COASTAL RESILIENCY: ADAPTING TO CLIMATE CHANGE IN HAMPTON ROADS

This report was funded, in part, by the Virginia Coastal Zone Management Program at the Virginia Department of Environmental Quality through Grant # NA11NOS4190122 of the U.S Department of Commerce, National Oceanic and Atmospheric Administration, under the Coastal Zone Management Act of 1972, as amended.

The views expressed herein are those of the authors and do not necessarily reflect the views of the U.S Department of Commerce, NOAA or any of its subagencies.

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Prepared by the staff of the Hampton Roads Planning District Commission

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ABSTRACT

This report provides a summary of the Hampton Roads Planning District Commission's Coastal Resiliency work for FY2012 and FY2013. The report contains six major parts. The first part describes global sea level rise scenarios and projections, including recent scientific findings related to the acceleration of sea level rise. The second part discusses how adaptive management, a form of planning usually associated with natural resources planning, and other planning paradigms can be used to plan for sea level rise. The third part discusses where and how local governments can plan for sea level rise in their existing planning processes. The fourth part describes efforts to update sea level rise inundation maps with new elevation data. The fifth part summarizes the various outreach and coordination efforts HRPDC staff has participated in during the grant. The sixth and final part summarizes the project's activities, findings, and recommendations. There are also four appendices.

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EXECUTIVE SUMMARY

Since 2008, the Hampton Roads Planning District Commission has been engaged in a series of projects, studies, and efforts related to helping the region adapt to more frequent flooding, rising sea levels and other projected impacts of climate change. These efforts have been funded in part by the National Oceanic and Atmospheric Administration (NOAA) through the Virginia Coastal Zone Management Program (VCZMP) and Virginia Sea Grant (VSG) as well as contributions from local governments in Hampton Roads. The largest of these efforts was a three-year Focal Area Grant from the VCZMP, which resulted in the publishing of three reports documenting the projected impacts of climate change on the Hampton Roads region and analyzing the region's exposure to storms and future sea level rise. This report, which documents the work done under a one-year competitive grant from the VCZMP, continues the work begun under the focal area grant. This project had three goals: continue working to develop useful geographic information systems (GIS) tools for local governments to use when planning for sea level rise, research and identify ways local governments incorporate planning for sea level rise into their existing plans and policies, and continue outreach and coordination efforts with regional stakeholders on sea level rise and related issues. The report makes the case that planning for sea level rise now or in the near future is essential, even though there is no way to know with certainty how much sea level rise will eventually occur nor how fast it will rise.

This report consists of six substantive sections. The first part describes global sea level rise scenarios and projections, including recent scientific findings related to the acceleration of sea level rise. The second part discusses how adaptive management, a form of planning usually associated with natural resources planning, and other planning paradigms can be used to plan for sea level rise. The third part discusses examples of where and how local governments can plan for sea level rise in their existing planning processes. The fourth part describes efforts to update sea level rise inundation maps with new elevation data. The fifth part summarizes the various outreach and coordination efforts HRPDC staff has participated in during the grant. The sixth and final part summarizes the project's activities, findings, and recommendations. There

are five appendices. The first contains sample presentations used for public outreach. The second includes draft handouts or brochures that can be posted online or used at meetings to educate the public. The third contains a list of the various elevation datasets used in creating the seamless regional digital elevation model discussed in part four. The fourth appendix consists of a new map book produced for the project, also discussed in part four. The fifth appendix contains an excerpt from U.S. Army Corps of Engineers guidance on how to incorporate sea level rise into projects in coastal areas.

Projecting Future Sea Level Rise

Research on sea level rise continues to suggest that the rate of both global and local sea level rise is accelerating, which supports various projections of global sea level rise based on climate change models. Based on this recent research, the U.S. National Climate Assessment is using four scenarios of global sea level rise as part of a risk management approach to planning for sea level rise impacts. These scenarios are 0.2m, 0.5m, 1.2m, and 2.0m of global sea level rise between 1992 and 2100. Recent research focused specifically on the Mid-Atlantic U.S. coast indicates that sea level rise is accelerating faster there than the global rate. **Local governments should seriously consider accounting for accelerated sea level rise in their development and infrastructure planning decisions.**

Adaptive Management and Sea Level Rise

Traditional planning practices are not designed to address the long time scale and uncertainty that are inherent in effectively planning for climate change and sea level rise impacts, which may not be felt for several years. Several practices exist that could be used to supplement local planning efforts; these include scenario planning, adaptive management, and anticipatory governance. **Local governments should consider using these practices to begin planning for the impacts of sea level rise.**

Incorporating Sea Level Rise Adaptation into Local Plans

Existing and ongoing local planning processes can effectively incorporate planning for sea level rise. Existing state already enables local governments to address the impacts of flooding in their plans, specifically in their comprehensive plans, capital improvement programs, and zoning ordinances. **Local governments should use appropriate studies and analyses, such as build-out analyses and mapping of vulnerable areas, to identify preferred adaptation strategies and incorporate those into their plans and policies.**

Mapping Sea Level Rise

Previous regional sea level rise mapping exercises were constrained by the absence of high resolution elevation data. To improve these mapping products, HRPDC staff identified the best available elevation data for the entire planning district and merged the several datasets to create a seamless regional digital elevation model (DEM). This DEM was then used with the scenarios from the 2013 National Climate Assessment to develop a map of areas inundated under each scenario at Mean Higher High Water by 2100. **Local governments should consider using this map for their plans or work with HRPDC staff to develop similar, locally-specific maps for planning and educational purposes.**

Climate Change Public Outreach and Education

HRPDC staff continued to present information on climate change and sea level rise impacts to groups across the region. HRPDC staff also worked with several local, regional, state, and federal partners to coordinate between related projects and inform outside efforts. HRPDC staff has also developed examples of outreach materials that can be used to help educate the public. **HRPDC staff should continue to provide updates and presentations on these issues when requested to support public education on sea level rise impacts and adaptation. HRPDC staff should continue to work with government, academic, and other partners and stakeholders on efforts in Hampton Roads to support planning for coastal resilience and adaptation to sea level rise.**

INTRODUCTION

As a coastal region engaged in industry, commerce, and tourism, the Hampton Roads region is both dependent on and threatened by the sea. Comprised of sixteen cities and counties, fourteen of which are touched by tidal waters, modern-day Hampton Roads has its location on one of the world's greatest natural harbors to thank for its economic prosperity, represented by the vast amounts of shipping that pass through its ports and the thousands of servicemen and women who report to work at the region's many military facilities each day, and its temperate climate and location at the confluence of the Atlantic Ocean and the Chesapeake Bay to thank for the millions of visitors that come each year to experience the region's amenities, culture, and history. Coastal areas like Hampton Roads are responsible for the majority of the nation's economic activity.[1] However, with the economic and quality of life benefits of living on the coast come the natural hazards that the region is exposed to each year.[2] Tropical storms, hurricanes, and nor'easters threaten the region regularly, and the same water that beckons tourists can also result in significant erosion as well as tidal flooding. Numerous studies have documented the region's exposure to storms.[3,4,5,6] However, recent research has begun to add climate change and the resulting sea level rise as another threat Hampton Roads residents and localities must address.[7,8,9] In some ways sea level rise is a great threat than storm flooding, even though its worst effects have yet to be seen. Sea level rise will both cause new problems,

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[1] Jordan Rappaport and Jeffrey D. Sachs. "The United States as a Coastal Nation." Journal of Economic Growth, Vol. 8, p5-46, 2003

[2] National Oceanic and Atmospheric Administration. "Achieving Hazard-Resilient Coastal & Waterfront Smart Growth: Coastal and Waterfront Smart Growth and Hazard Mitigation Roundtable Report. NOAA. No Date.

[3] 2011 CoreLogic Storm Surge Report: Residential Storm-Surge Exposure Estimates for 10 U.S. Cities. CoreLogic, 2011, Santa Ana, California

[4] Howard Botts, Wei Du, Thomas Jeffery, Steven Kolk, Zachary Pennycook, Logan Suhr. 2013 CoreLogic Storm Surge Report. CoreLogic, 2013, Irvine, California

[5] VIMS Recurrent Flooding Study, 2013.

[6] Benjamin McFarlane. Climate Change in Hampton Roads Phase II: Storm Surge Vulnerability and Public Outreach. Chesapeake, Virginia: Hampton Roads Planning District Commission, 2011.

[7] Susan Hanson, Robert Nicholls, N. Ranger, S. Hallegatte, J. Corfee-Morlot, C. Herweijer, J. Chateau. "A global ranking of port cities with high exposure to climate extremes." Climatic Change, 2011, 104:89-111

[8] R. J. Nicholls, S. Hanson, C. Herweijer, N. Patmore, S. Hallegatte, J. Corfee-Morlot, Jean Chateau, Robert Muir Wood. "Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates" OECD Environment Working Papers, No. 1, OECD Publishing. 2008.

[9] Benjamin McFarlane. Climate Change in Hampton Roads Phase III: Sea Level Rise in Hampton Roads, Virginia. Chesapeake, Virginia: Hampton Roads Planning District Commission, 2012.

such as inundation of coastal areas, and amplify existing issues, such as erosion, flooding, and water quality.[10] It is therefore critical that the region and its local governments continue working to adapt to the new conditions that sea level rise and climate change will force on the region's natural resources and inhabitants. It is important that local governments beginning planning for sea level rise now for two main reasons. First, many communities have developed in such a way that they are already vulnerable to sea level rise.[11] Second, in both places that have developed and those that have not, many areas that will be vulnerable or that would otherwise provide migration opportunities for natural resources are planned development areas.[12] In other words, given what is projected in terms of future sea level rise, costly decisions have already been made and are continuing to be made as more and more development occurs near the coast.

Since 2008, the Hampton Roads Planning District Commission has been engaged in a series of projects, studies, and efforts related to helping the region adapt to more frequent flooding, rising sea levels and other projected impacts of climate change. These efforts have been funded in part by the National Oceanic and Atmospheric Administration (NOAA) through the Virginia Coastal Zone Management Program (VCZMP) and Virginia Sea Grant (VSG) as well as contributions from local governments in Hampton Roads. The largest of these efforts was a three-year Focal Area Grant from the VCZMP, which resulted in the publishing of three reports documenting the projected impacts of climate change on the Hampton Roads region and analyzing the region's exposure to storms and future sea level rise. These reports have laid the foundation for the Hampton Roads Planning District Commission's continued work to provide technical assistance to local governments working on these issues. In addition to this effort, HRPDC staff has also worked jointly with several partners within and outside the region, including Old Dominion University, the University of Virginia, and the Virginia Institute of

[10] National Oceanic and Atmospheric Administration (NOAA). 2010. Adapting to Climate Change: A Planning Guide for Sate Coastal Managers. NOAA Office of Ocean and Coastal Resource Management. http://coastalmanagement.noaa.gov/climate/adaptation.html.

[11] Benjamin H. Strauss, Remik Ziemlinski, Jeremy L. Weiss, and Jonathan T. Overpeck. "Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States." Environmental Research Letters 7 (2012)

[12] "State and local governments plan for development of most land vulnerable to rising sea level along the US Atlantic coast". Environmental Research Letters 4 (2009)

Marine Science, on related efforts to promote planning for climate change, coastal resiliency, and sea level rise.

This report, which documents the work done under a one-year competitive grant from the VCZMP, continues the work begun under the focal area grant. This project had three goals: continue working to develop useful geographic information systems (GIS) tools for local governments to use when planning for sea level rise, research and identify ways local governments incorporate planning for sea level rise into their existing plans and policies, and continue outreach and coordination efforts with regional stakeholders on sea level rise and related issues. More specifically, this project continued to work on producing sea level rise inundation maps suitable for local and regional vulnerability analyses and potential inclusion in local plans. This project also looked at how localities can address sea level rise in their existing planning processes, including accounting for the significant uncertainty inherent in addressing future impacts. The report makes the case that planning for sea level rise now or in the near future is essential, even though there is no way to know with certainty how much sea level rise will eventually occur nor how fast it will rise.

This report consists of six substantive sections. The first part describes global sea level rise scenarios and projections, including recent scientific findings related to the acceleration of sea level rise. The second part discusses how adaptive management, a form of planning usually associated with natural resources planning, and other planning paradigms can be used to plan for sea level rise. The third part discusses examples of where and how local governments can plan for sea level rise in their existing planning processes. The fourth part describes efforts to update sea level rise inundation maps with new elevation data. The fifth part summarizes the various outreach and coordination efforts HRPDC staff has participated in during the grant. The sixth and final part summarizes the project's activities, findings, and recommendations. There are four appendices. The first contains sample presentations used for public outreach. The second includes draft handouts or brochures that can be posted online or used at meetings to educate the public. The third contains a list of the various elevation datasets used in creating the seamless regional digital elevation model discussed in part four. The fourth appendix consists of a new map book produced for the project, also discussed in part four. The fifth appendix contains an excerpt from U.S. Army Corps of Engineers guidance on how to incorporate sea level rise into projects in coastal areas.

PROJECTING FUTURE SEA LEVEL RISE

Effective planning for development and infrastructure near the shore requires understanding various shore processes, including erosion, tidal patterns, and sea level change. Given the significant amount of research documenting both that there is a sustained and long-running trend of sea level rise and that sea level is likely to accelerate, it is important for local planners to understand how much sea level rise is projected to occur and at what rate. Understanding the drivers of sea level rise and how they affect sea level rise rates can also help decision-makers tasked with selecting appropriate policy and infrastructure responses.

CAUSES OF SEA LEVEL RISE

Global sea level rise is one of the main effects of global climate change.[13] As atmospheric and ocean temperatures increase, several processes occur which result in higher sea levels. The largest of these factors are thermal expansion and ice melt. As water warms it expands; this on its own can result in significant global sea level rise, even without the addition of extra water from ice melt occurring over land. This ice melt comes from two sources. The first source is glaciers that are shrinking, with the resulting water eventually makes its way to the oceans. The second source occurs where massive ice sheets in Greenland and Antarctica meet the oceans; melting and ice discharge can result in significant loss to these sheets. Although there is considerable uncertainty in how and how fast this process occurs, it is expected to be one of the largest contributors to future sea level rise.[14] In addition to these sources, human activity can also directly affect global sea levels, although not on the same scale as ice melt. Examples of these types of activity include the construction of dams, which may lessen the amount of water reaching the oceans, and groundwater withdrawals, which can increase runoff.

[13] U.S. Global Change Research Program 2009

[14] Parris, Adam, Peter Bromirski, Virginia Burkett, Dan Cayan, Mary Culver, John Hall, Radley Horton, Kevin Knuuti, Richard Moss, Jayantha Obeysekera, Abby Sallenger, Jeremy Weiss. 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

At the coasts, local or relative sea level is affected by several factors. The largest of these are vertical land movement (either uplift or subsidence) and changes in large-scale ocean currents. Both factors are increasing the rate of relative sea level rise in Hampton Roads. Subsidence is the result of several geological processes, including sediment consolidation, glacial isostatic adjustment, groundwater extraction, and plate tectonics.[15] In Hampton Road, the most important of these are glacial isostatic adjustment and groundwater extraction or withdrawal. Glacial isostatic adjustment is the process by which land adjusts as heavy glaciers shift around on the surface. As glaciers cover an area, the land is actually pressed down, which results in neighboring areas not covered rising slightly in response. As glaciers melt and recede toward the poles, land that was once covered rises back up, and the areas that had been pushed up sink back down. Hampton Roads falls into the latter category, and is now sinking slowly in response to glaciers melting in the northern United States and Canada.[16] This process occurs at a scale of hundreds of miles. Groundwater withdrawals affect subsidence at a significantly smaller scale. As water is pumped out of aquifers, those formations react to the lost water by compacting. This compaction causes land at the surface to sink. Subsidence caused by groundwater withdrawal varies spatially much more than subsidence caused by glacial isostatic adjustment; rates are highest near the sites of large pumps and wells. For example, near Hampton Roads the highest rates have been observed near Franklin and West Point, both the sites of large scale paper processing facilities that rely on groundwater withdrawals. Though these high rates are localized, these large groundwater withdrawals cause subsidence across southeastern Virginia.[17]

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[15] Parris, Adam, Peter Bromirski, Virginia Burkett, Dan Cayan, Mary Culver, John Hall, Radley Horton, Kevin Knuuti, Richard Moss, Jayantha Obeysekera, Abby Sallenger, Jeremy Weiss. 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

[16] Sella, Giovanni, Seth Stein, Timothy H. Dixon, Michael Craymer, Thomas S. James, Stephane Mazzotti, and Roy K. Dokka. "Observation of glacial isostatic adjustment in "stable" North America with GPS." Geophysical Research Letters, Vol. 34. January 2007.

[17] Pope, Jason P. and Thomas J. Burbey, 2004. "Multiple-Aquifer Characterization from Single Borehold Extensometer Records." Ground Water, Vol. 42, No. 1, 2004, pp. 45-58.

GLOBAL SEA LEVEL RISE PROJECTIONS

The historic rate of global sea level rise, calculated based on long-running tide gauge records starting in 1900, is approximately 1.7mm/year.[18] However, more recent observations based on satellite altimetry have recorded rates of over 3 mm/year, and projections of future climate change indicate that rates of sea level rise could be even higher. So, while having a long historical sea level record is helpful, it should not be relied upon on its own for future planning purposes. However, on the other hand, there is considerable difficulty in projecting future sea levels based on climate models, both because the understanding of the processes that drive sea level rise and how climate change will affect sea level rise is not perfect, and because projecting future sea levels require making assumptions about events that have not yet occurred. The 2013 National Climate Assessment accounts for this uncertainty by using a suite of scenarios to develop several projections of global sea level rise by 2100, which can be incorporated into vulnerability and impact studies to inform long-term adaptation.[19] The scenarios are developed based on different methods used by researchers, with higher scenarios incorporating additional sea level rise drivers. Using this method recognizes both the need to plan for sea level rise while also not relying on a single prediction. While the scenarios could be used as individual projections, the authors' intent is for them to be used together as a risk-management exercise. Instead of a single projection for a locality or region, decisions of how to adapt to sea level rise would be made on a case-by-case basis and would depend on the use, value, and planned lifespan of the project in question. Risk tolerance would be based on the consequences that would occur and the cost that would be required to protect against sea level rise. Risk tolerance derived based on the consequences that would occur and the cost it would require to protect against that failure. Some public infrastructure or facilities are critically important, so should be designed in such a way to be protected in most or all circumstances, while other uses, such as homes, may be built to lesser standards (but still with some safeguards in mind), while others,

[18] Parris, Adam, Peter Bromirski, Virginia Burkett, Dan Cayan, Mary Culver, John Hall, Radley Horton, Kevin Knuuti, Richard Moss, Jayantha Obeysekera, Abby Sallenger, Jeremy Weiss. 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

[19] Parris, Adam, Peter Bromirski, Virginia Burkett, Dan Cayan, Mary Culver, John Hall, Radley Horton, Kevin Knuuti, Richard Moss, Jayantha Obeysekera, Abby Sallenger, Jeremy Weiss. 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

such as parks or golf courses, may be built with minimal protections in vulnerable areas because the consequences of flooding or storm surges would not be as great. The 2013 National Climate uses four scenarios of global sea level rise between 1992 and 2100, as shown in Table 1.

Table 1: Global Sea Level Rise Scenarios for the 2013 U.S. National Climate Assessment

Scenario	Global SLR, 1992-2100	Description	Appropriate Risk Tolerance
High	2.0 m (6.6 ft.)	This scenario incorporates ocean warming and the maximum possible amount of ice melt from both glaciers and ice sheet loss.	Low to none
Intermediate-High	1.2 m (3.9 ft.)	This scenario is based on semi-empirical projections of ocean warming, glacier melt, and ice sheet loss.	Some
Intermediate-Low	0.5 m (1.6 ft.)	This scenario incorporates ocean warming, glacier melt, and a limited amount of ice sheet loss.	Significant
Low	0.2 m (0.7 ft.)	This scenario is based on the long-term historic rate of global sea level rise derived from tide gauge records.	Highest

Sea level rise projection curves were developed based on these estimates using a simple quadratic equation, which incorporates the baseline historic rate (0.0017m/year) and includes a different constant for each scenario to represent acceleration:

$$E(t) = 0.0017t + bt^2$$

E(t) = global sea level rise (in meters)

t = Years since 1992[20]

b = a constant derived from each 2100 projections

These curves are shown in Figure 1.

[20] 1992 is used as the starting point for these projections because that is the midpoint for the current National Tidal Datum Epoch (NTDE) that is used to establish all tidal benchmarks (such as Mean Sea Level) for the United States. This allows for these sea level rise projections to be referenced directly to accepted tidal benchmarks.

