third most common land categories. Looking at the entire peninsula, less than 1% of dry land is predicted to be lost to the effects of sea-level rise. Between 0% and 2% of the total study area swamp lands are predicted to be lost across all scenarios. While the site is predicted to lose 14% of its tidal flat, some of this loss is likely to have already occurred since the 1977 National Wetlands Inventory initial condition (see White Paper for more complete discussion of this issue). Additional loss is predicted primarily due to erosion. Substantial losses of ocean beach seem to be triggered at eustatic rates of sea-level rise above 1.5 meters. However, ocean beach predictions are uncertain due to highly spatially variable erosion and sedimentation rates that may not be accurately predicted by the SLAMM model.

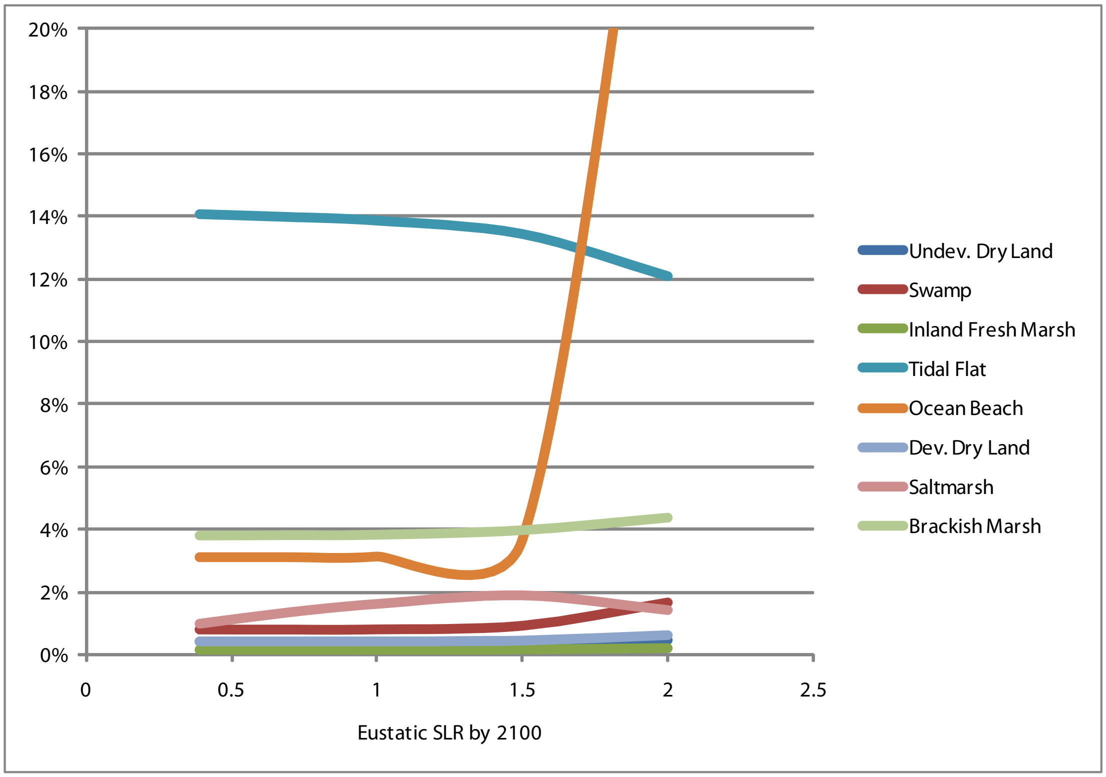
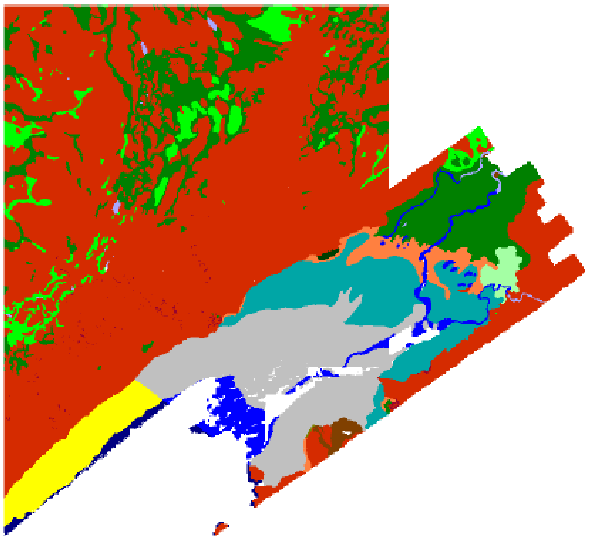


