REPORT OF THE
VIRGINIA INSTITUTE OF MARINE SCIENCE

Recurrent Flooding Study for Tidewater Virginia (SJR 76, 2012)

TO THE GOVERNOR AND
THE GENERAL ASSEMBLY OF VIRGINIA

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Cover Letter

To: Division of Legislative Automated Services (DLAS)

Division of Legislative Automated Services (DLAS)
910 Capitol Square
General Assembly Building, Suite 660
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Attention: Legislative Documents and Reports Processing

Report submitted via email: reportdocs@dlas.virginia.gov

The attached document is a legislatitive document submitted in .pdf format .

Title: Recurrent Flooding Study for Tidewater Virginia

Mandate: SJ76ER; Requesting the Virginia Institute of Marine Science to study strategies for adaptation to prevent recurrent flooding in Tidewater and Eastern Shore Virginia localities.

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Preface

Authority directing the study

This study was directed by SJ76ER, and was for the purpose of requesting the Virginia Institute of Marine Science to study strategies for adaptation to prevent recurrent flooding in Tidewater and Eastern Shore Virginia localities. It was passed by the Senate (February 28, 2012) and the House of Delegates (February 24 2012).

Study Group Membership

The study group consisted of The Virginia Institute of Marine Science, Center for Coastal Resources Management, Old Dominion University, the Hampton Roads Planning District Comission, the City of Norfolk, the Accomack-Northampton Planning District Commission and Wetlands Watch.

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We would like to acknowledge all the participants in the stakeholder advisory group, many of whom traveled far distances to attend the meeting and who all contributed unique perspectives which helped shape the report.

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Executive Summary

Recurrent flooding is flooding that happens repeatedly in the same areas, typically leading to economic losses. Recurrent flooding is a problem throughout Tidewater Virginia, both in coastal areas (typically due to storm surge) and in inland areas (typically due to heavy rainfall).

The Virginia General Assembly requested that in conducting its study, the Virginia Institute of Marine Science

- review and develop a comprehensive list of ideas and examples of strategies used in similar settings around the United States and the world;
- convene a stakeholder advisory panel for the purpose of discussing and assessing the feasibility of employing these strategies in Tidewater and Eastern Shore Virginia; and offer specific recommendations for the detailed investigation of preferred options for adapting to relative sea-level rise.

The study was undertaken with the collaboration and assistance of Old Dominion University, the Hampton Roads Planning District Commission, Wetlands Watch, the University of Virginia Institute for Environmental Negotiation, the William and Mary Coastal Policy Clinic, and relevant state agencies. Data and analyses were collected from multiple local, state, and federal agencies, as well as NGOs and regional authorities.

This Recurrent Flooding Study addresses all localities in Virginia's coastal zone. It documents flooding risks based on available records of past road and infrastructure inundation as well as potential flooding risks based on the best available topographic information. It assesses future risk based on projections for sea level rise from the National Climate Assessment program modified to incorporate factors specific to Virginia's coastal zone. The study also inventories adaptation options from regional, national, and international sources. Options include planning, management, and engineering strategies that merit particular consideration for application in Virginia.

In preparing this report we found:

1. Recurrent flooding is a significant issue in Virginia coastal localities and one that is predicted to become worse over reasonable planning horizons (20-50 years).
2. The risks associated with recurrent flooding are not the same throughout all areas of Tidewater Virginia.
3. Data are often lacking for comprehensive and/or fine resolution analysis of flood risks in the region.

4. Review of global flood and sea level rise management strategies suggests that it is possible for Virginia to have an effective response to increasing flood issues BUT it takes time (20-30 years) to effectively plan and implement many of the adaptation strategies. There are a wide variety of adaptation strategies used throughout the world, many of which are suitable for use in some part of Tidewater Virginia. The optimal strategy is going to be development of flexible plans that match adaptation options to the unique circumstances of each coastal locality and link option implementation to the evolving risks. This is the strategy now employed by an increasing number of states and localities in the United States. It requires serious planning, commitment of resources, and careful analysis of evolving conditions. It reduces unnecessary expenses, ensures development decisions are informed, and recognizes the long lead times required for effective implementation of many adaptation options.

The stakeholder advisory panel assembled for this report consisted of 25 individuals selected to provide a broad representation of the Virginia coastal localities and agencies working within the region. The panel focused on the roles of the state and localities in addressing flooding and sea level rise issues. The advisory panel felt strongly that Virginia localities are not adequately empowered to address the issues through policy and management actions, and localities do not have the necessary financial resources for many accommodation or protection strategies. Therefore, the advisory panel felt the state should take a strong leadership role, incorporating flood and sea level rise management into state purviews. They specifically believed localities should be enabled to implement adaptation strategies, but did not want the state to mandate specific adaptation strategies. The advisory panel recommended state authorization and support that would allow each locality the opportunity to address flooding and sea level rise in their own way.

To begin the process of addressing recurrent flooding at the state and local levels, we offer the following recommendations:

1. Given the long time frame necessary to effectively address recurrent flooding and sea level rise issues and given the speed at which risks are projected to increase, Virginia and its coastal localities should immediately begin comprehensive and coordinated planning efforts.
2. The State should initiate identification, collection and analysis of data needed to support effective planning for response to recurrent flooding issues in Virginia.
3. The State should take a lead role in addressing recurrent flooding in Virginia for the following reasons:
    a. Accessing relevant federal resources for planning and mitigation may be enhanced through state mediation.

b. Flooding problems are linked to water bodies and therefore often transcend locality boundaries.
c. Resource prioritization efforts will require consistent or standardized assessment protocols across all localities and regions.
d. Localities do not feel enabled to address all flooding and sea level rise issues.

4. The State should request an expert review of local government legal authority to address current and projected flooding risks and what levels of evidence are likely to be required to justify locality action. The State should then enact any enabling authority needed to allow localities to address current and projected flooding issues.
5. The State should develop a comprehensive strategy for addressing recurrent flooding issues throughout Tidewater Virginia.
    a. Part of that strategy should include prioritization of areas for flood management actions based (in part) on risk.
    b. Detailed studies should be done of prioritized areas to determine:
        i. Potential adaptation strategies appropriate to the area
        ii. Implementation feasibility of identified strategies
        iii. Cost/benefit of identified strategies

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Definitions

Adaptation
Adaptation is an adjustment in ecological, social or economic systems in response to actual or expected stimuli and their effects or impacts (IPCC 2001). It refers to changes in practices or structures that moderate the effects of, or reduce the impacts of an outside force to reduce potential damages. In particular, it refers to practices that reduce vulnerability to or consequences of outside forces.

There are 3 main types of flood adaptation: 1) Management/Retreat, when natural forces are allowed to continue to function and human impacts are minimized by avoiding, minimizing or regulating human use of the coastal area; 2) Accommodation, when people continue to use and occupy the coastal zone, but adapt their lifestyle to reduce flood impacts; 3) Protection, when structural (hard or soft) engineering aims to protect the land from the water (similar to Mclean and Tysban 2001).

Planned adaptations are those based on policy changes either reacting to, or anticipating changes in conditions. Autonomous (or spontaneous) adaptations are reactive changes, typically private sector initiatives (individuals or communities) (Smit and Pilifosova 2001).

Consequences
Consequences are the economic and human damages resulting from a given flood event.

Flood Risk
Flood risk is the probability of a flood occurring. It is typically expressed as the likelihood of a flood occurring in a given year or as a recurrence frequency (e.g. the 10-year storm).

Global Sea Level Rise
Global sea level rise is the worldwide increase in the volume of the world's oceans that occurs as a result of thermal expansion and melting ice caps and glaciers (Titus et al. 2010).

Nor'easters or Winter Storms
Winter coastal storms are characterized by strong winds from the northeast quadrant over long reaches of coast. These winds are part of a counter clock-wise cyclonic atmospheric circulation about a center of atmospheric low pressure at sea. The proximity of warm Gulf Stream water to the colder continent during winter and spring favors the development of such storms (Ho et al. 1976).

Relative Sea Level Rise
Relative sea level rise refers to the change in sea level relative to the elevation of the land, which includes global sea level rise, land subsidence and changes in ocean circulation (Titus et al. 2010).

Sea Level
Sea level refers to the average level of tidal waters, generally measured over a 19-year period. The 19-year cycle is necessary to smooth out variations in water levels caused by seasonal weather fluctuations and the 18.6-year cycle in the moon's orbit. The sea level measured at a particular tide gauge is often referred to as local mean sea level (LMSL) (Titus et al. 2010).

Storm Surge
Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide. It is caused primarily by the winds from a storm and is linked to both tropical and extratropical storms.

Storm Tide
Storm tide is the water level rise during a storm due to the combination of storm surge and the astronomical tide.

Vulnerability
Vulnerability is the potential for damage to individuals, society and the environment. It can be reduced through the use of adaptation strategies.

Section 1: Recurrent Flooding in Tidewater Virginia Localities

Introduction: What is the problem?

Recurrent flooding is flooding that occurs repeatedly in the same area over time. It can be due to precipitation events, high tides or storm surge. In coastal Virginia, all three of these factors cause recurrent flooding, and all three are predicted to get worse, resulting in more frequent or larger scale flood events.

Precipitation events typically cause flooding when the intensity of runoff exceeds the capacity of soil infiltration or stormwater drainage systems. This results in a backup of water into roads, homes and businesses. Precipitation-based flooding in Virginia occurs in both urban and rural areas, in coastal and non-coastal areas. Intense precipitation can lead to riverine flooding, which tends to be a bigger problem in the western part of Virginia, but can also occur in the coastal plain. It worsens when the frequency and intensity of heavy rain events increase or when new development increases the load on existing drainage systems.

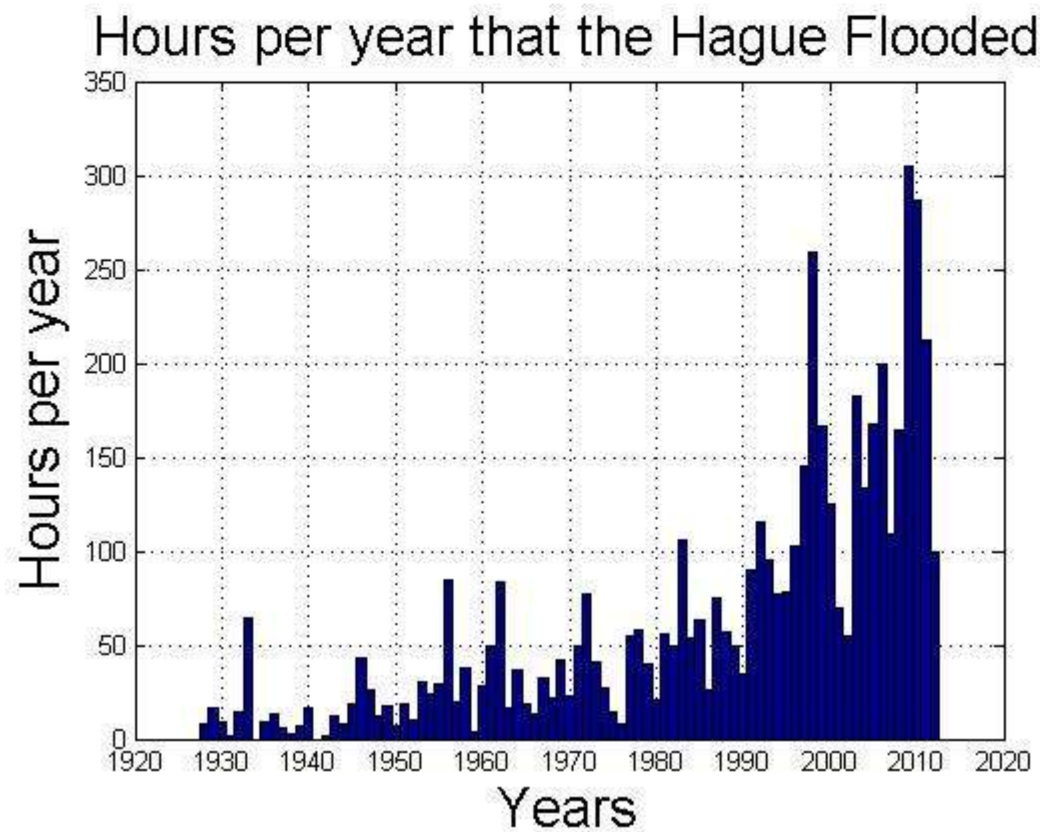
High tides cause flooding in low-lying coastal areas. Typically, areas flood only during extreme high tide events, frequently due to storm-related pressure systems. However, some areas in Virginia may flood on spring tides (which recur semi-monthly). The frequency of tidal flooding will increase with sea level rise.

Storm surge flooding is caused by large storms (hurricanes, tropical storms, and nor'easters). These storms are associated with pressure systems and intense winds that cause water to pile up against the coast. Storm surges can affect large areas of coastal lands, but the extent of flooding depends on the characteristics of the particular storm and the direction it approaches the coast. Flooding tends to be worse when the storm hits during high tide (thus combining tidal flooding with storm surge flooding). Storm surge flooding will worsen with increases in sea level, and an increase in the frequency and intensity of large storm systems.

Impacts from flooding can range from temporary road closures to the loss of homes, property and life. In coastal Virginia, the cost of large storm damage can range from millions to hundreds of millions of dollars per storm (VDEM, Hurricane History. A report found at: http://www.vaemergency.gov/readyvirginia/stay-informed/hurricanes/hurricane-history. Last checked July 20, 2012.). With a long history of flooding from coastal storms (first reference to storm-related flooding was in 1667), there is an understandable interest in Virginia to identify areas of potential flooding and establish measures (adaptation strategies) to reduce the impact of future flood events.

The problem is increasingly frequent storm-driven water levels that flood developed areas.

An example of an increase in flooding issues can be seen in this graph of the hours per year that the Hague (Norfolk, VA) has flooded based on measurements at the NOAA Sewells Point tide gauge (graph courtesy of Dr. Larry Atkinson, CCSLRI, Old Dominion University).



For this report we have reviewed information on issue identification, risk assessment, planning tools, and other related material, which is summarized in Section 4.1 of this report as background for the summary presented here. In response to the charge from the General Assembly, we have developed information for localities in Virginia's coastal zone (Figure 1). Because the area is so large, for purposes of the report we present much of the mapped information by individual Tidewater regions (Figure 2). Even at this scale much of the detail is obscured, and so we will establish and maintain a website for the report and supporting information that will provide access to the digital data used to generate the maps.

Risk Assessment: Where is the problem?

There are two ways to determine the location of flooding problems. The most direct is to document observations of flooding and flood damages. The second is to review elevation maps and identify areas where flooding can occur. For this report both approaches have been used. Each has limitations based on the fact that comprehensive and highly accurate data are not yet available for either analysis.

Where has flooding been observed?

While there are frequent media reports of areas flooded by large rain events and coastal storms, records and maps of these locations do not exist in any comprehensive database. Some localities maintain records of emergency calls or storm sewer backups, but these records are neither uniform nor consistently available across the coastal region. Assembling records into a consistent database would be useful for development of a state strategy, but it will require time and resources beyond those available for this report.

There are two data sets that are available for the entire region: a repetitive loss record maintained by the Federal Emergency Management Agency (FEMA); and a road closure database maintained by the Virginia Department of Transportation (VDOT). Neither is truly comprehensive in so far as the FEMA records only identify properties for which FEMA resources have been utilized, and the VDOT data only address state maintained roadways.

The FEMA database identifies properties that have received two or more claim payments of more than $1,000 from the National Flood Insurance Program within any rolling 10-year period for a home or business. Information is available on the number of repetitive loss properties by census block. We have mapped that information for each of the Virginia coastal regions covered by this report (Figures 3, 4, 5, 6, 7). FEMA also reports cumulative repetitive loss claims which provide another picture of the geographic distribution of flooding problems in Virginia's coastal zone (Figure 8). It is important to remember in viewing this information that it is limited to claims in the National Flood Insurance Program, and only a fraction of Virginia properties participate in that program.

The VDOT database is a 4 year record of road closures due to flooding on state maintained roads (Figure 9). Similar information is not uniformly available for locally maintained roads. The VDOT database provides one picture of areas at risk from flooding. Areas of recurrent flooding are of particular interest because they indicate locations that should be priorities for management. Flooding in tunnels and near bridges is of concern, since road closures in these areas can be a hindrance to evacuation and emergency services. Coastal Virginia's unique geography (a series of peninsulas connected by bridges and tunnels) frequently means that there are few alternative routes, and that a closure on a main road can result in long and complicated detours.

Results from EM surveys

Emergency managers are the last line of defense against flooding and are a crucial part of hazard mitigation planning efforts. Due to their experience, they often have unique knowledge regarding the causes and frequency of flooding in their localities. To tap into this knowledge base, we attended two regional emergency managers meetings (the *Northern Neck and Middle Peninsula Regional Emergency Manager Meeting* and the *Regional Emergency Management*

Technical Advisory Committee (A Hampton Roads Regional group)). At both meetings, we gave a presentation about the flooding study and then asked the emergency managers in attendance to respond to some questions. We sent the same set of questions to the other emergency manager meetings that had members from Tidewater Virginia.

A list of all the localities that responded to the survey, and the survey questions and answers can be found in Section 4.5: Emergency Manager Survey Responses.

Almost all respondents said that they were aware of roads that must be closed or signed for flooding issues, which concurs with VDOTs road flooding data (see Precipitation flooding: Road Closures, Section 4.1). Nearly half of respondents say areas flood during normal high tides and nearly ¾ say that areas flood during extreme high tides. All but 3 respondents claim that some portion of their locality floods during large storms. This indicates that flooding is a widespread problem.

Localities are addressing flooding issues. Most emergency managers were aware of locality plans that dealt with some aspect of flooding issues and claimed that critical infrastructure inside of flooding areas had been identified. Most localities have considered some type of adaptation strategy to address flooding. Northern Neck and Middle Peninsula localities considered elevating road surfaces and raising structures as the primary adaptation strategies. These localities tend to have populations that are relatively spread out and roads with little associated infrastructure (e.g. stormwater drainage systems). The Regional Emergency Management Technical Advisory Committee (REMTAC; composed of Hampton Roads localities) localities considered a wide variety of adaptations, including (in order of popularity): raising structures, relocating people, elevating road surfaces and sea walls, and pumping stations/dams/levees. Pumping stations, dams, and levees are expensive engineering strategies and therefore are most likely to be considered in areas where concentrated development allows for each engineering structure to protect a large number of properties, bringing the cost per property down.

Despite the fact that flooding is an issue for almost all respondent localities, less than 1/3 saw sea level rise as contributing to their flooding issues. However, most of them were interested in learning more about the impacts of sea level rise in their localities.

Flooding has been observed in all of Virginia's coastal localities, but assessing the magnitude of past issues is constrained by lack of compiled data.

Where can flooding be expected?

The risk of flooding can be assessed by examining detailed information about land elevation and proximity to water. In recent years, this type of analysis has been done for a variety of purposes generating a multitude of maps purporting to show areas at risk for potential flooding now and into the future. The key factor for all of these analyses is the accuracy of the underlying elevation data. Only recently have there been significant efforts to acquire state-of-the-art topographic information for all of Virginia's coastal localities. This information, collected with LIDAR (Light Detection and Ranging) is not yet available for all localities and so the analyses undertaken for this report are based on the best available information. LIDAR data have been used where available and elevation data generated by the Virginia Base Mapping Program have been used for the remaining areas (Figure 10). The methodology used to generate the topographic surfaces, establish the tidal references, and develop the estimates of impacts is described in Section 4.2 of this report.

To assess the extent and distribution of risks associated with coastal flooding and storm surges for this report we have used the best available elevation information as described above. We have mapped the potentially inundated area assuming a 1.5 foot rise in sea level and a 3 foot storm surge. Both of these values represent very moderate assumptions. The sea level rise is well within the range of the best available forecasts for Virginia over the next 20 to 50 years. The 3 foot storm surge is similarly within the range of surges that have been experienced in this region historically. The Sewell's Point tide gauge in Hampton Roads recorded storm surges of 4.2 feet during Hurricane Irene in 2011 and 4.4 feet during Hurricane Isabel in 2003. Maps of the at-risk areas with these assumptions are presented in Figures 11, 12, 13, 14, and 15.

Maps of the potentially flooded areas were analyzed to assess:

- the proportion of each coastal locality that was at risk for increasingly frequent flooding over the next 30 to 50 years;
- the proportion of the potentially flooded area that is currently classified as developed land; and
- the number of miles of primary, secondary, and tertiary roads within the potentially flooded area of each locality.

This information is summarized in the table below (Table of Coastal Vulerability to Predicted Sea Level Rise and Vulerability). On the basis of these parameters many of the coastal localities are confronting significant challenges, particularly the cities of Virginia Beach, Norfolk, Portsmouth, Chesapeake, Hampton, and Poquoson, as well as the counties of Accomack and Mathews. It is important to remember in reviewing these numbers that these are analyses based on current development patterns and populations. Change is anticipated in both of these factors, and that change also will not be uniform across all localities. This indicates a need for an iterating risk assessment to inform policy and management.

Table of Coastal Vulerability to Predicted Sea Level Rise and Storm Surge

This table shows the following information for Virginia coastal localities: A. total area in locality; B. proportion of total area potentially flooded; C. proportion of potentially flooded area that is classified as developed; D. miles of roads within potentially flooded area.

	A total area in acres	B % total area potentially flooded	C % potentially flooded = developed	D road miles potentially flooded
Eastern Shore				
Accomack	289,612	0.41	0.02	326
Northampton	132,032	0.46	0.01	44
Southside				
Chesapeake	217,011	0.11	0.11	103
Chesterfield	276,847	0.02	0.02	4
Colonial Heights	4,907	0.11	0.02	1
Hopewell	6,587	0.04	0.00	0
Isle of Wight	204,515	0.04	0.02	5
Norfolk	34,723	0.12	0.60	119
Petersburg	14,735	0.00	0.20	0
Portsmouth	21,578	0.09	0.57	51
Prince George	170,537	0.02	0.01	5
Suffolk	261,592	0.03	0.04	4
Surry	179,217	0.02	0.00	6
Virginia Beach	145,465	0.26	0.11	289
Peninsula				
Charles City	117,546	0.08	0.00	15
Hampton	33,171	0.15	0.28	50
Hanover	303,025	0.00	0.00	0
Henrico	153,746	0.01	0.01	0
James City	91,716	0.11	0.01	11
New Kent	135,661	0.08	0.00	7
Newport News	44,297	0.13	0.08	15
Poquoson	9,882	0.69	0.11	38
Richmond City	39,507	0.01	0.46	0
Williamsburg	5,710	0.03	0.01	0
York	68,484	0.07	0.06	24

Middle Peninsula				
Caroline	343,383	0.01	0.00	1
Essex	165,738	0.06	0.02	15
Gloucester	139,849	0.13	0.03	118
King and Queen	202,495	0.04	0.00	9
King William	176,443	0.07	0.00	14
Mathews	54,470	0.29	0.02	139
Middlesex	83,758	0.05	0.05	13
Spotsylvania	263,262	0.00	0.01	0
Northern Neck				
Alexandria	9,641	0.02	0.55	2
Arlington	16,661	0.01	0.38	1
Fairfax	257,956	0.01	0.12	5
King George	115,002	0.04	0.03	4
Lancaster	85,434	0.07	0.05	43
Northumberland	123,404	0.07	0.04	25
Prince William	218,319	0.01	0.08	2

Results of a recently completed study by the US Army Engineer Research and Development Center (ERDC, Vicksburg MS) has modeled 25 different combinations of storm surge on projected sea level rise scenarios for Tidewater Virginia (Copes and Russo *in press*). This work allows some examination of differences in the level of flooding associated with different sea level rise scenarios and could be used to conduct sensitivity analyses of each locality to sea level rise (i.e. in which localities does it matter most what the rate of sea level rise turns out to be?) Also, it allows comparison of the storm surge associated with different storm tracks and wind levels, potentially enhancing capacity to predict storm impacts. Maps of one storm scenario and more details on the study can be found in Section 4.4 of this report.