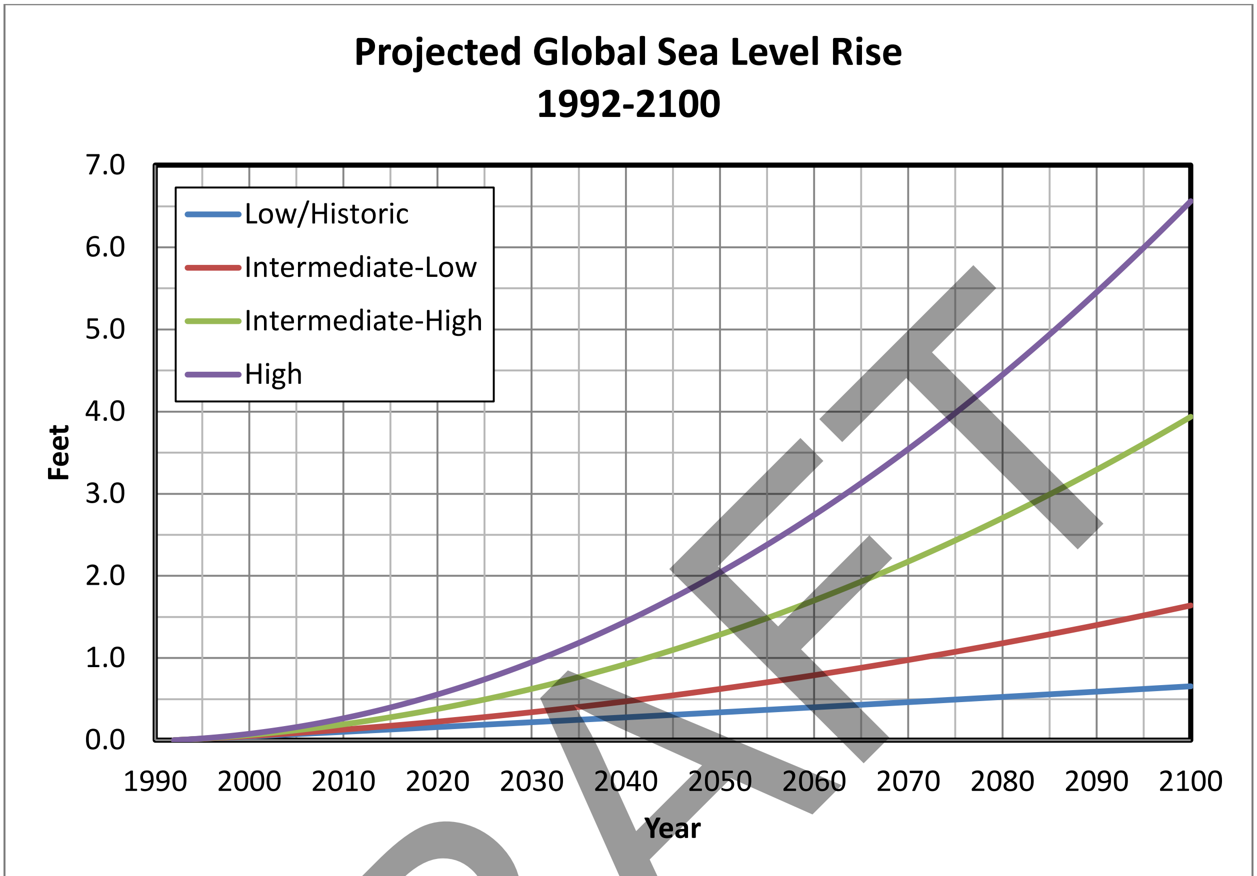

FIGURE 1: PROJECTED GLOBAL SEA LEVEL RISE, 1992-2100

LOCAL SEA LEVEL RISE PROJECTIONS

Utilizing these global sea level rise projections for local planning purposes requires adjusting the historic rate of sea level rise to account for vertical land movement. Where and when possible and necessary, a second or linear quadratic factor could be added to account for sea level rise or acceleration due to ocean currents (see discussion below). The U.S. Army Corps of Engineers, which has a policy of considering sea level rise in its civil works projects, uses 2.61 mm/year as the subsidence value for Norfolk, which results in a total historic relative sea level rise rate of approximately 4.3 mm/year.[21] The values and curves developed using the local rate with the global sea level rise scenarios are shown in Table 2 and Figure 2. This chart also incorporates the long-term historic observations, including both monthly and average mean sea level trends.

[21] http://corpsclimate.us/ccaceslcurves.cfm

This observational data was obtained from the Permanent Service for Mean Sea Level.[22] These curves can be used to develop time-based sea level rise exposure maps for the Hampton Roads region. An example of this exercise is discussed later in this report.

TABLE 2: SEA LEVEL RISE PROJECTIONS FOR NORFOLK, VIRGINIA

Scenario	Sea Level Rise, 1992-2100
High	7.5 feet
Intermediate-High	4.9 feet
Intermediate-Low	2.6 feet
Low	1.6 feet

RECENT RESEARCH

While sea level rise due to thermal expansion, ice melt, and subsidence has been studied for many years, recent research has found that changes in ocean currents are having a significant impact on local sea level rise rates. Three papers published in 2012 specifically identify accelerating rates of sea level rise affecting the Mid-Atlantic seaboard of the United States, including Hampton Roads. The first of these studies, written by Sallenger et al., identified the so-called "Northeast Hotspot", which showed increases in sea level rise between three and four time the global average from Cape Hatteras to Boston. They hypothesize that this is caused by shifts in ocean currents resulting from changes in temperature and salinity that altering the large-scale currents that move water throughout the Atlantic Ocean.[23] Specifically, a slowing of the Atlantic Meridional Overturning Circulation (AMOC), of which the Gulf Stream is a part, may be causing pressure gradients between the current and coastal waters to be decreasing, causing those coastal waters to rise.

Locally, researchers at both Old Dominion University in Norfolk and the Virginia Institute of Marine Science have been studying sea level rise by statistically analyzing records from tide

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[22] http://www.psmsl.org/

[23] Sallenger, Asbury H., Kara S. Doran, and Peter A. Howd. "Hotspot of accelerated sea-level rise on the Atlantic coast of North America." Nature Climate Change, June 2012: 884-888.

gauges. Boon (VIMS) has found statistically significant acceleration of relative sea level rise from Virginia to Nova Scotia, with acceleration as high as 0.30 mm/year^2.[24] Ezer and Corlett (ODU) found that relative sea level rise has accelerated around the Chesapeake Bay from 1 to 3 mm/year in the 1930s to 4 to 10 mm/year in 2011; they contend that this supports Sallenger et al.’s findings that changes in ocean dynamics are causing acceleration of sea level rise for the Mid-Atlantic United States.[25]

For local governments, these recent findings support several conclusions. First, observations of accelerating sea level rise have been made, both locally in Hampton Roads and across the Mid-Atlantic. While global sea level rise projections do not account for local factors such as ocean circulation, these observations of accelerating sea level rise support the position that local governments should plan for higher rates. However, this acceleration is not as well understood as other factors, and it is not clear if and how long it will continue. Continued study is needed so that this can be accounted for in local sea level rise projections.

FINDINGS

Research on sea level rise continues to suggest that the rate of both global and local sea level rise is accelerating, which supports various projections of global sea level rise based on climate change models. Based on this recent research, the U.S. National Climate Assessment is using four scenarios of global sea level rise as part of a risk management approach to planning for sea level rise impacts. These scenarios are 0.2m, 0.5m, 1.2m, and 2.0m of global sea level rise between 1992 and 2100. Recent research focused specifically on the Mid-Atlantic U.S. coast indicates that sea level rise is accelerating faster there than the global rate.

RECOMMENDATION

Local governments should seriously consider accounting for accelerated sea level rise in their development and infrastructure planning decisions.

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[24] Boon, John D. "Evidence of Sea Level Acceleration at U.S. and Canadian Tide Stations, Atlantic Coast, North America." Journal of Coastal Research 28, no. 6 (November 2012): 1437-1445.

[25] Ezer, Tal, and William Bryce Corlett. "Is sea level rise accelerating in the Chesapeake Bay? A demonstration of a novel new approach analyzing sea level data." Geophysical Research Letters 39, no. 19 (October 2012).

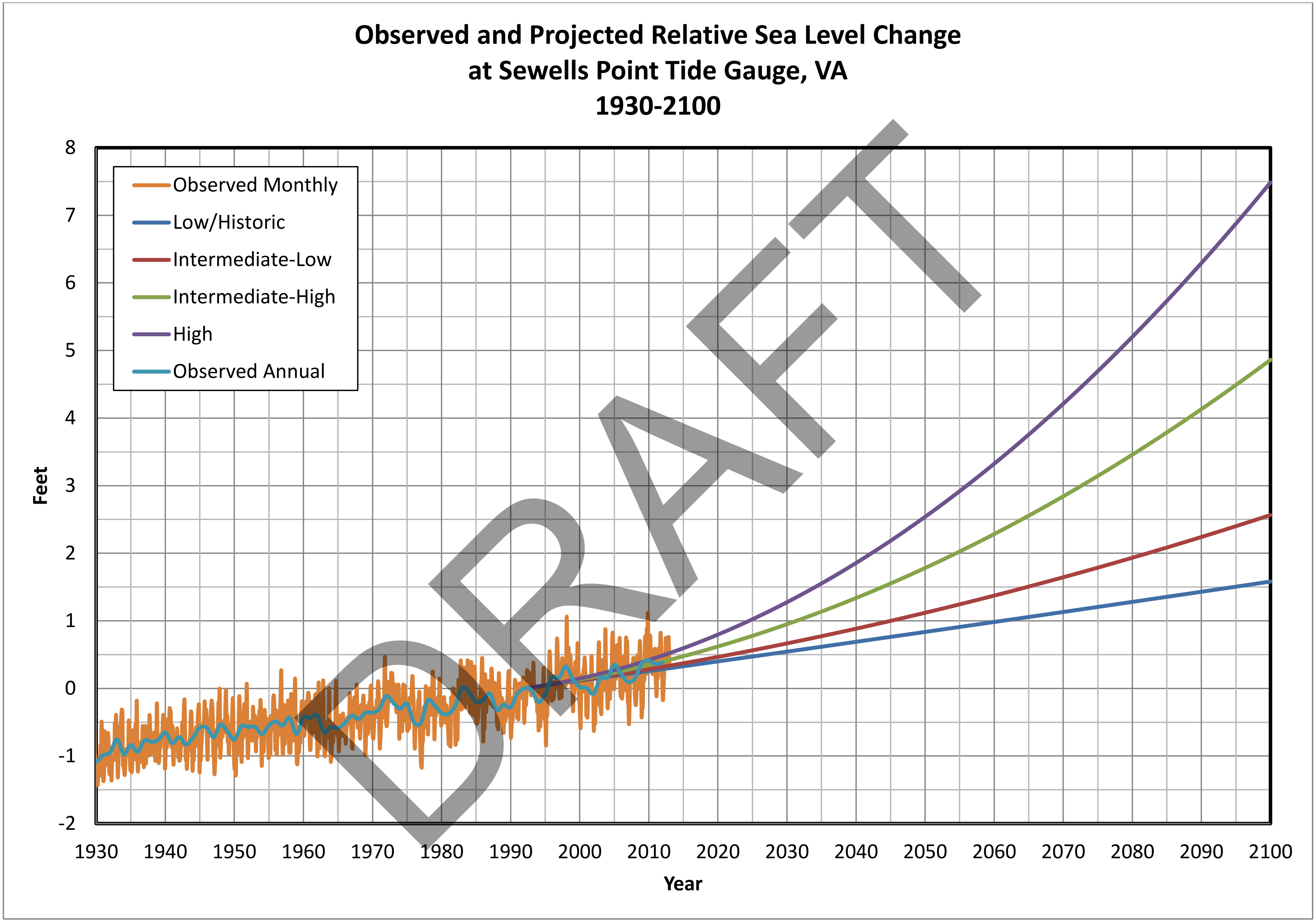

FIGURE 2: OBSERVED AND PROJECTED RELATIVE SEA LEVEL CHANGE, NORFOLK, VIRGINIA, 1930-2100

PLANNING FOR SEA LEVEL RISE

Traditional planning relies on assessing current conditions and trends using assessments and analysis of historical data. For example, large datasets such as rainfall measurements or traffic counts drive regulations and planning for water supplies, stormwater management, and transportation. However, the widespread practice of using of past data to predict the future makes this form of planning unsuitable to addressing the impacts of climate change. Climate change presents local governments with several challenges that are not typically present in most planning endeavors, including a high degree of uncertainty and a long time horizon.[26] Most planning consists of some form of assessing, predicting, and planning; a likely or desired future is expressed, and the policies needed to bring that future into being are discussed and implemented. The uncertainty in predicting climate change, as discussed in the section on sea level rise above, complicates planning by all but eliminating the possibility of a single best solution. Most plans are also limited in their time horizons; while some infrastructure plans make look several decades ahead, local comprehensive plans are often only concerned with twenty to twenty-five years, and those are usually the local plans with the longest time horizon. The time gap between when planning for climate change adaptation is needed and when the impacts will mostly be felt also makes planning and deciding more difficult, because it requires those in the present to not only make decisions without knowing the future, but also to sacrifice possible benefits in the present for potential future gain. Additional barriers include conflicting goals between agencies, citizens, and other entities, backward-looking regulatory regimes, coordination failures, and limits on institutional authority.[27] However, there are several planning practices that could, if implemented, help localities successfully adapt to the impacts of climate change, including sea level rise. Among these practices are scenario planning, adaptive management, and anticipatory governance.

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[26] Ray Quay. "Anticipatory Governance" in Journal of the American Planning Association 76:4, 496-511, 2010
[27] Louise W. Bedsworth & Ellen Hanak, Journal of the American Planning Association, "Adaptation to Climate Change" 2010, Volume 76, Number 4, Autumn 2010

SCENARIO PLANNING

Scenario planning is a technique that addresses uncertainty by considering multiple possible futures simultaneously so that decision-makers can prepare for a wide range of outcomes. [28] The underlying assumption behind scenario planning is that when dealing with uncertainty there is no "silver bullet" that will work and be preferable in all scenarios. The goal instead is to identify a strategy or a set of strategies that work in multiple scenarios; these actions are called "robust" strategies.[29] Scenarios can vary in complexity, from single factor (such as focusing only various increments of sea level rise) to complex multi-factor (which could consider additional possibilities such as the presence or absence of federal funds to assist local governments, for example). The point of scenario planning is to recognize that since there is no way to effectively predict the future, planning based on a single prediction can have significant negative consequences. In some cases, communities may spend money for infrastructure that ends up not being needed; in others, they could end up underprepared. Susskind calls for incorporating adaption planning into existing planning processes and suggests several ways to actually implement scenario planning.[30] One method is to plan incrementally as more information becomes available. Another is to identify investments or decisions that have multiple benefits and serve multiple purposes. So-called "no regrets" strategies or actions are another method; these address needs in the present while also allowing for future adaptation.

Example 1: A locality wants to address the risk of future sea level rise in the design of its public infrastructure projects. Using the local sea level rise scenarios described above, the locality assesses what specific measures must be taken to ensure the facilities do not become inundated under scenario. The marginal costs of each improvement (such as raising a road several feet, putting in additional stormwater management capacity, or changing a facility's location) can be taken into account when the locality decides whether or not to include them in the final design.

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[28] Engaging the Future: Forecasts, Scenarios, Plans, and Projects. Edited by Lewis D. Hopkins and Marisa A. Zapata. Lincoln Institute of Land Policy. Cambridge, MA. 2007.

[29] "Responding to the Risks Posed by Climate Change: Cities Have No Choice But to Adapt" Lawrence Susskind

[30] "Responding to the Risks Posed by Climate Change: Cities Have No Choice But to Adapt" Lawrence Susskind

Example 2: A locality wants to address the risk of future sea level rise and the possibility of federal assistance in the selecting adaptation strategies to address flooding issues. Sea level rise scenarios are used to assess the effectiveness of adaptation strategies, while a second set of scenarios is used to judge the possibility of implementing those strategies.

Adaptive Management

Adaptive management is a practice that promotes flexible decision-making as a way to address uncertainty in both future conditions and in the outcomes from decisions and actions. It is often used in natural resources management, as with the U.S. Forest Service, where there may be no best strategy, yet managers have to take action anyway.[31, 32] Uncertainty is addressed by acting and learning at the same time. Whereas the focus of scenario planning is still, as with traditional planning, on selecting the best or good strategies from the beginning, adaptive management focuses more on the process of finding out what those strategies are by strategizing, experimenting, learning, and reassessing and possibly changing the initial decisions that were made. The initially selected strategies are in some ways less important than the commitment to gathering feedback by observation and adjusting strategies based on that gathered knowledge.[33] Adaptive management consists of six general steps:

1) Identifying program or project goals and potential strategies
2) Selecting and implementing initial actions
3) Monitoring of implementation and results of management actions
4) Assessing performance
5) Reassessing strategies
6) Implementing new strategies (if needed)

[31] Byron K. Williams, Robert C. Szaro, and Carl D. Shapiro. Adaptive Management: The U.S. Department of the Interior Technical Guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington DC. 2009.
[32] Enabling Effective Adaptive Management in the Chesapeake Bay Program, Approved by the Principals' Staff Committee May 10, 2011
[33] Bormann, B. T. 1998. Ecosystem sustainability through adaptive management research. USDA Forest Service, Pacific Northwest Research Station, Corvallis, Oregon, USA. [online] URL:http://www.fs.fed.us/eco/s27pre.htm.

Monitoring and assessing play major roles in effective adaptive management. It is only by critically assessing whether or not actions are having their desired effects that planning can achieve its goals. Indicators are one way of assessing performance. The Thames Estuary 2100 plan, which sets the plan for how the London region will adapt to sea level rise, documents a suite of indicators that are to be monitored; these will inform what and decisions need to be made, what strategies will work, and when actions need to be planned and implemented.[34] Some of these indicators are mean sea level, the physical condition of flood defense infrastructure, how often this infrastructure is used, and how many people live in vulnerable areas. The indicators are intended to both be used in monitoring but also to help with decision-making; reaching certain previously identified levels or thresholds can signal to decision-makers that certain actions must be taken.

The difference between conscious adaptive management and more traditional planning process is that the monitoring and assessing of performance is more rigorous. This rigor aims to produce a planning process that is more informed than would be otherwise, with the hope that a more informed process will result in better strategies and actions:

> "When goals and actions are identified and justified, monitoring needs can be clearly defined and monitoring resources prioritized. When monitoring information is available, assessment of progress becomes feasible, and reporting of performance is enabled. When performance is assessed in this manner, decisions are informed, and adaptive management occurs."[35]

Example: A locality wishes to use land use policies and incentives to gradually move development out of areas that are vulnerable or will be vulnerable to flooding caused by sea

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[34] Thames Estuary 2100 Plan Chapter 5

[35] Enabling Effective Adaptive Management in the Chesapeake Bay Program, Approved by the Principals' Staff Committee May 10, 2011

level rise. Several policies are selected, with metrics identified to test whether or not these new programs are being taken advantage of and used by the public. Monitoring of these metrics can be used to adjust the incentives over time to increase participation or reduce public support if it is not needed.

Anticipatory Governance

Anticipatory government is essentially the combination of scenario planning and adaptive management, with an emphasis on choosing strategies and decision pathways that are flexible. Anticipatory governance uses scenario planning to envision possible futures and develop strategies and combinations of strategies. Adaptive management is then used to modify and change strategies to account for new information and changing conditions. According to Ray Quay, anticipatory governance is "a system of institutions, rules and norms" that relies on anticipating future conditions in order to both reduce risk and increase capacity to respond to those conditions early on.[36] Quay identifies three main steps to implementing anticipatory governance. The first is analysis of possible futures (i.e. scenario planning). Following this, decision-makers would develop, consider, and implement one or more adaptation strategies. Once these strategies are implemented, they and the environment are monitored, with additional actions taken as necessary (i.e. adaptive management). Quay identifies three specific categories of strategies. No regrets strategies that can be implemented in the present and will provide ongoing benefits without impeding future decision making. Worst case strategies are the most extreme and are designed to work under all possible futures. Robust strategies work across multiple scenarios, balancing the need to adapt with the recognition that accepting some level of risk can be more cost-effective than simply planning for the worst case.

Similar to adaptive management, anticipatory governance requires the implementation of a monitoring program that informs future decision making. Metrics are used to assess how individual strategies are working out, and indicators (also referred to as "signposts" or "trigger

[36] Ray Quay. "Anticipatory Governance" in Journal of the American Planning Association 76:4, 496-511, 2010

points"[37]) are identified to provide warning of when future decisions will need to be made or actions implemented. However, anticipatory goes above and beyond both scenario planning and adaptive management in a few key ways. First, anticipatory governance recognizes that actions and strategies are related to and depend on one other for their success or failure; a strategy embarked on in present may enable or impede another strategy in future years. Anticipatory governance also emphasizes prioritizing strategy development and implementation based on managing risk: the higher the consequences and/or likelihood of impacts, the more important it is to develop and implement strategies. The use of "flexible adaptation pathways," a term developed for New York City's climate change adaptation plans, allows decisions to be made starting in the present and then, based on monitoring, communities can ramp up adaptation efforts or scale them back. Another key difference is that anticipatory governance also emphasizes early recognition of and planning for decisions that will have to be made in the future. Accounting for the lead time necessary before implementing a strategy, such as that required for planning, designing, permitting, and constructing large infrastructure projects, is a highlighted component of anticipatory governance. Early consideration of and preparation for future adaptation strategies helps to maintain flexibility. In general, communities should take low-cost, no-regrets actions in the present while investigating strategies to implement in the future. An example of such a no-regrets action could be developing and implementing a floodplain management plan. Similarly, communities should both avoid making final decisions before they are required and should if possible avoid strategies that limit future flexibility.

Example: To account for the uncertainty in planning for sea level rise, a locality uses several scenarios to identify appropriate adaptation measures. These measures are grouped into paths, with easier/less-expensive measures at the beginning and more expensive/resource-intensive measures identified for future action. The locality also identifies several indicators to monitor to determine whether the adaptation measures are sufficient. The locality adopts three decision paths:

[37] Ray Quay. "Anticipatory Governance" in Journal of the American Planning Association 76:4, 496-511, 2010

1) This path is based on a slightly acceleration of the historic rate of sea level rise. The locality begins studying policy responses, such as incentive programs for moving out of low-lying/vulnerable areas and restrictions on shoreline protection in rural areas. The locality also identifies retrofits and maintenance needed for infrastructure facilities to improve their resilience in the face of more frequent flooding. These retrofits are prioritized based on how critical they are, and will be implemented as funding becomes available.
2) This path is based on an accelerated rate of sea level rise. Vulnerable areas and facilities to be abandoned or protected are identified (including policies and projects to achieve these results). The locality also identifies needed upgrades to flood protection infrastructure.
3) This path is based on a significant acceleration of sea level rise. Major new flood protection infrastructure projects are identified and studied because their design, funding, and construction will require many years to complete.

Indicators identified for this process include mean sea level, the rate of sea level rise, and storm activity. Monitoring any changes in the frequency of storms can indicate the need for more flood protection efforts (as opposed to adapting to inundation), while monitoring mean sea level and the rate of sea level rise can help the locality maintain its actions on the first path or move onto a more aggressive adaptation schedule.

FINDINGS

Traditional planning practices are not designed to address the long time scale and uncertainty that are inherent in effectively planning for climate change and sea level rise impacts, which may not be felt for several years. Several practices exist that could be used to supplement local planning efforts; these include scenario planning, adaptive management, and anticipatory governance.

RECOMMENDATION

Local governments should consider using these practices to begin planning for the impacts of sea level rise.

Incorporating Sea Level Rise Adaptation into Local Plans

Local governments in Virginia regularly conduct significant planning and programming exercises to guide future development, build infrastructure, and address various issues related to the relationship between the built and natural environments. Although some local governments may wish to develop standalone adaptation plans, several of these existing processes and documents are natural avenues for local governments to begin planning for sea level rise. Among these are local comprehensive plans, capital improvement programs, and zoning ordinances. Sea level rise planning and adaptation can be discussed and/or implemented in various ways through each of these documents. Governor Kaine's Climate Change Commission identified these opportunities several years ago, when it called for local governments in coastal Virginia to include projected sea level rise impacts in their comprehensive plans and to revise zoning and other ordinances to address threats to life, property, and infrastructure.[38] The Climate Change Commission also called for sea level rise to be accounted for by both state agencies and local governments in the planning, design, and selection of infrastructure projects. While planning for climate change may be a challenge, several planning and development philosophies exist that may provide some insight to localities seeking to address future vulnerable while also addressing existing needs beyond hazard mitigation. Such a multiple benefits would prove far more useful to local governments than an adaptation-only approach. Among these philosophies are resilience, smart growth, and no adverse impact.

