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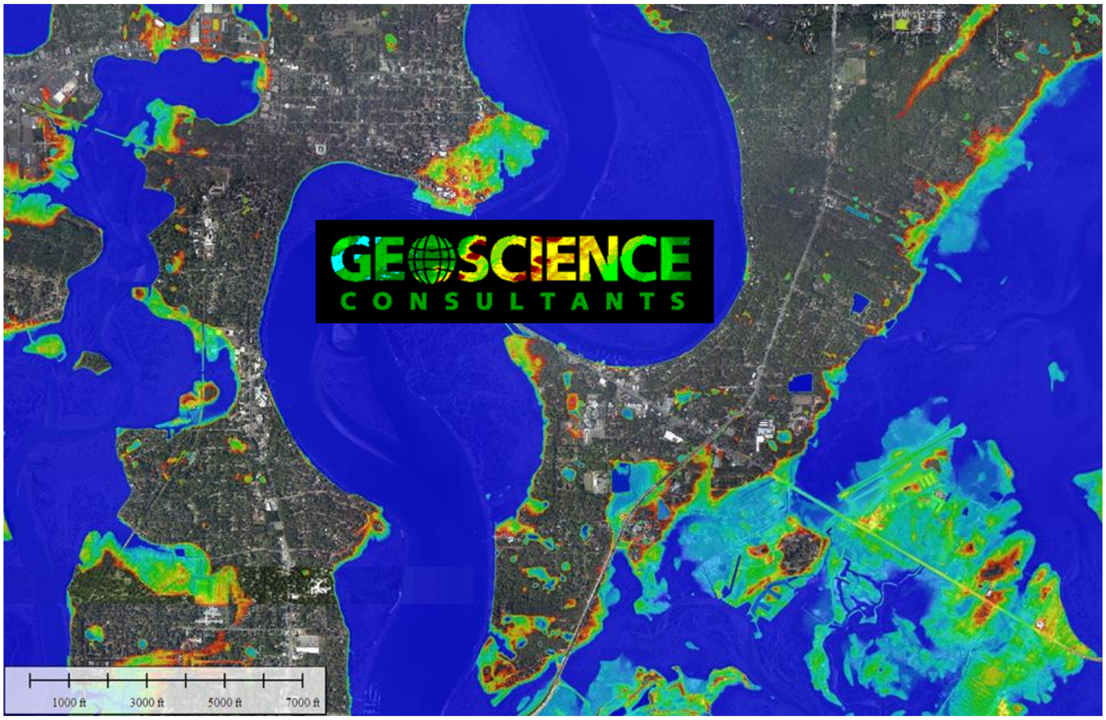

Beaufort Joint Land Use Study: SLR and Infrastructure

MAINTAINING MILITARY MISSIONS: COORDINATED APPROACH TO SEA LEVEL RISE INFRASTRUCTURE IMPACTS

GEOSCIENCE CONSULTANTS, LLC

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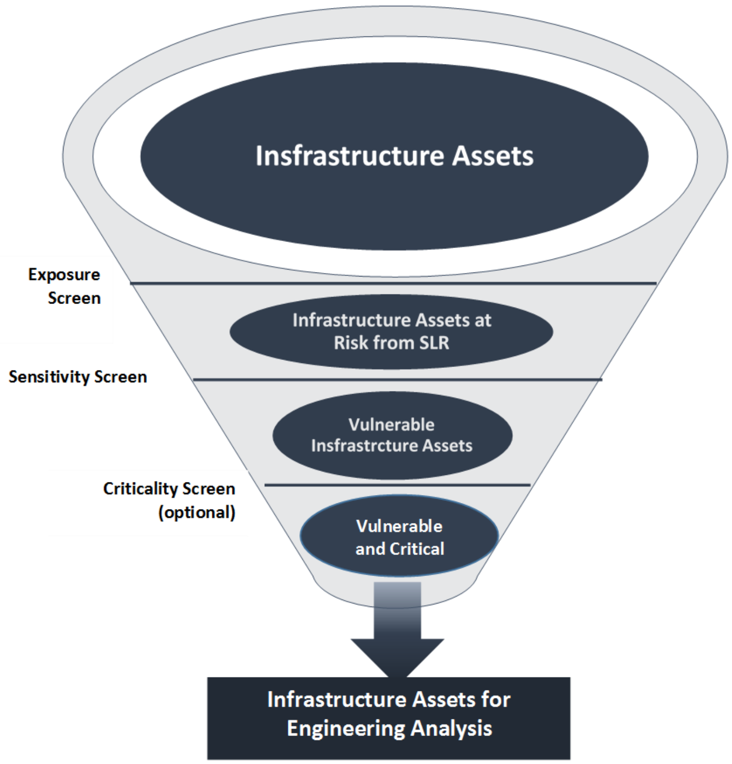
Exec Summary

The Beaufort area, largely through the work of the SLR Working Group, has begun to examine the many effects of SLR on the built and green infrastructure that provides the area a unique economic base and a way of life. As a part of the overall vision, this project's goal is to begin documenting the vulnerability of infrastructure within the greater Northern Beaufort area to potential increased sea levels in the future that also supports the MCAS Beaufort and MCRD Parris Island bases. There is a very intimate relationship in Beaufort county between the ocean and land, which brings a wealth of benefits and also a level of risk. This study represents only a portion of the overall resiliency planning that was outlined in the Sea Level Adaptation Report for Beaufort County.

Exposure risk – potential future increases in sea level – is a primary factor in this reports examination of vulnerability and was assessed using a bath-tub type model, sea level projections from Ft Pulaski from the USACE, the latest available lidar data for the county (2013), and a tidal correction model (VDatum) from NOAA. A frequency analysis of water levels was used to set the flooding threshold for mapping exposure risk. The water level chosen, 2.7 m (9 ft.) above MLLW, is roughly the monthly high tide and about 1 ft. above MHHW.

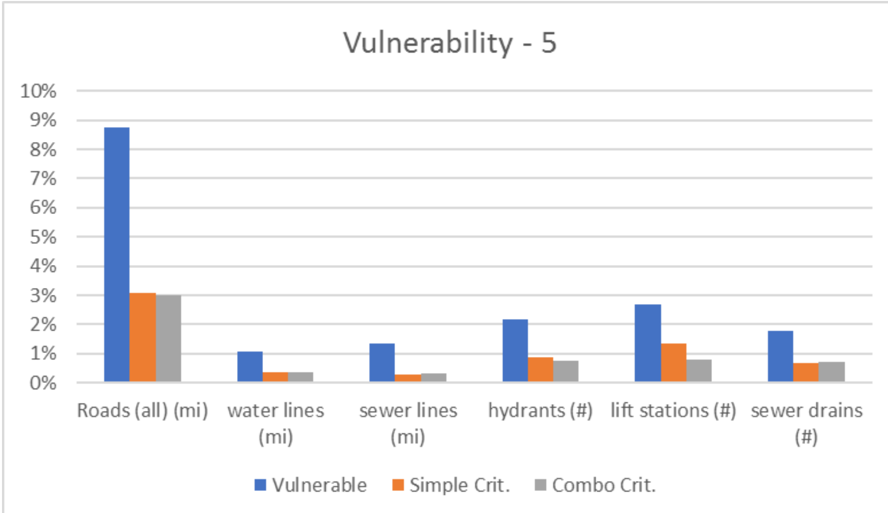
The unique projections of sea level in the future (from ca. 1 to 7 ft. by 2100) were analyzed as an envelope of possibilities (zone of risk) with a 90% chance, based on existing studies, of capturing the actual future change. Each infrastructure unit was then assigned a relative risk value for exposure to a monthly high tide based on the modeling results.

A systematic scheme was developed to highlight vulnerable and critical infrastructure and r as a funnel (see below). The three screens represent 1) the exposure risk – what is the risk that the infrastructure will be 'wet' during monthly high tides; 2) the sensitivity of the infrastructure to being 'wet' once a month (on average); and 3) the importance of that infrastructure to goals of the project. The screen thresholds (i.e., what is let through) can be tuned depending on the input from citizens, officials, scientists, engineers, etc.



A unique screening value (ranging from 1 to 3) was computed for each piece of infrastructure based on its location, elevation, type of infrastructure, and the projections of potential sea level increases. Values were assigned based on future projections for 2020, 2030, 2040, 2060, and 2085. The infrastructure passing through all three screens would be considered both vulnerable and critical for the specific projects goals; again these screens can be tuned to reflect the ideas of the stakeholders.

As a starting point for identifying at-risk infrastructure, we choose a moderate vulnerability (exposure risk + sensitivity risk = 5 or more), a simple criticality screening, and the infrastructure provided for the Northern Beaufort County area by Lowcountry Council of Governments. In this baseline scenario, the amount of infrastructure that may be vulnerable and critical is on the order of 4% or less in 2040 (see graph below). Transportation assets (roads and highways) is at the high end of this range and the percent of vulnerable transportation assets increase more rapidly through time than the other types – water utilities and storm water.



Infrastructure costs were determined on a per-unit basis using a preliminary engineering analysis of the asset types and a single recommended strategy – relocate, raise, or protect in place – to minimize risk. There were thousands of miles of transportation networks, thousands of miles of pipes, and thousands of individual assets (drains, hydrants, lift-stations, etc), which precluded in-depth engineering given the scope of this project. Total costs for the specific resiliency planning targets (screen values) were computed using the generic unit costs.

Year	scenario	Total Cost	Transportation	Water & Sewer	Storm Water
2030	vul,5; crit 5	$ 196,942,054.00	$ 193,250,346.00	$ 3,016,708.00	$ 675,000.00
2040	vul,5; crit 5	$ 257,377,025.00	$ 251,812,545.00	$ 4,759,480.00	$ 805,000.00
2060	vul,5; crit 5	$ 467,192,639.00	$ 456,426,316.00	$ 9,281,323.00	$ 1,485,000.00

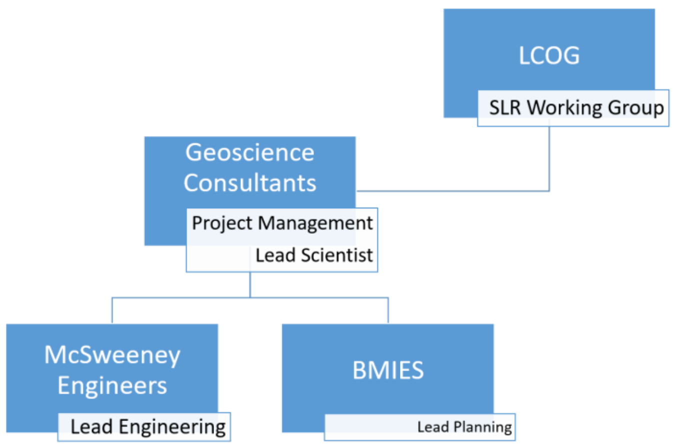
The total costs are, as a result of the generic handling of infrastructure, tallied in isolation and represent worst-case scenarios. They do not account for potential systematic gains – e.g., installing tide flaps at outfalls that reduce risks to connected drainage features or nearby roadways – nor do they account for maintenance costs that would be required anyway. As such, the costs associated with the adaptive measures to mitigate the risks can, in the normal course of cyclical maintenance, be significantly amortized. So while the values themselves may be higher than anticipated, it is more important that they are used as an example that strategic actions (adaptive management) taken in the coming years can help save money in the longer run.

This report details the science and engineering used and the logic employed to begin the process of helping the areas surrounding the MCAS Beaufort and MCRD Parris Island assess potential actions to ensure the continued operation of the bases and the way of life in these Lowcountry communities.

Introduction

Team

The results of this preliminary project are the product of the combined effort of many groups working together. It was managed by the Lowcountry Council of Governments (LCOG) in their role as a team member (administrator) in the Joint Land Use Study Committee. Project management, coastal planning, and engineering inputs were provided by the Geoscience Consultants team which included Geoscience Consultants, McSweeney Engineers and BMI Environmental Services. An advisory group, the Sea Level Rise (SLR) Working Group, consisting of representatives from various local government, Department of Defense, and academic institutions provided oversight of, and input on, the study's direction and progress. The goal of the organizational arrangement was to allow for both rapid and consistent response to The Council's needs using the appropriate team resources.



Project Background

The Beaufort area, largely through the work of the SLR Working Group, has begun to examine the many effects of SLR on the built and green infrastructure that provides the area a unique economic base and a way of life. There is a very intimate relationship in Beaufort County between the ocean and land, which brings a wealth of benefits and also a level of risk. This study represents only a portion of the overall resiliency planning that was outlined in the Sea Level Adaptation Report for Beaufort County[1]. Specifically the project was intended to develop a technique to identify infrastructure at risk and determining how those risks can best be minimized or mitigated to maintain service to the community and the military bases.

The risks posed to infrastructure from SLR are time dependent and, as such, future solutions are best addressed in order of priority. Prioritization requires both an understanding of the asset (infrastructure) in question as well as its location relative to the specific risk posed by climate driven change. Simply put, not all infrastructure assets within the envelope of forecasted inundation require the same level and/or timing of mitigation.

Prioritization is an important aspect of the present infrastructure assessment project and the efforts to establish them were undertaken methodically to achieve consensus rather than cause contention. To achieve consensus it was important to provide underlying understanding and common agreement of the

[1] Sea Level Adaptation Report Beaufort County, SC

natural risks (exposure), level of disruption from the risk (sensitivity) and relative importance (criticality) of the existing infrastructure within the study.

Several fundamental processes were provided to the SLR working group including a "5-Step Approach" and an infrastructure screening logic model. The 5-Step Approach was used as the blue-print for the study as a whole. The screening logic model provided a structured way to generate pertinent information, relative to the goals of the study, from the varied data sources used in the project.

Previous Work/SLR and Infrastructure

This report includes a list of scientific literature (e.g. reports, technical notes, white papers, websites) that was reviewed to provide guidance and develop the techniques used in the present SLR study for Beaufort County, South Carolina. It was decided to include this important aspect of the project as a stand-alone annotated bibliography in the Appendix (Appendix B) The annotated bibliography is not an exhaustive all-encompassing list of references relative to SLR, but rather a pointer to the most recent and informative sources used in developing this study. It highlights the potential impacts of SLR on man and the environment, the processes for evaluating those impacts, scenario planning techniques, and adaptive management tools that can be implemented to reduce impacts of SLR. The information presented herein is intended to document the research conducted for the Beaufort County SLR study and to share this information in hopes that it will enable others interested SLR to begin at a place further up the learning curve.

Study Site

The study site consists of several towns, cities, and unincorporated communities surrounding the military installations, Marine Corps Air Station Beaufort (MCAS) and Marine Corps Recruit Depot Paris Island (PI). The boundaries of the study area were generally consistent with the Northern Beaufort County Planning Commission's extents and were intended to capture areas that were within about 10 miles of the MCAS Beaufort and MCRD Parris Island.

Figure 1. Study area outlined in blue

Objectives/Goals

Project Goals

The project goal is to begin documenting the vulnerability of infrastructure within the greater Northern Beaufort area that also supports the MCAS Beaufort and MCRD Parris Island bases to potential increased sea levels in the future. To that end, and with the understanding that this is an initial inventory, the objectives to achieve the goal included developing a project framework, a shared understanding of the threats, a logical constraint of the at-risk infrastructure, a robust treatment of the modeling and engineering information, and a flexible stakeholder filter based on the project's goal.

The end result is seen as a start toward incorporating the vulnerability of critical infrastructure into a system of "strategic cyclical maintenance". Each piece of infrastructure has a lifespan, it is envisioned that this study will help steer or prioritize the required maintenance in the future to include modifications or precautions to a changing sea level. With the completion of this preliminary report the Northern Beaufort County will build on previous work and will have taken another step towards living with a changing environment. Awareness of the threat/issues and an understanding of the level of effort that may be required are important parts of a solution.

Planning Objectives

The first planning objective was to develop a project framework. Climate change vulnerability assessment and adaptation planning is a rapidly developing, interdisciplinary field[2]. The approaches vary by community, region, proximity to the coastline, and projected rate of SLR. Historically, the dominant focus has been on “soft” activities like planning, vulnerability assessments, and capacity building[3]. While planning is occurring at all levels of government the process has centered on an approach that follows a general sequence of 5 steps[4,5] which are summarized below.

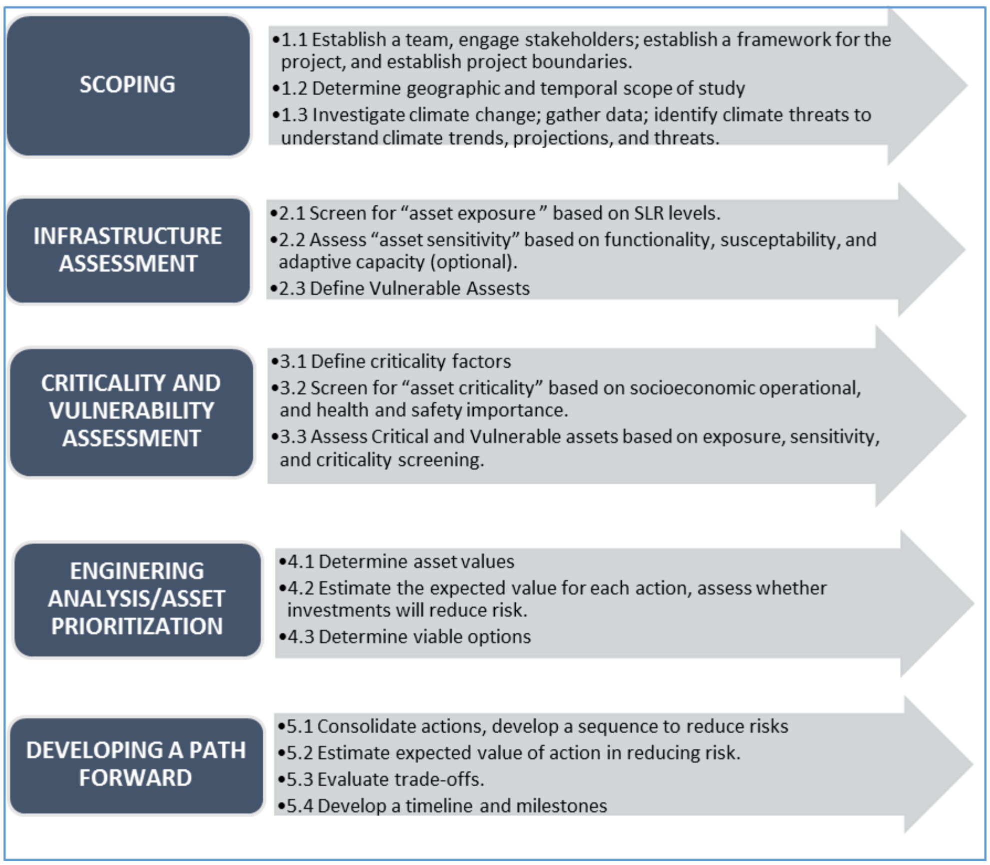


Figure 2. 5 Step Approach

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[2] Strategic Environmental Research and Development Program. 2013. Assessing Impacts of Climate Change on Coastal Military Installations: Policy Implications. US Department of Defense.
[3] Grannis, Jessica et. al. 2014. Preparing for Climate Impacts-Lessons from the Front Lines. Georgetown Climate Center, Georgetown University.
[4] Snover, A.K., L. Whitely Binder, J. Lopez, E. Willmott, J. Kay, D. Howell, and J. Simmonds. 2007. Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments. In association with and published by ICLEI-Local governments for Sustainability, Oakland, CA.
[5] U.S. Federal Government, 2014: U.S. Climate Resilience Toolkit.[Online] http://toolkit.climate.gov. Accessed [September 27, 2016].

Planning Scenario

The planning scenario is part of Step 1 – Scoping. This, along with background research, helped to establish a foundation from which the infrastructure vulnerability could be assessed.

Water Levels for Mapping

Several tidal levels and inundation frequencies were examined for the projects mapping threshold (i.e., what height of water will be mapped). Mean higher high water (MHHW) is a common tidal level and represents daily (on average) inundation frequency. Areas that are inundated daily, however, are commonly marshes/wetlands and require specialized infrastructure and permits to build on/in. This level of inundation, while important for highlighting at-risk infrastructure in the future, may leave infrastructure out of the planning discussion that will also be inundated, and thus at diminished capacity, but at less than a daily frequency for the targeted time-period.