Flooding occurs in all Virginia's coastal localities, but the potential risks from sea level rise and moderate storm surges are not uniformly distributed.

What trends in flooding can be anticipated?

Precipitation

There are no clear trends in historic records of annual rainfall in Virginia, although it is predicted to increase by approximately 6% in Virginia (NCA 2012). Analyses of the 24-hour maximum rainfall frequency indicate an upward trend in coastal Virginia (Bonnin et al. 2006). However, when considering flooding from precipitation, we are more concerned with the number of high intensity rain events, rather than the total annual precipitation. High intensity rain events are typically the ones that lead to flooding. Scientists predict increasing storm intensity (leading to higher per storm precipitation), but the trend varies globally and even within the United States. Between 1948 and 2006, there appears to have been a 25% increase in the frequency of extreme precipitation events in Virginia (Madsen and Figdor 2007). Extending the dataset to 2011, there appears to have been a 33% increase in the frequency of extreme precipitation events, with the 1-year storm now occurring every 9 months (Madsen and Wilcox 2012). As the frequency of extreme events has increased, so has the amount of rain that those storms produce (i.e. the biggest storms are getting bigger), with Virginia seeing an 11% increase in precipitation from the largest storms between 1948 and 2011 (Madsen and Wilcox 2012).

Tropical storms

Much recent research has been done on the question of whether tropical storm activity is increasing. Hurricane activity in the North Atlantic appears to have been increasing significantly since 1995 (Nyberg et al. 2008) although the mechanism is unclear. Research on tropical storms in the North Atlantic Basin suggest that there is an increase in storm activity in the 20th century, but not necessarily an increase in storm intensity (i.e. proportion of hurricanes to tropical storms remain constant) (Holland and Webster 2007). It also is unresolved whether the increase in tropical storm activity is part of a cycle or is a return to normal hurricane activity, following a period of anomalously low activity in the 1970’s.

The only research found on tropical storm frequency in Virginia (making landfall) looks at data from the 1800-1990’s and suggests that there is a 50-year cycle in the number of tropical storms and hurricanes, with the peak of the cycle lasting about 15 years (Roth and Cobb, year unknown). This concurs with other research suggesting that tropical storm tracks are driven by random fluctuations in atmospheric steering currents, making the data sets too “noisy” (filled with unexplained variations) to detect long-term trends in tropical storm landfall (Landsea 2005; Vecchi and Knutson 2011).

Winter Storms

Most of the storm tides with a 10-yr return period magnitude in coastal Virginia are caused by winter storms (or nor’easters) (Ho et al. 1976) making them a critical driver of the most frequent storm surges (Boon 2012). In the United States, the average loss per storm (in $$) as well as the average storm intensity (measured as numbers of states impacted by a single storm) appears to be increasing (Changnon 2007). In Virginia, winter storm occurrences between 1984 and 2003 were 130% higher than during the previous 20 year time period, potentially related to a southern shift in the Arctic front in the latter time period (Changnon 2007). Research on 50 years of data suggests that the annual frequency of the strongest nor’easters is related to the position of the southerly jet-stream, which varies on an annual basis (Davis and Dolan 1993) and may be cyclical.

Sea Level Rise

Sea level rise in Virginia is a documented fact. Water levels in Hampton Roads have risen more than one foot over the past 80 years. The causes of this rise are well understood and current analyses suggest the rate of rise is increasing. The consequence of higher sea level is evident in the increased frequency of significant flooding events in coastal Virginia communities. A brief explanation of current understanding about the factors driving sea level change in this region can be found in Section 4.3 of this report.

The future of sea level change in Virginia is most appropriately forecast by reference to the state-of-the-science synthesis and recommendations prepared for the National Climate Assessment (Parris et al. 2012). The consensus of scientists working on this report is that by 2100 global sea level will be between 8 inches and 6.6 feet above the level in 1992. When modified by local and regional factors this information provides the best available basis for planning.

In order to generate sea level rise scenarios to inform planning in Virginia, we have used the four scenarios developed for the National Climate Assessment and modified them by incorporating an estimation of land subsidence in southeastern Virginia. Regional subsidence has historically represented about one half of the change in relative sea level observed locally. In the future it is anticipated that the regional rates of subsidence will remain relatively constant while global rates of sea level rise increase. Therefore the future sea level scenarios presented in Figure 16 are the global scenarios modified to include local subsidence (estimated at 2.7 millimeters/year or about 0.1 inch/year).

The four scenarios represent plausible trajectories for local sea level based on a combination of factors. The lowest or “historic” scenario is simply a projection of observed long-term rates of sea level rise going back a century or more, and contains no acceleration. Current rates of global sea level change based on satellite altimetry already are well above this trend line. The other three scenarios assume sea level rise rates are accelerating, which seems more consistent with recent studies (Boon 2012; Ezer and Corlett 2012; Sallenger et al. 2012). The “highest” scenario is based on estimated consequences from global warming combined with the maximum possible contribution from ice sheet loss and glacial melting (Pfeffer et al. 2008). This is a practical worst case scenario based on current understandings. The “high” scenario is based on the upper end of projections from semi-empirical models using statistical relationships in global observations of sea level and air temperature (Ramstorf 2007, Ramstorf et al. 2011). The “low” scenario is based on the IPCC fourth Assessment model using conservative assumptions about future greenhouse gas emission (the B1 scenario). The science team that developed the scenarios for the National Climate Assessment (Parris et al. 2012) indicated the high scenario should allow assessment of risk from limited ice sheet loss, while the low scenario represents risk primarily from ocean warming.

Using the National Climate Assessment sea level rise scenarios modified for conditions in Virginia, we recommend anticipating a sea level rise in Virginia of approximately 1.5 feet over the next 20 to 50 years.

Consequences for Recurrent Flooding in Virginia

Considering the projections for all of the factors that drive recurrent flooding in Virginia – precipitation, storm frequency, and sea level rise – the frequency and severity of flooding events is only likely to increase. Sea level rise will make it easier for the current patterns of weather events to generate damaging flood events in the future. Increases in storm intensity and/or frequency will only aggravate that circumstance. For these reasons, serious consideration of adaptation options should be a priority.

Section 2: Adaptation Strategies

Once the extent of the flooding problem has been established, appropriate adaptation strategies can be targeted for each area where flooding is a concern. Precipitation-based flooding and coastal flooding should be handled separately, where possible, because adaptation strategies differ for each. However, it is important to ensure that the solution to one flooding problem doesn't cause a new flooding problem. For example, storm surge barriers (which are designed to reduce coastal flooding) have been known to create or exacerbate precipitation flooding by reducing drainage potential upriver of the barrier.

There are 3 main categories of adaptation strategies: **Management/Retreat actions, Accommodation, and Protection**.

Management/Retreat actions include zoning policies aimed at preventing development in high risk areas, policies aimed at discouraging rebuilding in high risk areas, and the reclamation or abandonment of highly flood prone lands.

Accommodation actions are currently the most common in Virginia's coastal plain. They include raising buildings and roads above flood levels, established evacuation routes and warning systems, and the creation or enhancement of stormwater system capacity.

Protection measures typically involve some form of engineering to protect existing land uses. Hard engineering solutions, such as levees and storm surge barriers are probably the best known. However, there is a growing interest in soft engineering structures, such as marsh creation.

Which strategy is most appropriate for an area depends on the existing infrastructure and uses, population size, economic conditions and projected growth, and the surrounding landuse. The costs of different strategies are borne by different groups; for example, the cost of building at a higher first floor elevation is typically borne by the individual property owner, while the cost of large scale structures (e.g. floodgates) may be shared by local, state and federal partners.

Below is a table of different adaptation strategies and grouped by category.

Strategy	Examples	Description
Management/Retreat		
Coastal and Marine Management	Rolling Easement	Rolling easements allow wetlands or beaches to migrate inland as sea levels rise
	Ecological Buffer Zones	A conserved natural habitat for plants and animals
	Ecosystem Protection and Restoration	Encourage corridor connectivity and restoration of native aquatic and terrestrial habitats

	Open Space Preservation and Conservation	Restricts use of areas, can be used to store floodwaters
	Invasive Species Management	Process for preserving native species and preventing the spread of invasive species, under anticipated conditions of climate change
Growth and Development Management	Zoning	Restricts the types of appropriate use for a given parcel of land
	Redevelopment Restrictions	Restrictions applying to a structure that is destroyed or substantially damaged.
	Conservation Easements	Restricts use of areas, can be used to store floodwaters
	Compact Community Design	Reduces the footprint of development
	Government purchase of development rights	Provides landowners with compensation for their farmland or other property in order to prevent development
Loss Reduction	Acquisition, Demolition, and Relocation	Federal, state or local government buyout of at risk properties
	Horizontal Setbacks	Requirement that development be located a fixed distance landward
	Vertical setbacks	Requirement that development be located landward of a fixed elevation
	Insurance incentives/disincentives ; clarification of coverage	Cost of insurance, based on flood risk, can create a disincentive for building in high risk areas
Accommodation		
Emergency Management	Emergency response plans	Detailed plan for managing floods
	Early warning alert systems / surveillance	Siren or telephone warning system
Loss Reduction	Building Codes	Guidelines for construction and land use in areas likely to be inundated
	Retrofitting	May include elevating or floodproofing flood-prone structures, reinforcing, bracing and anchoring homes, removing impervious surfaces, etc.
	Raise roads	Raising the elevation of parts of or a whole road through addition of asphalt layers
	Floodplain storage	Create dry basins for holding storm water
Protection		

Integrated Flood Management	Public infrastructure vulnerability reduction	Relocation of various facilities and the institution of flood proofing measures for vulnerable drinking water and wastewater facilities
Loss Reduction	Shore Protection Structures	Typically levees, which are a "wall" of earth and concrete designed to prevent flooding behind them
	Traditional coastal hardening	seawalls, revetments, breakwaters, groins etc.
	Floodgates or tidal barriers	Gates placed in a waterway that can open and close to control high tides, storm surges or flood waters
	Stormwater Management	Stormwater drainage and storage systems to move water off roads and away from houses
Water Resource Management and Protection	Green Infrastructure	Measures aimed at slowing or retaining stormwater, includes green roofs, rain gardens, parks, etc.
Soft engineering	Beach nourishment	Addition of sand to an existing beach to widen
	Dune building	Artificial creation or enhancement of a shoreline dune system
	Wetland creation	Artificial creation or enhancement of a wetland for shore stabilization and ecosystem services

The following sections include examples of adaptation strategies with some discussion of their positive and negative attributes and areas of use.

Section 2.1 Overview of Adaptation Strategies

Management / Retreat Options

These options tend to be the most environmentally friendly since they actively encourage the long-term maintenance of natural coastal resources, such as marshes. Marshes and beaches are, by their nature, high risk zones for development. Zoning and planning actions that avoid development in these areas prevent flood issues while maintaining ecosystem services (including their potential for flood reduction). While management actions are fairly straightforward, retreat actions are harder to imagine. Options for retreat include planned phase-out of development along the coast (which requires extensive, long-term planning), the withdrawal of government subsidies combined with public education regarding the risks of living on the coast (IPCC 1990) or a direct buy-out of coastal properties for conversion to natural lands. Retreat options are likely to be most easily implemented in lightly developed areas. In highly developed areas, extensive planning is required to successfully implement a retreat process. Retreat is more feasible in areas with shore-perpendicular roads, rather than shore parallel roads, where loss of a road section is likely to disrupt access to property and can affect evacuation routes (Titus 2003).

Use/local taxes

Land owners pay taxes for protection structures that protect their property

- Examples: Dutch Waterboards administer funding and maintenance for protection structures within their boundaries. Inhabitants of each dike ring pay taxes related to the value of their property. (In the Netherlands, dike renovations due to changes in hydraulic condition or state of the science are funded nationally.) In Sandbridge, VA, residents help fund beach nourishment activities through an overlay tax district.
- Pros:
    - Property owners only pay for protection in which they have a vested interest
    - Only requires agreement and cooperation between a small group of people
    - Similar structure to Home Owners Associations, which exist throughout Virginia
- Cons:
    - There may be situations where the cost per homeowner is prohibitive, causing the homeowners to forgo protection

Horizontal Setbacks (Horizontal zoning)

Setbacks are zoning ordinances that require structures to be a certain distance from some reference point.

- Examples: Commonly used in subdivisions to ensure that houses are set back a uniform distance from the road. In Virginia, the Chesapeake Bay Act acts in a similar way, requiring most new construction to be placed 100-feet landward of wetlands. The purpose of the Chesapeake Bay act is to protect ecological functions, not prevent flooding, but functionally, it should help reduce flooding potential.
- Pros:
    - Already a commonly accepted form of zoning
    - Adjusting the width of the setbacks allows for future-proofing of the adaptation measure
    - Can allow for the use of rolling easements
- Cons:
    - Much more effective on shorelines with higher elevations. On shorelines with low elevations, horizontal setbacks would need to be very large to reduce flood risk

Vertical zoning

Vertical Setbacks are zoning ordinances that require structures to be built at an elevation above some set contour.

- Examples: There are few examples of this, although Chrisfield MD contains vertical zoning in their comprehensive plan. A similar concept is the requirement for all first floors in new construction to be built above the base flood elevation. This requirement is found throughout Virginia. The major difference is that having the first floor above a certain elevation only minimizes losses to the inside of the house (and only when the flood is below that elevation). Cars are still commonly lost, and this requirement can create evacuation issues when people stay too long at their residence.
- Pros:
    - Protects homes, vehicles, and people better than first-floor elevation requirements
    - Effective in areas with both low elevations and high elevations
    - Adjusting the elevation of the setback allows for future-proofing of the adaptation measure
- Cons:
    - In areas with low elevations, large swaths of land may be too low for building

Rolling Easements

A rolling easement allows the natural movement of the shoreline landward, restricting property owner's efforts to prevent shoreline retreat and/or erosion. It can be either a government regulation or a property right. As a regulation it prohibits shoreline protection structures, allowing wetlands and beaches to migrate inland. As a property right it can restrict landowner activities or authorize certain rights to other entities.

- Examples: In Virginia, this would be similar to two existing programs. As a regulation, it would be similar to the Chesapeake Bay Act, which limits the actions that a property owner can take in the Riparian Buffer Area. As a property right it would be similar to Conservation Easements (a voluntary program), where the property belongs to one entity, but other rights (such as the right to develop or harvest trees) belongs to a different entity.
- Pros:
    - Preserves the natural resources along the shoreline and their connections with the water
    - This is a policy that encourages retreat, but still allows use of the land until the shoreline moves
    - An inexpensive policy to implement compared to structural solutions

    - If the sea level rises slower than predicted or stops rising, no action/no change is necessary
- Cons:
    - Eventually results in relocation, so it has the same economic and social impacts

Managed retreat (permanent evacuation)

Managed retreat is the movement of people, residences and business landward, out of areas likely to flood.

- Examples: 1999 relocation of the Cape Hatteras lighthouse; 2002 Pacifica State Beach, San Mateo County, California where vulnerable houses were purchased and removed and the beach rebuilt; 1993 acquisition of houses in the Missouri River floodplain; Acquisition and demolition of recurrent loss properties in Fairfax County, VA
- Pros:
    - Relocation of buildings is cost effective
    - Can be scaled to the problem (move one building or a whole town)
    - This is a future proof measure that can easily accommodate sea level rise
- Cons:
    - The displacement of populations is a technical, social, political and economic issue (Tong 2012)
    - The relocation of accompanying infrastructure to buildings (roads, sewers, utilities) is often cost prohibitive
    - Relocating houses from higher tax district to lower tax district is unappealing

Strategic retreat

Strategic retreat is the gradual abandonment of dwellings in high risk areas and new development in low risk areas.

- Examples: This is being considered by some small island states and is considered a viable strategy for barrier islands.
- Pros:
    - Permanent (future proof solution) for areas that are entirely low-lying
- Cons:
    - Many potential distributional, economic and social consequences

Flood Insurance

Insurance that pays out on flood related losses. In the United States, this program is called the National Flood Insurance Program and covers buildings and contents, but not land. Although not federally required, a lender can require the property owner to buy flood insurance. Rates depend on age of the structure, type of construction and the area’s level of risk.

- Examples: Flood insurance is used throughout the United States, and is provided through a national program. In the United Kingdom, flood insurance is provided through the private market but they have an agreement with the government to ensure continuation of service.
- Pros:
    - Reduces individual losses associated with flood events
    - To a certain extent, people pay based on the level of risk at which they choose to live
- Cons:
    - May encourage people to move to or stay in high risk flood areas by reducing potential individual losses

Accommodation Options

Accommodation strategies are the most commonly used flood adaptations in Virginia. Some of these options require little long-term planning efforts, such as raising the first floor elevation on buildings (although some consideration of sea level rise would be beneficial), while others, such as evacuation routes and warning systems, can require extensive spatial planning efforts. Accommodation strategies also vary in adaptability. Raising roads is relatively inexpensive, particularly in rural areas where the stormwater drainage system is typically composed of ditches, so there is no additional infrastructure. Roads require regular maintenance anyway, and they can be raised incrementally if flood levels continue to increase over time (Titus 2003). Repeatedly elevating buildings, bridges and tunnel entrances is less practical, so due consideration to future conditions (e.g. sea level rise, development) during the planning process can have long term benefits.

Emergency Response Systems

Emergency response systems are plans used during emergencies to get responders to the correct locations, warn residents and put emergency measures into practice (e.g. road closures, warning sirens, etc.)

- Examples: Countries that experience frequent flooding tend to have well-developed emergency response systems, typically organized around local regions or river basins. Both the Netherlands and Japan have extensive information available about their emergency response systems. In Japan, they take advantage of technological advances to make information on flooding easily available to the public through websites and phone apps. In Virginia, all regions and many localities have hazard mitigation plans and some state agencies (e.g. VDOT) and localities employ websites and push notifications to warn residents of hazards.
- Pros:

    - Communicates danger to those at risk, allowing them to take action
    - Cuts response time during an emergency by having a plan and the necessary equipment
- Cons:
    - There are no cons to this measure, but it requires up-to-date information and is reactive (not proactive) so should be combined with other measures

Early Warning Systems

SLOSH (Sea Lake Overland Surge for Hurricanes)

The SLOSH model is a tool for predicting coastal flooding, which has been used throughout the United States. It was developed by the National Weather Service (NWS) to estimate storm surge depths resulting from historical, hypothetical or predicted hurricanes by using a storm's characteristics in conjunction with elevation data and local barriers (flood protection structures, bridges, etc.). SLOSH is the basis for a number of storm surge models. SLOSH data can be viewed by emergency managers in the SLOSH Display Program (SDP), allowing them to visualize forecasted storm surges. However, it does not explicitly model the impacts of waves or tide on top of storm surge, nor does it account for normal river flow and rain flooding (http://www.nhc.noaa.gov/ssurge/ssurge_slosh.shtml). In addition, it was designed for storms over areas of warm air and water, unlike those that typically make landfall in Virginia which have moved over colder water, reducing its accuracy for coastal Virginia (B. Sammler, May 31, 2012, quoted in: http://www.vims.edu/newsandevents/_docs/tidewatch_2012_hurricane_season.pdf).

TideWatch and the Real-Time Storm Tide Observation and Forecast System (Rstofs)

TideWatch (with its extension Rstofs) is an online, real-time water level monitoring tool. It was developed by researchers at the Virginia Institute of Marine Science. TideWatch charts the difference between actual and predicted tides at 9 locations within the Chesapeake Bay over a 36-hour window. It provides information that can help predict the magnitude of coastal flooding in an area and allow comparison of storm tides in areas with different tidal ranges. http://www.vims.edu/bayinfo/tidewatch/index.php

Evacuation

Evacuation is the temporary removal of people from areas at risk from flooding. Typically individuals are expected to remove themselves (individual cars) but in some areas there is organized public transit for evacuation. A map of Hampton Roads evacuation routes can be found at http://www.virginiadot.org/alpha/2012hurricaneswf/12048_newGuide.html.

- Examples: This is a common strategy used throughout the world and throughout Virginia. Many Virginia localities cite evacuation as part of their hazard management plans, but they require relatively far migrations inland. In some countries, raised areas (typically levees) can be used for temporary, near-home evacuation.

- Pros:
    - Protects people by removing them from high risk areas
    - A flexible strategy, can evacuate large areas or small areas
    - Saves money by reducing the need for rescues
- Cons:
    - Can be expensive to implement and socially disruptive, so there is incentive to not evacuate until a disaster is certain
    - Need predictive powers that are longer than clearance time for evacuation. In Virginia, reports suggest it would take approximately 36 hours to evacuate at-risk residents in South Hampton Roads if a major hurricane came through (Messina 2010). Since bridges, tunnels and ferries are closed at the onset of tropical force winds (39 - 45mph, VDOT, 12048_newGuide); the need for evacuation would likely need to be apparent 48 hours in advance of the hurricane arrival*. For this reason, evacuation as an adaptation strategy is most appropriate for localities that can evacuate without crossing bridges or tunnels.*
    - There needs to be adequate housing/hotels for evacuees
    - Does nothing to protect structures or private property

Shelter

Shelters are a safe location for people to congregate during flood events. They typically need to be designed for at least several days of use, and in some instances (where flooding causes widespread destruction) may need to function indefinitely.

- Examples: This is a common strategy used throughout the world and throughout Virginia. Many Virginia localities cite evacuation to shelters as part of their hazard management plans; shelter facilities are frequently school buildings located outside of the floodplain.
- Pros:
    - Protects people by removing them from high risk areas
    - A flexible strategy, can accommodate large areas or small areas (if facilities are sufficient)
    - Saves money by reducing the need for rescues
    - Does not require the lead time that evacuations require
- Cons:
    - Requires sufficient facilities in locations not subject to flooding
    - Requires non-flooded access
    - Does nothing to protect structures or private property

- Can be very expensive to supply shelters, especially if people end up staying long term

Elevating structures

Elevating houses and other structures above the base flood level (or the base flood plus wave level) is a common strategy for reducing flood damages. In Virginia, houses are typically raised 1-foot above the base flood elevation (although in certain areas they are elevated to higher levels). With this strategy, the cost is per house, not relative to the area of land being protected. For that reason, it is a reasonable strategy in areas with low density development.

