
Final Report

Community Resilience Pilot Project Wilmington, North Carolina

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CH2MHILL®

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Executive Summary

Coastal communities face an increasing degree of uncertainty related to the impacts future climatic conditions may have on their areas. Increases in long-term air temperatures may result in higher sea levels; storm surges that occur during extreme events may have even greater impacts when combined with increasing surface water elevations due to sea level rise (SLR). The uncertainty surrounding changes in climate and sea level requires an approach that identifies and implements adaptation strategies to reduce a community's risk related to changes in sea level and extreme storm events. The U.S. Environmental Protection Agency (USEPA) has set long-term goals to support national efforts to prepare for and build resilience to climate change, including SLR¹.

The potential impacts of SLR will be highly dependent on uncertain probabilities of occurrence and amplitude of sea level change. The level of impact from SLR will not only depend on the uncertain future of SLR but also the vulnerability of the community exposed to the changes. A wide range of public and private property (homes, businesses, roads, water and wastewater infrastructure, and schools) has the potential to be impacted by SLR. This pilot project focuses on water and wastewater infrastructure within the broader planning context related to SLR. Potential impacts on water and wastewater infrastructure related to SLR include the following:

- Structural damage to infrastructure due to inundation and wave action
- Failure of treatment plant components and pump stations due to flooding of electrical controls and/or ancillary equipment
- Decay of infrastructure not designed for saltwater exposure
- Increase of inflow of seawater to sewer pipelines resulting in:
 - Disturbance of wastewater treatment plant processes
 - Changes in system hydraulics
 - Increased operation and maintenance requirements
 - Water quality standard compliance issues
 - More frequent combined sewer overflows (CSOs) or sanitary sewer overflows (SSOs)
- Saltwater migration further inland into aquifers and freshwater estuaries used for water supply

In understanding the potential influence future SLR may have on its area, the City of Wilmington, North Carolina, in partnership with New Hanover County and the Cape Fear Public Utility Authority (CFPUA), requested assistance from USEPA's Office of Sustainable Communities to help identify adaptation strategies that could help to reduce the vulnerability of water and wastewater infrastructure to potential SLR and more intense storms. Adaptation (strategies) in the context of planning for future SLR involves planners adjusting existing programs and policies to minimize the impact of future changes and considering new options that can be flexibly implemented as more information on SLR trends are acquired.

The City of Wilmington, New Hanover County, CFPUA, and USEPA should be applauded for their partnership and work on this project to proactively take on a key public health and safety issue; in addition, the willingness of all partners to discuss long-term strategies, even though there are meaningful uncertainties with current SLR estimates and limited short-term capital funds to spend on adaptation strategies for long-term potential impacts. In regards to the expenditure of capital funds, it is important to note that this pilot project is intended to assess vulnerabilities and identify adaptation strategies that will reduce risk and improve community resilience. The outcome of this project is not intended to direct or require local actions that are in conflict with any existing local regulations or state laws nor is it intended to imply or direct CFPUA to move or relocate any existing infrastructure or otherwise impact the current capital improvement program (CIP). Monitoring of SLR, revisiting the assessments provided in this report, and re-assessing the identified adaptation strategies will be important to inform each organization's decisions regarding to future actions to adapt to changes in SLR, as needed.

¹ USEPA. 2012. *National Water Program 2012 Strategy: Response to Climate Change*. 132pp.

There were two primary steps completed as part of this pilot project, a vulnerability assessment and the identification of adaptation strategies. The vulnerability assessment focused on the direct physical effects of SLR and storm surge to CFPUA's water and wastewater system infrastructure, for the planning period of 2012 through 2100, and included the determination of the potential for major assets (treatment facilities, pump stations, pipelines, manholes, and water supply wells) to be impacted by SLR and the consequence of the impact. Two SLR scenarios were evaluated as part of the vulnerability assessment:

- Historical SLR Trend: continuation of historical SLR rate (40-centimeter [cm; 1.3-foot] by 2100)
 - Historical rate as identified by the North Carolina Coastal Resource Commission (CRC) Science Panel on Coastal Hazard²
- Precautionary SLR Trend: precautionary rate of SLR scenario (100-cm [3.3-foot] by 2100).
 - Rate of SLR higher than historical rates as determined by the North Carolina CRC Science Panel on Coastal Hazard²

Three inundation events were reviewed for each SLR scenario: mean higher high water (MHHW) line and two storm events (10-year and 100-year) to assess the inundation extent and depth for each SLR scenario. The inundation depths and extents for each SLR scenario used in the vulnerability assessment were based on the data developed for the North Carolina Division of Emergency Management's (NCDEM's) North Carolina Sea Level Rise Impact Study (NCSLRIS), funded by the Federal Emergency Management Administration (FEMA) and currently underway. The results of the vulnerability assessment identified a number of areas within New Hanover County and CFPUA's infrastructure that has the potential to be vulnerable to the impact of SLR under both scenarios. The primary concerns (risks) identified included the following:

- Flooding of treatment facilities (particularly, the Southside wastewater treatment plant)
- Flooding of pump stations
- Inundation of manholes causing increased inflow to the collection system

The effectiveness of adaptation strategy planning to reduce risks to SLR is highly dependent on access to high-quality information about SLR and associated risks. This pilot project has benefitted significantly from two previous efforts that informed the vulnerability assessment—one being NCDEM's effort on the NCSLRIS and modeling work completed for that project to define inundation extents and depth for a number of SLR scenarios. In addition, CFPUA's asset management programs effort to spatially identify assets throughout the service area and define consequence of failure of individual assets. The information combined on the two efforts provided for a robust analysis of SLR risks for CFPUA's water and wastewater infrastructure. This type of data is essential to provide decision makers the ability to make data-driven decisions on the SLR scenarios reviewed and potential adaptation strategies.

The vulnerability assessment was intended to identify the potential impact from SLR to existing CFPUA infrastructure; the identified vulnerabilities guided the selection of adaptation strategies to increase resilience directly related to these assets. An important consideration, especially for the long-duration of the planning period this project covers, through 2100, are strategies to minimize the potential risk related to SLR for future infrastructure as CFPUA expands its services into new areas. The reduction of risk (SLR effects on existing infrastructure) will primarily be derived from infrastructure/asset specific strategies. Future infrastructure will benefit from these strategies as well, but the greatest risk reduction potential will be from land use planning and policies that guide future development away from areas that are potentially vulnerable to SLR.

A suite of 54 adaptation strategies were identified for the City of Wilmington, New Hanover County, and CFPUA to select from to provide a range of strategies that can be employed to increase resilience knowing that each organization has its own unique operating and political contexts. Each organization will choose how it will adapt

² North Carolina Coastal Resources Commission's Science Panel on Coastal Hazard. 2010. *North Carolina Sea-Level Rise Assessment Report*. Raleigh, N.C.

to the potential changes it faces from SLR based on its individual needs, governance, and authority; this report is intended to be a guide for each organization and does not represent any obligation for implementation.

The identified adaptation strategies included the following categories:

- Infrastructure Strategies—Strategies that are focused on the reduction of risks related to SLR for existing and future water and wastewater assets
- Land Use and Planning Strategies—This strategy grouping included two sub-types:
 - Planning efforts or studies to help guide and inform the decisions related to future land use, capital project implementation and the adaptation to SLR
 - Regulatory/Incentive tools that can be used to guide development in the future to minimize risks related to SLR

This pilot project (1) identified potential risks to the water and wastewater infrastructure in the City of Wilmington and New Hanover County, and (2) provided potential adaptation measures to reduce the risks to these existing assets and future service areas. Throughout the course of this pilot project, a number of key process take-aways were identified that will provide valuable insights for other communities considering an adaptive planning effort for potential SLR impacts on their water and/or wastewater system. The take-aways include the following:

- There must be a clear understanding of the goals and objectives of the planning effort, as well as a plan for dealing explicitly with uncertainty.
 - Clearly stated project objectives will ensure the planning effort is answering the right questions.
 - Uncertainty for this pilot project was handled by the use of a scenario based vulnerability assessment. There was a consistent understanding of the uncertainties related to SLR and the scenarios were selected to provide an indication of the potential range of impacts from SLR, without an explicit determination of likelihood of one scenario over the other.
- A collaborative, stakeholder involvement process is essential.
 - Assessing the implication of SLR touches a wide variety of subject matters: engineering, land use planning, finance, emergency response, governance, and legal. All of this expertise rarely resides in one individual department or within an organization. In the case of this pilot project, this expertise was spread across three different organizations.
 - The input of different perspectives from all stakeholders provides for a valuable opportunity to identify a range of potential solutions, rather than just a singularly focused set of solutions (for instance, engineered infrastructure-specific solutions).
 - In addition, if the results of the planning process affect multiple organizations the representation of stakeholders from each provides for insight into each organization’s decision making process and unique issues.
- Well managed and maintained geographic information system (GIS) data provide a solid foundation for spatial planning efforts related to SLR.
 - Not only is an understanding of the overall vulnerability to SLR important, but the spatial distribution of the vulnerability is helpful for utilities that manage infrastructure throughout large service areas and for local governments that are charged with planning and regulating land use and development for their entire jurisdictions.
 - CFPUA’s GIS data played an integral role in identifying the water and wastewater infrastructure throughout the City of Wilmington and New Hanover County that are potentially vulnerable to SLR.

- Asset management program data can be beneficially leveraged to support vulnerability assessments.
 - The well developed understanding of risk and criticality of a utility’s infrastructure provides a foundation by which any vulnerability assessment can be built.
 - For this pilot project, CFPUA’s asset management program provided key input to the vulnerability assessment – infrastructure consequence of failure scores. The scores identify the overall criticality of a piece of infrastructure to CFPUA’s delivery of water and wastewater services.
- Existing SLR scenario modeling, developed by NCDDEM, allows for the quick definition of the extent of SLR implications.
 - For this pilot project, SLR scenario inundation extent and depth data came from modeling efforts completed for the NCSLRIS, managed by NCDDEM and funded by FEMA. The availability of this information provided the opportunity to complete a comprehensive service area–wide SLR vulnerability assessment for CFPUA’s water and wastewater infrastructure.
 - The development of this type of SLR scenario data at the state level provides a consistent basis of assessment for SLR for all utilities and local governments.
- A prioritization framework is a valuable tool to identify priority adaptation strategies that are clearly linked to an organization’s values, goals, and objectives.
 - Multi-criteria decision analysis provides an industry standard methodology for the development of a strategy prioritization framework that is fundamentally transparent, credible, and repeatable.
 - This pilot project identified a total of 54 potential adaptation strategies; not all of the strategies can be implemented at the same time or without added resources. The highest priority strategies that should be considered for implementation should be those that are aligned with the values, goals, and objectives of the implementing organization.
- A facilitative leader with technical understanding of adaptive planning and training in decision support techniques is valuable to guide the planning process to high-quality decisions.
 - The decisions made in the near-term on adaptive planning for the highly uncertain, potentially high consequence impacts of SLR require guidance through an approach that focuses on the critical issues, considers the long time horizons, and accounts for uncertainty. High-quality decisions are fundamentally based on the people involved, a structured process, and high-quality content.

This pilot project, inclusive of the planning process take-aways, will serve as a long-term guide and reference for the City of Wilmington, New Hanover County, CFPUA, and other coastal communities for building resilience to future changes in sea level.

