Climate Resilience Evaluation and Awareness Tool Exercise with Manteo and Columbia, North Carolina and the Albemarle-Pamlico National Estuary Partnership

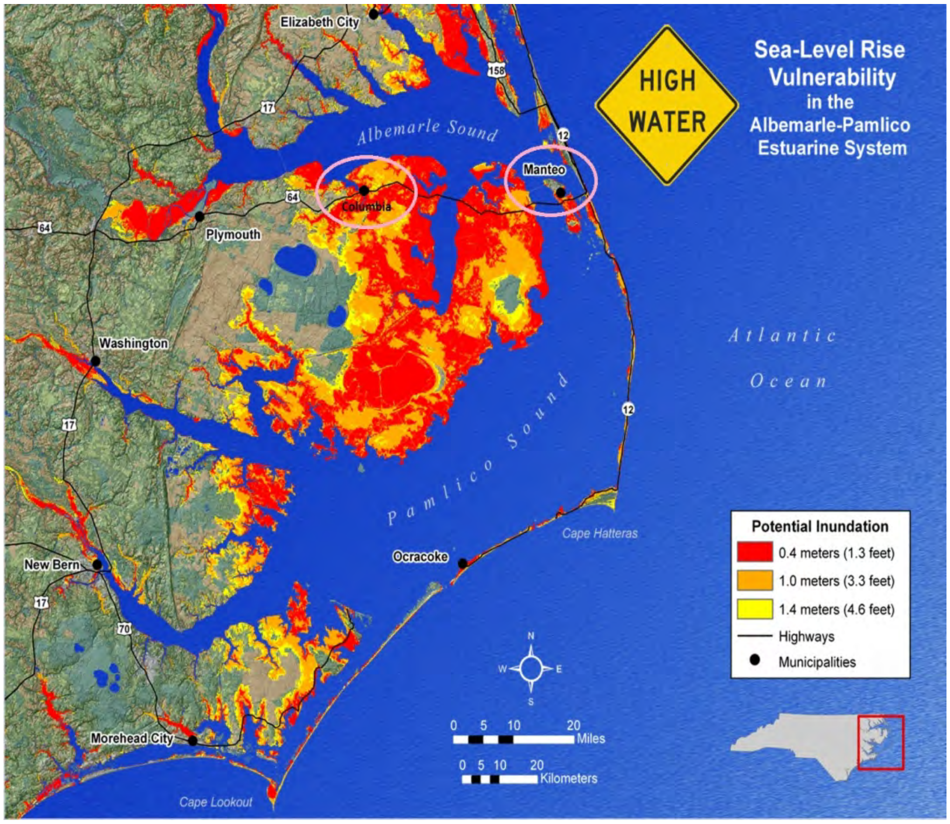

Figure 1. Map of Sea Level Rise Vulnerability
Credit: Tom Allen, Eastern Carolina University

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Foreword

Current watershed management practices may not be sufficient to cope with the potential effects of climate change on aquatic ecosystems, water supply, water quality and coastal flooding. As a result, there is a need to identify regional consequences from climate change and to develop adaptation strategies that can be integrated at a watershed scale. The U.S. Environmental Protection Agency's (EPA) Climate Ready Water Utilities (CRWU) and Climate Ready Estuaries (CRE) initiatives are working to coordinate their efforts and support climate change risk assessment and adaptation planning. Both EPA initiatives focus on addressing climate change and water resource issues with stakeholders that share common interests regarding watershed management. This report details a recent climate change adaptation exercise that provided an opportunity for these parties to collaborate on assessment and planning with respect to potential climate change impacts on natural resources and utility infrastructure.

EPA's CRWU and CRE initiatives collaborated with a workgroup comprised of town officials and water managers from Manteo and Columbia, North Carolina, as well as representatives from the Albemarle-Pamlico National Estuary Partnership (APNEP). This exercise provided an opportunity for the towns to increase their awareness of climate change and begin the process of developing both a climate change risk assessment and adaptation plan. Additionally, this exercise educated workgroup members, including APNEP staff, on EPA's Climate Resilience Evaluation and Awareness Tool (CREAT) in order to support their use of the tool in other APNEP communities.

For this exercise, CREAT was used as a framework to identify climate change threats and vulnerable assets and to evaluate adaptation options in both Manteo and Columbia. Stakeholders collaborated on risk assessment and adaptation planning related to projected climate change impacts. The exercise also provided an opportunity to compare climate change projections for sea level rise (SLR) from CREAT to SLR projections developed by the North Carolina Coastal Resources Commission's Science Panel on Coastal Hazards (NC Science Panel). CREAT also provides climate change projections for temperature, precipitation and intense precipitation. These projections helped to support the identification of potentially vulnerable assets and assist each town with beginning the process of adaptation planning to address potential vulnerabilities. CREAT's risk assessment framework and input from workgroup members provided valuable information and perspectives on water resources management throughout this exercise. To address projected climate change impacts in each town, participants discussed potential adaptive measures that may be implemented in the future.

Participants noted the value of the collaborative process throughout the CREAT exercise, especially as the workgroup identified vulnerable assets and climate change threats in Manteo and Columbia, refined consequence levels and examined potential implications related to future regional SLR. The risk assessment and planning framework supported by CREAT enabled stakeholders to gain new perspectives to inform future planning efforts.

1. Introduction

To assess projected climate change impacts and build upon ongoing water resources management efforts in the Albemarle-Pamlico watershed, EPA's CRWU and CRE initiatives collaborated with a workgroup comprised of representatives from APNEP and the Towns of Manteo and Columbia[1], NC. This workgroup identified consequences from climate change, began to develop adaptation strategies at the watershed level and helped to inform ongoing planning efforts in the region. This exercise consisted of a series of webinars and two-in person meetings held from June through September 2012, as well as follow-on discussions.

Exercise Objectives:

- Utilize EPA's Climate Resilience Evaluation and Awareness Tool (CREAT) to develop and document climate change risks/consequences as they relate to Manteo and Columbia, including consideration of the reasonable range of potential climate impacts.
- Begin to assemble adaptation strategies for effectively addressing climate change risks through implementation of adaptive measures in Manteo and Columbia.
- Educate workgroup members, including APNEP staff, on EPA's CREAT in order to support the use of the tool in other APNEP communities.

Note: Throughout this exercise, inputs for each town's CREAT analysis files were suggested by various members of the workgroup. These inputs are not necessarily exhaustive of all possible inputs and can be revised in the future.

1.1 Project Background

The Towns of Manteo and Columbia are located in North Carolina's Albemarle-Pamlico watershed. Manteo is situated along the coast on Roanoke Island in Dare County. Columbia is located approximately 40 miles west of Manteo, along the banks of the Scuppernong River in Tyrell County.

Both locations have suffered some damage to natural resources and water-sector infrastructure from heavy precipitation events, as well as coastal and inland storm surge. This damage is expected to be further exacerbated by projected climate change impacts unless adaptation steps are taken. Scientific projections indicate that coastal North Carolina may experience significant SLR of approximately 1 meter by 2100 (NC Science Panel, 2010). Climate change projections also indicate that the southeastern United States will experience an increase in the intensity of Atlantic hurricanes. Projected increases in evaporation and plant water-use rates are also likely to lead to saltwater intrusion into shallow aquifers (EPA, 2012).

Manteo and Columbia are very familiar with impacts from extreme weather events such as hurricanes. In August 2011, Hurricane Irene made landfall in North Carolina, bringing approximately 7-8 inches of rainfall to many coastal and inland communities. Climate change

[1] For a list of exercise participants, see Appendix A.

projections, in addition to recent impacts from extreme weather events, illustrate the current and potential natural resource and infrastructure vulnerabilities along the North Carolina coast.

1.2. Manteo – Background Information

Manteo is a small coastal community, with a resident population of approximately 1,434 (U.S. Census Bureau, 2010). Manteo is approximately 1.8 square miles in size, and situated within the 100-year floodplain of the Albemarle and Pamlico sounds. Because of its geographic location, Manteo experiences extreme weather events and is susceptible to climate change impacts.

Recently, Manteo experienced severe impacts from Hurricane Irene and has taken action to adapt to impacts from extreme weather events and climate change. To better adapt to flooding from coastal storm surge and heavy precipitation events and associated disruptions in wastewater treatment processes, Manteo raised its wastewater treatment plant's (WWTP) master lift station at Bowsertown Road. Manteo also installed a new SCADA system, allowing the plant to operate in a more energy efficient manner at various treatment stages, which has reduced the utility's energy bills. While the increased resilience of the WWTP master lift station and energy bill savings are encouraging steps, stakeholders noted that the town's capital budget for future upgrades is currently limited due to these recent expenditures.