- Examples: This is a common strategy used throughout the world and throughout Virginia. Almost all beach towns have some percentage of homes which have been elevated. Along the Outer Banks of North Carolina, entire towns are elevated. FEMA has a cost-share program for elevating Repetitive Loss Properties. However, it may be difficult to finance if a property has not experienced any flooding and the property owner is attempting to be proactive.
- Pros:
  - Protects homes, vehicles, and people by raising them above flood levels
  - Relatively inexpensive compared to other engineering strategies (for a few houses)
  - Particularly cost effective on new construction where the costs of elevation can be rolled into the mortgage.
- Cons:
  - Effectiveness is reduced when a greater than anticipated storm surge occurs
  - Not future-proof, when sea level rises the relative gain in elevation declines
  - Does not protect cars or boats, which are typically parked under the house
  - Must raise HVAC and electrical systems with the house to be effective
  - It only protects the structures that have been elevated, in heavily populated areas elevating all the structures may be cost prohibitive
  - Social implications as elevated houses may be difficult to access
  - May be difficult to obtain loans for this type of improvement project

Elevating roads

Elevating roads helps ensure access to properties and secures safe evacuation routes. The cost and difficulty of the project depend entirely upon the type and setting of the road that needs to be raised. In rural areas, where drainage systems are typically ditches, raising the road may be as easy as adding an extra lift of pavement. In more developed areas, with smaller lots and interconnected storm sewer systems, elevating roads becomes costly and more complicated because adequate drainage from both the road and the adjacent properties has to be designed into the project.

- Examples: Used throughout the world; in Virginia, it has been done in a few localities
- Pros:
  - Elevated roads can act as a levee, protecting both the road and the area behind it
  - Future-proof in rural areas where roads can be raised to the necessary level every cycle of paving; if there is no longer a need to raise them, the process is easily stopped
- Cons:
  - Elevated roads may cause ponding of water on adjacent properties
  - Can be expensive and complicated in urban areas
  - May need to be done repeatedly, unless there are reasonable predictions of the final elevation needed and the available funds to do a large, one time project

Floatable development

These are houses that have a floatable base to them, allowing them to rise with rising waters. They are anchored to something static (poles or walkways) that provide an upper limit on how high they can float and which prevent them from drifting while afloat.

- Examples: Floating homes are used in Seattle and Amsterdam (but these houses float permanently, not just during flood events). This is being considered as an option in several areas throughout the world; some examples are LIFT housing in Bangladesh and the FLOAT house in New Orleans.
- Pros:
  - Future-proof, allows houses to adapt to sea level rise
  - Some consider it to be environmentally friendly (Tong 2012)
  - Unlike elevated structures, these houses are typically on the ground so there are no access issues
  - Handles flooding, but not necessarily designed to handle wave action or winds
- Cons:
  - Requires engineering skills that may be expensive or difficult to find
  - Utilities are usually designed to separate from the house during floating which a) leaves residents without sewer or water systems and b) allows HVAC systems and such to flood
  - Handles flooding, but not necessarily designed to handle wave action or wind
  - Effectiveness is reduced when a greater than anticipated storm surge occurs

Floodable development

These are structures designed to collect and hold water during times of flooding, but typically have other uses during non-flood periods. A related strategy involves creating a "high water channel" which is separate from the main channel, preventing overflow of the main channel and briefly storing water.

- Examples: Both in the Netherlands and Japan, they have been considering the use of parking garages to collect floodwaters and release them slowly after the flood danger has passed.
- Pros:
  - Effective in urban areas where these types of structures already exist and stormwater is already being collected and channeled
  - Reduces water volume downstream
  - Can be used as urban solutions (parking garage) during normal flow time
- Cons:
  - Requires a strategy for safely draining the storage area afterwards and preventing disease carrying organisms from growing in the stored water
  - When using parking garages, must have alternative parking arrangements during flood events and a notification system
  - Collection of large amounts of stormwater can concentrate pollutants found in the water

Floodplain Restoration/Storage

These measures involve widening the floodplains to historic or new widths to allow overspill areas for water during flood events. There are a variety of ways to achieve floodplain restoration; examples include lowering floodplains, moving dikes and levees away from the river, and removing or renovating obstacles (such as bridges) that artificially narrow the river.

- Examples: Room for the River program in the Netherlands, Staten Island Blue Belt program in NYC
- Pros:
  - Allowing overspill areas for the river reduces water velocities and water volume at downstream sites
  - Floodplains can be used for agriculture or recreation during normal flow times
- Cons:
  - Requires either wide bands of uninhabited riverfront or the acquisition of riverfront lands
  - Requires a strategy for safely draining the storage area afterwards and preventing disease carrying organisms from growing in the stored water

- Collection of large amounts of stormwater can concentrate pollutants found in the water

Protection Options

Engineered solutions allow continued use of a developed area and vary in their environmental impacts. Hard engineering (e.g. seawalls, levees, and tide gates) tends to impact or eliminate the natural environment, while soft engineering (e.g. marshes, beach nourishment) can benefit the natural environment. Both hard and soft engineering structures can be designed for future modification (by increasing the height of levees or dunes, or increasing the rotation of storm surge barriers), and therefore can be designed for a certain degree of "future-proofness". Levees are probably the best known hard engineering solution and they have been used effectively throughout the world; however, they require advanced planning and are expensive, large scale projects. In addition, they have a design-flood, which if exceeded, can have disastrous consequences.

Levees are most effective in areas with nearshore, shore-parallel roads, which minimize the need to obtain additional land to build the structure on (Titus 2003). Typically, levees are built along the shore, requiring a long structure. However, structures such as locks and storm surge barriers go across the mouth of a river, effectively shortening the shoreline and protecting the entire upriver section with a relatively short structure. In the Netherlands, a combination of levees and storm surge barriers are used, with the storm surge barrier protecting flooding from storm surges and the levees protecting the shoreline from wind-driven pileup of water.

The main issues with hard engineering are the potential for catastrophic failure and the potential to worsen stormwater flooding by preventing drainage.

Levees are designed to handle particular water levels, and beyond that point they are subject to overflow and wave overtopping, which traps water behind the structure. Other failure mechanisms are linked to the structural integrity of the levee and include piping (where the water passes through a passage in or under the levee), sliding (weight of the water pushes the levee landward), liquefaction and revetment erosion leading to internal erosion. Levees are subject to the "length effect", which states that the longer a levee is, the greater the likelihood of a failure. A levee system is only as strong as its weakest section, and the longer the levee is, the higher the probability that there is a weak section due to variation in geotechnical characteristics along the shoreline. Storm surge barriers and other hydraulic structures are also subject to overflow and wave overtopping and structural failure; furthermore, they can experience mechanical failures (such as failing to close).

Any structures designed to hold out tidal and storm flooding are potentially capable of trapping stormwater in the area, leading to flooding. This is typically a problem during slow moving storms, where heavy precipitation is coupled with longlasting storm surges. Such structures may need drainage systems, pumps and water storage areas to reduce flooding potential.

Soft engineering is gaining in popularity as a means of combating flooding. On the Outer Banks, NC, large sand dunes act as "natural" levees to protect the main road. Beach nourishment is used in Virginia Beach and throughout the world as a means of widening and elevating the shore zone. Marsh construction, aimed at reducing wave action and/or absorbing floodwaters is being considered in Alexandria, VA (Dyke Marsh). However, soft engineering solutions require the use of swathes of waterfront property, which in Virginia is typically privately held. Either the local government must acquire the property or reach some sort of accommodation with the property owners. Soft engineering structures are also subject to erosion during storm events, but the erosion is typically considered sacrificial (i.e. anticipated to some degree), which may reduce the impacts of failure. However, it does mean that a level of maintenance should be expected.

Shore Protection Structures: Levees

Levees are natural or created embankments along the water's edge that prevent flood waters from accessing the land behind them. They are considered most appropriate (and easiest to acquire land) where roads are shore parallel, and close to the shore.

- Examples: Levees are used throughout the world, but are probably most well-known from the Netherlands. In the United States, they are used along the Mississippi River (among other places) and are used to protect the city of New Orleans.
- Pros:
    - Large areas can be protected by levees, makes them very appropriate for urban areas
    - They can be planned for future expansion, making them relatively future-proof
    - Properly designed and maintained, they can be very effective
- Cons:
    - They are only as strong as their weakest point
    - Unless the area is being newly developed or redeveloped, they require acquisition of large pieces of shoreline
    - They are expensive and require on-going maintenance, so they can be cost prohibitive, particularly in areas of low-intensity development
    - They break the connection between the upland and the shoreline, and reduce access to the water
    - They are prone to failure when floodwaters exceed design standards

    - They encourage development in floodplain areas and may give a false sense of security

Shore Protection Structures: Super Levees

Super levees are very wide (suggested: width = 30 x height) levees with gently sloping embankments. The top part of the embankment can be used for residential construction and evacuation routes.

- Examples: These have been proposed in five river systems in Japan (in Tokyo and Osaka)
- Pros:
    - The width reduces the potential for seepage of the water through the embankment
    - Soil stabilization work can increase ground resistance to soil liquefaction or landslides during earthquakes
    - They allow views of, and access to, the waterfront
- Cons:
    - They require huge quantities of fill
    - Unless the area is being newly developed or redeveloped, they require acquisition of large tracts of shoreline

Dike/levee rings

Dike/levee rings are localized levees surrounding only a community. In some locations, such as the Netherlands, they are used in conjunction with shore parallel levees or dune systems. In other locations, they replace shore parallel structures, protecting houses and development while still allowing undeveloped areas to flood. This strategy is most appropriate in areas with mixed land use, where there are pockets of developed and undeveloped land.

- Examples: In the Netherlands, these rings are used in conjunction with shore parallel defense structures to increase protection. In Japan, rings (in conjunction with land use planning) are used to replace shore parallel structures, allowing development within the floodplains.
- Pros:
    - Minimizes the cost of protection by only protecting developed areas
    - Appropriate in areas with mixed land use
    - To a certain extent, the floodplain can still function naturally
    - Easy to shift costs from central government to local property owners
- Cons:
    - May encourage development in floodplain zones; risk may be low, but consequences may be high

Floodgates/Tidal barriers/Storm surge barriers

These are restricted openings that can close during times of flooding, high tides or storm surges to protect upriver areas. They go across the mouth of rivers, streams or creeks and effectively shorten the shoreline, protecting very large areas with relatively small structures. They come in a variety of sizes depending on the width of the water body and the amount of water they are controlling. (Note: floodgates can also refer to moveable floodwalls which are more like temporary levees)

- Examples: These are used throughout the world, but two famous examples are Oosterscheldekering in the Netherlands and the Thames Barrier in the United Kingdom. In Virginia, smaller barriers are used in a number of locations (e.g. Portsmouth)
- Pros:
  - One structure protects large areas, good for highly developed areas
  - Some designs still allow boat traffic which is necessary in port areas
- Cons:
  - May encourage development in floodplain zones; risk may be low, but consequences may be high
  - Can be very expensive
  - Can increase the risk for precipitation flooding in upriver areas by preventing drainage and therefore may need to be combined with pump stations

Coastal Hardening: Seawalls/Floodwalls

Floodwalls and seawalls are essentially vertical levees, but generally the scale is much smaller and they protect smaller areas against lower levels of flooding.

- Examples: These are used throughout the world; in Virginia, there are floodwalls in most of the large coastal cities, including Richmond.
- Pros:
  - Large areas can be protected by floodwalls, makes them very appropriate for urban areas
  - They can be planned for future expansion, making them relatively future-proof
  - Properly designed and maintained, they can be very effective
  - They have a narrow footprint compared to levees and therefore don't require as much land acquisition to install
  - Seawalls also harden the shoreline to prevent erosion
- Cons:
  - They break the connection between the upland and the shoreline and reduce access to the water

    - They can be overtopped when floodwaters exceed design standards, trapping the floodwaters behind them
    - They encourage development in floodplain areas and may give a false sense of security
    - They can increase the risk for precipitation flooding in inland areas by preventing drainage and therefore may need to be combined with pump stations

Soft Engineering: Beach Nourishment, Wetland Creation/Restoration, Dune Creation/Restoration

These involve the creation (or re-creation) of natural shoreline systems to reduce the impacts of flooding. They have the added benefit of reducing wave energy, and therefore are very appropriate along coastlines. Created dunes are essentially soft levees and have many of the same benefits as levee systems. Created marshes can also be used in riverine and upland areas as wet stormwater retention ponds.

- Examples: Beach nourishment is used in Virginia Beach as protection against flooding; dunes are used throughout the Outer Banks, NC to protect the roads from flooding and erosion. In Alexandria, the National Park Service is considering restoring Dyke Marsh, in part to reduce flooding.
- Pros:
    - Enhance the natural systems
    - Still allow access to the water and typically improve views and recreational activities
- Cons:
    - Both beaches and dunes are built from sand, and are intended to be partially sacrificed during storm events, so they require on-going maintenance
    - Can be expensive
    - Can be difficult to estimate the design standards

Section 2.2 Review of Global Adaptation Strategies

Below is a table of examples of adaptation strategies used around the world to handle similar flooding issues but with different social drivers. In the table, this symbol → means ‘causes’.

Country	Issues	Primary threats	Adaptation strategies	Needs	Source
Bangkok, Thailand	Hotspot for increasing hydrometeorological variability; Urban growth has occurred without a unified plan	Changing precipitation --> River floods; Groundwater pumping --> Land subsidence	Flood embankment with pumped drainage system; sacrificial agricultural floodplains; long-term flood management plan	Increase dike height, canal widths, pumping capacity; Mangrove restoration; Shoreline structures	IPCC 2007; The World Bank 2010
Bang Khun Thian District, Bangkok, Thailand	Agriculture and aquaculture area where people don't have skills to move to other jobs	High coastal erosion; Groundwater pumping --> Land subsidence	Individual: Various protection structures; Moving aquaculture pens landward; Increase pond dike heights; Raising houses; Community has stone breakwater	Livelihood diversification; Bangkok Metropolitan Administration has plans to manage coastal erosion issues	Jarungrattanpong and Manasboonphempool 2009
Ho Chi Minh City, Vietnam	Approximately 45% of land is between 0-1m elevation; Subject to both regular and extreme flooding; poorest areas are those most prone to flooding	Sea level rise and Storm surge	Dams and reservoirs control river flooding; Dike and sluice system (planned); Program of resettlement away from rivers	Livelihood diversification; Improved warning systems; zoning controls; wetland restoration and reforestation	The World Bank 2010

Manila, Philippines	Major economic center and tourist destination; Informal and unregulated settlements built in risky areas	Decreased river channel capacity from building and deforestation --> River flooding; Groundwater pumping --> Land subsidence	Mangahan Floodway diverts river waters; Flood Protection Master Plan; Storm surge barriers; House raising: Pumps	Raise river embankments; Construct a dam; Increase storm surge barrier height; install pumping stations	The World Bank 2010
Kolkata, India	Has a large slum population, comprising 30% of population and toxic manufacturing	Intense precipitation --> River overtopping; Storm surge	Current adaptation strategies are lacking	Clean and upgrade sewer systems; Storm-proof water supply and electricity; Protect open space and wetlands	The World Bank 2010
Japan	Most of major cities (and industry) are located in the coastal zone	Sea level rise and Coastal erosion	Mainly protection measures: embankments, seawalls, detached breakwaters, artificial reefs		Kojima 2000
Fiji	Large tourist industry	Coastal erosion and Storm surge	Seawalls; planting of coconut palms and mangroves		Beckon 2005
Egypt	Large tourist industry	Sea level rise	Jetties; Breakwaters; Beach nourishment; Dikes		El Raey et al. 1999
Tokyo	Experiences flood disasters every year	Precipitation and Storm surge	River improvements; diversion channels and reservoirs; Levees and		Tokyo Metropolitan Government 2008

			super levees; infiltration facilities		
Bangladesh		Storm surge and coastal erosion	Afforestation (Planting mangroves)		Ali 1999
Netherlands	Floods are rare (due to existing protection) but potential consequences are high		Reassess flood defenses every 6-years; legislated levels of protection; "Room for the River" increase in floodplain capacity		IWR 2011
United Kingdom	Floods are relatively frequent, but also localized		National flood insurance program; flood walls; storm surge barriers; river channel maintenance		IWR 2011
Japan	Floods are relatively frequent, but localized; high potential for earthquake; population migration from rural to urban areas --> development	Increased intensity of torrential rains (precipitation);Increased Typhoons and Hurricanes	River management; embankments; water storage; water infiltration facilities; land use management; river widening/restoration; real-time observation and evacuation systems	Flood control facilities (retarding basins); Runoff control (reservoirs, storage, infiltration); levees, ring dikes, roads & railroad embankments	IWR 2011

Time horizons

Time horizons for planning activities are important mainly in areas where sea level rise is expected to create or worsen flooding issues. The challenge in picking appropriate time horizons is to be sufficiently long-sighted to prevent future problems, but still flexible enough to change with changing knowledge and circumstances. Uncertainty inherent in climate change projections complicates the decision making process and makes choosing the right planning horizon critical (IWR 2011). Preparing for the worst case may result in significant over expenditures, while under expenditures could lead to avoidable catastrophic consequences.

In looking at projected flood issues and adaptation strategies in Asia, The World Bank (2010) used a 40-year planning horizon because they felt this appropriately reflected city-level planning horizons and the typical time frame for major flood protection measures. This is similar to the general planning horizon used in the Netherlands, which is 50 years. The rationale for the 50 year planning horizon is to minimize uncertainty in sea level rise projections, while still using a long enough time frame for the investment required in large flood protection measures.

Multiple planning horizons and "Adaptive Deltamanagement" is used in the Netherlands (http://www.deltacommissaris.nl/english/topics/adaptive_deltamanagement/) to help minimize the impacts of uncertainty. This requires taking short term measures that tie into long term measures. Working with multiple strategies on different time scales is a flexible approach which allows for switches in management with changing conditions. This allows them to postpone major works until they have increased confidence in the climate change projections (IWR 2011). The following "design" horizons are used for projects requiring significant improvement or construction.

Small projects or dike improvements	10-50 years
Capital works (sluices, locks)	100 years
Major works (storm surge barriers)	200 years

For public water supply utilities, the following time frames are recommended for consideration during the decision making process (PWSUCIWG 2012):

Operations decisions	>3 years
Capital expense	3-6 years
Comprehensive planning	10 years
Water supply planning	20 years
Water treatment plant construction	50 years

In Virginia, localities tend to plan on shorter time spans, with comprehensive plans being re-visited every five years and other plans ranging from 10-20 years. These time frames are probably too short for major flood protection measures, so these types of adaptation will require some adjustment in planning horizons.

Protection levels

Ideally, protection levels should be set based on a desired or acceptable level of risk; however, in reality, there is always an economic consideration included. In some cases, the decision-making process is driven solely by the amount of available money, and how much risk reduction can be bought with available funds (IWR 2011). The Netherlands is conducting a national risk assessment to consider what protection levels should be used (IWR 2011). In the Netherlands, flood protection plans are always based on cost-benefit analyses, including loss-of-life calculations.

Calculating Flood Impacts

Flooding has direct and indirect impacts. Direct impacts are ones that cause immediate physical harm to humans, property, infrastructure and the environment (Massner et al. 2007). They include losses of crops, buildings, and human life. Indirect impacts are ones resulting from a loss of flow of goods and services to the economy (ECLAC 2003, Messner et al. 2007). These include traffic delays due road closures, production losses from closed factories, emergency expenditures, and time delays associated with clean-up and rebuilding efforts.

Direct and Indirect Costs of Flooding (adapted from The World Bank 2010)

	Tangible	Intangible
Direct Costs	Repair, replacement, and cleaning costs of assets (cars, buildings, etc.)	Loss of human life
	Damage to public infrastructure	Loss of ecological functions
	Damage to commercial and residential buildings	Loss of historic/archeological resources
	Crop and livestock loss	
	Loss of productive land/shallow water	
Indirect Costs	Loss of industrial production or revenues	Long-term health costs from toxins in flood waters or injuries
	Increased operational costs (commercial or public service entities)	Post-flood recovery inconvenience and vulnerability
	Lost earnings or wages	
	Time costs from traffic issues	
	Emergency flood management costs	
	Flood-proofing costs	

The World Bank (2010) recommends estimating direct and indirect costs in 4 areas: 1) buildings, industry and commerce; 2) transportations and related infrastructure; 3) public utilities such as energy, water supply, and sanitation services; and 4) people, income and health.

Adaptation strategies in fast growing urban areas

There are a myriad of problems associated with fast growing development in flood prone areas. One issue is a rapid increase in impervious area associated with development. Impervious surface reduces the ability of precipitation to infiltrate into the ground. Increased impervious surface can create flooding problems in areas that previously did not have precipitation flood issues. In Tokyo, where annual rainfall is about twice the world average, they have seen a 36% increase in urbanization over the past 60 years, making adaptations for handling stormwater a priority (Tokyo Metropolitan Government 2008). These include the use of storage facilities, such as parks and tennis courts, and infiltration adaptations, such as pervious pavement and infiltration trenches.

Another problem in rapidly growing urban areas is the migration of housing and businesses into undesirable areas. As the safer areas become built out, there is pressure to develop areas in floodplains or with poor drainage. This increases the vulnerability of the population to flooding, and creates new problems. In Manila, as the city expanded to the suburbs, many structures were built on unsafe ground and are now subject to flooding and landslides (The World Bank 2010). In addition, the encroachment of development into the floodplain has decreased the river channel capacity, leading to flooding (The World Bank 2010). In Bangkok, most development is occurring in land outside of the flood embankments. This is the area most at risk for increased flooding in the future and is likely to lead to future flooding problems (The World Bank 2010). A master plan for development that considers flood control issues and seeks to minimize development in high risk areas may help. However, even in areas with Master plans, development can still increase the potential for flood catastrophes. In London, where there are multiple flood protection measures including floodwalls and a storm surge barrier, the increased level of protection has led to development in the old floodplains (Lavery and Donovan 2005). Although the risk of these areas flooding is low, the continued development results in high potential consequences should flooding occur. In these areas, multi-level planning (raising or floodproofing houses) would help reduce consequences if the floodwall should overtop.

Adaptation strategies in rural areas

Rural areas have several unique characteristics: housing in rural areas is more spread out; land and coastline tend to be huge assets, and frequently the only form of income; and people are tied to their property. These characteristics mean that adaptation strategies tend to center on measures taken by individuals rather than the government. In Bang Khun Thian District, Thailand, adaptation strategies are almost entirely realized by individual property owners and households spend approximately 23% of their income annually on adaptation strategies (Jarungrattanapong and Manasboonphempool 2009). The incentive for individuals to adapt to flooding is high however, for few of them have the education and skills necessary to find work in a new location (Jarungrattanapong and Manasboonphempool 2009). Their property is their sole source of income, and thus relative sea level rise is literally robbing them of their living.

This social construct, which is not usual in rural areas, makes retreat-type options problematic in many areas. While there may be potential to move agricultural operations inland (if suitable growing lands can be found); aquaculture typically requires coastlines and/or ready access to water sources. Retreat in these areas is typically obtained through generational diversification, where the children of farmers are educated for jobs in the city and the family lands are eventually abandoned. In addition to the cultural losses associated with this form of retreat, there may eventually become food source issues due to the loss of farmers. Similar issues can be found in areas of Virginia with high levels of aquaculture such as the Eastern Shore and Tangier Island; however, in Virginia, aquaculturists can lease land throughout the Bay and are not necessarily tied to living on the water.

Another issue in rural areas is saltwater intrusion into agricultural fields. Predictions suggest that by 2050, 60% of agricultural land in Ho Chi Minh City will be regularly flooded by saltwater (The World Bank 2010). Although in many areas of Virginia, low-lying, coastal areas have been developed, there are still several rural agricultural areas such as the Eastern Shore and Mathews County. There are few adaptations aimed at this issue. Where retreat is not an option, changes in crop type can help mitigate the issue. Tree nurseries and the fruit growing sector are highly sensitive to increasing salt concentration, and even at low concentrations considerable damage can occur; however, grass, grains and sugar beets are relatively tolerant of salt in the soil (http://www.climateadaptation.eu/netherlands/en#salt-intrusion).