Contents

Executive Summary	iii
Abbreviations and Acronyms	ix
1 Introduction	1-1
1.1 Potential Sea Level Rise and Storm Surge Impacts.....	1-1
1.2 Sea Level Rise and Storm Surge Impact on Water and Wastewater Infrastructure.....	1-2
1.3 USEPA Assistance to City of Wilmington, North Carolina, and Partners.....	1-3
2 Assessing Vulnerability to Sea Level Rise	2-1
2.1 Vulnerability Assessment Method Overview	2-2
2.2 Summary of Assessment Results	2-9
3 Adaptation Strategies	3-1
3.1 Identification of Adaptation Strategies	3-1
3.2 Steps Moving Forward with Adaptive Planning.....	3-15
3.3 Prioritization	3-16
4 Summary and Conclusions	4-1

Exhibits

Exhibit 1	Comparison of the current sea level and a 100-cm SLR scenario (by 2100) extent of inundation for the mean higher high tide water line and 100-year storm event for the same residential area in the City of Wilmington
Exhibit 2	Overview of Jurisdictional Boundaries and Major Water and Wastewater Treatment Facility Locations
Exhibit 3	General Adaptive Management Framework for an SLR Application
Exhibit 4	Spatial Extent of the 100-year Storm Event
Exhibit 5	40-cm SLR Scenario Extent Example
Exhibit 6	Summary of Asset Risk Identification for the 40-cm and 100-cm SLR Scenarios and Inundation Event
Exhibit 7	Manhole Risk Identification Example—40-cm SLR Scenario
Exhibit 8	CFPUA's Current Water Service Area
Exhibit 9	Adaptation Strategy List

Appendixes

Appendix A	Wilmington Community Resilience Pilot Project Site Visit Workshop Summary
Appendix B	Community Resilience Pilot Project—Wilmington, N.C., Vulnerability Assessment Technical Memorandum
Appendix C	Prioritization Decision Criteria and Cumulative Benefit Score Formula

Abbreviations and Acronyms

ASR	aquifer storage and recovery
CFPUA	Cape Fear Public Utility Authority
CIP	capital improvement program
cm	centimeter
CRC	North Carolina Coastal Resources Commission
CSO	combined sewer overflow
CWMTF	North Carolina Clean Water Management Trust Fund
NCDEM	North Carolina Division of Emergency Management
FEMA	Federal Emergency Management Administration
ft	feet
GIS	geographic information system
IPCC	Intergovernmental Panel on Climate Change
MCDA	multi-criteria decision analysis
MHHW	mean higher high water
NCSLRIS	North Carolina Sea Level Rise Impact Study
NOAA	National Oceanic and Atmospheric Administration
SLR	sea level rise
SSO	sanitary sewer overflow
TRC	Technical Review Committee
USEPA	U.S. Environmental Protection Agency
WTP	water treatment plant
WWTP	wastewater treatment plant

Introduction

Coastal communities face an increasing degree of uncertainty related to the impacts future climatic conditions may have on their areas. Increases in long-term air temperatures may result in higher sea levels; storm surges that occur during extreme events may have even greater impacts when combined with increasing surface water elevations due to sea level rise (SLR). The uncertainty surrounding changes in climate and sea level requires an approach that identifies and implements adaptation strategies to reduce a community's risk related to changes in SLR and extreme storm events. Adaptation (strategies) in the context of planning for future SLR involves planners and decision makers adjusting existing programs and policies to minimize the impact of future changes and considering new options that can be flexibly implemented as more information on SLR trends is acquired.

The potential impacts of SLR will be highly dependent on uncertain probabilities of occurrence and amplitude of sea level change. The level of impact from SLR will not only depend on the uncertain future of SLR but also the vulnerability of the community exposed to the changes. A wide range of public and private property (homes, businesses, roads, water and wastewater infrastructure, and schools) has the potential to be impacted by SLR. This pilot project focuses on the vulnerabilities of water and wastewater infrastructure within the broader planning context related to SLR. In order to adaptively plan for changing future conditions, an understanding of vulnerability is necessary to determine the adaptation strategies that will provide the most meaningful increase in community resilience to SLR.

1.1 Potential Sea Level Rise and Storm Surge Impacts

The Intergovernmental Panel on Climate Change's (IPCC's) Fourth Assessment Report estimates global sea level rise ranging from 18 centimeters (cm) (0.6 foot [ft]) to 59 cm (1.9 ft) over the next century³. More recent scientific studies identify the potential for global sea level rise to reach 100 cm (3 ft) or higher over the next century if there is increased melting of the ice sheets in Greenland and Antarctica added to the IPCC estimates⁴. Updates to the IPCC estimates are ongoing and incorporating new information acquired since 2007; the next assessment report will be published in 2013. The U.S. Environmental Protection Agency (USEPA) has set long-term goals to support national efforts to prepare for and build resilience to climate change, including SLR⁵.

A report developed by the North Carolina Coastal Resources Commission's (CRC's) Science Panel on Coastal Hazard reviewed a number of SLR studies and historical tide gage data to estimate the potential rise for the North Carolina coast. Their projections of potential SLR ranged from 40 cm (1.3 ft) to 140 cm (4.6 ft) by 2100⁶. A rise in sea level of this magnitude has significant implications for the North Carolina coast.

There is uncertainty as to the causes, probability, and amplitude of future SLR. These uncertainties often cloud or confuse decision makers' attempts at adaptive planning to prepare for a future under altered climatic conditions. Historical trends, since 1900, show increases in air temperature, greater rainfall variability, less predictability in hydrologic and meteorological conditions, and continued SLR⁷. Changes in these conditions require a different planning approach than previous efforts that were fundamentally based on "stationarity"—that is, the past will predict the future.

³ Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment of the Intergovernmental Panel on Climate Change*. Edited by Pachauri, R.K. and A. Reisinger. IPCC, Geneva, Switzerland. 104 pp.

⁴ Rahmstorf, S. 2007. A Semi-empirical Approach to Projecting Future Sea Level Rise. *Science*. 315(5810). Pp. 368-370.

⁵ USEPA. 2012. *National Water Program 2012 Strategy: Response to Climate Change*. 132pp.

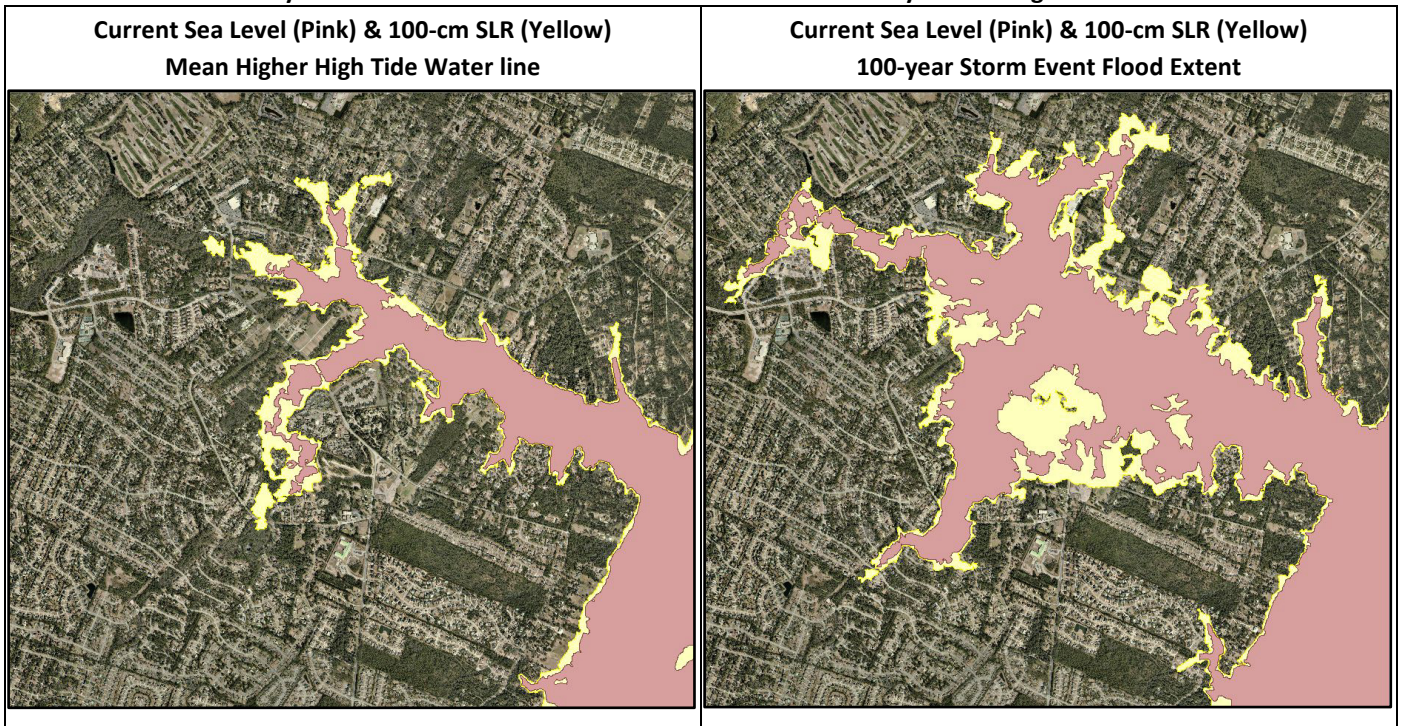
⁶ North Carolina Coastal Resources Commission's Science Panel on Coastal Hazard. 2010. *North Carolina Sea-Level Rise Assessment Report*. Raleigh, N.C.

⁷ Karl, T.R, J.M. Melillo, and T.C. Peterson, (eds.) *Global Climate Change Impacts in the United States*. Cambridge University Press, 2009.

Storm surge as a result of extreme events can have a devastating effect on coastal communities. High winds, combined with tides, cause waves to run up on shore and inundate areas at elevations much higher than under normal tides. These types of storm surge events are a result of natural weather patterns, and coastal communities have developed guidelines and strategies to protect against them. SLR, however, can reduce the effectiveness of the guidelines and strategies because the baseline conditions from which any surge begins is higher. Exhibit 1 provides a comparison of the extent of inundation for current sea level and a 100-cm SLR scenario, mean higher high water (MHHW) tide line and 100-year storm event, within a City of Wilmington residential area.

EXHIBIT 1

Comparison of the current sea level and a 100-cm SLR scenario (by 2100) extent of inundation for the mean higher high tide water line and 100-year storm event for the same residential area in the City of Wilmington.



Data source of the inundation extents is the North Carolina Sea Level Rise Impact Study.

1.2 Sea Level Rise and Storm Surge Impact on Water and Wastewater Infrastructure

SLR and the increase in the elevation of storm surges have the potential to have a direct impact on coastal communities’ infrastructure, including water and wastewater systems. Likely impacts of SLR have been evaluated by numerous agencies and researchers worldwide, including New York City (prior to Hurricane Sandy). In a summary report of predicted consequences of climate change⁸, the New York City Panel on Climate Change noted potential impacts on wastewater infrastructure related to SLR, which included the following:

- Structural damage to infrastructure due to inundation and wave action
- Failure of treatment plant components and pump stations due to flooding of electrical controls and/or ancillary equipment
- Decay of infrastructure not designed for saltwater exposure
- Increase of inflow of seawater to sewer pipelines resulting in the following:
 - Disturbance of wastewater treatment plant processes

⁸ New York City Panel on Climate Change. Climate Risk Information. New York, N.Y. 2009.

- Changes in system hydraulics
- Increased operation and maintenance requirements
- Water quality standards compliance issues.
- More frequent combined sewer overflows (CSOs) or sanitary sewer overflows (SSOs)

These types of impacts are not unique to New York City or wastewater infrastructure; most municipalities with water and wastewater infrastructure in low-lying coastal areas are likely to face some or all of the potential threats. In addition to those impacts listed above, saltwater migration further inland into aquifers or freshwater estuaries used for water supply will require water utilities to make decisions related to source water supplies and changes to treatment processes. The failure of septic systems with rising water tables in low-lying areas as a result of SLR will impact utilities with the potential requirement for the failing systems to be connected to the centralized wastewater collection system.

1.3 USEPA Assistance to City of Wilmington, North Carolina, and Partners

The City of Wilmington, North Carolina, in partnership with New Hanover County and the Cape Fear Public Utility Authority (CFPUA), requested assistance from USEPA's Office of Sustainable Communities to help identify land use and infrastructure policy options that can help reduce the vulnerability of water and wastewater infrastructure to potential SLR scenarios. USEPA, along with project partners from the Federal Emergency Management Agency (FEMA) and National Oceanic and Atmospheric Administration (NOAA), worked jointly with the City of Wilmington to develop a scope of work to guide assistance. Assistance is being provided through a team of international specialists from CH2M HILL. Project funding was provided through USEPA.

SLR and storm surge from more intense coastal storms pose challenges to existing water and wastewater infrastructure in the service area of CFPUA, throughout the City of Wilmington, and in unincorporated areas of New Hanover County (Exhibit 2). Much of the area is low-lying, and water and wastewater infrastructure, including underground pipelines, pump stations, treatment facilities, and groundwater resources, are potentially vulnerable to rising sea levels and storm surge. For example, older pipes made of iron, steel, or concrete, when exposed to salt water, may corrode, deteriorate, or fail at an accelerated rate, which could potentially cause a disruption of service to the public, negatively impacting public health and water quality. As water levels rise into low-lying areas, access to infrastructure may be compromised, impeding maintenance and repair work or halting services completely. In order to enhance resilience to potential changes in sea level, for existing and future water and wastewater infrastructure, a combination of land use and infrastructure policy options will provide the greatest collective potential for improved resilience.