Resilience when applied to cities refers to "sustainable network[s] of physical systems and human communities" that are "capable of withstanding severe shock without immediate chaos or permanent harm."[39] In other words, they may bend during a crisis, but they will not break. A more concrete example would be a community that must shut down during a hurricane (businesses closed and residents staying home) but whose infrastructure will protect against storm surge and where flooding will not cause permanent harm to city facilities or private

[38] Governor's Commission on Climate Change
[39] Godschalk, David R. "Urban Hazard Mitigation: Creating Resilient Cities" in Natural Hazards Review Auust 2003

property. The specifics will depend on individual communities and the hazards they face. Resilient communities are efficient, but also have redundancy built in – multiple options for transportation, for example. Their constituent parts can survive being disconnected from larger systems, such as with prepared emergency shelters.

Smart growth refers to a collection of planning policies that aim to produce livable communities that protect natural resources, mix land uses, and provide a range of options (living, transportation, working) to their residents.[40] Using smart growth can provide several benefits that also apply to adapting to climate change. Preserving and protecting green infrastructure can provide result in a community amenity, protected areas of wildlife habitat, better water quality, and flood protection (both by providing green areas that can absorb and protect against flood waters and by keeping development out of these vulnerable areas).[41] Smart growth also calls for compact growth, which can result in communities having more choices of where to locate within a given region (such as areas of higher elevation) and having less area to protect.[42] Other smart growth/adaptation policies include promoting redevelopment (in non-vulnerable areas) and investing in existing communities (by maintaining and retrofitting existing infrastructure systems).[43]

No Adverse Impact is a philosophy developed by the Association of State Floodplain Managers (ASFPM) that seeks to implement policies that promote "do no harm" policies in floodplains and coastal areas – no harm to one's own property, to one's neighbors, or to one's community.[44] This philosophy calls for anticipating the possible negative impacts of development and preventing them through public policies. These policies include higher

[40] National Oceanic and Atmospheric Administration. "Smart Growth for Coastal and Waterfront Communities." NOAA. No Date. September 2009.
[41] National Oceanic and Atmospheric Administration. "Achieving Hazard-Resilient Coastal & Waterfront Smart Growth: Coastal and Waterfront Smart Growth and Hazard Mitigation Roundtable Report." NOAA. No Date.
[42] Zoning Practice: Practice Resilience
Zoning Practice (January 2011) American Planning Association, Issue Number 1 "Coastal Hazards and Smart Growth" by John Jacob and Tommy Pacello
[43] National Oceanic and Atmospheric Administration. "Achieving Hazard-Resilient Coastal & Waterfront Smart Growth: Coastal and Waterfront Smart Growth and Hazard Mitigation Roundtable Report." NOAA. No Date.
[44] Mark Mauriello, Pam Pogue, Rodney Emmer, Phil Keillor, Alan Lulloff, Bruce Baird, Ed Thomas, Sam Riley Medlock. Coastal No Adverse Impact Handbook. Association of State Floodplain Managers. May 2007.

building code standards for development on the coasts, to protect it against flooding, storm surge, and wind damage. Another example is restricting development in floodplains to uses such as parks, golf courses, and conservation. Like smart growth and resiliency, No Adverse Impact suggests protecting natural resources on the coast and in floodplains, since they help to mitigate against flood impact. More information is available on the ASFPM's No Adverse Impact web page.[45]

Studies and Analyses

Studies (or data collection and analysis) are important components of local planning efforts, including comprehensive plans. Studies can be used to educate the public and elected officials. They can be used to inform decision-making processes. They can also provide crucial evidentiary support for policy decisions that may later be the object of legal challenges.[46] Several types of studies and analysis are particularly useful when planning for climate change or sea level rise adaptation. These include buildout analyses, mapping efforts, vulnerability analyses, and safe growth audits.

Buildout Analysis

A buildout analysis is simply a calculation of how much growth can occur in a locality, given what development is already present, how much undeveloped land is left, and what the current rules and regulations are regarding development. Buildout analyses can be used to assess how future development measures against existing capacity, to determine whether or not the allowed form of growth is desirable at its maximum extent, and whether or not future development will occur in hazard areas.[47] A buildout analysis has two main steps. The first is to prepare maps of current and projected development areas. The latter would include both completely undeveloped areas as well as areas that are underdeveloped and those that are

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[45] http://www.floods.org/index.asp?menuID=460

[46] Grannis, Jessica. October 2011. Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use. Georgetown Climate Center, Washington DC.

[47] Zoning Practice: Practice Buildout Analysis
Zoning Practice (March 2006) American Planning Association, Issue Number 3 "Buildout Analysis: A Valuable Planning and Hazard Mitigation Tool" by David R. Godschalk, FAICP

targeted for densification. The second step is to combine development regulations with projected development areas to calculate the amount of new growth that is possible under the current regime. Upon completion, the results of the analysis can be used to determine whether or not existing growth regulations are suitable or desirable.

Data Needed:

- parcel boundaries
    - zoning designations
    - development status (undeveloped, fully developed, underdeveloped)
- easements (or other undevelopable land)

Documents and Information Needed:

- zoning ordinance
    - density regulations
    - setbacks requirements
- comprehensive plan

MAPPING

Mapping exercises are particularly useful as both analytical and informational tools. When planning for sea level rise, knowledge of which areas are likely to be affected by either inundation or more frequent flooding is important to developing sound policies to address those impacts. These maps of vulnerable areas can be incorporated directly into comprehensive plans and should become important inputs to the future land use plan and map. In addition to simply mapping vulnerable areas, combining those areas with data on existing development can help planners identify which areas need to be evacuated, preserved, or protected. Jacob and Pacello advocate mapping areas based on their resilience and development status.[48] For example, vulnerable areas that are undeveloped would have low resiliency, as would areas that are developed but suffer repetitive losses. Areas with excess development capacity that are

[48] Zoning Practice: Practice Resilience
Zoning Practice (January 2011) American Planning Association, Issue Number 1 "Coastal Hazards and Smart Growth" by John Jacob and Tommy Pacello

located outside vulnerable areas would have high resilience. Generally, the goal of these mapping exercises would be to directly affect land use, development, and adaptation policies.

Data Needed:

- elevation
- sea level rise/flooding water levels

Documents and Information Needed:

- descriptions of sea level rise/inundation scenarios

Vulnerability Analysis

Vulnerability analyses build on vulnerability maps, in that they utilize GIS analysis to calculate the amount of population, assets, and resources in vulnerable areas. Somewhat related to buildout analysis, a comprehensive vulnerability or exposure analysis can help inform a community as to how vulnerable they may be as a whole and where their most valuable areas are. As with the mapping exercises described above, the goal of a vulnerability analysis should be to directly affect public policy. A second goal would be to educate the public and decision-makers about the importance of the issue.

Data Needed:

- sea level rise inundation zones
- parcel boundaries and values
- population
- businesses
- public facilities and infrastructure (roads, utilities, etc.)
- natural resources

Documents and Information Needed:

- descriptions of sea level rise/inundation scenarios

Safe Growth Audit

Safe growth audits are a comprehensive way of assessing the impact of a locality's policies and practices on its vulnerability. A safe growth audit is similar to a buildout analysis, but more comprehensive in that it would look at all of a municipality's policies, ordinances, and plans rather than just the zoning and subdivision ordinances. For example, a safe growth audit may look at a locality's policies regarding constructing new roads or accepting private roads into the public network. The goals of a safe growth audit are to: identify vulnerable areas, identify what policies may be encouraging growth in unsafe areas, and to guide new development away from those areas and retrofit or relocate existing development.[49]

Data Needed:

- parcel boundaries with zoning designations
- planned developments
- planned public facilities and infrastructure

Documents and Information Needed:

- zoning ordinance
- comprehensive plan
- capital improvements program

Comprehensive Plans

Comprehensive plans are common policy documents developed by municipalities to assess conditions and guide future growth. They are broad and general, covering a range of sectors and issues (such as transportation, land use, and natural resources). A common feature of comprehensive plans is the future land use map, which is a graphical depiction of what the municipality would like to look like by the end of the planning horizon.[50] Cities and counties in Virginia are required to develop and adopt comprehensive plans; these plans are to guide and accomplish a "coordinated, adjusted, and harmonious development" the locality's territory and

[49] Zoning Practice: Practice Safe Growth Audits
Zoning Practice (October 2009) American Planning Association, Issue Number 10 "Safe Growth Audits" by David R. Godschalk, FAICP

[50] Local Planning: Contemporary Principles and Practice. Edited by Gary Hack, Eugénie L. Birch, Paul H. Sedway, and Mitchell J. Silver. ICMA. Washington, DC. 2009 ("Making Plans – Plans that Fit the Purpose" by Barry Miller)

to “best promote the health, safety, morals, order, convenience, prosperity and general welfare of the inhabitants.”[51] Planning for flooding and floodplains is also specifically mentioned several times in the same and other sections of the Code of Virginia. The Code also directs localities to conduct surveys and studies to support the plan. In addition, comprehensive plans are to be reassessed every five years, which is an opportunity to address new research and policy developments related to climate change and sea level rise.[52] As such, planning for sea level rise is certainly in line with the goals and purposes of comprehensive planning in Virginia.

Comprehensive plans provide the most convenient and easiest way for localities to begin addressing sea level rise.[53] There are at least three types of content, already present in most comprehensive plans, that can be used: qualitative and quantitative information or data, maps, and policy discussions. Information and data can include discussions of climate change projections and impacts and the results of buildout, vulnerability, and other analyses. This information can be expressed graphically using maps, which could show vulnerable areas and local infrastructure or other assets that are within those vulnerable areas. In addition, these maps can be a very effective public outreach and education tool. Taken together, the information and maps can inform discussions of appropriate adaptation policies, such as where to implement strategies to protect, accommodate, or retreat.

Capital Improvement Programs

Capital Improvement Programs or Plans (CIPs) are documents developed by local governments to help implement parts of the comprehensive plan. These documents are significantly detailed, with a shorter time horizon (usually four to six years). The main focus of the CIP is to lay out the details of a municipality’s plans to construct new infrastructure and public facilities. Thus, a CIP will include a list of projects, along with their projected costs and timelines of construction; it

[51] Code of Virginia §15.2-2223
[52] Code of Virginia §15.2-2230
[53] Jessica Grannis. *Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use.* Georgetown Climate Center. Washington, DC. October 2011.

may also include some policy discussions or other explanatory text.[54] In Virginia, local planning commissions given authority to develop and submit capital improvement programs annual, with each CIP intended to cover a five-year period.[55] Each project description is to include a cost estimate, including an estimate of the life cycle costs. Addressing the life cycle costs of either adapting a design from the beginning or continuously updating it is an important way that local CIPs can be used to address sea level rise.

It is important for local governments to address sea level rise and climate change impacts in their capital improvement programs because these documents determine what public facilities and infrastructure get built, where they get built, when they get built, and how they are designed. They represent a significant investment on the part of local governments and their citizens. In addition, public infrastructure is a major driver of private development; new construction by locality generates new private development and where it gets built. Localities should want to build public infrastructure where they want private infrastructure to go as well. Thus, building new roads or other facilities in areas that will be vulnerable to sea level rise can be counterproductive in two ways: it can result in more vulnerable private development and waste public funds.[56] It is therefore important for CIPs to be in alignment with comprehensive plans (that address sea level rise) in determining the types and locations of new infrastructure projects.

If a locality needs or wants to build a facility in an area that is or could be vulnerable to sea level rise, it should consider using a scenario-driven approach to determine what, if any modifications should be made to the design of the facility to ensure it performs its necessary functions. This can be a general assessment of the facility's expected life and its importance; the longer it will last and the more important it is for it to be operational, the more it should be strengthened to account for sea level rise. A more rigorous example of this sort of assessment

[54] Local Planning: Contemporary Principles and Practice. Edited by Gary Hack, Eugénie L. Birch, Paul H. Sedway, and Mitchell J. Silver. ICMA. Washington, DC. 2009 ("Making Plans – Plans that Fit the Purpose" by Barry Miller)

[55] §15.2-2239

[56] Louise W. Bedsworth & Ellen Hanak, Journal of the American Planning Association, "Adaptation to Climate Change" 2010, Volume 76, Number 4, Autumn 2010

is provided by the U.S. Army Corps of Engineers in a recent circular. Engineering Circular 1165-2-212, consisting of scientific background information, a question/decision tree, and a flowchart, shows how planners can determine if and sea level rise should be incorporated into a project’s design.[57] The decision tree and flow chart are included in Appendix E.

The CIP can also incorporate sea level rise adaptation and planning through the actual selection of projects. It is possible that, given the uncertainty in how much sea level rise will occur, when it will occur, and whether historical funding sources will be available, traditional forms of large-scale infrastructure facilities and projects will be possible or feasible. Projects that can be funded incrementally, so that they can be improved without completely reconstructing them, may be preferable.[58] Distributed, modular systems, if possible, may also work better, in terms of both funding and disaster preparedness.[59]

ZONING ORDINANCES

While capital improvement programs are where localities can adapt their infrastructure to climate change impacts, local zoning ordinances are where public policies and influence and regulate private decisions. The Code of Virginia specifically authorizes local governments to adopt zoning ordinances to regulate the use of land, buildings, and structures for various uses, including flood plains, all to promote the “health, safety or general welfare of the public.”60 Zoning ordinances are a very powerful tool for local governments trying to use regulations to make their communities adapt. At the most basic level, zoning ordinances can be used to control what types of uses go in which locations, and how intense those uses may be. For example, a locality could zone its floodplains to be used only for very light residential development or uses such as parks. Though more effective for regulating new development, since existing development has quite a few vested rights, there are additional policies that can also be put into action using the zoning ordinance. In general, zoning ordinances can be used to

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[57] EC 1165-2-212. 1 October 2011. Sea-Level Change Considerations for Civil Works Programs. U.S. Army Corps of Engineers. Washington, DC.
[58] Godschalk, David R. “Urban Hazard Mitigation: Creating Resilient Cities” Natural Hazards Review August 2003.
[59] Morrish, William R. “Resilient Everyday Infrastructure.” Places 20.3
[60] §15.2-2280 and §15.2-2283

move development out of vulnerable areas, either by restricting (directly, through density maximums) or regulating growth (through setbacks and other requirements) in those areas or by incentivizing growth in other places. An additional approach could be to establish overlay district designations for vulnerable areas, which would implement new regulations (such as base flood elevations) for development in those areas.[61] Local governments can also regulate floodplains, including areas prone to flooding that are outside the 100-year floodplain designated by FEMA.[62] Incentives could be as simple as not building public facilities in vulnerable areas or using density bonuses combined with cluster development[63] or transfer of development rights[64] (TDR) programs.

Resources for Local Governments

Beyond the resources referenced above, there are many others available for local governments looking for examples of good development, standards, model ordinances, and other information. The Farmland Preservation Task Force, under the Virginia Department of Agriculture and Consumer Services, developed a model Purchase of Development Rights ordinance for local government use. The model ordinance is available on the VDACS website.[65] The Virginia Association of Counties has similar developed a model Transfer of Development Rights ordinance, which is also available online.[66] The Federal Emergency Management Agency (FEMA) also publishes guidance documents and construction manuals for coastal areas; these

[61] Jessica Grannis. *Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use.* Georgetown Climate Center. Washington, DC. October 2011.

[62] Andrew C. Silton and Jessica Grannis. Virginia Case Study. Stemming the Tide: How Local Governments Can Manage Rising Flood Risks. Georgetown Climate Center. May 2012 (Revised January 2013). http://www.georgetownclimate.org/virginia-case-study-stemming-the-tide-how-local-governments-can-manage-rising-flood-risks

[63] §15.2-2286.1

[64] §15.2-2316.2

[65] Virginia Department of Agriculture and Consumer Services Farmland Preservation Task Force. A Model Purchase of Development Rights (PDR) Program for Virginia. Virginia Department of Agriculture and Consumer Services. November 2005. http://www.vdacs.virginia.gov/preservation/pdf/pdfprogram.pdf

[66] Virginia Association of Counties. A Model Transfer of Development Rights Ordinance for Virginia Localities. Virginia Department of Agriculture and Consumer Services. January 2010. http://www.vaco.org/LegislativeNews/LegPubs/Model%20TDR%20Ordinance.pdf

are available online through FEMA's website.[67, 68] For local governments considering adaptation planning, both the Virginia Institute of Marine Science[69] and the Georgetown Climate Center[70] have recently published extensive reports describing the merits of various strategies.

FINDINGS

Existing and ongoing local planning processes can effectively incorporate planning for sea level rise. Existing state already enables local governments to address the impacts of flooding in their plans, specifically in their comprehensive plans, capital improvement programs, and zoning ordinances.

RECOMMENDATION

Local governments should use appropriate studies and analyses, such as build-out analyses and mapping of vulnerable areas, to identify preferred adaptation strategies and incorporate those into their plans and policies.

[67] FEMA. Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas, Volumes I and II (Fourth Edition). FEMA P-55. August 2011 http://www.fema.gov/library/viewRecord.do?id=1671

[68] FEMA. Local Officials Guide for Coastal Construction: Design Considerations, Regulatory Guidance, and Best Practices for Coastal Communities. FEMA P-762. February 2009 https://www.fema.gov/library/viewRecord.do?id=3647

[69] Recurrent Flooding Study for Tidewater Virginia http://ccrm.vims.edu/recurrent_flooding/Recurrent_Flooding_Study_web.pdf

[70] Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use http://www.georgetownclimate.org/adaptation-tool-kit-sea-level-rise-and-coastal-land-use

Mapping Sea Level Rise

Sea level rise has already resulted in significant impacts to Hampton Roads, affecting coastal and low-lying areas through temporary flooding and inundation and exacerbating issues such as erosion. Climate models from national and international bodies such as the U.S. Global Change Research Program and the Intergovernmental Panel on Climate Change project that global sea level rise will accelerate over the coming decades, which, combined intense development in coastal areas will result in even more significant impacts. Understanding both the rate and magnitude of sea level rise is critical to effective planning and adaptation in vulnerable areas. Sea level rise projections can be used to map exposed areas and analyze vulnerability, educate the public, and to develop regulations or policies for development within the identified areas. To be most useful, these projections and resulting products need to be based on both a sound understanding of how sea level rise occurs at the local scale and on geospatial data that is both accurate and precise. Since sea level rise is ongoing, maps should also reflect when the conditions they depict will occur. When these conditions are met, the resulting products should be of sufficient accuracy and utility to inform public discussion and policy.

Previous Mapping Efforts

Recognizing that sea level rise was a pressing issue for the Hampton Roads region and that geospatial analysis would help the region plan for its impacts, HRPDC staff, as part of the final year of a three-year focal area grant project[71], undertook an effort to map areas potentially vulnerable to sea level rise and calculated the natural, physical, and economic assets that could be affected within those areas. Mapping areas that are vulnerable to sea level rise is one of the first steps that must be taken in assessing an area's vulnerability.[72] This analysis was based in part on previous work by the U.S. Environmental Protection Agency, which had developed an

[71] This effort was funded in part by the Virginia Coastal Zone Management Program and the National Oceanic and Atmospheric Administration.
[72] Gesch, Dean, and Wilson, Robert, 2002, Development of a Seamless Multisource Topographic/Bathymetric Elevation Model of Tampa Bay: Marine Technology Society Journal, v. 25, no. 4, p. 58-64

elevation dataset specifically for estimating sea level rise impacts that was referenced to Spring High Water.[73] HRPDC staff used this elevation data and several regional geographical information systems (GIS) datasets to calculate the region's potential vulnerability to one meter of sea level rise in terms of population, housing, property, roads, businesses, and natural resources. This analysis demonstrated that GIS analysis could be used to help the region plan for sea level rise and that one meter of sea level rise could have significant impacts on the region's local governments and residents. As part of this analysis, HRPDC staff published a map book of areas in the region vulnerable to sea level rise. This analysis is described in greater detail in the project final report, Climate Change in Hampton Roads Phase III: Sea Level Rise in Hampton Roads, Virginia.[74]

While the previous sea level rise vulnerability analysis was useful in illustrating and quantifying the potential impacts of sea level rise on Hampton Roads, issues with the data used in the analysis made it more useful as a demonstration or first-run analysis. Specifically, HRPDC staff, with assistance from local government staff, identified two particular issues with elevation data used in the analysis. First, the dataset was very coarse. It was in an imagery format consisting of pixels that each represented 900 square meters, or nearly 10,000 square feet. This made the resulting maps too imprecise for use in local planning, either in delineating vulnerable areas for legal or regulatory purposes or for projecting impacts to specific structures or properties. Second, there was a large degree of uncertainty in the data due to the methods used in collection and processing. This made it difficult to analyze the impacts of sea level rise of less than a meter, which made it infeasible to use the various global sea level rise projections, so as those used by the U.S. Army Corps of Engineers.[75] These data issues reduced the utility of the analysis, and resulted in the report finding that the region should acquire better elevation data to improve planning for sea level rise.

[73] Titus et al. work - reference
[74] http://www.hrpdcva.gov/news/index/view/id/19
[75] USACE Circular

Recognizing the need for better elevation data, HRPDC staff worked with local, state, and federal partners to identify and collect the best available elevation data for the entire Hampton Roads region. This effort, described in the final report for HRPDC's 2011-2012 Coastal Resources Technical Assistance Program[76], resulted in collection, processing, and merging of eleven separate elevation datasets, ten of which were derived from LIDAR data. The only exception was for the areas of Fort Eustis/Mulberry Island in Newport News and Craney Island in Portsmouth; for these areas 1/3-arcsecond (10m) resolution imagery from the National Elevation Dataset (NED) was used instead. More information on these datasets is shown in Appendix C. Prior to merging these datasets, HRPDC staff reviewed literature for similar efforts to create seamless regional elevation datasets for guidance on processing the dataset.[77,78,79] In general, creating a seamless dataset requires first putting all of the input datasets into the same coordinate system, horizontal and vertical datums, and units, then, using various raster processing tools in ArcGIS, mosaicking the individual rasters together into a single dataset.

The end result of this effort was the creation of a regional seamless elevation dataset for the entire Hampton Roads Planning District that is both more accurate and higher resolution than the previous maps. Thus, it should be more useful to local governments in Hampton Roads in their adaptation efforts. This dataset is referenced to the North American Datum of 1983 (Virginia State Plane South) and the North American Vertical Datum of 1988 with a horizontal resolution of five feet. In addition to this effort, the Hampton Roads Planning District Commission, based on recommendations from HRPDC staff on the need for consistent, high-resolution elevation data, voted in July 2012 to provide financial support for a federal-state-local effort to acquire new LIDAR data for eight localities in Hampton Roads (Chesapeake, Hampton, Newport News, Norfolk, Poquoson, Portsmouth, Virginia Beach, and York County).