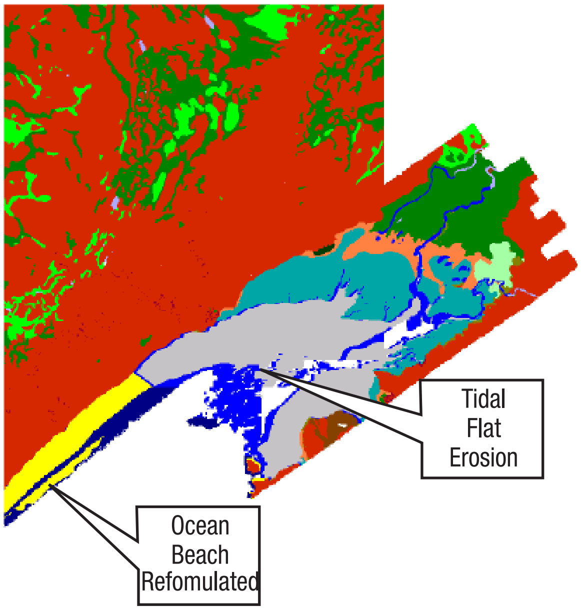
Figure 4: Rates of Land Loss for Kenai

Fox River Flats (Eastern Kachemak Bay)

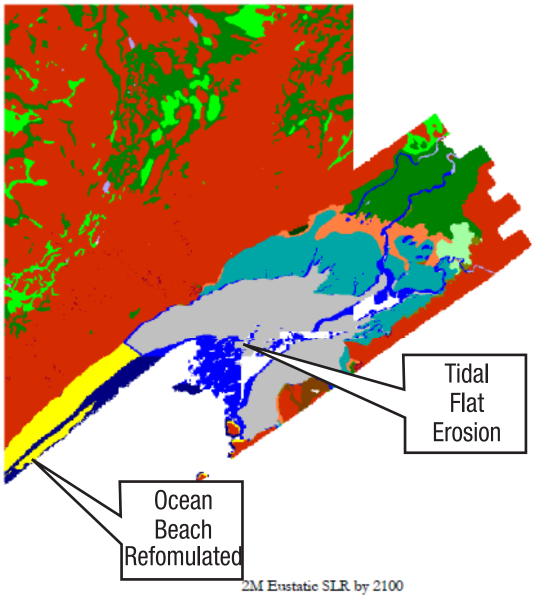
The ocean beach to the west of this output site is predicted to be reformulated, primarily as a result of the initial condition LiDAR elevations we received for this site. Tidal flat erosion is predicted to occur, although the model does not predict the precise spatial location of such erosion.



Initial Condition



A1B-Max (0.69M Eustatic SLR by 2100)

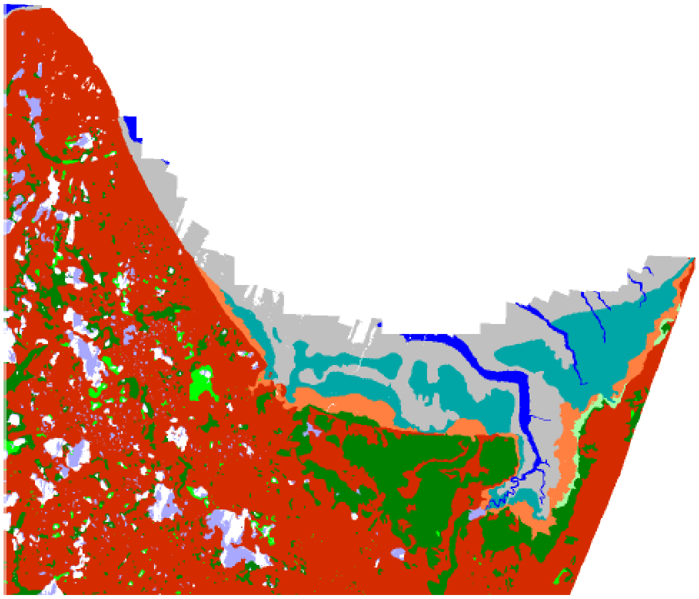


2M Eustatic SLR by 2100

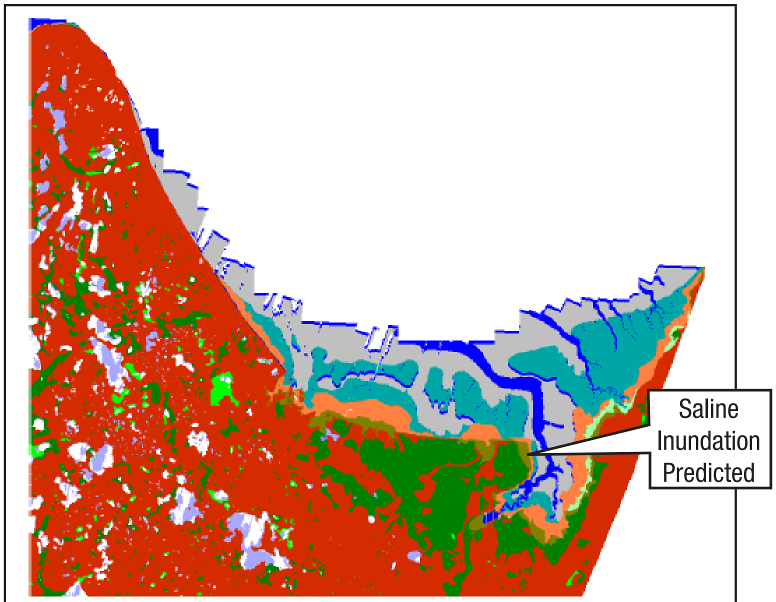
Developed Dry Land	🟥	Estuarine Beach	🟨	Tidal Creek	🟦
Undeveloped Dry Land	🟥	Tidal Flat	⬜	Open Ocean	🟦
Swamp	🟩	Ocean Beach	🟨	Irreg. Flooded Marsh	🟧
Cypress Swamp	🟩	Ocean Flat	🟧	Inland Shore	🟫
Inland Fresh Marsh	🟩	Rocky Intertidal	🟪	Tidal Swamp	🟩
Tidal Fresh Marsh	🟩	Inland Open Water	🟪	Blank	⬜
Trans. Salt Marsh	🟫	Riverine Tidal	🟦	Vegetated Tidal Flat	🟩
Regularly Flooded Marsh	🟦	Estuarine Open Water	🟦	Backshore	🟨