Shallow coastal flooding, which occurs several times a year is another potential 'datum' that was examined for use in the planning discussion. For example the Highest Astronomical Tide (HAT), which is approximately equal to the shallow coastal flooding threshold assigned by the National Weather Service, was exceeded 18 times (or a total of about 26 hours) in the past year (May, 2015 to June, 2016) at Fort Pulaski. For stormwater infrastructure or transportation this approximate level of inundation frequency (Figure 3) was deemed more appropriate than MHHW.

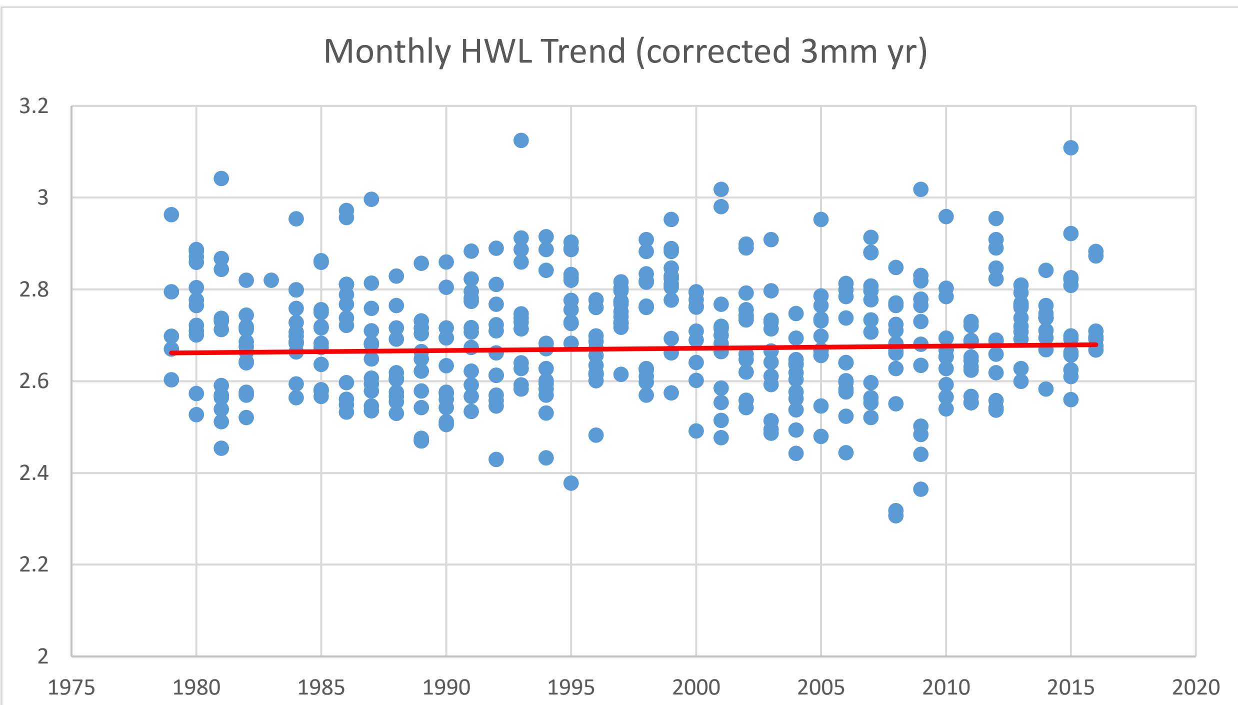

Figure 3. Monthly High Water Levels above MLLW for Ft Pulaski. Values corrected for SLR, red line is linear trend (average)

Other potential tidal threshold options, based on the monthly high water levels (Figure 2) since 1980, include:

- 2.5 m above MLLW: occurs **at least** once a month 95% of the time and is about six inches above MHHW.

- 2.7 m above MLLW: occurs **at least** once a month 50% of the time and is a little more than one foot above MHHW.
- 2.8 m above MLLW: occurs **at least** once a month 20% of the time and is approaching 1.5 ft. above MHHW.

Although Figure 3 shows monthly maximums the thresholds values shown are likely to occur more than once a month (i.e., on consecutive high tides). They were provided to the team as viable options, and for most infrastructure these values may be more appropriate than MHHW. If the project had a habitat or environmental planning focus, MHHW would likely be a better threshold.

It was agreed that 2.7 m above MLLW (at Fort Pulaski, GA) was a good mid-point between shallow coastal flooding and MHHW. This level of flooding occurred 55 times (85 hours of inundation) the past year (May, 2015 to June 2016). It approximates the "Monthly High Tide" (MHT) occurring in about 50% of the months from 1980 to present. A fuller discussion of the tide data and use of the specific inundation frequency level is presented in Technical Note JLUS-SLR-2[6]

Sea Level Rise Projections

This document is not intended to be an in-depth review of the information available on SLR projections or use of them in planning. Rather, the process and logic used in this project is based on guidance from two Department of Defense publications: the USACE's Comprehensive Evaluation of Projects with Respect to Sea-Level Change project[7] and the DoD's Regional Sea Level Scenarios For Coastal Risk Management[8]. The techniques and options developed based on these documents will be used to map potential monthly tidal inundation in the study area. The information from these maps will then be employed in attributing the potential of the various infrastructure, as provided by the Lowcountry COG, to inundation (i.e., exposure).

Sea levels have been rising at nearby Fort Pulaski over the period of nearly 80 years (Figure 4). The historical trend is roughly 3 mm a year, which is higher than the global average of about 1.8 mm. The reasons for the difference can be attributed, largely, to subsidence and variations in the ocean surface rise – called Dynamical Sea-Level Adjustment, which together almost ensures that every location experiences a different magnitude of sea level change. Although there is a geographic difference, the previous and forecasted sea level change at Fort Pulaski, which are slightly higher than the Charleston gauge, was used as a proxy for the change expected in the study area based on its location and similarity of morphology (i.e., Low Country setting).

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[6] http://www.geosciconsultants.com/low-country-cog/2016/9/16/technical-note-2-overview-of-mapping-technique

[7] USACE Engineer Technical Letter 1100-2-1, June 30, 2014

[8] Hall, J.A., S. Gill, J. Obeysekera, W. Sweet, K. Knuuti, and J. Marburger. 2016. Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme Water Levels for Department of Defense Coastal Sites Worldwide. U.S. Department of Defense, Strategic Environmental Research and Development Program. 224 pp.

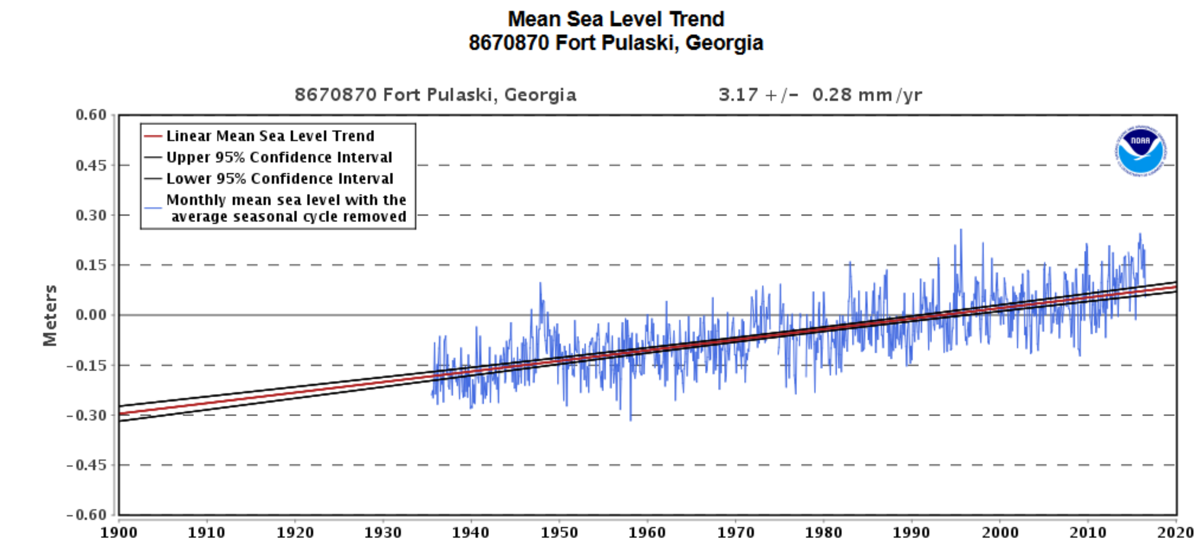

Figure 4. Long-term MSL tide measurements at Fort Pulaski

So while the trend of relative SLR at Fort Pulaski is clear (Figure 2), it is the change in SLR that is the driving aspect of the project. Unfortunately, the forecasted change remains largely unknown. There are lots of projections and ideas about the potential for sea level rise; however, there is growing consensus for a range of global curves (Figure 3) that represent a global average SLR rise of between 0.2 m and 2.0 m by 2100 (see: REGIONAL SEA LEVEL SCENARIOS FOR COASTAL RISK MANAGEMENT). The general thinking is that this envelope of SLR trends represents the expected range with about a 90% confidence level[9]. The magnitude of difference between the low and high projections (1.8 meters or 5 feet by 2100) obviously has large implications in the Low Country. Similarly the unknowns in timing, e.g., will it rise steadily or accelerate at a certain point in the future, makes choosing specific time periods for planning more difficult.

The recommended action to the group was to adopt the suite of Sea Level Rise Curves developed for Fort Pulaski by the USACE's Comprehensive Evaluation of Projects with Respect to Sea-Level Change project (Figure 5). These curves are in keeping with the DoD Regional Sea Level Scenarios For Coastal Risk Management's recommendations and also incorporate local trends. Technical Note JLUS-SLR -2[10] provides a fuller discussion of the use and selection of the USACE curves for the present project.

[9] Parris, A.P., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss. 2012. Global Sea Level Rise Scenarios for the United States National Climate Assessment. NOAA Technical Report OAR CPO-1.

[10] http://www.geosciconsultants.com/low-country-cog/2016/8/15/guidance-for-slr-parameters

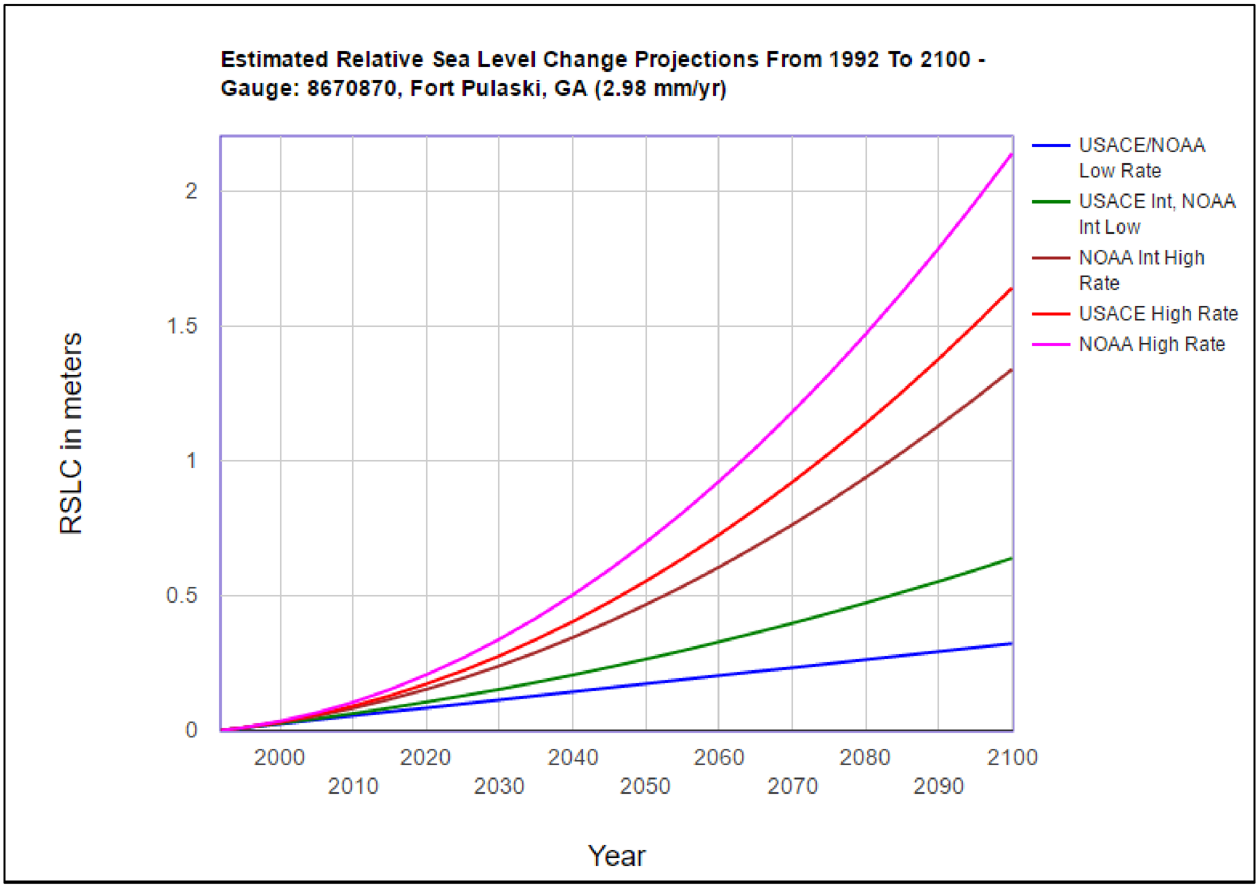

Figure 5. SLC curves from USACE and NOAA

Mapping Horizons

An important question in planning for SLR is defining what time-frame constitutes a 'short-term' decision and what constitutes a 'long-term' decision. Given the goal of maintaining service to functional military bases, it was decided to examine the potential lifespan of these bases under SLR scenarios.

In a simple "bath-tub" type model of SLR Paris Island could, under the highest scenario from the Ft Pulaski SLR curves (Figure 5), begin to have daily flooding (MHHW) of upland and paved areas by 2060 (Figure 6), which would lead to major changes and infrastructure decisions. MCAS Beaufort may start to experience runway closures near high tides each day under the highest SLR scenario by 2085 (NE end of main runway in Figure 7). This may not signal base closure, but may prompt major alternative infrastructure decisions.

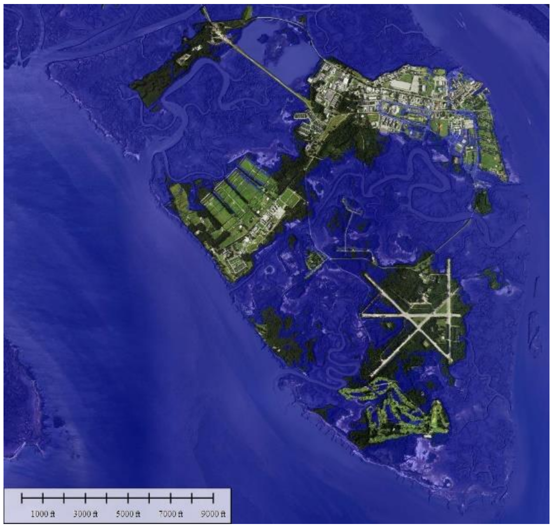

Figure 6. Paris Island; MHHW under high scenario for 2060

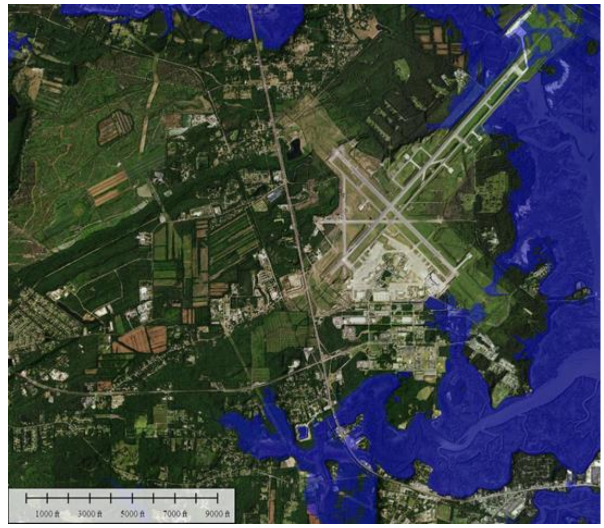

Figure 7. MCAS Beaufort; MHHW under high scenario for 2085

The SLR values used in these trigger points are considered to be conservative (i.e., using the highest scenarios), and <u>are applied here only to provide potential guidance on planning horizons, not infrastructure risks</u>. Based on these scenarios the maximum extent of the planning timeline is seen as 2085 with intermediate points at 2040 and 2060. Earlier time-frames (2020 -2030) are considered important for preparedness and maintenance in the coming decades.

- Short term time frames of 2020, 2030, 2040 for preparedness (2030) and response (2020).
- Mid-term time frames of 2040 and 2060 for planning adaptive measures.
- Long-term time frame of 2085 used for scenario planning.

Study Approach

The techniques for defining potential inundation limits in the future were developed using risk-based framing concepts[11]. The technique does not explicitly assign likelihoods or probabilities, however, the scenarios chosen for each planning horizon (2020, 2030, 2040, 2060, 2085) are related by a percentage (%) to the overall range of scenarios adopted in this study (Figure 5). In this way the envelope of chosen scenarios (i.e., the USACE SLR scenarios) for each planning horizon (e.g., 2040) are considered.

For example, if a scenario is chosen for 2040 that is a split between the USACE and NOAA High Rates (0.44 m) it would be assigned about a 20% relative risk value using the envelop of projected values. This **does not** explicitly mean that there is a 80% likelihood of the scenario encapsulating the range of **actual water elevations** (i.e., only 20% likelihood of the water being higher) in 2040. It **does**, however, **provide a scaler value of the choice's tolerance of risk** (low in this case) **with regards to the considered**

[11] The approach acknowledges that risk under conditions of deep uncertainty cannot be defined in a strictly probabilistic sense and instead is dependent on the type of decision involved, its intended longevity, and a decision-maker's tolerance for the adverse consequences of a wrong decision

population of scenarios (i.e., USACE SLR scenarios for 2040). For more detailed information – please see Technical Note JLUS-SLR-1 &2.

Lidar and Tidal Data

The latest (2013) light detection and ranging (lidar) data and most recent V-Datum information were used to map the present elevation of the land surface and the elevation of the water surface, respectively, in the study area. Although the 2013 lidar data is the most recent data available, there are limitations (Figure x). The 2013 lidar data was collected to meet a 10 cm RMSE (root mean square error; about 1 standard deviation) accuracy in open areas, meaning the actual elevation is typically (about 68% of the time) within +/- 10 cm of the surface represented in open areas (no high vegetation). In vegetated areas (besides short grass) higher error values are common especially in marshes/wetlands. The specific data used for this study is known as Quality Level 2 data, which has an error specification of 10 cm RMSE for non-vegetated areas and approximately a 15 cm RMSE for vegetated areas. We choose to use the 15 cm RMSE error value in the modeling as a conservative value given the mixed land covers in the study area.

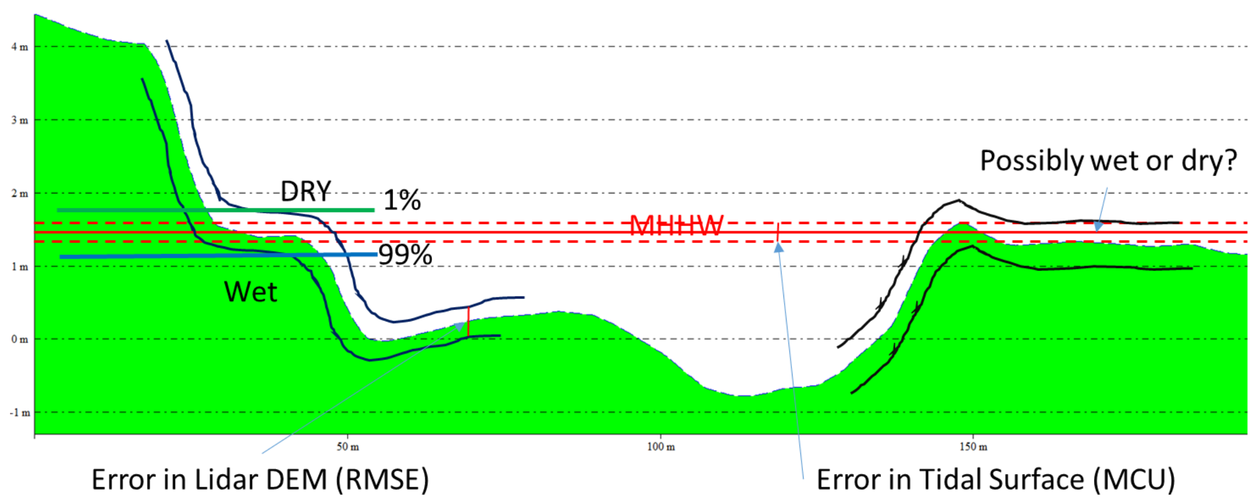

Figure 8. Time-zero data and errors; Lidar DEM error = 15cm, Tidal surface MCU = 14.8cm

Like the land surface, the ocean surface is not flat. The tidal surface used in this project is the product of models run by NOAA and known as V-Datum. The modeling, like the lidar, is not perfect and in the Beaufort area the model has a maximum cumulative uncertainty (MCU) (about 1 standard deviation) error of 14.8 cm. It should also be noted that tidal data (i.e., VDatum) is not available for 'dry land'; thus all theoretical tide elevations for land areas (i.e., the whole study area) must be interpolated from nearby data. Therefore, in this case, the 14.8 cm value is possibly a bit optimistic.