[76] http://www.hrpdcva.gov/news/index/view/id/1503

[77] Gesch, Dean, and Wilson, Robert, 2002, Development of a Seamless Multisource Topographic/Bathymetric Elevation Model of Tampa Bay: Marine Technology Society Journal, v. 25, no. 4, p. 58-64

[78] Dean B. Gesch. "Analysis of Lidar Elevation Data for Improved Identification and Delineation of Lands Vulnerable to Sea-Level Rise." Journal of Coastal Research Fall 2009

[79] Jason M. Stoker, Dean J. Tyler, D. Phil Turnipseed, K. Van Wilson, Jr., and Michael J. Oimoen. "Integrating Disparate Lidar Datasets for a Regional Storm Tide Inundation Analysis of Hurricane Katrina." Journal of Coastal Research. Fall 2009.

This data will be collected and processed in 2013, with a projected delivery by December 2013. Once this dataset is delivered, all of Hampton Roads will have LIDAR coverage collected since 2010.

Sea Level Rise Scenarios for Mapping

In addition to having better elevation data, the impending completion of the 2013 National Climate Assessment[80] provided a good opportunity to update sea level rise vulnerability maps for Hampton Roads that would directly relate to global sea level rise scenarios developed by the National Oceanic and Atmospheric Administration. These scenarios, as contained in the NOAA Technical Report *Global Sea Level Rise Scenarios for the United States National Climate Assessment*[81], are based on the best understanding of the forces, such as ice melt, thermal expansion, and ice sheet loss, which drive global sea level rise. These scenarios are discussed more in Section X of this report. The four global sea level rise scenarios from the National Climate Assessment are 0.2m, 0.5m, 1.2m, and 2.0 m. In developing maps for Hampton Roads, these values were converted to local sea level rise projections, using subsidence values for the Sewells Point Tide Gauge in Norfolk, Virginia. The local subsidence factor was combined with the global sea level rise rate using the same quadratic equation used by the National Research Council, U.S. Army Corps of Engineers, and the National Climate Assessment:

Global SLR Formula	$E(t) = 0.0017t + bt^2$
Local SLR Formula[82]	$E(t) = 0.0043t + bt^2$

In this formula, E(t) represents sea level rise, t represents the time in years since 1992, and b is a constant needed to fit the curve to the projected values at the end of the century. 1992 is

[80] http://www.globalchange.gov/what-we-do/assessment

[81] http://cpo.noaa.gov/Home/AllNews/TabId/315/ArtMID/668/ArticleID/80/Global-Sea-Level-Rise-Scenarios-for-the-United-States-National-Climate-Assessment.aspx
Parris, Adam, Peter Bromirski, Virginia Burkett, Dan Cayan, Mary Culver, John Hall, Radley Horton, Kevin Knuuti, Richard Moss, Jayantha Obeysekera, Abby Sallenger, Jeremy Weiss. 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

[82] This incorporates a local subsidence value of approximately 2.6mm/year

used as the base year since that is the mid-point of the current National Tidal Datum Epoch[83], which governs the establishment of tidal benchmarks. The current values for tidal datums such as Mean Higher High Water, Mean Sea Level, and Mean Low Water are all associated with that mid-point year, even though they are still in use today. For example, referenced to NAVD88, Mean Higher High Water for the Sewells Point Tide Gauge is 1.11 feet, Mean Sea Level is -0.3 feet, and Mean Low Water is -1.52 feet (the gauge is at 6.03 feet, NAVD88).[84] Thus, projections of sea level rise using 1992 as the starting year can also be viewed as projections of sea level rise from those current tidal benchmarks. Using above local sea level rise formula with the four global sea level rise scenarios from the National Climate Assessment resulted in projections of 1.6, 2.6, 4.9, and 7.5 feet of relative sea level rise in Hampton Roads by 2100.

Mapping Sea Level Rise

Local sea level rise scenarios and the seamless regional digital elevation model were the first two inputs in the development of regional sea level rise inundation maps. The methodology used to develop the inundation maps was based on the one developed by NOAA's Coastal Services Center for its Sea Level Rise and Coastal Flooding Impacts Viewer.[85] There are three basic steps to mapping inundation[86]:

1) Preparing elevation data
2) Preparing water levels
3) Mapping inundation by overlaying water levels on elevation data

Using this methodology results in maps showing areas inundated during Mean Higher High Water under given scenarios of sea level rise; in addition, the mapping process incorporates hydrologic connectivity. The process first generates a tidal surface, then calculates which areas would be inundated as that tidal surface rises due to higher sea levels.[87] Mean Higher High Water was used for this analysis because little if any development exists below that line, since it

[83] NOAA Tides & Currents
[84] NOAA Tides & Currents: Station 8638610, Sewells Point, VA
[85] http://www.csc.noaa.gov/digitalcoast/tools/slrviewer
[86] NOAA Coastal Services Center. "Mapping Coastal Inundation Primer." National Oceanic and Atmospheric Administration Coastal Services Center. April 2012. Charleston, SC.
[87] http://www.csc.noaa.gov/slr/viewer/assets/pdfs/Inundation_Methods.pdf

is regularly under water. It is also a condition that many people who work or live on the coast should be familiar with.

Creation of the tidal surface requires using NOAA's VDATUM software[88], which was developed to perform vertical transformations between various datums, including orthometric datums, such as NAVD88, and tidal datums, such as Mean Higher High Water (MHHW). An artificial grid is created in ArcMap around the region to be modeled. This grid is then converted to points that are each assigned an elevation of 0. These points are fed into the VDATUM software and are then converted from MHHW to NAVD88 to generate a conversion factor for each point. This data is fed back into ArcMap, where the conversion factors are used to interpolate a tidal surface for the entire region, since VDATUM can only directly model water bodies and areas along the coast. Once this regional tidal surface is created, mapping a set of inundation scenarios requires seven steps:

1) Merging the tidal surface with the digital elevation model (DEM) to establish a continuous land-water surface
2) Creating a single value DEM for each inundation scenario, using the Raster Calculator function
3) Evaluating connectivity using the Region Group function
4) Extracting hydrologically connected regions greater than 1 acre in size using the Extract by Attributes function
5) Clipping the resulting raster to the original DEM shoreline using a mask and the Raster Calculator function
6) Reclassifying each clipped raster to individual values for each set of sea level rise scenarios (for 2100, the low scenario was given a value of 1, the intermediate-low scenario a value of 2, etc.)
7) Merging the set of four reclassified rasters into a single raster using the mosaic function

[88] http://vdatum.noaa.gov/

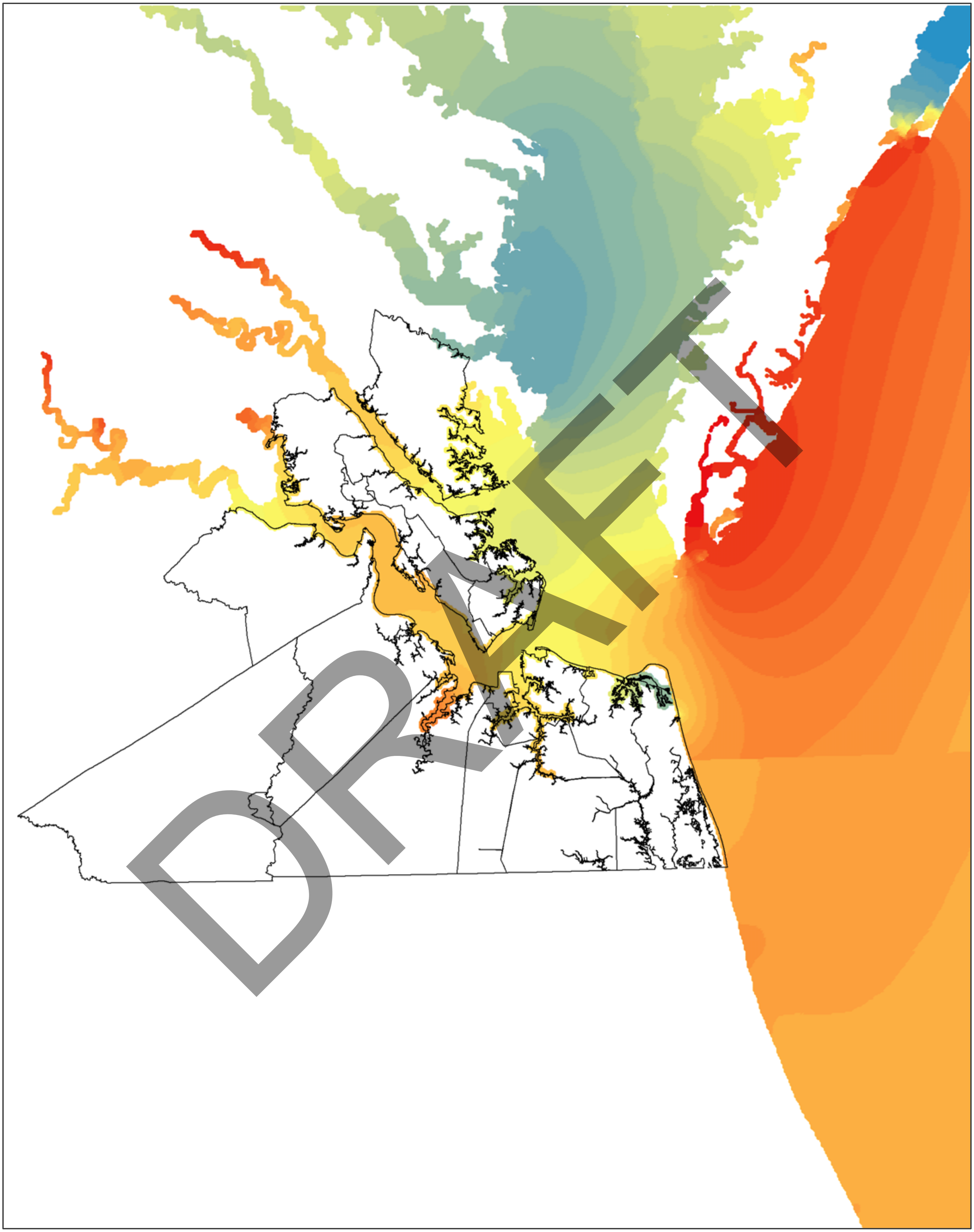
The resulting raster can then be used to illustrate vulnerable areas on maps or to analyze exposure of population and assets under each scenario. The steps in the process are illustrated below. Once finished, the merged raster was used in the creation of two map books, one using aerial photography as a background and the other using road centerlines in front of a solid background, which were provided to regional local government staff. The merged raster was also provided to local government staff in several GIS-ready formats for review and use. The map book using road centerlines was selected by the regional Joint Environmental Committee as its preferred option; it is included in Appendix D. The GIS data is available to local governments upon request. A regional map showing areas projected to be inundated at MHHW under each of the four scenarios is included below.

Findings

Previous regional sea level rise mapping exercises were constrained by the absence of high resolution elevation data. To improve these mapping products, HRPDC staff identified the best available elevation data for the entire planning district and merged the several datasets to create a seamless regional digital elevation model (DEM). This DEM was then used with the scenarios from the 2013 National Climate Assessment to develop a map of areas inundated under each scenario at Mean Higher High Water by 2100.

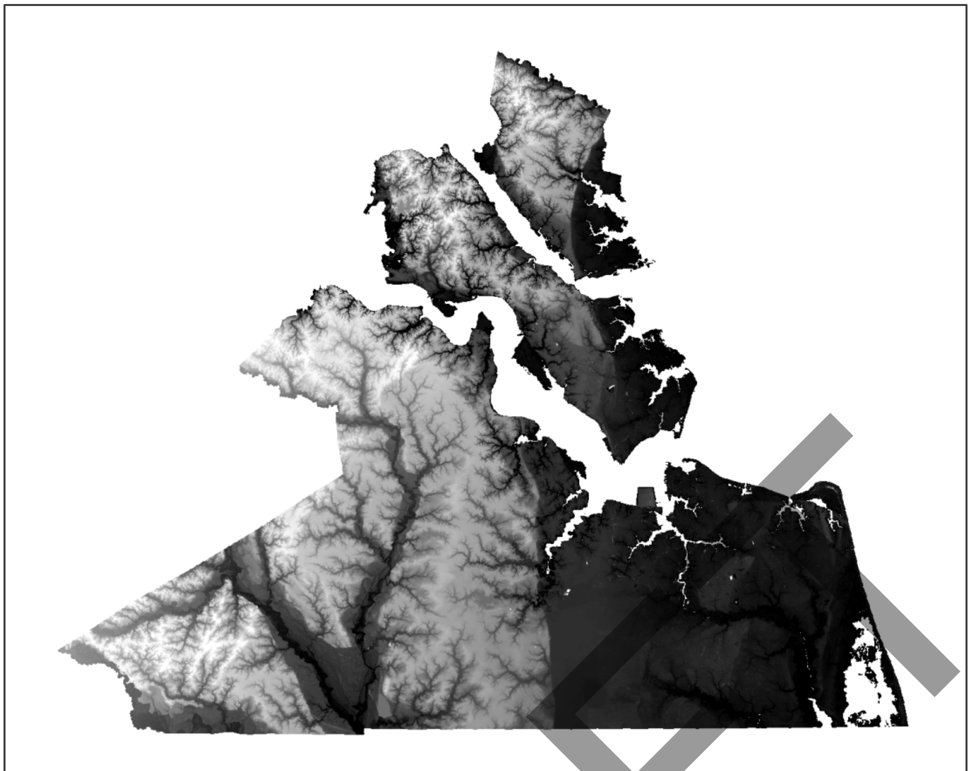
Recommendation

Local governments should consider using this map for their plans or work with HRPDC staff to develop similar, locally-specific maps for planning and educational purposes.

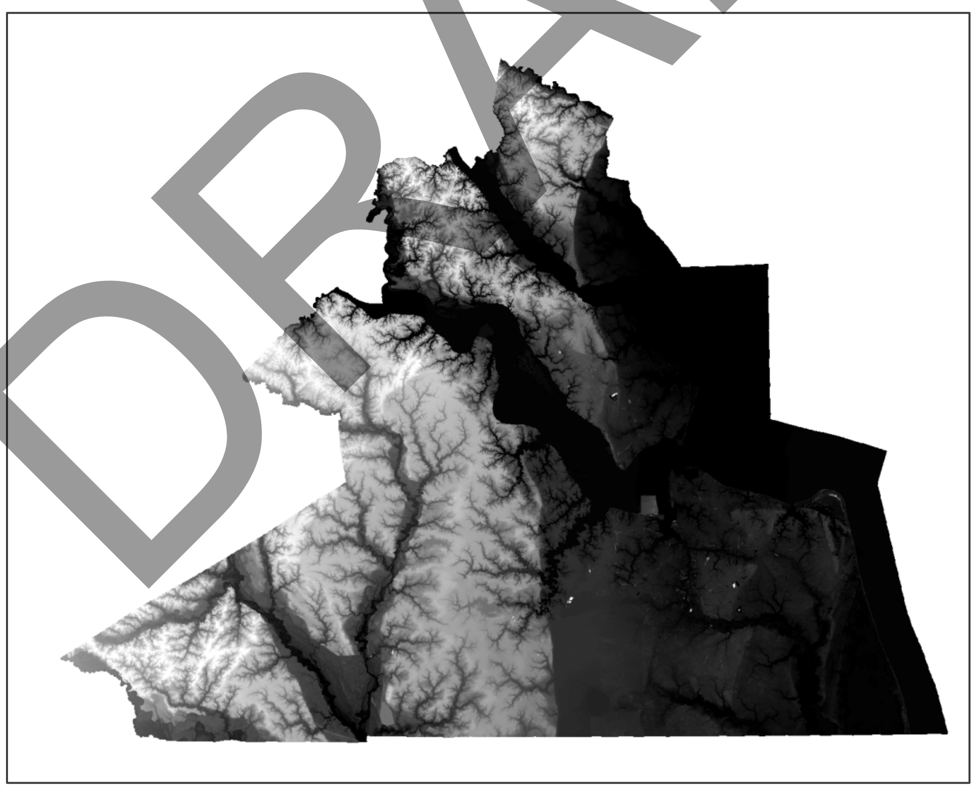


The colored areas (actually points) represent the conversion factors between MHHW and NAVD88. Bluer points have smaller conversion factors, while the red values are larger. The values are positive: [Point Value] + NAVD88 = MHHW.

The regional Mean Higher High Water surface was created using Inverse Distance Weighting (IDW) Interpolation. The regional boundary is shown to illustrate scale.

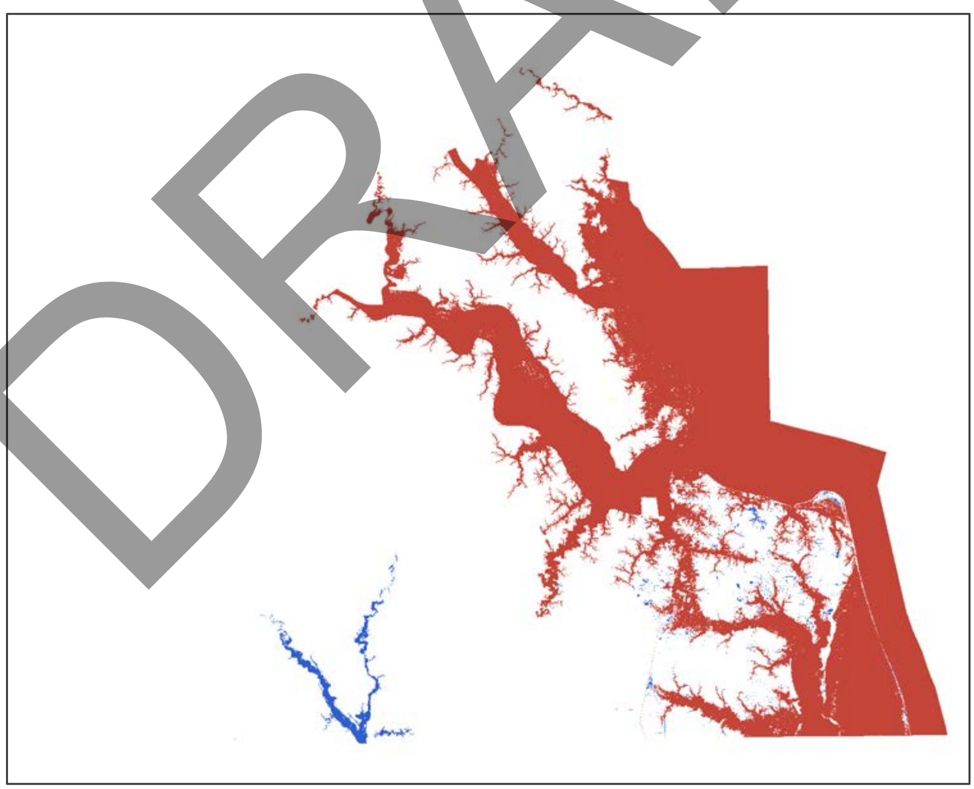


The original seamless regional Digital Elevation Model. Lighter areas are higher in elevation.

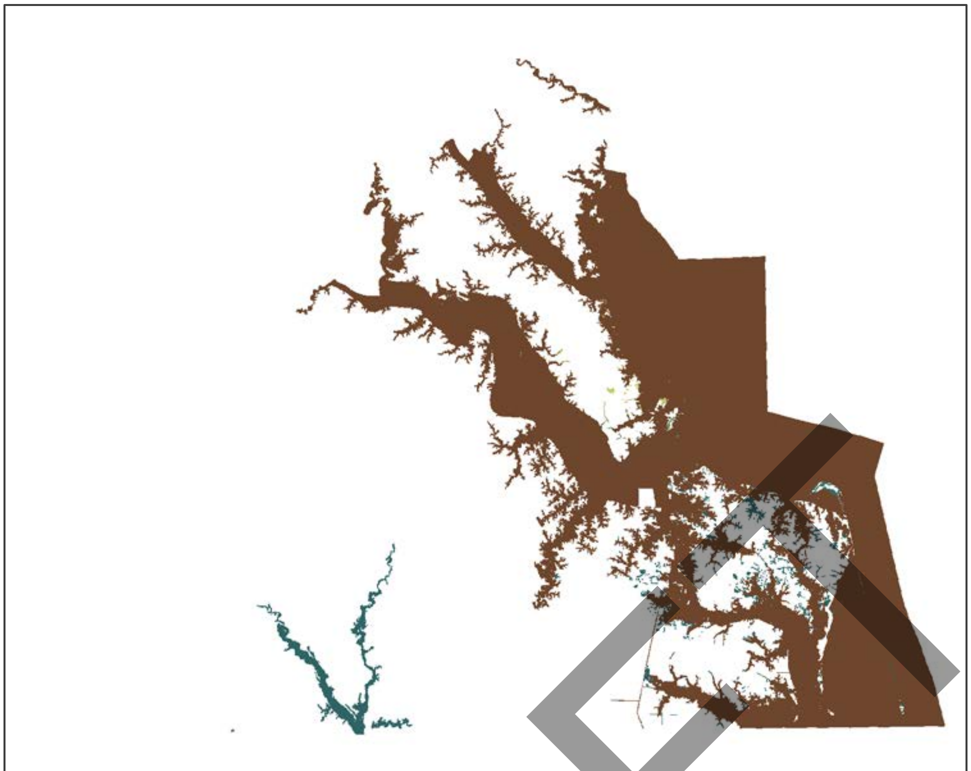


Step 1: Merging the regional DEM and MHHW surface.

Step 2: Creating the single value raster. This shows all areas with a value of a less than 7.5 feet above MHHW (the highest scenario).

