A White Paper on

A Synthesis of Sea Level Rise Impacts on Water Infrastructures in Coastal South Carolina and Adaptation Countermeasures Undertaken

Kalyan R. Piratla

Assistant Professor of Civil Engineering

Clemson University

South Carolina

Daniel M. Harrison

Professor of Sociology

Lander University

South Carolina

Executive Summary

Sea level rise is a slowly emerging threat that has already started to pose significant challenges to residents and public agencies across various low-lying coastal regions in the southeastern United States. Increased tidal flooding, both in terms of intensity and frequency, along with rising water tables and salt-water intrusion into freshwater aquifers, are the major consequences of sea level rise in coastal South Carolina communities. Among several aspects that amplify these consequences, the aged, inadequate and outdated water infrastructure is of cardinal importance. It is crucial that this infrastructure be effectively renovated to cope up with the anticipated challenges of sea level rise in the years to come. As part of a research study sponsored by the South Carolina Sea Grant Consortium, representatives from various water infrastructure-related agencies (hereafter referred to as the Research Stakeholder Group or RSG members) operating in the region are engaged to learn about the perceived challenges and pressing outstanding needs in the context of sea level rise and resultant consequences. Relevant published documents were also reviewed to complement the understanding of the challenges and needs of the region. The overarching research study will comprise several follow-up tasks that include impact modeling of stormwater infrastructure and surveying of best practices for adaptation of stormwater systems to sea level rise. Major findings from the engagement of RSG members and review of relevant published documents are grouped into three categories:

- Major impacts of sea level rise on coastal South Carolina's water infrastructures.
    - The flooding of streets and homes from regular storm events and tidal activities is perceived to be a potent threat that is becoming increasingly common in some coastal communities of South Carolina such as Charleston and surrounding regions. The frequency of tidal flooding in Charleston has increased by about 5.5 times from

1970 to 2010 and it is projected to increase by over 16 times from 2010 to 2045. Sea level rise plays a prominent role in the rise of tidal flooding events. Major drainage-related challenges facing the greater Charleston area include the low land elevation, increased impervious ground cover, inadequate pipeline and pumping infrastructure.

- In some areas of the state, such as Hilton Head and in the rural communities of Beaufort and Jasper counties, citizens face the threat of salt water intruding into drinking water aquifers or wells. Some communities facing this threat have already switched water sources or are planning to do so in the near future. This is however a major challenge for communities that are not connected with a water utility system and rely solely on water wells. Additionally, there were reported complaints in the Mt. Pleasant area about salt water intruding into the marshes which a few golf courses tap for irrigation.
- Tidal flooding and the resulting inundation of septic tanks release contaminated water on to the ground on Sullivan's Island and the Isle of Palms where some dwellings are not connected to a sewer network. This contaminated wastewater can have serious impacts to humans and the environment.

- Adaptation countermeasures undertaken.
  - One practical solution to the frequent flooding problem in the low country of South Carolina would be to build more pumping stations that will provide the necessary head to rapidly push tidal flows and runoff through the outfalls even in a high tide period. Some areas such as Charleston have benefited from added pumping

capacity as part of their drainage improvement efforts which also includes upsizing of pipelines and building large diameter underground storage tunnels.

- There have also been efforts in areas like Mt. Pleasant to monitor the condition of stormwater pipelines in order to identify the critical pipelines which can be rehabilitated in a timely manner without waiting for them to completely fail at which stage they need to be absolutely replaced at a much higher cost.
- Efforts have been made in some areas to keep the stormwater inlets free of dry leaves, trash and other debris which may otherwise clog the drainage system and hinder the rapid removal of floodwater.

- Critical constraints to adaptation.
  - Although it is technically possible to adequately renovate the obsolete stormwater drainage systems which were not optimally planned when initially put in place, such action is probably prohibitively expensive to most coastal communities even if the work is completed in multiple phases over a period of time.
  - The quality of the storm-water returning to the ocean is becoming an important issue. Reports of dangerous water quality have been highlighted in local media outlets in the Charleston area. Myrtle Beach was also in the news recently (in the spring and summer of 2016) for its warnings to beachgoers about swimming in certain areas. Over the 4th of July weekend, a young girl from Murrell's Inlet was in the hospital with a very serious infection after swimming in bacteria infested water at North Myrtle Beach.
  - There appears to be a lack of educational programs to make the public aware of the challenges associated with flood management in the low country and actions

citizens can take to help remedy the situation. In order to maximize the efficacy of the drainage infrastructure, the public needs to be informed about preventing tree debris and trash from clogging storm-water inlets and drains.