The outcome from these sources of data, as shown schematically in Figure 8, is that even mapping MHHW (or any tidal level) at present (i.e., 2013) there is a level of uncertainty in the output. This is discussed in more detail in Technical Note JLUS-SLR-2.

The process being used to map the extents of relative risk for each time period (see Study Approach above) has incorporated the uncertainty contribution in time-zero data (elevation and tidal data) when assigning a relative risk value to infrastructure. So, unlike the SLR projections – the elevation data is used in a probabilistic manner in mapping because they have a measured population of errors.

Using the technique outlined in the NOAA SLR viewer[12] (and the same used for VDatum) for assessing combined uncertainty from the elevation and tidal data, the combined MCU of the lidar and tidal data errors is 21 cm. We decided to use a more conservative value for the error since much of the infrastructure are in open areas (roads); a strategy to employ 80% (17.8 cm) of the total error value (21 cm) was used in this project.

Digital Elevation Models (DEM) were constructed using the Lidar and Tidal data to map the relative risk. There are two general ways to map using a simple flooding model, which was used in this project. One is considering all 'low areas' connected (via sewers, culverts, etc.); the second is to consider only areas that are morphologically connected (e.g., only areas with direct access via DEM to flooding source – the ocean). The first implicitly assumes that conduits connect all low areas and the second relies on the DEM to be hydraulically correct. Unfortunately neither are accurate in their portrayal of the water flow since there are underground connections in some areas, and none in others.

In this application we chose to proceed with the 'All-Connected' scenario, which is the most conservative one. The proper fix would entail a high effort of work to modify the DEM to reflect culverts and include sewer and drainage features in the modelling. This level of work is beyond the scope of this assessment study. As a result, it should be noted that the results will likely tend to over-estimate the areas that are subject to the tidal flooding thresholds developed for the project. This is considered the better option for the use in an assessment study. A more in-depth discussion is available in Mapping Memo-1[13].

GIS Data

The GIS data for infrastructure in the study area was provided by LCOG. The infrastructure layer types included: 1) Highways, 2) Roads, 3) Lift Stations, 4) Hydrants, 5) Sewer Pipes, 6) Water pipes, and 7) Storm Drains/Sewers. Bridges were developed using the highway/roads layers combined with the DEM. Road and pipe layers (i.e., line features) were broken into 100 ft. sections for analysis.

The database for each layer was used to further differentiate the specific infrastructure types. The accuracy and completeness of the GIS data was not formally tested. It was noted that there were several database fields that were not consistently filled in for all entries. In addition, there were some road features that did not match up exactly with the other data; and at least one lift station was located in the field that was not in the GIS data. These issues aside, the data was deemed sufficient to accomplish the tasks under this preliminary study. Future work will benefit from updated and field verified GIS data.

Infrastructure Assessment

Overview

The procedure for assessing infrastructure asset vulnerability to SLR in this project follows a modified process outlined in a multi-agency document titled "Scanning the Conservation Horizon: A guide to Climate Change Vulnerability"[14]. The general process schema used in the present study, and outlined in Technical Note JLUS-SLR-3, is diagramed in Figure 9. The 'screens' are common to most resiliency studies, but arranged slightly differently here to allow for changes in the description of "Criticality",

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[12] http://dx.doi.org/10.2112/JCOASTRES-D-13-00118.1

[13] http://www.geosciconsultants.com/low-country-cog/2016/9/9/mapping-memo-1-connected-vs-unconnected-inundation-mapping

[14] Glick, P., B.A. Stein, and N.A. Edelson, Editors, 2011. Scanning the Conversation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife federation, Washington, D.C.

which will be covered in a following section. The goal of this approach is to facilitate defining vulnerable infrastructure that can, at a later stage, be modified for "criticality" to arrive at a highly screened sub-set of vulnerable infrastructure; i.e., that which is both vulnerable and critical.

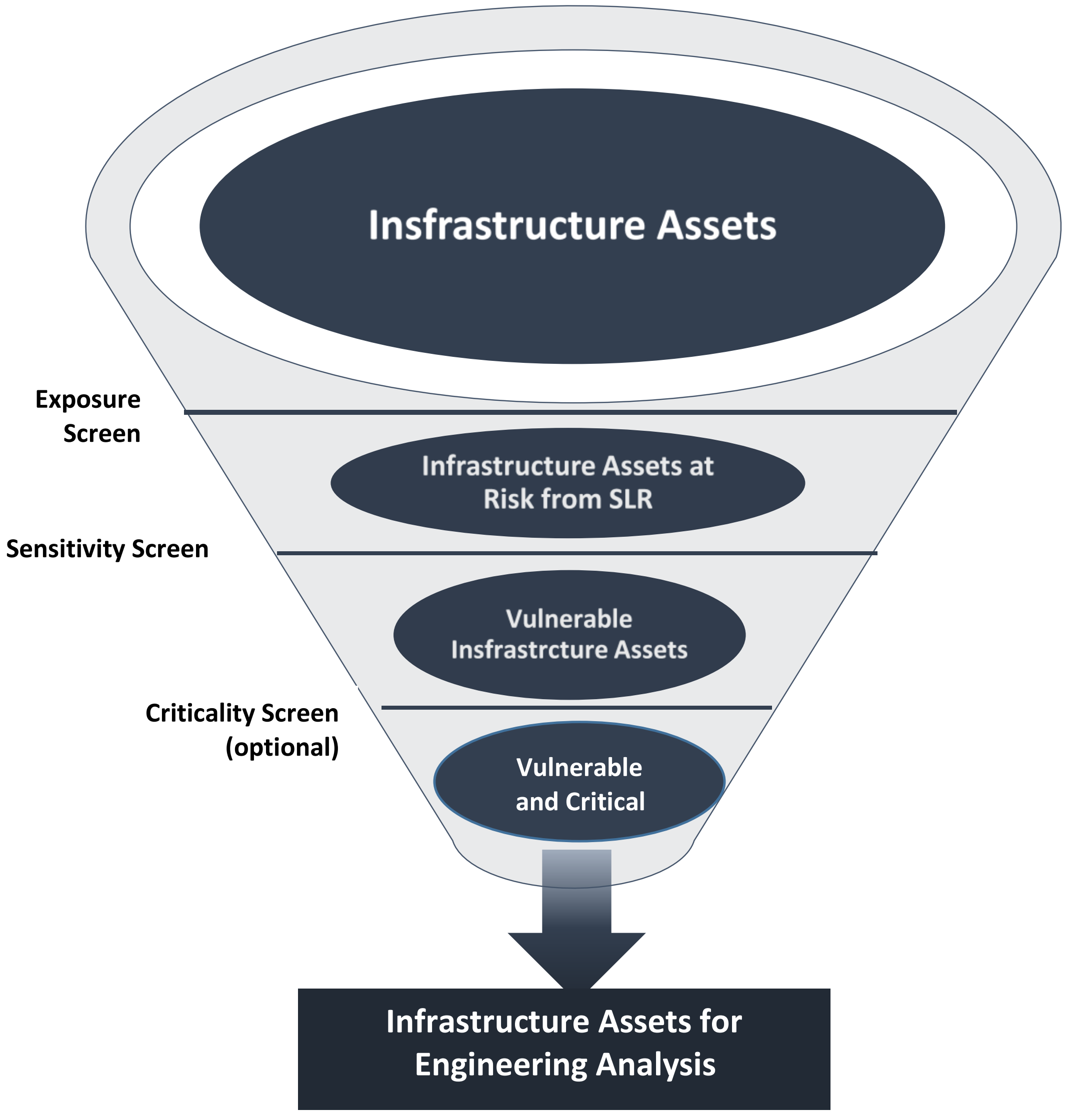

Figure 9. Schematic of screening process

The assessment of exposure to monthly tidal inundation through time has been performed using data and techniques described previously. Using the processes described in the following sections, the infrastructure assets in the study area that have a relative risk of being inundated between 2020 and 2085 at the tidal level chosen were passed through the exposure screen.

The second screen, the sensitivity assessment, is based on the innate characteristics of the asset and considers its tolerance to changes associated with inundation. For example, in a county level resiliency assessment the sensitivity to tidal inundation of a sewer main is lower than the sensitivity of a highway. The sewer main is likely to perform with little interruption; however, the highway may have to be closed. This does not mean that the sewer main is unaffected; there may be longer-term issues with increased saltwater soil saturation or pipe instability, but that sensitivity to inundation is less than the roadway, which could be rendered unusable and experience long-term stability issues as well. Where information was available, different types of infrastructure within each category (e.g., roads, sewers, water pipes, etc.) were assessed for sensitivity separately.

The last screen – The Criticality Screen – will help inform the planning aspect of the process. The input used in this step is, largely, shaped by stakeholders and the goals of the specific planning objectives.

Infrastructure Screening

Exposure (SLR)

Exposure of the various infrastructure components to SLR, the first screen, was computed using relative risk based on the various projections from the USACE.

Modeling Exposure

Modeling of Monthly High Tide (MHT) was performed using a 'bath-tub' approach. In this case the unconnected areas were included as discussed earlier in the report. The modeling does not use single scenarios (e.g., NOAA Low, USACE Moderate, etc) but rather all of the unique scenarios from the USACE SLR calculator (Figure x). The techniques for defining potential inundation limits from MHHW in the future are based on risk-based framing concepts[15] introduced in TN-JLUS-SLR-1. The technique does not explicitly assign likelihoods or probabilities, however, the scenarios chosen for each planning horizon (2020, 2030, 2040, 2060, 2085) are related by a percentage (%) to the overall range of scenarios adopted in this study (Figure x). In this way the envelope of chosen scenarios (i.e., the population sample of adopted scenarios) for each planning horizon (e.g., 2040) is considered.

For example, if a scenario is chosen for 2040 that is a split between the USACE and NOAA High Rates (0.44 m) it would be assigned about a 20% relative risk value using the scenario envelop as the population. This **does not** explicitly mean that there is a 80% likelihood of the scenario encapsulating the range of **actual water elevations** (i.e., only 20% likelihood of the water being higher) for the chosen time. It **does**, however, **provide a scaler value of the choice's tolerance of risk** (low in this case) **with regards to the considered population of alternatives** (i.e., considered SLR scenarios).

Mapping Exposure

Mapping of the exposure includes both errors in the base elevation and tidal data as well as mapping scaler values of the relative risk. The time-zero errors (elevation and tidal) were handled in a simple fashion by assuming a 80% safety margin. Using the technique outlined in the NOAA SLR viewer (and the same used for VDatum)[16] for assessing combined uncertainty from the elevation and tidal data, the combined MCU of the lidar and tidal data errors is 0.21 cm. Eighty percent of the value (17.8 cm; 7 inches) was used to build-in a conservative error estimation of the tidal DEM used to map the relative risk.

$$\text{Corrected DEM} = \text{Original DEM} - 17.8 \text{ cm}$$

The tidal elevation of the MHT was taken from Ft Pulaski as both an elevation above Mean Lower Low Water (MLLW) and MHHW. This was done because of the differences in tidal dynamics between Ft

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[15] The approach acknowledges that risk under conditions of deep uncertainty cannot be defined in a strictly probabilistic sense and instead is dependent on the type of decision involved, its intended longevity, and a decision-maker's tolerance for the adverse consequences of a wrong decision

[16] Estimation of Vertical Uncertainties in VDatum; http://vdatum.noaa.gov/docs/est_uncertainties.html

Pulaski and the study area. The initial use of the MLLW value (2.7 m above MLLW) overestimated flooding due to a lower tidal range in the coastal areas (eastern portion of study site). To correct this, the lowest flooding elevation at all locations, based on either the (MLLW +2.7m) or (MHHW + 0.41 m), value was used. This situation is the outcome of using a tidal station outside of the study area. The result of using the lower value is that the model flooding surface is conservative value (i.e., the actual flooding elevation may be slightly higher than modeled). The flooding extents of the mapping strategy were field verified during Fall 2016 by comparing DEM mapped flooding extents for MHT and site visits in the Beaufort area (Figure x).

Figure 10. Example of flooding in parking lot near Port Royal Boardwalk during a MHT in October.

Once a flooding DEM was created, it was used to map the relative risk values using a Z-Score technique. This technique is based on an adaption of the technique employed[17] in the NOAA Sea Level Rise and Coastal Flooding Impacts Viewer to incorporate data uncertainty (tidal and elevation data) into the mapping outputs. The process, as used in this study, returns the relative risk of an area to inundation based on the SLR projections for the specific time period and the flooding elevation (i.e., MHT). A map of the relative risk in the study area (see Figure x for example) was created for each time period. Simplified risk areas showing the entire envelope of risk (10 to 100%) were generated and are available as KMZ's.

[17] Schmid, K., B. Hadley, and K. Waters. 2014. Mapping and Portraying Inundation Uncertainty of Bathtub-Type Models. *Journal of Coastal Research* 30:548–561.

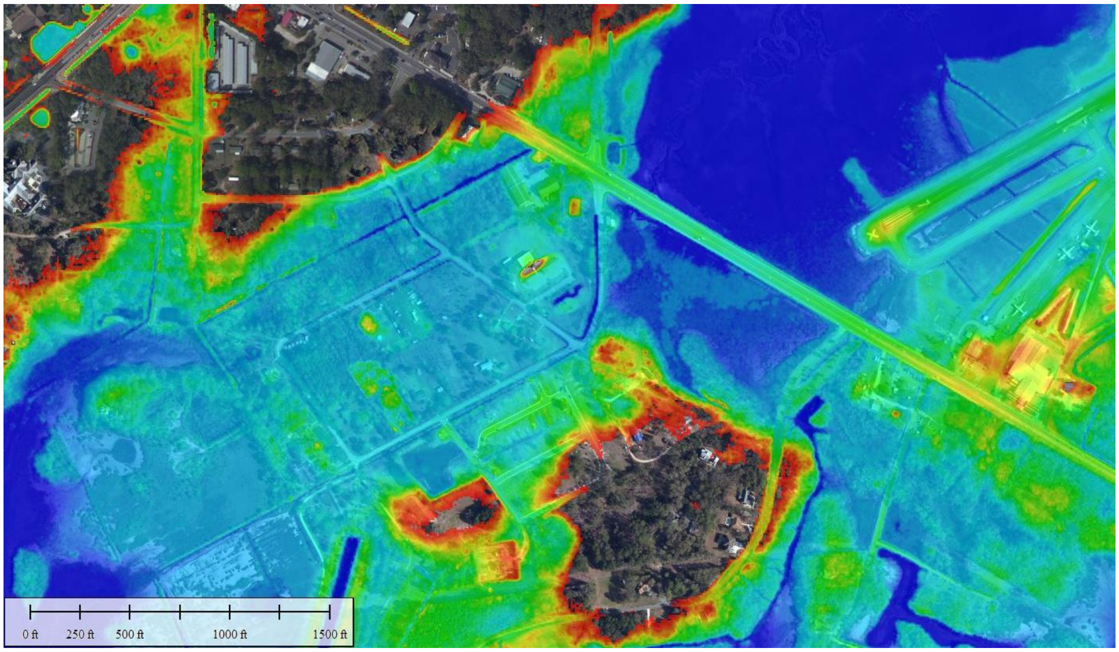

Figure 11. Example of mapped risk values for 2085. Blues represent the highest risk values, reds the lowest. Areas without shading are beyond the 10% risk zone.

The GIS data representing the infrastructure was populated with values from the various relative risk surfaces (Table 1). Each piece of infrastructure or length of pipe or road were given a ranking from 1 (low risk: < 30% relative risk) to 3 (high risk > 60% relative risk) based on the risk values for each year. The breakdown of infrastructure by exposure risk (i.e, relative risk) is provided in Appendix XX.

Table 1. Example of risk values for sewer drains, values are in relative safety (1 – relative risk).

ID	RISK_2020	RISK_2030	RISK_2040	RISK_2060	RISK_2085
SD_15386	0.82	0.36	0.19	0.103	0.082
SD_15395	0.32	0.13	0.08	0.073	0.071
SD_15404	0.42	0.17	0.09	0.219	0.129
SD_19143	0.00999999...	0.02	0.03	0.035	0.049

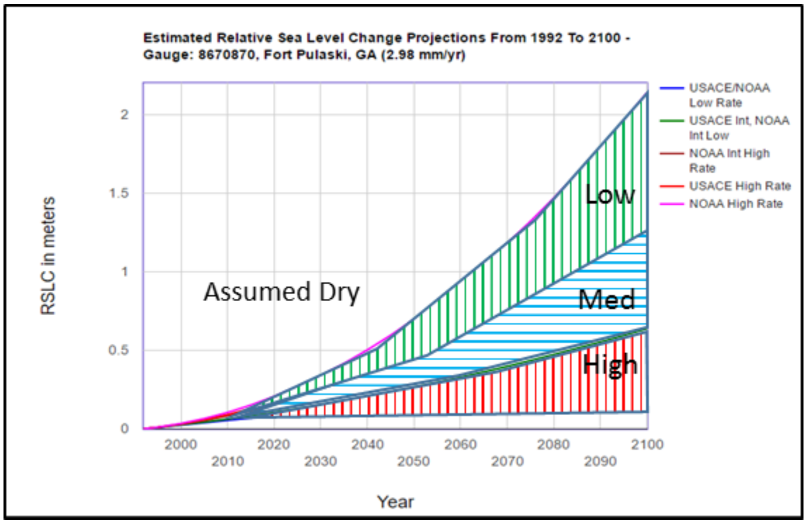

Figure 12. Exposure values schematic; high = 3, med = 2, and low = 1.

It should be noted that the risk values transferred to the infrastructure are sensitive to the GIS data accuracy in addition to the modeling. For example, If a sewer drain point feature was in error of 10 ft. the resulting relative risk score could be markedly different than actual depending on the slope of the area.

Sensitivity

The second screen, the sensitivity assessment, is based on the innate characteristics of the asset and considers its tolerance to changes associated with inundation. For example, in a county level resiliency assessment the sensitivity to tidal inundation of a sewer main is lower than the sensitivity of a highway. The sewer main is likely to perform with little interruption; however, the highway may have to be closed. This does not mean that the sewer main is unaffected; there may be longer-term issues with increased saltwater soil saturation or pipe instability, but that sensitivity to inundation is less than the roadway, which could be rendered unusable and experience long-term stability issues as well. Where information is available, different types of infrastructure within each category (e.g., roads, sewers, water pipes, etc.) are assessed for sensitivity separately.

The determination of the sensitivity of each type of asset (infrastructure) was determined using information gathered in interviews with the public utility agencies providing service to the greater Beaufort area, professional engineering input, and the information available in the GIS files provided by LCOG. The values assigned are based on high (3), medium (2), and low (1) sensitivity to monthly tidal inundation. These relative values are meant to be representative of the specific utilities categories being assessed in this project. More information on sensitivity is available in Technical Note JLUS-SLR-4.

GIS Data

The GIS data used in the project was supplied by LCOG as discussed previously. The general infrastructure type (e.g., storm drains, water pipes) as well as some of the asset specific information (e.g., pipe diameter, storm drain type) in the database entries were used to assign sensitivity to each piece of infrastructure, length of road, or length of pipe.