The City of Wilmington and New Hanover County are both individually responsible for the land use planning efforts in their respective jurisdictions, and have a jointly adopted Coastal Area Management Act land use plan as well as a number of collaborative initiatives with elements dedicated to improving resilience to climate change, including SLR. CFPUA is a quasi-governmental authority that provides water and sewer service throughout New Hanover County. CFPUA recently completed a long range master plan, which the city and county were both involved in the planning process. The master plan laid out the strategic framework for future water and wastewater services and included a reporting on the trends in climate change adaptation planning, a narrative description on the potential impact from SLR on CFPUA infrastructure and recommended the continuation of prudent planning for the impact of future uncertainties, including SLR, to ensure the communities water and wastewater needs are met. USEPA's assistance for this pilot project has allowed for the continuation of the collaborative planning efforts between the city, county, and CFPUA to address issues that lie at the intersection of infrastructure and land use planning.

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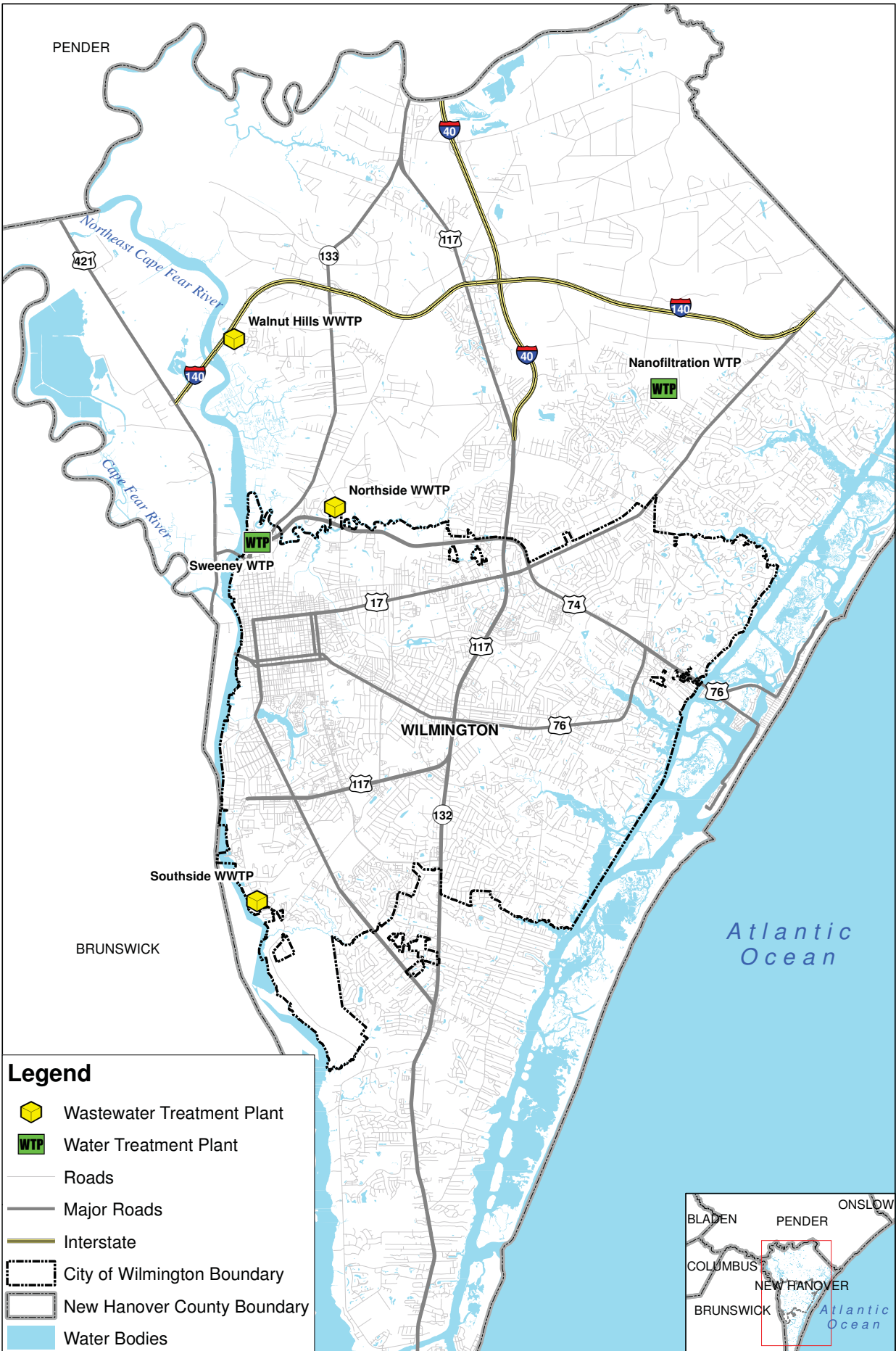


Exhibit 2 - Overview of Jurisdictional Boundaries and Major Water and Wastewater Treatment Facility Locations
EPA Community Resilience Pilot Project

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This pilot project identified potential risks to the water and wastewater infrastructure in the City of Wilmington and New Hanover County, as well as provided potential adaptation strategies to reduce the risks to the existing assets and future service areas. This guidance can serve as a template for other coastal communities to assess the vulnerability of their systems and identify adaptation strategies specific to their unique risks. With the template, local communities will be better able to decide how to allocate resources to meet challenges posed by SLR and extreme storm events. The effort included the following six steps to guide the City of Wilmington, New Hanover County, and CFPUA in adapting to potential changes associated with SLR. The following steps generally follow the pathway of an adaptive management framework, as presented in Exhibit 3.

1. **Frame the Problem and Identify SLR Scenarios**—A site visit and workshop was held on August 21 and 22, 2012. The workshop was attended by staff from USEPA, NOAA, City of Wilmington, New Hanover County, CFPUA, and CH2M HILL. During the workshop, federal and local partners and the CH2M HILL team defined the team mission statement and project scope, agreed upon a methodology for completing the vulnerability assessment and necessary assumptions, and began discussion related to potential options for protecting infrastructure from future SLR. It was also determined that SLR scenario data developed for the North Carolina Sea Level Rise Impact Study (NCSLRIS), a separate study discussed in the next section, would be used for this project. A summary of the workshop is provided as Appendix A.

EXHIBIT 3

General Adaptive Management Framework Steps for an SLR Application



2. **Identification of Vulnerabilities and Risk**—Assess vulnerability and risk as follows:
 - Vulnerability Assessment: Application of SLR and storm surge estimates identified in Step 1 to identify potentially vulnerable CFPUA water and wastewater infrastructure, which is a list of assets in one or more of the potential inundation areas under different SLR scenarios.
 - Risk Assessment: Determination of risk to CFPUA water and wastewater infrastructure based on the vulnerability assessment, the likelihood of inundation events, and the consequences of failure of an asset.
3. **Develop a list of potential adaptation strategies**—Using the vulnerability assessment and input from the site visit workshops a list of adaptation strategies was developed to reduce risk and increase resilience to SLR and

storm surge. In addition, strategies were identified to minimize future risks related to SLR and storm surge in areas for potential water and wastewater service expansion.

4. **Link adaptation strategies to current process**—A number of the identified adaptation strategies are simply expansions or modifications to existing plans, policies or processes already in place. Linkages to existing programs have been identified.
5. **Implement adaptation strategies**—Adaptation strategies that have the potential to reduce risk and improve community resilience were identified. The outcome of this pilot project, identified vulnerabilities and adaptation strategies, is not intended to direct or require local actions that are in conflict with any existing local regulations or state laws nor is it intended to imply or direct CFPWA to move or relocate any existing infrastructure or otherwise impact the current capital improvement program (CIP).
6. **Monitor and reassess**—Monitoring of SLR, revisiting the assessment, and reassessing the identified adaptation strategies, organizational policies and processes will be important to inform each organization's decisions in regards to future actions to adapt to changes in SLR, as needed.

Assessing Vulnerability to Sea Level Rise

The vulnerability assessment focused on the direct physical effects of SLR and storm surge to CFPUA's water and wastewater system infrastructure, for the planning period of 2012 through 2100. Direct physical effects were defined as the inundation of infrastructure and the impact on an individual asset's ability to continue to perform its intended function due to this inundation.

The vulnerability assessment included the following components:

- Select SLR scenarios and inundation events.
 - The State of North Carolina has been active in efforts to quantify the potential extent of inundation as a result of SLR. The North Carolina CRC Science Panel on Coastal Hazard developed a report in 2010 to explain how SLR is measured, the projection of SLR and related uncertainty, and how SLR should be monitored in the future⁹. The CRC Science Panel's report was based on historical North Carolina coastal tide gage data and the review of scientific literature on SLR. Subsequent research into SLR on the North Carolina coast is being undertaken by the North Carolina Division of Emergency Management (NCDDEM) as described in the NCSLRIS, funded by FEMA¹⁰. This effort includes the mapping of inundation as a result of a number of SLR scenarios, identified by the CRC Science Panel on Coastal Hazard (10-cm [0.3-ft], 40-cm [1.3-ft], 60-cm [2-ft], 80-cm [2.6-ft], and 100-cm rise [3.3-ft]), and storm surge and riverine flooding from storm events for various recurrence intervals (10, 25, 50, 100, and 500 years). A selection of the potential SLR scenarios and inundation events was used for this pilot project; the SLR scenarios were selected to represent the continuation of historical SLR trends and a precautionary, higher than historical SLR rate, scenario. The intention of the identified scenarios was to provide perspective on a range of potential vulnerabilities to SLR.
- Identify major asset types of interest (such as wastewater pump stations).
- Define the critical elevations for the assets.
 - The point at which an asset would no longer perform its intended function was defined.
- Identify vulnerable assets.
 - Vulnerability was identified based on location and depth of flooding due to SLR and storm events compared to the critical elevations.
- Define probability of inundation events and likelihood of damage.
 - The vulnerability assessment was a SLR scenario-based vulnerability assessment. The purpose of the assessment was to illustrate the possible impact of a range of future SLR; no probabilities were assigned to the SLR scenarios for this pilot project.
- Determine consequence of failure.
 - The impact of the failure of an asset was determined. For this project, the CFPUA asset management program had already developed consequence of failure scores for much of the CFPUA infrastructure and this data was used to assign the consequence scores.
- Determine risk level: high-, medium-, and low-risk groupings.
 - The level of risk is related to the failure of an asset due to events associated with SLR.

⁹ North Carolina Coastal Resources Commission's Science Panel on Coastal Hazard. *North Carolina Sea-Level Rise Assessment Report*. Raleigh, N.C. 2010.

¹⁰ North Carolina Division of Emergency Management Office of Geospatial and Technology Management. *North Carolina Sea Level Rise Risk Management Study*. Raleigh, N.C. 2011.

The vulnerability assessment was intended to identify potentially vulnerable assets for a range of SLR scenarios and demonstrate a methodology that can be used in other coastal areas in identifying vulnerable assets. The following subsections provide an overview of the assessment method and results.

2.1 Vulnerability Assessment Method Overview

The vulnerability assessment included the determination of the potential for an asset to be impacted by SLR and to determine the consequence of the impact. The vulnerability assessment focused on major water and wastewater infrastructure assets, including the following:

- Treatment facilities: wastewater treatment plants (WWTPs) and water treatment plants (WTPs)
- Lines: force mains, gravity pipeline, raw water transmission system, pressure mains (water)
- Ancillary assets: pump stations, manholes, water tanks, water supply wells, aquifer storage and recovery (ASR) wells

In order to evaluate the impacts of SLR, for this pilot project, baseline and future scenarios were used for a basis of comparison. For this analysis, a scenario was considered the combination of a SLR condition and an inundation event. For example, one scenario evaluated was a 40-cm SLR with a 10-year storm event. The potential for impacts to CFPWA infrastructure in New Hanover County were identified and analyzed for six selected future scenarios. The six scenarios are derived from a combination of two SLR conditions and three different potential inundation events:

- SLR Condition:
 - Historical SLR trend: continuation of the historical SLR rate (40-cm [1.3-ft] by 2100).
 - Historical rate as identified by the North Carolina CRC Science Panel on Coastal Hazard¹¹.
 - Precautionary SLR trend: precautionary high rate of SLR scenario (100-cm [3.3-ft] by 2100).
 - Rate of SLR higher than historical rates as determined by the North Carolina CRC Science Panel on Coastal Hazard¹¹.
- Potential Inundation Events:
 - MHHW, defined by NOAA as the average of the higher high water height of each tidal day¹²
 - 10-year storm event—flood elevation with wave action
 - 100-year storm event—flood elevation with wave action

A baseline “current conditions” scenario was also evaluated based on current conditions (that is, no SLR). This evaluation was only done for use as a basis for comparison to future SLR assessment results. Exhibit 4 provides a depiction of the spatial extent of the 100-year storm event flooding with wave action for the 40-cm and 100-cm SLR scenarios as they compare to the baseline scenario for the majority of New Hanover County land area.