- Until recently, the South Carolina public has generally not been very receptive to proposed systemic changes to counter the problems created by flooding and sea level rise; however, the October 2015 flooding events may have changed this attitude. Public sentiment now seems more favorable to adaptation measures, particularly buyout options for frequently-flooded properties by the cities (an option not met with much enthusiasm previously).
- Policy differences between cities and counties around the state can make it difficult for adopting a sustained adaptation action plan. For the entire region to adapt to the challenges of climate change, there will need to be a more collaborative approach across locales.

Table of Contents

Acknowledgements

The authors thank all members of the research stakeholder group for their valuable time and inputs which made the development of this report possible. The authors thank Dr. Ashok Mishra, Dr. Brandon Ross and Mr. Sreeganesh Yerri for their time and efforts in preparing for and organizing the stakeholder meeting and also for their feedback on this report. Finally, the authors thank the South Carolina Sea Grant Consortium for their support as part of the research grant #NA14OAR4170088. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of any governmental or institutional entity.

1. Introduction

Thermal expansion of water and melting of glaciers caused by global warming has resulted in a sea level rise (SLR) of approximately 1.7mm/year over the last century and over 3.2 mm/year in the last few decades (NOAA, 2014). This accelerated SLR and increase in atmospheric temperatures, often described as the two most detrimental impacts of climate change, have devastating societal impacts that are already being realized, especially in the low-lying coastal regions of the southeastern United States. Such impacts include but are not limited to changes in precipitation cycles, increased storm intensity and flooding, increased coastal erosion, rising water tables, and salt-water intrusion into freshwater aquifers. For example, many residents in Charleston, South Carolina (SC) are familiar with periodic tidal flooding ("king tides") that disrupts the routines of daily life. Similarly, several water infrastructure operators in low-lying areas along SC's coast are currently managing the challenges faced by inundation risks, inadequate pumping of storm-water and insufficient storage capacity. Several scientific models project a worsening scenario with an expected increase of at least a two feet SLR along South Carolina's coastline over the next century (SCDNR, 2011). The fact that three (Myrtle Beach, Hilton Head and Charleston) of the 20 fastest growing metro areas in the United States are located along SC's 190-mile coastline (U.S. Census Bureau, 2015), highlights the increased vulnerability of these populations to growing climate change impacts and the need for collaborative, long term intervention planning.

The need for such planning became even more apparent after a remarkable set of storm events were recorded in South Carolina in October of 2015, resulting in some of the most extensive flooding on record. Charleston International Airport recorded 11.5 inches of rainfall in 24 hours on October 3rd which was the most rain ever recorded at that location (City of Charleston, 2015).

Towards the end of October, floods occurred in Charleston due to astronomical activity during a super moon which caused a high tide that peaked at 8.69 feet. This was the highest crest on record in Charleston since Hurricane Hugo in 1989 which caused a storm surge crest of 12.56 ft (City of Charleston, 2015). Because of the tremendous destruction wrought by this latest round of severe storms, many citizens and water policy experts are working towards better ways to protect communities from future flooding.

Among several variables that can amplify climate change impacts, aged, inadequate and outdated water infrastructure is of particular importance. Strong societies have enduring, effective, hazard resilient infrastructures. Water infrastructures (both natural and man-made) facilitate drinking water, wastewater and storm-water services for communities. Several critical climate change impacts on coastal water infrastructures are identified in Table 1.

Table 1. Climate Change Impacts on Coastal Water Infrastructures

Drinking Water	Wastewater	Storm-water
• Intrusion of salt water into freshwater aquifers • Evapotranspiration of surface water • Freshwater shortages	• Inundation of low-lying pumping stations • Inflow & infiltration into deteriorated submerged pipelines • Backflow risk • Increased demand for wastewater treatment capacity • Effluent disposal problems	• Inadequate pumping and storage capacity during flooding • Backflow during tidal flooding • Accelerated deterioration of infrastructure due to repeated exposure to salt water

In response to persistent flooding, some water infrastructure related adaptation measures have already been implemented in coastal SC communities. These include, but are not limited to, installation of backflow preventers in storm drains, increasing pumping capacities, building storage tunnels for storm water, and raising elevations of the newly installed or renovated

infrastructure and associated control systems. While such *ad hoc* measures will defer the consequences of climate change in the short run, a more coordinated, long-term, and human-centric approach to climate change adaptation is imperative for sustainable mitigation of climate change consequences.