For this preliminary sensitivity analysis, only a few of the fully populated database fields were used. There is room for future use of the database to better constrain the sensitivity values as well as preparing cost estimates. Similar to the location accuracy, the sensitivity (and/or cost) values are dependent on the accuracy of the database entries.

Engineering Input

The infrastructure categories listed above has been assessed within the GIS/Sea Level Rise Models for several planning horizons (year 2020, 2030, 2040, 2060, and 2085) and the 2040 planning horizon was specifically chosen for evaluating *sensitivity*. Several publications were referenced in order to follow some established protocol in assessment of infrastructure sensitivity:

- Sea Level Rise Adaptation Report Beaufort County 2015
- Sea Level Rise and Coastal Infrastructure: Predictions, Risks, and Solutions published by the American Society of Civil Engineers (ASCE)
- US Army Corps of Engineers (USACE)Comprehensive Evaluation of Projects with Respect to Sea-Level Change Project
- Dept. Of Defense Regional Sea Level Scenarios for Coastal Risk Management.
- RS Means Heavy Construction Cost Data

As part of the local engineering community McSweeney Engineers has had experience working with the organizations which administer and maintain this infrastructure. Beaufort Public Works, County Engineering, MCAS Beaufort, BJWSA, and SCDOT were contacted prior to the performing this Study Task. Significant effort was made to engage these organizations which have authority and comprehensive knowledge over their respective infrastructure.

Transportation

In general, transportation infrastructure is highly sensitive to sea level rise. Some of the anticipated hazards associated with this include:

- Roadway overtopping
- Standing water – hydroplaning, stalling vehicles
- Undermining and erosion leading to washout of embankments
- Surcharging of storm drainage piping, culverts, and catch basins
- Complete washout of roadway
- Accelerated deterioration of bridge superstructures
- Undermining of bridge substructures due to channel bottom scour

There is significant variation of sensitivity from asset type, material, and age. For example, modern State and Federal Highways such as 802 and 170 are far less sensitive to risk than local streets in the historic *Old Point* neighborhood or *Mossy Oaks* neighborhood adjacent to Battery Creek due in large part to modern codes that incorporate probabilistic-risk mitigation analysis in design. Additionally, technological improvements have permitted higher bridge and roadway elevations as well as the use of higher performance materials that are less sensitive to the risk of sea level rise. Conversely, many of the older streets in and immediately surrounding the historic district were constructed in a manner which would be considered deficient by today's standards. Many older streets predate today's SCDOT Standard Specifications. For example, they may not be founded on a compacted limestone base as commonly as current specifications require or lower than minimum elevation requirements. Therefore these older roadways typically have a higher sensitivity to the hazards of over topping and erosion.

Older bridges typically have an increased sensitivity to deterioration due to age and finite lifespan of materials. Typically most deficiencies of water-crossing bridges are found in the tidal and splash zones of the structure. A typical 50-75 design lifespan is shortened by sea level rise because the tidal zone and splash zones inundate a greater portion of the supporting substructure and these susceptible zones become, over time, increasingly closer to the superstructure elements. Many of the older bridges were built at lower elevations than modern bridges, particularly swing-span type bridges, such as the Wood's Memorial Bridge and the Harbor Island Bridge.

Storm Water

Storm drainage assets are highly sensitive to inundation and there is significant variation of sensitivity with regards to asset type and age of infrastructure. Some of the anticipated hazards associated with this exposure include:

- Surcharging of pipes and overflowing of grate inlets and catch basins
- Full pipe flow condition causing pressure and failure of joints between concrete pipe
- Saturation of supporting soils leading to collapse and joint separation
- Scour and undermining of outfall structures, headwalls, etc.

Of the many storm drainage types throughout the study area many have lost capacity due to debris, are undersized for current design storm events, and not equipped with any check valve apparatus to control current tail water effects. From a hydraulic perspective, storm water capacity is already exceeded in some cases by current tail water effects; future tail water effects associated with sea level rise will likely exacerbate this condition. From a structural perspective, some of the older piping may likely be founded on native, poorly consolidated soils that are more susceptible to infiltration and erosion and which may potentially lead to settlement of piping, separation of joints, and failure due to sea level rise.

Water Utilities

Water utility assets are moderately sensitive to risk. Their risk is somewhat mitigated due to the fact that much of the infrastructure is buried. In general water utilities design and management and vulnerability is based on design storm events such as the 10-year and 25-year rain events, not tidal inundation. Beaufort Jasper Water and Sewer Authority (BJWSA) recently reported on its response to Hurricane Matthew which significantly impacted the area and their operations and is referenced in this report. Many different subcategories of infrastructure exist within this area and there is a broad range of identified risks:

- Increase of source water salinity
- Infiltration of storm water and seawater into gravity sewers
- Saturation of supporting soils leading to collapse and joint separation of pipelines
- Inaccessibility of fire hydrants due to flooding
- Corrosion of ductile iron components
- Damage to lift stations due to flooding

A full list of the infrastructure and the specific sensitivity of each is listed in the Engineering Report (Appendix A).

Criticality

The third screen is described as the "Criticality Screen" and it is designed to identify the most important cultural/institutional assets that an agency might wish to examine for vulnerability to climate change[18]. This is the most flexible of the three and is intended to reflect community interests; projects looking at similar infrastructure may have different criticality screens depending on the goals. More information on sensitivity is available in Technical Note JLUS-SLR-5.

For this project, the definition of "criticality" will build on the definition of a critical asset as...*an asset that is so important to the study area that its removal would result in significant losses*[19]. Criticality as used here is goal-oriented and reflects the importance of the asset to the projects goals. The components of the criticality screen are flexible and are envisioned to represent aspects of the resiliency goals of the project. For example, a project highlighting health and safety concerns may incorporate proximity to evacuation routes and shelters as key aspects in the criticality screening; whereas an alternate resiliency goal of socio-economic justice may emphasize aspects of the population in determining criticality of infrastructure. As such, "criticality" as used in this study requires an understanding of the project goals and to some degree the scenarios that are involved in meeting those goals. It is in this context that local stakeholder viewpoints are an important determinant of "criticality".

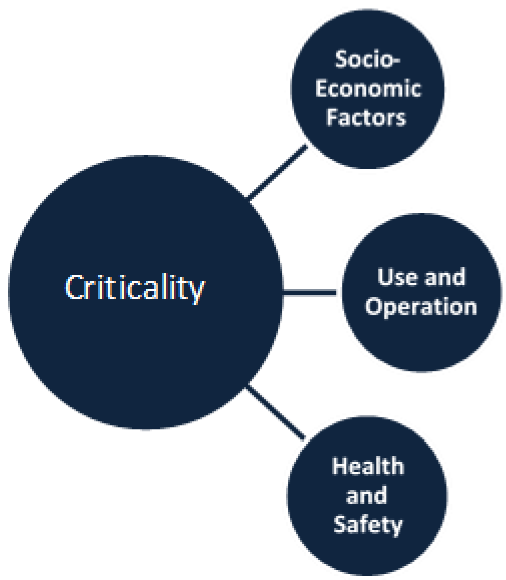

Figure 13. Criticality components

Criticality Factors

To facilitate the process of identifying criticality factors, the assessment approach was based on previous stakeholder work by local organizations such as the Beaufort Port Royall SLR Task Force's Adaptation Actions (Section III) [20] and the Beaufort County Hazzard Mitigation Plan, 2015 Update[21] to frame some of the important and measurable criticality factors. Again, it is not meant to be a full description of the criticality of a specific infrastructure asset, but rather a spatial indicator to use in

[18] ICF International. 2014. Assessing Criticality in Transportation Adaptation Planning. US Department of Transportation Center for Climate Change and Environmental Forecasting.

[19] DHS (2007). Transportation Systems: Critical Infrastructure and Key Resources Sector-Specific Plan as input to the National infrastructure Protection Plan. Department of Homeland Security. Arlington, VA.

[20] South Carolina Sea Grant Consortium. 2015. Sea Level Rise Adaptation Report Beaufort County, South Carolina. S.C. Sea Grant Consortium Project #SCSGC-T-15-02.

[21] Beaufort County Hazard Mitigation Plan 2015 Update, http://www.lowcountrycog.org/FEMA%20DRAFT.pdf

sorting/visualizing priorities. Criticality assessment factors for the three components that were assessed for this project include the following:

1) Socio-Economic Factors
    a. Proximity to schools
    b. Census weighting – Social Vulnerability Index (SOVI)
2) Use and Operation
    a. Proximity to DoD bases
    b. Use statistics (e.g., number of vehicles using a road)
    c. Ownership (e.g., private, local, state, federal)
    d. Watershed size
    e. Land cover type (e.g., high development, low development, forest or location relative to coastline)
3) Health and Safety
    a. On an evacuation route
    b. Proximity to hospitals or Critical Facilities

The factors chosen for inclusion were based on their importance in previous stakeholder work and the objectives of this project, which is focused on maintaining services to local DoD bases. For the Socio-economic component the location with respect to SOVI rankings and/or location with respect to schools were chosen. For the Operation/Use component it is proximity to DoD bases. For the Health and Safety component the options include the asset's location with respect to evacuation routes, and/or hospitals. Scoring (values between 1 and 3) for the factors in this project are based on distance or, in the case of the SOVI factor, the high-medium-low scores.

Two basic examples of varying criticality screens are shown below. One highlights the base's criticality and evacuation routes (Figure 13); the other has a higher weight on the socio economic component (Figure 14). A combination screen (Figure 15) was also computed from all factors shown in Figures 13 and 14; it highlights the flexibility of the screening technique, represents the level of complexity that a stakeholder defined screening would exhibit, and was used, along with example 1, to define criticality in this study.

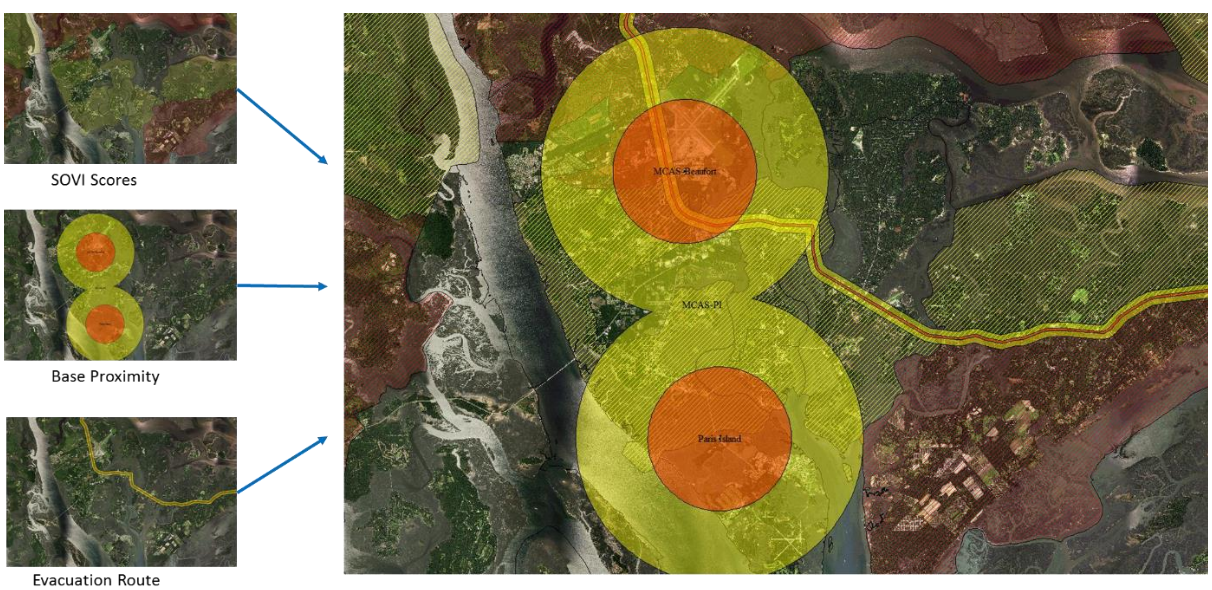

Figure 14. Example 1, criticality factors used for base criticality screening

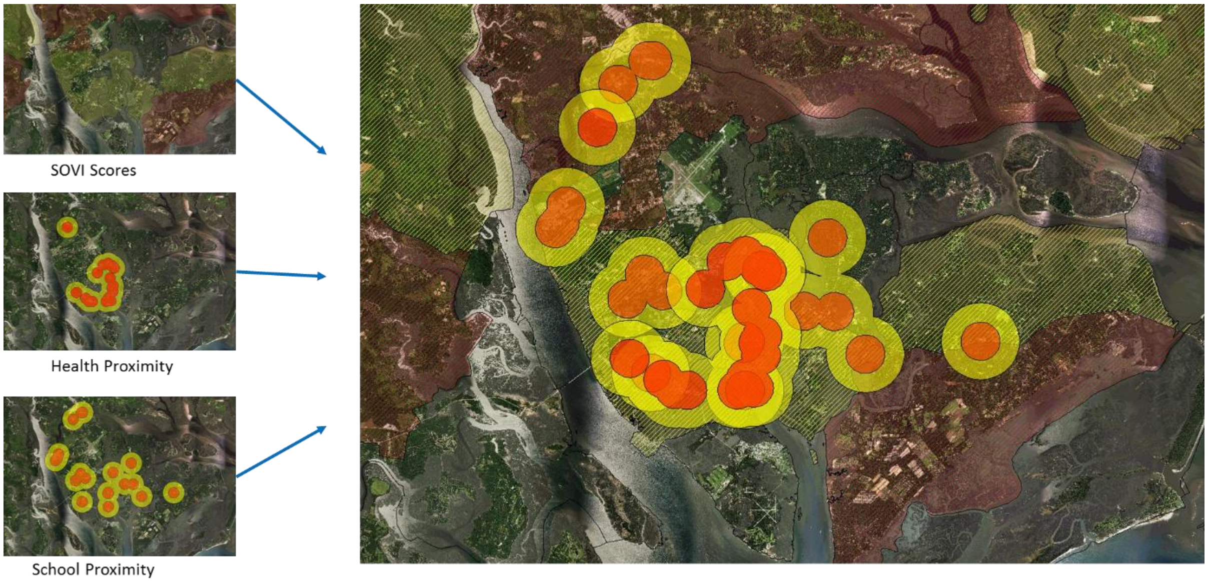

Figure 15. Example 2, higher weighting on socio-economic component; not used directly for screening.

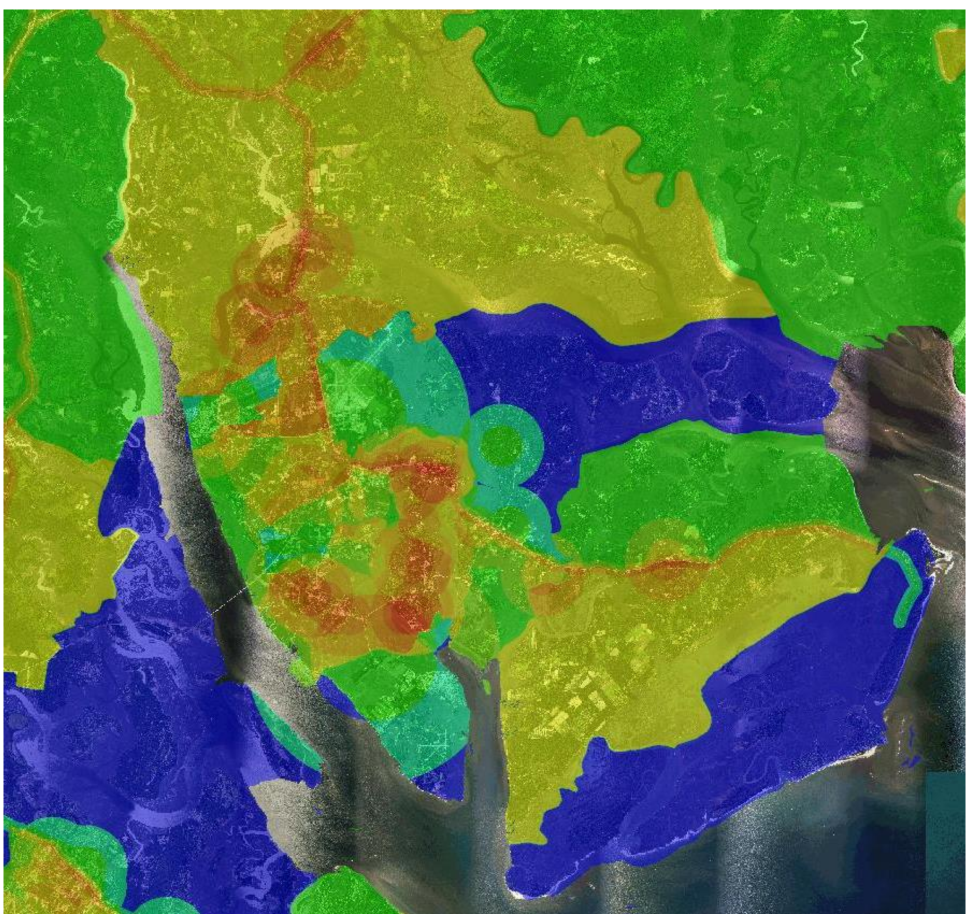

Figure 16. Combination screen with high values represented by warm colors; this screen was also used to calculate criticality values.

Vulnerability of Critical Infrastructure

For the purposes of this project, the process for assessing infrastructure asset vulnerability to SLR follows a modified process outlined in a multi-agency document titled "Scanning the Conservation Horizon: A guide to Climate Change Vulnerability"[22]. The results from scores developed in each of the screening levels (Infrastructure Screening) are used to highlight the degree of vulnerability and criticality for each unit of infrastructure.

Vulnerability

Calculations

The vulnerability determination used for this project is based on the results of the asset's exposure and sensitivity (Figure 16) assessments. The adaptive capacity is not explicitly being incorporated at this point because it generally plays less of a role in infrastructure assets than in habitats and requires a comprehensive understanding of the specific components and institutional mechanisms involved in each infrastructure category.

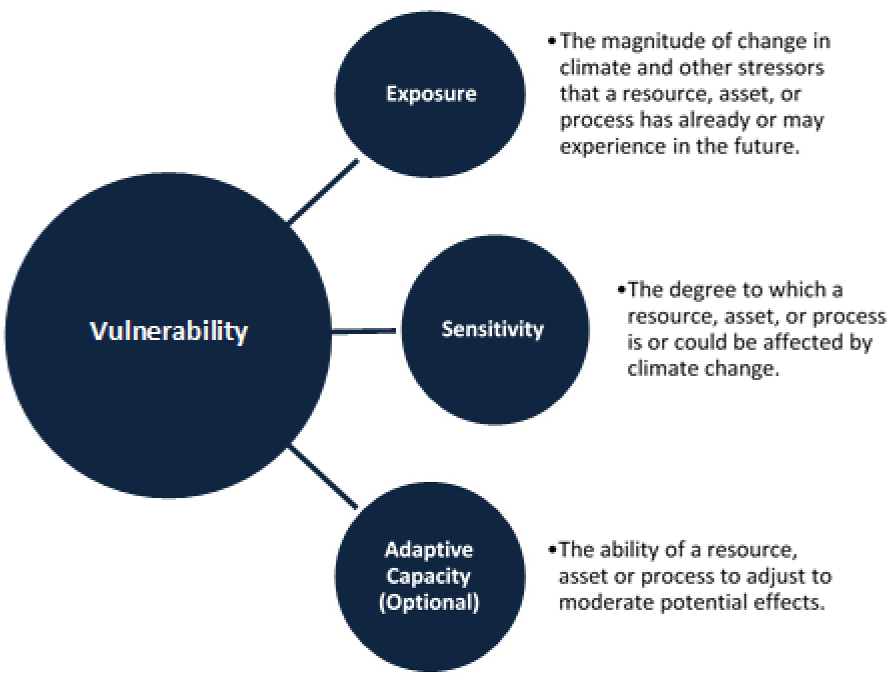

Figure 17. Vulnerability scheme

Using the results from the Exposure Screen, three levels of exposure were calculated from the relative risk values for each time period (see Exposure section). These values were added to the sensitivity values (see Sensitivity section) to determine the vulnerability (i.e., Vulnerability = Exposure Score + Sensitivity Score). Vulnerability values of the infrastructure range from 1 to 6; the values highlighted in this report are 4 and above.