The inundation depths and MHHW extent for each SLR condition used in the vulnerability assessment were based on the data developed for the NCSLRIS. Exhibit 5 provides an example of the inundation event extents for the 40-cm SLR scenario, inclusive of CFPWA wastewater collection system infrastructure, for one portion of New Hanover County. As part of this process, it was necessary to identify the different assets that could potentially be at risk for the different SLR and storm event combinations. Identification was done primarily through the use of a spatial analysis, using a geographic information system (GIS). The SLR inundation boundaries and depths were available in GIS format, from the NCSLRIS, as was the infrastructure location data, as provided by CFPWA. Treatment plant facility information was derived from CFPWA asset management program data and aerial photographs.

¹¹ North Carolina Coastal Resources Commission’s Science Panel on Coastal Hazard. 2010. *North Carolina Sea-Level Rise Assessment Report*. Raleigh, N.C.

¹² NOAA. 2012. Center for Operational Oceanographic Products and Services website: <http://tidesandcurrents.noaa.gov/mhwh.html>.

The infrastructure data layers were overlain with the NCSLRIS SLR data layers for each combined SLR and inundation event scenario to identify infrastructure that could potentially be impacted by SLR and the depth of inundation from the storm events. Some of the CFPUA assets were identified as not being vulnerable in any of the evaluated scenarios and therefore were not carried into the remaining evaluation.

Appendix B contains additional details on the vulnerability assessment methodology.

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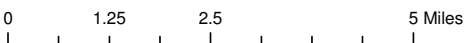
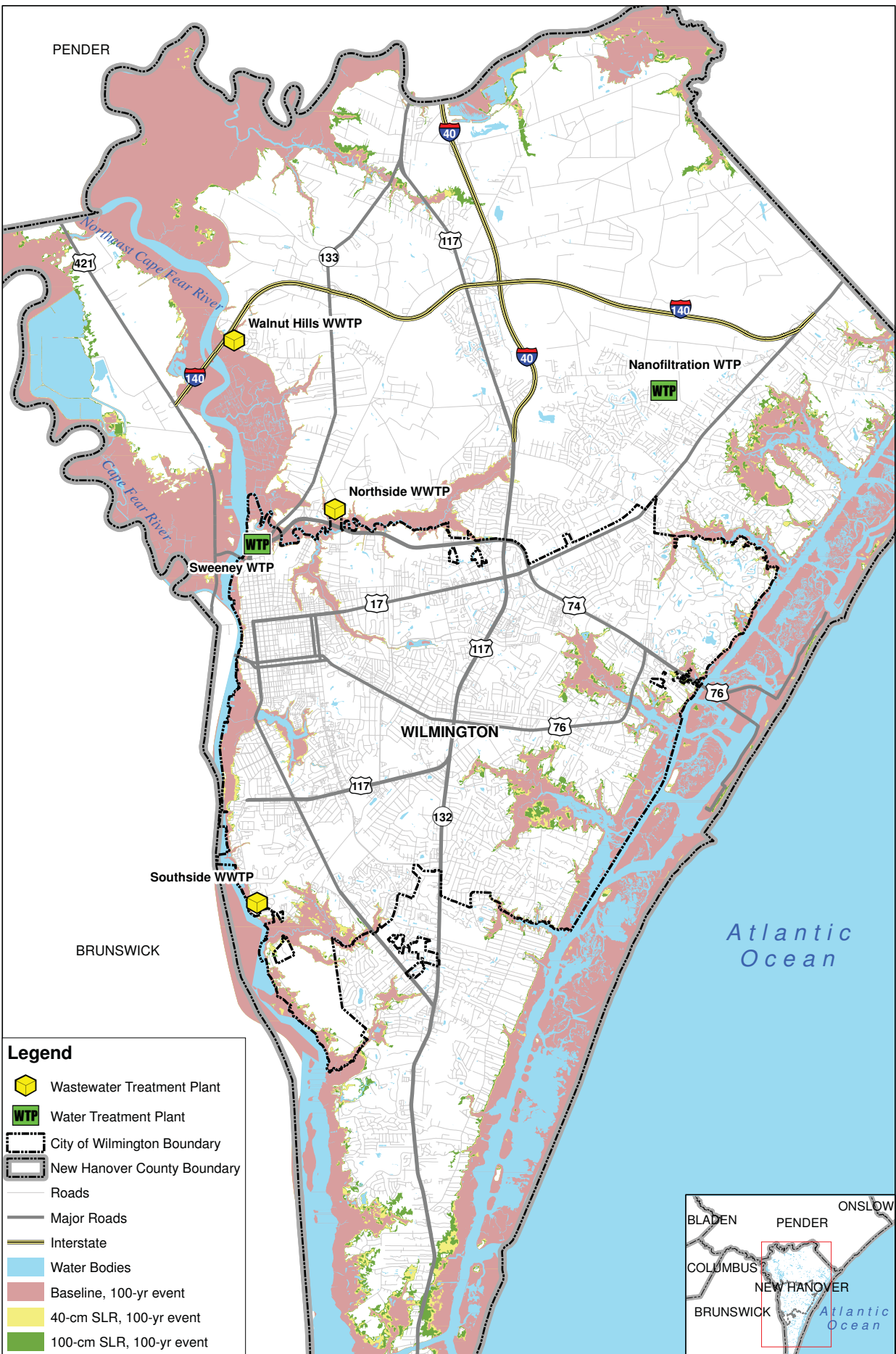


Exhibit 4 - Spatial Extent of the 100-year Storm Event
EPA Community Resilience Pilot Project

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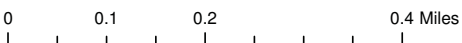
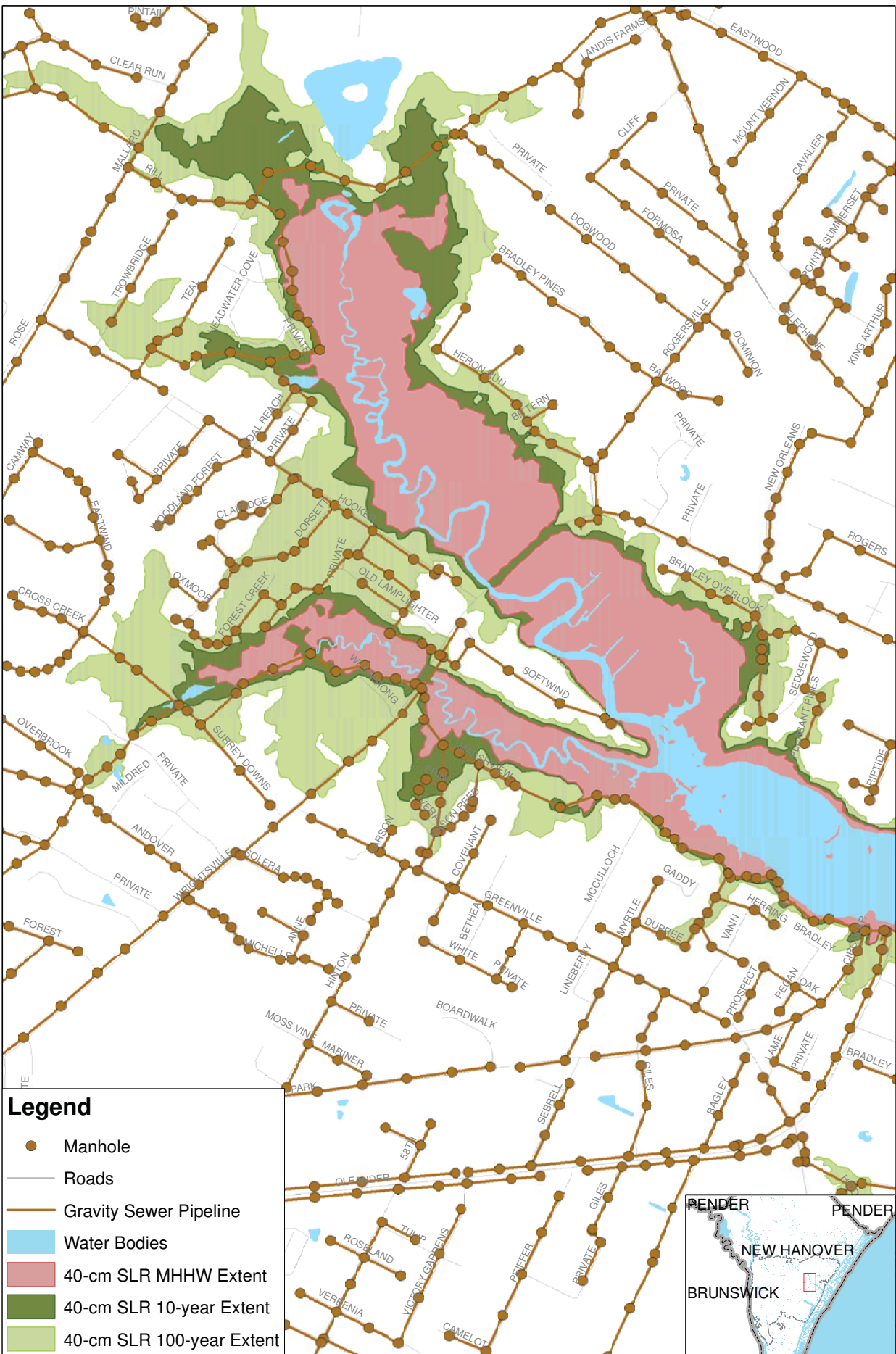


Exhibit 5 - 40 cm SLR Scenario Extent Example
 EPA Community Resilience Pilot Project

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2.2 Summary of Assessment Results

The end objective of the vulnerability assessment for this pilot project was to develop an understanding of the CFPWA water and wastewater assets that are potentially vulnerable to SLR. This understanding provides an illustration of the potential impact from SLR and the context by which adaptation strategies can be identified for selection by the City of Wilmington, New Hanover County, and CFPWA to become more resilient to SLR.

The vulnerability assessment task applied SLR and storm event inundation estimates to identify potentially vulnerable infrastructure and to determine risk to water and wastewater infrastructure. Exhibit 6 summarizes the number or length of vulnerable assets within the low (L), medium (M), and high (H) risk groups for the three inundation events evaluated (MHHW, and 10- and 100-year storm events) for both SLR scenarios (40-cm and 100-cm). Risk is defined, for the purposes of this project, as the loss of an assets ability to deliver its intended function and the consequential loss of the ability to provide service (water or wastewater). The level of risk is strongly linked to the consequence of an assets failure.

It should be noted that Exhibit 6 accounts for the incremental number of vulnerable assets, as opposed to cumulative number vulnerable. The risk event affiliated with each vulnerable asset was identified as the most frequent event (for instance, MHHW will occur more frequently over time than the 100-year event) causing that asset to be vulnerable. Additional details on the data presented in Exhibit 6, by treatment facility and major asset types, are provided in Appendix B. In addition, the discussion related to pressurized linear assets and assets that were not identified as vulnerable are contained in Appendix B.

EXHIBIT 6

Summary of Asset Risk Identification for the 40-cm and 100-cm SLR Scenarios and Inundation Event

SLR Scenario	Inundation Event	Risk Group and Asset Count/Length											
		Southside WWTP (Incremental No. of Sub-processes ^a)			Pump Stations (Incremental No.)			Manholes (Incremental No.)			Gravity Sewer Pipelines (Incremental Length, feet)		
		L	M	H	L	M	H	L	M	H	L	M	H
40-cm (Historical SLR trend)	MHHW	1	2	0	0	1	0	1	8	105	100	6,250	26,700
	10-yr storm with wave action	1	0	0	4	11	1	0	2	60	2,700	54,150	69,900
	100-yr storm with wave action	3	1	0	25	2	0	336	518	0	126,800	142,050	0
	Total	5	3	0	29	14	1	337	528	165	129,600	202,450	96,600
100-cm (Precautionary SLR trend)	MHHW	2	2	0	2	6	1	1	14	143	500	17,750	47,050
	10-yr storm with wave action	0	0	0	12	10	2	0	23	43	4,200	91,650	94,750
	100-yr storm with wave action	4	1	0	21	0	0	360	557	113	129,350	133,350	0
	Total	6	3	0	35	16	3	361	594	299	134,050	242,750	141,800

Note: The level of risk (low (L), medium (M), and high (H)) is directly linked to the consequence of an assets failure.