Unfortunately, there is limited information available on the current level of climate change impacts on SC's coastal water infrastructures. It is vital to assess and document the current level of SLR impacts to understand the crucial challenges that will need further attention.

This report presents a synthesis of SLR impacts on the water infrastructures of coastal South Carolina and an analysis of specific measures currently undertaken to adapt to SLR. The information presented in this report is based on: (a) a review of reports and other relevant documents published by water agencies operating in the region, and (b) experiential accounts offered by "stakeholders" (i.e., water infrastructure managers) in the South Carolina coastal community. Due to changing precipitation cycles, associated storm intensities and flooding, special emphasis is laid upon the realities of storm-water infrastructure in the South Carolina low country. We are interested in finding answers to some of the following questions: Just how resilient are storm-water infrastructures in SC? How are they failing? How can they be improved? How can we learn to better manage the storm-water surges of the future? How can we decrease the vulnerabilities of populations (businesses, schools, neighborhoods) to SLR? In this report, we hope to shed light on these issues by documenting the *status quo* in terms of perceptions of SLR on water infrastructure and cataloguing adaptation measures already introduced. In a subsequent report, we will suggest possible improvements to storm-water infrastructure that will enable preserving South Carolina's coastal environment, culture, and economy in the years ahead.

2. Study Methodology

The methodology for this project is two-fold. It entails (a) a synthesis of knowledge from primary documents and published reports concerning sea level rise on water infrastructures in coastal SC, and (b) direct engagement with practitioners of water infrastructure management in coastal SC through a collaborative process known as the *participatory learning and action* (PLA*)* approach.

The PLA method views research as a dialogical process between experts, practitioners and members of the community. While the history of PLA can be traced to the 1960s (Voinov, 2010), in the 1990s it became an accepted tool for research, planning and development (Chambers, 2007; Sandker et. al., 2010). There are a variety of specific data generating practices associated with the PLA approach, including participatory mapping; participatory modelling; proportional piling; pocket voting; as well as linkage, trend and seasonal diagramming (Chambers, 2002; Chambers, 2007). Contrasted with more traditional scientific approaches where the researcher is removed from the object of his or her research, PLA minimizes distance by empowering local actors to take ownership in the research project. Researchers are not viewed as outside investigators, but as collaborators who will assist in the analysis of local data and exchange information and ideas.

Figure 1. Proposed Participatory Learning and Action Process

To this end, in early 2015 the research team reached out to a number of relevant water management practitioners in the South Carolina low country. These experts consisted of managers of water utility organizations and also members of consumer/social and environmental groups. They were informed about the purposes of the study. They were invited to participate in order to document current impacts of climate change in their local communities and share adaptation measures currently underway. Individuals who answered in the affirmative in the project became a member of the Research Stakeholder Group (RSG).

As depicted in Figure 4, the main idea in the PLA is to facilitate information sharing and consensus building, in this case, on the impacts and respective timelines of SLR in relation to water infrastructure in SC's coastal communities. Follow-up discussions and subsequent meetings over the next two years will provide additional levels of detail about the extent of SLR impacts and feasibility of current and future adaptability measures. The essential idea is for the research team to learn from local actors, classify, categorize, and synthesize the information they provide, and then investigate further to develop the best set of adaptation measures possible.

The first meeting with the RSG was held in Charleston, SC on Friday, April 22, 2016. A total number of ten RSG members from nine different organizations participated in this meeting in addition to four members of the research team. The organizations represented included a few municipal corporations, public water utilities, environmental protection groups, a non-profit water infrastructure-related trade association, and the research sponsor South Carolina Sea Grant Consortium.

The purpose of the first meeting was to host an introductory exchange of ideas with RSG members, document the status quo of climate change impacts, discuss the currently-implemented mitigation or adaptation measures of SLR in coastal South Carolina, and identify the critical

constraints in the adaptation process. Our exchange with the RSG members in this meeting along with careful study of other relevant reports, has led us to the preliminary findings presented in this document.

3. Study Findings

The findings of this study are grouped into three broad categories: (a) observed impacts of SLR in coastal SC communities, (b) currently undertaken adaptation countermeasures to mitigate the effects of SLR, and (c) the critical constraints in adaptation processes to SLR.