[22] Glick, P., B.A. Stein, and N.A. Edelson, Editors, 2011. Scanning the Conversation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife federation, Washington, D.C.

Results

The amount of vulnerable infrastructure is provided as a percentage (Tables 2 and 3) of the overall infrastructure (GIS data) in the study area. Infrastructure with a vulnerability score of 4 is considered moderately vulnerable to monthly flooding; a score of 5 or above would be considered highly vulnerable. These values represent the assumed as-is condition, such that any present modifications to the infrastructure (i.e., one-way flow valves, replacement of lift station control panels with waterproof devices, use of BMP's in flood prone areas) are not included and may lower the vulnerability % by reducing the sensitivity value.

Table 2. Percentage of infrastructure that has a vulnerability score of 4 or above

Infrastructure	2020	2030	2040	2065	2085
Roads (all)	7%	9%	12%	20%	33%
water lines	2%	3%	4%	7%	12%
sewer lines	3%	4%	5%	7%	12%
hydrants (#)	1%	2%	3%	6%	13%
lift stations (#)	1%	3%	5%	11%	22%
sewer drains (#)	1%	2%	3%	6%	14%

Table 3. Percentage of infrastructure that has a vulnerability score of 5 or above

Infrastructure	2020	2030	2040	2065	2085
Roads (all)	6%	7%	9%	14%	23%
water lines	1%	1%	1%	2%	4%
sewer lines	1%	1%	1%	2%	3%
hydrants	1%	2%	2%	4%	6%
lift stations	1%	1%	3%	6%	11%
sewer drains	1%	1%	2%	4%	7%

When comparing all the infrastructure, roads (all) are clearly the most vulnerable infrastructure type (Figure 18), since they are highly sensitive to flooding. Looking at the general trend through time, given the present SLR projection envelope, the increase in the percent of vulnerability for most infrastructure (not roadways) is fairly flat until after 2040. At this point, the common development areas (i.e., "a safe elevation") appear to begin overlapping with elevations in the envelope of risk. The highly vulnerable infrastructure (score of 5 or above) in 2020, 2030, and possibly even 2040 is likely to be already highlighted by the utilities and infrastructure agencies in Beaufort County. The more pertinent planning decisions maybe those infrastructure that are risk in 2040 and beyond. This time frame, ~25 years, will see, both, present infrastructure assets beginning to reach the end of their lifespan and new infrastructure installed in areas with little existing infrastructure. In these cases it would be advantageous to account for the vulnerability risks when replacing or installing infrastructure of any type.

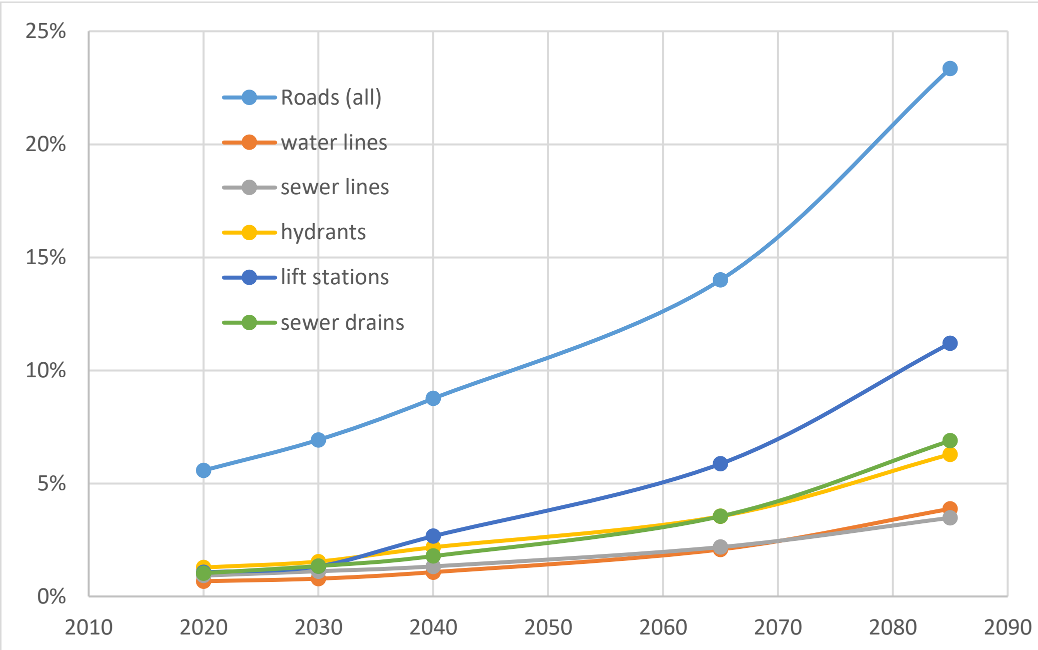

Figure 18. Graph of percentage of overall infrastructure with a score of 5 or above from 2020 to 2085. Percent value was determined from the number or length of the infrastructure provided in the GIS database.

Vulnerable Critical Infrastructure

The intent of this criticality screening process is to provide a real-world example of a prioritization strategy for important infrastructure assets through a qualitative/quantitative score-based comparison of each asset's criticality in the goals of this project.

Calculations

Two screening examples were used: a simple 3 -factor screen, and a more complex 5-factor screen as discussed previously. The infrastructure passing the 2040 exposure and sensitivity screen with a score of 4 or more are considered vulnerable in this example. Those infrastructure that also have a criticality score of 5 or more are considered Critical Vulnerable Infrastructure. No infrastructure scored the maximum (9); the top value was an eight, and the average was about 4.3. The value chosen as 'critical' (5) is about the 75% level, such that it represents the top 25% of the criticality values.

Results

Two examples are presented, using the simple and combination criticality screens (Figures 19 and 20). The first is a conservative 2040 example using the infrastructure that has a vulnerability of 4 or more; the second is a more optimistic example using the infrastructure with a vulnerability of 5 or more.

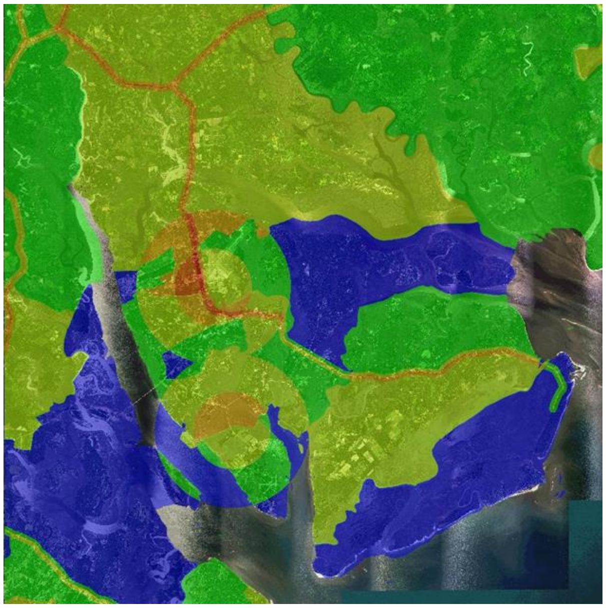

Figure 19. Simple criticality screen

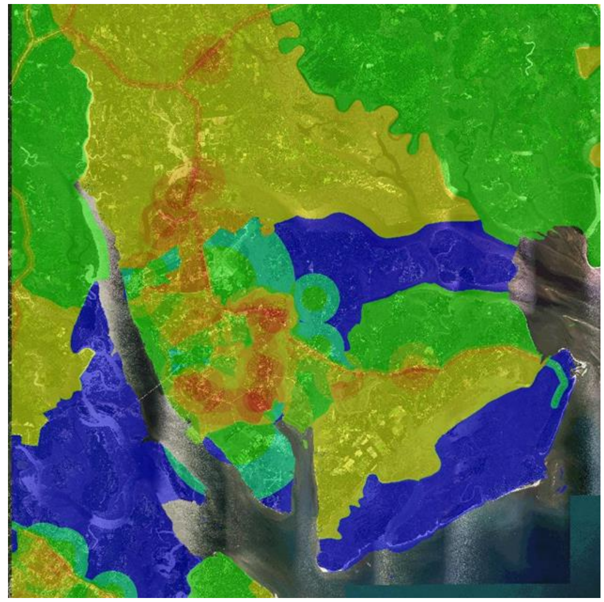

Figure 20. Combination criticality screen

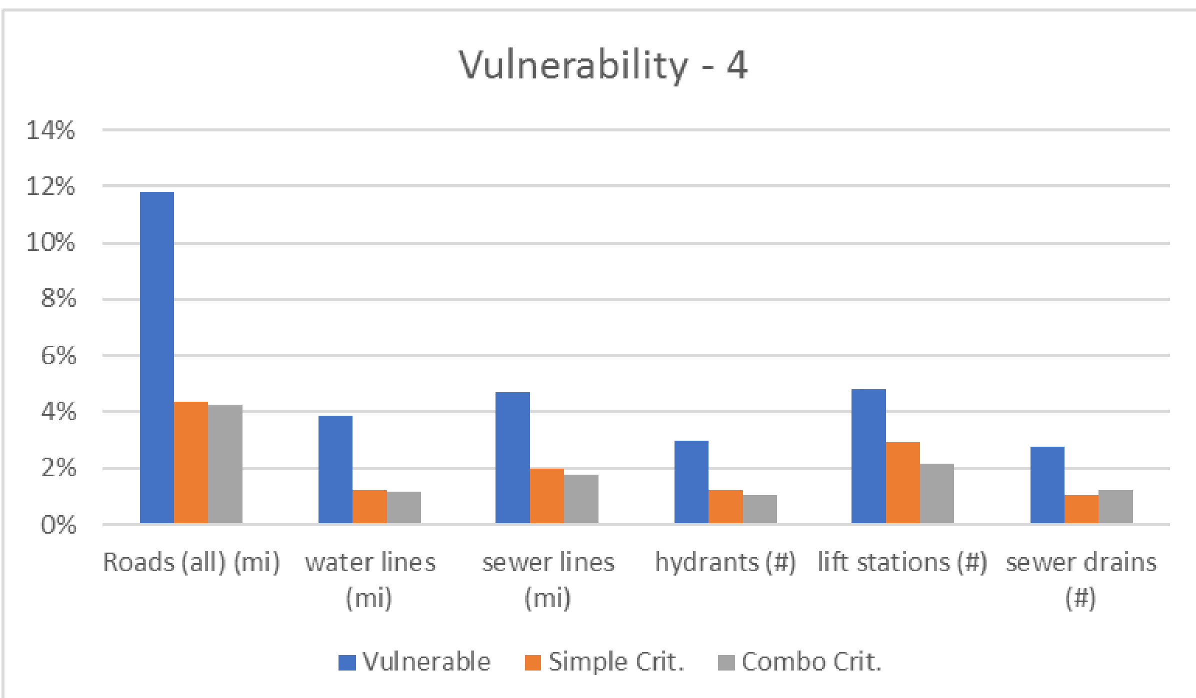

Figure 21. Percentage of infrastructure that is at least moderately vulnerable (4-6), and that same vulnerable fraction that is also critical under two criticality scenarios for 2040.

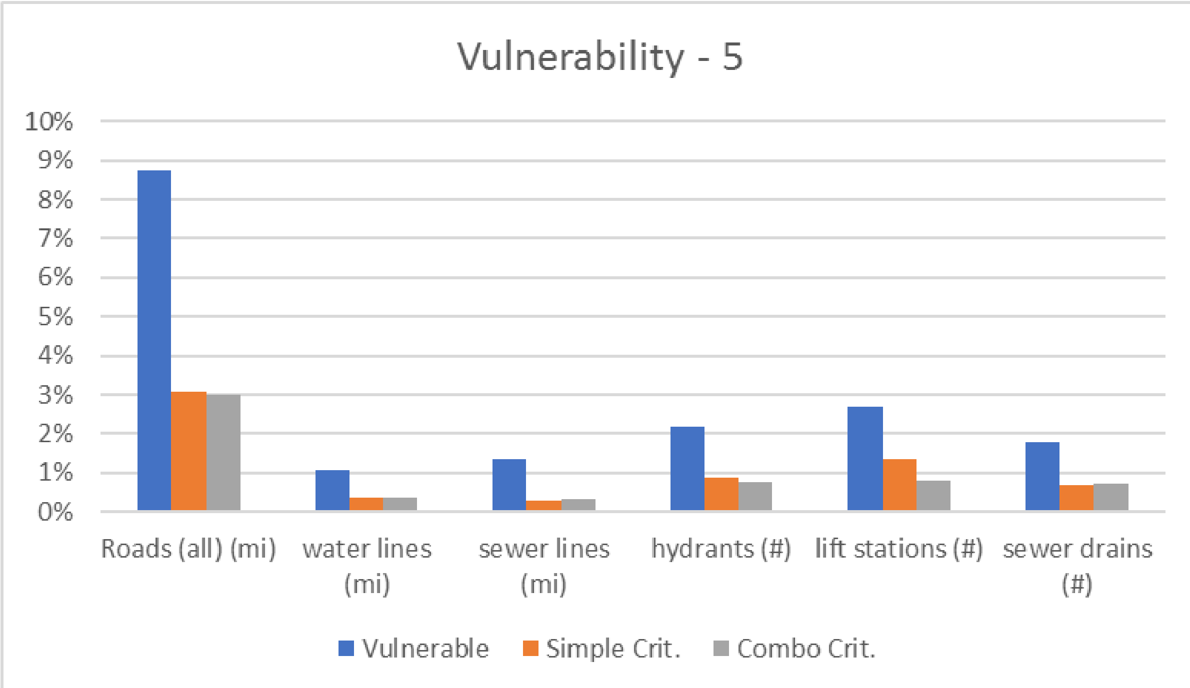

Figure 22. Percentage of infrastructure that is highly vulnerable (5-6), and that same vulnerable fraction that is also critical and vulnerable under two criticality scenarios

The fraction that is both vulnerable and critical is about 30% of the fraction of infrastructure that is just vulnerable. It is roughly the same for both criticality scenarios, which is not surprising given that they both have similar components. There are some minor spatial differences, at the chosen level of criticality, under the two scenarios (Figure 23). The differences are larger if considering different level of criticality, i.e., criticality of 6 or more.

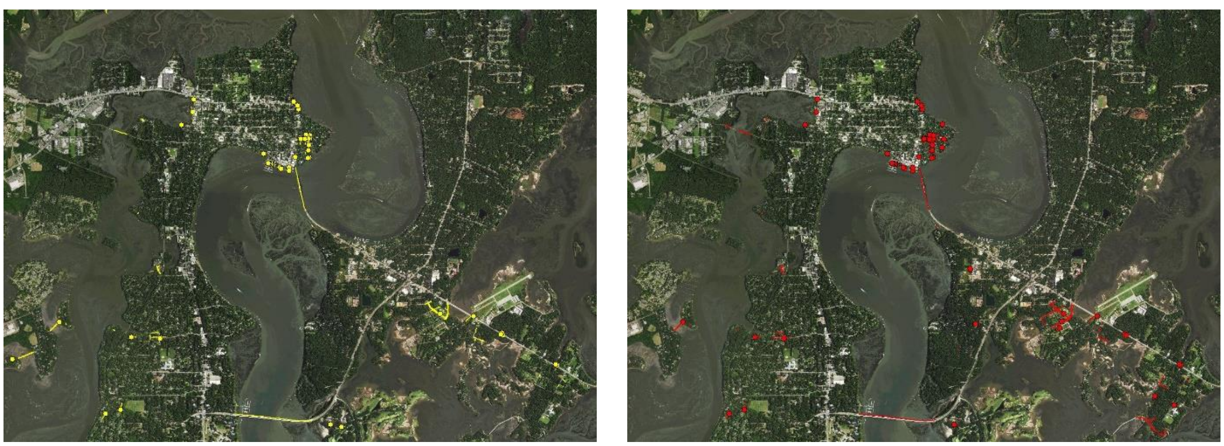

Figure 23. Example area showing the slight differences in the two critical and vulnerable scenarios; the simple scenario is on the left, the combination scenario is on the right. Infrastructure is highlighted in yellow and red.

Figure 24. Similar to the previous figure, but with a higher cut-off for criticality; the simple scenario is on the left, the combination scenario is on the right. Infrastructure is highlighted in red in both scenarios.

Planning/Response Options

The previous sections on vulnerability and criticality highlight the flexibility in choosing the screening specifications. In planning, the vulnerability screen cut-off (i.e., what threshold level of vulnerability is chosen) is a reflection of the level of exposure to SLR that the decision makers are comfortable with. Likewise, the criticality screen can be chosen to reflect budgeting constraints or overall level of effort available. And these screen thresholds can, and probably should, change in dealing with different planning horizons, i.e., 2030 vs. 2060.

Based on the recommendations in the Department of Defense report on managing uncertainty of future sea level[23] the first steps (planning for near-term sea levels) should be towards keeping options available for future responses. The USACE's document on procedures to evaluate sea level changes[24] likewise suggests a best management approach during the period of low uncertainty (present time).

[23] Hall, J.A., S. Gill, J. Obeysekera, W. Sweet, K. Knuuti, and J. Marburger. 2016. Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme Water Levels for Department of Defense Coastal Sites Worldwide. U.S. Department of Defense, Strategic Environmental Research and Development Program. 224 pp.

[24] http://www.publications.usace.army.mil/Portals/76/Publications/EngineerTechnicalLetters/ETL_1100-2-1.pdf

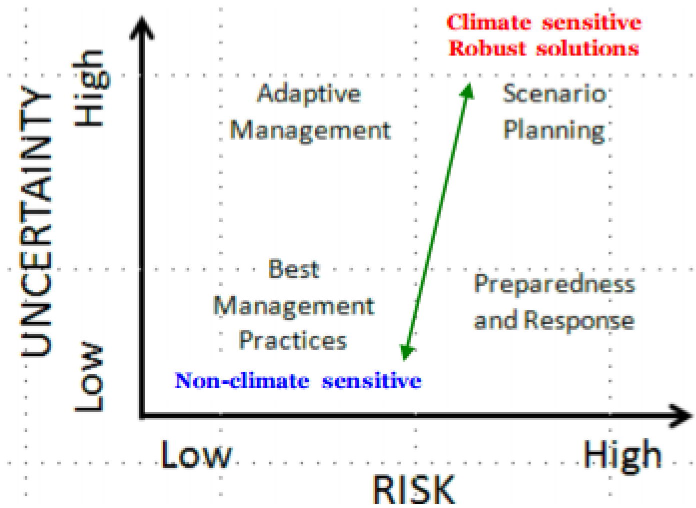

Figure 25. Consideration of risk and uncertainty in climate-change-related decision-making from USACE ETL 1100-2-1

The use of best management practices and keeping options open for available responses are consistent with the idea of a managed adaptive approach to infrastructure (Figure 26). Using a steady level of acceptable risk (vulnerability in this report's context) provides a consistent blue-print that can be used across multiple agencies for future modifications and upgrades – i.e., strategic cyclical maintenance. And as the science of SL change evolves and the understanding of the sensitivity to SLR of the various infrastructure becomes better understood, the new values can be plugged in to better define the vulnerability; but the same level of risk (e.g., vulnerability is 5 or more) can still be used. In this way the choice of a level of acceptable risk (vulnerability) is an important and fairly straightforward way of defining the resilience direction (planning direction).

Like vulnerability, the other planning aspect covered in this report, criticality, will likely continue to vary through time depending on development trends, population changes, and community use and goals. This is a more fluid screen and hard to define consistently through time as the level of criticality as well as the make-up of the screen may change. Criticality differs from vulnerability, which is generally a matter of when not what, because it is a social ranking with no specific eventuality.

So, if it is assumed that SLR is going to occur, and there is no science to suggest otherwise for the next fifty years, then the criticality screen can be looked at as the resilience timing strategy. Areas at high-risk will eventually be flooded during monthly high tides and require some intervention (cyclical maintenance), whether that maintenance occurs prior to issues occurring (strategic cyclical maintenance or adaptive management strategy) or after (cyclical maintenance, reactive strategy) is dependent on how critical that infrastructure is deemed. For example, repeatedly shutting down a section of I-95 for several hours each month for flooding could cause serious problems and, as such, would likely be considered a good candidate for adaptive management strategies (strategic cyclical maintenance). Along those same lines, anticipatory strategies (or a precautionary approach), which are decisions taking place in the project design phase, should also be considered for infrastructure that is or will be deemed critical such as bridges. On the other end of the spectrum, a local road serving only several seasonal homes may be deemed a good candidate for a reactive strategy of replacing the road only when it eventually fails.