^a Sub-process is defined as an individual component of the water or wastewater treatment process, such as a settling basin or primary clarifier.

Exhibit 7 provides an example of the inundation extent for one portion of New Hanover County under the 40-cm SLR scenario and includes a visual presentation of the manhole risk identification. The inundation event affecting the displayed manholes, accounting for critical elevation, is also depicted in Exhibit 7. Appendix B includes larger maps, for many of the major asset types, showing the extent of the study area for the SLR scenarios and risk identification for these assets.

The vulnerability assessment indicated that one of the three CFPWA WWTPs (Southside) in the study area had a number of processes vulnerable to SLR, even under a 40-cm SLR scenario, while both of CFPWA's WTPs were identified as not vulnerable to the SLR scenarios reviewed. Based on the analysis, a 100-cm SLR would only incrementally increase the risk to the Southside WWTP above the 40-cm SLR scenario.

Inundation of water and sewer pipelines can result in more difficult access for operation and maintenance activities with the potential for more severe impacts occurring during storm events. A large increase is seen in the length of pipeline that is inundated for the SLR scenarios, but the increase in risk is low since the majority of the pipelines are buried. CFPWA's raw water pipelines face a greater risk since long sections are above ground (aerial lines), but the length of pipeline that is inundated does not increase significantly between the SLR scenarios. Risk to aerial raw water pipelines may increase since rising waters may increase erosion of supports or increase the chance of impacts from floating debris.

An additional threat that may affect CFPWA is the potential for saltwater intrusion into aquifers used for drinking water supply. The movement of the salt water inland into the aquifer with increasing sea levels may begin to limit fresh groundwater supply. As this occurs, CFPWA will need to evaluate alternative sources or transition from filtration treatment to reverse osmosis to address the salinity. The monitoring of salinity in raw groundwater—as well as the impact of potentially rising salinity levels on finished water quality, compared to USEPA advisory guidelines for sodium—could be used as indicators for making decisions on the need for alternative supply sources or transitioning to a new treatment process.

Each asset type evaluated in this assessment faces different threats from SLR and inundation from storm events. The selection of adaptation strategies, topic of the following section, will therefore depend on the unique function of and threats faced by each asset type. Based on the vulnerability assessment, the primary concerns (risks) are as follows:

- Flooding of wastewater treatment facilities
- Flooding of pump stations
- Inundation of wastewater collection system manholes

Strategies for lower risk assets, such as pipelines, as well as other beneficial activities are also identified and may be considered as part of a comprehensive adaptation program.

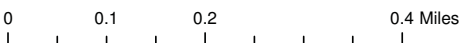
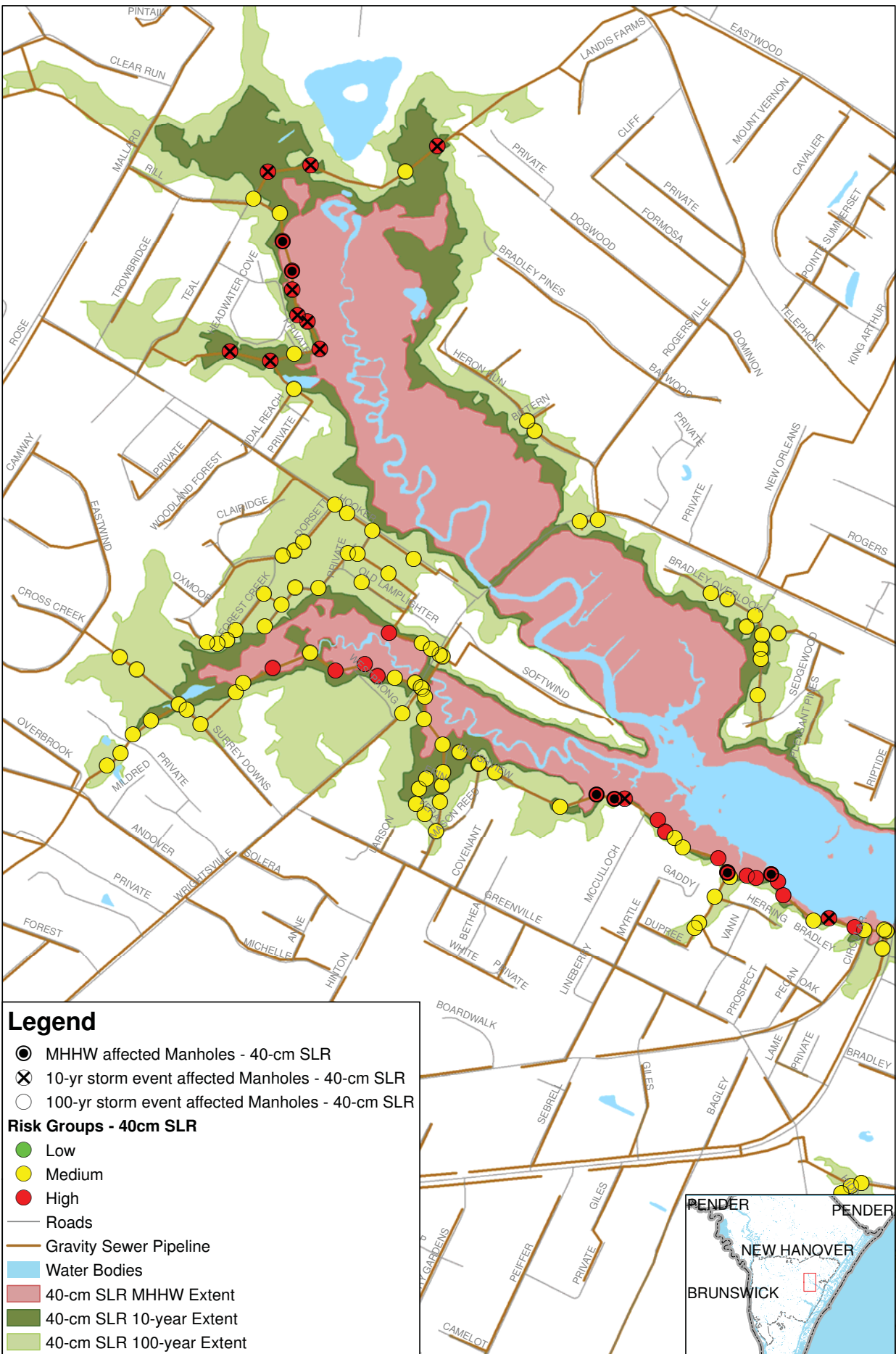


Exhibit 7 - Manhole Risk Identification Example - 40 cm SLR Scenario
EPA Community Resilience Pilot Project

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Adaptation Strategies

The effectiveness of adaptation strategy planning to reduce risks to SLR is highly dependent on access to high-quality information about SLR and associated risks. This pilot project has benefitted significantly from two preceding efforts that informed the vulnerability assessment, one being NCDDEM's effort on the NCSLRIS, and modeling work completed for that project to define inundation extents and depth for a number of SLR scenarios. In addition, CFPUA's asset management programs effort to spatially identify assets throughout the service area and define consequence of failure of individual assets provided vital data input for the vulnerability assessment. The information combined on the two efforts provided for a robust analysis of SLR risks for CFPUA's water and wastewater infrastructure. This type of data is essential to provide decision makers the ability to make data-driven decisions on the SLR scenarios reviewed and potential adaptation strategies.

The vulnerability assessment was intended to identify the potential impact from SLR to existing CFPUA infrastructure; the identified vulnerabilities guided the selection of adaptation strategies to increase resilience directly related to the assets. An important consideration, especially for the long duration of the planning period this project covers, through 2100, are strategies to minimize the potential risk related to SLR for future infrastructure as CFPUA expands its services into new areas. CFPUA's current water service area is presented in Exhibit 8. The reduction of risk, from SLR, to existing infrastructure will primarily be derived from infrastructure- and asset-specific strategies. Future infrastructure will benefit from the strategies as well, but the greatest risk reduction potential will be from land use planning and policies that guide future development away from areas that are potentially vulnerable to SLR. SLR is one of the issues that lies at the intersection of infrastructure and land use planning; a coordinated and collaborative planning approach for future infrastructure and land use is essential to build resiliency to the uncertain future changes in sea level.

This section outlines the identified adaptation strategies, steps forward for continued adaptive planning and a prioritization methodology for application by the city, county, and CFPUA to identify priority strategies for consideration.

3.1 Identification of Adaptation Strategies

The objective of identifying a suite of adaptation strategies for the City of Wilmington, New Hanover County, and CFPUA to select from is to provide a range of strategies that can be employed to increase resilience knowing that each organization has its own unique operating and political contexts. Each organization will choose how they will adapt to the potential changes they face from SLR based on their individual needs, governance, and authority; this report is intended to be a guidance for each organization and does not represent any obligation for implementation.

The end result of increasing SLR, flooding, and extreme storm events is not an impact coastal communities are unfamiliar with. There is a wide range of strategies that are currently used to minimize the impacts from flooding. The strategies range from floodplain development ordinances to operational strategies such as placing manhole inserts under manhole covers to reduce the amount of inflow to the wastewater collection system during flood events. Many of the flood risk mitigation strategies that municipalities and utilities employ currently are viable as SLR adaptation strategies; some may just need repurposing or adjustment to fit the application. Certainly the spatial scope of application of the measures would be broader under changes in sea level.

The body of knowledge on climate change adaptation is ever increasing as it becomes a focus of a number of organizations; including municipalities, the federal government, state governments and non-profit research organizations. A pairing of input from international specialists in climate change from CH2M HILL, discussions at the site visit workshop with local planners (City of Wilmington, New Hanover County, and CFPUA) and a review of a number of reference materials that are representative of the SLR adaptation knowledge base were used to develop a list of adaptation strategies.

The following list summarizes the reference material reviewed:

- *Current and Proposed Climate Change Adaptation and Optimization Strategies*¹³
 - A literature review was performed by CH2M HILL to support the evaluation of climate change adaptation strategies for New York City. This review identified published studies that focused on what utilities, municipalities, states, and other countries are doing to adapt to climate change. The literature review identified a wide variety of strategies and approaches for adapting to impacts from climate change.
- *Adaptation Strategies Guide for Water Utilities*¹⁴
 - The guide provides an overview of adaptation strategies for a number of climate change challenges that will face water utilities in the future.
- *Confronting Climate Change: An Early Analysis of Water and Wastewater Adaptation Costs*¹⁵
 - This report provides a characterization of future climate change impacts, adaptation to ensure reliable water and wastewater service in the future, and the potential range of costs nationwide for adaptation.
- *Adaptation Tool Kit: Sea Level Rise and Coastal Land Use*¹⁶
 - This toolkit provides a detailed summary of a number of planning, regulatory, spending, and tax/market based tools that have the potential for use in adapting to SLR.
- *Wilmington Community Resilience Pilot Project Site Visit Workshop Summary* (Appendix A)
 - An initial discussion with local planners (City of Wilmington, New Hanover County, and CFPUA), USEPA, and CH2M HILL yielded a number of strategies for consideration. Many of the identified strategies provided a local context for a number of the broader strategies identified in the preceding reference sources.

Exhibit 9 contains a listing of the identified adaptation strategies. The strategies have been separated into the following two groups:

- Infrastructure Strategies—Strategies that are focused on the reduction of risks related to SLR for existing and future water and wastewater assets.
- Land Use and Planning Strategies—This strategy grouping includes two sub-types:
 - Planning efforts or studies to help guide and inform the decisions related to future land use, capital project implementation and adaptation to SLR. Included in this group are actions taken in advance, such as the purchase of riparian properties or policy for the placement of facilities outside of the 500-year floodplain, to protect against future SLR.
 - Regulatory/Incentive tools that can be used to guide development in the future to minimize risks related to SLR.