3.1 Impacts of Sea Level Rise in Costal SC Communities

From the consulted reports and RSG feedback, the general consensus seems to be that despite the recognition of threats resulting from SLR, the rapidity with which hurricanes strike and the magnitude of their destruction make them (along with other extreme storm events) a greater priority in planning. As a slowly emerging threat, SLR can be imperceptible in the short term, leading some to be skeptical of even studying the issue, let alone spending money trying to address it. Tropical storms and hurricanes, on the other hand, have an immediate urgency which cannot be wished away. Rather than viewing them as discrete phenomena, however, it is better to understand how SLR and extreme weather events feed off each other. The effects of sea level rise are magnified by storms that can potentially bring to the streets more water than would occur just through sea level rise and tidal flooding alone. This threat is given serious consideration by many water agencies operating in the region, whose missions involve extreme weather management. Nevertheless, the perception of various threats from sea level rise was clearly evident among various RSG members, who indicated that the frequency and intensity of coastal flooding was getting worse. However, not all water agencies responded to threats of SLR in the same way. The threats of SLR on coastal SC communities themselves varied depending on factors such as land elevation, proximity to the ocean, drinking water intakes, land use patterns, policies, and financial capacities. Nevertheless, a few general impacts have been reported that are worth discussing.

3.1.1 Nuisance Flooding

Flooding of streets and homes from regular storm events and tidal activities is perceived to be a potent threat that is becoming increasingly common in some coastal communities of South Carolina such as Charleston and surrounding regions. These "king tides" often inundate streets, and not only pose safety threats to motorists and roads, but also disrupt businesses and damage property. Flooding has severe economic consequences. Communities quickly shut down when movement of people and goods is restrained due to inundated roads. For the tourism-based economies of Coastal Carolina, these issues are even more acute, as visitors expect their holiday time to be as stress-free as possible. Tidal flooding in Charleston in the 1970s averaged 2 times per year, while in the early 2010s it is up to 11 times per year and projected to be 180 times per year by 2045 (City of Charleston, 2015).

One major challenge to drainage is the impervious cover due to the urban land use (e.g. cobblestone streets) in the peninsula region which prevents the seepage of water directly into the ground, thereby producing greater storm-water runoff (Kirk, 2010). Another reason tidal flooding is such a problem in places like Charleston is due to lack of adequate drainage systems. It is difficult to rapidly drain many areas in coastal South Carolina after a storm event due to the close proximity to the ocean and low land elevation (i.e., only a few feet above mean sea level). Furthermore, tidal activity often compromises the efficacy of outfall pipes resulting in backflow in high tide periods. As can be observed from Figure 1, outfalls can get submerged in a high tide period exacerbating the drainage problem due to lack of any differential head (Kirk, 2010).

Figure 2. Effect of high tides on storm water outfalls (Adapted from Kirk, 2010)

Exacerbating the problem of flooding are clogged storm-water inlets and drains due to trash and other debris, which diminishes the capacity of these drainage systems. Clogging poses a significant challenge to water agencies and raises questions about individual and state responsibility. For example, as a homeowner, am I responsible for keeping the surrounding drainage corridors or inlets clean or is this the responsibility of city or county government? Several water agencies currently maintain crews that clean the streets and de-clog the inlets; however, members of the RSG suggested that better citizen education will help in alleviating this problem. If citizens or neighborhood groups took more responsibility for reducing the clogging problems in and around their own homes or places of work, drainage infrastructure would be more likely to operate at full capacity and remove the storm-water more efficiently.

Recent tidal flooding in South Carolina has produced water volume previously associated with only hurricanes and other extreme weather events. The once abnormal and extreme is slowly becoming normal and customary. Flooding is one of the biggest threats to life on South Carolina's

coast and it is an issue many water infrastructure managers are grappling with. As noted later in this document, several measures have already been undertaken to deal with this growing menace.

3.1.2 Other Impacts of Sea Level Rise

In addition to nuisance flooding, several other impacts of sea level rise have been reported in the coastal region of South Carolina. For example, in areas such as Hilton Head and in the rural communities of Beaufort and Jasper counties, citizens face the threat of salt water intruding into drinking water aquifers or wells. Some vulnerable communities have already switched water sources or are planning to do so in the near future. Yet this would be difficult in the case of communities unconnected to a water utility system and who solely rely on water wells. Beaufort Jasper Water and Sewer Authority participated in a past study that evaluated the risk of salt water intrusion into their water aquifer (Savannah River) and determined that even a considerable amount of sea level rise will not have any significant impact on their source water (Conrads et al., 2013). However, as a precautionary measure, Beaufort Jasper made plans for another inlet five miles up the river in case salt water were somehow to be found in the drinking water. It is clear that the agency is cognizant of the SLR threats and subsequently evaluated the risk of salt water intrusion and determined that the risk is insignificant. It should also be pointed out that their water plant is built at higher elevation, making inundation risks negligible.