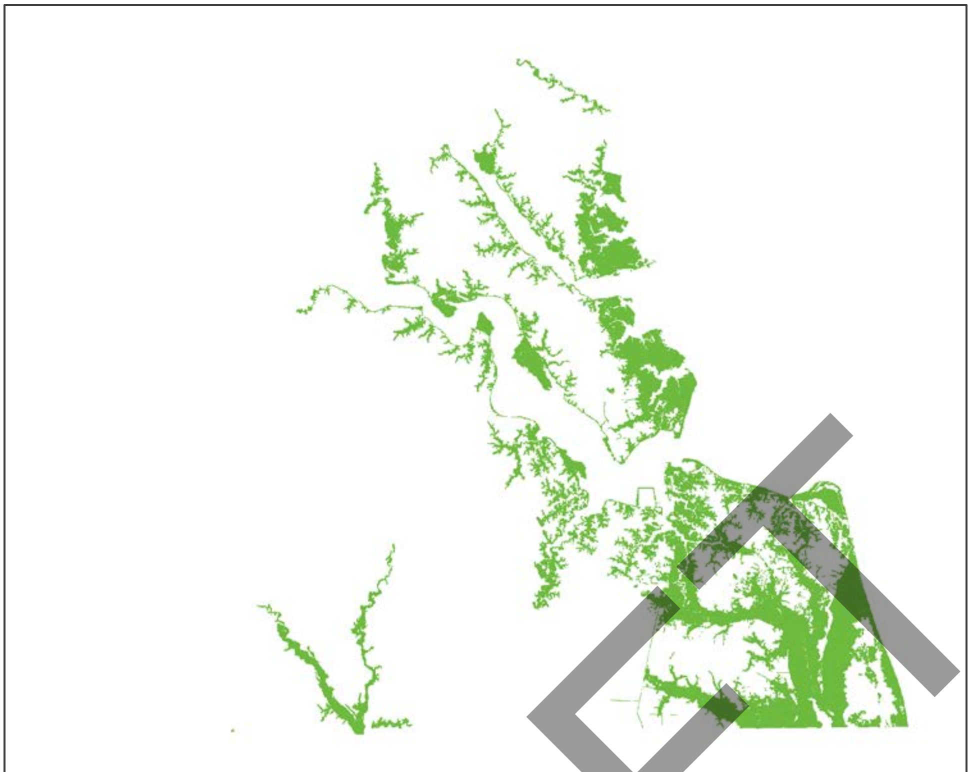


Step 3: Grouping the various hydrologically connect regions.

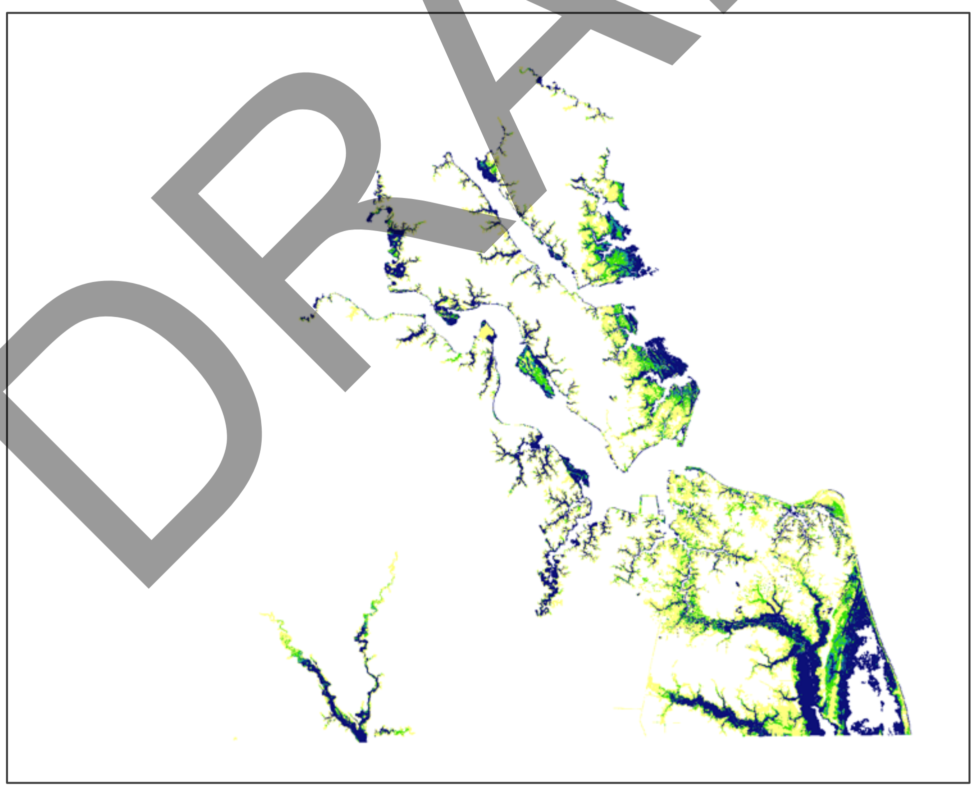


Step 4: Extracting significantly large hydrologically connected regions.

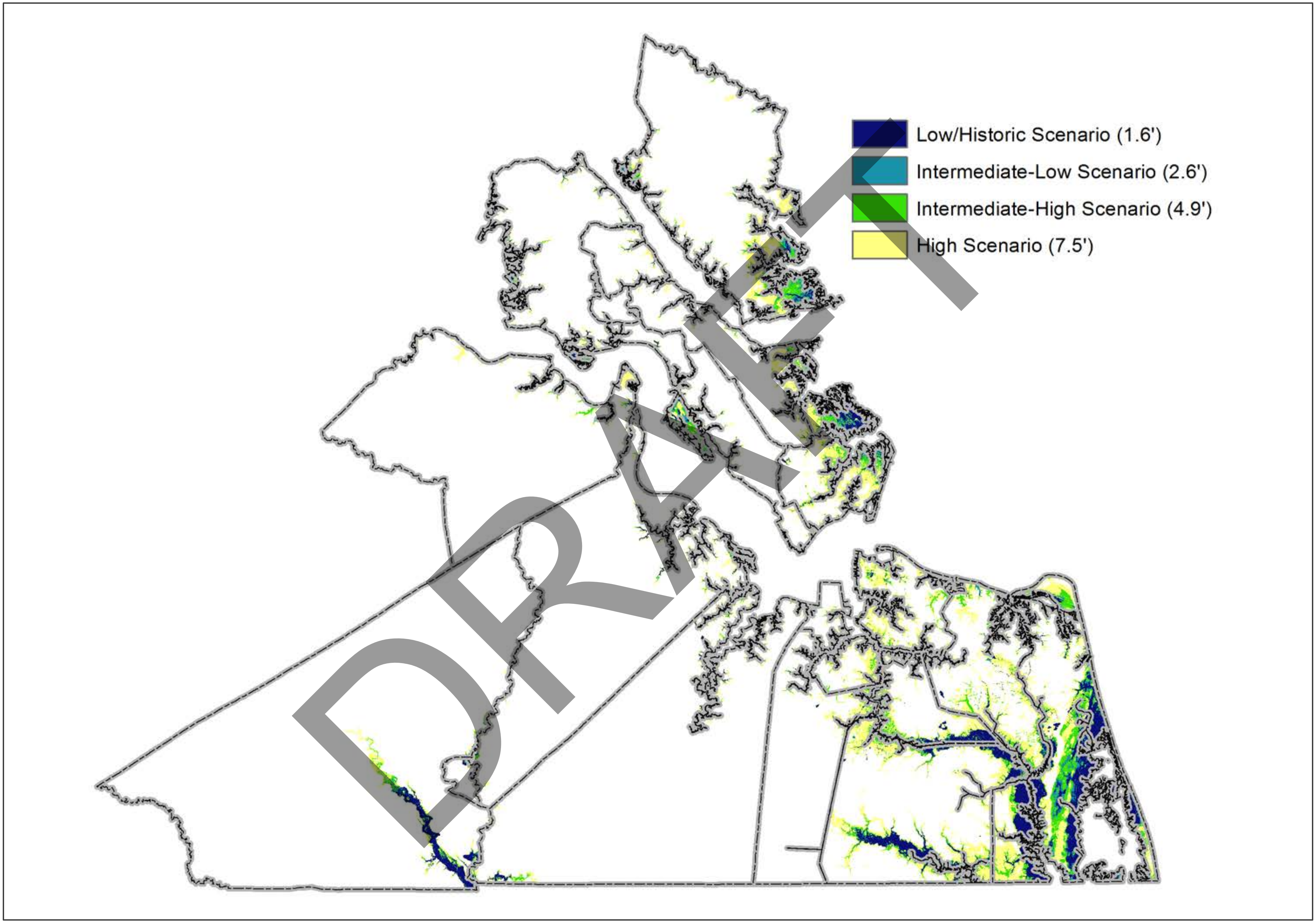
Step 5: Clipping the extracted raster to the original DEM's shoreline.



Step 6: Reclassifying the clipped raster to a single value.



Step 7: Merging the four 2100 projection scenarios (1.6’, 2.6’, 4.9’, and 7.6’) to create a single raster for mapping.



The final map showing areas potentially inundated at MHHW in 2100 under each sea level rise scenario.

CLIMATE CHANGE PUBLIC OUTREACH AND EDUCATION

Although this grant project is separate from the three-year Focal Area Grant which ended in 2012, HRPDC staff continues to build on the lessons learned and materials developed over the course of that period. This extends to HRPDC's public outreach and coordination efforts, which have become a significant part of HRPDC's efforts to promote resilient practices in the coastal communities and areas of Hampton Roads. HRPDC staff has regularly offered to give presentations to non-governmental groups and to meet directly with the staffs from individual localities to answer questions about sea level rise, coastal resiliency, and related products developed by HRPDC. In addition to these outreach efforts, HRPDC staff continues to coordinate with many different partners throughout Hampton Roads and the Mid-Atlantic to promote coastal resiliency and to benefit from other regions' experiences and knowledge. Major coordination and collaboration efforts that occurred over the course of this grant included:

- Assisting the Virginia Institute of Marine Science with the planning and completion of the Recurrent Flooding Study ordered by the Virginia General Assembly;
- Continuing work with the Institute for the Environmental Negotiation and the City of Virginia Beach to develop and bring about a small stakeholder workshop to discuss potential sea level rise and flooding adaptation strategies;
- Partnering with Virginia Sea Grant and Old Dominion University to establish and seek funding for the Hampton Roads Sea Level Rise and Flooding Adaptation Forum; and
- Continuing working with Old Dominion University to analyze the economic impacts of flooding and sea level rise on Hampton Roads.

Presentations and meetings that were supported in whole or in part by this grant are described below. Those events that overlapped with the previous Focal Area Grant are marked with an asterisk (*), with fuller descriptions included in the FY2010-2011 report.[89] Attendance numbers are approximate. Events are divided into two categories: presentations and outreach efforts (to both government and non-government groups) and coordination efforts with other agencies or partners. The coordination efforts listed above are also described in greater detail. HRPDC staff that participated in these efforts during this grant period included:

- John Carlock, AICP, Deputy Executive Director (former staff)

[89] *Climate Change in Hampton Roads Phase III: Sea Level Rise in Hampton Roads,* available online at http://www.hrpdcva.gov/news/index/view/id/19

- Dwight Farmer, Executive Director
- Greg Grootendorst, AICP, Chief Economist
- Lisa Hardy, Physical and Environmental Planner
- Julia Hillegass, Public Information & Community Affairs Administrator
- Whitney Katchmark, P.E., Principal Water Resources Engineer
- Jai McBride, Principal Regional Planner
- Benjamin McFarlane, AICP, Regional Planner

Staff from the Hampton Roads Transportation Planning Organization (HRTPO) also participated in some of the events. Staff that participated included:

- Pavithra Parthasarathi, Principal Transportation Engineer, HRTPO
- Benito Perez, Transportation Engineer, HRTPO (former staff)
- Camelia Ravanbakht, Deputy Executive Director, HRTPO

PRESENTATIONS & OUTREACH

Speaking to groups and educating local government staff, citizens, and other stakeholders on the potential impacts of sea level rise remain important components of HRPDC's efforts to promote resilient planning practices in Hampton Roads. Educating citizens can help build public support for effective planning decisions and can also lead to more resilient communities. These presentations also help spread best practices and lessons learned between communities. During this grant, HRPDC staff participated in twenty-two (22) of these events, three (3) of which overlapped with the preceding Focal Area Grant. A sample presentation from one of these events is included in Appendix A.

DATE	OUTREACH EVENT DESCRIPTION
October 26, 2011*	Mr. McFarlane gave a presentation as part of a stakeholder panel to the NOAA Hydrographic Services Review Panel at a meeting held in Norfolk, Virginia. *Attendance: 40* *Stakeholder Groups: 5*
November 11, 2011*	Mr. McFarlane gave a presentation, titled "Using GIS to Plan for Sea Level Rise in Hampton Roads", at Old Dominion University's GIS Day. *Attendance: 30* *Stakeholder Groups: 3*

DATE	OUTREACH EVENT DESCRIPTION
December 1, 2011*	Mr. McFarlane briefed the Hampton Roads Joint Environmental Committee, the official environmental advisory committee to the Hampton Roads Planning District Commission, on the status of various ongoing projects in the region related to climate change and sea level rise. *Attendance: 46* *Stakeholder Groups: 21*
January 25, 2012	Mr. McFarlane gave a presentation on adapting to sea level rise to the Hampton Roads chapter of the Urban Land Institute in Norfolk, Virginia. *Attendance: 40* *Stakeholder Groups: 20*
February 16, 2012	Mr. McFarlane gave a presentation at a meeting of the Norfolk Flooding Task Force on sea level rise planning and adaptation. *Attendance: 20* *Stakeholder Groups: 12*
February 29, 2012	Mr. McFarlane gave a presentation to the Norfolk Citizen Flooding Task Force on sea level rise planning and adaptation. *Attendance: 25* *Stakeholder Groups: 5*
April 4, 2012	Mr. McFarlane gave a presentation as part of a panel on the impacts of climate change on transportation infrastructure at Hampton University. *Attendance: 30* *Stakeholder Groups: 6*
April 5, 2012	Mr. McFarlane briefed the Hampton Roads Joint Environmental Committee on the FY2011-2012 HRPDC Climate Change report and related projects. *Attendance: 41* *Stakeholder Groups: 16*
May 3, 2012	Mr. McFarlane updated the Hampton Roads Joint Environmental Committee on the FY2011-2012 HRPDC Climate Change report and related projects. *Attendance: 46* *Stakeholder Groups: 18*
May 9, 2012	Mr. McFarlane gave a presentation and help lead a discussion on sea level rise planning and adaptation at a stakeholder workshop in Virginia Beach hosted by the Institute for Environmental Negotiation, the City of Virginia Beach, and HRPDC *Attendance: 15* *Stakeholder Groups: 12*

DATE	OUTREACH EVENT DESCRIPTION
May 31, 2012	Mr. McFarlane gave a presentation on planning for and adapting to sea level rise to the Norfolk Flooding Mitigation Advisory Group. *Attendance: 30* *Stakeholder Groups: 5*
June 7, 2012	Mr. McFarlane updated the Hampton Roads Joint Environmental Committee on the FY2011-2012 HRPDC Climate Change report and related projects. *Attendance: 44* *Stakeholder Groups: 18*
June 12, 2012	Mr. Carlock and Mr. McFarlane met with staff from the City of Hampton to discuss the Phase III HRPDC Climate Change report and its findings. Mr. McFarlane gave a presentation on the findings and the methodology used for the sea level rise mapping and exposure analysis. *Attendance: 12* *Stakeholder Groups: 2*
June 21, 2012	Mr. McFarlane briefed the Hampton Roads Planning District Commission on the FY2011-2012 HRPDC Climate Change report. This presentation included a summary of recommendations and comments made by local government staff. *Attendance: 25* *Stakeholder Groups: 15*
July 12, 2012	Mr. McFarlane briefed the Hampton Roads Joint Environmental Committee on the FY2011-2012 HRPDC Climate Change report and related projects. This presentation included a summary of changes made in response to local comments. The Committee voted to recommend approval of the report by the Commission. *Attendance: 45* *Stakeholder Groups: 17*
July 19, 2012	Mr. McFarlane briefed the Hampton Roads Planning District Commission on the FY2011-2012 HRPDC Climate Change report. This presentation included a summary of changes made in response to local comments. The Commission voted to approve the report for publication and distribution. *Attendance: 25* *Stakeholder Groups: 15*
October 4, 2012	Ms. Katchmark and Mr. McFarlane briefed the Hampton Roads Joint Environmental Committee on HRPDC staff's participation in a Sea Level Rise and Extreme Events workshop sponsored by the Water Environment Research Foundation (WERF) and a meeting with VIMS staff for the Recurrent Flooding Study. *Attendance: 40* *Stakeholder Groups: 24*

DATE	OUTREACH EVENT DESCRIPTION
October 15, 2012	Mr. McFarlane gave a presentation, titled "Regional Planning for Sea-Level Rise in Hampton Roads", as part of a panel and workshop on sea level rise at the Oceans '12 Conference in Virginia Beach, Virginia. *Attendance: 40* *Stakeholder Groups: 30*
November 8, 2012	Mr. McFarlane participated as part of panel discussing the impacts of sea level rise on the Hampton Roads region for a meeting of the Virginia Natural Resources Leadership Institute in Suffolk, Virginia. *Attendance: 30* *Stakeholder Groups: 20*
November 16, 2012	Mr. McFarlane gave a brief presentation on regional planning for sea level rise and also facilitated a breakout session at a meeting of the Hampton Roads Adaptation Forum in Suffolk, Virginia. *Attendance: 50* *Stakeholder Groups: 30*
December 5, 2012	Mr. McFarlane participated as part of a panel at the 2012 Virginia Coastal Partners Workshop discussing engaging the public in climate change adaptation efforts. *Attendance: 50* *Stakeholder Groups: 35*
December 20, 2012	Mr. McFarlane briefed the Hampton Roads Joint Environmental Committee on HRPDC staff participation in the CZM Coastal Partners Workshop and the MARCO Climate Change Adaptation Workshop, as well as items of general interest from both events. *Attendance: 41* *Stakeholder Groups: 22*

Coordination Events

In addition to HRPDC's climate change adaptation planning, there are many other related or similar efforts in Hampton Roads that are ongoing. Most of these are occurring without direct support by HRPDC, although HRPDC is an official partner in several. The Hampton Roads Planning District Commission recognizes the significance of planning for climate change and sea level rise impacts, and as a result has directed and/or supported HRPDC staff's efforts to work with other stakeholders in the region. Past examples of this sort of partnership and coordination are the series of Sea Level Rise Listening Sessions held in Virginia Beach with the Institute of Environmental Negotiation, Wetlands Watch, and the City of Virginia Beach and the FHWA-funded pilot study with UVA; these efforts were described in the second and third HRPDC climate changes reports, respectively. HRPDC staff views the funding for the previous Focal Area Grant and this grant as opportunities to both conduct relevant research and analysis and to seek opportunities to work with various partners to promote the larger goal of making

Hampton Roads a more resilient region. HRPDC staff continues to work with other regional, state, and federal partners on planning or sea level rise and climate change. In 2011 and 2012, partnership and coordination efforts which began in part as a result of this grant included working with Virginia Sea Grant and Old Dominion University to start the Hampton Roads Sea Level Rise and Flooding Adaptation Forum and continuing work with the Institute of Environmental Negotiation to hold a sea level rise stakeholder workshop in Virginia Beach. Coordination efforts and events included meetings, workshops, and conference calls. During this grant, HRPDC staff participated in thirty-two (32) of these events, three (3) of which overlapped with the preceding Focal Area Grant.

DATE	COORDINATION EVENT DESCRIPTION
October 25, 2011*	Ms. Hillegass and Mr. McFarlane attended and participated in a discussion at a Coastal Zone Program-sponsored workshop in Richmond on Civil Public Participation. *Attendance: 25* *Stakeholder Groups: 10*
December 6, 2011*	Mr. McFarlane attended a meeting with representatives form the Federal Emergency Management Agency (FEMA), the U.S. Army Corps of Engineers (USACE), and their consults to learn about he Region III Storm Surge Study. *Attendance: 20* *Stakeholder Groups: 10*
December 12, 2011*	Mr. Carlock, Ms. McBride, and Mr. McFarlane met with department heads and staff from Hampton Roads localities to discuss regional and local efforts to address sea level rise and flooding. *Attendance: 22* *Stakeholder Groups: 11*
January 10, 2012	Mr. McFarlane participated in a conference call with representatives from the University of Virginia's Institute for Environmental Negotiation (IEN), Wetlands Watch, and the City of Virginia Beach to discuss plans for a stakeholder workshop to be held in Virginia Beach to discuss adapting to sea level rise. *Attendance: 5* *Stakeholder Groups: 4*
January 10, 2012	Mr. McFarlane participated in a conference call with researchers from the University of Virginia to discuss the FHWA-funded pilot project studying how to account for potential climate change impacts in transportation planning.