In areas with high tourist traffic, there is an additional challenge for managing floods. Tourists are frequently attracted beauty of the natural coastline, so flood protection measures need to compliment or enhance the natural shoreline. In Fiji and Egypt, where tourism are important industries, protection structures are paired with soft engineering solutions such as planting mangroves and beach nourishment (Beckon 2005, El Raey et al. 1999, respectively). Similar strategies in Virginia include beach nourishment and marsh creation. Dyke Marsh in Alexandria is an example of a proposed marsh restoration project that helps reduce flooding while creating recreation opportunities and wildlife habitat (NPS 2012).

Groundwater withdrawal and other contributors to subsidence

Groundwater withdrawal is a problem throughout the world; in some areas it can contribute more to flooding issues than climate change (The World Bank 2010). When long term pumping rates exceed those of the recharge, issues such as land subsidence and salt intrusion into freshwater aquifers begin to occur. Land subsidence occurs through the compaction of the ground when empty aquifers slowly collapse down. In coastal aquifers, salt intrusion into drinking water supplies occurs when a reversal of groundwater flow causes seawater to be pulled into the aquifers (http://ca.water.usgs.gov/misc/asr/)

Adaptation strategies are limited. In California (where groundwater provides about 40% of the freshwater), “artificial recharge” is employed to hold back saltwater intrusion. This strategy could be employed to reduce land subsidence associated with groundwater withdrawal. However, it requires a source of clean water and has several side effects associated with it. The water can bring contaminants with it, or mobilize contaminants that had been fixed in the soil. In addition, liquefaction of the ground can occur following earthquakes, which can have devastating consequences in a developed area (http://ca.water.usgs.gov/misc/asr/). Some cities have put stronger controls on groundwater pumping. In Bangkok, predictions are that the increased efforts to control groundwater pumping will result in a decline in subsidence rates by approximately 10% per year (The World Bank 2010).

In addition to groundwater withdrawal, hydrocarbon extraction has been blamed for high local subsidence rates in some areas, including Wilmington, CA, Goose Creek, TX, Ekofisk in the North Sea and Venice, Italy (Cassiani and Zoccatelli 2000). Although this is not a problem in Virginia, if hydrocarbon extraction were proposed, extensive studies would be necessary to ensure that extraction did not exacerbate sea level rise issues.

The need for comprehensive planning

In areas where the government takes little or no action to stem flooding issues, individuals will take actions to protect their properties. However, property owners have different incomes to work with and different levels of education about the effectiveness of flood adaptation strategies, leading to a coastline scattered with a variety of protection measures that have variable success. The failure of one protection measure may impact the success of adjacent structures (Jarungrattanapong and Manasboonphempool 2009); therefore, the lack of community scale planning is likely to contribute to community level failures. In Virginia, where flooding is a widespread problem, the cooperation of the federal, state and local governments in conjunction with the property owners will increase chances of successful adoption of adaptation strategies.

Multiple strategies approach and Flexible adaptation pathways

Two of the most important lessons that can be learned from a review of global adaptation strategies are that a multi-layered approach to flood prevention is most effective and that when predictions of the future are uncertain, flexible plans for adaptation are imperative.

Using multiple strategies to reduce flood damage is a comprehensive approach that builds a certain level of redundancy into the protection system. In the Netherlands, there has recently been a shift in the core element of their flood damage reduction plans from protection to risk management (Councils for the Environment and Infrastructure 2010). This is a more comprehensive approach that seeks to manage flood consequences (e.g. development in the floodplain) as well as provide protection from floods. Therefore, it necessitates the use of multiple strategies, such as taking into account the probability of a flood, spatial planning, and disaster mitigation (emergency services) This approach, while more comprehensive, also necessitates a great deal of coordination and cooperation among different agencies and entities (van den Heuval et al 2011) .

Because no adaptation strategy (other than abandonment) completely removes the risk of flood damage, multi-level adaptation strategies allow states to decide on priorities (typically protection, but can be management and planning) and then to "buy-down" the remaining risk using other strategies. These can be visualized as a staircase, in which each step results in some reduction in risk. In this approach, a storm surge barrier might be the initial adaptation, and other adaptations would include elevating structures and investing in emergency management (both to reduce consequences of a levee failure). Each step would reduce risk to some extent, together resulting in lower risk than any single measure. In areas with low-intensity development and little money for adaptations, the initial step might be stringent regulations on new development to keep it away from floodplains and additional steps might be an early warning system and a detailed evacuation plan. Good plans should include some consideration of protection, spatial planning/management and emergency services.

In most cases, adaptation measures will require significant investment, making it imperative to conduct rigorous assessments of cost- and flood reduction effectiveness. But calculation of future risk is uncertain (due to inherent uncertainty in the timing and extent of climate change impacts), emphasizing the need for development of Flexible Adaptation Pathways (LeBlanc and Linkin 2010). These are pathways that are that are low regret, reversible, or incorporate margins of error.

An example is the Thames Estuary 2100 (TE2100) Plan, which contains a schedule of alternate adaptation options, triggered by changes in 10 flood-risk parameters (Wilby and Dessai 2010). Because there is uncertainty attached to estimates of each of these parameters, the plan is phased, with the first phase being maintenance of existing defenses, the second phase being replacement of existing defenses and new structures waiting until the third phase (Wilby and Dessai 2010). This allows the plan to change (e.g. alterations to new defenses, no new defenses, or acceleration of the phases) if conditions change from projected. Flexible

Adaptation Pathways are also being considered in New York City, NY (Rosenzweig and Solecki 2010).

Lessons Learned

Flood issues and potential should be considered as an integral part of locality and state planning

As urban areas grow and expand, flood-considerate planning efforts can ameliorate existing flood issues while preventing new ones. Future development should be planned away from hazard areas and long-term plans should be made for the retirement of infrastructure in vulnerable areas.

Decision-making should occur within a watershed framework and include social considerations

Political boundaries typically only include portions of a watershed, making it impossible to solve flood issues without cooperation and coordination between localities.

Improve the knowledge base regarding changes in future flood potential

Studies to predict changes in development patterns, economic growth, storm surge, sea level rise and precipitation patterns should be encouraged to ensure that rational long-term planning can occur.

Targeted, city/locality specific solutions that combine all three forms of adaptation are required

Adaptations measures need to be designed based on the unique setting of each locality, incorporating local causes of flooding and social and economic characteristics.

Combining hard and soft infrastructure can protect while adding to quality of life

Parks and other green spaces can beautify and contribute recreational value, while serving as water storage areas. Marsh creation and beach nourishment result in recreational areas, are economic assets and provide flood protection.

State wide assessments of flood risk help move towards solutions

When available funding is limited, state-wide prioritization of flood issues can help localities address problems in a logical fashion.

Solutions should be flexible to allow for new understandings of risk

Overtime, changing conditions (populations, development and climate) change the challenges faced in reducing flood risk. The essential challenge is to create management systems that take a long term view of the issues, but are flexible enough to work under changing conditions.

Effective public communication and emergency management should be an essential part of any management plan

No flood protection scheme or set of schemes will completely remove the underlying risk. Therefore, it is essential to emphasis public awareness and promote real-time communication of risk so that the public can make informed decisions. A strong emergency management program will help mitigate the consequences of floods if they occur. In areas where flooding is rare, but potential consequences are high, regular drills of the emergency management procedures should be carried out.

Section 2.3 Viability of Management/Retreat Options in Virginia's Political Climate

Existing Planning Authorities in Virginia That Include Flooding/Sea Level Rise

Every Virginia locality is required to develop a long range land use plan and review those plans every five years (Code of Virginia [Va. Code] § 15.2-2223):

"The comprehensive plan shall be made with the purpose of guiding and accomplishing a coordinated, adjusted and harmonious development of the territory which will, in accordance with present and probable future needs and resources, best promote the health, safety, morals, order, convenience, prosperity and general welfare of the inhabitants, including the elderly and persons with disabilities."

These plans usually have a 20-year planning horizon and the "probable future needs" clause above would logically include long range flooding and sea level rise adaptation planning.

In "Tidewater" localities (those localities with tidal waters, delineated at § 10.1-2001), comprehensive plans and zoning authorities are also required under the Chesapeake Bay Protection Act to include water quality protection measures, including zones protected from disturbance along the shoreline (Va. Code § 10.1-2100). These additional natural resource planning requirements provide opportunities to discuss and plan for tidal flooding and sea level rise.

Inundation and sea level rise concerns are reflected in every long-range land use plan developed and approved by a "Tidewater" locality since 2008. (Accomack County 2008, City of Virginia Beach 2009, Mathews County 2011). None of these plans have gone beyond a general discussion of these inundation risks to suggest development policy, however.

Under Va. Code § 15.2-2223.2, localities in "Tidewater" Virginia starting in 2013 will need to include coastal resource management guidance in their comprehensive plans. This guidance will be developed in part by the Virginia Institute of Marine Science and, "The guidance shall identify preferred options for shoreline management and taking into consideration the resource condition, priority planning, and forecasting of the condition of the Commonwealth's shoreline with respect to projected sea-level rise." (Va. Code § 28.2-1100.9) This new requirement should provide more detail and depth to the evaluation of inundation and sea level rise impacts in tidal localities in Virginia.

In order for a locality in Virginia to be eligible for programs under the Federal Emergency Management Agency (FEMA), a community must undertake hazard mitigation planning (Title 44 Code of Federal Regulations [C.F.R.], Chapter 1, Part 201.3). The community must also have a floodplain management program and appropriate building ordinances in high-risk flood zones in order to qualify for the National Flood Insurance Program [NFIP] (44 C.F.R. Subchapter B). The Virginia Department of Conservation and Recreation is the lead agency on floodplain management planning (Va. Code § 10.1-602).

These FEMA-required programs are natural places to start local government planning for inundation and sea level rise impacts. Federal regulations allow localities to exceed the stringency of minimum federal standards, allowing for location-specific sea level rise adaptation strategies. Discounts in NFIP rates can be obtained by going beyond minimum federal and state requirements and some communities (Gloucester County, Chesapeake) are using committees of citizens to help plan those additional steps. Many hazard mitigation plans in Virginia include sea level rise discussions (e.g. City of Poquoson 2008). Other localities are including sea level rise in their floodplain management plans (Gloucester 2008, Portsmouth 2010).

The US Department of Transportation requires states (23 CFR § 450.206) and regions (23 CFR § 450.306) to complete long range transportation plans prior to receiving federal transportation funding and these plans require extensive public notice and participation opportunities. In shoreline communities, inundation of transportation segments with sea level rise/storm surges is a long-range risk that should be included in these plans.

The current Virginia long-range transportation plan has a section discussing climate change impacts including sea level rise, although there are no recommendations for acting on those projected impacts. On September 24, 2012, the Federal Highway Administration announced federal cost-sharing would be available for "activities to plan, design, and construct highways to adapt to current and future climate change and extreme weather events."

The US Department of Commerce requires a regional Comprehensive Economic Development Strategy (CEDS) prior to being eligible for many Commerce funding programs (Title 42 United States Code [U.S.C.] § 3162). These regional plans are another opportunity for climate change planning to take place. The Hampton Roads, Virginia CEDS (Vision Hampton Roads) mentions climate change/sea level rise as part of the economic challenge facing the region.

The Coastal Zone Management Act (CZMA) authorizes state coastal zone programs, such as Virginia's, and requires that it prepare a management program for its coastal zone (16 U.S.C. § 1455.) This program must include a number of assessments of the natural resources in that zone. In addition, a Coastal Nonpoint Pollution Control Program must be developed (16 U.S.C. § 1455b.) Grants are provided to eligible coastal states in response. This state planning and reporting process provides opportunities for shoreline flooding and sea level rise adaptation planning.

The CZMA language specifically mentions sea level rise as an element of concern at Title 16 U.S.C. § 1451, "(l) Because global warming may result in a substantial sea level rise with serious adverse effects in the coastal zone, coastal states must anticipate and plan for such an occurrence." In response, the Virginia CZM program in 2008 funded three regional planning districts to undertake climate change/sea level rise planning. It is continuing this work with shoreline resiliency planning activities.

The US Fish and Wildlife Service requires each state and territory to prepare a Wildlife Action Plan in order to receive funding under the Wildlife Conservation and Restoration Program and the State Wildlife Grants Program (16 U.S.C. § 669e). The Wildlife Action Plans present a strategy for meeting critical wildlife conservation needs in a state. The plans are periodically updated, providing an ongoing opportunity for involvement. There is voluntary guidance for states to include climate change in their plans and Virginia's Wildlife Action Plan has an appendix that includes habitat adaptation to climate change impacts such as sea level rise.

Virginia requires localities to submit water supply plans (Va. Code § 62.1-44.38:1). Given the potential threats to coastal water supplies from sea level rise impacts, these plans can be used in adaptation planning. Since some coastal communities are already experiencing salt water intrusion on their well systems, this authority becomes a useful tool for future planning activities.

Planning Authorities That Could Include Flooding/Sea Level Rise in Virginia

The Clean Water Act requires municipalities to have a storm water management plan (42 CFR § 122.26). Given projections of increased flooding due to sea level rise and increased storm intensity, this planning process should be a place where local governments start sea level rise adaptation planning. The Municipal Separate Storm Sewer System Management Program (MS4) requires regional or watershed plans developed with public input (33 U.S.C. 1251 §402) (4 Virginia Administrative Code [V.A.C.] 50-60-90) and provides an opportunity for including inundation and sea level rise impacts.

The US Department of Housing and Urban Development requires a consolidated plan prior to a locality receiving HUD housing funding (24 CFR Part 91). This planning process is another tool for sea level rise adaptation planning, especially when using federal funds to place housing along tidal shorelines.

The US Forest Service requires long range plans for National Forests (16 U.S.C. § 1604) and Virginia has the George Washington and Jefferson National Forest system within its boundaries. The National Forest plans are updated on a 10 – 15 year cycle and provide an opportunity to address climate change impacts. The George Washington-Jefferson National Forest plan revision is currently underway in Virginia and a background document in the revision mentions climate change as a management issue there.

Local governments in Virginia are authorized at Code of Virginia § 15.2-2230.1 to study the cost of public facilities (roads, sewer, water, etc.) needed to implement a comprehensive plan. This authority would allow life-cycle cost planning at the local level. If the life-cycle cost or total ownership cost of land use decisions along the shoreline were included, it changes the calculations for local governments in the face of sea level rise and higher storm surges. This long-term evaluation of infrastructure should become part of decisions on public infrastructure construction since future costs of repairing roads, sewer and storm water lines, and other utilities in the face of increased inundation and sea level rise would become apparent.

The Department of Defense is authorized to make community planning assistance grants to undertake Joint Land Use Studies where use conflicts emerge between a military facility and the surrounding community (10 U.S.C. § 2391). These grants have been primarily used to study use conflicts between military aircraft operations and incompatible land use surrounding a facility that compromise operations, usually buildings in potential accident and high aircraft noise zones. However, with sea level rise and inundation, the surrounding community's response (or lack of response) will affect military base operations and could be eligible for inclusion in this planning program.

Financial Incentives That Could Include Flooding/Sea Level Rise

Shoreline lands need to be kept open wherever possible in a sea level rise adaptation strategy. Virginia offers generous tax treatment for Land Preservation Tax Credits generated under these programs at Code of Virginia § 58.1-512: a tax credit equal to 50% of the value of any conservation easement donated by a Virginia taxpayer over land in Virginia (providing that the easement qualifies as a charitable contribution under IRC § 170[h]) up to $600,000. In addition, the Code of Virginia at § 58.1-3666 allows local governments to exempt from taxation wetlands and shoreline buffers under permanent easements allowing inundation. Buffers must be at least 35 feet wide.

Keeping development and redevelopment out of areas at high risk of inundation is essential. Transfer of development rights is a process whereby the rights to develop a parcel (in an area where a locality wants to discourage development and redevelopment) are transferred to another parcel (where this development is preferred). This tool is used to preserve open space or protect natural resources and could be a way of keeping development out of inundation zones while allowing property owners to recoup some of their investment. Virginia allows localities to authorize the transfer of development rights at Code of Virginia § 15.2-2316.2.

Owners of developed land in areas of high risk of inundation have vested rights in the current land use, a land use that may be increasingly at risk with sea level rise. Amortizing those vested rights over time – in a phase out period – allows the landowner to recoup investment but moves those nonconforming land uses out of high risk inundation zones over time. Courts have recognized a reasonable amortization period as preventing a "takings" claim wherein the property owner seeks full compensation for the loss of the higher use of their land. Vested rights are discussed at Code of Virginia § 15.2-2307.

The Federal Emergency Management Agency (FEMA) operates the National Flood Insurance Program (NFIP), a significant economic force in shoreline areas at risk from inundation, with flood insurance required in high flood risk zones. Eligibility for the NFIP is already conditioned on a locality undertaking a number of adaptation measures for existing flooding risks (see both planning and regulatory sections). If properly focused on sea level rise inundation, this program could create additional incentives directed at adaptation to sea level rise risk. A federal study was recently completed to determine the impacts of climate change on the NFIP and, while not released, is reported to estimate a 40 to 45 percent increase in mandatory coverage with sea level rise projections. In addition, the recently enacted reauthorization of the NFIP requires a study on how FEMA would include projections of sea level rise into their flood rate insurance maps.

Virginia, like all states, regulates the private insurance industry. Insurance cost and availability sends a strong market signal to areas with high risk of inundation, and as insurance companies set rates and determine availability, these decisions will affect adaptation responses. With more expensive insurance and/or limited availability, property and business owners in high risk zones may seek other, safer areas to live and operate businesses or may seek insurance policies that reward adaptation. At present, private sector providers of wind insurance have begun to limit coverage in coastal areas in Virginia or have withdrawn completely from some areas. If these actions continue, they may begin to shape investment patterns along the tidal shoreline in Virginia and create a new set of financial incentives/disincentives. Conversely, state action to moderate these price signals along the shoreline could reverse needed adaptation measures.

In areas of high risk from inundation, expenses will rise to provide public services necessary to maintain current land uses and landowner expectations. When those costs increase to significant levels, local government budgets may become compromised. One way to offset and properly apportion those expenses to properties requiring extra expenses would be through the use of a special taxing district wherein residents in high risk zones are assessed a higher tax to pay for those services, sending a clear financial signal as well into those areas. Virginia Code at § 15.2-2400 allows the creation of local government special districts to accomplish certain necessary tasks and could be used in high-risk inundation zones to create disincentives for land uses at odds with higher risk from flooding and sea level rise.

Direct Investment and Infrastructure Decisions That Could Include Flooding/Sea Level Rise

Each Virginia locality is authorized at Virginia Code §15.2-2239 to prepare a capital improvement plan (CIP) to plan needed capital investments. The preparation of the CIP usually occurs with comprehensive land use planning updates and offers a chance for inundation and sea level rise impacts to be made part of local government infrastructure investment decisions. Placement of roads, schools, fire houses, police stations, and other public facilities are governed by the CIP, and all these facilities need to account for sea level rise in coastal communities.

At the federal level, projects built under the authority of the US Army Corps of Engineers (USACE) Civil Works program, are required to take sea level rise into account, according to an engineering guidance issued October 1, 2011. This guidance states, "Potential relative sea-level change must be considered in every USACE coastal activity as far inland as the extent of estimated tidal influence." The guidance and a web-based tool maintained by the USACE outline the steps needed for all civil works infrastructure projects along the coastline.

This policy is the only example of a prospective policy in federal and Virginia state authorities, one that anticipates a future state of inundation risk and sea level rise. It has been verified that the proposed port facility at Craney Island, developed with USACE involvement, does take modest sea level rise into account in its design.

Regulatory Authorities in Virginia that Could Include Flooding/Sea level Rise

Programs exist at the local, state, and federal level to regulate development activities along the tidal shoreline in Virginia, areas that are increasingly at risk from sea level rise and inundation. Some of these authorities reside in local government zoning and building ordinances. Other authorities place restrictions on development along these shorelines in order to protect the natural ecosystem. These authorities can be used to keep the shoreline open and resilient and better able to adapt to sea level rise. They can also be used to keep infrastructure and housing out of shoreline areas that will be at increasing risk from sea level rise.

The strongest potential climate change adaptation regulatory tools are local zoning and building code authorities since these govern the use of land and the placement of infrastructure along the shoreline and also set minimum building safety and performance standards. Counties in

Virginia are given broad powers to protect the public health and welfare at Va. Code § 15.2-1200. Counties are given general zoning authority at Virginia Code § 15.2-2280 and specific authority to use zoning to "facilitate the provision of adequate…flood protection..." [§ 15.2-2283 (iv)]. These local government zoning authorities have great potential for controlling development and redevelopment in high risk inundation zones, sending proper risk signals about shoreline development in the face of increased inundation risk due to sea level rise.

Localities have zoning and building code authorities granted to them by state and federal statutes as well that can be used in flooding/sea level rise adaptation strategies. The Chesapeake Bay Preservation Act (Va. Code §10.1-2100/9VAC10-20) provides local governments with tidal shorelines a number of land use authorities including "overlay districts" along the shoreline within which development and redevelopment is restricted to protect water quality. Local ordinances implement this statute and while there is a range of approaches, most localities require oversight and approval of any land disturbance (development/redevelopment) in the "Resource Protection Area," a zone extending 100 feet shoreward of the upper limits of the tidal wetlands.

A significant part of the Federal Emergency Management Administration's (FEMA) National Flood Insurance Program (NFIP) are floodplain ordinances necessary to implement local floodplain management plans. FEMA requires local government floodplain zoning and building code requirements (42 U.S.C. § 4001/ 44 CFR § 60.1) as a mandatory requirement prior to any locality receiving federal flood insurance. This authority is overseen in Virginia by the Department of Conservation and Recreation's (DCR) floodplain management program (Va. Code § 10.1-602), which suggests minimum local ordinances required to meet the FEMA/DCR requirements.

Floodplain management plans reach to local government ordinances and can require "freeboard," a requirement that living space in a structure be at least a certain height above "base flood elevation" or the level of flooding expected from a once in 100-year flood. Currently in Virginia, there are at least 107 communities with 1- foot freeboards, which is almost 40%. Seven communities have a 1.5-foot freeboard, four have a 2-foot freeboard, and four have 3-foot freeboard.

Virginia, like most coastal states, has regulatory programs to protect its coastal and tidal estuarine ecosystem. Much river and tidal estuarine bottomland is state owned and disturbance requires a permit from the Virginia Marine Resources Commission. Development and redevelopment impacting mudflats, non-vegetated wetlands, and vegetated intertidal wetlands require a permit from federal regulators and state regulatory bodies. State authority for wetlands protection is found at (9 VAC 25-210 /Va. Code §§ 62.1-44.15 and 62.1-44.15:20). For tidal wetlands, the primary state authority is given to the Virginia Marine Resources

Commission at Code of Virginia § 28.2-1300, which has delegated that authority to most of the local governments in tidal areas of Virginia. The federal government also regulates wetlands through the Clean Water Act (33 U.S.C. § 1344) and the Rivers and Harbors Act (33 U.S.C § 403). The coordination of state and federal wetlands regulatory programs occurs during a joint permit application process.