Members of the RSG also mentioned complaints of salt water intruding into the marshes which a few golf courses tap for irrigation in the Mt. Pleasant area. Salt testing on pond systems in conjunction with gauge data may reveal whether this is happening due to saltwater intruding through the ground or tidal flooding/storm drain backflows through leakages in the system.

Other impacts of flooding are the inundation of septic tanks and subsequent release of contaminated water on to the ground on Sullivan's Island and the Isle of Palms where some dwellings are not connected to a sewer network.

3.1.3 Critical Challenges

Several challenges were identified by the RSG that magnify the impacts of sea level rise in coastal South Carolina. While a majority of these issues are related to deteriorating pipeline systems that were inadequately designed in the first place, other problems have regulatory dimensions that must be addressed.

A common problem identified by several RSG members is the deteriorating pipeline infrastructure that is critical to efficient drainage of the urban environment. While the pipeline infrastructure was inadequately designed when it was put in place, severe deterioration resulting from aging and salt water exposure has introduced inflow/infiltration issues that exacerbate flooding-related challenges. There are many uncertainties regarding the life span of pipe materials, especially in environments of less favorable soil, high pH water, and salt water. For example, in Mt. Pleasant, it was particularly highlighted that the reinforced concrete pipes used for storm-water drainage corroded due to salt water exposure. Similar deterioration trends were reported for clay pipe in Charleston.

Many storm-water pipelines in coastal South Carolina region are inadequate in size and inappropriate in layout. The storm-water infrastructure makes it harder to drain the city during extreme storm events and/or tidal activities. Lack of comprehensive system-level planning limits the capacity to plan for additional drainage inlets and backflow preventers. While the upsizing of pipelines could help, such a strategy would not only involve significant costs, but also practical challenges. For example, issues of right of way and the need for sufficient cover depth may result

in the deep burial of replaced storm-water pipelines making the drainage problem even more intractable due to negative head at outfalls which results in severe backflows.

Other significant challenges related to SLR and water infrastructure reported by RSG members included: (a) the fact that Charleston City is mostly built upon shallow depths of soil cover that have historically been filled with trash and garbage resulting in subsidence from tidal flooding and sea level rise, (b) the observation that newer neighborhoods are built on very unstable marshland in poor drainage areas which could create serious structural problems for the buildings in the event of a major storm or earthquake, and (c) the remark that while a majority of the structures built after the flood maps were developed are designed for the storm surge (and therefore should be better able to weather the threats of SLR), many roadways which were allowed to be built at relatively low elevations makes them highly vulnerable to inundation. It was suggested by the RSG that more robust regulations for road elevations could have alleviated some of the flooding in the area.

3.2 Adaptation Countermeasures Undertaken

In the face of a natural disaster, one initial possible response is that of evacuation – of fleeing one's community for higher ground. While there are times when evacuation is the most appropriate option, there are also adaptation measures to SLR that try to prevent or minimize the effects of a disaster in the first place. Some SC water agencies have already implemented preventative adaptation measures while others are at various levels of planning to formulate strategies for adaptation. This section summarizes adaptation measures currently undertaken by water agencies in the region as well as regulatory changes passed to make communities more resilient.

3.2.1 Implemented Adaptation Measures

In 2015, the City of Charleston drafted a comprehensive strategic plan that will enhance the city's infrastructure to cope with the emerging flooding-related threats of sea level rise (City of Charleston, 2015). In their sea level rise strategy document, the city identified 78 specific initiatives that are grouped into three overarching categories: "Reinvesting," "Being Ready," and "Responding" classes. An example of *reinvesting* would be capital improvements to existing infrastructure. *Being ready* involves everything from educating the public to revising building codes. *Responding* involves assistance and safety during and after an extreme weather event. The City has already implemented (some partially and others completely) several of the initiatives identified in their strategic plan. The plan emphasizes the need to enhance the drainage infrastructure in the region and describes in great detail the specific measures already adopted or in the planning to adopt.