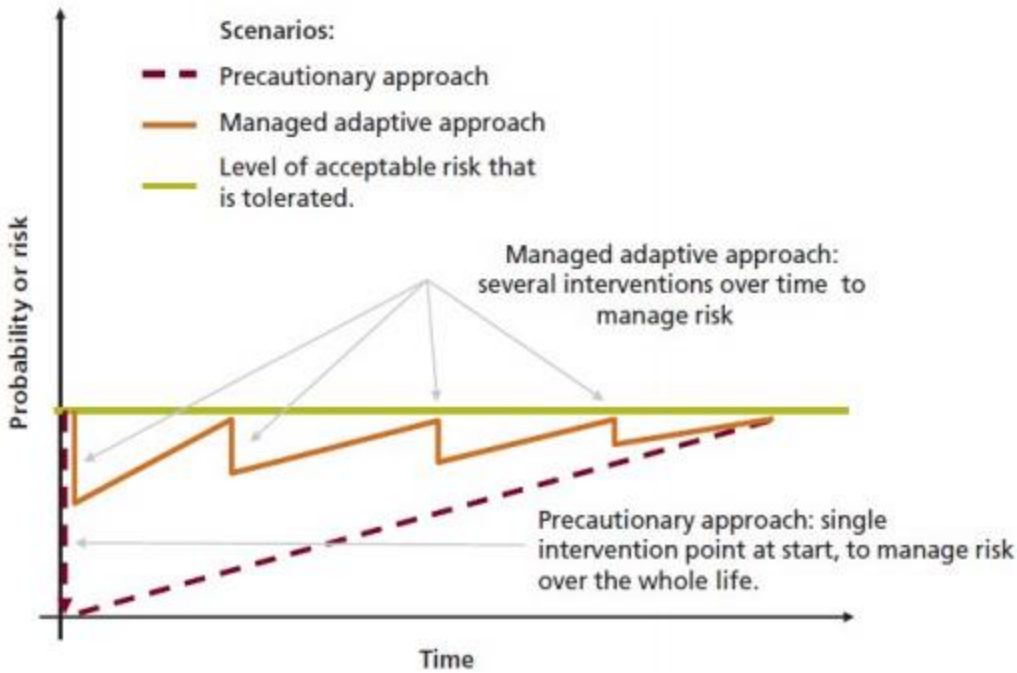

Figure 26. Precautionary (i.e., anticipatory) and managed adaptive approaches from USACE ETL 1100-2-1. (Courtesy of DEFRA 2009.)

Example Response Scenarios and Costs

An example of the use of the screening logic is used with an acceptable level of vulnerability (risk) of 5 as well as use of the criticality screen with a score of 5. This is an example of a managed adaptive approach. Three time frames are used – 2030, 2040 and 2060. Concept level cost estimates are intended to provide a rough estimate of the overall response budget are for a "best option" solution. The specifics of each targeted piece of infrastructure are not included, so lifespan considerations – i.e., cyclical maintenance – are not factored in.

Infrastructure Costs

In each of the following civil engineering disciplines – Transportation, Water and Sewer, and Stormwater – approximate costs were developed to implement adaptive measures. These are general costs based on either established published data or from actual ongoing projects within the study area. Although within each asset category there may be combination of adaptive measures taken to promote resilience to sea level rise, for the purpose of general planning and budgetary purposes, this study selects one chosen adaptive measure per asset type and assigns a unit cost to implement this adaptive measure. Please refer to Appendix A for a risk and adaptive measure matrix which identifies the risk associated with each defined asset, a chosen adaptive measure to mitigate the risk , and approximate budgetary cost associated to implement that chosen adaptive measure.

The general costs of retrofitting, moving, or protecting infrastructure are provided below (Table A) and reflect an order of magnitude estimate. These costs were developed for the GIS data provided and do not account for specific infrastructure and unique conditions, which would require more detailed engineering information. These per-infrastructure costs are, thus, a rounded figure (generic), which is based on the database information and costs of local work that have been made available.

Table 4. Generic costs for infrastructure adaptive measures

Infrastructure Asset	Cost	Unit
STORM WATER		
Culvert	$25,000	each
Flap Gate	$15,000	each
Flume	$5,000	each
Headwall	$25,000	each
Inlet	$5,000	each
Manhole	$5,000	each
Outlet Drain	$15,000	each
Storm Drain	$5,000	each
Swale	$25	LF
Weir	$10,000	each
Access Gate	$5,000	each
Catch basin	$10,000	each
Concrete Junction box	$10,000	each
Drainage Box	$10,000	each
Detention Pond	$50,000	each
WATER SUPPLY		
4"-6" Lines DIP	$100	LF
Fire Hydrants	$7,500	each
Supply Intake Source	$30,000,000	each
SANITARY SEWER		
Gravity 4"-6"	$100	LF
Force Main	$200	LF
Manhole	$7,500	LF
Lift Station/Wetwell	$250,000	each
Large Diam. directionally bored pipeline	$2,000	LF
Treatment Plant	$30,000,000	each
TRANSPORTATION		
Local Streets	$6,000,000	mile
Highways	$12,500,000	mile
Bridges	$50,000,000	mile

Another very important aspect that cannot be captured at the broad scale of this preliminary report is the interdependence of the infrastructure. For example installing a tide-flap on an outlet may be all that is needed to reduce the risk for nearby roads, pipes, fire hydrants, etc. This type of a system approach is needed and, if there is one main-takeaway, it is hoped that this report and its findings will help make it clear that separate agencies, commissions, and service providers will need to tackle these potential issues as a team.

For a fuller explanation of the measures to protect, raise, or relocate please reference Appendix A.

SLR Resiliency Costs

Several sample resiliency costs were prepared using the GIS data, associated infrastructure costs, sea level vulnerability, and example criticality information. These costs are the outcome of the process outlined in this report; they are intended to be an order of magnitude estimate (e.g., $5 million could be $9 million or $1 million) to facilitate resiliency discussions.

Table 5. Costs associated with resiliency scenarios for several time periods

Year	scenario	Total Cost	Transportation	Water & Sewer	Storm Water
2030	vul,5; crit 5	$ 196,942,054.00	$ 193,250,346.00	$ 3,016,708.00	$ 675,000.00
2040	vul,5; crit 5	$ 257,377,025.00	$ 251,812,545.00	$ 4,759,480.00	$ 805,000.00
2060	vul,5; crit 5	$ 467,192,639.00	$ 456,426,316.00	$ 9,281,323.00	$ 1,485,000.00

A few assumptions are made for cost estimation purposes. Un-paved roads were assumed to be $100 per linear ft. for repair and/or additional fill material; and swales were assumed to 50 ft. long.

As can be seen, the bulk of the costs are associated with transportation and the smallest fraction in the storm water infrastructure. These two asset groups are also very intertwined. Although not specifically covered in this report, improvements in storm water infrastructure with an eye towards potential flooding from sea level changes will likely help minimize real world affects to the roads in the area. To put some perspective on these values – the most exposed roads (vulnerability of 6) with criticality values of 5 or higher in 2020 (next 5 years) have a cost of about $130 million; storm water improvement costs are $270,000.

As there are long-term cyclical maintenance requirements on these assets that would need to be budgeted regardless of future sea level considerations, a helpful next step may be to look at the ages of the infrastructure (i.e., as a criticality factor) in question and build-in strategic adaptive management when they are resurfaced/replaced. The resiliency fraction of the maintenance costs will significantly less than the values presented (Table 4). Failure to account for changing conditions in the future may shift the incremental investments for adaptive measures to larger lump-sum investments when conditions deteriorate to the point of requiring un-scheduled repair. So while the values themselves may be sobering, it is more important that they are used as an example that strategic actions (adaptive management) taken in the coming years can help save money in the longer run.

Next Steps – Recommendations

This report has laid out a logical screening scheme and techniques that are in-keeping with the general state of the science for resiliency planning. It is understood that the specifics and aspects of the process outlined will be modified and that is expected; the important aspect is that there are steps taken and new efforts toward the goals.

Next Steps

The recommended next steps are, broadly, to develop interest and understanding of sea level change and to put some potential targets/resiliency goals out for comment.

Stakeholder involvement

The involvement of the utilities and infrastructure agencies is, obviously, paramount to the success of this project. It is hoped that the inventories of exposed and vulnerable infrastructure begins to provide these agencies with a shared understanding of the general magnitude of the effects of SLR.

Likewise, the involvement of citizens and government is important for funding purposes. The more informed the customers of these services are, the more understanding of the potential inconveniences, whether financial or practical, will be. The maps (KMZ's or GIS data) generated for this project are unique to the study area and can be used to educate the citizens on the overall scope of the projections as it relates to them through time.

Assess Vulnerability Threshold

Once the stakeholders are exposed to the potential risks a central aspect will be to develop an acceptable level of safety. This is the trigger for planning on the extent that this project will become. Vulnerability thresholds can be different for different infrastructure, or with the use of a criticality screen, can be different for different locations.

Assess Criticality Threshold

This is potentially the most difficult aspect as it is assumed that people will become involved and that vulnerability thresholds will either be formally adopted or adopted ad hoc as the effects of SL changes are felt. It is recommended that a simple criticality scheme be used initially as there are some shared priorities (e.g., having working hospitals or having a dry evacuation route) in most people's daily lives that will help begin the process of focusing efforts and the timing of fixes – e.g., adaptive management strategy or reactive strategy.

Assess Planning Horizons

An important consensus builder is the selection of a planning horizon that both provides enough time to develop a budget and also provides results. It may be advantageous to work on multiple time frames – e.g., a 2025 vision and 2040 vision. Given the unknowns in sea level projections, it is recommended that time frames do not extend beyond 2060, and more reasonably beyond 2040. Projections for planning will also depend on the infrastructure life-span itself and is another reason to look at multiple planning horizons.

Pilot Projects

Starting early and small, such as outfitting one-way flaps on storm drains with a vulnerability above 5 in 2020, is a good way to start making improvements and putting together real-world costs together for future visions. There will be management costs, such as increased cleaning, that will likely have to be included in budgets. A similar learning curve will exist for each retrofit for each piece of infrastructure and getting started on those will help future budgeting.

Isolating a highly vulnerable and critical area, preferably with older infrastructure, may be a good way to begin working across agencies to develop shared goals and techniques towards resilience. There are many inter-dependencies and systematic gains that can be achieved by treating the infrastructure as a whole instead of a sum of parts, which is how the costs were calculated. The realized savings can then be highlighted as an impetus to continue working on resilience as a shared goal.

Recommendations

There were several potential aspects noted during the study that will help with future planning for SL change.

Incorporate Housing/Structure Information

Incorporating Housing/Structure Information will improve not only the ability to assess infrastructure at a more localized level (i.e., where are the critical or largest uses), but also provide information to the towns and citizens, which will help to engage the community. This is not envisioned as a base flood (FEMA) type exercise but rather a view towards future resource needs for private citizens and potentially increased service needs from communities, cities, and towns. This includes the potential issues with ponding water and mosquitos and decreases in the effectiveness of onsite waste-water treatment.

Along this theme are the individual gravity sewer lines that go from each house to the sanitary system. These are potentially very 'sensitive' to flooding as they are very near the land surface (shallow burial) and are of various age and construction. It is understood that this is less of an issue when looking at the present goals of the study, but could affect much of the bases' workforce.

Incorporate Natural or Green Infrastructure

Since this is a study of exposure from the ocean (rain events were not included) on a frequency basis, not strictly from tides, changes in the coastal environments will influence the outcomes. If these environments are lost, the protection that they afford – buffering energy – will be diminished and more flooding is possible than presently predicted.

From an ecological perspective, the environments play a large part in the 'quality of life' if not the economic base in the study area. For example, the conversion/loss of wetlands could become significant development/use issue on the Parris Island base. The gradual shift in upland to wetland habitats in people's back yards will likely see an expanded use of retaining walls and thus changes in storm water pathways and associated flooding.

Improve Information (tides, GIS databases)

This preliminary report was served well by the existing GIS information provided by LCOG. There appeared to be some spatial errors in road centerlines and missing infrastructure, but these should not have a major effect on the final results of this broad study. Moving forward, however, engineering data quality (sub-meter accuracy) will be necessary to better assess the potential infrastructure at risk and the associated costs involved.

Along with the spatial accuracy, the GIS database information was appropriate for this work, but again, the next steps will require a bit more information to begin assessing costs for specific resilience options. This information probably exists at the agency level, but may not have made it to the more public GIS databases used in this preliminary project.

The projections of sea level are bound to improve, at least for the near to mid-term, in the next decade. To help translate that increased confidence (less risk) in forecast water levels to the specific area of Beaufort, MCAS Beaufort, and Parris Island a local tide gauge would help. Even though a tidal model was used (VDatum), the application of a frequency study (e.g., monthly highest tides) is helped by a local source of information. If mapping MHHW this would be less of an issue, but this tide stage would not capture the types of water levels, which have local influences such as fetch or river flow, that will drive the strategic cyclical maintenance of infrastructure.

Bridge Information

Bridges were not specifically handled in this report since they are unique structures requiring significant information on specifics of the design. For example, many bridges have significant ‘freeboard’ above the water surface and will be relatively unaffected by increases in sea level; however, some have lower-most spans that are not significantly above the water surface and may have sea level considerations. Unfortunately this type information was not readily available in the GIS data, nor were specifics of the supports. Bridges are a significant asset and require an anticipatory strategy (precautionary approach) upon construction.

For these reasons, this assessment did not specifically handle bridges. There were a total of about 5.5 miles of ‘bridges’ in the study; they are grouped into the transportation assessment as roads. A more significant effort will be required to study the potential sea level change effects on the bridges in the area.

Appendices

APPENDIX A: ENGINEERING REPORT

APPENDIX B: ANNOTATED BIBLIOGRAPHY

APPENDIX C: GIS DATA DOCUMENTATION

APPENDIX A

McSweeney Engineers

Engineering Report – Sea Level Rise: Adaptive Measures to Secure At-Risk Infrastructure

INTRODUCTION

1.1 *Background, Purpose and Scope*

The Low Country Council of Government (LCOG) has administered two Joint Land Use Studies (JLUS), led by the Northern Beaufort County Regional Plan Implementation Committee, which focused on the Marine Corps Air Station (MCAS) Beaufort and the Marine Corps Recruit Depot (MCRD) Parris Island. One of the JLUS' recommendations was to "Research Key Land-Use Issues." Sea Level Rise was identified as one of the issues.

In July 2016 the LCOG awarded GeoScience Consultants the contract to perform the Beaufort Area JLUS Implementation-Sea Level Rise Preliminary Infrastructure Assessment. The development of the study was divided into the following tasks:

Task 1- Review Existing SLR Methodology, Data, and Scenarios
Task 2- Assessment of Infrastructure and Priorities
Task 3-Calculate Costs Associated with Measures to Secure At-Risk Infrastructure
Task 4-Develop Narratives and Review Available Actions to Address Future Risks and Goals
Task 5- Build Consensus on Pathways Forward
Task 6- Present results and follow-up on specific action items

This report follows the development of Task 1-Sea Level Rise Methodology and Data, and Scenarios as well as Task 2- Assessment of Infrastructure and Priorities. This report focuses on Tasks 3 and 4. It examines the Sensitivity to risk of civil infrastructure to Sea Level Rise. In addition, this task offers Adaptive Measures and the approximate cost to implement these measures. The Beaufort County Geographic Information System (GIS) was referenced to provide an inventory of civil engineering infrastructure assets in the study area. The GIS lists a limited number of infrastructure categories as follows:

- Roads (Highways)
- Storm Drains
- Water Pipes
- Sewer Lines

- Lift stations
- Fire hydrants

Within each of these GIS-based categories there are numerous subcategories. For example within the Storm Drains category, the GIS lists Catch Basins, Detention Ponds, Headwalls, Culvert, etc. From a civil engineering perspective these numerous infrastructure categories fall within three well established civil engineering disciplines: Transportation, Storm Water, and Water Utilities. For example, Roads as well as bridges would logically fall within transportation, Sewer, Water Lines, and Hydrants within Water Utilities. It is intended that by combining these many assets into these three disciplines the analysis is made simpler and more useful to the community as well as to the agencies responsible for their administration and maintenance.

1.2 ***Method of Assessment***

The infrastructure categories listed above has been assessed within the GIS/Sea Level Rise Models for several planning horizons (Year 2020, 2030, 2040, 2060, and 2085) and the 2040 planning horizon was specifically chosen for evaluating sensitivity. Several publications were referenced in order to follow some established protocol in assessing risk sensitivity:

- Sea Level Rise Adaptation Report Beaufort County 2015
- Sea Level Rise and Coastal Infrastructure: Predictions, Risks, and Solutions published by the American Society of Civil Engineers (ASCE)
- US Army Corps of Engineers (USACE) Comprehensive Evaluation of Projects with Respect to Sea-Level Change Project
- Dept. Of Defense Regional Sea Level Scenarios for Coastal Risk Management.
- RS Means Heavy Construction Cost Data

As part of the local engineering community McSweeney Engineers has over a decade of experience working with the organizations which administer and maintain infrastructure within the study area. Beaufort Public Works, County Engineering, MCAS Beaufort, BJWSA, and SCDOT were contacted prior to the preparing this report. Significant effort was made to engage these organizations which have authority and comprehensive knowledge over their respective infrastructure.

Interviews were conducted with the following agencies and representatives on the following dates:

Beaufort County Storm Water, Mr. Eric Larson, Director of Storm Water -October 4, 2016
City of Beaufort Public Works, Mr. Lamar Taylor, Public Works Director-October 27, 2016
Beaufort Jasper Water and Sewer Authority, Mr. Ed Saxon, General Manager-November 15, 2016

The following publications were referenced in this assessment:

- Beaufort County GIS
- Beaufort County Storm Water Plan 2010
- Beaufort Jasper Water and Sewer Authority Standard Specifications
- South Carolina Dept. of Transportation District 6

Data from these documents, as well as meetings with staff or these organizations, was utilized to determine ownership of and authority over each infrastructure asset type and to understand its sensitivity to risk posed by Sea Level Rise.

2.0 SENSITIVITY

2.1 *Transportation*

In general, transportation infrastructure is highly sensitive to sea level rise. Some of the anticipated hazards associated with this include:

- Roadway overtopping
- Standing water – hydroplaning, stalling vehicles
- Undermining and erosion leading to washout of embankments
- Surcharging of storm drainage piping, culverts, and catch basins
- Complete washout of roadway
- Accelerated deterioration of bridge superstructures
- Undermining of bridge substructures due to channel bottom scour

There is significant variation of sensitivity from asset type, material, and age. For example, modern State and Federal Highways, such as 802 and 170, are far less sensitive to risk than local streets in the historic Old Point neighborhood or Mossy Oaks neighborhood adjacent to Battery Creek. This is due, in part, to modern codes that incorporate probabilistic-risk mitigation analysis in design. Additionally, technological improvements have permitted higher bridge and roadway elevations as well as the use of higher performance materials that are less sensitive to the risk of sea level rise. Conversely, many of the older streets in and immediately surrounding the historic district were constructed in a manner which would be considered deficient by today's standards. Many older streets predate today's SCDOT Standard Specifications. For example, they may not be founded on a compacted limestone base as commonly as current specifications require or lower than minimum elevation requirements. Therefore these older roadways typically have a higher sensitivity to the hazards of over topping and erosion.

Older bridges typically have an increased sensitivity to deterioration due to age and finite lifespan of materials. Typically most deficiencies of water-crossing bridges are found in the tidal and splash zones of the structure. A typical 50-75 design lifespan is shortened by sea level rise because the tidal zone and splash zones inundate a greater portion of the supporting substructure and these susceptible zones become, over time, increasingly closer to the superstructure elements. Many of the older bridges were built at lower elevations than modern bridges, particularly swing-span type bridges, such as the Wood's Memorial Bridge and the Harbor Island Bridge.

2.2 *Storm Water*

Storm drainage assets are highly sensitive to risk and there is significant variation of sensitivity with regards to asset type and age of infrastructure. Some of the anticipated hazards associated with this exposure include:

- Surcharging of pipes and overflowing of grate inlets and catch basins
- Full pipe flow condition causing pressure and failure of joints between concrete pipe
- Saturation of supporting soils leading to collapse and joint separation
- Scour and undermining of outfall structures, headwalls, etc.