Chickaloon Bay

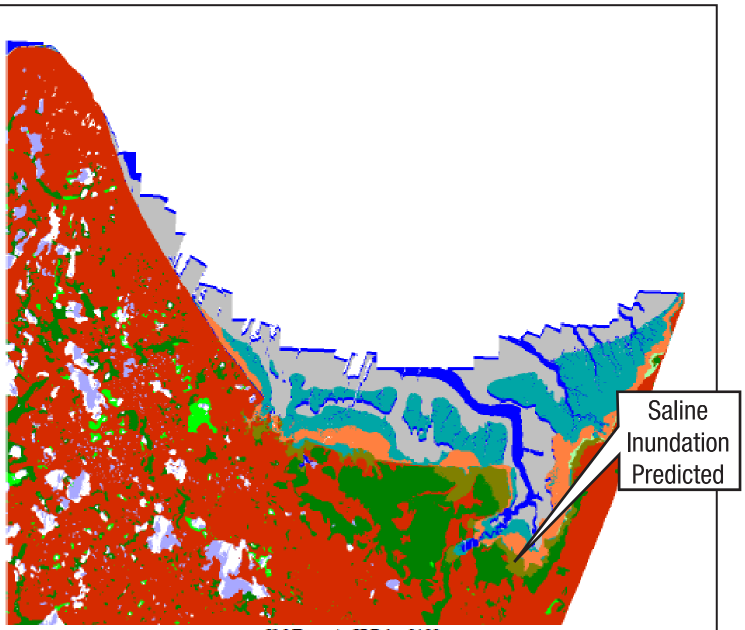
Freshwater swamps at the south end of this site are predicted to start to convert to transitional salt marsh as they fall below the salt boundary. The spatial extent of this conversion depends on the sea-level rise scenario utilized.



Initial Condition



A1B-Max (0.69M Eustatic SLR by 2100)