In addition, Exhibit 9 provides a strategy description and the following information:

- Lead organization:
 - Identification of the organization (State of North Carolina, City of Wilmington, New Hanover County, CFPUA) that would lead the strategy implementation; many are identified as a multi-organization implementation.

¹³ CH2M HILL. 2012. *Review of Current and Proposed Climate Change Adaptation and Optimization Strategies Memorandum*.

¹⁴ USEPA Adaptation Strategies Guide for Water Utilities. 2012. PDF available at: water.epa.gov/infrastructure/watersecurity/climate/upload/epa817k11003.pdf

¹⁵ National Association of Clean Water Agencies. 2009. *Confronting Climate Change: An Early Analysis of Water and Wastewater Adaptation Costs*. Available at: www.nacwa.org/images/stories/public/2009-10-28ccreport.pdf

¹⁶ Georgetown Climate Center. 2011. *Adaptation Tool Kit: Sea Level Rise and Coastal Land Use—How Governments Can Use Land-use Practices to Adapt to Sea Level Rise*. Available at: www.georgetownclimate.org/sites/default/files/Adaptation_Tool_Kit_SLR.pdf

- Existing versus future program or policy (linkage to current processes):
 - Existing (E)—Program or policy **is** currently being implemented by the City of Wilmington, New Hanover County, or CFPUA.
 - Future (F)—Program or policy **is not** currently being implemented by the City of Wilmington, New Hanover County, or CFPUA.
 - Existing /Future (E/F)—Program or policy is currently being implemented by the City of Wilmington, New Hanover County or CFPUA, but could be modified to provide additional resilience to future SLR.
- “No regrets” (NR) strategy:
 - Strategies that provide resilience under current and potential future climate conditions.
- Relative cost:
 - \$ = low = less than \$1,000,000
 - \$\$ = medium = \$1,000,000 to \$5,000,000
 - \$\$\$ = high = more than \$5,000,000

The relative costs are those costs to the implementing organization for an expenditure on an individual strategy with the goal of a large-scale benefit for SLR risk reduction, including application to vulnerable water and wastewater infrastructure. Costs include a consideration for capital and operating costs.

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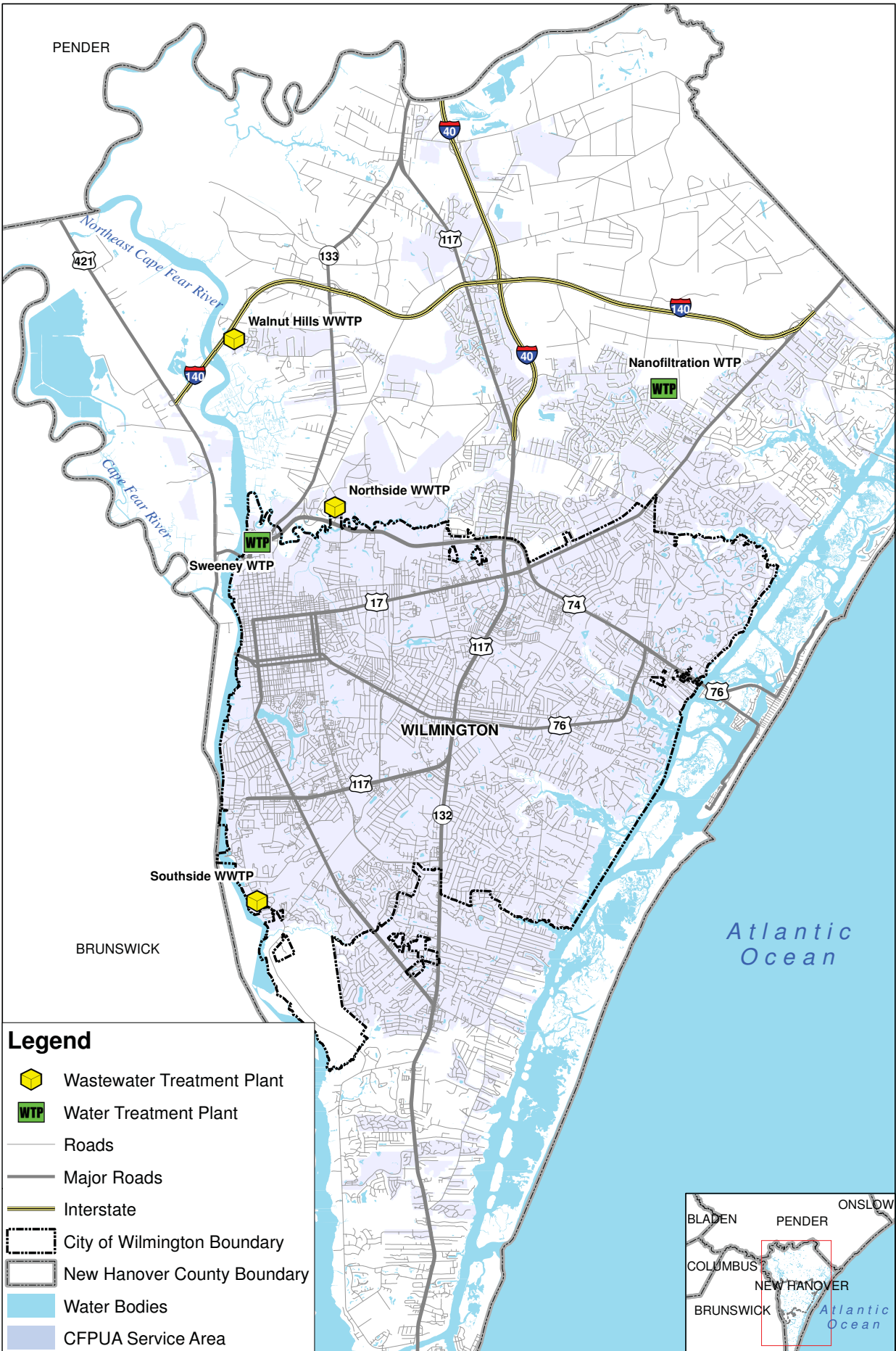


Exhibit 8 - CFPUA's Current Water Service Area
EPA Community Resilience Pilot Project

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EXHIBIT 9

Adaptation Strategy List

Strategy No.	Strategy Name	Strategy Description	Lead Organization	Existing (E) vs. Future (F) Policy/Program	No Regrets Strategy	Relative Cost (\$ = low, \$\$ = medium, \$\$\$ = high)
Infrastructure Strategies						
1	Flood proofing, flood-resilient structures	<p>Combination of structural and non-structural additions or modifications to CFPUA facilities to reduce or eliminate flood damage.</p> <ul style="list-style-type: none"> ▪ Dry flood-proofing, including flood shields, water tight doors, installation of flood proof materials, seal exterior walls ▪ Wet flood-proofing, including modifying structures to allow flood water to enter and exit <p>This strategy has the potential to increase resilience to future flood levels; this strategy is dependent on site-specific conditions since a consideration for flood-proofing is the duration and depth of flooding.</p>	CFPUA	E/F		\$\$
2	Raise critical facilities or vulnerable system components	The vulnerability assessment identified that the critical component for a majority of CFPUA water and wastewater infrastructure were the electrical panels. Raising the panels above future flood levels will build increase resilience to high flood waters; an entire facility/structure may need to be raised if flood depths warrant (flood depths greater than 3 to 4 ft).	CFPUA	F		\$\$\$
3	Move critical facilities	Relocation of facilities from the pathway of future flood waters.	CFPUA	F		\$\$\$
4	Policy to shift to submersible pump – pump stations	Submersible pumps are designed to operate underwater, as opposed to suction lift and dry well pumps. Submersible pumps provide greater resilience to flooding and potential high flood depths than do the other pump options.	CFPUA	F	NR	\$\$
5	Install backflow prevention (gates, valves, duckbills)	Backflow prevention provides a protection against flood waters entering discharge pipelines or channels.	CFPUA	E/F	NR	\$\$\$

EXHIBIT 9

Adaptation Strategy List

Strategy No.	Strategy Name	Strategy Description	Lead Organization	Existing (E) vs. Future (F) Policy/Program	No Regrets Strategy	Relative Cost (\$ = low, \$\$ = medium, \$\$\$ = high)
6	Construct flood walls or levees	Levees and flood walls/sea walls are barriers to block flood waters, levees are earthen embankments and floodwalls are manmade structures. The structures will provide flood protection for an individual site footprint such as pump stations or treatment plants; a consideration for the structures is the depth of future flooding and the offsite impacts of redirecting flood waters away from the site.	CFPUA	F		\$\$\$
7	Build dynamic tidal barrier structure	Tidal barriers are structures that sit in the water that can be closed to prevent high tidal peaks.	State, City, County, CFPUA	F		\$\$\$
8	Install redundant infrastructure	Installation of redundant water supplies, pipelines, treatment capacity, etc., to hedge against losses and disruptions.	CFPUA	E/F		\$\$\$
9	Sandbag critical pathways	Accessible sandbags provide protection of pathways to critical infrastructure, for either access to or protection of critical operational components.	CFPUA	F		\$
10	Use effluent pumping to overcome reductions in WWTP outfall capacity	With rising water surface elevations there is potential for reduced outfall discharge capacity from wastewater treatment plants, which can be overcome by installing or increasing effluent pumping capacity.	CFPUA	F		\$
11	Implement green infrastructure	Implement green infrastructure on-site or within the city or county jurisdictions (for example, convert impervious surfaces to pervious surfaces, tree planting, pervious paving materials, zero-discharge parking lots, rain gardens, etc.) to reduce runoff.	City, County, CFPUA	F	NR	\$--\$\$\$
12	Upgrade culverts and overland flow routes	Upgrade and expand stormwater flow routes to ensure unimpaired recession of flood waters.	City, County	F		\$\$--\$\$\$
13	Provide portable generators, pumps and other emergency equipment onsite or nearby for flood control	Have in-house or on standby (through contractual agreements) equipment for flood control.	CFPUA	E/F	NR	\$
14	Diversify water supply options	Expand water supply sources to include surface water, groundwater, ASR, recycled water, conjunctive use, and stormwater capture.	City, County CFPUA	F	NR	\$\$\$

EXHIBIT 9

Adaptation Strategy List

Strategy No.	Strategy Name	Strategy Description	Lead Organization	Existing (E) vs. Future (F) Policy/Program	No Regrets Strategy	Relative Cost (\$ = low, \$\$ = medium, \$\$\$ = high)
15	Establish alternative power supplies	Alternative power supplies including onsite generation to support operation in the event of power loss.	CFPUA	F	NR	\$\$\$
16	Increase wastewater capacity and stormwater collection capacity	Increase conveyance and treatment capacity to hedge infrastructure capacity losses and service interruptions.	City, County, CFPUA	F		\$\$\$
17	Expand water and wastewater treatment capability	Address water quality changes (increase in suspended solids and salinity).	CFPUA	F		\$\$\$
18	Groundwater barriers against salt water intrusion into aquifers	The use of potable or reclaimed water ASR to provide a barrier to salt water intrusion farther inland, resulting from SLR, into aquifers used for drinking water supply.	CFPUA	F		\$\$\$
Land Use and Planning Strategies						
19	Establish mutual aid agreements	Establish mutual aid agreements to enable continuation of service during extreme events from outside jurisdictional boundaries.	CFPUA	E/F	NR	\$
20	Refine risk scoring for high-vulnerability infrastructure with site-specific information	For this pilot project, a number of simplifying assumptions were required for the vulnerability assessment. A further refinement to the risk determination for the water and wastewater infrastructure could be completed by surveying actual critical elevations.	CFPUA	E/F	NR	\$
21	Continue to build asset management program database of consequence of failure for water and wastewater infrastructure	CFPUA would continue its asset management program to facilitate the continued assessment of risk and consequence of failure of existing and new assets.	CFPUA	E/F	NR	\$
22	Inventory flood protection measures currently in place	Identify and inventory flood protection measures already in place for infrastructure already in the floodplain. Ensure records are kept on measures taken for each location.	CFPUA	F	NR	\$
23	Monitor and inspect the integrity of existing infrastructure	Continuation of CFPUA asset management program's monitoring and inspection of the condition and integrity of infrastructure.	CFPUA	E	NR	\$