Of the many storm drainage types throughout the study area many have lost capacity due to debris, are undersized for current design storm events, and not equipped with any check valve apparatus to control what is referred to as *tail water effects*. This is effect is caused by the combination of high tide causing a coastal pipe network to fill or "surcharge" with seawater at the same time of a rain event so that there is no remaining storage capacity in the pipe network and results in flooding. For example, one highly visible example of this effect is the yard inlet in the middle of the amphitheater of the Henry C Chambers Waterfront Park. It is known to occasionally overflow (surcharge) during higher than usual tides coinciding with heavy rain. Future tail water effects associated with sea level rise will likely exacerbate this condition. Check valves are a one way valve that allows the storm water to exit the drainage system without the sea water to enter the system.

In addition to hydraulic effects, there are also potential structural failures of pipe due to Sea Level Rise. Some of the older piping may likely be founded on native, poorly consolidated soils that are more susceptible to infiltration and erosion and which may potentially lead to settlement of piping, separation of joints, and failure due to sea level rise.

2.3 *Water Utilities*

Water utility assets are moderately sensitive to risk. Their risk is somewhat mitigated due to the fact that much of the infrastructure is buried. In general, water utilities design and management, as well as vulnerability assessment, is based on design storm events such as the 10-year and 25-year rain events, not tidal inundation. Beaufort Jasper Water and Sewer Authority (BJWSA) recently reported on its response to Hurricane Matthew which significantly impacted the area and their operations. However, the report also demonstrated their preparedness and prompt emergency response. As there are many different subcategories of infrastructure within Water Utilities there is also a broad range of indentified risks:

- Increase of source water salinity
- Infiltration of storm water and seawater into gravity sewers
- Saturation of supporting soils leading to collapse and joint separation of pipelines
- Inaccessibility of fire hydrants due to flooding
- Corrosion of ductile iron components
- Damage to lift stations due to flooding

3.0 ADAPTIVE MEASURES

Awareness is the first step in developing any adaptive management of sea level rise risk to infrastructure. The Beaufort community has been aware of this risk for decades, perhaps centuries. The JLUS study area has recently experienced regular flooding from King Tides, the October 2015 extreme precipitation event known as the 1000-year storm, and from Hurricane Mathew on October 8, 2016. Improved infrastructure management and planning in response to these causes of flooding are, in essence,adaptive measures, even if they are not directly responding to Sea Level Rise, per se.

There are dozens, or more, adaptive measures potentially taken to mitigate risk within each of these infrastructure categories. The complexity of evaluating all types of measures for each is far beyond the scope of this report. Instead, the intent of this report is to choose one of three general actions to mitigate the risk for each asset type:

- Raise
- Relocate
- Protect in Place

3.1 Transportation

Most roads in the JLUS SLR study area were built many decades ago to at the lowest elevation required to provide some measure of adaptive management to hazards associated with high water; however, these measures were relative to a lower tidal datum and less extreme precipitation patterns of that time. By contrast, recent transportation projects follow current SCDOT design criteria for construction of roadways and bridges and often are designed with significant freeboard above deign rain event and hurricane surge elevations.

It is important to consider that risk to transportation infrastructure is greatly impacted by storm water risk. Water that is not effectively conveyed from roadways leads to increased risk to roadways. Although the degree of risk of the area's roads and bridges varies, risk is always increased by deficient storm drainage.

Some existing, as well as potential future, adaptive measures may include:

- Raising vulnerable roadways in areas ½ -1 ft in elevation
- Protecting roadways in place with bulkheads, riprap, and other shore protection devices
- Implement improvements to storm drainage serving roadways
- Re-routing /horizontal re-alignment of future routes to minimize effects from risk

Some of these measures are already implemented intrinsically; shoreline protection and storm drainage improvements are routinely implemented in response to current flood risk and these same measures may easily be adapted to mitigate risk from future Sea Level Rise. Raising and relocation are much more costly measures and careful consideration must be given to cost versus risk with these costlier measures. Due to the geographical limits and topographical constraints there may be few viable options in terms of route selection; however, potential future projects including the Northern Beaufort Bypass and others should proactively consider routing in consideration of Sea Level Rise. Raising roadways should be considered particularly when traffic capacities warrant widening them.

Overall, it is recommended that future roadway and bridge projects including improvements to existing assets in the study area be evaluated for their current design criteria to ensure that Sea Level Rise was considered in the decision making and design processes

3.2 ***Storm Water***

In general, storm water design and management is based on design storm events such as the 10-year and 25-year events with a designed capacity in storm drainage piping and appurtenances to store and convey runoff from those events. Although tidal *tail water effects* may be considered in the hydraulic analysis of storm drainage design, the risk posed by future Sea Level Rise is not commonly considered. Nevertheless there are some existing measures, in place, that could be adapted to mitigate some risks posed by Sea Level Rise. There are also potentially new measures to be undertaken as well.

Some existing and potential adaptive measures include:

- Limit of Development-Promote Low Impact Development
- Raising drainage inlet structures in conjunction with roadways
- Enlarge detention ponds and drainage swales

- Installation of rubber check valves and tide gates
- Install bulkheads and berms
- Promote living shorelines and dune growth at Ocean front
- Building Pump stations

3.3 ***Water Utilities***

BJWSA has existing adaptive measures to mitigate flooding risk in response to normally occurring flooding, extreme rain, and hurricane events. Many of these measures may be adapted in response to Sea Level Rise. Some existing as well as potential future adaptive measures may include:

- Raising rim elevations of manholes and other potential infiltration locations
- Water tight manhole lids to prevent inflow and infiltration
- Raising pads supporting lift stations
- Relocation of hydrants from increasingly flood prone areas
- Corrosion resistant/flooding resilience specifications for their infrastructure

4.0 IMPLEMENTATION COSTS

Within this section approximate costs to implement adaptive measures are discussed. These are general costs based on either established published data or from actual ongoing projects within the study area.

4.1 ***Transportation***

Likely the most costly adaptive measures are those to secure at-risk roads and bridges. Roadway work is very unpredictable to predict accurately, in part, due to the fact that other infrastructure, such as storm water and water utilities, are buried or carried in the same right of way as the roadway. These buried utilities often interfere with roadway improvements and can dramatically increase costs. The following are some generally accepted costs published by the Federal Highway Administration as well as some specific Beaufort County/study area examples:

- The replacement of the old Harbor Island swing Bridge is estimated to be $56 million
- Typically to construct a new 4-lane highway —$8 million to $10 million per mile in urban areas
- Resurface a 4-lane road – approximately $1.25 million per mile
- Boundary Street presently under construction -1.2 Miles/ $26 million
- Bladen Street downtown urban streetscape revitalization approximate cost - $2 million

- Likely cost to simply raise a one mile section of at-risk highway 1 ft would be $10-15 million

4.2 ***Storm Water***

Storm Water has the widest range of adaptive measures as well as the widest range of cost to implement. The following are some approximate costs obtained through research of City of Beaufort as well as Beaufort County Strom Water projects:

- Installation of Tidal Gate at the Federal Street Pond Project in the Old Point $150,000
- Flexible rubber flap valves or hinged tide flap at outfalls of medium size pipes $10,000-20,000
- Installing erosion control measures and flumes and outfalls $10,000-$50,000
- Raising rim elevation of catch basins $10,000 each
- Enlarge or add Detention Ponds and Drainage Swales $100,000-$250,000 (e.g. Beaufort County's Palmetto Headlands Project 2016)
- Likely costs to install typical pump station range from $10- $50 million. A large system such as the City of Charleston's Spring /Fishburn Drainage Project budgeted at approximately $150 million

4.3 ***Water Utilities***

Water Utilities have adaptive measures have a wide range of complexity and cost to implement. Some adaptive measures are already presently undertaken to mitigate against hurricane surge and nuisance flooding caused by a combination of precipitation and tide. The following are some approximate costs for potential adaptive measures:

- Raising rim elevations of manhole and other potential infiltration locations $5,000/per location
- Raising pads supporting lift stations $100,000
- Lift station replacement/relocation $250,000-$500,000
- Sanitary Sewer Lines replacement/relocation- $100 per linear foot
- Force main replacement/relocation - $200 per linear foot

Although there may actually be a very complex combination of adaptive measures taken to mitigate the risks posed by Sea Level Rise, for the purpose of simplifying this complexity, this study selects only one adaptive measure per asset type and assigns a unit cost to implement this adaptive measure.

5.0 CONCLUSION

One goal of this study is to assign "order-of-magnitude" costs to chosen adaptive measures. In reality each asset category may utilize a combination of adaptive measures taken to offer resilience to Sea

Level Rise. However, this study limits a single adaptive measure per asset type and assigns an approximate unit cost to implement. Ideally, the cost to build resiliency is calculated by assigning a cost of an adaptive measure and multiplying it by the number of at-risk assets utilizing that chosen adaptive measure.

It is important to consider that many of the individual assets listed in the Beaufort County GIS act within a greater system and are not simply individual units functioning independently. The storm drainage system is a good example of this: the GIS lists individual query categories *Catch Basin, Inlet,* and *Outlet Drain* but they all are part of a storm drainage network. Therefore, to prevent a catch basin from surcharging and flooding it may not only be required to raise the catch basin itself, it may also require the installation of a flap valve at the outfall a mile downstream to prevent rising sea levels from reaching the catch basin through tail water effects.

The complexity of assigning comprehensive and system-wide costs is beyond the scope of this report. As stated previously, the costs are based on assigning a reasonable unit cost for a recognized adaptive measure and applying this to the number of at-risk assets within the year 2040 planning horizon. In reality, the implementation of every possible adaptive measure is far more complicated and nearly impossible to calculate with the limited information presently available. It is recommended that Beaufort County GIS continue to collect more data and that this data set be more specifically tailored to the engineering community responsible for its administration. Nevertheless, the simplified basis of assigning costs contained in this report is computationally feasible and provides a general idea of cost for community planning purposes.

Please refer to Appendix 1 for an adaptive measure matrix which identifies the risk associated with sea level rise to each GIS-defined asset, a chosen adaptive measure to mitigate the risk, and a cost associated to implement that chosen adaptive measure.

APPENDIX 1 –ADAPTIVE MEASURES AND APPROXIMATE COST MATRIX

Infrastructure Asset	Sensitivity Value (1,2,3)	Why Sensitive	Adaptive Measure Chosen (Protect in place/Relocate/Raise)	How/Why	Cost	Unit
STORM WATER						
Culvert	3	Scour/erosion	Protect in Place/Replacement	Rip rap/sheet pile- scour	$25,000	each
Flap Gate	3	Tail water effects	Protect in Place/Replacement	Block tail water during high tide	$15,000	each
Flume	3	Scour/erosion	Protect in Place/Replacement	Rip rap-scour protection	$5,000	each
Headwall	3	Surcharge	Protect in Place/Replacement	Rip rap/sheet pile-scour protection	$25,000	each
Inlet	3	Surcharge	Raise	Regrade/ raise area and add riser	$5,000	each
Manhole	3	Surcharge	Raise	Add precast riser section	$5,000	each
Outlet Drain	3	Tail water effects	Protect in Place	Add tide gate /check valve	$15,000	each
Storm Drain	3	Undermining	Replace/raise	Relocate/Replace	$10,000	LF
Swale	3	Scour/Erosion	Protect in Place	Excavate/Clean	$25	LF
Weir	3	Scour/Erosion	Protect in Place	Rip rap/sheet pile	$10,000	each
Access Gate	2	Scour	Protect in Place	Rip rap/sheet pile	$5,000	each
Catch basin	2	Surcharge	Replace/raise	Install larger pre cast box	$10,000	each
Concrete Junction box	2	Surcharge	Protect in Place	Install larger pre cast box	$10,000	each
Drainage Box	2	Surcharge	Protect in Place	Install larger pre cast box	$10,000	each
Detention Pond	2	Scour	Protect in Place	Excavate/Clean	$50,000	each

WATER SUPPLY						
Infrastructure Asset	**Sensitivity**	**Why Sensitive**	**Adaptive Measure Chosen**	**How/Why**	**Cost**	**Unit**
	Value (1,2,3)	**(Protect in place/Relocate/Raise)**				
						LF
Fire Hydrants	1	Corrosion/Undermining	Relocate (replace)	Replace with corrosion resistant mat.	$7,500	LF
Supply Intake Source	1	Salinity Increase	Relocate	Construct new supply network	$30,000,000	each
SANITARY SEWER						
Gravity 4"-6"	2	Undermining Rupture	Relocate (replace)	Replace w/corrosion resistant mat.	$100	
Force Main	2	Undermining Rupture	Relocate (replace)	Replace w/corrosion resistant mat.	$200	LF
Manhole	3	Infiltration	Protect in Place	Add riser and watertight lid	$7,500	LF
Lift Station/Wetwell	2	Infiltration	Protect in Place	Rebuild at higher elevation	$250,000	each
Large Diam. directionally	1	Undermining Rupture	Relocate (replace)	Relocate (replace)	$2,000	LF
bored pipeline						
Treatment Plant	1	Tail water effects	Relocate (replace)	Relocate (replace)	$30,000,000	each

Infrastructure Asset	Sensitivity	Why Sensitive	Adaptive Measure Chosen	How/Why	Cost	Unit
TRANSPORTATION						
Local Streets	3	Flooding/Erosion	Raise	Raise 1/2'-1'	$6,000,000	mile
Highways	3	Flooding/Erosion	Raise/Protect in Place	Raise 1/2'-1'	$12,500,000	mile
Bridges	2	Scour/Corrosion	Replace	Design for	$50,000,000	mile

APPENDIX B

BMI Environmental Services, LLC
Environmental Consultants

Introduction

In recent years, the Lowcountry Council of Governments (LCOG) has begun in earnest to examine the potential impacts of Sea Level Rise (SLR) on the natural and built environment. Early efforts were undertaken by the Beaufort County Planning Department in conjunction with the South Carolina Sea Grant Consortium, the Social and Environmental Research Institute, North Carolina Sea Grant, and the Carolinas Integrated Sciences and Assessments Program at the University of South Carolina (the "project team") to investigate opportunities for the County to adapt, or increase its capacity to adapt, to future sea level rise impacts.

In September of 2016 LCOG initiated a preliminary study of the potential impacts of SLR on the built environment. This study was envisioned by LCOG and the Beaufort and Port Royal Task SLR Force as a follow-up to the adaptation study and as a way of addressing the recommendations from two Joint Land Use Studies (JLUSs) which identified SLR as a key issue that could impact public property, critical infrastructure, and the safety and well-being of citizens under different scenarios of storm surge and SLR. The objective of this study is to develop a better understanding of the areas within Beaufort County that are vulnerable to implications of sea level rise with the goal of providing tools for resource managers and planners to assess impacts and form the foundation of a SLR adaptation strategy to increase the effectiveness of existing management approaches. In addition, these results can be used to identify additional long-term restoration and conservation targets throughout the County.

Context

This white paper provides a list of scientific literature (e.g. reports, technical notes, white papers, websites) that was reviewed in preparation for SLR study for Beaufort County, South Carolina. This list is not an exhaustive list and by no means an all-encompassing list of information relative to SLR, its potential impacts on man and the environment, the processes for evaluating those impacts, scenario planning techniques, and adaptive management tools that can be implemented to reduce impacts of SLR. The information presented herein is intended to document the research conducted for the Beaufort County SLR study and to share this information in hopes that it will enable others interested SLR to begin at a place a little bit further up the learning curve than were when we began.

Publications

Beavers, R.L., A.L. Babson, and C.A. Schupp [eds.]. 2016. Coastal Adaptation Strategies Handbook. NPS 999/134090. National Park Service. Washington, DC. Retrieved from: https://www.nps.gov/subjects/climatechange/upload/CASH_Entire_Handbook_FINAL_100716.pdf

This handbook provides guidance NPS managers, partners, and other practitioners in exploring and implementing climate change adaptation strategies in estuarine and coastal areas, including the Great Lakes. This handbook provides a discussion of the NPS current understanding of a rapidly developing field as it relates to coastal parks; identifies tools and strategies; provides examples of approaches that the NPS as an agency and individual parks are using to address coastal vulnerabilities and climate change impacts; and provides policy and decision-making guidelines.

Key Words: Climate Change | Coastal Resources | Planning Framework |Climate Adaptation | Sea Level Rise | Infrastructure | Built Environment | Coastal Adaptation Stratigies

Blakely, Edward. (2007). Urban Planning for Climate Change. Lincoln Institute of Land Policy Working Paper. Lincoln Institute Product Code: WP07EBI. http://www.lincolninst.edu/publications/working-papers/urban-planning-climate-change

A brief paper on urban planning for climate change which includes a case study profiling climate change risk for New Orleans, Louisiana. The report discusses potential impacts to tourism, damage to the built environment, storm tides and storm surges, and city planning zones.

Key Words: Urban Planning |Case Studies |Outreach | Stakeholder Engagement | City Planning |Storm Tides and Storm Surges

California Emergency Management Agency and California Natural Resources Agency. (2012). California Adaptation Planning Guide (APG)-Planning for Adaptive Communities. Retrieved from http://resources.ca.gov/docs/climate/01APG_Planning_for_Adaptive_Communities.pdf

The APG a set of four complementary documents that provide guidance to support communities in addressing the unavoidable consequences of climate change. The APG was developed by the California Emergency Management Agency and California Natural Resources Agency and introduces the basis for climate change adaptation planning and details a step-by-step process for local and regional climate vulnerability assessment and adaptation strategy development.

Key Words: Guidance Documents |Climate Change | Adaptation Planning| Regional Climate Vulnerability Assessment | Adaptation Strategy Development

Chadwick, B, et.al. 2014. A Methodology for Assessing the Impact of Sea Level Rise on Representative Military Installations in the Southwestern United States (RC-1703). SPAWAR Systems Center Pacific. San Diego, CA. Retrieved from: https://www.serdp-estcp.org/Program-Areas/Resource-Conservation-and-Resiliency/Infrastructure-Resiliency/Vulnerability-and-Impact-Assessment/RC-1703

The report presents the analysis framework and methodologies for evaluation of coastal military installation vulnerabilities and tests them under scenarios of increased local mean sea level rise over various periods of time. The methodologies were developed to assess the potential scope and magnitude of impacts from physical effects of flooding, inundation, erosion, seawater intrusion, and alteration of tidal flows. The assessment methodologies presented in the report targeted potential vulnerabilities of buildings, civil infrastructure, training areas, and waterfront and coastal structures in southwestern United States and utilized the key coastal military installations at Naval Base Coronado (NBC) and Marine Corps Base Camp Pendleton (MCBCP) to test the approach.

Key Words: Analysis Framework | Methodologies | Coastal Military Installations | Vulnerabilities | Sea Level Rise |Flooding | Inundation | Seawater Intrusion |Tidal Flows | Civil Infrastructure |Coastal Structures

Climate Change Science Program. (2009). Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [James G. Titus (Coordinating Lead Author), K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Gutierrez, E. Robert Thieler, and S. Jeffress Williams (Lead Authors)]. U.S. Environmental Protection Agency, Washington D.C., USA, 320 pp. Retrieved from: https://downloads.globalchange.gov/sap/sap4-1/sap4-1-final-report-all.pdf

This Synthesis and Assessment Product (SAP), developed as part of the U.S. Climate Change Science Program, examines potential effects of sea-level rise from climate change during the twenty-first century, with a focus on the mid-Atlantic coast of the United States. Using scientific literature and policy-related documents, the SAP describes the physical environments; potential changes to coastal environments, wetlands, and vulnerable species; societal impacts and implications of sea-level rise; decisions that may be sensitive to sea-level rise; opportunities for adaptation; and institutional barriers to adaptation. The SAP also outlines the policy context in the mid-Atlantic region and describes the implications of sea-level rise impacts for other regions of the United States. Finally, this SAP discusses ways natural and social science research can improve understanding and prediction of potential impacts to aid planning and decision making.