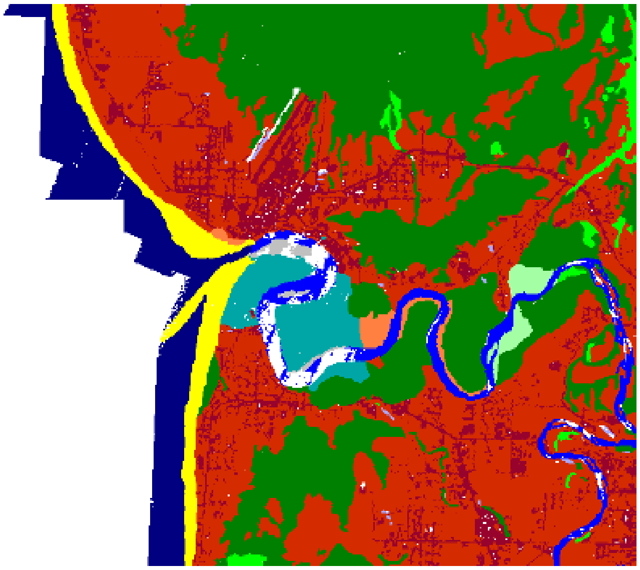


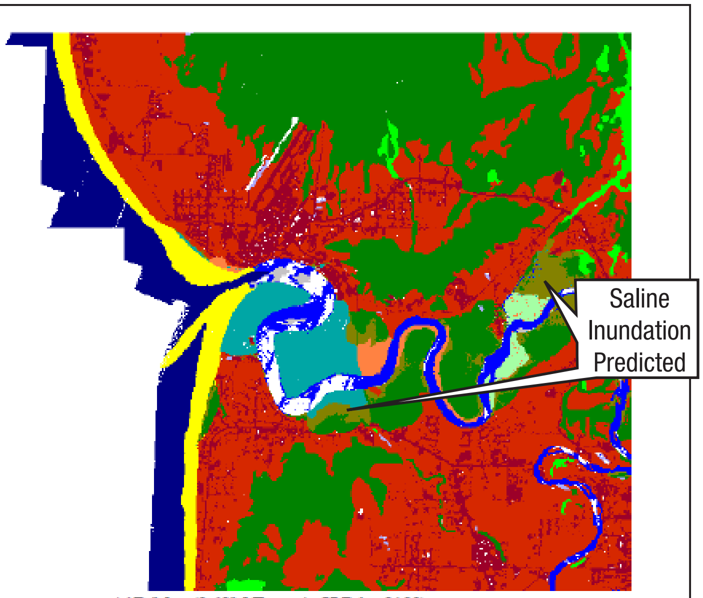
2M Eustatic SLR by 2100

Developed Dry Land	🟥	Estuarine Beach	🟨	Tidal Creek	🟦
Undeveloped Dry Land	🟥	Tidal Flat	⬜	Open Ocean	🟦
Swamp	🟩	Ocean Beach	🟨	Irreg. Flooded Marsh	🟧
Cypress Swamp	🟩	Ocean Flat	🟧	Inland Shore	🟫
Inland Fresh Marsh	🟩	Rocky Intertidal	🟪	Tidal Swamp	🟩
Tidal Fresh Marsh	🟩	Inland Open Water	🟪	Blank	⬜
Trans. Salt Marsh	🟫	Riverine Tidal	🟦	Vegetated Tidal Flat	🟩
Regularly Flooded Marsh	🟦	Estuarine Open Water	🟦	Backshore	🟨

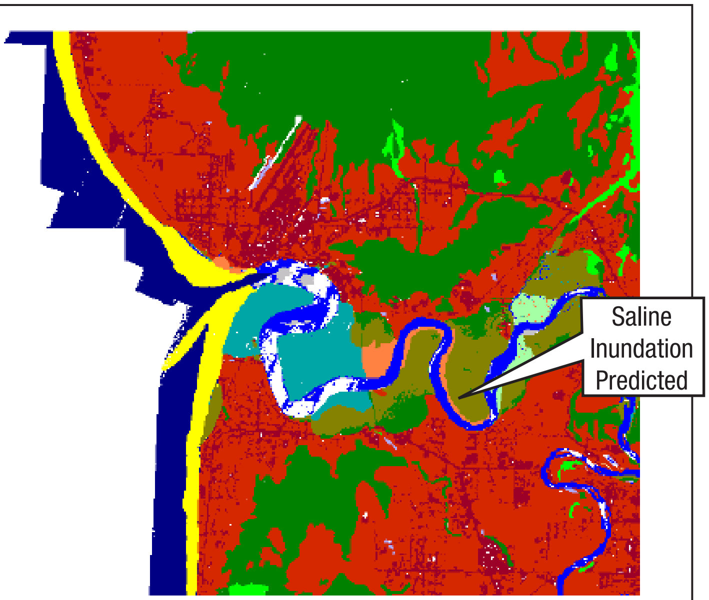
Town of Kenai

The freshwater swamps along the Kenai River are predicted to start to show salinity effects, especially under the highest rate of sea-level rise simulated (2 meters by 2100).


Initial Condition


Saline Inundation Predicted

A1B-Max (0.69M Eustatic SLR by 2100)

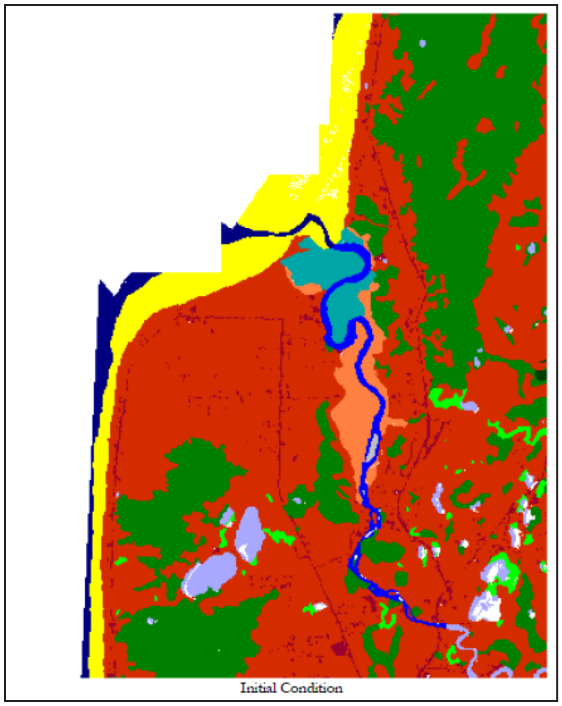

Saline Inundation Predicted

2M Eustatic SLR by 2100

Developed Dry Land	🟥	Estuarine Beach	🟨	Tidal Creek	🟦
Undeveloped Dry Land	🟥	Tidal Flat	⬜	Open Ocean	🟦
Swamp	🟩	Ocean Beach	🟨	Irreg. Flooded Marsh	🟧
Cypress Swamp	🟩	Ocean Flat	🟧	Inland Shore	🟫
Inland Fresh Marsh	🟩	Rocky Intertidal	🟪	Tidal Swamp	🟩
Tidal Fresh Marsh	🟩	Inland Open Water	🟪	Blank	⬜
Trans. Salt Marsh	🟫	Riverine Tidal	🟦	Vegetated Tidal Flat	🟩
Regularly Flooded Marsh	🟦	Estuarine Open Water	🟦	Backshore	🟨

Northern Cohoe/Kasilof

Some saline inundation of the dry lands and swamps to the east of the river are predicted, especially under higher eustatic scenarios of sea-level rise.