During the CREAT exercise, Manteo focused on assessing impacts associated with wastewater infrastructure. Manteo receives its drinking water from a wholesale provider, Dare County Water Department. While stakeholders from Manteo acknowledged that drinking water infrastructure may be impacted by climate change, the town's drinking water infrastructure was not considered during the CREAT analysis.

1.3 Columbia – Background Information

Columbia's resident population is approximately 891. The town is situated almost entirely in the 100-year floodplain of the Scuppernong River, and the water table is just inches below the ground's surface (Nicholas Institute, 2011).

Heavy precipitation events and inland effects from coastal storm surge, as well as saltwater intrusion, already impact Columbia's natural and built infrastructure. During Hurricane Irene, Columbia's drinking water treatment plant was not flooded, but the water was uncomfortably close to inundating its facility. Given projections of increased rainfall amounts and the risk associated with flooding from extreme weather events, the treatment plant is projected to be more vulnerable in the future. Saltwater intrusion into the town's Castle-Hayne Aquifer is starting to occur, and the town relies on three groundwater wells in this aquifer for its drinking water supply. Columbia's WWTP infrastructure includes a treatment plant, three lift stations, three secondary pump stations, and one primary pump station. Columbia treats its wastewater and discharges it using a dispersed discharge system into the Scuppernong River. In addition to residences and small businesses, two major industries in Columbia contribute to the amount of treated wastewater, a professional laundry facility and a seasonal blue crab processing plant. Currently, heavy precipitation events and inland flooding from storm surge already impact pump stations and parts of the collection system. In order to reduce inflow and infiltration into its wastewater collection system during intense heavy precipitation and flood events, Columbia recently replaced many of its sewer lines. Local stakeholders noted that additional projects to adapt to climate change impacts may be limited by lack of available staff to manage projects, given the small size of the town's workforce.

1.4 Albemarle-Pamlico National Estuary Partnership (APNEP)

Prior to the CREAT exercise, APNEP supported a number of scientific and planning initiatives designed to initiate the process of climate change adaptation planning. In 2008, APNEP hosted listening sessions throughout the APNEP region, and in 2010 the program partnered with Duke University's Nicholas Institute for Environmental Policy Solutions to develop strategies for addressing climate change. The result of this partnership was the report "Climate Ready Estuaries Blueprint". APNEP also works with communities to address climate change in the region. APNEP's 2012 "Comprehensive Conservation and Management Plan" is designed to address the challenges posed by a changing climate on the Albemarle-Pamlico region. This plan calls for the development of improved scientific products that support decision-making, with a specific charge for APNEP to engage with local communities to help them integrate climate projections into their planning processes.

Staff from APNEP played an integral role throughout the CREAT exercise. The workgroup leveraged APNEP's experience with water resource management in and around Manteo and Columbia. Additionally, APNEP provided the workgroup with relevant background information on environmental management in North Carolina, as well as the state's policy and calculations for future SLR. APNEP is active throughout the Albemarle-Pamlico watershed, with management efforts in both North Carolina and Virginia. Efforts by APNEP staff to engage and collaborate with partners across community and state boundaries made them valuable members of the workgroup.

2. CREAT Exercise Results

The workgroup used CREAT to examine climate change impacts to water resources and infrastructure to inform adaptation planning efforts in Manteo and Columbia. More specifically, the workgroup discussed potential adaptive measures that may reduce impacts associated with SLR and coastal/inland storm surge, heavy precipitation events, and saltwater intrusion. The workgroup also used CREAT's risk assessment framework to discuss the implementation of these potential adaptive measures to reduce risk from climate change impacts.

2.1 CREAT 2.0 and Sea Level Rise (SLR) Data and Resources

While each town's CREAT analysis utilized CREAT version 1.0, this exercise provided an opportunity for EPA to evaluate data included in CREAT version 2.0. This version of CREAT provides access to more comprehensive climate datasets for historical and projected conditions to support awareness building, definition of future climate scenarios and risk assessment. For this reason, climate data from CREAT 2.0 was presented to the workgroup during this exercise.

Historical climate data within CREAT 2.0 provides a benchmark of historical climate conditions for comparison to projected changes. Historical temperature and precipitation data represent spatial averages of observed data for a 30-year time period (1971-2000) accessed from the Parameter-elevation Regressions on Independent Slopes Model (PRISM). PRISM is recognized globally as the highest quality spatial climate dataset. Data for historical intense precipitation are sourced from the National Oceanic and Atmospheric Administration's National Climatic Data Center, which collects information for over 10,000 climate stations in the U.S. Historical data were selected based on climate station proximity to Manteo and Columbia. For Manteo, data were selected from the Manteo AP Climate Station. Data for Columbia were selected from the Plymouth 5 E Climate Station.

For each defined location, CREAT provides three pre-loaded scenarios – hot and dry, central, and warm and wet model projections – which capture a range of possible future climate conditions. Future scenarios include projections for temperature, precipitation, intense precipitation, and SLR at 2035 and 2060. The years 2035 and 2060 represent a 30-year average for data from 15 years on either side of 2035 and 2060, respectively. Therefore, it is important to note that these projections do not explicitly reflect the climate projections for the years 2035 and 2060. Temperature and precipitation data provided context during the exercise discussions, while SLR was discussed in greater detail. Based on the data presented to workgroup participants, Manteo and Columbia representatives felt that their utility infrastructure and operations could be impacted by projected climate change. While CREAT's range of future climate scenarios provides valuable information about potential conditions; future utility thresholds related to temperature and precipitation are not yet known. Local historical and projected climate conditions for temperature, precipitation and intense precipitation are included in Tables 1 & 2.

Table 1. Temperature and Precipitation Data from CREAT 2.0[2]

Temperature (Degrees Fahrenheit)	**Manteo**	**Columbia**
Historical Temperature	61.8	61.7
2035 Temperature Projection	63.4	63.3
2060 Temperature Projection	64.8	64.7
Precipitation (Inches)		
Historical Precipitation	52.1	51.3
2035 Precipitation Projection	53.7	53.0
2060 Precipitation Projection	55.1	54.5

[2] Table 1 illustrates CREAT's 'warm and wet' scenario, providing CCSM model projections for temperature and precipitation data. CREAT users can also select 'hot and dry' and 'central' model projections to examine a range of future scenarios.

Table 2. Intense Precipitation Event Data from CREAT 2.0[3]

Intense Precipitation (Inches per 24-hour event)	5-year	10-year	15-year	30-year	50-year	100-year
Manteo						
Historical	4.25	4.72	4.97	5.35	5.59	5.91
2035 Projection	4.36	4.85	5.10	5.52	5.78	6.13
2060 Projection	4.45	4.95	5.22	5.66	5.94	6.32
Columbia						
Historical	4.29	4.80	5.08	5.47	5.71	6.02
2035 Projection	4.40	4.94	5.23	5.66	5.93	6.29
2060 Projection	4.50	5.05	5.36	5.82	6.11	6.50

2.1.1 SLR Projections

Many scientific reports indicate that the North Carolina coast is vulnerable to impacts from SLR, with approximately 2,300 square miles of land below one meter in elevation, over 300 miles of beaches, and more than 4,600 miles of shoreline along sounds, coastal rivers and wetlands (RENCI, 2012). In addition to the current and projected climate impacts in Manteo and Columbia, North Carolina's population growth is estimated to increase by 14.8% between 2010 and 2020. Much of that growth will occur along coasts, leading to more densely populated shorelines (McGlade, et al., 2009). The combination of these factors illustrates the importance of looking at SLR projections during the CREAT analysis.

2.1.2 CREAT SLR Data

Using climate model data and simulation outputs from MAGICC / SCENGEN[4], CREAT provides information on a range of SLR projections in addition to other climate change data. More specifically, CREAT provides projections of sea level that is rising as a result of two processes: thermal expansion of the ocean and ice melt. The SLR curves in CREAT are based on model averages for global SLR with local scalar calculations. Locations, such as Manteo and Columbia, are found in 0.5-degree grid cells that also contain coastlines of tidally influenced water bodies including oceans, bays, estuaries and large river systems. Due to the influence of regional and local factors, such as subsidence, the local rate of SLR can be much greater or much less than the global average. To accommodate this, CREAT allows users to incorporate local subsidence rates obtained from outside sources, like observed tidal gauge data. For the purposes of this exercise, the workgroup input a subsidence value of 0.168 inches per year to represent the current rate of SLR at the Duck, NC tidal gage. This value is then applied to CREAT's regional projection to calculate future SLR that may be observed. While the local SLR data for Columbia is a few percentage points lower than that for Manteo, the difference in SLR projections is small

[3] Table 2 illustrates CREAT's 'warm and wet' scenario, providing CCSM model projections for intense precipitation data. CREAT users can also select 'hot and dry' and 'central' model projections to examine a range of future scenarios.