An obvious practical solution for the nuisance flooding problem is to build more pump stations for the flood-prone regions that will provide the necessary head to rapidly push tidal flows and runoff through the outfalls even in a high tide period. Two pump stations have already been constructed on the Charleston peninsula (namely at Concord Street and MUSC) (Kirk, 2010). Efforts are underway to build more pumps. The City of Charleston has spent or has set aside funding to complete ongoing projects in the amount of approximately $235 million. A major chunk of this investment went into the Spring/Fishburne Drainage Improvement project for which the design alone cost the city $5 million (Kirk, 2010). Construction of this five phase project began in 2011 and it is expected to be completed by 2020 (City of Charleston, 2015). The total estimated cost of this project is $154 million. The effort will upsize drainage pipelines, improve surface collection efficiency, install multiple drop shafts and a system of 12-ft diameter tunnels deeper

(≈140 ft cover depth) in the ground, and build additional pumping capacity and discharge piping for outfalls (City of Charleston, 2015).

Water managers in other municipalities (e.g. Mt. Pleasant) are systematically assessing their water pipeline infrastructure, especially the condition of reinforced concrete pipelines exposed to salt water. The goal is to identify deteriorated pipelines to be rehabilitated using pipe lining methods. Pipeline rehabilitation through lining is a relatively cheaper option than replacing entire pipeline systems and it defers the need for absolute replacement by at least twenty years, if not more.

As the City of Charleston suggests, "the biggest detriment to the surface collection system is trash and debris" (Kirk, 2010). Mt. Pleasant and Charleston have workers frequently cleaning storm water intake points. This reduces the clogging problem and allows drains to work more effectively. Jet vacuum trucks are used in Charleston to clear storm drains from trash, leaves and other debris on both sides of city streets.

3.2.2 Adaptation Measures at Various Levels of Planning

Several additional adaptation measures that are either in the planning stage or scheduled to be executed in the near future were pointed out by members of the RSG. Some noteworthy initiatives include the following:

- To be able to better adapt to hurricanes, a few cities seemed interested in replacing causeways with bridges, thus physically bypassing flood prone regions for motorists and others. Apparently, this consideration has been proposed to other relevant agencies in the region.
- The South Carolina Department of Natural Resources (SCDNR) is doing a study on rehabilitating stream flow gauges throughout the state and reactivating them. A lot of the

freshwater gauges were reported casualties of the October 2015 flooding events. The DNR study is proposing to mimic a FIMAN (Flood Inundation Mapping and Alert Network) currently in use in North Carolina. This is a real-time stream flow model that alerts counties who have bought into the model for better preparedness. It is expected that SC Counties will soon be given the opportunity to participate in this multi-million dollar project.

- The City of Charleston is planning to increase the height of the wall of the historic Battery by 30 inches. This comes on the heels of renovations to the 100 year old 1.2 mile structure already underway (Kropf, 2013).
- RSG members from different regions of the study area reported participation in internal or external research projects related to storm-water flooding.
    - The City of Mt. Pleasant is studying (from the October 2015 flooding event) low-level vulnerable roads to predict the level of tides for which they would need to set up road closure signs, and to eventually benchmark the noted elevations. They are also participating in studies to evaluate and gather model level data (SWMM) on infrastructure vulnerabilities. To address the salt water issues at golf courses, the city is evaluating the tidal backflow preventers, replacing them where necessary, to protect the storm-water infrastructure. They have also invested in monitoring predicted tidal activity in relation to wind intensity as it has been observed that the tides can become larger than expected due to wind.
    - The City of Charleston's engineers are currently developing a flood model for the Calhoun west drainage basin by incorporating the storm-water pipeline infrastructure. City of Charleston is also currently participating in another study funded by the South Carolina Sea Grant Consortium in which Charleston's storm-

water infrastructure data is used to assess how predicted flooding is impacted by the existing pipeline infrastructure.

Overall, there appears to be a general recognition among the RSG of the interdependencies among infrastructure systems; especially the dependency of water infrastructure on the functioning of power infrastructure and the subsequent need to analyze both the infrastructures together for hazard-related planning purposes. For example, power supply systems should be installed above predicted storm surge levels due to their prominence in the functioning of other critical infrastructures.

3.2.3 Regulatory Measures

In addition to physical infrastructure improvements, water agencies have also relied on regulatory changes that would reduce the consequences of sea level rise in general and nuisance flooding in particular. For example, City of Charleston currently participates in the National Flood Insurance Program (NFIP) and as a result, the City enforces regulations and building codes that require flood resistant construction, storm-water quality and quantity control (City of Charleston, 2015). Most recently, the City has adopted a new ordinance which requires new structures and those classified as substantial improvements to be built an additional one foot above the designated base flood elevation. This program is expected to make the community more flood resistant and also reduce insurance costs for citizens and businesses. It should also be noted that the City is expected to give consideration to the sea level rise's impacts while updating its Comprehensive Plan in 2016 (City of Charleston, 2015).