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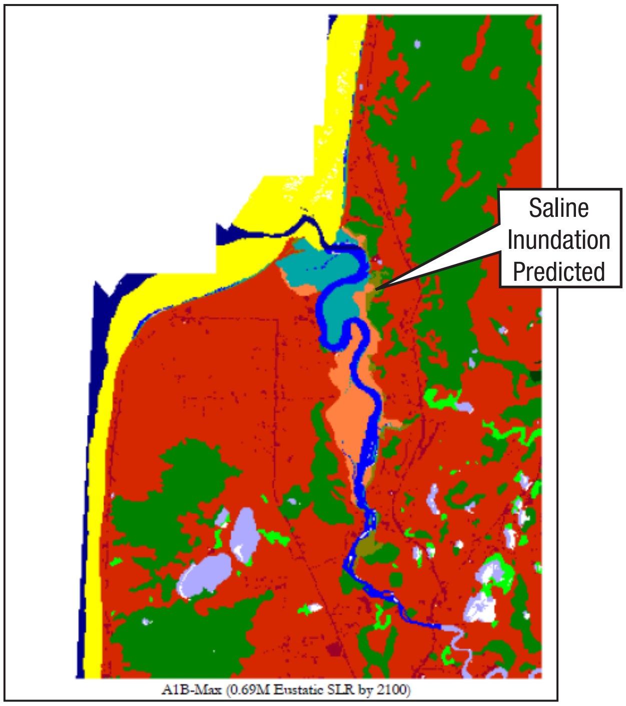
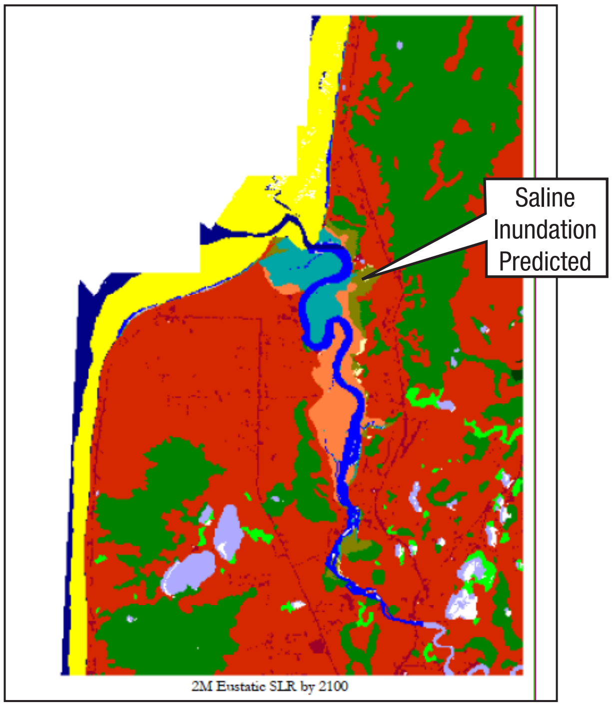
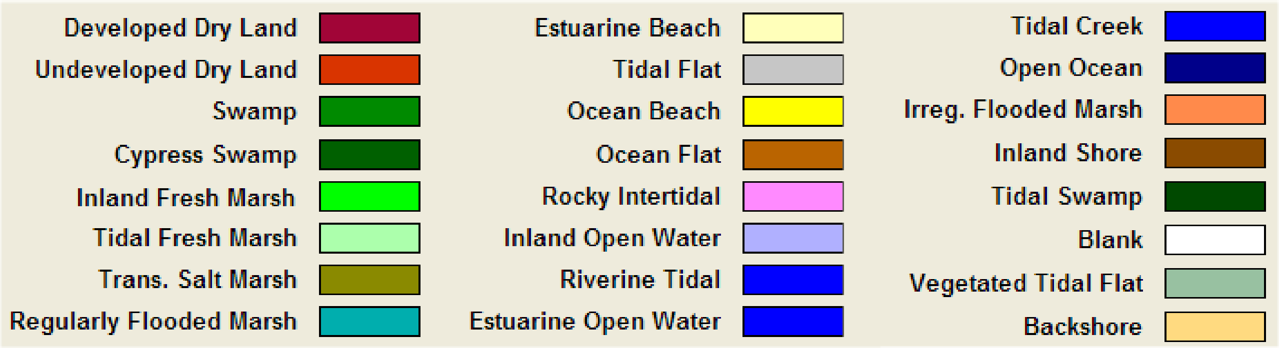


A1B-Max (0.69M Eustatic SLR by 2100)



2M Eustatic SLR by 2100



Anchorage

Figure 5 shows relative changes in habitat types over time for the overall Anchorage study region. Results for this region show only minor susceptibility to the effects of sea-level rise. Dry land, which comprises slightly more than one third of the study area, is calculated to lose between 2% and 3% of its initial land coverage across all sea-level rise scenarios. Swamp lands – which comprise roughly 4% of the study area – are predicted to lose between 4% and 10% of their initial land coverage across all sea-level rise scenarios.