EXHIBIT 9

Adaptation Strategy List

Strategy No.	Strategy Name	Strategy Description	Lead Organization	Existing (E) vs. Future (F) Policy/Program	No Regrets Strategy	Relative Cost (\$ = low, \$\$ = medium, \$\$\$ = high)
24	Include critical (flood) elevation information in asset management database	Survey critical elevations for water and wastewater assets, adding the information to asset databases. A starting point for this type of work would be those assets with the greater risk to SLR as identified in the vulnerability assessment.	CFPUA	F	NR	\$
25	Consider revisions to infrastructure design standards	Monitor and review design standards every 5 to 10 years as assets are replaced (elevation, flood-proofing, removing of aerial lines from service, decommissioning pump stations, etc.).	CFPUA	F	NR	\$
26	SLR vulnerability information informs capital planning process	As capital projects are reviewed, include SLR as part of the review process to ensure existing assets (to be rehabilitated or replaced) and new assets with long life cycles are not maintained or placed in areas that may be vulnerable to SLR.	CFPUA	F	NR	\$
27	Plan for alternative power supplies to support operation in the event of loss of power	Plan to ensure power supplies are in place in the event of loss of power, including considerations for back-up generators (owned vs. contract, rolling vs. fixed position) and onsite power generation.	CFPUA	F	NR	\$
28	Develop emergency response contracts in advance of emergencies.	Contract to manage and support post-disaster recovery and for stand-by equipment (generators, pumps, etc.) to ensure short-term restoration of services.	CFPUA	E/F	NR	\$
29	Disaster cost recovery plan	Have a plan in place for the recovery post-disaster, both in return to operations as well as cost recovery for damage infrastructure. Cost recovery for costs incurred related to disaster preparation, service restoration and system recovery (replaces or repairs for damaged infrastructure). As part of the plan, identify insurance mechanisms and financial instruments to protect against financial losses associated with infrastructure losses.	CFPUA	F	NR	\$
30	Develop coastal restoration plans.	Planning for the build up and management of coastal ecosystems for tidal surge protection.	State, City, County, CFPUA	F	NR	\$

EXHIBIT 9

Adaptation Strategy List

Strategy No.	Strategy Name	Strategy Description	Lead Organization	Existing (E) vs. Future (F) Policy/Program	No Regrets Strategy	Relative Cost (\$ = low, \$\$ = medium, \$\$\$ = high)
31	Consider 500-year floodplain for new critical facilities	The city, county, and CFPUA could consider requiring the placement of new critical facilities outside of the 500-year floodplain. Critical facilities include hospitals, police and fire stations, schools, power-related facilities, and treatment facilities.	City, County, CFPUA	F	NR	\$
32	Aquifer monitoring to track saltwater intrusion	Continue efforts to monitor aquifer water quality and the impacts of salt water intrusion.	State, CFPUA	E	NR	\$
33	Explore methods for studying groundwater and potential impact of higher water level due to SLR	Study impacts of increased groundwater elevations due to SLR and the potential impact on future runoff and inflow and infiltration into the wastewater collection system.	City, County, CFPUA	F	NR	\$
34	Participate in community planning and regional collaborations related to SLR adaptation	Continue discussions related to SLR between the city, county and CFPUA, as well as local involvement in state-sponsored efforts. Ensure a method of communication and dissemination of information between all entities on new information from planning and study efforts.	City, County, CFPUA	E/F	NR	\$
35	Create an interagency group to develop and implement a coordinated watershed based approach to update stormwater management plans.	Group to comprehensively plan for the overall reduction in impermeability of County watersheds; reducing runoff and inflow, and potentially increasing aquifer recharge.	City, County, CFPUA	F	NR	\$
36	Better communication/interaction with beach communities regarding infrastructure/growth/planning	Expand discussion with beach communities related to infrastructure, growth and planning, including the potential impact of SLR. Include the following in the discussion: Wrightsville Beach, Carolina Beach, Kure Beach and Figure Eight Island.	City, County, CFPUA	E/F	NR	\$
37	Technical Review Committee (TRC) – SLR integration (TRC: review committee responsible for ensuring all development is compliant with local codes and guidelines)	TRC could integrate SLR into discussions when reviewing development plans.	City, County, CFPUA	F		\$
38	Emergency response plans	Ensure that emergency response plans deal with flooding and include emergency measures, triggers, and time to implement, and public notifications and communication.	City, County, CFPUA	E	NR	\$

EXHIBIT 9

Adaptation Strategy List

Strategy No.	Strategy Name	Strategy Description	Lead Organization	Existing (E) vs. Future (F) Policy/Program	No Regrets Strategy	Relative Cost (\$ = low, \$\$ = medium, \$\$\$ = high)
39	Expand emergency response planning and training to reflect SLR	Expansion of emergency response planning and training to include considerations of higher levels of flooding due to SLR.	City, County, CFPUA	F	NR	\$
40	Lessons learned for emergency response preparation	Formally collect, store and distribute lessons learned related to staging rolling/mobile equipment and other pre-event preparation.	City, County, CFPUA	F	NR	\$
41	Multijurisdictional hazard mitigation plan	Expand planning efforts to include consideration of SLR paired with extreme storm events, ensure the plan continues to be highly interfaced between all entities. Ensure CFPUA is part of the hazard mitigation planning effort in the future.	City, County, CFPUA	E/F	NR	\$
42	Monitor weather and tidal patterns	Begin to monitor local sea level patterns and trends to inform long-term planning strategies related to SLR.	State, City, County, CFPUA	F	NR	\$
43	Comprehensive Plan, inclusion of SLR	The consideration of SLR in the city/county comprehensive plans should support the long-term vision of the future land use. The vulnerability assessment completed for the pilot project as well as the NCSLRIS will provide studies to support the need for consideration of the potential influence of SLR on land use decisions. Evaluate the potential to include data from the NCSLRIS in the land suitability analysis for the Comprehensive Plan as required for inclusion in the planning process under the Coastal Area Management Act.	City, County, CFPUA	F	NR	\$
44	Purchase riparian properties both pre/post disaster	Riparian properties provide a natural buffer for rising flood waters and storm surge, the protection of the areas could be provided through the purchase and preservation of these areas. Funds from FEMA and the North Carolina Clean Water Management Trust Fund (CWMTF) could be leveraged to support the purchase of properties.	City, County	F	NR	\$\$-\$\$\$

EXHIBIT 9

Adaptation Strategy List

Strategy No.	Strategy Name	Strategy Description	Lead Organization	Existing (E) vs. Future (F) Policy/Program	No Regrets Strategy	Relative Cost (\$ = low, \$\$ = medium, \$\$\$ = high)
45	Zoning and Overlay districts, include considerations of SLR	Consider limiting new development in areas that are vulnerable to SLR. The city and county could revise existing conservation resource protection areas and consider expanding them to include consideration of SLR. This strategy could be implemented as a regulatory requirement in the zoning ordinance or as an incentive, through reduced fees, tax credits, streamlined permitting, density bonuses, or financial incentives.	Regulatory: State Incentive: City, County	F		\$-\$\$
46	Floodplain regulations, standards/guidance beyond the National Floodplain Insurance Program regulations	Consider establishing standards or guidance for additional restrictions beyond the minimum National Floodplain Insurance Program requirements in the 100-year floodplain and potentially include building guidelines for SLR flood elevations. Consider incorporating appropriate elements of the community rating system into the floodplain management program. This strategy could be implemented as a regulatory requirement in the floodplain development ordinance or as an incentive, through reduced fees, tax credits, streamlined permitting, height or density bonuses, or financial incentives.	Regulatory: State Incentive: City, County	F		\$-\$\$
47	Building code considerations of SLR flood elevations	Consider revision of the building code regulations to require new structures to be constructed more flood resilient, including elevations above the 500-year flood level or take into consideration SLR over the life of the structure. This strategy could be implemented as guidance, or as a regulatory requirement in the building code or as an incentive, through reduced fees, tax credits, streamlined permitting, height or density bonuses, or financial incentives.	Regulatory: State Incentive: City, County	F		\$-\$\$\$
48	Setback/buffer requirements to include consideration of future SLR flooding	Larger setbacks from water bodies and greater buffers for natural protection from rising flood waters. This strategy could be implemented as a regulatory requirement by the state or in the zoning ordinance or as an incentive, through reduced fees, tax credits, streamlined permitting, height or density bonuses, or financial incentives.	Regulatory: State Incentive: City, County	F		\$-\$\$

EXHIBIT 9

Adaptation Strategy List

Strategy No.	Strategy Name	Strategy Description	Lead Organization	Existing (E) vs. Future (F) Policy/Program	No Regrets Strategy	Relative Cost (\$ = low, \$\$ = medium, \$\$\$ = high)
49	Conditional development requirements	Special conditions administered by the state on development that occurs in areas identified as vulnerable to future SLR, including requirements for coastal buffers, impacts fees to cover emergency response during disasters or for the construction of flood protection structures, or require greater levels of flood protection.	Regulatory: State	F		\$
50	Rebuilding standards/guidance on areas vulnerable to SLR	Standards or guidance to inform property owners on where, when and how structures that have been destroyed are rebuilt. This strategy could be expanded to include redevelopment of existing structures that have not been destroyed.	Regulatory: State Incentive: City, County	F		\$
51	Cluster development	Encourage the concentration of new development in upland areas away from future SLR inundation areas. Incentives could include streamlined permitting, relaxed setback and lot size requirements, and height or density bonuses.	Incentive: City, County	E/F		\$
52	Post-construction stormwater standards	Post-construction stormwater standards to manage storm event runoff. The city and county already have the standards in place.	Regulatory: City, County	E	NR	\$
53	Tax and development incentives, to direct growth away from areas vulnerable to SLR	Encourage new development to occur outside of areas identified as vulnerable to SLR using tax and development incentives. Incentives could include tax credits, streamlined permitting for upland development, or financial incentives for infill or redevelopment in currently developed upland areas.	Incentive: City, County	F		\$-\$
54	Identification of properties in areas vulnerable to SLR	Publicly available information on properties located in an area that is vulnerable to SLR. This strategy could be implemented by the State as a regulatory requirement through real estate disclosures or as publically available information for review by property owners and those looking to purchase a property.	Disclosure: State Public Information: City, County	F		\$

3.2 Steps Moving Forward with Adaptive Planning

The vulnerability of CFPUA’s water and wastewater infrastructure was assessed and a range of potential adaptation strategies identified, effectively completing Steps 1 through 4 of the adaptive management framework presented in Exhibit 3. The following bulleted list outlines a number of potential steps in moving forward, beyond Step 4 in Exhibit 3, with an adaptive planning process to increase resilience to SLR for the City of Wilmington, New Hanover County, and CFPUA:

- Establish an SLR working group:
 - The objective of a SLR working group would be to continue the discussions between the City of Wilmington, New Hanover County, and CFPUA. The team assembled from each organization in support of this pilot project is a good example of a cross-organization, cross-functional team; ideally, the working group should comprise staff from each organization that represents different technical and functional roles. This type of team make-up will be essential to provide the diverse perspectives necessary for SLR adaptation planning.
 - In addition to the role of this working group for planning efforts locally; it could also be an avenue for information-sharing related to initiatives related to SLR at the regional, state, and federal levels.
- Develop a monitoring plan for SLR:
 - Identify an appropriate tidal gage station for monitoring and review of historical data:
 - This may include a coastal gage station and a riverine gage station as the SLR effect in the future may be different for the eastern and western sides of New Hanover County.
 - Establish a baseline tidal record for comparison of future tidal data.
 - Determine the responsible organization for executing the monitoring plan and communicating with all organizations.
- Adaptation strategy appraisal:
 - Identify adaptation strategy priorities:
 - The prioritization of the identified adaptation strategies, Section 3.1, based on the overall goals, objectives, and values of each organization. This type of evaluation will provide the city, county, and CFPUA the ability to reduce the “long list” of strategies down to a “short list” to take forward to a more detailed level of appraisal.
 - Section 3.3 outlines a methodology for strategy prioritization.
 - The short list of strategies will essentially provide the city, county, and CFPUA with a suite of options to select from that provide resilience to future changes in SLR and are aligned with values, goal and objectives of each organization.
 - Link priority adaptation strategies to vulnerable water and wastewater assets
 - Identify the adaptation strategies that will provide the greatest resilience to future changes in sea level for existing assets identified as vulnerable to SLR, using both of the assessed SLR scenarios (40-cm and 100-cm). This type of exercise will identify strategies that are most practical for an individual asset’s conditions (such as location or elevation). For example, if flood levels during a storm surge at a pump station are 10-ft above ground surface, under the 100-cm SLR scenario, the only practical strategy may be to relocate that facility. This type of asset-level strategy identification will provide a means for adaptation decisions that can be matched to the SLR trends observed over time.
 - The previous bullet focuses primarily on existing water and wastewater assets identified as vulnerable. For areas of future development a similar exercise can be done to identify those strategies that would prevent future risks to water and wastewater infrastructure and the proactive adaptation

strategies that could be put in place to ensure resilience to future changes in sea level within currently undeveloped areas that are vulnerable to SLR.