Increased inundation and sea level rise have been predicted to have considerable negative consequences for the amount and function of tidal wetlands in Virginia. The use of these increased inundation impacts in wetland permit applications could both conserve the area and function of tidal wetlands and discourage wetlands-disrupting development activity along the tidal shoreline.

Virginia has not moved to explicitly include sea level rise into its state regulatory programs and the Virginia Department of Environmental Quality (DEQ) rejected a recent challenge to a wetlands permit that objected to sea level rise not being taken into account. The DEQ stated, "The DEQ VWPP (Virginia Water Protection Permit) Program does not have the regulatory authority to speculate on how sea level rise may affect the distribution and type of wetlands present in the project watershed."

Similar challenges to wetlands permit applications with the US Army Corps of Engineers under the authority of the Clean Water Act have been made and, although the permits were not issued, it is unclear whether the arguments regarding increased inundation risk and sea level rise factored into those decisions.

Disturbance of primary coastal dunes requires a permit to insure that development does not encroach upon these dunes (Va. Code § 28.2-1408/4VAC20-440-10.). Development is allowed only within a zone 20 times the average shoreline recession rate over the last 100 years. Again, an explicit inclusion of sea level rise in this authority would protect both the natural resource and discourage coastal development.

Erosion and sediment control programs (Va. Code §10.1-560/4VAC30-50) and municipal storm water control programs (Va. Code § 10.1-603.3) regulate development and developed areas along the shoreline and are designed to control shoreline runoff pollution. To the extent that these authorities affect shoreline development, they have the potential to be used in adapting to increased inundation risk and sea level rise.

The Virginia Department of Historic Resources (DHR) has a role to play in adaptation to increasing inundation and sea level rise, since DHR approval must be granted before any disturbance/development can happen near an historic site (Va. Code § 10.1-2200/17VAC10).

Limitations on Adaptation Authorities

The use of any of these authorities for adaptation to increased flooding/sea level rise is limited by two major factors. First, with adaptation authorities based on state statute there are potential limitations caused by the fact that in Virginia, localities only have the authorities specifically given to them by the state, a constitutional approach referred to as "Dillon's Rule." Virginia Courts have held that "municipal governments have only those powers which are expressly granted by the state legislature, those powers fairly or necessarily implied from expressly granted powers, and those powers which are essential and indispensable" *(Commonwealth v. County Board of Arlington County*, 217 Va. 558, 575, 232 S.E.2d 30, 41 (1977)).

This limitation becomes a significant factor in looking at the authorities available to local governments to adapt to future changes in inundation along the tidal shoreline. At the regulatory end of the approaches described above, as localities attempt to change development and redevelopment patterns through zoning and building codes, their actions may be subject to a constitutional challenge under the Dillon rule. While general authority exists for localities to protect the health and welfare of their citizens, specific actions taken to restrict development on private property raise a set of issues that may need to be settled in court, unless specific legislative authority is granted.

Second, all but one of the authorities outlined above share a significant challenge in anticipating future conditions since they use past conditions to predict the future and cannot anticipate changes beyond those past trends. With the exception of the US Army Corps of Engineers Guidance, all of the statutes and regulations rely on a retrospective analysis of flooding and sea level rise impacts. One-hundred year floodplains under FEMA programs, rates of shoreline recession under the primary dune regulations, and all of the other regulatory analyses do not anticipate future conditions in their scope. Until these statutes and regulations become prospective and look to future conditions, they are of little use in inundation and sea level rise adaptation.

Section 2.4 Adaptation strategies appropriate for Tidewater Virginia

An appropriate strategy for the state of Virginia would be the adoption of a multi-level, flexible adaptation plan with specific roles for the state, localities and individuals. Continued partnership with federal programs would be beneficial. A potential plan for adaptation follows:

Level 1 – State actions

The state would be primarily responsible for the construction of large structural protection, road elevation, monitoring of changing water levels, sea level projections and investing in early warning system/storm prediction capacity. The rational for state involvement in large structural protection projects is that property rights in Virginia extend to mean low water and our shorelines tend to have many, small perpendicular roads, so tide gates and storm surge barriers are likely to be a more appropriate strategy than levees for most areas. Island localities and areas with state-owned waterfront are exceptions, and may be appropriate for levees. Water bodies large enough to warrant structures may cross locality boundaries, making state coordination appropriate. In addition, these structures are expensive and potentially out of reach of individual localities.

To create a flexible adaptation plan, the state would need to look at flooding throughout Tidewater Virginia and group issues into tiers: 1) Areas that need immediate attention, 2) Areas that will be facing problems ~40 years from now (given current predictions), and 3) Areas that will be facing problems ~100 years from now (given current predictions). The plan would include a series of steps and time frames for each step, addressing the first tier in the first steps and then moving through the tiers in order. As the state continues to monitor sea level rise and flood issues, it could slow the time frames if sea level rise acceleration slowed or flooding decreased and accelerate them if flooding increased. The plan can include different pathways depending on changes in population that might move an area from one tier to the next.

A state-wide road plan for road elevation could combine incremental elevation with routine maintenance, targeting areas that are predicted to be impacted by flooding. Again, if sea level rises more slowly than predictions, the elevation portion of the program could be suspended with minimal effort.

Level 2 – Locality actions

The localities would be primarily responsible for implementing the management and spatial planning actions to minimize future risk from flooding. This should be done on a locality level because each locality has a unique culture and geology, and likely a unique set of appropriate management actions. Management actions should be "low regret" actions, allowing more flexibility under changing conditions. Localities would also maintain the emergency services as part of the multi-level plan.

A comprehensive list of policy/management actions can be found in Section 4.1 (Dumais and Ness 2011). Localities can use this list to help determine the best actions for their localities. Specific suggestions for Virginia Beach and the Eastern Shore can be found at: http://www.virginia.edu/ien/sealevelrise/regionalfocusgroups.html.

Level 3 – Individual actions

Individuals should be encouraged to use soft engineering strategies when protecting their properties as these tend to retain ecological services and are typically "low-regret" options in the long term. Where possible, individuals should be educated regarding current and future flood risk prior to acquiring property or constructing new buildings and all buildings should be constructed using current best practices for reducing potential for flood damage.

Section 2.5: Stakeholder meeting notes and outcomes

Outcomes from Stakeholder Advisory Group

The stakeholder advisory group met September 20th in Williamsburg, VA. Invitees were nominated by the Planning District Commissions, members of the core advisory group for this study or taken from lists of Emergency Managers involved in either floodplain management plans or hazard mitigation plans. They were chosen to represent Tidewater Virginia as broadly as possible.

There was a lot of discussion about the roles of the state and localities in addressing flooding and sea level rise issues. Stakeholders felt strongly that the localities are not empowered to address the issues through policy and management, and do not have the financial resources for many accommodation or protection strategies. Therefore, they felt that the state needs to take a strong leadership role, incorporate flood and sea level rise management into state purviews, and enact state mandates that allow the localities to follow suit. However, the stakeholders are not in favor of the state mandating what type of adaptations should be used. They want each locality to have the flexibility to address flooding and sea level rise issues in their own way.

Stakeholders would like to see the state involved in the following ways:

1) They would like the state to review state policies that encourage development in flood prone areas. Specifically, they mentioned the changes in the state health codes that allow engineered septic systems in areas that were previously unsuitable for use. Many of these areas are flood prone; however, the localities feel that they do not have the authority to deny development if the state will allow septic systems.
2) They would like the state to decide for the localities what rate of sea level rise to use for planning purposes. Ideally, they would like the state to issue maps of sea level rise impacts at different times in the future (for different planning windows). This would give localities defined boundaries for planning efforts.
3) They are concerned how communities (especially rural ones) will finance adaptation strategies. They would like to see state leadership on this issue.
4) They would like to see the state (through the Virginia Department of Transportation) develop a comprehensive plan for the management of recurrently flooding roads. There are concerns that as sea level rise makes flooding worse on coastal roads, the state will choose to abandon them, leaving the localities responsible for raising or maintaining the roads.

Stakeholders identified research, information and education as particular needs, especially in regards to sea level rise predictions. They specifically mentioned:

1) They see a need for more refined predictions of sea level rise. They would like to see this refinement on both a temporal and geographical scale. Due to differing rates of local subsidence, relative sea level rise is slightly different throughout the state. Stakeholders would like the relative rates determined for each locality separately (but endorsed by the state; see above).
2) They see a need for better predictions of Nor'easter activity. Nor'easters cause a great deal of flooding issues in Virginia both through heavy precipitation and storm surge; they tend to linger longer than hurricanes, contributing to longer flood episodes. Therefore, being able to predict when Nor'easters are coming and understanding how Nor'easter activity is likely to change in the future should be as, or more, important than predicating shifts in hurricane/tropical storm patterns.
3) They see a need for increased education and outreach in all sectors. Specifically, they called out education and outreach to the public, and local and state decision makers as being priorities.
4) They encourage economic and cost-benefit studies of do-nothing versus adaptation strategies followed by state prioritization of different strategies. There was some discussion of how adaptation strategies should be funded (state versus local revenue), and these considerations should be included as part of the economic studies.

Most stakeholders felt that sea level rise was an issue that needed to be addressed; however, they saw significant legal and socioeconomic obstacles. Stakeholders were concerned about socioeconomic drivers that affected planning efforts. They saw a disconnect between the immediate demands and pressures from commercial and residential development, which operates within a short term planning window, and sea level rise which requires a longer term planning effort. They were concerned that society has a preference for worrying more about short term planning than about long term planning, leading to a lack of interest in deferring development in order to address long term sea level rise concerns. Stakeholders also were concerned about localities being empowered to enact management/policy type actions. They saw these actions (such as changes in zoning, particularly downzoning) as potentially reducing property values and were concerned about the legal implications of such actions. To empower localities to use management type options, they suggested that action needed to come from the state first. They felt this would require a "core group" who could motivate and educate others in the state. Stakeholders suggested that more meetings and stakeholder groups would be a good way to further the discussion at both the state and local levels.

Final invitee list:

Name	Organization
Baker, Stewart	Virginia Department of Emergency Management
Bernas, Jay	Hampton Roads Sanitation District
Brusso, Fred	City of Portsmouth
Byrnes, Kevin	George Washington Regional Commission
Crichton, Gwynn	The Nature Conservancy
Farmer, Anthony	Navy, NAVFAC Mid-Atlantic
Fink, Bob	Westmoreland County
Kelly, Alice	Public Works, Norfolk
Lawrence, Lewie	Middle Peninsula Planning District Commission
Mangum, Cathy	NASA Langley
McFarlane, Ben	Hampton Roads PDC
McGowan, Holly	Town of West Point
McKenzie, Stuart	Northern Neck Planning District Commission
Moon, Shep	Virginia Coastal Zone Management Program
Morrison, Rich	Accomack County
Parks, Ed	Town of Tangier
Penn, Mark	City of Alexandria
Polak, Beth	Virginia Coastal Zone Management Program
Ritter, Robert	Town of Chincoteague
Roberts, Ellen	City of Poquoson
Smith, Curtis	Accomack-Northampton Planning District Commission

Smith, Liz	Old Dominion University
Stiles, Skip	Wetlands Watch
Twigg, Wallace	Mathews County/ Virginia Department of Emergency Management
White, John	Norfolk

Agenda:

Virginia Recurrent Flooding Study
Stakeholder Advisory Group
September 20, 2012
Sadler Center, Chesapeake B
The College of William and Mary, Williamsburg, VA

Agenda

12:00 PM	LUNCH
12:30 PM	Introduction to Virginia Recurrent Flooding Study
1:00 PM	Sea Level Rise: the State of the Science
1:30 PM	Adaptations to Address Flooding
2:00 PM	Stakeholder Input Activities
3:00 PM	End of meeting

Discussion questions/activity:

The following questions were asked during the presentations:

1. Is precipitation or tidal/storm surge flooding a bigger problem in VA?
    A. Precipitation
    B. Tidal/Storm surge
    C. Both equal problems, but varies locally

2. Which does the public perceive as a bigger problem, precipitation or tidal/storm surge flooding?
    A. Precipitation
    B. Tidal/Storm surge
    C. They are equally concerned about both
    D. They are equally unconcerned about both

3. What is a useful planning horizon for the State?

A. 10 years

B. 20-30 years

C. 50 years

D. 100 years

4. What is a useful planning horizon for localities?

A. 10 years

B. 20-30 years

C. 50 years

D. 100 years

5. When presenting risk to the public, which method is most informative?

A. Risk of flooding during life of mortgage
B. Damage $$ due to storm events
C. Probabilities of floods
D. Case studies
E. Other

6. What level of protection should VA strive for?

A. 1/100 year storm
B. 1/500 year storm
C. Greater than these

7. Should all areas strive for same level of protection?

A. Yes
B. No, higher levels in urban areas

C. No, localities should decide

8. Should we strive for same level of protection for stormwater and storm surge?

A. Yes
B. No, stormwater should be higher

C. No, storm surge should be higher

D. It should vary by locality

9. Which Adaptation strategy organization method makes the most sense to you?

A. Reduce: Risk, Vulnerability, Consequences

B. Type: Management, Accommodation, Protection

C. Layers: Prevention, Spatial Scale, Emergency Management

D. Category: Temporary, Permanent, Land Use Management

Stakeholders were also asked to identify desired goals and outcomes for the state and localities regarding flooding issues, to prioritize actions to achieves those goals, and indicate the responsible parties for those actions.

Section 2.6: Findings and Recommendations

Findings:

1. Recurrent flooding is a significant issue in Virginia coastal localities and one which is predicted to become worse over reasonable planning horizons (20-50 years).
2. The risks associated with recurrent flooding are not the same throughout all areas of Tidewater Virginia.
3. Data is often lacking for comprehensive and/or fine resolution analysis of flood risk sin the region.
4. Review of global flood and sea level rise management strategies suggest that it is possible for Virginia to have an effective response to increasing flood issues BUT it takes time (20-30 years) to effectively plan and implement many of the adaptation strategies

Recommendations:

1. Given the long time frame necessary to effectively address recurrent flooding and sea level rise issues and given the speed at which risks are projected to increase, Virginia and its coastal localities should immediately begin comprehensive and coordinated planning efforts.
2. The State should initiate identification, collection and analysis of data needed to support effective planning for response to recurrent flooding issues in Virginia.
3. The State should take a lead role in addressing recurrent flooding in Virginia for the following reasons:
    a. Accessing relevant federal resources for planning and mitigation may be enhanced through state mediation.
    b. Flooding problems are linked to water bodies and therefore often transcend locality boundaries.
    c. Resource prioritization efforts will require consistent or standardized assessment protocols across all localities and regions.
    d. Localities do not feel enabled to address all flooding and sea level rise issues.
4. The State should request an expert review of local government legal authority to address current and projected flooding risks and what levels of evidence are likely to be required to justify locality action. The State should then enact any enabling authority needed to allow localities to address current and projected flooding issues.
5. The State should develop a comprehensive strategy for addressing recurrent flooding issues throughout Tidewater Virginia.

a. Part of that strategy should include prioritization of areas for flood management actions based (in part) on risk
b. Detailed studies should be done of prioritized areas to determine:
    i. Potential adaptation strategies appropriate to the area
    ii. Implementation feasibility of identified strategies
    iii. Cost/benefit of identified strategies

Section 3: Figures

Figure Legends

Figure 1. Tidewater Localities: *Map showing localities in Tidewater Virginia*
Figure 2. Tidewater Regions: *Map showing designated regions used to summarize information.*
Figure 3. Repetitive Loss, Region 1: *FEMA identifies properties that have received two or more claim payments of more than $1,000 from the National Flood Insurance Program within any rolling 10-year period for a home or business. Data presented is the number of repetitive loss properties aggregated by census block.*
Figure 4. Repetitive Loss, Region 2: *FEMA identifies properties that have received two or more claim payments of more than $1,000 from the National Flood Insurance Program within any rolling 10-year period for a home or business. Data presented is the number of repetitive loss properties aggregated by census block.*
Figure 5. Repetitive Loss, Region 3: *FEMA identifies properties that have received two or more claim payments of more than $1,000 from the National Flood Insurance Program within any rolling 10-year period for a home or business. Data presented is the number of repetitive loss properties aggregated by census block.*
Figure 6. Repetitive Loss, Region 4: *FEMA identifies properties that have received two or more claim payments of more than $1,000 from the National Flood Insurance Program within any rolling 10-year period for a home or business. Data presented is the number of repetitive loss properties aggregated by census block.*
Figure 7. Repetitive Loss, Region 5: *FEMA identifies properties that have received two or more claim payments of more than $1,000 from the National Flood Insurance Program within any rolling 10-year period for a home or business. Data presented is the number of repetitive loss properties aggregated by census block.*
Figure 8. Repetitive Loss Costs: *Total repetitive loss costs for each locality as reported by FEMA.*
Figure 9. Flood Related Road Closures: *Number and location of road closures of state maintained roads over a 4 year time period as reported by VDOT.*
Figure 10. Elevation Data Availability: *Types of elevation data available for each locality.*
Figure 11. Vulnerability to Storm Surge with Predicted Sea Level Rise, Region 1: *A map of the potentially inundated areas assuming a 1.5 foot rise in sea level and a 3 foot storm surge.*
Figure 12. Vulnerability to Storm Surge with Predicted Sea Level Rise, Region 2: *A map of the potentially inundated areas assuming a 1.5 foot rise in sea level and a 3 foot storm surge.*
Figure 13. Vulnerability to Storm Surge with Predicted Sea Level Rise, Region 3: *A map of the potentially inundated areas assuming a 1.5 foot rise in sea level and a 3 foot storm surge.*
Figure 14. Vulnerability to Storm Surge with Predicted Sea Level Rise, Region 4: *A map of the potentially inundated areas assuming a 1.5 foot rise in sea level and a 3 foot storm surge.*
Figure 15. Vulnerability to Storm Surge with Predicted Sea Level Rise, Region 5: *A map of the potentially inundated areas assuming a 1.5 foot rise in sea level and a 3 foot storm surge.*
Figure 16. Predictions of Future Sea Level Rise Rates: *A graph showing several future sea level rise scenarios, including an estimate of local subsidence.*
Figure 17. Vulnerability to Storm Surge with 2m Sea Level Rise, Region 1. *A map of the potentially inundated areas generated by SERDP's (see Section 4.4) model which assumes storm surge on top of a 2 meter sea level rise.*

Figure 18. Vulnerability to Storm Surge with 2m Sea Level Rise, Region 2*. A map of the potentially inundated areas generated by SERDP's (see Section 4.4) model which assumes storm surge on top of a 2 meter sea level rise.*

Figure 19. Vulnerability to Storm Surge with 2m Sea Level Rise, Region 3. *A map of the potentially inundated areas generated by SERDP's (see Section 4.4) model which assumes storm surge on top of a 2 meter sea level rise.*

Figure 20. Vulnerability to Storm Surge with 2m Sea Level Rise, Region 4. *A map of the potentially inundated areas generated by SERDP's (see Section 4.4) model which assumes storm surge on top of a 2 meter sea level rise.*

Figure 21. Vulnerability to Storm Surge with 2m Sea Level Rise, Region 5. *A map of the potentially inundated areas generated by SERDP's (see Section 4.4) model which assumes storm surge on top of a 2 meter sea level rise.*

Figure 1

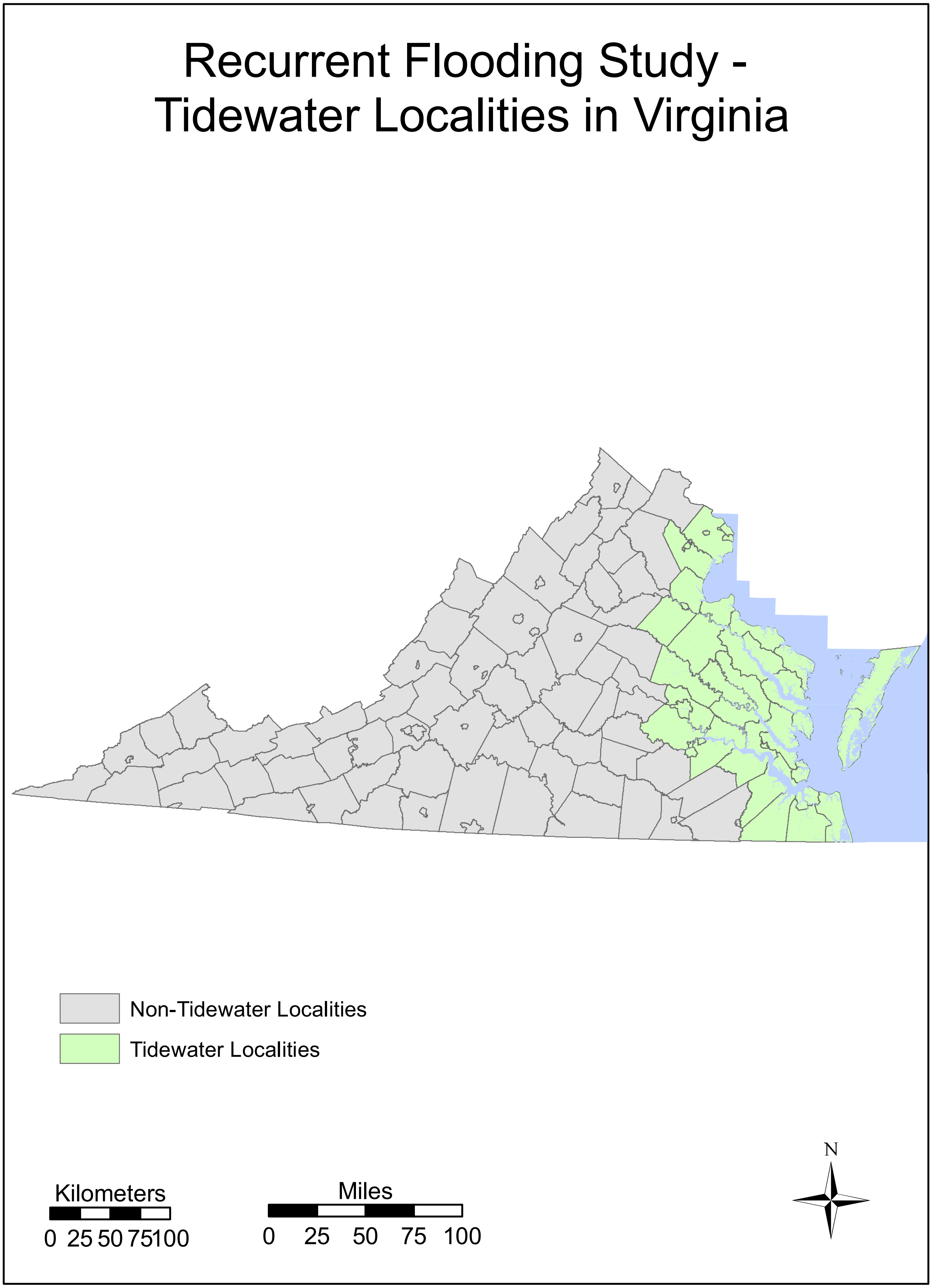

Recurrent Flooding Study -
Tidewater Localities in Virginia
Non-Tidewater Localities
Tidewater Localities
Kilometers
0 25 50 75100
Miles
0 25 50 75 100
N