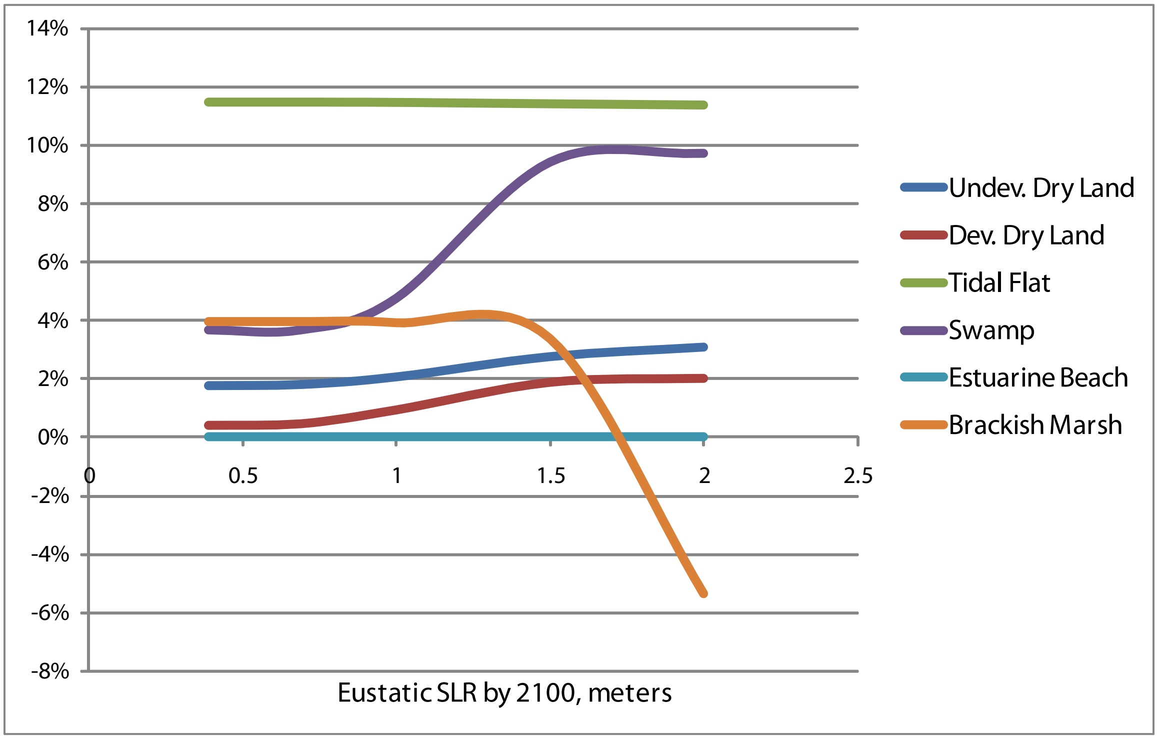
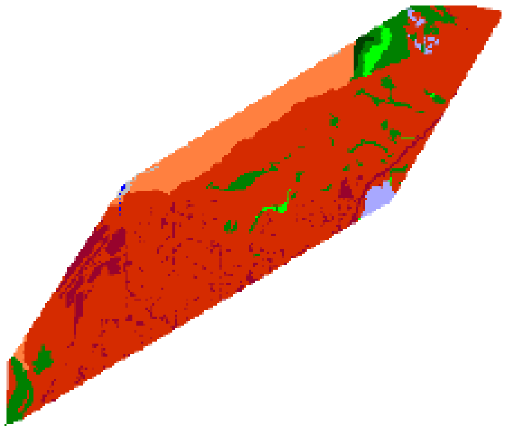


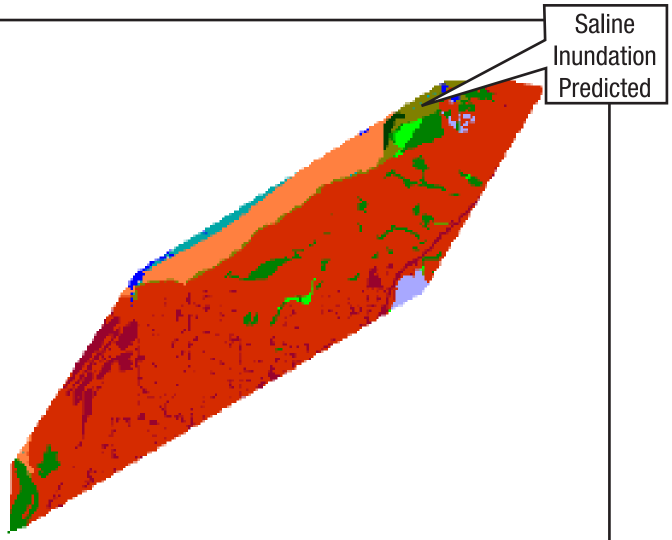
Figure 5: Rates of Land Loss forAnchorage

Irregularly flooded marsh – often called “brackish marsh” – makes up roughly 3% of this site. This category is predicted to lose up to 4% of its initial land coverage to sea-level rise on a site-wide scale. However, in the most extreme scenarios of sea-level rise, some tidal swamp is predicted to convert to irregularly flooded marsh, resulting in overall gain in area for that habitat category.