- Detailed strategy appraisal:
 - A cost-benefit analysis will provide the defensible basis for the selection of a preferred strategy. This type of analysis will be especially important when existing assets have multiple priority strategies identified as practical for an asset’s specific conditions or in the case of strategies to minimize risks to future assets in currently undeveloped areas.
 - The detail and quantitative basis of a cost-benefit analysis will vary depending on the importance of the decision, timing of the decision, data availability, level of uncertainty and the number of identified strategies. A cost-benefit analysis will allow decision makers to understand the tradeoffs between costs and benefits under future uncertainty. If the data is available a monetary value can be assigned to economic, environmental, and social benefits as well as costs. The expression of benefits and costs in the same units provides the ability for the direct comparison of alternative strategies.
- Define decision trigger points or thresholds
 - When the preferred adaptation strategies have been identified for implementation, the decision on timing for implementation is the next step. Decision trigger points or thresholds allow for the identification of timing or future sea level conditions that provide an indication that a strategy will be required. Trigger points that are linked to observed SLR trends, with linkage to the SLR monitoring plan, will provide the ability to plan implementation based on actual trend information.
 - Strategies that are identified as “No Regrets” in Exhibit 9 provide benefits to the city, county, and CFPUA under both current and future climatic conditions. Therefore, the strategies could be considered differently, rather than based on trigger points, for implementation.
 - The decision trigger points may be earlier in the planning horizon for the land use and planning strategies that guide development, and the consequent construction of water and wastewater infrastructure, away from areas of potential vulnerability to SLR. The more time that passes before these types of strategies are implemented represents missed opportunities to potentially minimize future risk. The decisions will be the most sensitive to the future uncertainties related to SLR.

The preceding bullets outline a number of steps to provide the city, county, and CFPUA with a guide for future adaptive planning efforts for SLR, based on efforts completed for this pilot project. This guide provides flexibility in strategy implementation based on the observed SLR trends, with some recognized exceptions. Each organization will need to choose how it will adapt to the potential changes it faces from SLR based on its individual needs, governance, and authority.

3.3 Prioritization

Section 3.1 provides a comprehensive listing of a range of adaptation strategies to increase the resilience to SLR for the City of Wilmington, New Hanover County, and CFPUA to consider. In moving forward with the consideration of the strategies, the organizations will need to consider the following two aspects that will be important for implementation: (1) priority assets to focus on first, and (2) priority strategies for implementation. Priority assets should be selected based on level of risk and consequence of failure as identified in the vulnerability assessment; this will allow the biggest level of risk reduction for the investment. The prioritization of adaptation strategies requires a meaningful framework by which strategies are measured for their contribution to the overall goals, objectives, and values of each organization.

A multi-criteria decision analysis (MCDA) approach will provide the city, county, and CFPUA the ability to identify the goals, objectives, and values to be applied in the decision making process and then measure the contribution of each strategy to meeting those objectives. MCDA is a structured decision making process that documents the contribution of a strategy toward the weighted goals and objectives of an organization. This approach has been found preferable to traditional voting and matrix methods because it provides an explicit statement of the

decision criteria and their relative importance. The benefit of the MCDA methodology is that it provides for the following: (1) the incorporation of multiple objectives across a number of stakeholders, (2) the capabilities to make decisions on a broad range of potential strategies, and (3) a transparent decision-making process that is verifiable, defensible, and repeatable when necessary. The following list outlines the general steps in developing a prioritization framework using MCDA:

- Develop a project objective/mission statement:
 - A project objective/mission statement should be representative of the project purpose and the values of decision makers and an organization’s goals.
 - At the site visit workshop a project mission statement was developed by participants; Appendix A contains a workshop summary and includes the mission statement. This project mission statement can provide a template for the city, county, and CPFUA moving forward on decisions related to how they will adapt to SLR in the future.
- Identify decision criteria:
 - The selected criteria should reflect the criteria/objectives that are critical for measuring the potential effectiveness of the adaptation strategies toward meeting the project objective/mission statement.
 - Necessary characteristics for decision criteria include: comprehensive, linked to values, non-redundant, and independent.
 - The decision criteria are typically developed with a stakeholder group. At the site visit workshop a draft list of decision criteria and attributes (used to provide a definition of the criteria) was developed by participants. These same workshop participants (local partners) met again after the site visit workshop and created an updated list of decision criteria, which can be found in Appendix C.
- Weighting of decision criteria:
 - For MCDA, the decision criteria require an explicit weighting to identify the relative importance of each of the criterion.
 - Weighting is typically completed by assigning up to 100 value points to each criterion; with 100 points representing the criterion assigned the greatest value. The scores are then normalized to a 100-point scale.
 - The development of criteria weightings requires a similar level of input from a stakeholder group as the development of the decision criteria.
- Development of performance measures:
 - Performance measures are used to assess the contribution of a strategy to meeting each of the identified, weighted decision criteria. The measures can be qualitative, using a series of verifiable levels of performance (high, medium, and low), or quantitative, using actual measureable parameters including quantities such as time (days or years).
 - For each performance measure different levels of performance (performance scale) that can be verified objectively and repeated across all strategies is important.
 - The levels of performance should be defined to comprise a performance scale and a numeric performance score. The performance measure benefit score range is always based on a 10-point scale, with 10 points representing the maximum contribution a strategy could receive.

Once the prioritization framework is established, the strategies can be scored for their contribution to the decision criteria. Scoring is completed by determining each strategies contribution to the performance measures developed for each of the decision criteria using input from a stakeholder group. The combination of the performance scores and the weighting for each decision criteria provides a single cumulative benefit score, which represents a strategy’s overall contribution to the weighted, goals, and objectives (decision criteria).

The prioritization scores can be leveraged to rank the strategies to identify the priority strategies for implementation. Appendix C contains an example formula to generate the cumulative benefit score.

The prioritization of adaptation strategies will provide an identification of the strategies that are aligned with each of the organization's goal and objectives, and represent the strategies that are best suited based on the local context. For example, the prioritization will answer the following question: Are tidal barriers or flood-proofing strategies more aligned with the goals and objectives of the city, county, and CFPUA? Site-specific considerations for the actual application of the adaptation strategies will still be required to determine the priority strategy that will provide the most cost-effective adaptation to future SLR (for instance, flood-proofing versus raising a facility).

Summary and Conclusions

SLR and storm surges from more intense coastal storms pose challenges for CFPWA's existing and future water and wastewater infrastructure, throughout the City of Wilmington and the unincorporated areas of New Hanover County. This pilot project's vulnerability assessment illustrated the potential risks to CFPWA's infrastructure using estimates of SLR, GIS data, and information from CFPWA's asset management program. The vulnerable assets were reviewed to determine the potential risks related to SLR, and the primary concerns focused on the potential impact of SLR on the wastewater system. The vulnerability assessment results were leveraged to support the identification of a suite of 54 adaptation strategies for the City of Wilmington, New Hanover County, and CFPWA to consider for increasing resilience to future SLR. The adaptation strategies range from infrastructure-specific strategies to land use planning and policies to guide future development away from areas that are potentially vulnerable to SLR. The implementation of any of the strategies will be specific to each organization's unique operating and political contexts.

Coastal communities will continue, for the foreseeable future, to face an increasing degree of uncertainty related to the impacts future SLR may have on their areas. The use of high-quality information, such as the data from the NCSLRIS and CFPWA asset management program leveraged in this pilot project, to derive an understanding of the potential risks to SLR and identify adaptation strategies to increase resilience provide a foundation by which decision makers can start to adaptively plan for the future under altered sea level conditions. The monitoring of tidal and sea level trends over time will provide additional insight for decisions related to adaptation strategy implementation; including strategy selection, scale, and timing.

Through the course of this pilot project a number of key process take-aways were identified that will provide valuable insights for other communities considering an adaptive planning effort for potential SLR impacts on their water and/or wastewater system. The take-aways include the following:

- There must be a clear understanding of the goals and objectives of the planning effort, as well as a plan for dealing explicitly with uncertainty.
 - Clearly stated project objectives will ensure the planning effort is answering the right questions.
 - Uncertainty for this pilot project was handled by the use of a scenario-based vulnerability assessment. There was a consistent understanding of the uncertainties related to SLR and the scenarios were selected to provide an indication of the potential range of impacts from SLR, without an explicit determination of likelihood of one scenario over the other.
- A collaborative, stakeholder involvement process is essential.
 - Assessing the implication of SLR touches a wide variety of subject matters, including engineering, land use planning, finance, emergency response, governance, and legal. All of this expertise rarely resides in one individual department or organization. In the case of this pilot project, this expertise was spread across three different organizations.
 - The input of different perspectives from all stakeholders provides for a valuable opportunity to identify a range of potential solutions, rather than just a singularly focused set of solutions (for instance, engineered infrastructure specific solutions).
 - In addition, if the results of the planning process affect multiple organizations, representation of stakeholders from each provides for insight into each organization's decision making process and unique issues.
- Well managed and maintained GIS data provides a solid foundation for spatial planning efforts related to SLR.
 - Not only is an understanding of the overall vulnerability to SLR important, but the spatial distribution of the vulnerability is helpful for utilities that manage infrastructure throughout large service areas and for

local governments that are charged with planning and regulating land use and development for their entire jurisdictions.

- CFPUA’s GIS data played an integral role in identifying the water and wastewater infrastructure throughout the City of Wilmington and New Hanover County that is potentially vulnerable to SLR.
- Asset management program data can be beneficially leveraged to support vulnerability assessments.
 - The well developed understanding of risk and criticality of a utility’s infrastructure provides a foundation by which any vulnerability assessment can be built.
 - For this pilot project CFPUA’s asset management program provided key input to the vulnerability assessment—infrastructure consequence of failure scores. The scores identify the overall criticality of a piece of infrastructure to CFPUA’s delivery of water and wastewater services.
- Existing SLR scenario modeling, developed by NCDDEM, allows for the quick definition of the extent of SLR implications.
 - For this pilot project SLR scenario inundation extent and depth data came from modeling efforts completed for the NCSLRIS, managed by NCDDEM, and funded by FEMA. The availability of this information provided the ability to complete a comprehensive service area-wide SLR vulnerability assessment for CFPUA’s water and wastewater infrastructure.
 - The development of this type of SLR scenario data at the state level provides a consistent basis of assessment for SLR for all utilities and local governments.
- A prioritization framework is a valuable tool to identify priority adaptation strategies that are clearly linked to an organization’s values, goals, and objectives.
 - MCDA provides an industry standard methodology for the development of a strategy prioritization framework that is fundamentally transparent, credible, and repeatable.
 - This pilot project identified a total of 54 potential adaptation strategies; not all of the strategies can be implemented at the same time or without additional resources. The highest priority strategies that should be considered for implementation should be those that are aligned with the values, goals, and objectives of the implementing organization.
- A facilitative leader with technical understanding of adaptive planning and training in decision support techniques is valuable to guide the planning process to high-quality decisions.
 - The decisions made in the near-term on adaptive planning for the highly uncertain, potentially high consequence impacts of SLR require guidance through an approach that focuses on the critical issues, considers the long time horizons, and accounts for uncertainty. High-quality decisions are fundamentally based on the people involved, a structured process, and high-quality content.

For their efforts and desire to proactively plan, the partnership of the City of Wilmington, New Hanover County, and CFPUA, with USEPA, should be applauded for the following:

- The partners’ willingness to proactively take on a key public health and safety issue, and their partnerships with each other to date
- CFPUA’s vision of consolidating and assembling system GIS data
- CFPUA’s continued commitment to the value of its asset management program, including the risk and consequence analysis
- The willingness of all partners to discuss long-term strategies, despite meaningful uncertainties with current SLR estimates and limited short-term funds to spend on adaptation strategies for long-term potential impacts

This type of proactive planning interaction between the diverse set of organizations will serve the citizens, businesses and leaders of the City of Wilmington and New Hanover County well in the long run.