[4] Reference: http://www.cgd.ucar.edu/cas/wigley/magicc.

Figure 2 shows CREAT SLR curves using Manteo AP climate station data, with a one meter sea level rise scenario at 2100. Figure 3 shows the CREAT SLR curves using Manteo AP climate station data with an applied local subsidence value of 0.168 inches.

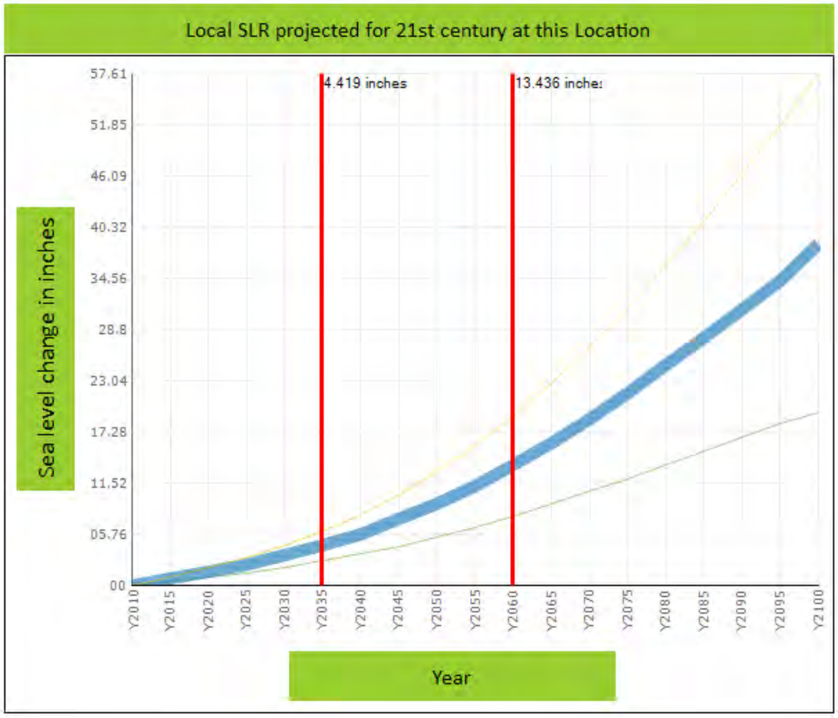

Figure 2. CREAT SLR Curves, Manteo

Figure 3. CREAT SLR Curves with Subsidence, Manteo

2.1.3 Data from the NC Science Panel

The NC Science Panel produced a report in 2010 assessing relevant peer-reviewed literature and reviewing available North Carolina SLR data. The report concluded that the most likely SLR scenario for 2100 is a rise of 15 to 55 inches (0.4m to 1.4m), with 39 inches (1m) recommended as the amount of anticipated rise for policy development and planning purposes. While the NC Science Panel has not formally endorsed SLR projections or planning recommendations before the year 2100, a relatively simple constant acceleration model was used to estimate SLR scenarios in 2035 and 2060. The constant acceleration model assumes that: tidal gage data from Duck, NC is used for initial velocity of rise; the rate of acceleration is assumed to be constant, and the SLR curve should not be extrapolated past 2100. As illustrated in Table 3, CREAT SLR rates and the SLR rates from the constant acceleration method are relatively similar, and these slight differences did not have an impact on the ultimate adaptation strategies recommended in this report. Table 3 illustrates CREAT SLR data with and without subsidence rates; along with SLR values calculated using the constant acceleration method.

Table 3. SLR Projections[5]

Data	Projected SLR at 2035 (inches)	Projected SLR at 2060 (inches)
CREAT	4.4	13.4
CREAT with subsidence	6.6	17.8
Constant acceleration method	6	16

Derived independently, the constant acceleration method provides an easily calculable check for the sophisticated SLR projections provided by CREAT. This method is not a mechanistic model of SLR. Rather, it is a kinematic equation that describes linear motion[6]. In a region where some citizens and officials are distrustful of complex modeling approaches, examination of this complementary approach may be warranted as a way to confirm the veracity of CREAT modeling outputs for skeptical participants. It may also provide a useful preliminary estimate for officials building support for a climate planning exercise such as that facilitated by CREAT. Table 4 provides a range of SLR estimates that were calculated using the constant acceleration method. The high, medium, and low scenarios in Table 4 describe varying degrees of SLR projected for 2100, with the one meter scenario recommended for planning purposes in North Carolina. Figure 4 provides a visual illustration of the SLR rates that were calculated using the constant acceleration method.

Table 4. SLR Rate in Manteo and Columbia Constant Acceleration Method

Scenario	2035	2060
High – 1.4m by 2100	7 inches	21 inches
Medium – 1m by 2100	6 inches	16 inches
Low – 0.4m by 2100	4 inches	9 inches

[5] Based on 1 meter SLR scenarios at 2100, which is the median scenario provided by CREAT and the one chosen for planning by town participants.

[6] The following equation was presented to the exercise workgroup to describe the SLR calculation used by the NC Science Panel: $D = V(T-2010) + 0.5A(T-2010)^2$, where D = distance (amount of SLR); V = velocity (rate of SLR); A= acceleration of SLR; and T = time (year of projection).

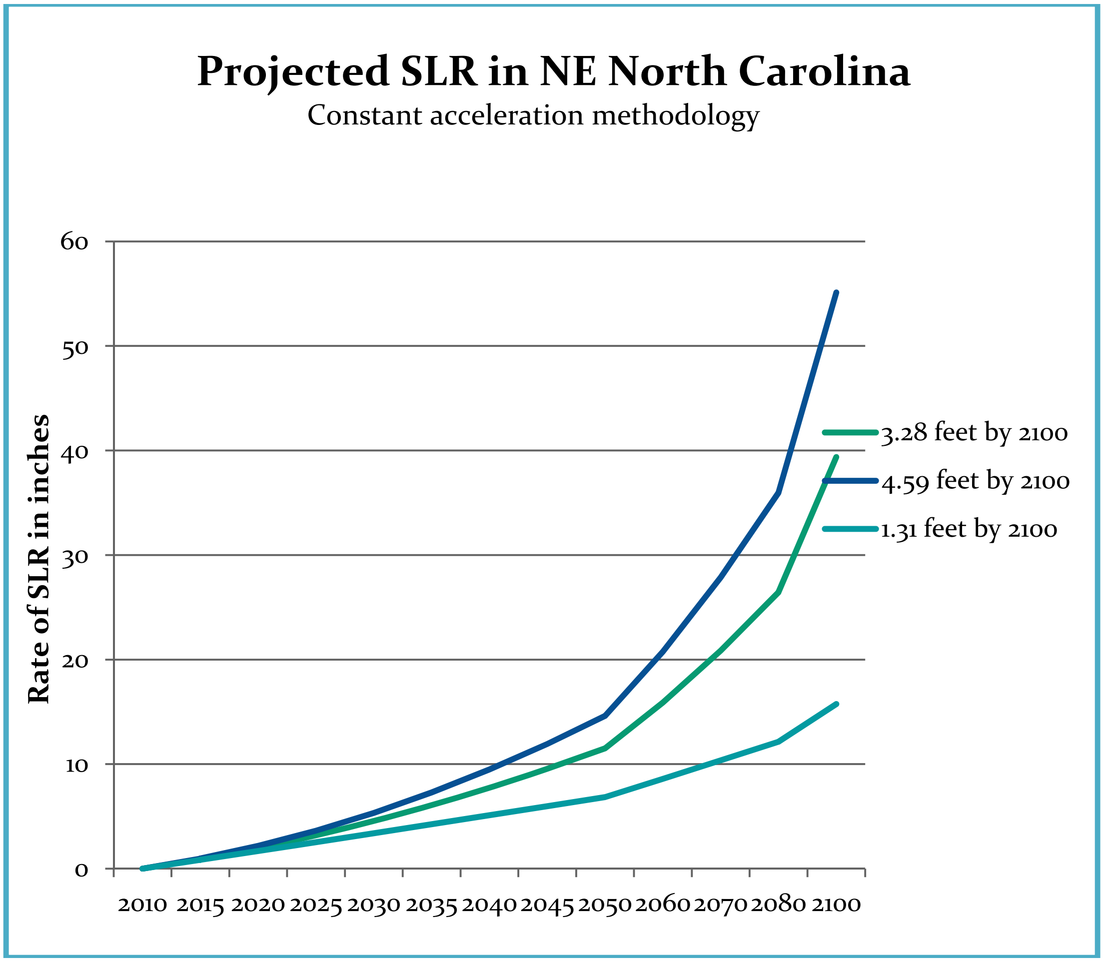

Figure 4. SLR Projections - NC Science Panel

2.1.4 SLR Mapping–NC Coastal Atlas Tool

During Meeting 3 of this exercise, the North Carolina Coastal Atlas Tool was demonstrated for participants. This tool is an interactive map that uses a compilation of SLR geospatial tools to provide users with an illustrative map of SLR and floodplain layers. While the tool may not be appropriate for site-specific analysis, it provides local insights on the geographical patterns and extent of SLR projections over time. The maps are primarily based on elevation data, with some refinements to better approximate rising water levels. Potential uses of this tool include: identifying changing land use patterns, siting infrastructure projects, and developing SLR adaptation strategies. The North Carolina Atlas Tool is currently in development, but the preliminary version can be found here: http://nccohaz.ecu.edu/flex/.