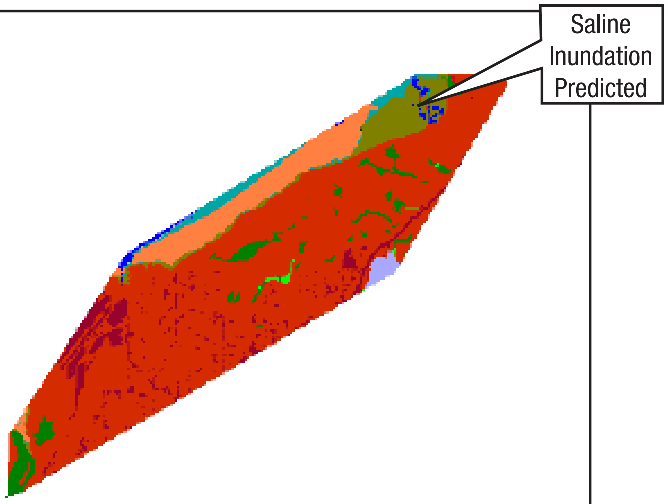
North of Chugiak (Near Birchwood Airport)

The dry lands and swamps at the north of this portion of the study area are predicted to be subject to saline inundation, especially under the highest scenarios run.


Initial Condition



Scenario A1B-Max (0.69M Eustatic SLR by 2100)



2M Eustatic SLR by 2100

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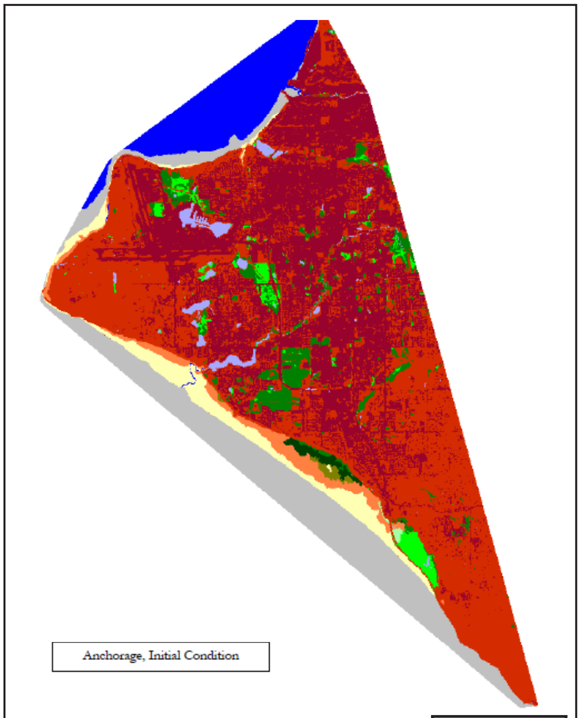
Tidal Fresh Marsh	🟩	Inland Open Water	🟪	Blank	⬜
Trans. Salt Marsh	🟫	Riverine Tidal	🟦	Vegetated Tidal Flat	🟩
Regularly Flooded Marsh	🟦	Estuarine Open Water	🟦	Backshore	🟨

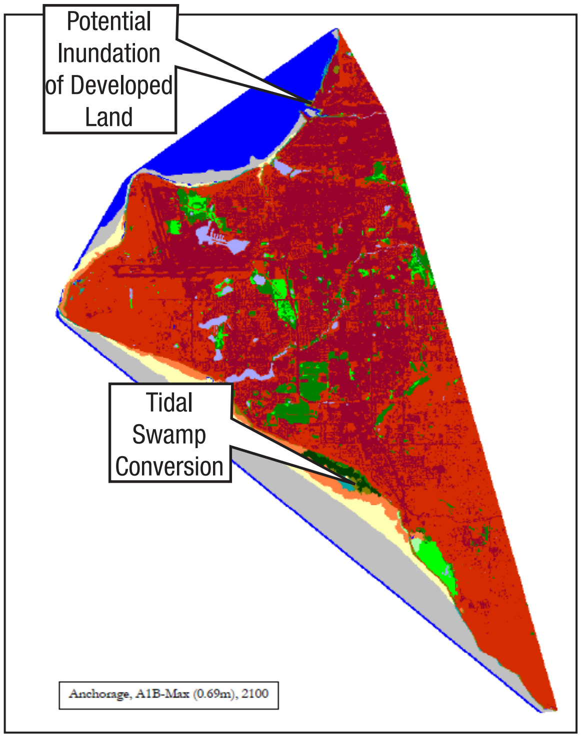
* This prediction does not incorporate the sea wall and new land construction under way at the Port.