Figure 2

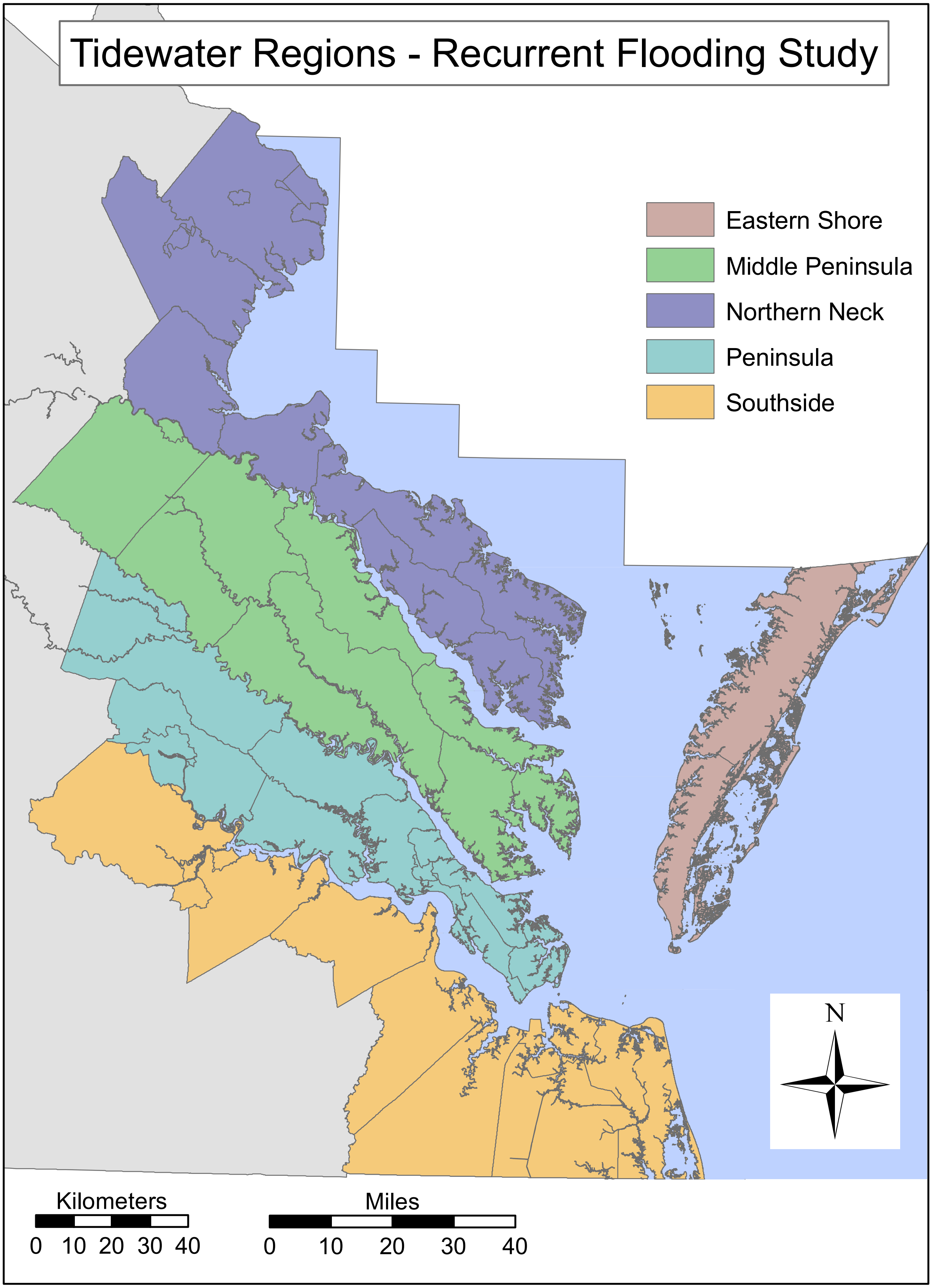
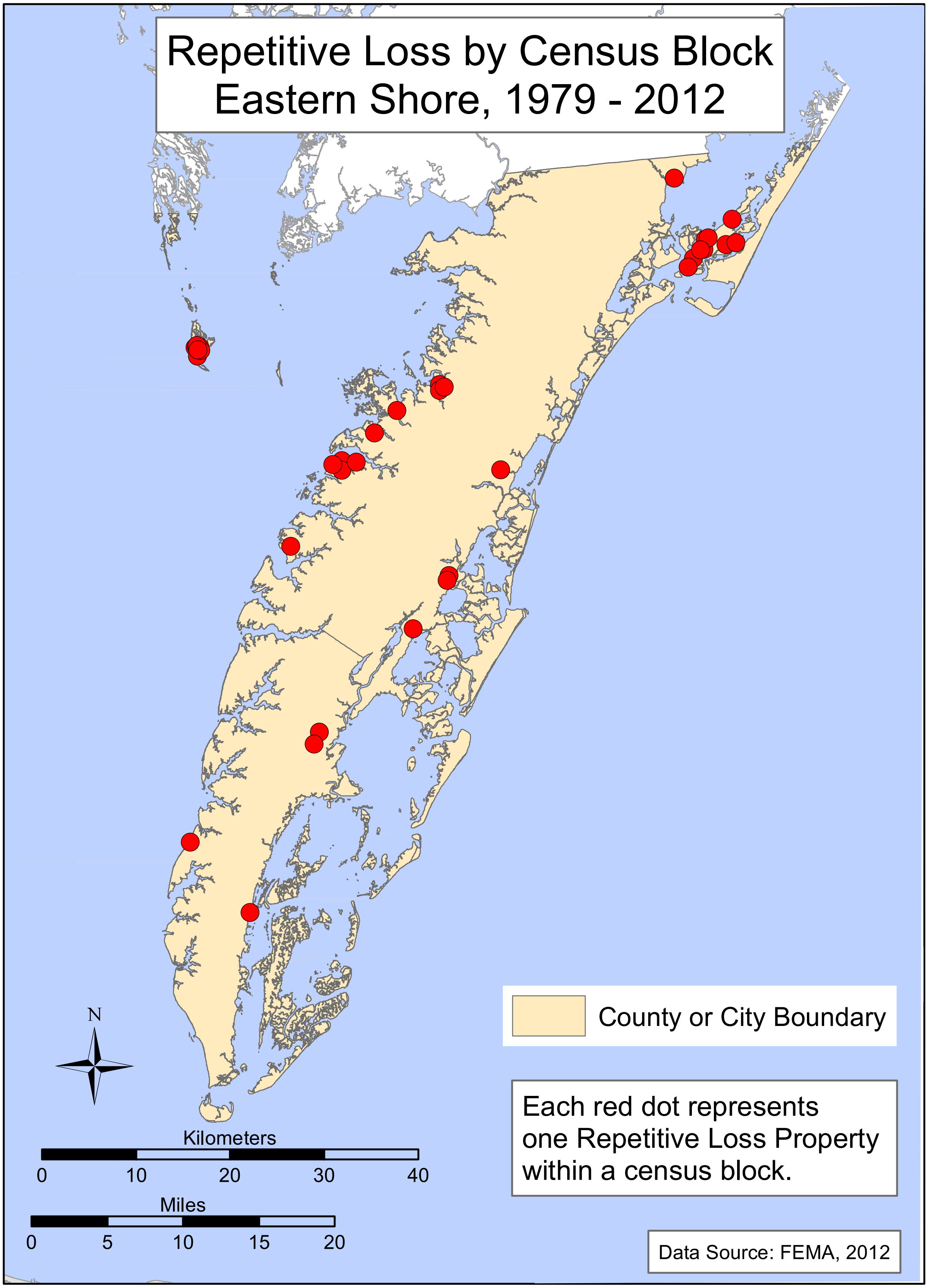

Tidewater Regions - Recurrent Flooding Study
Eastern Shore
Middle Peninsula
Northern Neck
Peninsula
Southside
N
Kilometers
0 10 20 30 40
Miles
0 10 20 30 40

Figure 3


Repetitive Loss by Census Block
Eastern Shore, 1979 - 2012
County or City Boundary
Each red dot represents one Repetitive Loss Property within a census block.
Data Source: FEMA, 2012
N
Kilometers
0 10 20 30 40
Miles
0 5 10 15 20

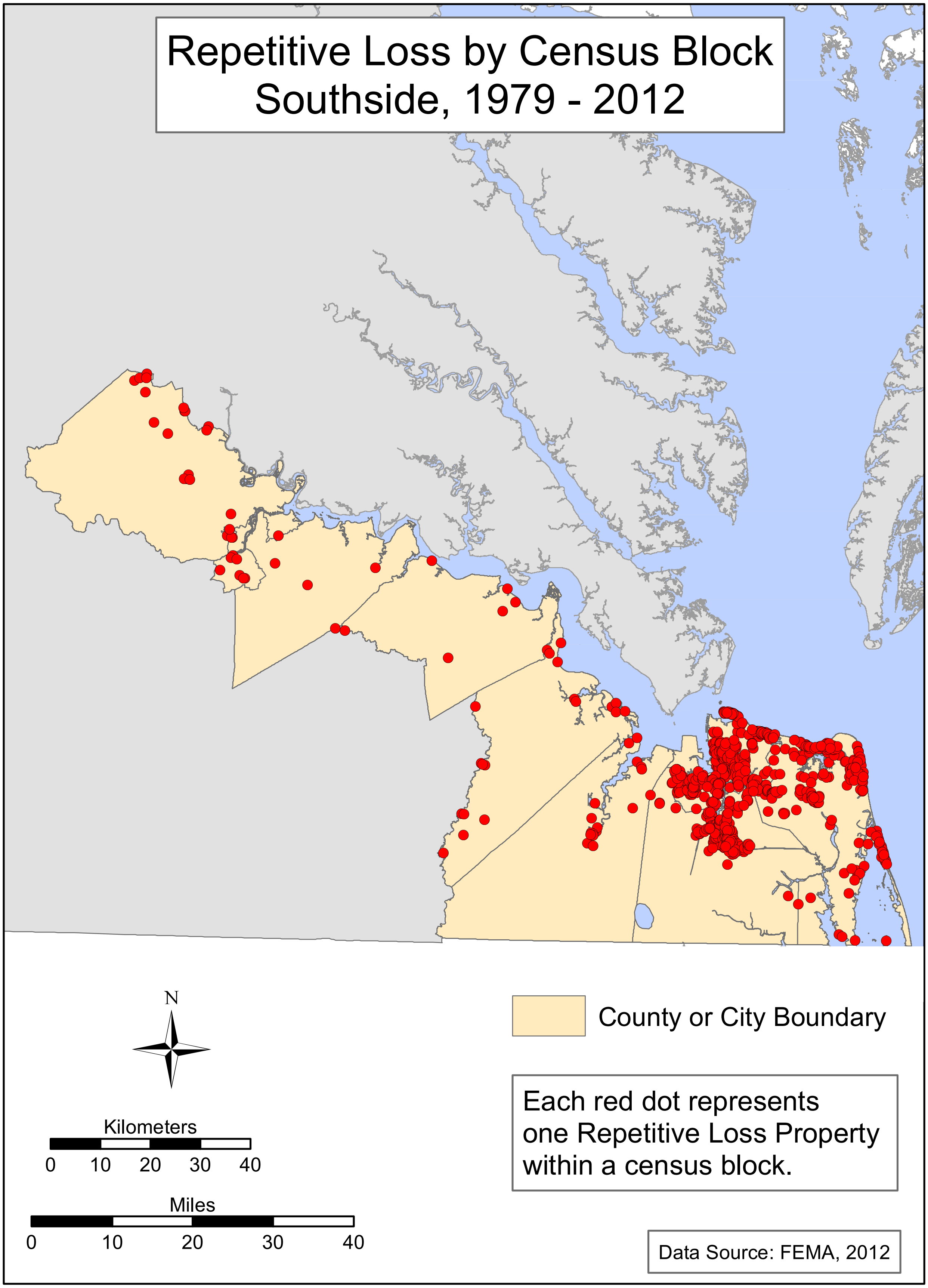
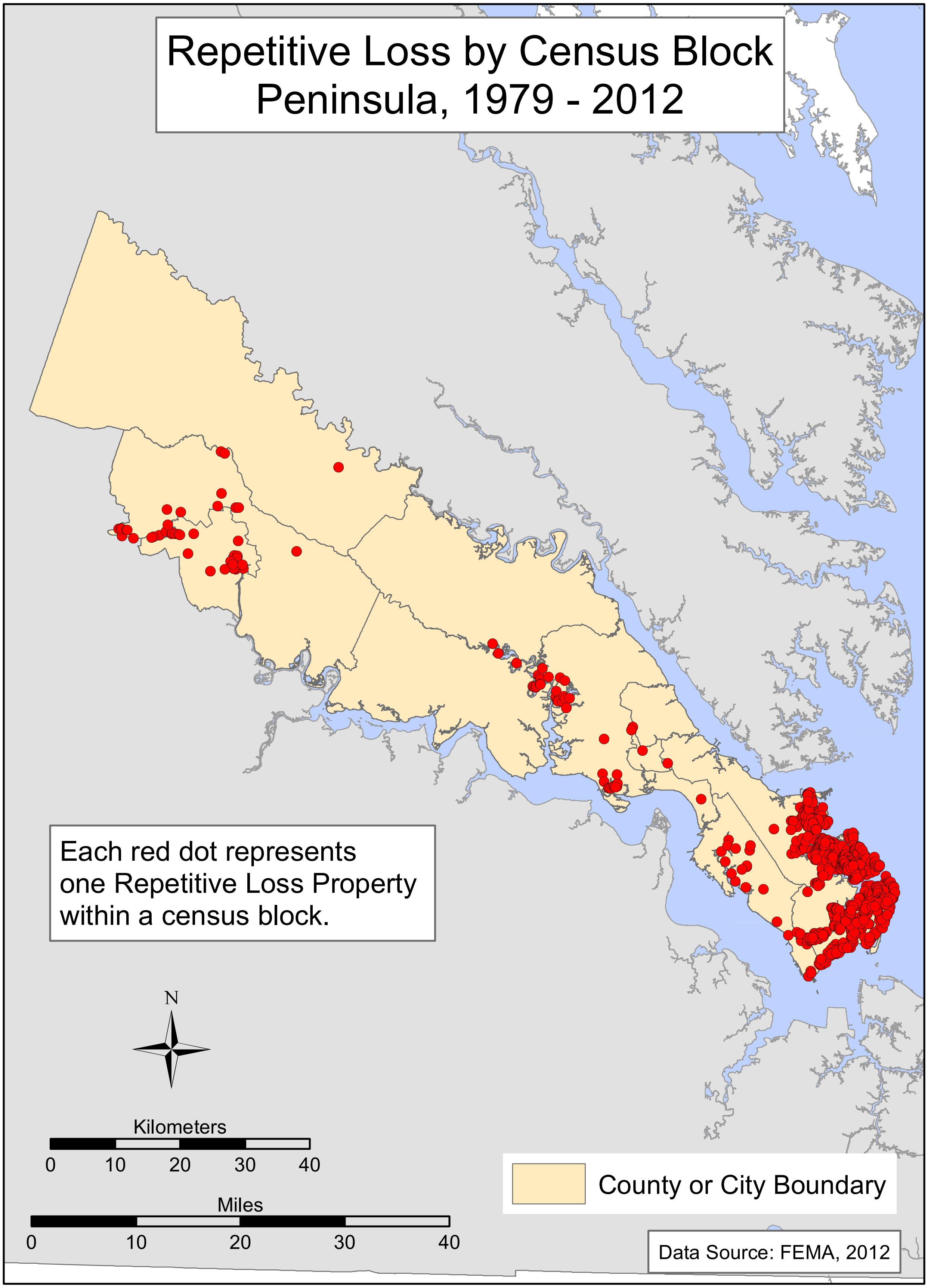
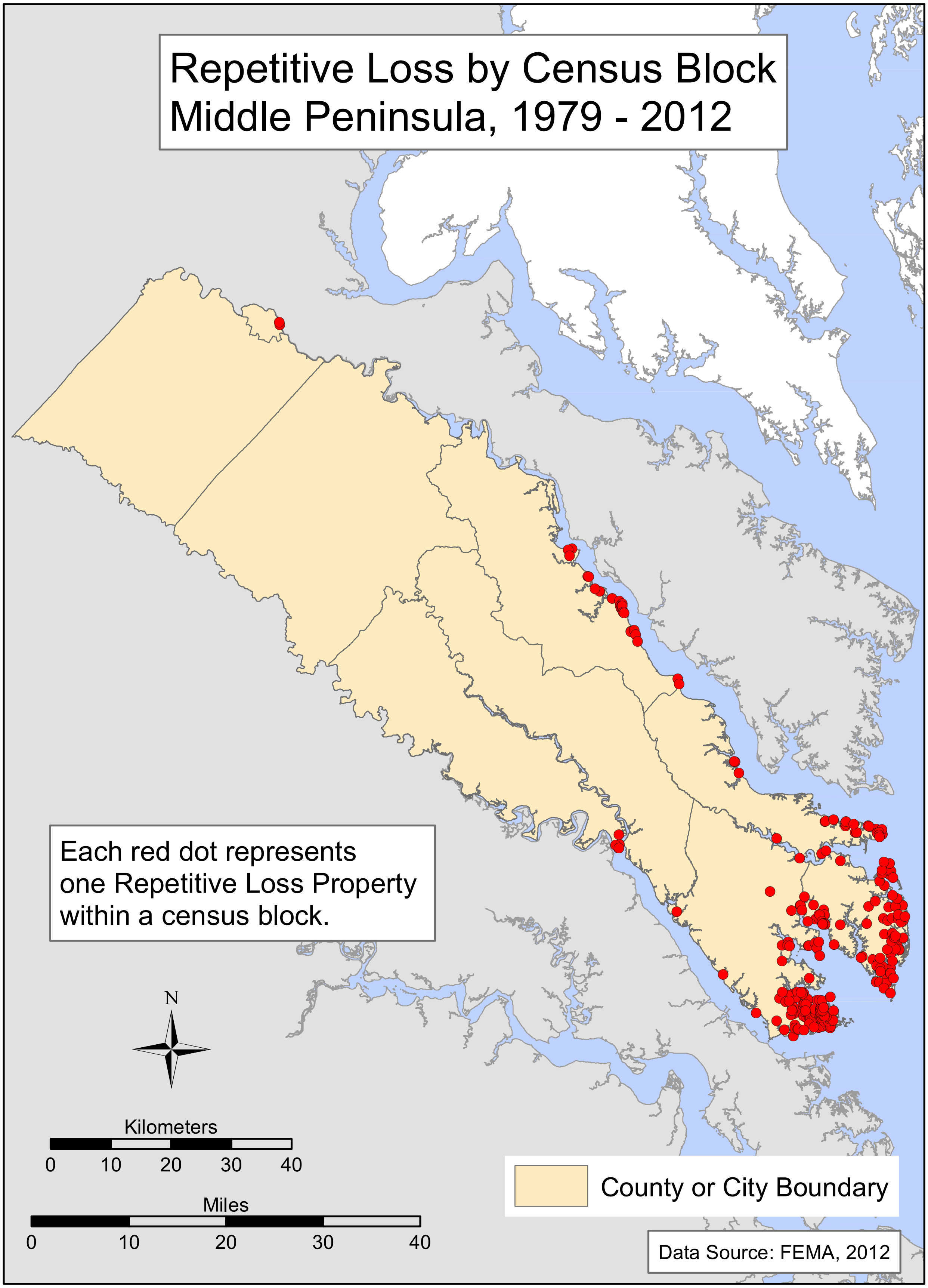

Repetitive Loss by Census Block
Southside, 1979 - 2012
N
Kilometers
0 10 20 30 40
Miles
0 10 20 30 40
County or City Boundary
Each red dot represents one Repetitive Loss Property within a census block.
Data Source: FEMA, 2012

Figure 5


Repetitive Loss by Census Block
Peninsula, 1979 - 2012
Each red dot represents one Repetitive Loss Property within a census block.
N
Kilometers
0 10 20 30 40
Miles
0 10 20 30 40
County or City Boundary
Data Source: FEMA, 2012


Repetitive Loss by Census Block
Middle Peninsula, 1979 - 2012
Each red dot represents
one Repetitive Loss Property
within a census block.
N
Kilometers
0 10 20 30 40
Miles
0 10 20 30 40
County or City Boundary
Data Source: FEMA, 2012