2.2 Scenario Planning, Time Periods, and Consequence Weighting

During CREAT's Setup step, users can select basic settings which include: scenario planning, time period selection, and consequence weighting. Each of these setup features is described below in more detail.

2.2.1 Scenario Planning

CREAT provides two options for assessing the likelihood of specific climate change threats. The scenario-based approach assumes that all specified threats will occur in the time periods considered. The assessing likelihood approach allows users to qualitatively assess the likelihood of threat occurrence as low, moderate, high, and very high. The workgroup selected the scenario-based approach as they did not have enough information to determine the specific timing or probable likelihood of threat occurrence. Because the specified threats are currently occurring to some degree in each town, this approach seemed appropriate.

2.2.2 Time Periods

A total of five time periods can be selected in a CREAT analysis. Users may choose time periods for a variety of reasons such as to coincide with existing time periods for asset management cycles, capital/infrastructure planning cycles, or projected timing of climate change impacts. For this exercise, the workgroup selected the time periods 2035 and 2060 to match the time periods of climate data provided. As previously mentioned, during the exercise, EPA was in the process of finalizing its update the CREAT software, and this exercise provided an opportunity to evaluate the data included in CREAT version 2.0. See Section 2.1 for further discussion on the data presented during this exercise.

2.2.3 Consequence Weighting

CREAT also allows users to evaluate consequences across five impact categories. The categories are provided to ensure that the analysis considers a range of impacts throughout the watershed due to climate change:

- Business Impacts
- Equipment/facility Impacts
- Source/receiving water Impacts
- Environmental Impacts
- Community Impacts

Users can choose one of two methods for combining the consequence assessments across categories. The highest level method assigns the highest level of consequence for any category as the overall consequence value. The weighted sum aggregates the categories based on relative weights. This method allows users to weigh some categories more heavily than others in order to reflect overall priorities. For example, Community Impacts may be weighted more highly than all other categories, while discounting Business Impacts.

Stakeholders chose to use the weighted sum method to aggregate the categories based on equal weights. During this exercise, weighting values of twenty percent were distributed evenly across the categories. Later in the CREAT process, workgroup members further examined these consequence evaluation categories as they relate to each asset-threat pair. For more complete definitions of the above categories, see Table 5.

Table 5. Consequence Evaluation Categories

Consequence Evaluation Categories	Definition
Business Impacts	Revenue or operating income loss evaluated in terms of the magnitude and recurrence of service interruptions.
Equipment/facility Impacts	Costs of replacing the service equivalent provided by a facility or piece of equipment evaluated in terms of the magnitude of damage and financial impacts.
Source/receiving water Impacts	Degradation or loss of source water or receiving water quality and/or quantity evaluated in terms of the recurrence.
Environmental Impacts	Evaluated in terms of environmental/ecosystem damage or loss and compliance with environmental regulations
Community/Public Health Impacts	Public health impacts evaluated in terms of the duration and extent.

2.3 Prioritizing Assets

CREAT users have an opportunity to analyze each vulnerable asset and climate-related threat at specific time periods. Within CREAT, users can select vulnerable assets from two categories: natural resources and infrastructure. For example, the Albemarle-Pamlico Estuary would be a "natural resource" asset, while WWTP infrastructure would be considered an "infrastructure" asset. Specific natural resource assets were not assessed during the Manteo and Columbia CREAT exercise. Rather, it was understood that impacts to the natural environment would be considered when evaluating consequences/risk to Environmental Impacts for each asset-threat pair.

During this exercise, a few participants mentioned that "receiving waters" were not listed as priority assets. While CREAT intends to examine concerns at the watershed level, participants decided to leave receiving waters off the prioritized assets lists for each town and consider receiving waters when evaluating consequences during the Baseline and Resilience Analyses. While there are a number of natural resource and infrastructure assets in Manteo and Columbia, the workgroup realized that they could not analyze all vulnerable assets throughout the watershed, and therefore would need to prioritize these assets.

2.4 Prioritizing Threats

Discussions about climate-related threats in each town revealed a variety of important considerations. Manteo and Columbia are impacted by similar climate-related threats. High flow situations from heavy precipitation events impact both towns currently and projections indicate that heavy precipitation events are estimated to increase in frequency and magnitude in the future (EPA, 2012). Manteo is directly impacted by coastal storm surge, while Columbia sees impacts to inland waters from coastal storm surge. Columbia is also experiencing saltwater intrusion in its aquifer. Furthermore, two of Columbia's three groundwater wells have flooded in the past, and the wastewater treatment plant has also experienced flooding. Columbia's drinking water treatment plant has not been impacted by past flooding, but recent flood waters came very close to the facility.

Manteo has three lift stations at sea level, which flood regularly during storm surge and high precipitation/high flow events. Manteo retrofitted those pump stations so that they are submersible, but they still may face impacts from future severe flooding and floating storm debris.

Threats related to climate change are considered in respect to the potentially impacted asset. Together, CREAT refers to this combination as a user's "asset-threat pair". For a complete list of prioritized asset-threat pairs in each town, see Table 6.

Table 6. Prioritized Assets and Threats at 2035 and 2060

Town	Asset	Threat
Manteo	Bowsertown Rd. Facilities (Structures- Buildings and SCADA)	Coastal Storm Surge
	Bowsertown Rd. Facilities (Structures- Buildings and SCADA)	High Flow/Heavy Precipitation Events
	WWTP Collection System (pumps, gravity sewers, and mains)	Coastal Storm Surge
	WWTP Collection System (pumps, gravity sewers, and mains)	High Flow/Heavy Precipitation Events
	Wastewater Treatment (MLSS/MLVSS and treatment equipment)	Coastal Storm Surge
	Wastewater Treatment (MLSS/MLVSS and treatment equipment)	High Flow/Heavy Precipitation Events
Columbia	Drinking Water Treatment Plant, Wells, and Equipment	High Flow/Heavy Precipitation Events
	Drinking Water Treatment Plant, Wells, and Equipment	Saltwater intrusion into aquifers
	Wastewater Collection System (pump stations, sewers and manholes)	High Flow/Heavy Precipitation Events
	Wastewater Treatment Plant	Effects from coastal storm surge on inland surface waters
	Wastewater Treatment Plant	High Flow/Heavy Precipitation Events

2.5 Existing Adaptive Measures

Each town provided input on existing adaptive measures. The measures listed in Table 7 are the existing adaptive measures for all asset-threat pairs at the 2035 and 2060 time periods identified by Manteo and Columbia. Adaptive measures do not necessarily need to involve infrastructure improvements. Adaptive measures can also include planning and/or operational actions. For example, Columbia recently created a town ordinance requiring that all new residential and commercial buildings be constructed two feet above base flood elevation.

Table 7. Existing Adaptive Measures in Manteo and Columbia

Columbia
Monitor sludge
Insurance adjusted to climate change
Emergency response plan – water supply
Backflow prevention
Infiltration reduction
Manteo
Optimized pumping
Supply-demand models
Water quality models
Sewer/collection models
Infrastructure inspection
Monitor treatment or system
Monitor pressure, structures, weather, temperature, runoff, water quality, sludge, treatment
Facility safety plan
Insurance adjusted to climate change
Emergency response plan – community, flooding, water supply
Partner with research community
Treatment alternatives
Community outreach
Rationing
Adaptive rates
Temporary flood barrier
Alternate water supply
Alternate wastewater/storm water capabilities
Back-up power
Interconnections
Backflow prevention
Sedimentation points
Altered treatment
Infiltration reduction
Wet repair
Leakage reduction
Silt removal
Sewage separation
Ecosystem for water quality
Ecosystem in greenhouse gas inventory
Wetlands for flood protection
Targets for land use change
Land acquisition
Building code changes
Green infrastructure at facility and Rainwater collection/use

2.6 Potential Adaptive Measures

With a better understanding of anticipated climate-related threats at 2035 and 2060, stakeholders discussed optimal climate change adaptation strategies to help adapt to projected climate change impacts. As part of the Resilience Analysis in CREAT, users select "potential" adaptive measures aimed at reducing asset vulnerabilities associated with the specified threats. During the CREAT exercise, workgroup participants identified potential adaptive measures that could be implemented at both time periods. A list of potential adaptive measures for each town is included in Table 8. Further discussion of potential adaptive measures is warranted, as stakeholders recognized that each measure has varying costs and benefits associated with implementation. Potential adaptive measures are discussed in more detail later in this report.