Key Words: Climate Change Science | Sea Level Rise |Mid-Atlantic Coast| Social Impacts |Coastal Environments |Planning | Vulnerable Species | Decision Making | Adaptation | Hurricanes and Storm Surge | SLR Scenarios | Benefit-Coast Criteria | Adaptation Actions

Department of the Army. (2014). Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation. Technical Letter No. 1100-2-1. Retrieved from http://www.publications.usace.army.mil/Portals/76/Publications/EngineerTechnicalLetters/ETL_1100-2-1.pdf

The technical letter provides guidance for integrating climate change and sea level rise information into the recommended Specific, Measurable, Attainable, Risk Informed, Timely (SMART) planning and engineering to understand and adapt to impacts of projected sea level change decisions and review points that identify the level of analysis required as a function of project type, planning horizon, and potential consequences.

Key Words: SMART Planning |Climate Change | Sea Level Rise| Regional Climate Vulnerability Assessment | Planning Horizon

Evans, Jason, Rob McDowell, Chuck Hopkinson, Jill Gambill, David Bryant, Kelly Spratt, and Wick Prichard. (2016). "Tybee Island Sea Level Rise Adaptation Plan Final Report." City of Tybee Island. Retrieved from: http://research.fit.edu/sealevelriselibrary/documents/doc_mgr/441/Evans_et_al._2016._Tybee_Island_SLR_Adaptation_Plan.pdf

The sea level rise adaptation report for Tybee Island provides a synthesis of the technical research, sea-level rise adaptation strategies, and public engagement processes conducted by the City of Tybee Island in association with researchers and outreach professional from Georgia Sea Grant, University of Georgia, and Stetson University through a Community Climate Adaptation Initiative NOAA National Sea Grant College Program. The objectives of the study were to identify impacts due to current and future tidal flooding; educate the community members about the potential vulnerability to flooding and SLR how to avoid or mitigate impacts of sea level rise.

Key Words: Sea Level Rise | SLR Adaptation Strategies | Public Engagement | Tidal Flooding | Mitigation | Vulnerability |Shoreline Erosion |

Garster, J.G., M. W. Huber, and K.D. White. (2015). US Army Corps of Engineers Screening-Level Assessment of Projects with Respect to Sea Level Change. Civil Works Technical Report, CWTS 2015-16, US Army Corps of Engineers: Washington, DC. Retrieved from: http://www.corpsclimate.us/docs/CESL_Screening_level_assessment_sea_level_change_JUN_2015.pdf

This report contains a summary of the USACE initial screening-level assessment of the vulnerability of projects with respect sea level change completed by USACE district staff using a web-based tool that interfaces with USACE geospatial databases. The report also includes a discussion of the comprehensive evaluation with respect to sea level (CESL) web tool and identifies various types of information developed by other agencies, including FEMA, NOAA, and the US Geological Survey (USGS).

Key Words: Vulnerability Assessment | Screening-Level Assessment | Web Based Tool | Sea Level Change | USACE Geospatial Database

Hall, J.A., S. Gill, J. Obeysekera, W. Sweet, K. Knuuti, and J. Marburger. (2016). Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme Water Levels for Department of Defense Coastal Sites Worldwide. U.S. Department of Defense, Strategic Environmental Research and Development Program. 224 pp. Retrieved from https://www.serdp-estcp.org/News-and-Events/News-Announcements/Program-News/DoD-Report-on-Regional-Sea-Level-Scenarios

This far-reaching report contains a wide range of suggested decision-making options and guidance on use of SLR projections. It stresses the need to use multiple scenario's as a base for future actions and the fact that there is no single answer. The overarching theme is that the science of predicting a most-likely future is still lacking and that SLR curves should be treated as information having a deep level of uncertainty. All planning based on the information should reflect this uncertainty.

Key Words: Vulnerability Assessment | Screening-Level Assessment | Department of Defense | Sea Level Change | USACE Geospatial Database | Deep Uncertainty

ICLEI-Local Environmental Initiatives. (2008). Cities for Climate Protection Australia Adaptation Initiative- Local Government Climate Change Adaptation Toolkit. Retrieved from http://archive.iclei.org/fileadmin/user_upload/documents/ANZ/CCP/CCP-AU/Projects/AI/AdaptationToolkit/Toolkit_CCPAdaptation_Final.pdf

The climate change adaptation toolkit identifies and describes a group of tools and exercises designed to help governments navigate through an enhanced risk management process or adaptive

management process to assist in identifying aspects of their internal decision-making processes, plan for the impacts of climate change, generate and implement a plan to manage the risks, and harness the opportunities identified as for their respective communities.

Key Words: Climate Change Adaptation Toolkit | Enhanced Risk Management | Adaptive Management

ICF International. 2014. Assessing Criticality in Transportation Adaptation Planning. US Department of Transportation Center for Climate Change and Environmental Forecasting. Retrieved from: https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/modules/criticality_guidance/criticality_guidance.pdf

This document discusses challenges associated with assessing criticality, options for defining criticality and identifying scope, and the process of applying criteria and ranking assets. It provides examples from the FHWA pilots and the Gulf Coast 2 study to illustrate a variety of approaches that have been used for assessing criticality. The Appendix lists criticality criteria developed under the Gulf Coast Study, Phase 2, along with brief explanations for why each criterion was chosen.

Key Words: Criticality | Assessing Criticality | Identifying Scope | FHWA | Ranking Assets | Criteria |Approaches | FHWA Gulf Coast Study Phase 2

International Panel on Climate Change (IPCC). (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds. Cambridge University Press, Cambridge, UK, 976 pp. Retrieved from: http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm

The report provides the most comprehensive and up-to-date scientific assessment of the impacts of climate change, the vulnerability of natural and human environments, and the potential for response through adaptation. Included in the report are discussions of observed changes in climate and its impact on physical and biological systems, response actions through adaptation; the synergies and trade-offs between adaptation and mitigation, key vulnerabilities to climate change, and the role of multiple stressors.

Key Words: Climate Change | Vulnerability | Physical and Biological Systems | Response Actions | Adaptations | Mitigation | Key Vulnerabilities |Multiple Stressors

IPCC. (2012). Renewable Energy Sources and Climate Change Mitigation. Special Report of the Intergovernmental Panel on Climate Change (p. 1088). Cambridge University Press. Retrieved from: http://srren.ipcc-wg3.de/report/IPCC_SRREN_Full_Report.pdf

A comprehensive and lengthy report which includes many maps charts, graphs, illustrations, diagrams and infographics detailing the IPCC Working Group's assessment of scientific literature on renewable energy technologies and how they may reduce greenhouse gas emissions. The Report covers not only many types of renewable energy technology (biofuels, solar, etc) and their implementation and integration with current and future infrastructure, but also the policymaking, physical and financial barriers faced in the field.

Key Words: Climate Change | Renewal Energy Technologies | Greenhouse Gas Emissions | Infrastructure | Policy Making | Physical and Financial Barriers

Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss. (2012). Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

This report which was produced by NOAA's Climate Program Office in collaboration with twelve contributing authors from ten different federal and academic science institutions—including NOAA, NASA, the U.S. Geological Survey, the Scripps Institution of Oceanography, the U.S. Department of Defense, the U.S. Army Corps of Engineers, Columbia University, the University of Maryland, the University of Florida, and the South Florida Water Management District in response to a request from the U.S. National Climate Assessment Development and Advisory Committee. It provides a synthesis of the scientific literature on global sea level rise, and a set of four scenarios of future global sea level rise. The report includes input from national experts in climate science, physical coastal processes, and coastal management.

Key Words: Climate Change | Collaboration |National Climate Assessment | Sea Level Rise | Scenarios | Climate Science |Coastal Processes | Coastal Management

Rhode Island Climate Change Commission. (2012). Adapting to Climate Change in the Ocean State: A Starting. Retrieved from:

http://www.rilin.state.ri.us/Reports/Climate%20Change%20Commission%20Prog%20Report%20Final%2011%2015%2012%20final%202.pdf

The Rhode Island CCC report reviewed and summarized the key climate risks and vulnerabilities that will affect Rhode Island and southern New England, and adaptation efforts underway at the local, state and regional level. The report addressed potential impacts and vulnerabilities related to climate change and sea level rise on the built environment, natural resources, and human health and welfare.

Key Words: Climate Change Commission | Climate Change Sea Level Rise | Build Environment | Adaptation Planning | Natural Resources | Human Health and Welfare

Schmid, K., B. Hadley, and K. Waters. 2014. Mapping and Portraying Inundation Uncertainty of Bathtub-Type Models. *Journal of Coastal Research* 30:548–561. Retrieved From: http://www.jcronline.org/doi/abs/10.2112/JCOASTRES-D-13-00118.1?code=cerf-site

The publication describes a technique and defines levels of uncertainty for a root-mean-square error (RMSE) using reported RMSE data of both elevation and tidal surface and their relationship to a normal distribution. This technique allows for user-defined confidence levels and can be used to map uncertainty both above and below the deterministic value produced in typical single-surface or bathtub models. The technique is used in this context for SLR and inundation mapping but also has applicability in mapping other phenomena.

Key Words: Techniques | Root-Mean-Square-Error | Tidal Surface | Bath Tub Effect | Sea Level Rise | Contours |Resolution | Scale | Accuracy Limitation | Mapping

Social and Environmental Research (SERI) and Carolina Integrated Science and Assessment (CISA). (2013). Diagramming Climate Change-Related Vulnerability, Consequences, and Adaptation Planning Scenarios. (VCAPS)- A facilitation guide and tutorial. " Retrived from: http://vcapsforplanning.org/docs/VCAPS%20UserGuide%2025March13.pdf

This document describes procedures necessary to facilitate a Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS) diagramming session. The tutorial begins with an identifying a climate related concerns and then follows through the process of identifying and documenting possible consequences related to climate stressors, and the opportunities for mitigation and adaptation.

Key Words: Vulnerability | Adaptation | Adaptation Planning Scenarios | Climate Stressors | Mitigation

South Carolina Sea Grant Consortium. March (2015). Sea Level Rise Adaptation Report Beaufort County South Carolina. S.C. Sea Grant Consortium Product #SCSGC-T-15-02.

This report describes the initial effort by Beaufort County to investigate opportunities for the County to adapt, or increase its capacity to adapt, to future sea level rise impacts. The SLR report summarizes data on local sea level rise trends and reviews the 23 adaptation actions identified by the Beaufort County Stakeholder Group and members of the broader public.

Key Words: Beaufort County, South Carolina | Adapt |Future Sea Level Rise | Trends | Adaptation Actions | Stakeholder Group | Public

Tuler, S. and Webler. T. (2013). Results from a VCAPS Planning Workshop for Extreme Weather in Dauphin Island, Alabama: Final Report. Social and Environmental Research Institute: Greenfield MA. Retrieved from: http://vcapsforplanning.org/docs/Dauphin%20Island%20Report.pdf

This report describes the results of a workshop held at Dauphin Island, Alabama on December 5, 2012 that used a mediated modeling process called Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS) to document the vulnerability of Dauphin Island to extreme weather events in a time of climate change and to identify actions that the community could undertake to increase its resilience.

Key Words: Workshop | Dauphin Island, Alabama |Mediated Modeling Process | VCAPS | Extreme Weather Events | Climate Change | Community Actions

United States Agency for International Development (USAID). (2009). Adapting to Coastal Climate Change- A guidebook for Development Planners, prepared by the Coastal Resources Center-University of Rhode Island (CRC-URI) ant International Resources Group. Retrieved from: http://www.crc.uri.edu/download/CoastalAdaptationGuide.pdf

The guidebook provides an overview of the various processes, tools, and resources available to policymakers, coastal planners, and other development professional working to assess impacts of climate change and climate variability at the local, regional, and national level. The guidebook also provided references and links to important sources of information and tools and a broad overview of methods and best practices for conducting vulnerability assessments and evaluating adaptation measures.

Key Words: Guidebook |Capacity Building |Public Awareness, Education, and Outreach | Stakeholder Engagement | Adaptation Strategies |Infrastructure, Planning, and Development |Community Planning |Climate-Smart Communities

Websites

Climate Adaptation Knowledge Exchange: http://www.cakex.org/

About: The Climate Adaptation Knowledge Exchange (CAKE) was founded by EcoAdapt and Island Press in July 2010, and is managed by EcoAdapt. It aims to build a shared knowledge base for managing natural and built systems in the face of rapid climate change.

Carolinas Integrated Sciences Assessment (CISA): http://www.cisa.sc.edu

About: The CISA program was established in 2003 on the heels of a record-breaking drought, with a small team of researchers based at the University of South Carolina and the South Carolina Department of Natural Resources. CISA's work focused initially on the water resources sector and the development of information and tools to enhance drought management. Since then, the CISA program has evolved and expanded in order to meet regional needs for decision-relevant climate information and to support the capacity of communities to respond and adapt to climate-related stresses.

Federal Emergency Management Agency (FEMA)-Climate Change: https://www.fema.gov/climate-change

About: This site provides information about climate change and links to related tools and documents. The page is intended for anyone interested in learning more about our resources and other federal government resources to support climate preparedness and resilience.

The International Panel on Climate Change: https://www.ipcc.ch/index.htm

About: The IPCC is the international body for assessing the science related to climate change. The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Program (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation.

National Oceanic Atmospheric Administration (NOAA) Office for Coastal Management-Digital Coast: https://coast.noaa.gov/digitalcoast/about

About: The Digital Coast website provides not only coastal data, but also the tools, training, and information needed to make these data truly useful. Content comes from many sources, all of which are vetted by NOAA. Data sets range from economic data to satellite imagery. The site contains visualization tools, predictive tools, and tools that make data easier to find and use. Training courses are available online or can be brought to the user's location. Information is also organized by focus area or topic.

NOAA Sea Level Rise Viewer: https://coast.noaa.gov/digitalcoast/tools/slr

About: The Sea Level Rise Viewer is a web mapping tool that can be used to visualize community-level impacts from coastal flooding or sea level. Site also provides a photo simulation function which produces simulations of how future flooding might impact local landmarks, as well as data related to water depth, connectivity, flood frequency, socio-economic vulnerability, wetland loss and migration, and mapping confidence.

National Park Service (NPS): https://www.nps.gov/subjects/climatechange/index.htm

About: The NPS climate change website provides information about the impacts of climate change on the nation's 118 coastal parks and over 12,000 miles of shoreline and the work of the NPS to develop local, landscape, and ecosystem-scale adaptation strategies that protect coastal resources and promote their long-term resilience and sustainability.

Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP): https://www.serdp-estcp.org/Featured-Initiatives/Climate-Change-and-Impacts-of-Sea-Level-Rise

About: SERDP and ESTCP are the Department of Defense's (DOD) environmental research programs, which utilize the latest science and technology to improve DoD's environmental performance, reduce costs, and enhance and sustain mission capabilities. One of the initiatives of SERDP/ESTCP highlighted in the featured initiatives programs is Climate Change and Impacts of Sea Level Rise which addresses the information and decision support needs of DoD coastal installations relating to climate change, climate change vulnerability, and impact assessment. Products developed and available from this website include methodologies and tools to assess the physical effects of sea level rise and storm surge, and the impacts to mission-essential infrastructure at DOD facilities.

U.S Department of the Army Corps of Engineers (USACE) Climate Change Adaptation-Comprehensive Evaluation of Project with Respect to Sea-Level Change: http://www.corpsclimate.us/cca.cfm

About: The climate change portal provides an overview of the USACE's efforts to integrate climate change adaptation planning and actions into their missions, operations, programs, and projects. Links within the site also describe the USACE's efforts to conduct a series of progressively more detailed screening-level assessments of the vulnerability of USACE projects to the effects of changing sea levels.

U.S. Department of Transportation (USDOT)- Federal Highway Administration (FHWA):

https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/vulnerability_assessment_framework/ols

About: This section of FHWA's Climate Change Adaptation website provides resources, to FHWA's Climate Change and Extreme Weather Vulnerability Assessment Framework, a guide to assessing the vulnerability of transportation assets to climate change and extreme weather events. and guidance to help local and regional transportation agencies implement the

USDOT FHWS-Gulf Coast Study:
https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/gulf_coast_study

About: The groundbreaking U.S. DOT Gulf Coast Study produced tools and lessons learned that transportation agencies across the country are using to assess vulnerabilities and build resilience to climate change. Phase 2 was completed in 2015, Phase 1 in 2008.

USDOT FHWA Virtual Framework for Vulnerability Assessment:

https://www.fhwa.dot.gov/environment/climate_change/adaptation/adaptation_framework/

About: This site provides an overview of FHWA's Climate Change and Extreme Weather Vulnerability Assessment Framework, and describes the benefits of conducting a vulnerability assessment.

U.S. Climate Resilience Toolkit: https://toolkit.climate.gov

About: The U.S. Climate Resilience Toolkit is a website designed to help people find and use tools, information, and subject matter expertise to build climate resilience. The Toolkit offers information from all across the U.S. federal government in one easy-to-use location. The site was built in response to the President's Climate Action Plan and Executive Order 13653 (Preparing the United States for the Impacts of Climate Change), which calls for the federal government to "...develop and provide authoritative, easily accessible, usable, and timely data, information, and decision-support tools on climate preparedness and resilience" to support federal, regional, state, local, tribal, private-sector, and nonprofit-sector efforts to prepare for the impacts of climate change.

U.S. Climate Resilience Toolkit-Case Studies: "The Lowcountry Lowdoown on Sea Level Rise"
https://toolkit.climate.gov/case-studies/lowcountry-lowdown-sea-level-rise

About: The website link provides information about the SLR study for Beaufort County, South Carolina, and highlights the participatory approach to adaptation planning using Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS) process.

U.S. Environmental Protection Agency (USEPA) Climate Change Portal:
https://www.epa.gov/climatechange, and https://www.epa.gov/cre/coastal-adaptation-toolkit#frameworks

About: The USEPA Climate Change Portal is a website that provides information about climate science and links to information on climate change, sea level rise, climate adaptation, and guidance documents relating to planning, preparedness, adaptation and sustainability.

APPENDIX C

There were many intermediate GIS data files generated in this project. Some (KMZ's) have been posted to the website (http://www.geosciconsultants.com/low-country-cog) and represent abridged formats of the full featured data. Others contain an abundance of data and are likely not of value to end-users. So, although all of the information can be provided, we have slimmed the GIS data down to two basic types of information:

1. Exposure surfaces (raster) for each time period
2. Vulnerability information for each piece of infrastructure (vector)

The following information is meant to help end-users leverage the information for this as well as other projects.

Exposure Surfaces

The full featured versions of the exposure surfaces are provided in Erdas Imagine (.img) format, which is compatible with most GIS programs (including ESRI). The values range from 0 to 1 and are representative of the safety margin (1 – risk value). So a location with a value of 0.35 has 35% relative safety margin (65% relative risk) of being inundated on a monthly high tide based on the sea level curves used in this project (as described in the report). Five dates are provided: 2020, 2030, 2040, 2060, and 2085.

The KMZ versions (http://www.geosciconsultants.com/low-country-cog) for each time period have three divisions. The blue areas are below the 10% relative safety margin and assumed to be flooded during the monthly high tide. The red areas highlight relative safety values between 10 and 90% and represent the area of risk, where inundation may or may not occur based on the projections. And, finally, a white area that is above the 90% relative safety margin and assumed to be 'safe' from monthly flooding. This does not mean it will not be flooded by some extreme tidal events, but that it is not expected to flood at the frequency level used in this study. Five dates are provided: 2020, 2030, 2040, 2060, and 2085.

Vulnerability Information

There were six primary infrastructure types examined for vulnerability: Roads (highway and local), Water Lines, Sanitary Sewer Lines, Storm Drains, Lift Stations, and Fire Hydrants. The provided information also included bridge points, but bridges were re-defined from roads that passed over water. Bridges are not included in the vulnerability assessment because they represent unique structures and will require an in-depth engineering study. The following table describes the database fields for the provided infrastructure.

Database Field	Description	Example values
2020_VUL	vulnerability value in 2020	3
2030_VUL	vulnerability value in 2030	3
2040_VUL	vulnerability value in 2040	3
2060_VUL	vulnerability value in 2060	3
2085_VUL	vulnerability value in 2085	4
COSTS	cost per unit ($)	5000
CRIT_1	criticality as defined by the simple example	6
CRIT_2	criticality as defined the combination example	6.495
ID	generated ID	SD_11198
PRICE	price per database entry ($)	5000
RISK_2020	Safety factor in 2020 (values greater than 1 = 99.9%)	1.18
RISK_2030	Safety factor in 2030	1.18
RISK_2040	Safety factor in 2040	1.18
RISK_2060	Safety factor in 2060	1.082
RISK_2085	Safety factor in 2085	0.828
SENSITIVITY	engineering defined sensitivity	3