DATE	COORDINATION EVENT DESCRIPTION
January 12, 2012	Mr. McFarlane and Mr. Perez met to go over the FHWA-funded pilot project's findings and results and to discuss how the results could be used by HRTPO staff in their long-range planning efforts. *Attendance: 2:* *Stakeholder Groups: 2*
February 2, 2012	Mr. Carlock, Mr. Grootendorst, and Mr. McFarlane met with Professor Vinod Agarwal from Old Dominion University to discuss project status and data needs for the joint HRPDC-ODU study on the economic impacts of sea level rise and flooding on Hampton Roads. *Attendance: 4* *Stakeholder Groups: 2*
February 2, 2012	Mr. McFarlane participated in a conference call with representatives from IEN, Wetlands Watch, and the City of Virginia Beach to continue planning and developing the program for the Virginia Beach sea level rise stakeholder workshop. *Attendance: 5* *Stakeholder Groups: 4*
February 7, 2012	Mr. Farmer and Mr. McFarlane participated in a phone conversation with a representative from the U.S. Government Accountability Office to discuss how climate change is being incorporated into local and regional planning and project development efforts. *Attendance: 3* *Stakeholder Groups: 2*
February 8, 2012	Mr. McFarlane participated in a conference call with representatives from IEN, Wetlands Watch, and the City of Virginia Beach to continue planning and developing the program for the Virginia Beach sea level rise stakeholder workshop. *Attendance: 5* *Stakeholder Groups: 4*
February 15, 2012	Mr. McFarlane met with representatives from the City of Virginia Beach and Wetlands Watch to discuss presentations and other material for the Virginia Beach sea level rise stakeholder workshop. *Attendance: 3* *Stakeholder Groups: 3*
February 20, 2012	Mr. McFarlane participated in a conference call with representatives from IEN, Wetlands Watch, and the City of Virginia Beach to continue planning and developing the program for the Virginia Beach sea level rise stakeholder workshop. *Attendance: 5* *Stakeholder Groups: 4*

DATE	COORDINATION EVENT DESCRIPTION
February 24 & 27, 2012	Mr. McFarlane participated in two webinars and conference calls with other participants in the FHWA-funded pilot projects looking at how climate change adaptation can be incorporated into transportation planning.
February 28, 2012	Mr. Carlock, Mr. McFarlane, Ms. Parthasarathi, Mr. Perez, and Ms. Ravanbakht met with researchers from the University of Virginia to discuss the final report and findings from the FHWA-funded climate adaptation pilot study. *Attendance: 8* *Stakeholder Groups: 3*
March 12, 2012	Mr. Carlock and Mr. McFarlane attended a meeting of the Norfolk Flooding Task to participate in a discussion on a research proposal from Dr. David Basco, Old Dominion University, to assess the vulnerability of Norfolk's transportation system to sea level rise. *Attendance: 12* *Stakeholder Groups: 3*
March 14, 2012	Mr. McFarlane participated in a conference call to discuss the program for a panel on climate change and transportation to be held at Hampton University. *Attendance: 6* *Stakeholder Groups: 4*
March 28, 2012	Ms. Katchmark and Mr. McFarlane attended and participated in a forum on stormwater management and sea level rise hosted by Old Dominion University in Norfolk, Virginia. *Attendance: 30* *Stakeholder Groups: 15*
April 13, 2012	Mr. McFarlane met with representatives from Virginia Sea Grant, Old Dominion University, and other stakeholders to discuss plans for a Sea Grant-funded local government-researcher forum to discuss adapting to sea level rise in Hampton Roads. *Attendance: 5* *Stakeholder Groups: 3*
May 2, 2012	Mr. McFarlane met with Dr. Agarwal to assess the status of the HRPDC-ODU study of the potential economic impacts of sea level rise and flooding on Hampton Roads. *Attendance: 2* *Stakeholder Groups: 2*

DATE	COORDINATION EVENT DESCRIPTION
May 14, 2012	Mr. McFarlane attended a meeting with staff from the VIMS Center for Coastal Resources Management and other stakeholder organizations to discuss and provide input to the Recurrent Flooding Study ordered by the General Assembly. *Attendance: 15* *Stakeholder Groups: 5*
May 21, 2012	Mr. McFarlane participated in a conference call with representatives from Virginia Sea Grant, Old Dominion University, and other stakeholders to discuss plans for the Hampton Roads Adaptation Forum. *Attendance: 10* *Stakeholder Groups: 4*
June 25, 2012	Mr. Carlock and Mr. McFarlane attended a meeting of the Norfolk Flooding Task Force to hear and discuss lessons learned from Dutch experts on sea level rise and flood planning and adaptation. *Attendance: 12* *Stakeholder Groups: 4*
June 27, 2012	Mr. McFarlane attended a scoping workshop for the Hampton Roads Adaptation Forum with representatives from Virginia Sea Grant, Old Dominion University, and other partners to discuss forum discussion topics, potential guest speakers, and logistics. *Attendance: 12* *Stakeholder Groups: 6*
July 18, 2012	Mr. McFarlane attended an organizational meeting for the Hampton Roads Adaptation Forum with representatives from Virginia Sea Grant, Old Dominion University, and other partners. *Attendance: 12* *Stakeholder Groups: 6*
July 30, 2012	Mr. McFarlane attended a meeting with staff from the VIMS Center for Coastal Resources Management and other stakeholder organizations to discuss and provide input to comprehensive coastal resources management guidance being developed by VIMS for locality comprehensive plans. *Attendance: 12* *Stakeholder Groups: 4*
September 5, 2012	Mr. Carlock, Mr. Grootendorst, and Mr. McFarlane met with Dr. Agarwal to discuss the HRPDC-ODU study of the potential economic impacts of sea level rise and flooding on Hampton Roads. *Attendance: 4* *Stakeholder Groups: 2*

DATE	COORDINATION EVENT DESCRIPTION
September 20, 2012	Ms. Katchmark and Mr. McFarlane attended and participated in a workshop and discussion on Extreme Events and Water Utilities sponsored by the Water Environment Research Foundation (WERF) in Williamsburg, Virginia. *Attendance: 30* *Stakeholder Groups: 20*
September 20, 2012	Mr. McFarlane attended and participated in an advisory committee meeting for the VIMS Recurrent Flooding Study in Williamsburg, Virginia. *Attendance: 30* *Stakeholder Groups: 20*
November 5, 2012	Mr. Carlock and Mr. McFarlane attended a meeting along with staff from the City of Norfolk with the Governor's Policy Office in Richmond, Virginia to discuss potential next steps in state-level planning for sea level rise and flooding. *Attendance: 9* *Stakeholder Groups: 5*
November 30, 2012	Mr. McFarlane attended a meeting of the Scientific and Technical Advisory Committee (STAC) of the Albemarle-Pamlico National Estuarine Partnership in Manteo, North Carolina to discuss sea level rise. *Attendance: 30* *Stakeholder Groups: 25*
December 10-11, 2012	Mr. McFarlane attended a sea level rise workshop sponsored by the Mid-Atlantic Regional Council on the Ocean (MARCO) in Wilmington, Delaware. Participants included several state coastal management programs, federal agencies, and researchers. *Attendance: 30* *Stakeholder Groups: 20*
December 20, 2012	Mr. McFarlane met with Ms. Shana Jones, Director of the Virginia Coastal Policy Clinic at the William & Mary School of Law, to discuss how Hampton Roads localities could benefit from and provide input to the clinic. *Attendance: 2* *Stakeholder Groups: 2*

Coordination Efforts

Larger and more intensive coordination efforts allow HRPDC staff to leverage the work being done with funding from the Virginia Coastal Zone Management Program into working with other partners in the region on related projects that reinforce the goals of these CZM grants. These efforts are most often conducted with academic partners and in the past have been funded by HRPDC funds, grants from the Virginia Sea Grant program, or a combination of the two. While HRPDC staff has worked with many partners during the period of this grant, three efforts stand out for the depth of the partnership between HRPDC and the other parties involved as well as the potential for these efforts to inform the region's planning for coastal resiliency.

ASSESSING THE ECONOMIC IMPACTS OF SEA LEVEL RISE AND FLOODING ON HAMPTON ROADS

Partner: Old Dominion University

Status: Ongoing

Description: HRPDC staff began working with Dr. James Koch and Dr. Vinod Agarwal on this effort in 2011. The goal of this effort is to model the economic impacts of sea level rise and flooding on Hampton Roads in terms of jobs and businesses lost and moved. HRPDC staff has utilized data from the Virginia Employment Commission to develop a GIS database of businesses and employment in Hampton Roads. This data has been analyzed with sea level rise inundation GIS data developed during the course of this Coastal Resiliency project to identify businesses located in areas vulnerable to sea level rise. In addition to businesses, HRPDC staff has also analyzed Census data and property data using the same sea level rise maps to develop estimates of affected population and property. This data has been given to the ODU partners to complete the study.

HAMPTON ROADS SEA LEVEL RISE ADAPTATION FORUM

Partners: Old Dominion University, Virginia Sea Grant

Status: Ongoing

Description: HRPDC staff began working in late 2011 with representatives from Virginia Sea Grant and Old Dominion University's Climate Change and Sea Level Rise Initiative to develop and institutionalize regular meetings between local government staff, academic researchers, and other stakeholders and experts. A proposal was submitted for funding from the National Sea Grant program in November 2011, and received funding in spring 2012. The Adaptation Forum is a regional dialogue for local government staff and representatives from federal and state agencies to discuss needs and best practices for adapting to both flooding and sea level rise. It builds on previous efforts, including HRPDC efforts funded by the Virginia Coastal Zone Management Program. The focus of this forum is be on developing strategies that are specifically suited for Hampton Roads, with a goal of building a resource that can be readily accessed by local governments seeking information, case studies, and data needed for local planning and adaptation efforts. Participants in the forum meetings held to date, include local planning, public works, and emergency management staff, academic researchers, consultants, and federal partners. The first forum meeting was held on November 16, 2012 at the Virginia Modeling and Simulation Center in Suffolk, Virginia. There were over forty participants in attendance, representing approximately twenty stakeholder groups or organizations. The forum will continue to meet throughout 2013, and will also sponsor and host a public town hall meeting at some point during 2013.

Virginia Beach Sea Level Rise Stakeholder Workshop

Partners: UVA Institute for Environmental Negotiation, City of Virginia Beach, Wetlands Watch
Status: Complete
Description: In March 2011, a partnership composed of the UVA Institute for Environmental Negotiation (IEN), the City of Virginia Beach, Wetlands Watch, and the HRPDC hosted a series of four sea level rise listening sessions in Virginia Beach. These sessions were attended by over a hundred residents. The same partnership applied for a second round of grant funding to host a more involved stakeholder/focus group workshop the following year. This workshop was held in May 2012 at the Virginia Beach Aquarium and included fifteen participants representing a wide range of stakeholder groups and interests. The workshop featured presentation on sea level rise impacts and planning and considerable discussion amongst the participants and facilitators. The workshop also incorporated real-time polling of the participants on experiences with flooding and sea level rise, attitudes toward planning, and feedback on potential strategies. The workshop has been documented in a report by IEN, which can be found on the organization's website.[90]

Outreach Materials

As part of its efforts to educate local officials, staff, and the general public about the potential impacts of sea level rise and possible measures for addressing those impacts, HRPDC staff has developed both presentations, to be delivered at outreach events such as those described above, and other materials that can be given out at public events or made available online for anyone interested in learning about HRPDC's coastal resilience work. Each of HRPDC's reports funded by the Virginia Coastal Zone Management Program is made available online and can be viewed in person at HRPDC's offices in Chesapeake, Virginia. However, these reports are often long, technical documents. As part of this grant, HRPDC staff has summarized the various findings and efforts related to coastal resiliency and sea level rise to develop a series of short "one-pager" handouts or flyers that will be made available through the HRPDC website. These flyers cover topics such as climate change, climate change adaptation, and sea level rise. These documents are included in this report in Appendix B.

Findings

[90] http://www.virginia.edu/ien/sealevelrise/regionalfocusgroups.html

HRPDC staff continued to present information on climate change and sea level rise impacts to groups across the region. HRPDC staff also worked with several local, regional, state, and federal partners to coordinate between related projects and inform outside efforts. HRPDC staff has also developed examples of outreach materials that can be used to help educate the public.

RECOMMENDATION

HRPDC staff should continue to provide updates and presentations on these issues when requested to support public education on sea level rise impacts and adaptation. HRPDC staff should continue to work with government, academic, and other partners and stakeholders on efforts in Hampton Roads to support planning for coastal resilience and adaptation to sea level rise.

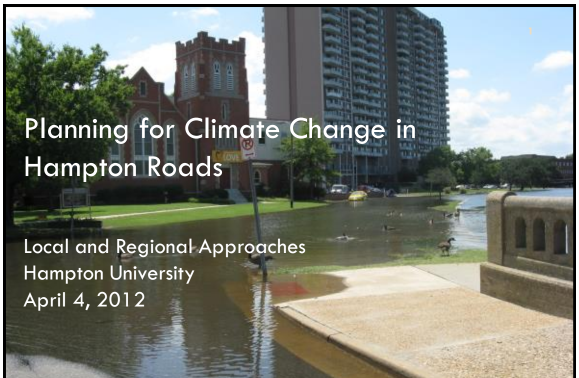
FINDINGS AND CONCLUSIONS

Since 2008, the Hampton Roads Planning District Commission has been engaged in a series of projects, studies, and efforts related to helping the region adapt to more frequent flooding, rising sea levels and other projected impacts of climate change. These efforts have been funded in part by the National Oceanic and Atmospheric Administration (NOAA) through the Virginia Coastal Zone Management Program (VCZMP) and Virginia Sea Grant (VSG) as well as contributions from local governments in Hampton Roads. The largest of these efforts was a three-year Focal Area Grant from the VCZMP, which resulted in the publishing of three reports documenting the projected impacts of climate change on the Hampton Roads region and analyzing the region's exposure to storms and future sea level rise. This report, which documents the work done under a one-year competitive grant from the VCZMP, continues the work begun under the focal area grant. This project had three goals: continue working to develop useful geographic information systems (GIS) tools for local governments to use when planning for sea level rise, research and identify ways local governments incorporate planning for sea level rise into their existing plans and policies, and continue outreach and coordination efforts with regional stakeholders on sea level rise and related issues. The report makes the case that planning for sea level rise now or in the near future is essential, even though there is no way to know with certainty how much sea level rise will eventually occur nor how fast it will rise. Based on the research conducted for this project, HRPDC staff makes the following findings and recommendations.

Findings	Recommendations
Research on sea level rise continues to suggest that the rate of both global and local sea level rise is accelerating, which supports various projections of global sea level rise based on climate change models. Based on this recent research, the U.S. National Climate Assessment is using four scenarios of global sea level rise as part of a risk management approach to planning for sea level rise impacts. These scenarios are 0.2m, 0.5m, 1.2m, and 2.0m of global sea level rise between 1992 and 2100. Recent research focused specifically on the Mid-Atlantic U.S. coast indicates that sea level rise is accelerating faster there than the global rate.	Local governments should seriously consider accounting for accelerated sea level rise in their development and infrastructure planning decisions.
Traditional planning practices are not designed to address the long time scale and uncertainty that are inherent in effectively planning for climate change and sea level rise impacts, which may not be felt for several years. Several practices exist that could be used to supplement local planning efforts; these include scenario planning, adaptive management, and anticipatory governance.	Local governments should use appropriate studies and analyses, such as build-out analyses and mapping of vulnerable areas, to identify preferred adaptation strategies and incorporate those into their plans and policies.
Existing and ongoing local planning processes should incorporate planning for sea level rise. Existing state already enables local governments to address the impacts of flooding in their plans, specifically in their comprehensive plans, capital improvement programs, and zoning ordinances.	Local governments should consider using these practices to begin planning for the impacts of sea level rise.
Previous regional sea level rise mapping exercises were constrained by the absence of high resolution elevation data. To improve these mapping products, HRPDC staff identified the best available elevation data for the entire planning district and merged the several datasets to create a seamless regional digital elevation model (DEM). This DEM was then used with the scenarios from the 2013 National Climate Assessment to develop a map of areas inundated under each scenario at Mean Higher High Water by 2100.	Local governments should consider using this map for their plans or work with HRPDC staff to develop similar, locally-specific maps for planning and educational purposes.

Findings	Recommendations
HRPDC staff continued to present information on climate change and sea level rise impacts to groups across the region. HRPDC staff also worked with several local, regional, state, and federal partners to coordinate between related projects and inform outside efforts. HRPDC staff has also developed examples of outreach materials that can be used to help educate the public.	HRPDC staff should continue to provide updates and presentations on these issues when requested to support public education on sea level rise impacts and adaptation. HRPDC staff should continue to work with government, academic, and other partners and stakeholders on efforts in Hampton Roads to support planning for coastal resilience and adaptation to sea level rise.

APPENDIX A – SAMPLE PRESENTATIONS



Planning for Climate Change in Hampton Roads

Local and Regional Approaches
Hampton University
April 4, 2012

Benjamin McFarlane, AICP
Regional Planner, HRPDC

What is the HRPDC?

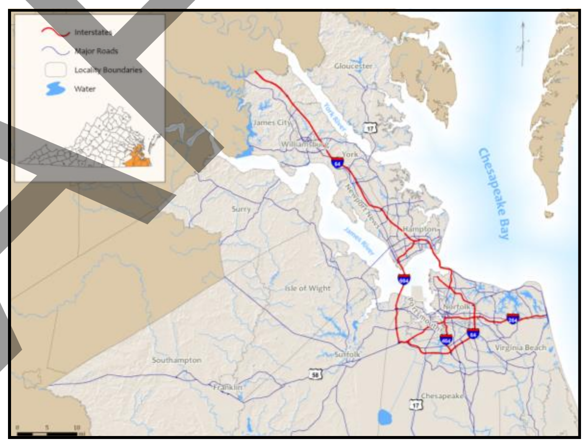
2

- 1 of 21 Regional Planning Agencies
- State enabled; locally created
- 16 Cities & Counties; several Towns; 1.7 million people; 3,000 square miles; 5,000 miles shoreline
- Commission – 45 local elected officials & CAO
- Staff – Executive Director & 45 staff
- Funding – Local contributions, grants, and contracts
- Functions – Economics, Housing, Transportation, Environmental, Emergency Management
- Budget $12,000,000 +
- Role – Policy & Technical Analysis, Planning & Engineering Studies, Cooperative Problem Solving, Coordination

What does HRPDC do?

3

- The Commission:
  - "**serves as a forum** for local and elected officials and chief administrators to **deliberate** and **decide** issues of **regional importance**"
- The Staff:
  - "provides the local governments and citizens of Hampton Roads credible and timely **planning, research, and analysis** on matters of mutual concern, and"
  - "**provides leadership and offers strategies and support services** to other public and private, local, and regional agencies, in their efforts to improve the region's quality of life."



What is climate change?

5

- Global warming caused by increased emissions of greenhouse gases
- This results in impacts such as higher sea levels and changing precipitation patterns

What does Climate Change mean for Hampton Roads?

6

- Rising sea level
  - More inundation and tidal flooding
  - Larger storm surges
- Higher average temperatures
  - Infrastructure impacts from high-heat days
  - Health impacts
- Changing precipitation patterns
  - Stormwater treatment and storage issues
  - Water supply concerns

What is climate change?

7

- Climate change is a "wicked" problem
  - Not easily understood in its entirety
  - No stopping rule (the problem is not finite)
  - No right or wrong solutions (only better or worse)
  - Essentially unique
  - Every solution is a "one shot" solution
  - No defined set of solutions

HAMPTON ROADS PDC

What is climate change?

8

- Actually, climate change is a "super wicked" problem
  - Time is not costless
    - The problem continues to get worse
    - Interim damages before actions
    - Acting later may cost more
  - Those who can address or solve the problem caused the problem and have the least incentive to solve it
  - There is no institutional framework to solve the problem – no government has the authority

HAMPTON ROADS PDC

Planning for Climate Change

9

- Defining terms
  - Planning
  - Climate
  - Change
- Climate change forces us to rethink our explicit and implicit assumptions in the planning and design of infrastructure systems, buildings, and cities
- Most planning is based on either past or current conditions – not future conditions

HAMPTON ROADS PDC

Planning for Climate Change

10

- Climate Change will force cities to adapt
- Protection
  - Seawall, storm surge barriers
- Accommodation
  - Elevating structures, beach nourishment
- Retreat
  - Setbacks, easements

HAMPTON ROADS PDC

Planning for Climate Change

11

- Incorporate sea level rise and precipitation projections into building and infrastructure location and construction
- Alter zoning codes to reduce construction in vulnerable areas, through density restrictions, setbacks, and easements

HAMPTON ROADS PDC

Planning for Climate Change

12

- Design structures to be adaptable (as conditions change, can alter them without having to completely rebuild)
- Use scenario planning to identify likely scenarios of future conditions and incorporate into cost-benefit analyses
  - U.S. Army Corps of Engineers Guidance

HAMPTON ROADS PDC

HRPDC Climate Change Initiative

13

- Year 1: Begin stakeholder process and identify broad impacts of climate change on Hampton Roads
- Year 2: Assessment of impacts and development of policy recommendations
- Year 3: Analysis of infrastructure and economic impacts and developing a regional framework for mitigation and adaptation to climate change

HRPDC Climate Change Initiative

14

- Since 2008, HRPDC has received focal area grant funding from the Virginia Coastal Zone Management Program to study how climate change will affect Hampton Roads.
- HRPDC has collaborated with the Northern Virginia Regional Commission and the Middle Peninsula Planning District Commission to share knowledge and practices.
- This three-year grant project is nearly finished.

HRPDC Climate Change Initiative

15

- Three parts:
  1. Outreach
  2. Coordination
  3. Research and Analysis

Outreach

16

- Engaging local governments, citizens, and stakeholders through public meetings
- UVA-IEN/Wetlands Watch: Listening sessions in Virginia Beach
- Other public meetings to city councils and citizen groups

Coordination

17

- Working with other organizations and institutions to promote awareness of sea level rise and flooding issues in Hampton Roads
- ODU Initiative
- UVA-CRMES: Vulnerability of transportation infrastructure
- ODU: Economic impacts of flooding and sea level rise
- Storm Surge modeling with VIMS

Sea Level Rise Listening Sessions in Virginia Beach

18

- Virginia Sea Grant funded Partnership between HRPDC, Wetlands Watch, City of Virginia Beach, UVA – IEN, and ODU
- Engage general public about flooding and sea level rise
- Four public meetings with total public attendance of over 120 residents from across the region

Vulnerability of Transportation Infrastructure to Climate Change

19

- One of five pilot studies being funded by FHWA across the county looking at the impacts of climate change on transportation assets and plans
- UVA/VDOT/HRPDC/HRTPO partnership
- Result is a scenario planning tool designed to show how climate change and other "system shocks" can affect priorities for new construction, managing existing assets, and adopting policies

Other Efforts

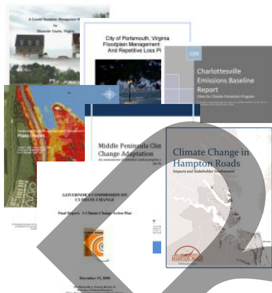
20

- Local Governments:
  - Hampton Comprehensive Waterway Committee and planning effort
  - Norfolk Floodplain Management Effort
  - Gloucester Floodplain Management Plan and Comprehensive Plan Update
  - Virginia Beach Comprehensive Plan Update
- Research Institutions:
  - Old Dominion University Climate Change and Sea Level Rise Initiative

Climate Change Initiatives

21

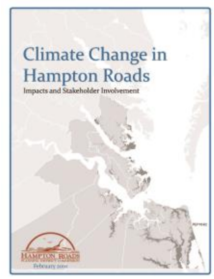
- Local
- Regional
- State



HRPDC Phase I Report

22

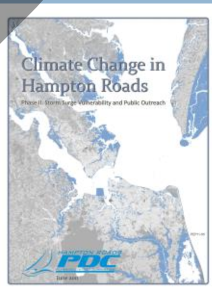
- General Impacts and Knowledge Assessment
- Results of studies of impacts on Hampton Roads – natural resources
- Local government stakeholder involvement process



HRPDC Phase II Report

23

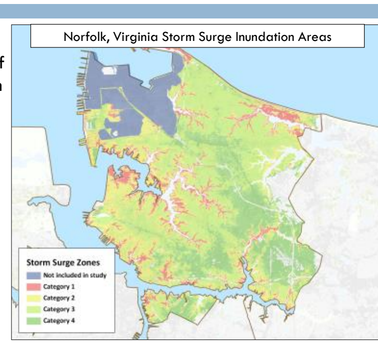
- Assessment of exposure and vulnerability of Hampton Roads to storm surge
- GIS analysis using data from multiple sources
- Utilized USACE/VDEM Hurricane Evacuation Study storm surge zones



Results – Norfolk (example)

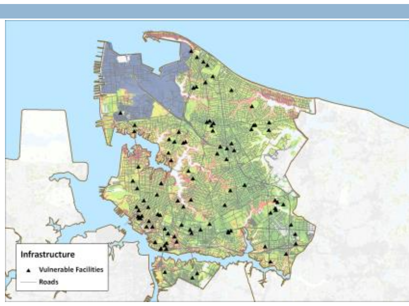
24

- Local results are included for each of the twelve Hampton Roads localities included in the 2008 Virginia Hurricane Evacuation Study



Results – Norfolk (example)