They City of Charleston has adopted an increasingly proactive strategy of dealing with flood events. The Emergency Management division leads the effort to coordinate with Charleston Police and Fire Departments to ensure safe access to the City. Additionally, public safety and GIS

staff at the City coordinate efforts to share real-time information regarding road closures, openings of shelters, etc.

3.3 Critical Constraints in the Adaptation Process

There seemed to be several constraints for framing and implementing adaptation measures to SLR in the concerned region. The identified constraints are classified into the following categories of economic constraints, environmental constraints, societal constraints and regulatory constraints.

3.3.1 Economic Constraints

Charleston's drainage infrastructure has been plagued with problems and inefficiencies for centuries and it is proving to be increasingly inadequate in dealing with the frequent flooding issues. Although physical infrastructure improvement in the form of newly built storage tunnels, upsized storm-water pipelines and increased pumping capacity could alleviate the flooding issues to some extent, the region fundamentally suffers from the lack of a comprehensively planned and built drainage system. This situation poses major financial challenges. Revamping the entire drainage infrastructure, even if done in many phases, would be prohibitively expensive for many locales. Even in relatively wealthy Charleston, it may cost the city billions of dollars to revamp its storm-water pipeline infrastructure. Raising capital for physical infrastructure improvements is always a challenge. Charleston has dealt with this issue successfully through a small increase in millage rates on property taxes, but that strategy might not be possible in other locations.

3.3.2 Environmental Constraints

Although not much attention has been devoted to the "quality" of the storm-water returning to the ocean, it has started to raise alarms as an issue. There are concerns of contaminated floodwater polluting natural and urban areas and the need to appropriately protect the waterways from issues resulting from stormwater drainage. Reports of low water quality have been reported in local media

outlets in the Charleston area (Peterson, 2015; Nuzum, 2016; Hucks, 2016). Myrtle Beach was also in the news recently (summer 2016) for its warnings to beachgoers about swimming in certain areas (Lipman, 2016).

3.3.3 Societal Constraints

One of the major challenges several water agencies faced until the October 2015 flooding event had been the attitude of public towards flooding and sea level rise issues. Before this event, the public was reportedly not very receptive of the proposed changes to deal with the flooding issues. Since the October 2015, however, the citizenry is reportedly more agreeable to addressing sea level rise and flooding challenges. Specifically, citizens have been more open to the buyout options of the frequently-flooded properties by the cities – an option not enthusiastically entertained prior to the October 2015 flooding event.

However, while there does seem to be better awareness about extreme related weather events and their consequences, members of the RSG members were also concerned by a lack of responsibility on the part of citizens. They lamented the lack of educational programs that, for example, make the public aware of the challenges associated with rapidly draining a large city and ways the public can help. Specifically, preventing tree cuttings and trash from clogging the storm-water inlets and drains is something the public can do easily enough to maximize the efficacy of the drainage infrastructure. It is vital to make the public part of the solution for the sea level rise problem, but giving them incentive to do so may be difficult.

3.3.4 Regulatory Constraints

The RSG members spoke of the need for consistent policies in adaptation measures across locales of the entire region (i.e., coastal SC) which might experience the effects of sea level rise issues at a similar pace. The differences between the policies adopted by counties and cities, for example,

can make it difficult for adopting a sustained adaptation action plan for the region. It was suggested that a more collaborative approach from the entire coastal region of South Carolina to deal with the challenges of sea level rise would be helpful.

4. Conclusions and Recommendations

From a global perspective, North America does not have much to worry about in terms of SLR. There will be impacts, but not nearly as serious as those faced by people in other places around the world. The general conclusion from this study is that SLR and climate change are concerns for water infrastructure managers in the South Carolina coastal community, but they are not exactly addressed as such. Rather, such concerns are expressed in a way that highlights the impact of extraordinary tidal activity combined with the effects of extreme weather events. In short, communities seem to be more worried about the immediate impacts of extreme rain, wind and flooding from hurricanes and tropical storms, rather than SLR *per se*. The rationale seems to be that if you plan for the one, eventually you will take care of the other.

One member of the RSG mentioned that water infrastructure built today is designed for a life of approximately 50 years. That seems to represent the vanishing point of urban planning. The implication seems to be that we need to think of adaptation measures that will last us at least 50 years. If the infrastructure does last 50 years and then gets replaced with an upgrade to last another 50 years, etc. one might conclude that, over time, coastal communities should be able to withstand the impacts of SLR. But, on the other hand, if it gets to the point where our infrastructure/technology is becoming obsolete or unable to cope within a faster time horizon of less than 50 years, then perhaps the problems associated with SLR will become even more pernicious and intractable.