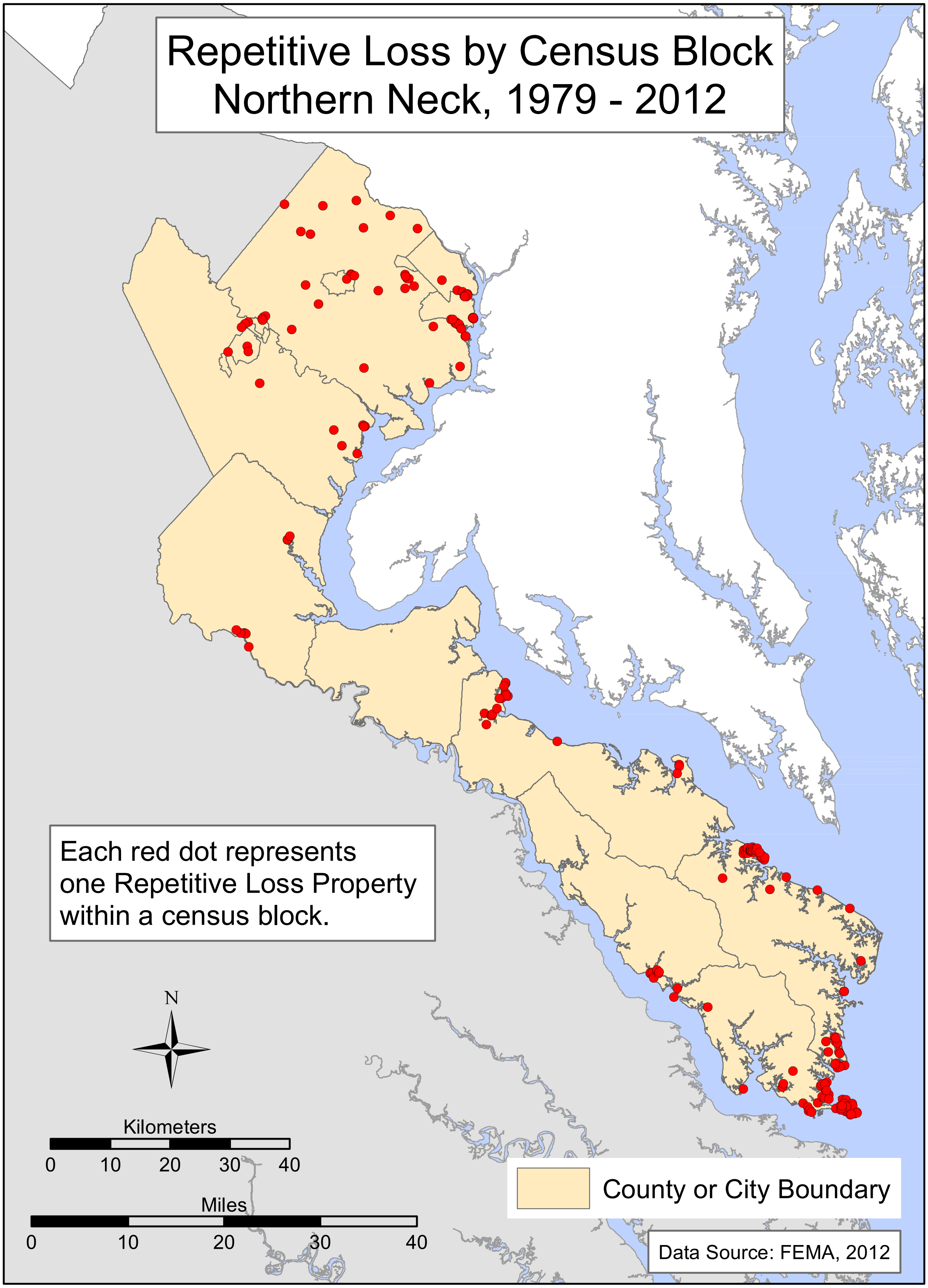
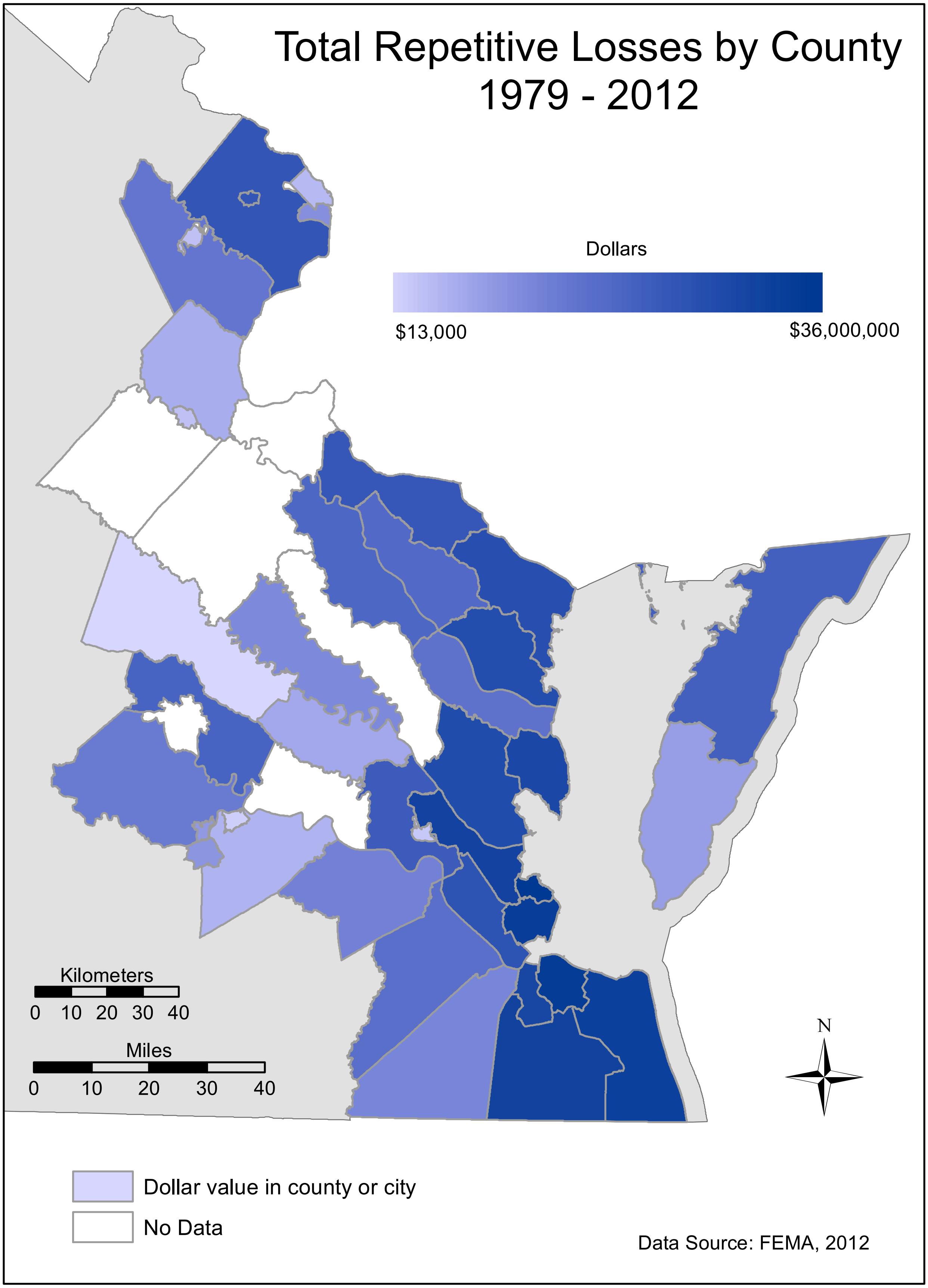

Repetitive Loss by Census Block
Northern Neck, 1979 - 2012
Each red dot represents one Repetitive Loss Property within a census block.
N
Kilometers
0 10 20 30 40
Miles
0 10 20 30 40
County or City Boundary
Data Source: FEMA, 2012

Figure 8



Total Repetitive Losses by County
1979 - 2012
Dollars
$13,000
$36,000,000
Kilometers
0 10 20 30 40
Miles
0 10 20 30 40
N
Dollar value in county or city
No Data
Data Source: FEMA, 2012

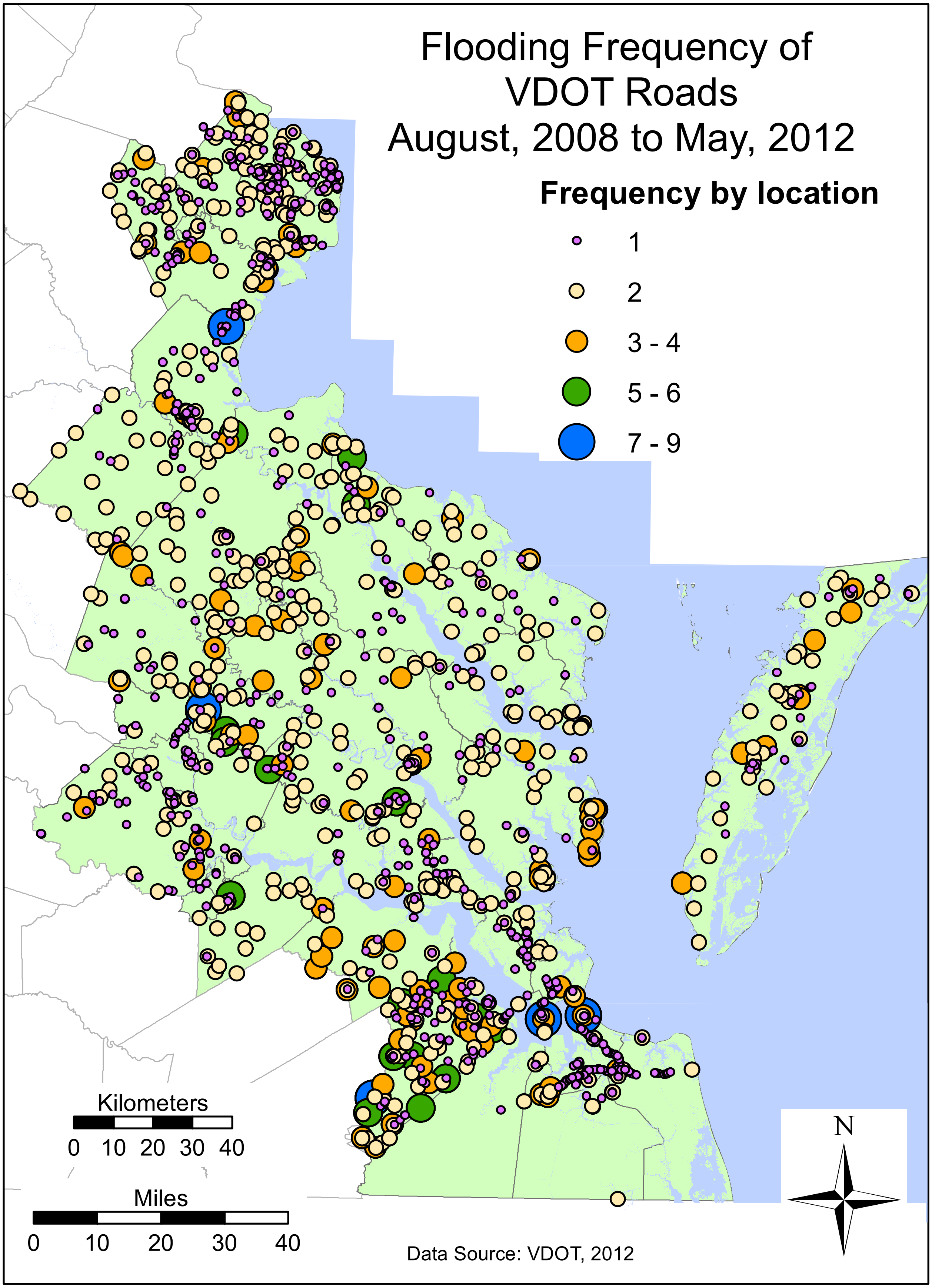
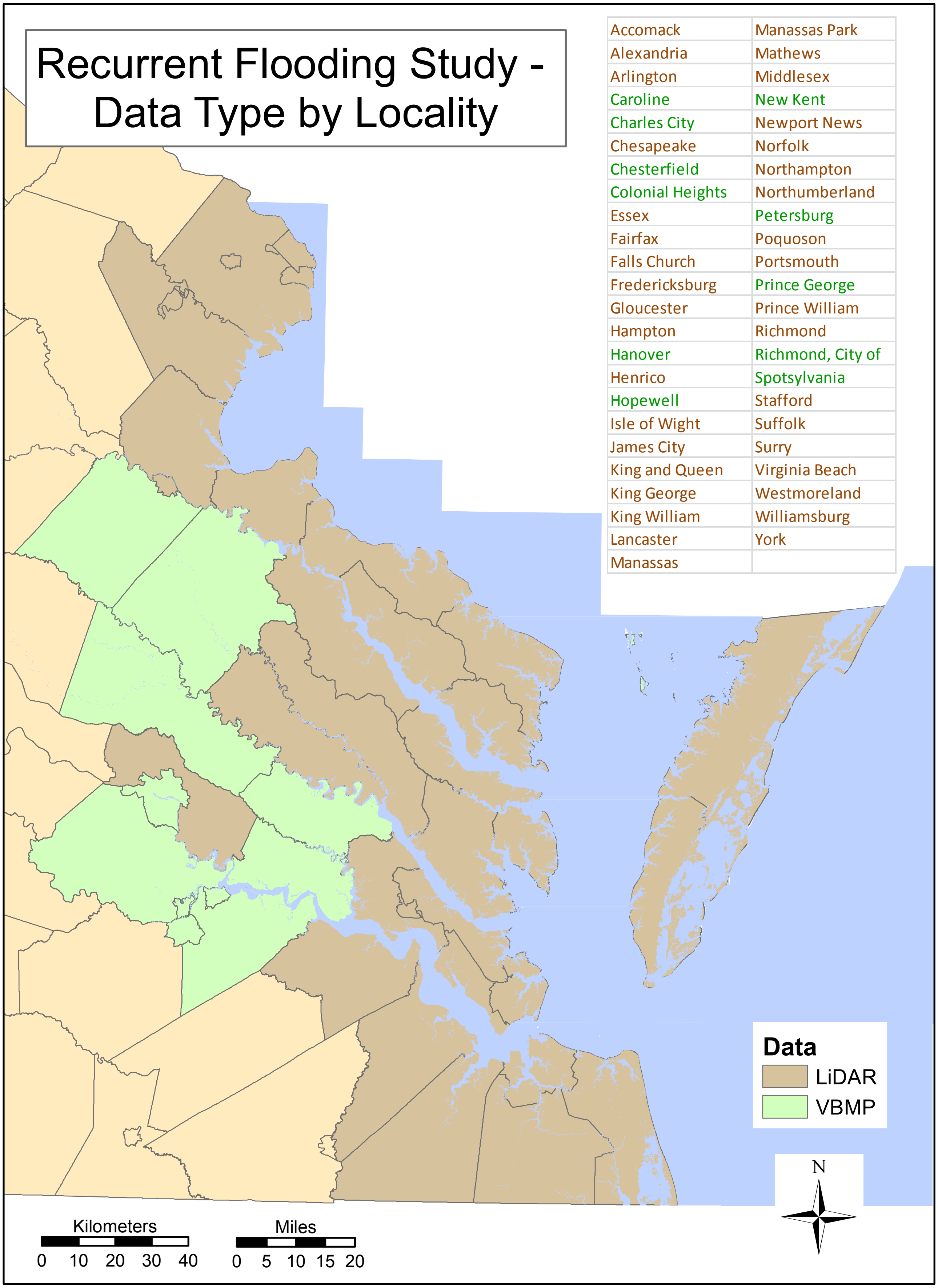

Flooding Frequency of
VDOT Roads
August, 2008 to May, 2012
Frequency by location
1
2
3 - 4
5 - 6
7 - 9
Kilometers
0 10 20 30 40
Miles
0 10 20 30 40
Data Source: VDOT, 2012
N

Figure 10


Recurrent Flooding Study - Data Type by Locality
Accomack
Alexandria
Arlington
Caroline
Charles City
Chesapeake
Chesterfield
Colonial Heights
Essex
Fairfax
Falls Church
Fredericksburg
Gloucester
Hampton
Hanover
Henrico
Hopewell
Isle of Wight
James City
King and Queen
King George
King William
Lancaster
Manassas
Manassas Park
Mathews
Middlesex
New Kent
Newport News
Norfolk
Northampton
Northumberland
Petersburg
Poquoson
Portsmouth
Prince George
Prince William
Richmond
Richmond, City of
Spotsylvania
Stafford
Suffolk
Surry
Virginia Beach
Westmoreland
Williamsburg
York
Data
LiDAR
VBMP
N
Kilometers
0 10 20 30 40
Miles
0 5 10 15 20

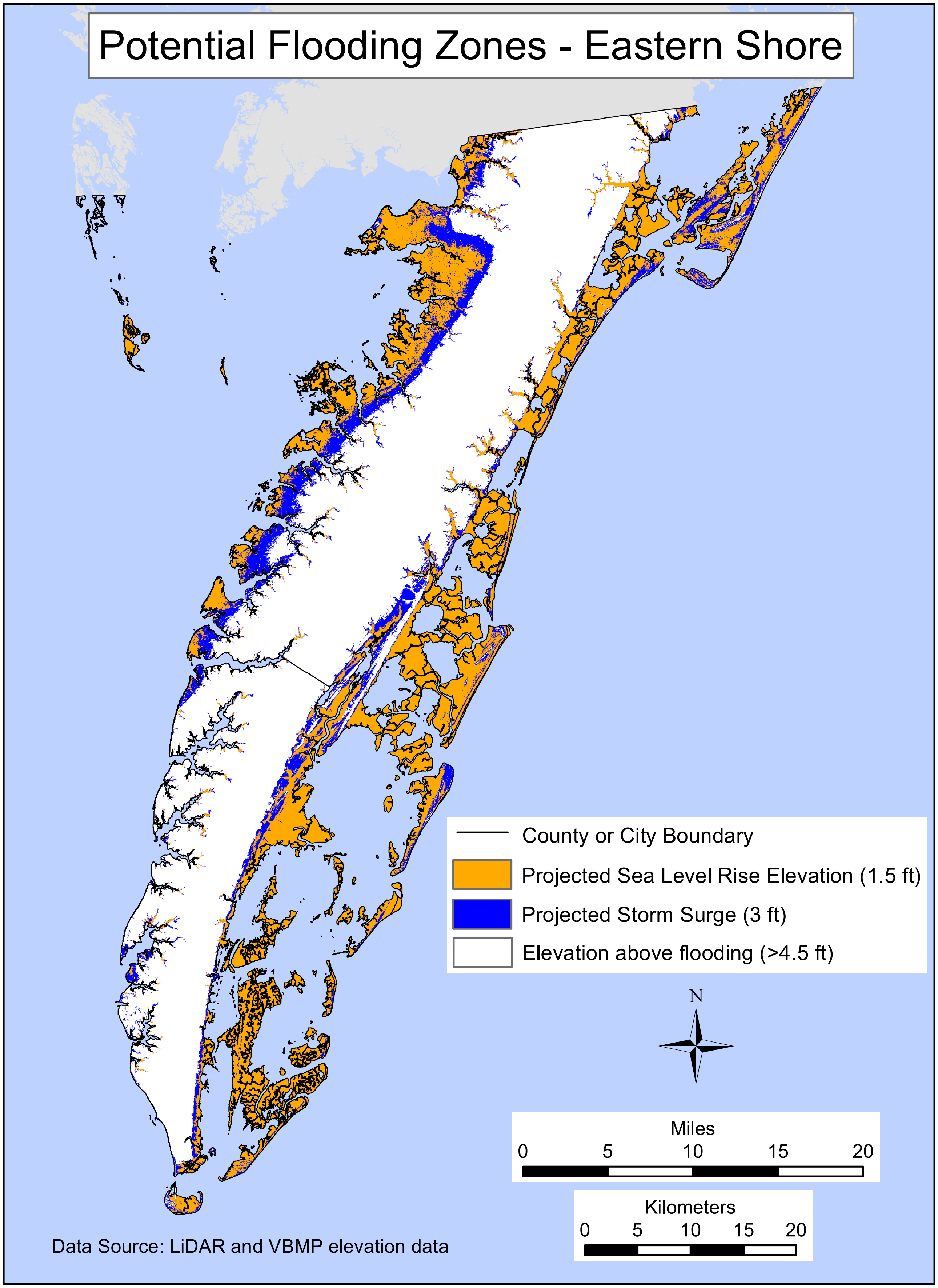

Potential Flooding Zones - Eastern Shore
County or City Boundary
Projected Sea Level Rise Elevation (1.5 ft)
Projected Storm Surge (3 ft)
Elevation above flooding (>4.5 ft)
N
Miles
0 5 10 15 20
Kilometers
0 5 10 15 20
Data Source: LiDAR and VBMP elevation data

Figure 12

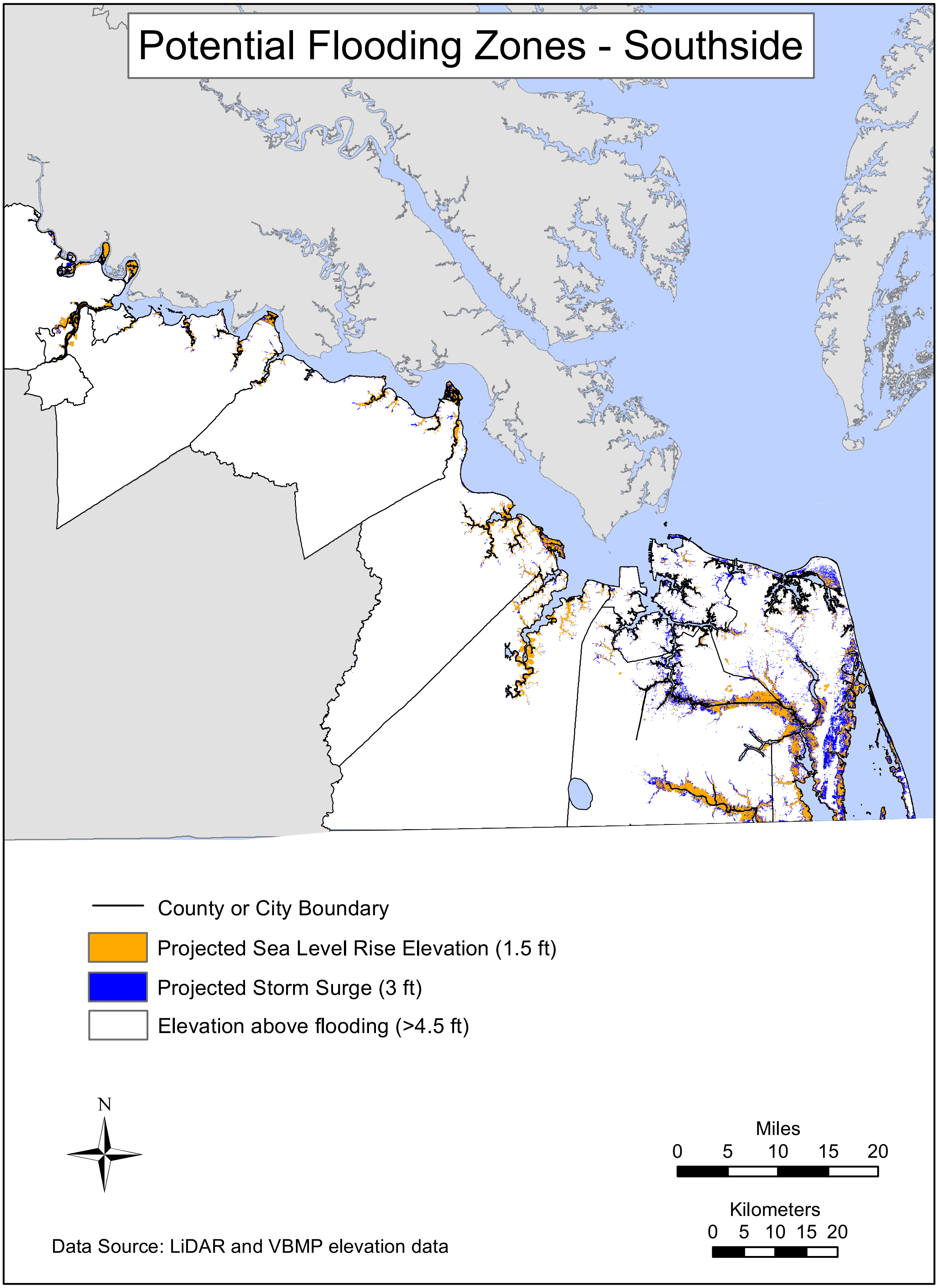
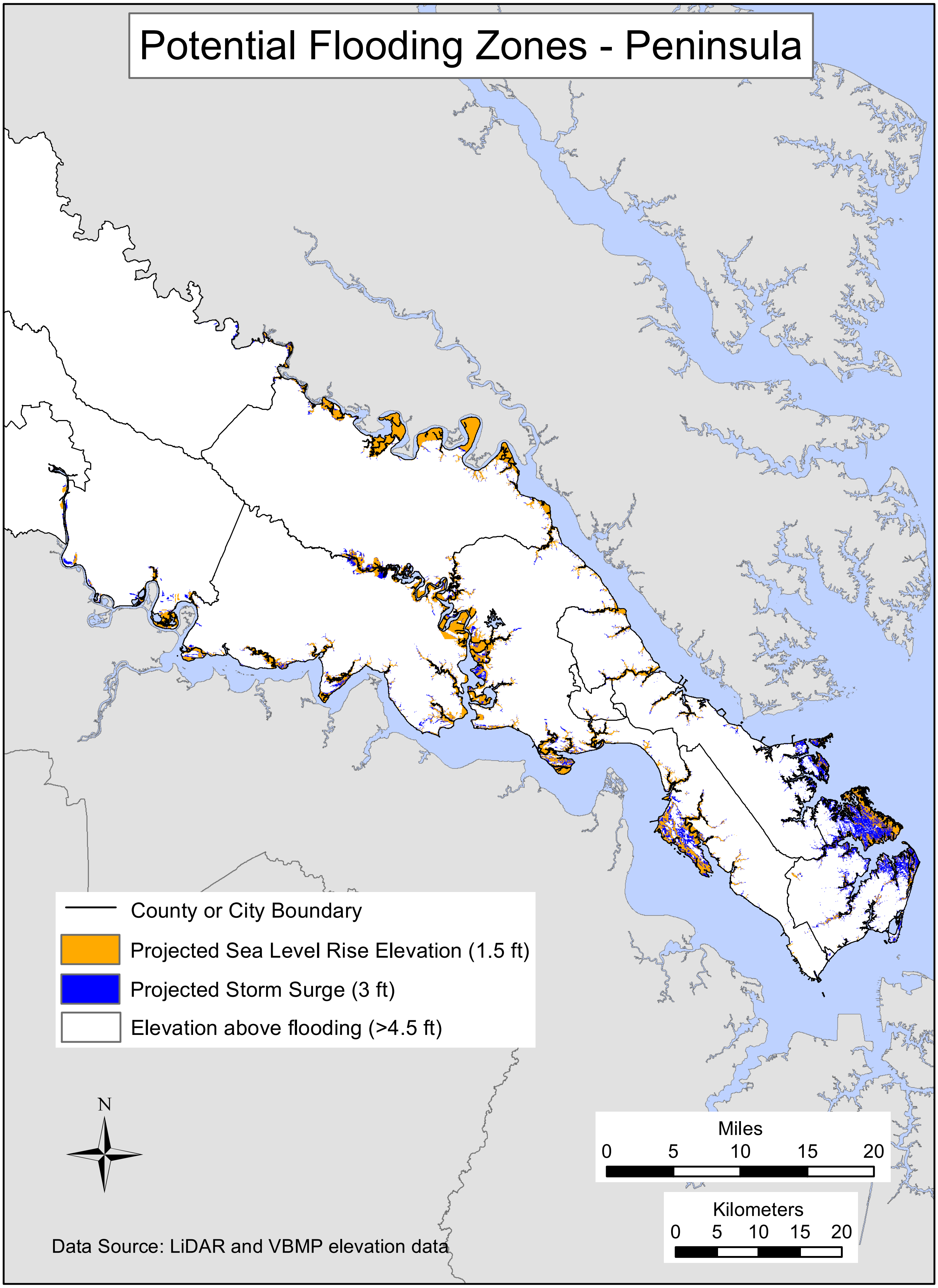