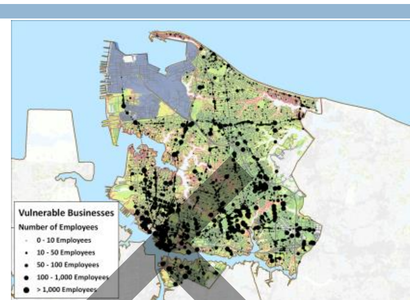
25



Roads and Critical Infrastructure Vulnerable to Storm Surge in Norfolk, Virginia

Results – Norfolk (example)

26

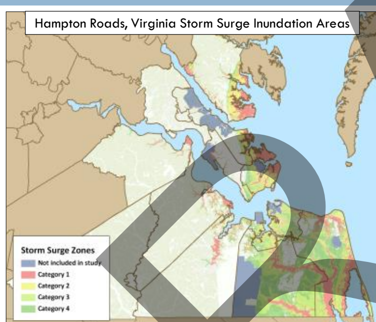


Businesses Vulnerable to Storm Surge in Norfolk, Virginia

Results – Region

27

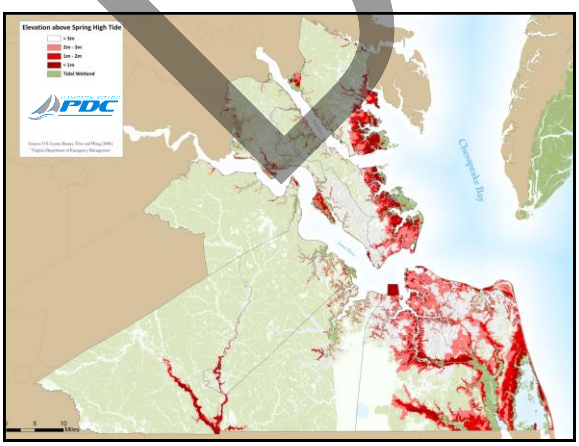
- Overall, high level of exposure to storm surge across the region
- Southside is more vulnerable to larger events than the Peninsula
- Significant population, infrastructure, critical facilities, and businesses at risk



Current Work

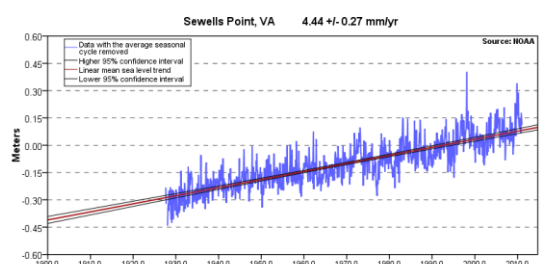
28

- Finishing Year 3 report
  - Sea Level Rise Vulnerability Analysis
  - Recommendations on how to plan for sea level rise
  - Future research needs
    - Subsidence
    - Elevation
    - Sea level
  - Anticipated delivery in March/April 2012
- 1-year VCZMP grant to study how to plan for sea level rise and climate change using an adaptive management approach
  - Incorporating climate change into existing planning processes and policies



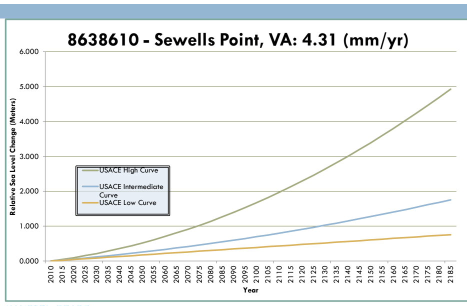
Norfolk, VA

30



Planning for Sea Level Rise

31



Questions?

32

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Hampton Roads Planning District Commission
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HRPDC FY2010-2011 Climate Change Final Report

Presentation to Hampton City Staff
June 12, 2012

John Carlock, AICP
Ben McFarlane, AICP

Overview

1. Project Background
2. Study Goals
3. Analysis Methodology and Results
4. Implications for Planning
5. Recommendations

Project Background

- Funded by Focal Area Grant from Virginia Coastal Zone Management Program
- Three-year project
  - Year 1: General Impacts of Climate Change on Hampton Roads
  - Year 2: Storm Surge
  - Year 3: Sea Level Rise

Sea Level Rise Study

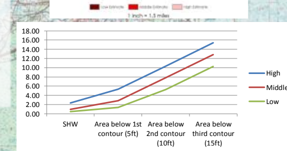
- Two Goals
  - Develop a GIS tool to model the impacts of future sea level rise on the region
  - Demonstrate the use of this tool to assess the region's exposure to sea level rise in terms of population, property, infrastructure, economic activity, and natural resources

Analysis Methodology

- Spatial Overlay using GIS
- Data Sources
  - Census (population and housing units)
  - Locality Parcel data (property boundaries and values)
  - VDOT Road Centerlines
  - Esri Business Analyst (business locations and #employees)
  - Virginia's Ecologically Valuable Areas (natural resources)
  - Locality and HRPDC protected lands (conservation easements, parks, etc.)

Analysis Methodology

- Identify Vulnerable Areas
  - Elevation relative to spring high tide
  - Three elevation estimates to account for data uncertainty
  - 1-meter of sea level rise



Analysis Methodology: Census

- Calculated by census block
  - Total Population * (vulnerable area/total area)
  - Repeated for housing units
  - Rounded to nearest whole person

Analysis Methodology: Built Environment

- # parcels intersected by vulnerable area
  - Sum improvement values
- # parcels whose centroid is within vulnerable area
  - Sum improvement values

Analysis Methodology: Infrastructure

- Clip centerlines to vulnerable areas
- Sum by classification (interstate, primary, secondary, local or private) for each locality

Analysis Methodology: Economy

- Identify businesses located in vulnerable areas
  - Sum number of employees
- Sum total values for all parcels
  - Intersection
  - centroid

Analysis Methodology: Natural Environment

- Identify local and protected lands within vulnerable areas and sum for each locality
- Identify total VEVA lands (outstanding, very high, high) that are within vulnerable areas for each locality

Analysis Results

- Exposure varies based on development patterns and total low-lying area
- Results in tables and maps
  - disclaimers

Exposure to One Meter of Sea Level Rise above Spring High Tide in Hampton, Virginia

	Total	Low Estimate	Middle Estimate	High Estimate
General				
Land Area (square miles)	52.9	6.8	12.6	16.2
Population	137,436	6,300	14,066	22,888
Housing Units	59,566	2,911	6,011	9,796
Built Environment				
Number of Parcels (intersection)	50,872	3,666	6,652	10,168
Number of Parcels (centroid)	50,872	1,869	4,829	8,436
Improvement Value of Parcels (intersection)	$10,977,296,700	$2,787,879,600	$3,383,609,700	$3,955,014,500
Improvement Value of Parcels (centroid)	$10,977,296,700	$552,166,900	$1,046,154,700	$1,689,250,000
Infrastructure				
Roads (total miles)	781.3	22.0	97.0	155.1
Roads (Interstate)	24.6	1.1	2.5	2.9
Roads (Primary)	73.5	1.4	5.2	8.8
Roads (Secondary)	0.1	0.0	0.0	0.0
Roads (Local or Private)	683.2	19.5	89.3	143.5
Economy				
Businesses	4,148	44	263	467
Employees	53,135	224	1,815	4,605
Total Value of Parcels (intersection)	$15,190,766,200	$3,668,339,600	$4,551,238,900	$5,354,577,300
Total Value of Parcels (centroid)	$15,190,766,200	$805,364,500	$1,605,416,200	$2,513,996,800
Natural Environment				
Protected Lands (acres)	2,349	575	642	690
VEVA – Outstanding (acres)	848	751	760	760
VEVA – Very High (acres)	2,489	1,278	1,565	1,653
VEVA – High (acres)	7,466	1,679	3,091	3,594

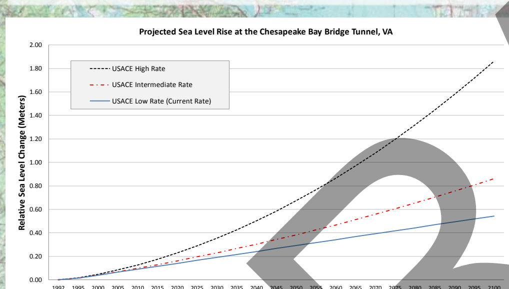
Implications for Planning

- Lifespans of structures and infrastructures are longer than the typical planning horizon
- Sea level rise projected to cause conditions that will be significantly different from those in the present
- Addressing those future conditions is essential to making wise long-term planning decisions, both private and public

Projecting Future Sea Level Rise

- USACE has developed a tool to estimate future sea level rise that combines various scenarios of global sea level rise by the end of the 21st century with local conditions
- Can be useful for identifying planning targets for local governments and for planning and designing specific projects

Projecting Future Sea Level Rise

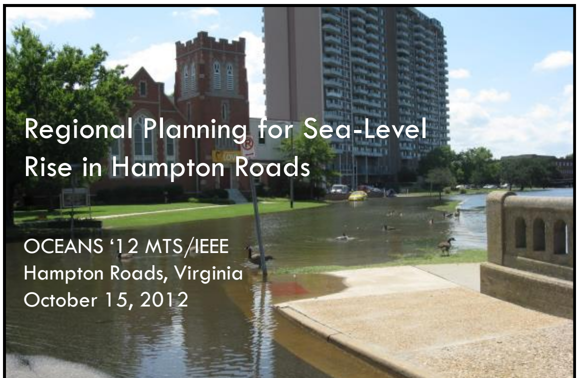


Report Recommendations

1. Localities should explicitly incorporate planning for climate change and sea level rise into their comprehensive and other long-term plans.
2. Localities should incorporate sea level rise adaptation planning into their infrastructure planning and maintenance programs.

Report Recommendations

3. Public and private actors in Hampton Roads should consider the use of the U.S. Army Corps of Engineers guidance for incorporating sea level rise into projects (as found in EC 1165-2-212) when planning, designing, and building projects in vulnerable areas.
4. Further efforts should be focused on:
   – Subsidence research
   – Elevation data
   – Specific adaptation measures



Regional Planning for Sea-Level Rise in Hampton Roads

OCEANS '12 MTS/IEEE
Hampton Roads, Virginia
October 15, 2012

Benjamin McFarlane, AICP
Regional Planner

Virginia Coastal Zone MANAGEMENT PROGRAM

Project Background

- In 2008, the Virginia Coastal Zone Management Program began funding efforts by three Planning District Commissions to study and address the impacts of climate change on their regions
  - Hampton Roads PDC
  - Middle Peninsula PDC
  - Northern Virginia Regional Commission

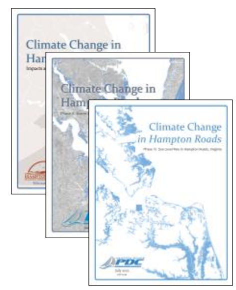
Project Background

- The mission of the Virginia Coastal Zone Management Program is to protect and manage Virginia's coastal zone.
- Goals of the VCZMP cover the sustainable use and protection of coastal resources, as well as coordination between agencies, interest groups, and citizens.
- VCZMP works directly with PDCs to provide technical assistance and resources to local governments

Virginia Coastal Zone Management Program

Project Background

- HRPDC has completed three reports under this focal area grant
- Year 1: General Impacts of Climate Change on Hampton Roads
- Year 2: Storm Surge
- Year 3: Sea Level Rise



Sea Level Rise Study Goals

5

- Assess the impacts of sea level rise on Hampton Roads (how much, when, etc.)
- Quantify the impacts of sea level rise on the region's population, economy, built environment, and natural environment
- Develop and test a tool that localities or the PDC can use to quantify exposure to sea level rise using GIS
- Identify areas that are potentially vulnerable to sea level rise for further study

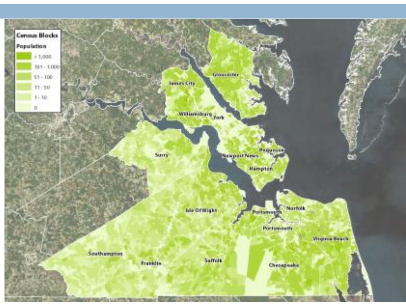
Data Used in Analysis

6

- Data used for GIS analysis:
  - 2010 Census population and housing units
  - VDOT road centerlines
  - Local property assessments
  - Esri Business Analyst businesses and employment
  - Coastal VEVA dataset
  - Protected Lands
  - EPA Elevation Dataset to Use While Waiting for LIDAR
    - Do not have LIDAR for entire region
    - Existing LIDAR is not consistent for all localities covered
    - EPA dataset developed specifically to analyze sea level rise vulnerability

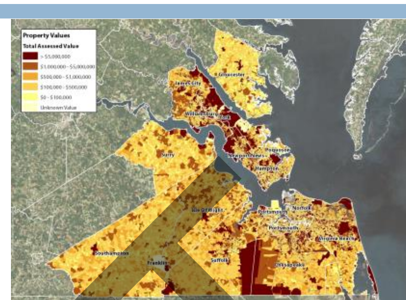
Data: Population

7



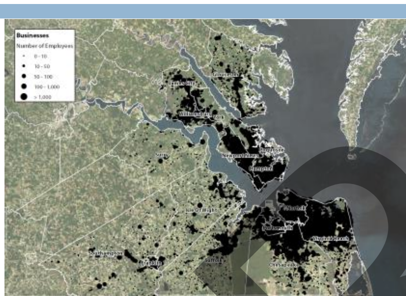
Data: Property Values

8



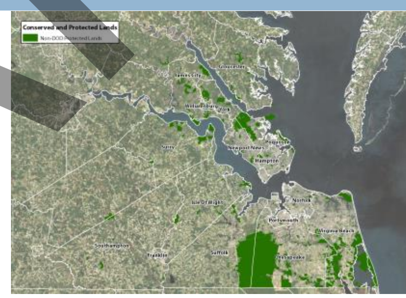
Data: Businesses

9



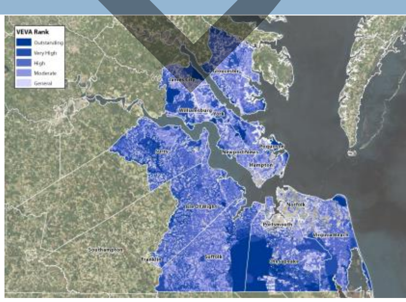
Data: Protected Lands

10



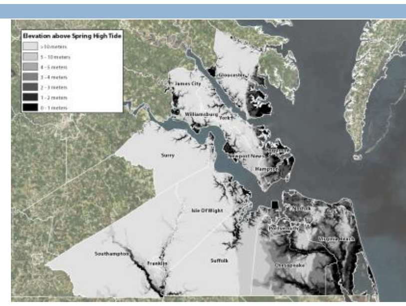
Data: Ecological Resources

11



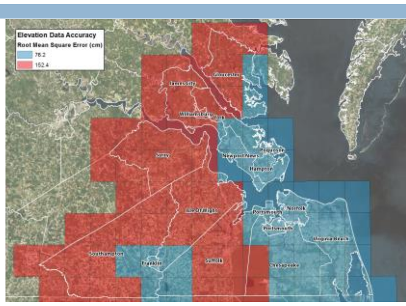
Data: Elevation

12



Data: Elevation Accuracy

13



Scenarios

14

- Three elevation scenarios (to account for elevation data quality) were used, based on one meter of local sea level rise
  - Low estimate = given elevation + total RMSE
  - Middle estimate = given elevation
  - High estimate = given elevation – RMSE
- Error analysis replicated based on EPA documentation

Assumptions and Caveats

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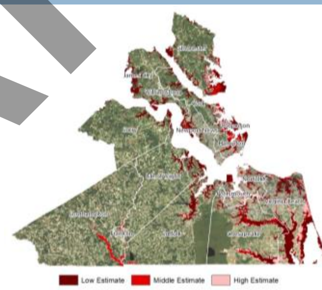
- One meter SLR within range of possibilities described in literature
- Inaccuracy in elevation data somewhat balanced by possibility of different rates of sea level rise
- Maps and results are not predictions – they are projections based on analysis assumptions

Results

16



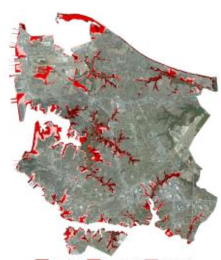
Results

17

- Results for each locality shown on map and in a table
- Currently being adjusted to recognize lack of precision in data and analysis

Results

18



	Total	1-Meter SLR (Low)	1-Meter SLR (Middle)	1-Meter SLR (High)
General				
Land Area (square miles)	55.90	3.14	6.53	9.20
Population	242,803	9,841	25,715	36,134
Housing Units	95,018	3,502	8,955	12,896
Built Environment				
Number of Parcels (intersection)	65,979	4,555	8,251	11,567
Number of Parcels (centroid)	65,979	1,757	4,968	8,204
Improvement Value of Parcels (intersection)	$13,494,681,500	$1,703,705,500	$3,207,444,200	$3,917,995,600
Improvement Value of Parcels (centroid)	$13,494,681,500	$350,808,300	$1,325,957,300	$2,234,621,300
Infrastructure				
Roads (total miles)	1,150.24	14.69	75.47	129.15
Roads (Interstate)	54.86	1.71	5.34	6.84
Roads (Primary)	152.53	0.95	9.07	13.20
Roads (Secondary)	0	0	0	0
Roads (Local or Private)	942.85	12.03	61.06	109.10
Economy				
Businesses	9,118	111	532	946
Employees	136,292	1,924	9,818	15,014
Total Value of Parcels (intersection)	$20,670,093,500	$3,189,941,400	$5,357,247,300	$6,485,310,600
Total Value of Parcels (centroid)	$20,670,093,500	$627,145,700	$2,225,096,200	$3,860,392,700
Natural Environment				
Protected Lands (acres)	868.44	122.19	195.22	244.57
VEVA – Outstanding (acres)	33.97	7.22	21.15	25.02
VEVA – Very High (acres)	1,509.57	378.21	541.44	617.74
VEVA – High (acres)	4,480.30	760.99	1,266.82	1,514.85

Report Recommendations

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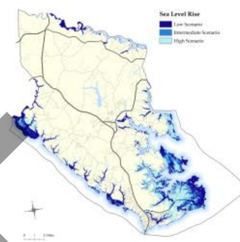
- Localities should explicitly incorporate planning for climate change and sea level rise into their comprehensive and other long-term plans by, for instance, identifying area vulnerable to sea level rise using maps or by revising zoning ordinances to encourage development away from vulnerable areas.
- Localities should incorporate sea level rise adaptation planning into their infrastructure planning and maintenance programs, taking advantage of regular maintenance procedures to identify system vulnerabilities or retrofit opportunities that will extend the lifespan of their infrastructure.
- Public and private actors in Hampton Roads should consider the use of the U.S. Army Corps of Engineers guidance for incorporating sea level rise into projects (as found in EC 1165-2-212) when planning, designing, and building projects in vulnerable areas.

Next Steps

- HRPDC Coastal Resiliency Grant
- Public Outreach
- Educational Materials
- Identification of adaptation strategies that can be incorporated into local and regional plans
- Obtain LIDAR for entire region



Next Steps

- HRPDC is working with Old Dominion and Virginia Sea Grant on the Hampton Roads Adaptation Forum
- HRPDC is also working with the Virginia Institute of Marine Science on the General Assembly-requested Recurrent Flooding Study

Hampton Roads Adaptation Forum

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- Collaboration between Virginia Sea Grant, Old Dominion University, and HRPDC
- Institutionalize technical discussions between local government staff, NGOs, and academic institutions to identify research needs and discuss potential responses to sea level rise and flooding
- Develop a Knowledge Management System to make information readily available to stakeholders

Questions?

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Virginia Coastal Zone MANAGEMENT PROGRAM

APPENDIX B – SAMPLE HANDOUTS

Adapting to Climate Change in Hampton Roads

Due to their topography and coastal location, Hampton Roads communities have an intimate relationship with the water. Coastal living, a major driver of the region's desirability and quality of life, brings with it exposure to coastal hazards, including flooding, storms, and sea level rise. The threat of climate change, which will increase the region's exposure to these hazards, demands a regional response to problems that show no respect for political boundaries. The Hampton Roads Planning District Commission, in partnership with the Virginia Coastal Zone Management Program and area local governments, is working to improve the resilience of the Hampton Roads region to help address the challenges posed by coastal hazards and climate change.

HRPDC's planning for climate change and coastal resiliency began in 2008 with a grant from the Virginia Coastal Zone Management Program. The first year of work focused on identifying the broad impacts of climate change on the region and engaging with area local governments to identify vulnerabilities and opportunities. This resulted in a report, published in February 2010, which outline the state of the science of climate change and described some work that had previously been done on the impacts of sea level rise on the region and its natural resources.

HRPDC's second year focused on analyzing the region's exposure to storm surge flooding and describing how sea level rise could affect the region. This work consisted of a geographic information systems (GIS) analysis combining storm surge vulnerability zones, Census population and housing totals, business locations and employment, roads, and critical infrastructure facilities to develop estimates of the region's exposure to storm surge flooding. This analysis included the development of maps for each Hampton Roads locality showing the locations of vulnerable areas and facilities.

HRPDC's third year focused solely on sea level rise, using data from a variety of sources to identify those low-lying areas in the region that would be vulnerable to inundation using a scenario of one meter of sea level rise. The report, published in July 2012, also documented the historic sea level rise observed the region using data from NOAA tide gauges and included projections of future sea level rise using global scenarios. The GIS analysis for this report included the mapping of vulnerable areas and calculated some of the potential impacts of sea level rise on the region's population, property, road infrastructure, economy, and natural environment.

HRPDC continues to work with partners throughout the region and the county to help promote the region's coastal resilience. Current partners include the Virginia Institute of Marine Science, Old Dominion University, Virginia Sea Grant, local governments, and others.

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Sources:

Climate Change in Hampton Roads: Impacts and Stakeholder Involvement
    http://www.hrpdcva.gov/news/index/view/id/31
Climate Change in Hampton Roads Phase II: Storm Surge Vulnerability and Public Outreach
    http://www.hrpdcva.gov/news/index/view/id/27
Climate Change in Hampton Roads Phase III: Sea Level Rise in Hampton Roads, Virginia
    http://www.hrpdcva.gov/news/index/view/id/19

What is Climate Change, and What Does It Mean for Hampton Roads?

Climate change poses a significant threat to Hampton Roads. Some changes, such as coastal flooding, warmer temperatures, and Scientists predict that increases in the levels of greenhouse gases such as carbon dioxide and methane in the atmosphere will result in severe impacts to communities around the globe. The three primary effects of climate change will be rising average temperatures, altered precipitation patterns, and sea level rise. Hampton Roads communities will be affected by all three, though as a coastal region, sea level rise will probably have the most visible impacts.