Table 8. Potential Adaptive Measures Selected during the CREAT Exercise

Manteo	Columbia
Increased capacity- wastewater & stormwater	Increased raw storage
Effluent re-use studies	Alternate water sources
Decision making to incorporate uncertainty	Optimized pumping
Performance models	Green infrastructure at facility
Biosolids management	Green infrastructure in community
Flood risk management	Facility safety plan
Sludge management	Partner with research community
Climate training for personnel	Infiltration reduction (potential)
Sanitary sewer overflow strategies	Collaborate with stakeholders
Effluent re-use	Sea walls and/or levees
Collaborate with stakeholders	Submersible pumps (new assets)
Sea walls and/or levees	Elevate vulnerable assets
Submersible pumps (new assets)	
Elevate vulnerable assets	

2.7 Baseline and Resilience Analysis Discussion

CREAT's Baseline Analysis establishes a benchmark for the level of risk that threats associated with climate change may pose to utility assets. The results of the Baseline Analysis include the examination of climate change threats with existing adaptive measures and describe the current risks to assets due to the occurrence of future climate-related threats. After performing a Baseline Analysis, CREAT users define and select potential adaptive measures to lower risk posed to assets. Similar to the Baseline Analysis, the Resilience Analysis involves a specific series of steps including: 1) selecting potential adaptive measures; 2) re-assessing consequences; 3) assigning contribution to each adaptive measure; and 4) reviewing analysis results. For Manteo and Columbia, the Resilience Analysis builds on the Baseline Analysis by examining the same asset-threat pairs while considering new, potential adaptive measures that can be implemented at 2035 and 2060.

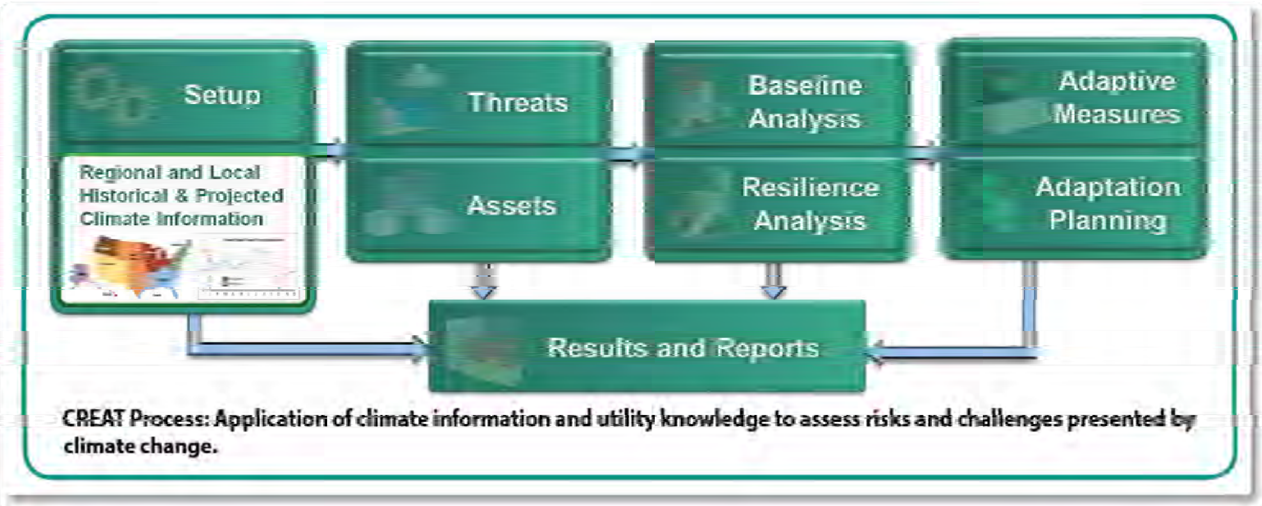

Figure 5. CREAT Process

2.7.1 Re-assessing Consequences

As with the Baseline Analysis, consequence levels must be selected in each of the five consequence categories for each asset-threat pair during the Resilience Analysis. As an example, Figure 6 illustrates a description of the consequence levels for the Environmental Impact category. CREAT users select consequence levels of Very High, High, Medium, or Low. The change in consequence level between the Baseline and Resilience Analyses, following the implementation of potential adaptive measures, contributes to the relative change in risk reduction provided for each asset-threat pair.

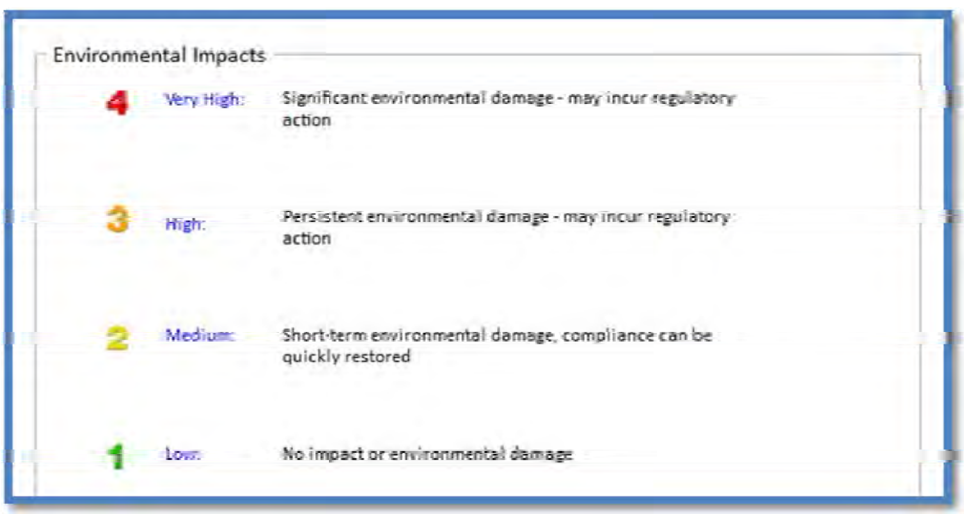

Figure 6. Consequence Levels for Environmental Impacts

2.7.2 Adaptive Measure Contribution

As part of the Resilience Analysis in CREAT, users select potential adaptive measures aimed at further reducing vulnerabilities from specified threats. The next step is to identify the risk reduction contribution for each potential adaptive measure and asset-threat pair. For example, Manteo identified increased treatment capacity for stormwater and wastewater and biosolids management as potential adaptive measures. These measures could significantly contribute to risk reduction associated with coastal storm surge and high precipitation events/high flow impacting Manteo's WWTP. An adaptive measure contribution value of 20 percent was assigned to increased stormwater and wastewater capacity and 10 percent was assigned to the implementation of biosolids management for this asset-threat pair. The adaptive measure contribution inputs were discussed among workgroup members, and these inputs can be revised in each town's analysis file in the future. For more information about the specific adaptive measure contribution values assigned by workgroup members, see Appendix C.

2.7.3 Examining Risk Reduction – Resilience Analysis

CREAT provides a way to compare current and future risk as it relates to threats posed by a changing climate. Building resilience to climate-related threats by considering and deciding to implement adaptive measures facilitates the decision making process. In CREAT, the reduction of risk can be visualized in a risk matrix (Figure 7), where each asset-threat pair analysis falls into a specific combination of likelihood of threat occurrence and level of consequence. This matrix considers both the user-defined reduction in consequence levels from the Baseline to Resilience Analysis and the attribution percentage value given to each selected potential adaptive measure. Risk matrices in Figure 7 also show the number of asset-threat pairs for each likelihood-consequence combination for all Baseline (top row) and Resilience (bottom row) analyses. For example, in Manteo's CREAT analysis six asset-threat pairs have a very high likelihood of occurrence, but their consequence level is reduced to medium during the Resilience Analysis after considering implementation of potential adaptive measures.