Anchorage Sub-site

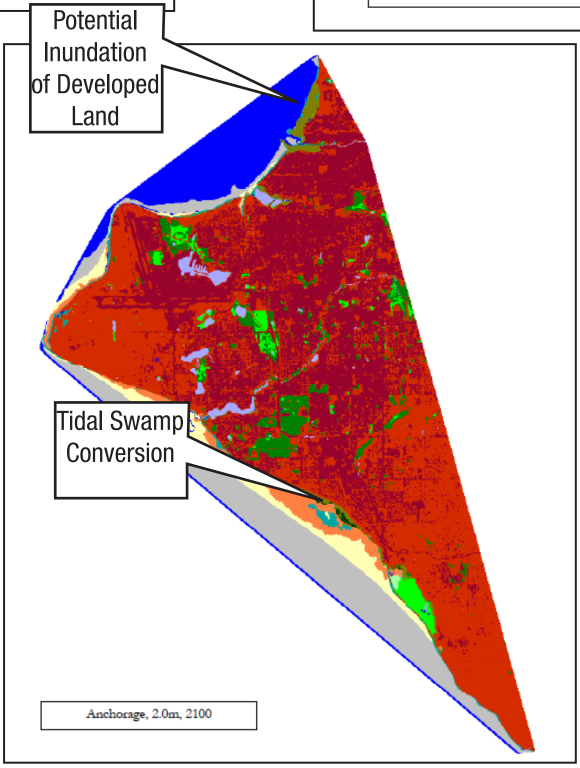
Looking at maps of results for Anchorage, the most substantial spatial predictions seem to be the potential inundation of developed land at the northern portion of the study site in the Ship Creek/Port of Anchorage area* and the potential vulnerability of the tidal swamp northwest of Potter Marsh, under the more aggressive prediction of a eustatic sea-level rise of 2.0 meters.



Anchorage, Initial Condition



Anchorage, A1B-Max (0.69m), 2100



Anchorage, 2.0m, 2100

Discussion of Model Results/Key Uncertainties

Overall, the simulated study area is not predicted to be particularly vulnerable to the effects of sea-level rise, primarily due to estimated land uplift over the next century. Coastal uplift is predicted to range from approximately 0.7 meters to 1.1 meters by 2100 based on long term GPS measurements for these sites. When this uplift is combined with a predicted eustatic rate of sea-level rise from 0.4 meters to 2 meters, the resulting predicted local sea-level rise ranges from negative 0.7 meters to positive 1.3 meters by 2100. In addition to this reduced range, we estimate that marsh lands will capture sediment and therefore vertically accrete at a rate roughly equivalent to an additional 0.4 meters per century. This further reduces predicted increases in water heights relative to marshes across the study area.

Tidal and mudflat erosion rates were modeled using a constant rate of 1.75 meters per year based on a single site-specific study.[17] This average rate was not spatially differentiated over the study area, meaning that prediction maps of tidal flat extents remain quite uncertain. Within this model, vertical movements of land have been held constant over time. Marsh loss or gain has the potential to be temporarily variable due to variations in land subsidence and rebound rates. Furthermore, there is significant uncertainty in modeling of tidal flats in Anchorage due to the limited spatial range of the LiDAR data source.

Finally, it is important to recognize that the entire study area, and the Anchorage site in particular, have relatively high tidal ranges. Areas with larger tide ranges are significantly less vulnerable to sea-level rise than are microtidal regimes, because marshes extend over a much wider vertical range. Additionally, any increase in sea-level rise relative to the overall tide range becomes much lower. This results in considerably less horizontal migration of wetlands in response to the same sea-level rise signal.

CONCLUSION AND RECOMMENDATIONS

Ultimately, this project has underscored the fact that Alaska poses unique challenges for sea-level rise modeling. Most importantly, the high quality elevation data required to accurately estimate impacts of sea-level rise are not available for the majority of the state. Other data coverages- such as land cover, tidal ranges, and vertical datum corrections- tend to be of lower resolution than those coverages in the contiguous United States. Furthermore, studies of marsh accretion are few and far between. That said, in the few areas in the region that had sufficient data to apply SLAMM, only a small portion of wetland habitat in the study region appears to be vulnerable to sea-level rise.

It should be noted that even though predictions of saline inundation for marshes and dry lands are not severe, global warming may still have a significant impact on these regions. The model does not account for water quality changes, changes in the snow-free season, changes in wildlife ranges due to temperature changes, nor increased erosion due to climate change. Nor does it mean that other coastal habitats in Alaska are immune to the impacts of sea-level rise. It is possible that coastal wetlands in other regions might not share the same variables (e.g., significant uplift and/or large tidal ranges) that make these study sites less vulnerable. In those areas, further application of the SLAMM model may be appropriate. Moreover, the rapidly eroding coastal zones in the north are testament to the fact that there are other habitats that are highly vulnerable to sea-level rise. Projecting future changes in that region may warrant use of models or other assessment techniques that are better able to capture dynamic geomorphic responses than SLAMM.

Despite the challenges (or perhaps because of them), the results of this study should help coastal researchers and other stakeholders in Alaska identify priority areas for additional analyses.

Recommendations

1. Identify and fill key data gaps, particularly in high resolution elevation data (e.g., LiDAR) as well as localized assessments of ecological processes such as marsh accretion.

2. Prioritize additional coastal areas for further sea-level rise impact studies. Wetland areas with similar characteristics to those in this study, for example, may not be as high priority for additional SLAMM modeling relative to wetlands in regions with lower rates of uplift, smaller tidal ranges, etc. Researchers also may want to consider alternative models in areas where geomorphology and related factors not as well captured by SLAMM are likely to be particularly important.

3. Identify potential management efforts within the habitat areas identified in this study as relatively vulnerable to sea-level rise (e.g., protecting key riparian areas along the Kenai River that are likely to be influenced by rising tides over the longer term).

4. Ensure sufficient funding for climate change research, monitoring, and adaptation planning and implementation at the state and federal levels.

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ENDNOTES:

(Endnotes)

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