Higher temperatures will be the most direct result of climate change. As greenhouse gas emissions accumulate, more of the sun's radiation will remain trapped in the atmosphere, causing temperatures throughout the year to rise. Winters will become milder, but summers will become hotter, with the potential for severe impacts to public health and wellbeing. In addition to higher average temperatures, extreme temperatures are likely to become more common. The second National Climate Assessment, produced by the U.S. Global Change Research Program, projected in 2009 that southeastern states, including Virginia, will see average temperatures rise by 4.5 to 9°F between the 1970s and the 2080s. The Virginia Governor's Commission on Climate Change utilized a projected increase of 5.6°F by the end of the 21st century.

One consequence of higher temperatures will be changes to the world's precipitation patterns. Some areas may receive more annual precipitation, while others receive less. What precipitation occurs may shift to different seasons, producing drier summers and wetter winters. Both droughts and storm events are projected to increase in frequency, intensity, and duration. More intense events could exacerbate storm driven flooding or strain regional water supplies. The Governor's Commission projected that Virginia would see an overall increase in precipitation of 11% by 2100.

Rising sea levels pose perhaps the greatest risk to Hampton Roads. Sea levels are rising globally due to the melting of land ice and the thermal expansion of the oceans. Locally, these global trends are compounded by land subsidence, the gradual sinking of land in response to various geologic causes. Many Hampton Roads communities have low-lying areas that are already vulnerable to flooding during high tides or storms. Sea level rise will increase the region's vulnerability to flooding. The 2009 National Climate Assessment projected global sea level rise between 1992 and 2100 to be between 3 and 4 feet.

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Sources:
U.S. Global Research Program National Climate Assessment
http://www.globalchange.gov/what-we-do/assessment
Climate Change in Hampton Roads: Impacts and Stakeholder Involvement
http://www.hrpdcva.gov/news/index/view/id/31

Storm Flooding in Hampton Roads

As a low-lying, coastal region, Hampton Roads is often at the mercy of coastal storms and tides, which can result in flooded yards and houses, impassable roads, and lost economic activity. While some areas of communities such as Norfolk, Poquoson, and Portsmouth have areas that are so low-lying that they flood during some high tides, a much larger part of the region is vulnerable to flooding from coastal storms such as hurricanes or nor'easters. These storms have the potential to affect large segments of several Hampton Roads communities, including Chesapeake, Gloucester County, Hampton, Norfolk, Poquoson, Portsmouth, Virginia Beach, and York County.

Though commonly used to describe the highest water level caused by a coastal storm, storm surge is actually the difference in water levels between the expected or astronomical tide and the observed water level during the storm. The total combined water level is referred to as the storm tide. Depending on the range between low and high tides, when a storm hits during the tidal cycle is a critical component of how much flooding and damage will occur. A large storm that arrives during a low tide may cause only minimal flooding, while a less powerful storm that arrives at high tide can result in significant damage.

An analysis of the Hampton Roads region's exposure to storm flooding conducted by the Hampton Roads Planning District Commission found that the areas generally to the east of U.S. Route 17 are the most vulnerable to flooding during storms. Utilizing the results of a U.S. Army Corps of Engineers and Virginia Department of Emergency Management hurricane evacuation study, the analysis estimated that over 100,000 Hampton Roads residents live in areas that could experience coastal flooding during a Category 1-type storm event. In addition, over 1,500 businesses with over 27,000 employees are also located in such vulnerable areas. The most vulnerable communities in terms of population, businesses, and employees affected are Chesapeake, Hampton, Norfolk, and Virginia Beach.

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Sources:

The Three Faces of Isabel: Storm Surge, Storm Tide, and Sea Level Rise
John Boon, Virginia Institute of Marine Science
http://web.vims.edu/physical/research/isabel/
Climate Change in Hampton Roads Phase II: Storm Surge Vulnerability and Public Outreach
http://www.hrpdcva.gov/news/index/view/id/31

Hampton Roads and the Threat of Sea Level Rise

The Hampton Roads region's current vulnerability to flooding from tides and storms foreshadows the impacts the region will feel as a result of sea level rise. Sea level rise caused by global warming is projected to be at least a meter on average worldwide by the end of the 21st century. That level of sea level rise, compounded by local-specific effects such as land subsidence and ocean currents, will have a profound effect on the coastline of Hampton Roads, and will result in significant impacts to the region's people, economy, and infrastructure.

Global, or eustatic, sea level rise is caused by two factors, both of which result from global warming. Thermal expansion occurs as the oceans warm up in response to the warming atmosphere; the water in the world's oceans actually expands. In addition, higher temperatures cause land-bound ice, such as that found on mountaintops and in glaciers, to melt and eventually reach the oceans as more water. Both factors are expected to contribute to significant amounts of sea level rise in the coming years.

Local sea level rise is the result of global sea level rise interacting with local influences. Land can either rise up or sink in response to various geological events, such as earthquakes, tectonic movement, or even the withdrawal of groundwater or oil from deep within the ground. Hampton Roads is gradually sinking or subsiding in response to decades of groundwater withdrawals combined with long-term geological causes, including glacial isostasy – as glaciers continue to recede to the north from their positions during the last ice age, land that was once weighed down by massive quantities of ice rises back up, and land that was just to the south of these areas begins to sink in response. In addition to subsidence, recent research suggests that ocean currents are changing, resulting in greater amounts of local sea level rise off the U.S. Mid-Atlantic coast than would otherwise be expected. Together, these effects form a substantial component of local sea level rise in Hampton Roads.

Sea level rise is already having a significant effect on Hampton Roads. Tide gauge records from Sewell's Point in Norfolk show that the long-term rate in the 20th century was over 4mm/year, which equals nearly 1.5 feet of sea level rise over a one hundred year period. For an area that is as flat as eastern Hampton Roads, 1.5 feet can make a big difference. Given that sea level rise appears to be accelerating, Hampton Roads communities should begin planning for its effects sooner rather than later.

For more information, please contact:
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Sources:
Climate Change in Hampton Roads Phase III: Sea Level Rise in Hampton Roads, Virginia
http://www.hrpdcva.gov/news/index/view/id/19
"Recurrent Flooding Study" in Rivers & Coasts, Fall 2012, Vol. 7, No. 2. Center for Coastal Resources Management, Virginia Institute of Marine Science
http://ccrm.vims.edu/publications/pubs/rivers&coast/index.html

Promoting Coastal Resilience in Hampton Roads

Resiliency is defined as the ability to withstand multiple stresses without compromising. Natural hazards such as flooding, storms, and sea level rise are an omnipresent threat to those living and working on or near the coast. Ignoring these hazards can result in injuries to residents and lost or damaged property. However, there are many steps that communities, employers, and residents can take to increase their resilience and reduce the potential impacts of these hazards. The Hampton Roads Planning District Commission is working with many partners across the region to encourage communities and residents to become more resilient by providing and improving access to information and promoting better practices in development, operations, and public safety.

One area in which HRPDC continues to help area local governments plan for sea level rise by providing GIS analysis and mapping of areas potentially vulnerable to sea level rise. This includes both keeping up to date on the latest projections of global sea level rise and local effects and also utilizing the best available data for these products. In 2012 and 2013, HRPDC staff merged existing high-resolution LIDAR elevation datasets for many different areas of Hampton Roads into a single, seamless dataset. This merged dataset was then used in the creation of improved sea level rise inundation maps. HRPDC has continued to support the need for quality mapping products by helping to fund the acquisition of new LIDAR data for eastern Hampton Roads.

Encouraging the sharing of best practices and lessons learned between all Hampton Roads localities is a major goal of HRPDC's coastal resiliency efforts. To accomplish this goal, HRPDC has partnered with Virginia Sea Grant and Old Dominion University to establish, with funding from NOAA's Sea Grant program, the Hampton Roads Sea Level Rise & Adaptation Forum. This forum provides an informal and semi-regular setting where local government staff can meet with state and federal agency representatives, researchers, industry experts, and other stakeholders to learn about adaption options, hear presentations on current research on sea level rise and flooding, and discuss items of common interest to the region.

In addition to the adaptation forum, HRPDC continues to work with other regional institutions to promote coastal resiliency. HRPDC staff provided assistance to the Virginia Institute of Marine Science on the recently released Recurrent Flooding Study. HRPDC staff is also providing input to the Virginia Coastal Policy Clinic, an academic effort by the College of William & Mary Law School to provide legal analysis of coastal policy issues such as flooding and sea level rise. This clinic will provide Hampton Roads local governments with sound research on local government responsibilities and authorities related to coastal hazards.

Sources:
VIMS Recurrent Flooding Study
Hampton Roads Sea Level Rise & Flooding Adaptation Forum
http://www.odu.edu/research/initiatives/ccslri/calendar/2013/3/hr_sea_level_rise_fo
Virginia coastal Policy Clinic
http://law.wm.edu/academics/programs/jd/electives/clinics/vacoastal/index.php

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APPENDIX C – DIGITAL ELEVATION MODEL INPUT DATA

TABLE 3: ORIGINAL HAMPTON ROADS DEMS USED IN THE CREATION OF A SEAMLESS REGIONAL DEM

Original Dataset Coverage	Source	Coordinate System (Units)	Vertical Datum (Units)	Horizontal Resolution	Processing Steps
Craney Island (Portsmouth)	NED	GCS_North_American_1983 (degrees)	NGVD29 (meters)	10 meters	• NGVD29 to NAVD88 using VERTCON • Reproject to Virginia State Plane South • Resample to 5-foot horizontal resolution • Convert vertical meters to feet (conversion factor = 3.28084)
Mulberry Island (Newport News/Ft. Eustis)	NED	GCS_North_American_1983 (degrees)	NGVD29 (meters)	10 meters	• NGVD29 to NAVD88 using VERTCON • Reproject to Virginia State Plane South • Resample to 5-foot horizontal resolution • Convert vertical meters to feet (conversion factor = 3.28084)
Lower Peninsula (Hampton, Newport News, Poquoson, York County)	NGA	UTM 18N (meters)	NAVD88 (meters)	1 meter	• Reproject to Virginia State Plane South • Resample to 5-foot horizontal resolution • Convert vertical meters to feet
Upper Peninsula (Gloucester, James City, Newport News, Williamsburg, York)	NGA	UTM 18N (meters)	NAVD88 (meters)	1 meter	• Reproject to Virginia State Plane South • Resample to 5-foot horizontal resolution • Convert vertical meters to feet
Chesapeake	NGA/Chesapeake	UTM 18N (meters)	NAVD88 (meters)	1.219 meters	• Reproject to Virginia State Plane South • Resample to 5-foot horizontal resolution • Convert vertical meters to feet
Newport News	Newport News	NAD 1983 Virginia State Plane South (HARN)	NAVD88 (feet)	1 foot	• Reproject to Virginia State Plane South • Resample to 5-foot horizontal resolution

Original Dataset Coverage	Source	Coordinate System (Units)	Vertical Datum (Units)	Horizontal Resolution	Processing Steps
South Hampton Roads (Chesapeake, Norfolk, Portsmouth, Virginia Beach)	NGA	UTM 18N (meters)	NAVD88 (meters)	1 meter	• Reproject to Virginia State Plane South • Resample to 5-foot horizontal resolution • Convert vertical meters to feet
York County	York County	NAD 1983 Virginia State Plane South	NAVD88 (feet)	5 feet	None
Western Tidewater (Gloucester, Isle of Wight, James City, Suffolk, Surry, Williamsburg)	VGIN	NAD 1983 Virginia State Plane South (HARN)	NAVD88 (feet)	4 feet	• Reproject to Virginia State Plane South • Resample to 5-foot horizontal resolution
Franklin, Southampton County	VGIN	NAD 1983 Virginia State Plane South (HARN)	NAVD88 (feet)	2.5 feet	• Reproject to Virginia State Plane South • Resample to 5-foot horizontal resolution
Portsmouth	VGIN	NAD 1983 Virginia State Plane South (HARN)	NAVD88 (feet)	2.5 feet	• Reproject to Virginia State Plane South • Resample to 5-foot horizontal resolution
Virginia Beach	NGA/Virginia Beach	UTM 18N (meters)	NAVD88 (meters)	1 meter	• Reproject to Virginia State Plane South • Resample to 5-foot horizontal resolution • Convert vertical meters to feet

NED = National Elevation Dataset

NGA = National Geospatial-Intelligence Agency

VGIN = Virginia Geographic Information Network

NGVD29 = National Geodetic Vertical Datum of 1929

NAVD88 = North American Vertical Datum of 1988

Appendix E – U.S. Army Corps of Engineers Guidance

APPENDIX C

Flowchart to Account for Changes in Mean Sea Level

C-1. Premise. Global mean sea level (GMSL) has risen over the past century, and the rate of rise will continue and may accelerate in the future. USACE projects need to be planned, designed, constructed, and operated with the understanding that the rate of rise of GMSL may increase and affect USACE water resource projects in and adjacent to the nation's coastal zone. In other locations, the relative sea-level is dropping, and USACE projects must account for the decrease in water levels and must balance this with the potential for increasing GMSL. The steps below are shown graphically in Figure C-1.

C-2. Flowchart.

Step 1. Is the project in the coastal/tidal/estuarine zone, or does it border those zones such that project features or outputs are now, or may be in the future, subject to influence by continued or accelerated rate of local relative sea-level change? YES-NO?

a. If YES, go to Step 2.
b. If NO, continue with product development process without considering sea-level change.

Step 2. Locate nearest tide station(s) with a current period of record. Is the period of record at least 40 years? YES-NO?

a. If YES, go to Step 4.
b. If NO, go to Step 3.

Step 3. Identify next closest long-term gauge. Assess whether or not the long-term gauge can be used to artificially extend the record of the short-term gauge. YES-NO?

a. If YES, go to Step 4.
b. If NO, Consult with a tidal hydrodynamics expert, such as CO-OPS[1].

[1] CO-OPS: Center for Operational Oceanographic Products and Services, National Ocean Service, National Oceanographic and Atmospheric Administration, Silver Spring, MD 301-7132981. http://tidesandcurrents.noaa.gov

Step 4. Assess whether identified long-term gauges can be used to adequately represent local sea-level conditions at project site. YES-NO?

a. If YES, go to Step 5.
b. If NO, Consult with a tidal hydrodynamics expert, such as CO-OPS.

Step 5. Assess whether the project site and gauge site have similar physical conditions (coastal/estuarine location, bathymetry, topography, shoreline geometry, and hydrodynamic conditions). YES-NO?

a. If YES, go to Step 6.
b. If NO, Consult with a tidal hydrodynamics expert, such as CO-OPS.

Step 6. Calculate local historic trends for MSL, MHW, and MHHW at long-term gauge. Use CO-OPS values, if available. If not available, use CO-OPS method for sea-level trend analysis.[1] This historic trend is now the low or baseline trend rate for project alternative analysis (see 8(a)). Go to Step 7.

Step 7. Calculate standard error of the linear trend line (use CO-OPS values, if available). Go to Step 8.

Step 8. The next step is to evaluate whether there is a regional mean sea-level trend (see definition) that is different from the eustatic mean sea-level trend of 1.7 mm/year (+/-0.5 mm/year, IPCC 2007a). See Figure C-2 for one example of such a region. Considering regional geology, is it possible to identify a vertically stable geologic platform within the same region as the project site? YES-NO?

a. If YES, go to Step 9.
b. If NO, go to Step 11.

Step 9. Calculate regional MSL trend for the identified vertically stable geologic platform within the region, and go to Step 10.

Step 10. Estimate local rate of vertical land movement by subtracting regional MSL trend from local MSL trend. Go to Step 12.

Step 11. Assume the regional mean sea-level trend is equal to the eustatic mean sea-level trend of 1.7 mm/year (+/-0.5mm/year) and estimate local rate of vertical land movement by subtracting eustatic MSL trend from local MSL trend. Go to Step 12.

[1] CO-OPS method for sea-level trend analysis is described in NOAA Technical Report NOS CO-OPS 36, "Sea Level Variations of the United States 1854-1999.”.

Step 12. Calculate future values for sea-level change for low (historic or baseline) rate: extrapolate historic linear trend into future at 5-year increments, OR reasonable increments based on both period of analysis and scope of study[1]. Go to Step 13.

Step 13. Calculate future values for sea-level change for intermediate rate (modified NRC Curve I), see 8(a)(1): calculate future sea-level change values at 5-year increments OR reasonable increments based on both period of analysis and scope of study by combining incremental values from equations B-2 and B-3 with values obtained by extrapolating rate of local vertical land movement. Go to Step 14.

Step 14. Calculate future values for sea-level change for high rate (modified NRC Curve III), see 8(a)(2): calculate future sea-level change values at 5-year increments OR reasonable increments based on both period of analysis and scope of study by combining incremental values from equations B-2 and B-3 with values obtained by extrapolating rates of local vertical land movement. Go to Step 15.

Step 15. Assess project performance for each sea-level change scenario developed in Steps 12, 13, and 14. This assessment and Steps 15-18 can occur at any point in the project life-cycle, and thus apply to existing as well as proposed projects. Go to Step 16.

Step 16. Calculate the risk for each project design alternative combined with each sea-level change scenario, as developed in Steps 12, 13, and 14 at 5-year increments OR reasonable increments based on both period of analysis and scope of study. Go to Step 17.

Step 17. Assess risk[2] and reevaluate project design alternatives. Consider at a minimum: planning for adaptive management[1], designing to facilitate future modifications, and designing for a more aggressive future sea-level change scenario. Go to Step 18.

Step 18. Select project designs that best accommodate the range of sea-level change scenarios throughout the project life cycle.

[1] Use 5-yr increments unless alternate reasonable increments based on both period of analysis and scope of study can be justified. The number of scenarios may be determined through exploratory or iterative analysis.
[2] Policies are under development at the time of this EC.

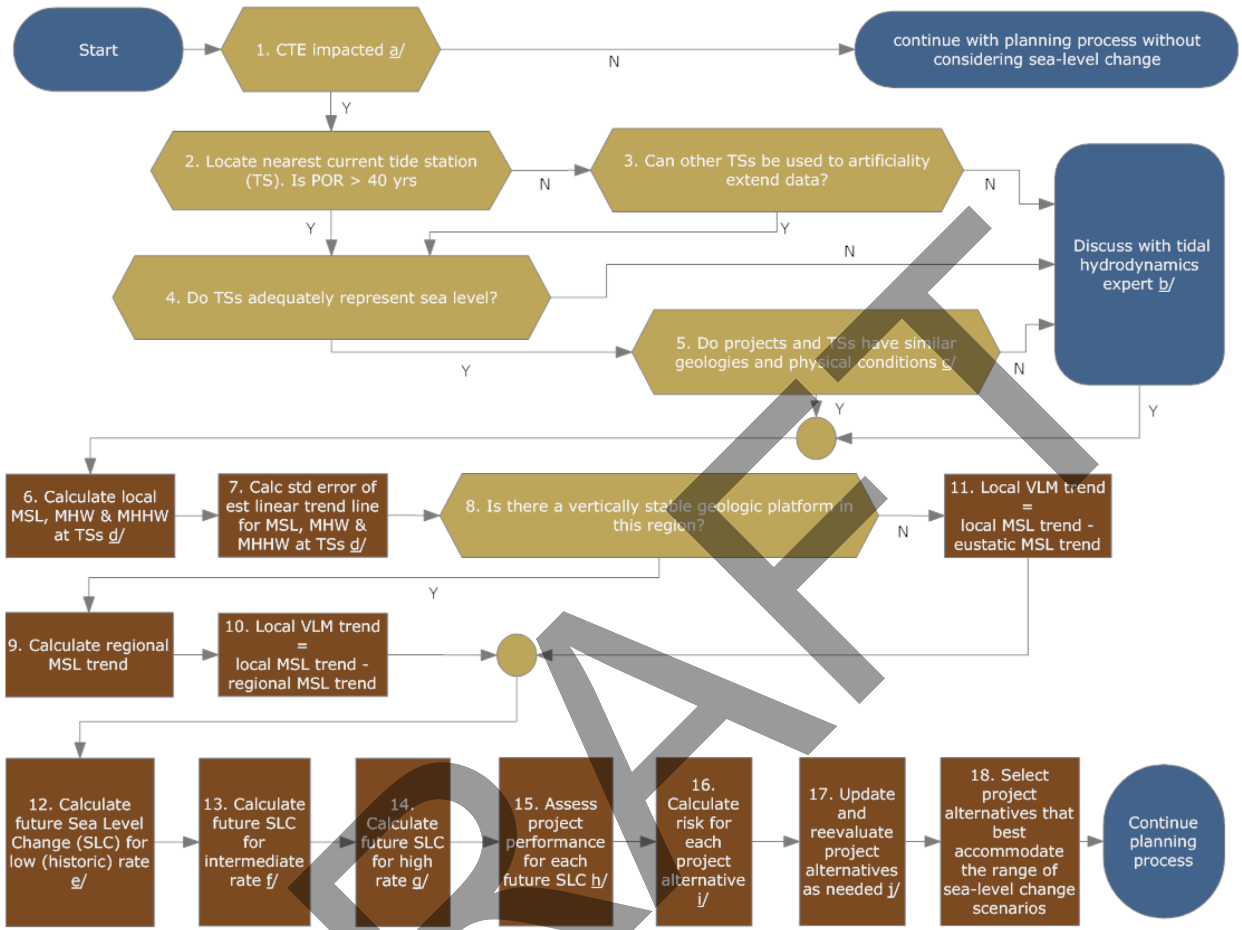

Figure C-1. Graphical illustration of process to account for changes in mean sea level.

a) Is the project in or bordering coastal/tidal/estuarine (CTE) zone such that project features or outputs are now, or may be in the future, subject to influence by continued or accelerated rate of change?
b) Discuss with tidal hydrodynamics expert, such as CO-OPS (NOAA).
c) Similar physical conditions such as coastal/estuarine location, bathymetry, topography, shoreline geometry, and hydrodynamic conditions.
d) Use CO-OPS (NOAA) values, if available.
e) Low rate: extrapolate historic linear trend into future at selected increments.
f) Intermediate rate (IPCC-2007, or modified NRC-Curve-I: calculate future SLC values at selected increments by combining incremental values from equations A-2 and A-3 with value obtained by extrapolating rate of local vertical land movement.
g) High rate (modified NRC-Curve-III): calculate future SLC values at selected increments by combining incremental values from equations A-2 and A-3 with value obtained by extrapolating rate of local vertical land movement.
h) Consider project design function at all phases of the project life cycle: performance, design issues; project stability; and project operation and maintenance.
i) Calculate the risk for each project alternative at selected increments. This assessment and Steps 15-18 can occur at any point in the project life-cycle, and thus apply to existing as well as proposed projects.
j) Consider at a minimum: planning for adaptive management (updating operational strategies based on new information); designing to facilitate future modifications; and adaptive engineering (designing for a more aggressive future SLC scenario