Manteo **Columbia**

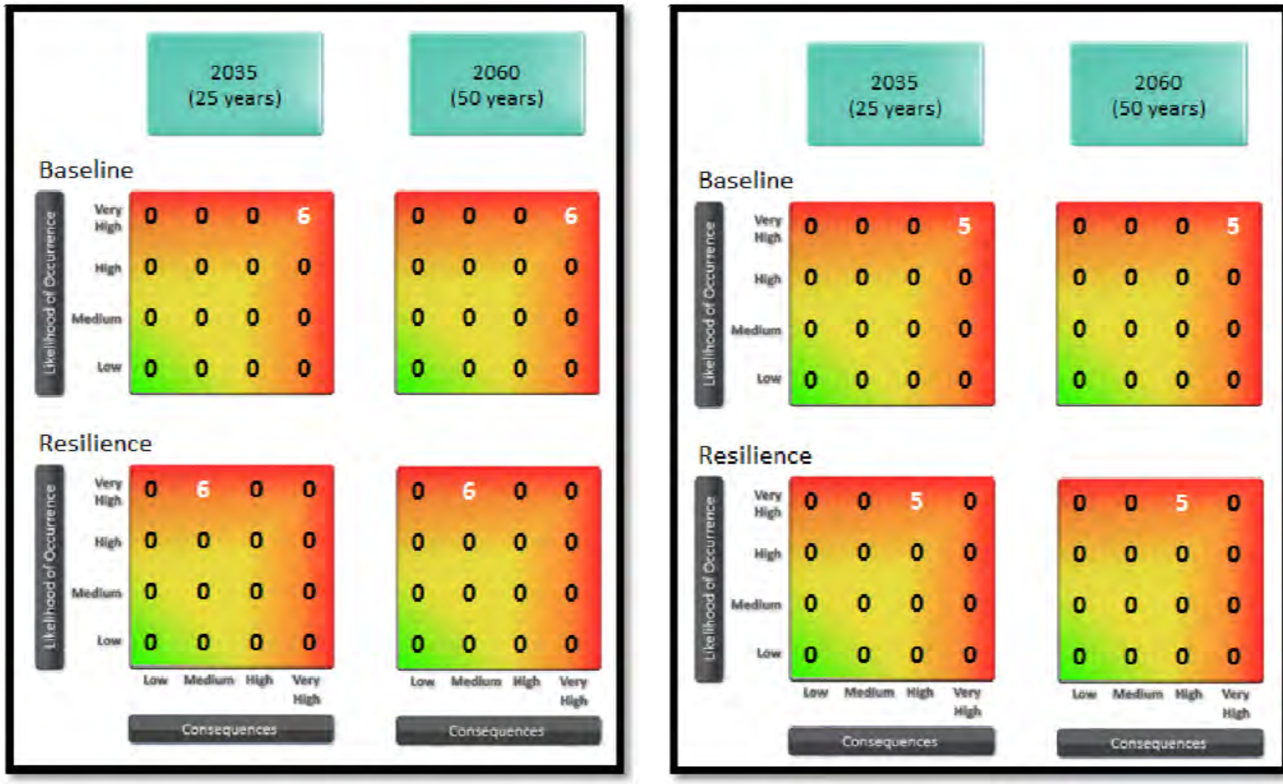

Figure 7. Risk Reduction Matrices for Manteo and Columbia

2.8 Implementation Planning – Adaptation Packages for Manteo and Columbia

Selecting potential adaptive measures in CREAT does not imply that these measures will resolve all impacts related to climate change in Manteo and Columbia. Rather, CREAT offers a comparative framework to analyze the risk reduction of consequences associated with existing and potential adaptive measures. During CREAT's Implementation Planning step, users can build adaptation packages, which include adaptive measures and user-defined estimated costs for each package. Example adaptation packages were developed for each town to illustrate which adaptive measures, if implemented, could potentially offer the highest level of risk reduction from specified climate change threats. These packages allow users to create reports and compare risk reduction units (RRUs) and estimated costs associated with the implementation of selected adaptive measures. RRUs within CREAT provide a metric for users to compare packages. The change in consequence level from the Baseline Analysis to the Resilience Analysis is used to calculate RRUs for each asset-threat-time period combination. For example, if the consequences for an asset paired with a high likelihood threat changes from Very High (Baseline) to Medium (Resilience), then the RRUs are calculated as 100 – 60 = 40 RRUs (circled locations in Figure 8).

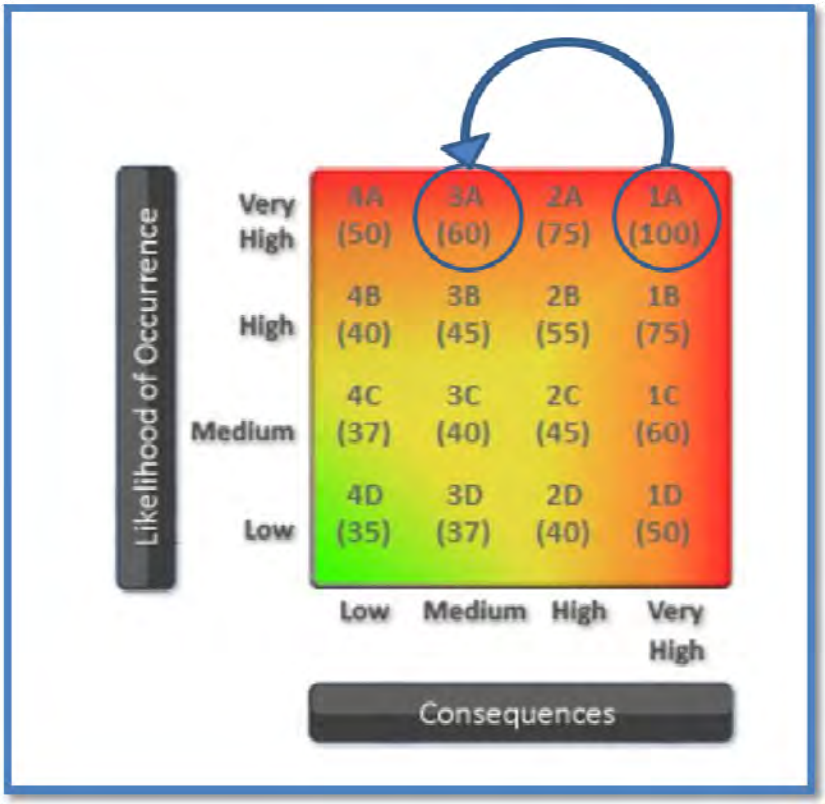

Figure 8. Matrix Used to Calculate Risk Reduction Units (RRUs)

Adaptation packages were assembled for both Manteo and Columbia. In both towns, the first package was assembled based on the potential for the greatest amount of risk reduction utilizing all selected potential adaptive measures. In Manteo's CREAT file, two additional packages were assembled and include: 1) an increase in WWTP capacity, and 2) infrastructure improvements related to flooding. For Columbia, three additional adaptation packages were assembled to adapt to various threats. These three packages include: 1) green infrastructure and sludge and biosolids management, 2) infrastructure improvements related to flooding, and 3) saltwater intrusion adaptive measures.

Table 9 provides an example adaptation package for Manteo, illustrating the RRUs associated with each adaptive measure at 2035 and 2060. The RRUs are the same at each time period (104), assuming that each potential adaptive measure will be implemented at both 2035 and 2060. CREAT calculates RRUs for asset-threat pairs by taking the value of reduction in consequences (Figure 8) combined with the individual adaptive measure contribution percentage. CREAT users can compare total RRUs for each adaptation package to support the implementation of specific adaptation packages during decision making processes.

Table 9. Example Adaptation Package for Manteo – "Increased WWTP Capacity"

Potential Adaptive Measures Included	RRUs at 2035	RRUs at 2060	Total Package RRUs
Collaborate with stakeholders	16	16	32
Biosolids management	20	20	40
Submersible Pumps (new assets)	8	8	16
Increased capacity – wastewater/stormwater	48	48	96
Decision-making frameworks that incorporate uncertainty	12	12	24
Total Package RRUs	**104**	**104**	**208**

In addition to evaluating potential risk reduction associated with each adaptive measure, users can compare costs. Estimated cost inputs are completely user-driven. Example cost estimate inputs were included for select adaptive measures in both towns' CREAT files. These cost estimates are meant to be illustrative and do not represent the actual costs for the selected adaptive measures. If more robust cost estimates are developed, town stakeholders can assemble a more complete adaptation package that illustrates costs related to implementing adaptive measures in comparison with the risk reduction associated with those measures.

2.9 Results and Reports

The Results & Reports feature in CREAT includes a variety of ways to visually illustrate relative risk reduction after considering the implementation of potential adaptive measures. This risk reduction can be seen in the bar graphs on the Results Summary tab, as illustrated in Figure 9.