While all the water agencies are not necessarily planning for sea level rise *per se*, they are certainly planning for changes in the weather. As we have seen, they are advocating some serious changes that will make areas along coastal SC more resilient to flooding. However, many communities are not consistently taking water management issues into account in terms of

development planning. They are not always making the most environmentally-sustainable decisions when it comes to exacerbating or mitigating the effects of flooding (whether through SLR or other events).

At the end of the day, water agencies in coastal SC seem to be doing what they can to ensure that their communities will survive the threats of SLR. In future work, we will address how water management planners in locales such as Miami, FL, New Orleans, LA, New York, NY, and Norfolk, VA, are addressing similar concerns to those faced in South Carolina. By assessing the efficacy of existing adaptation measures currently in place in SC and also by looking at measures undertaken elsewhere, it is hoped we can develop a set of recommendations that will better enable water agencies in coastal SC to deal with SLR impacts.

5. References

Chambers, Robert. 2002. Participatory Workshops: A Source Book for 21 Ideas and Activities. Routledge.

Chambers, R. (2007). Who counts? : the quiet revolution of participation and numbers. Working paper series, 296. Brighton: IDS. Available online at: https://www.ids.ac.uk/files/Wp296.pdf, Accessed on 1st July, 2016.

Conrads, P. A., Roehl, E. A., Jr., Daamen, R. C., and Cook, J. B. (2013). Simulation of salinity intrusion along the Georgia and South Carolina coasts using climate-change scenarios. USGS Scientific Investigations Rep. 2013–5036, Reston, VA.

City of Charleston. (2015). Sea Level Rise Strategy. Available online at: http://www.charleston-sc.gov/DocumentCenter/View/10089, Accessed on 1st July, 2016.

Hucks, Davis. (2016). Child Ill After Swimming in NMB. July 4. Available at: http://www.myrtlebeachsc.com/child-deathly-ill-swimming-nmb/.

Kirk, S. A. (2010). Why Does It Seem Like Charleston Always Floods When It Rains? Available online at: http://sc-charleston.civicplus.com/DocumentCenter/View/574, Accessed on 1st July, 2016.

Kroph, S. (2013). Battery seawall fixes moving ahead. Available online at: http://www.postandcourier.com/article/20130519/PC16/130519169/1009/battery-seawall-fixes-moving-ahead&source=RSS, Accessed on 25th July, 2016.

Lipman, A. (2016). Doctors respond to health concerns after Facebook post about beach bacteria. Available online at: http://www.wmbfnews.com/story/32377756/doctors-respond-to-health-concerns-after-facebook-post-about-beach-bacteria, Accessed on 6th July, 2016.

NOAA. (2014). Sea Level Rise and Nuisance Flood Frequency Changes around the United States, NOAA Technical Report NOS CO-OPS 073.

Nuzum, Lydia. (2016). Health Officials: Myrtle Beach Open, Not Under 'Do Not Swim. *Charleston Gazette-Mail*. March 19. Available online at: http://www.wvgazettemail.com/news/20160319/health-officials-myrtle-beach-open-not-under-do-not-swim.

Peterson, Bo. (2015). Fishable? Swimmable? Charleston Waters in Trouble. *Charleston Post & Courier*. April 19. Available online at: http://www.postandcourier.com/article/20150419/PC16/150419369.

Sandker, M., Campbell, B.M., Ruiz Perez, M., Sayer, J.A., Cowling, R.M., Kassa, H. and Knight, A. (2010). The role of participatory modeling in landscape approaches to reconcile conservation and development. *Ecology and Society*, 15(2).

S.C. Department of Natural Resources. (2011). Climate Change Impacts to Natural Resources in South Carolina. Available online at: http://www.dnr.sc.gov/pubs/CCINatResReport.pdf, Accessed on 1st July, 2016.

U.S. Census Bureau. (2015). New Census Bureau Population Estimates Reveal Metro Areas and Counties that Propelled Growth in Florida and the Nation, Press Release Number: CB15-56, Available online at: http://www.census.gov/newsroom/press-releases/2015/cb15-56.html, Accessed on 1st July, 2016.

Voinov, A. A. (2010). *Participatory Modeling: What, Why & How?* Document available at: http://www2.econ.iastate.edu/tesfatsi/ParticipatoryModelingWhatWhyHow.AVoinov.March2010.pdf, Accessed on 1st July, 2016.