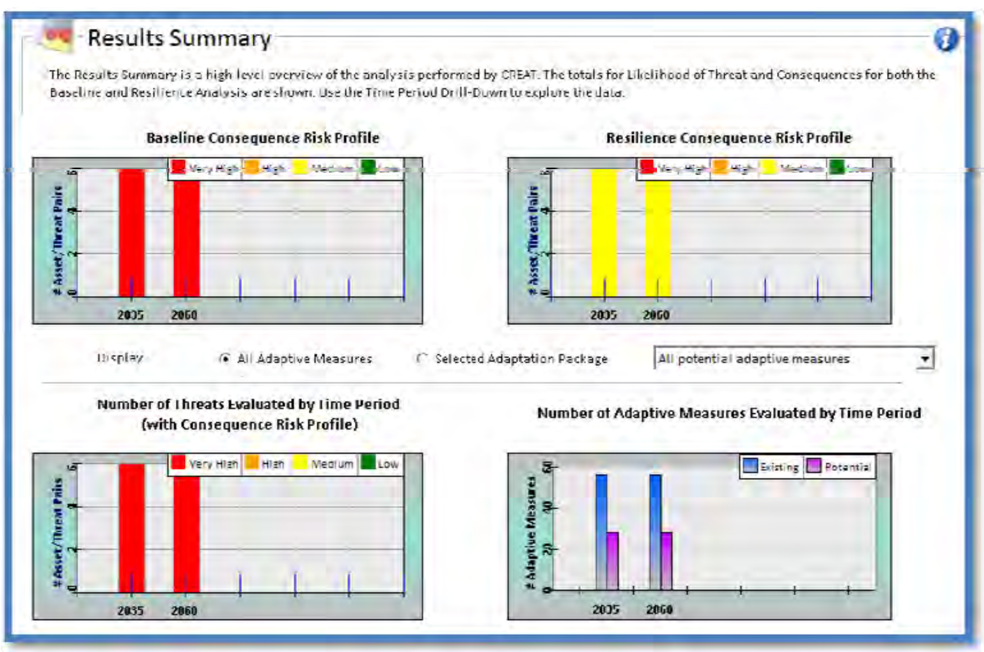

Figure 9. Example Results Summary Tab

Risk matrices are also displayed in CREAT's Results and Reports step. CREAT assesses risk based on the likelihood of occurrence and overall reduction in consequences. Figure 7 depicts these matrices and shows each town's total asset-threat pairs, six and five, for Manteo and Columbia respectively. This figure also illustrates the likelihood-consequence combination for all Baseline (top boxes) and Resilience (bottom boxes) Analyses at the 2035 and 2060 time periods. As previously mentioned, the "scenario-based" approach was selected during the setup step. This approach assumes a very high likelihood of occurrence for all asset-threat pairs. This concept is illustrated in Figure 7, as all asset-threat pairs remain in the top row. The implementation of potential adaptive measures during the Resilience Analysis can lower the consequences for each asset-threat pair. This concept is illustrated in Figure 7, as the asset-threat pairs move left from the Very High column into the Medium column for Manteo, and into the High column for Columbia to indicate lower consequences.

3. Conclusion

This exercise in North Carolina was an important step to determine how CREAT can best provide a useful risk assessment framework and planning tool for stakeholders in small communities. It also served as an important demonstration of how CREAT can be used in areas that are vulnerable to extreme weather and SLR.

3.1 Future Use of CREAT in Manteo, Columbia, and other North Carolina Communities

Manteo and Columbia will each receive a final CREAT analysis file to modify as new information and data become available. These files will be compatible with CREAT version 2.0 and can be edited in the future. Risk assessment involves a continuous cycle of review which may include examining vulnerable assets, projected climate change threats and adaptive measures to ensure adequate protection of the towns' natural resources and built infrastructure from future climate change impacts.

Town stakeholders noted that the CREAT exercise process was valuable, especially for gaining a better understanding of climate change threats, vulnerable assets and potential adaptive measures. In addition to the CREAT exercise in Manteo and Columbia, APNEP may continue working with CREAT in communities throughout North Carolina. Participants suggested that EPA could consider focusing outreach efforts for CREAT 2.0 on regional planning organizations, noting that towns like Manteo and Columbia already work with regional planning organizations for trainings and workshops. This approach may be helpful to promote the use of CREAT within these existing planning networks.

3.2 Additional Feedback from Participants and Next Steps

In addition to the formal discussions, this planning exercise spawned numerous discussions among participants that also helped to shape possible future asset management, capital improvement, and master plans for the implementation of potential adaptive measures in Manteo and Columbia. Participants mentioned that including the CREAT Analysis results as part of their capital improvement plans would be a useful way to incorporate the results from the exercise. Columbia is currently in the process of revising their capital improvement plan and will consider the discussions and results from the CREAT exercise as they plan for impacts from climate change. Participants also stated that documenting the CREAT risk assessment process in Manteo and Columbia was helpful as this documentation could be included on various grant applications, such as the North Carolina Clean Water Management Fund to potentially finance new adaptive measures. Demonstrating that the towns have already begun to assess their climate change vulnerabilities through a formal planning process such as the CREAT exercise may also increase their chances of receiving future grants.

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Appendix A

EPA CREAT Exercise for Manteo and Columbia, North Carolina

Participants List

EPA
Curt Baranowski, Office of Water, Climate Ready Water Utilities (CRWU)
John Whitler, CRWU

EPA Oak Ridge Institute for Science and Education (ORISE) Fellows
Laura Dubin
Amy Posner

Albemarle-Pamlico National Estuary Program (APNEP)
Jim Hawhee

Town of Manteo
Josh O'Brien
Kermit Skinner

Town of Columbia
Rhett White

EPA Contractors
Kathleen McAllister, Horsley Witten Group, Inc. (HW)
Tom Noble, HW

This list above includes individuals that participated in the project at various times from May-September 2012.

Appendix B

Baseline Analysis

Manteo's Consequence Weighting Inputs for Each Asset-Threat Pair at 2035 and 2060

Manteo's Asset –Threat Pairs	**Utility-Business Impact**	**Equipment/ Facility Impact**	**Source/ Receiving Water Impact**	**Environmental Impact**	**Community Impact**
Coastal Storm Surge - Bowsertown Rd. Facilities at 2035	Very High	Very High	High	High	High
Coastal Storm Surge - Bowsertown Rd. Facilities at 2060	Very High	Very High	Very High	Very High	Very High
High Flow/Heavy Precipitation Events - Bowsertown Rd. Facilities at 2035	Very High	Very High	High	High	High
High Flow/Heavy Precipitation Events - Bowsertown Rd. Facilities at 2060	Very High	Very High	Very High	Very High	Very High
Coastal Storm Surge - WWTP Collection System at 2035	Very High	Very High	High	High	High
Coastal Storm Surge - WWTP Collection System at 2060	Very High	Very High	Very High	Very High	Very High
High Flow/Heavy Precipitation Events - WWTP Collection System at 2035	Very High	Very High	High	High	High
High Flow/Heavy Precipitation Events - WWTP Collection System at 2060	Very High	Very High	Very High	Very High	Very High
Coastal Storm Surge - Wastewater Treatment ("Bugs", lagoons, etc.) at 2035	Very High	Very High	Medium	Medium	Medium
Coastal Storm Surge - Wastewater Treatment ("Bugs", lagoons, etc.) at 2060	Very High	Very High	High	High	High
High Flow/Heavy Precipitation Events - Wastewater Treatment ("Bugs", lagoons, etc.) at 2035	Very High	Very High	Medium	Medium	Medium
High Flow/Heavy Precipitation Events - Wastewater Treatment ("Bugs", lagoons, etc.) at 2060	Very High	Very High	High	High	High

Appendix B

Reslience Analysis

Manteo’s Consequence Weighting Inputs for Each Asset-Threat Pair at 2035 and 2060

Manteo’s Asset –Threat Pairs	Utility-Business Impact	Equipment/Facility Impact	Source/ Receiving Water Impact	Environmental Impact	Community Impact
Coastal Storm Surge - Bowsertown Rd. Facilities at 2035	Medium	Medium	Medium	Medium	Medium
Coastal Storm Surge - Bowsertown Rd. Facilities at 2060	Medium	Medium	Medium	Medium	Medium
High Flow/Heavy Precipitation Events - Bowsertown Rd. Facilities at 2035	Medium	Medium	Medium	Medium	Medium
High Flow/Heavy Precipitation Events - Bowsertown Rd. Facilities at 2060	Medium	Medium	Medium	Medium	Medium
Coastal Storm Surge - WWTP Collection System at 2035	Medium	Medium	Medium	Medium	Medium
Coastal Storm Surge - WWTP Collection System at 2060	Medium	Medium	Medium	Medium	Medium
High Flow/Heavy Precipitation Events - WWTP Collection System at 2035	Medium	Medium	Medium	Medium	Medium
High Flow/Heavy Precipitation Events - WWTP Collection System at 2060	Medium	Medium	Medium	Medium	Medium
Coastal Storm Surge - Wastewater Treatment (“Bugs”, lagoons, etc.) at 2035	Medium	Medium	Medium	Medium	Medium
Coastal Storm Surge - Wastewater Treatment (“Bugs”, lagoons, etc.) at 2060	Medium	Medium	Medium	Medium	Medium
High Flow/Heavy Precipitation Events - Wastewater Treatment (“Bugs”, lagoons, etc.) at 2035	Medium	Medium	Medium	Medium	Medium
High Flow/Heavy Precipitation Events - Wastewater Treatment (“Bugs”, lagoons, etc.) at 2060	Medium	Medium	Medium	Medium	Medium

Appendix B

Baseline Analysis

Columbia's Consequence Weighting Inputs for Each Asset-Threat Pair at 2035 and 2060

Columbia's Asset –Threat Pairs	Utility-Business Impact	Equipment/ Facility Impact	Source/ Receiving Water Impact	Environmental Impact	Community Impact
Saltwater Intrusion – DWTP Facility and Equipment at 2035	Very High	Very High	Medium	Medium	Medium
Saltwater Intrusion – DWTP Facility and Equipment at 2060	Very High	Very High	High	High	High
Coastal Storm Surge (on inland waters) – WWTP at 2035	Very High	Very High	High	High	High
Coastal Storm Surge (on inland waters) – WWTP at 2060	Very High	Very High	Very High	Very High	Very High
High Flow/Heavy Precipitation Events – WWTP at 2035	Very High	Very High	High	High	High
High Flow/Heavy Precipitation Events – WWTP at 2060	Very High	Very High	Very High	Very High	Very High
High Flow/Heavy Precipitation Events – WW Collection System at 2035	Very High	Very High	High	High	High
High Flow/Heavy Precipitation Events – WW Collection System at 2060	Very High	Very High	Very High	Very High	Very High
High Flow/Heavy Precipitation Events – DWTP Facility and Equipment at 2035	Very High	Very High	Medium	Medium	Medium
High Flow/Heavy Precipitation Events – DWTP Facility and Equipment at 2060	Very High	Very High	High	High	High

Resilience Analysis

Columbia's Consequence Weighting Inputs for Each Asset-Threat Pair at 2035 and 2060

Columbia's Asset –Threat Pairs	Utility-Business Impact	Equipment/ Facility Impact	Source/ Receiving Water Impact	Environmental Impact	Community Impact
Saltwater Intrusion – DWTP Facility and Equipment at 2035	High	High	Low	Low	Low
Saltwater Intrusion – DWTP Facility and Equipment at 2060	High	High	Low	Low	Low
Coastal Storm Surge (on inland waters) – WWTP at 2035	High	High	Medium	Medium	Medium
Coastal Storm Surge (on inland waters) – WWTP at 2060	High	High	High	High	High
High Flow/Heavy Precipitation Events – WWTP at 2035	High	High	Medium	Medium	Medium
High Flow/Heavy Precipitation Events – WWTP at 2060	High	High	High	High	High
High Flow/Heavy Precipitation Events – WW Collection System at 2035	High	High	Low	Low	Low
High Flow/Heavy Precipitation Events – WW Collection System at 2060	High	High	Low	Low	Low
High Flow/Heavy Precipitation Events – DWTP Facility and Equipment at 2035	High	High	Low	Low	Low
High Flow/Heavy Precipitation Events – DWTP Facility and Equipment at 2060	High	High	Medium	Medium	Medium

Appendix C

Asset –Threat Pairs	Increased Capacity - WW and Stormwater (%)	Effluent Re-use studies (%)	Decision-Making to Incorporate Uncertainty (%)	Performance Models (%)	Biosolids mgmt (%)	Flood risk mgmt (%)	Sludge mgmt (%)	Climate training for personnel (%)	SSO Strategies (%)	Effluent re-use (%)	Collaborate with Stakeholders (%)	Sea Walls and/or Levees	Submersible Pumps (new assets)	Elevate vulnerable assets	Total Contribution (%)
Bowsertown Rd. Facilities (Structures- Buildings and SCADA)															
Coastal Storm Surge at 2035	20	10	5	5	10	5	5	5	10	10	10	5			100
Coastal Storm Surge at 2060	20	10	5	5	10	5	5	5	10	10	10	5			100
High Flow/ Heavy Precipitation Events at 2035	20	10	5	5	10	5	5	5	10	10	10	5			100
High Flow/ Heavy Precipitation Events at 2060	20	10	5	5	10	5	5	5	10	10	10	5			100
WWTP Collection System (pumps, gravity sewers, and mains)															
Coastal Storm Surge at 2035	20	10	5	5	5	5	5	5	10	10	5		10	5	100
Coastal Storm Surge at 2060	20	10	5	5	5	5	5	5	10	10	5		10	5	100
High Flow/ Heavy Precipitation Events at 2035	20	10	5	5	5	5	5	5	10	10	5		10	5	100
High Flow/ Heavy Precipitation Events at 2060	20	10	5	5	5	5	5	5	10	10	5		10	5	100
Wastewater Treatment (MLSS/MLVSS and treatment equipment)															
Coastal Storm Surge at 2035	20	10	5	5	10	5	5	0	10	10	5	10		5	100
Coastal Storm Surge at 2060	20	10	5	5	10	5	5	0	10	10	5	10		5	100
High Flow/ Heavy Precipitation Events at 2035	20	10	5	5	10	5	5	0	10	10	5	10		5	100
High Flow/ Heavy Precipitation Events at 2060	20	10	5	5	10	5	5	0	10	10	5	10		5	100

Appendix C

Asset –Threat Pairs	Increased raw storage (%)	Alternate water sources (%)	Optimized pumping (%)	Green infrastructure at facility (%)	Green infrastructure in community (%)	Facility safety plan (%)	Partner with research community (%)	Infiltration reduction (potential) (%)	Collaborate with Stakeholders (%)	Sea Walls and/or Levees (%)	Submersible Pumps (new assets) (%)	Elevate vulnerable assets (%)	Total contribution (%)
Drinking Water Treatment Plant, Wells, and Equipment													
High flow events at 2035	10	10	10	5	0	10	5	10	10	10		20	**100**
High flow events at 2060	10	10	10	5	0	10	5	10	10	10		20	**100**

	Increased raw storage	Alternate water sources	Optimized pumping	Green infrastructure in community	Rainwater collection/use	Partner with research community	Collaborate with Stakeholders	Total contribution (%)
Saltwater intrusion into aquifers at 2035	20	30	0	10	20	10	10	**100**
Saltwater intrusion into aquifers at 2060	20	30	0	10	20	10	10	**100**

Wastewater Collection System (pump stations, sewers and manholes)	Biosolids mgmt	Facility safety plan	Sludge mgmt	Partner with research community	Backflow prevention (potential)	Infiltration reduction (potential)	Collaborate with Stakeholders	Sea Walls and/or Levees	Submersible Pumps (new assets)	Elevate vulnerable assets	Total contribution (%)
High flow events at 2035	5	5	5	5	20	20	10	10	10	10	**100**
High flow events at 2060	5	5	5	5	20	20	10	10	10	10	**100**

Wastewater Treatment Plant	Green infrastructure at facility	Green infrastructure in community	Biosolids mgmt	Facility safety plan	Sludge mgmt	Partner with research community	Backflow prevention (potential)	Infiltration reduction (potential)	Collaborate with Stakeholders	Sea Walls and/or Levees	Total contribution (%)
Effects from coastal storm surge on inland surface waters at 2035	5	5	10	10	10	10	10	10	10	20	**100**
Effects from coastal storm surge on inland surface waters at 2060	5	5	10	10	10	10	10	10	10	20	**100**

	Optimized Pumping	Green infrastructure at facility	Green infrastructure in community	Biosolids mgmt	Facility safety plan	Sludge mgmt	Partner with research community	Backflow prevention (potential)	Infiltration reduction (potential)	Collaborate with Stakeholders	Sea Walls and/or Levees	Total contribution (%)
High flow events at 2035	5	5	5	5	5	10	5	10	10	10	30	**100**
High flow events at 2060	5	5	5	5	5	10	5	10	10	10	30	**100**