Potential Flooding Zones - Southside
County or City Boundary
Projected Sea Level Rise Elevation (1.5 ft)
Projected Storm Surge (3 ft)
Elevation above flooding (>4.5 ft)
N
Miles
0 5 10 15 20
Kilometers
0 5 10 15 20
Data Source: LiDAR and VBMP elevation data

Figure 13



Potential Flooding Zones - Peninsula
County or City Boundary
Projected Sea Level Rise Elevation (1.5 ft)
Projected Storm Surge (3 ft)
Elevation above flooding (>4.5 ft)
N
Miles
0 5 10 15 20
Kilometers
0 5 10 15 20
Data Source: LiDAR and VBMP elevation data

Figure 14

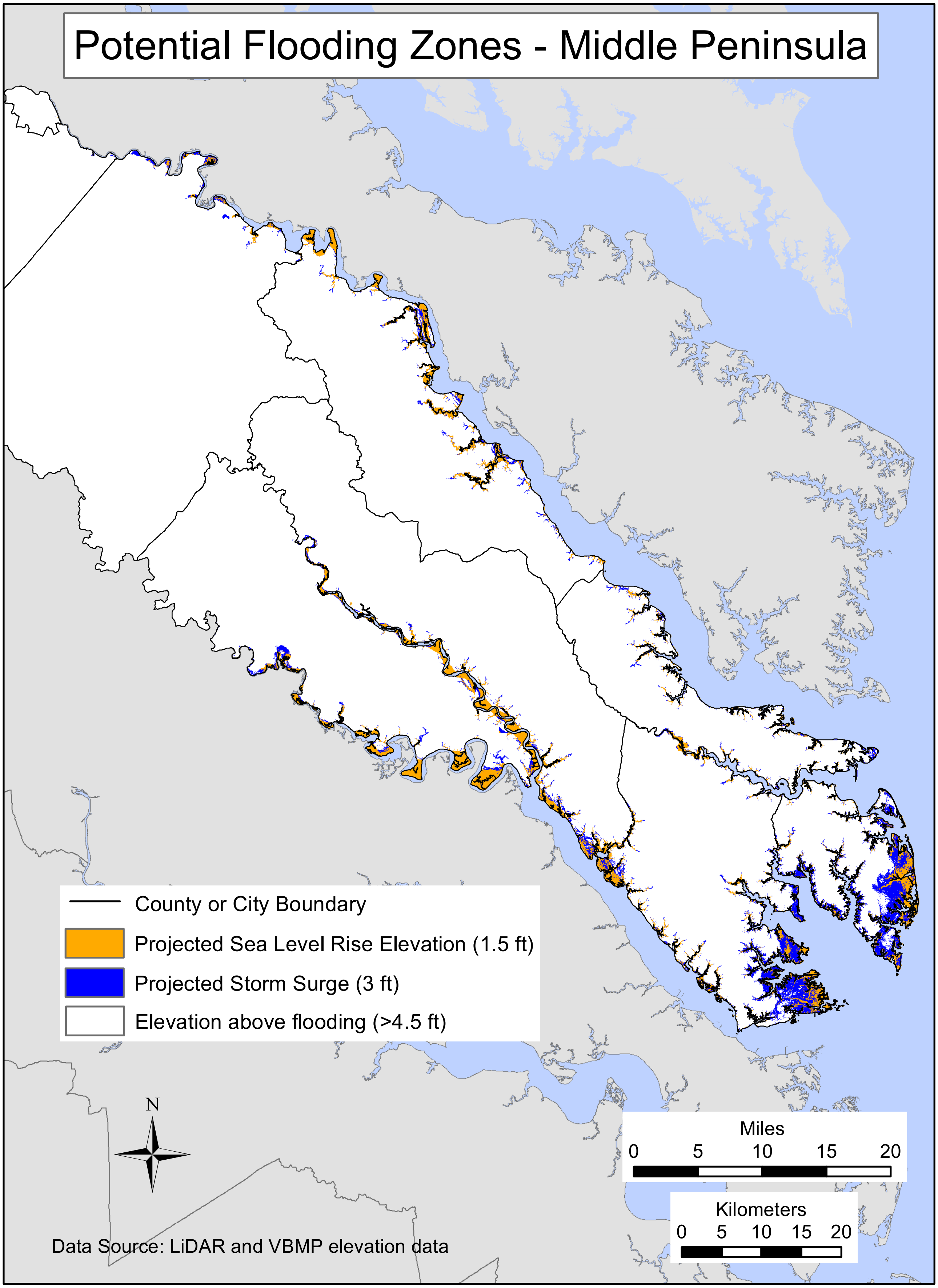
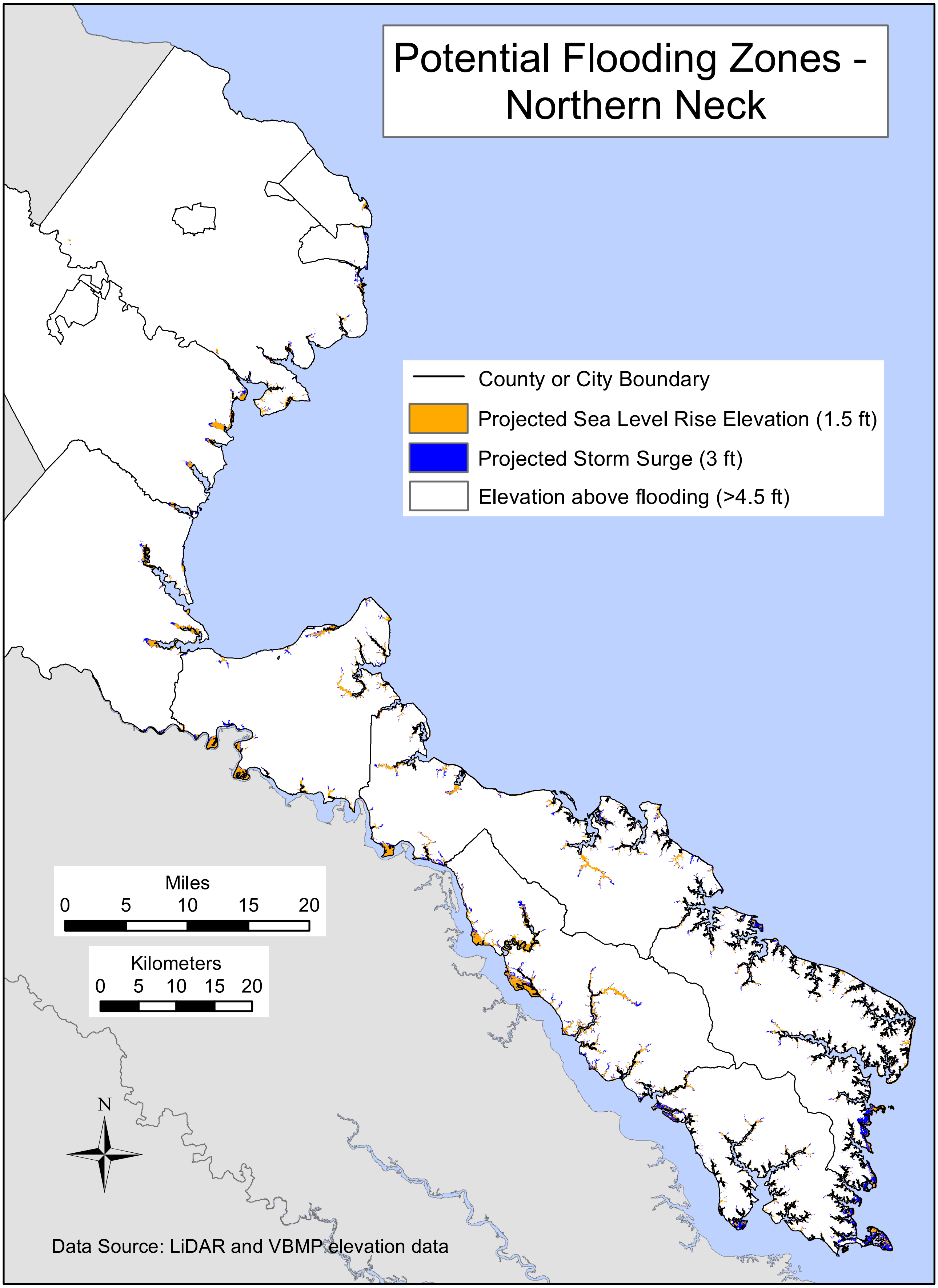
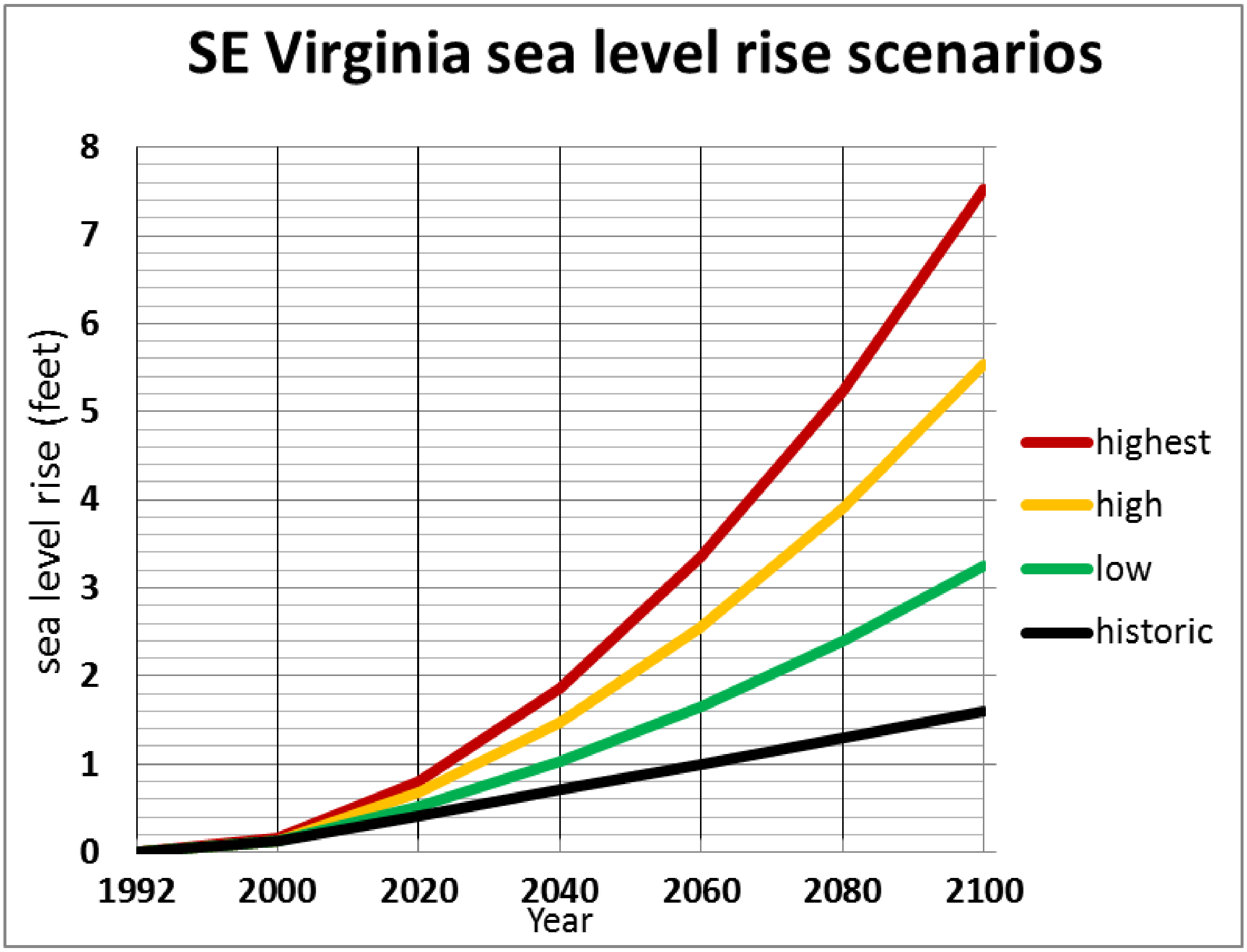

Potential Flooding Zones - Middle Peninsula
County or City Boundary
Projected Sea Level Rise Elevation (1.5 ft)
Projected Storm Surge (3 ft)
Elevation above flooding (>4.5 ft)
N
Miles
0 5 10 15 20
Kilometers
0 5 10 15 20
Data Source: LiDAR and VBMP elevation data

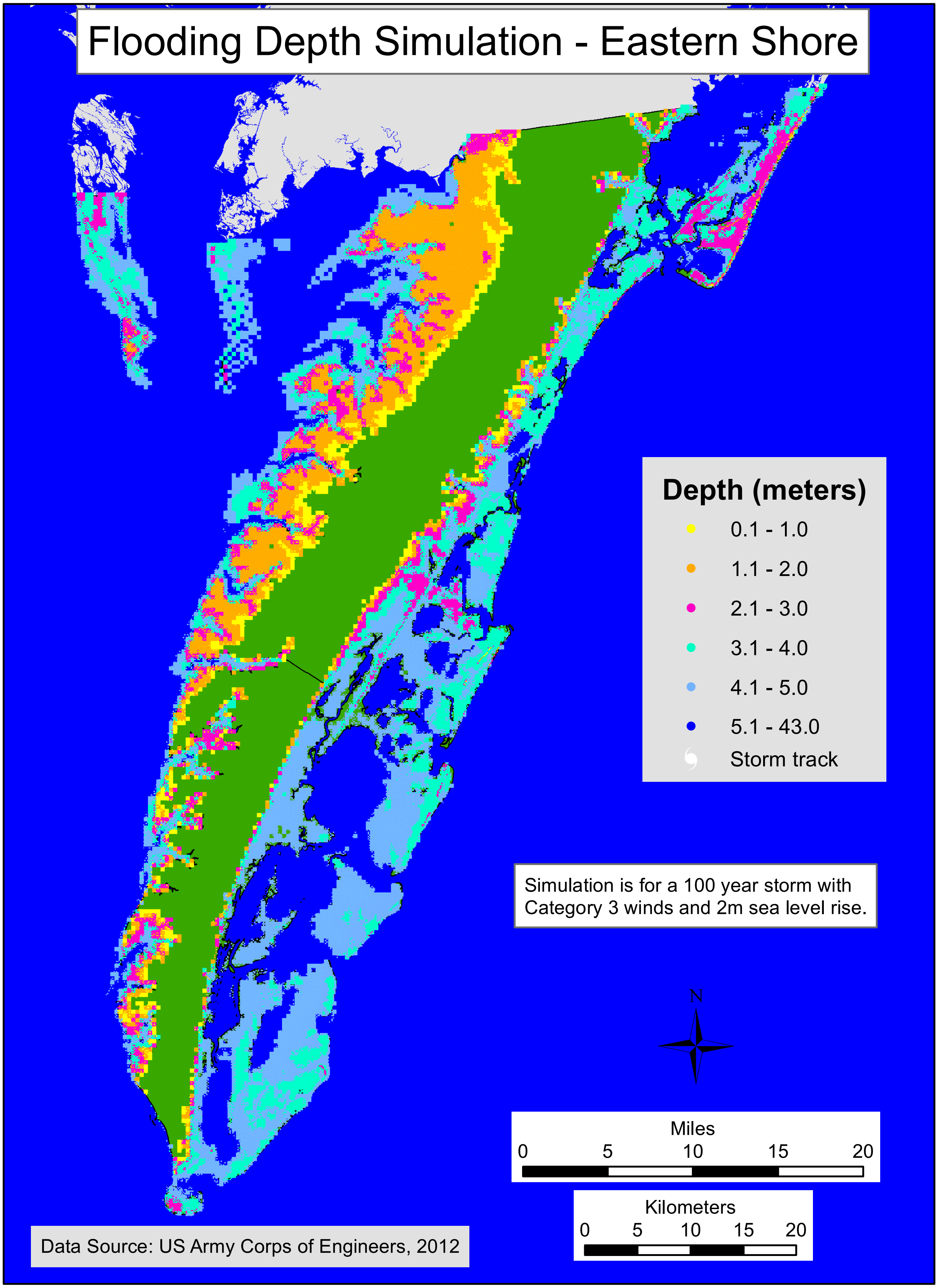
Figure 15

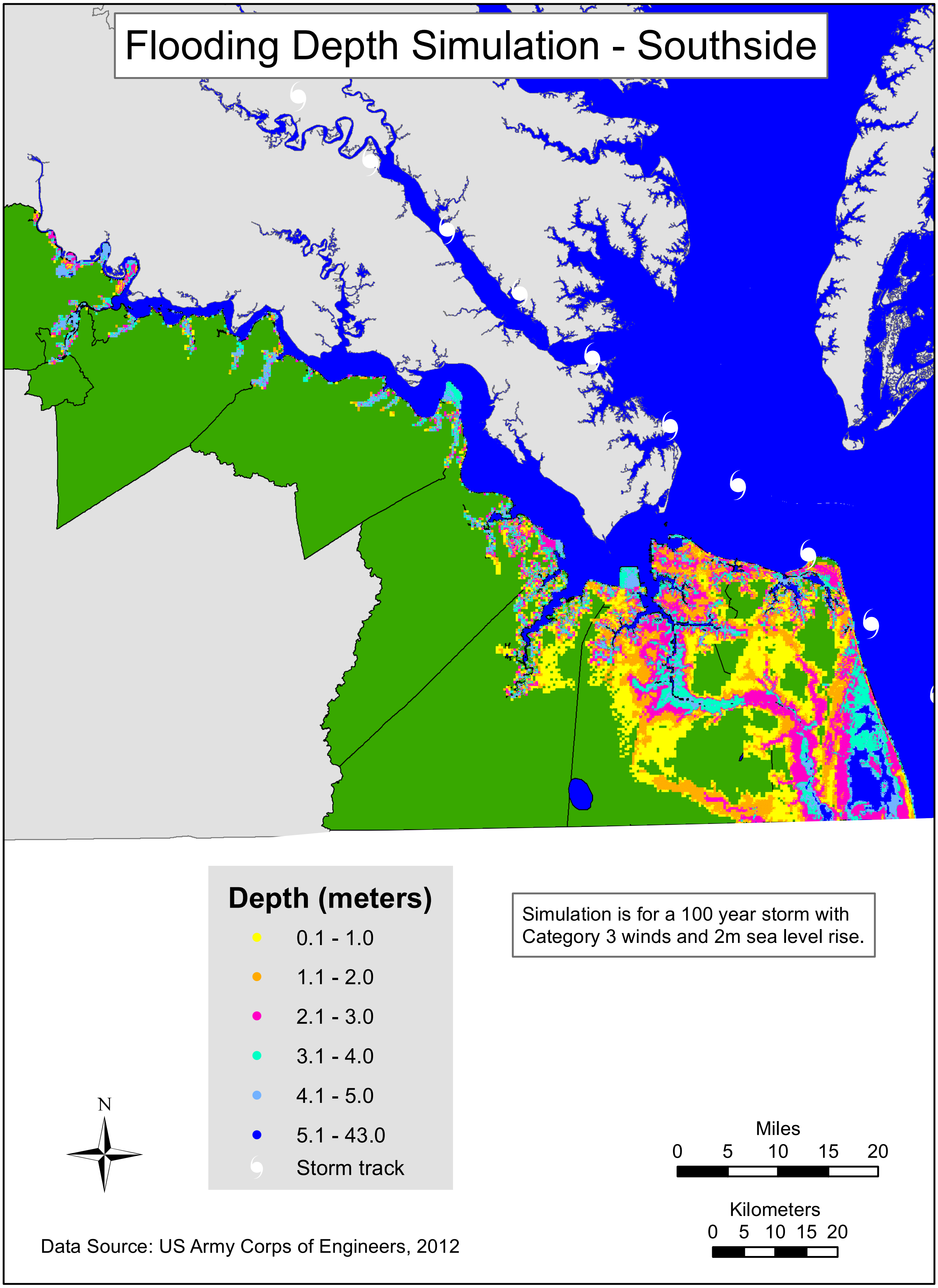


Potential Flooding Zones -
Northern Neck
County or City Boundary
Projected Sea Level Rise Elevation (1.5 ft)
Projected Storm Surge (3 ft)
Elevation above flooding (>4.5 ft)
Miles
0 5 10 15 20
Kilometers
0 5 10 15 20
N
Data Source: LiDAR and VBMP elevation data

Figure 16


SE Virginia sea level rise scenarios
sea level rise (feet)
8
7
6
5
4
3
2
1
0
1992
2000
2020
2040
2060
2080
2100
Year
highest
high
low
historic


Flooding Depth Simulation - Eastern Shore
Depth (meters)
0.1 - 1.0
1.1 - 2.0
2.1 - 3.0
3.1 - 4.0
4.1 - 5.0
5.1 - 43.0
Storm track
Simulation is for a 100 year storm with Category 3 winds and 2m sea level rise.
N
Miles
0
5
10
15
20
Kilometers
0
5
10
15
20
Data Source: US Army Corps of Engineers, 2012


Flooding Depth Simulation - Southside
Depth (meters)
0.1 - 1.0
1.1 - 2.0
2.1 - 3.0
3.1 - 4.0
4.1 - 5.0
5.1 - 43.0
Storm track
Simulation is for a 100 year storm with Category 3 winds and 2m sea level rise.
N
Miles
0 5 10 15 20
Kilometers
0 5 10 15 20
Data Source: US Army Corps of Engineers, 2012

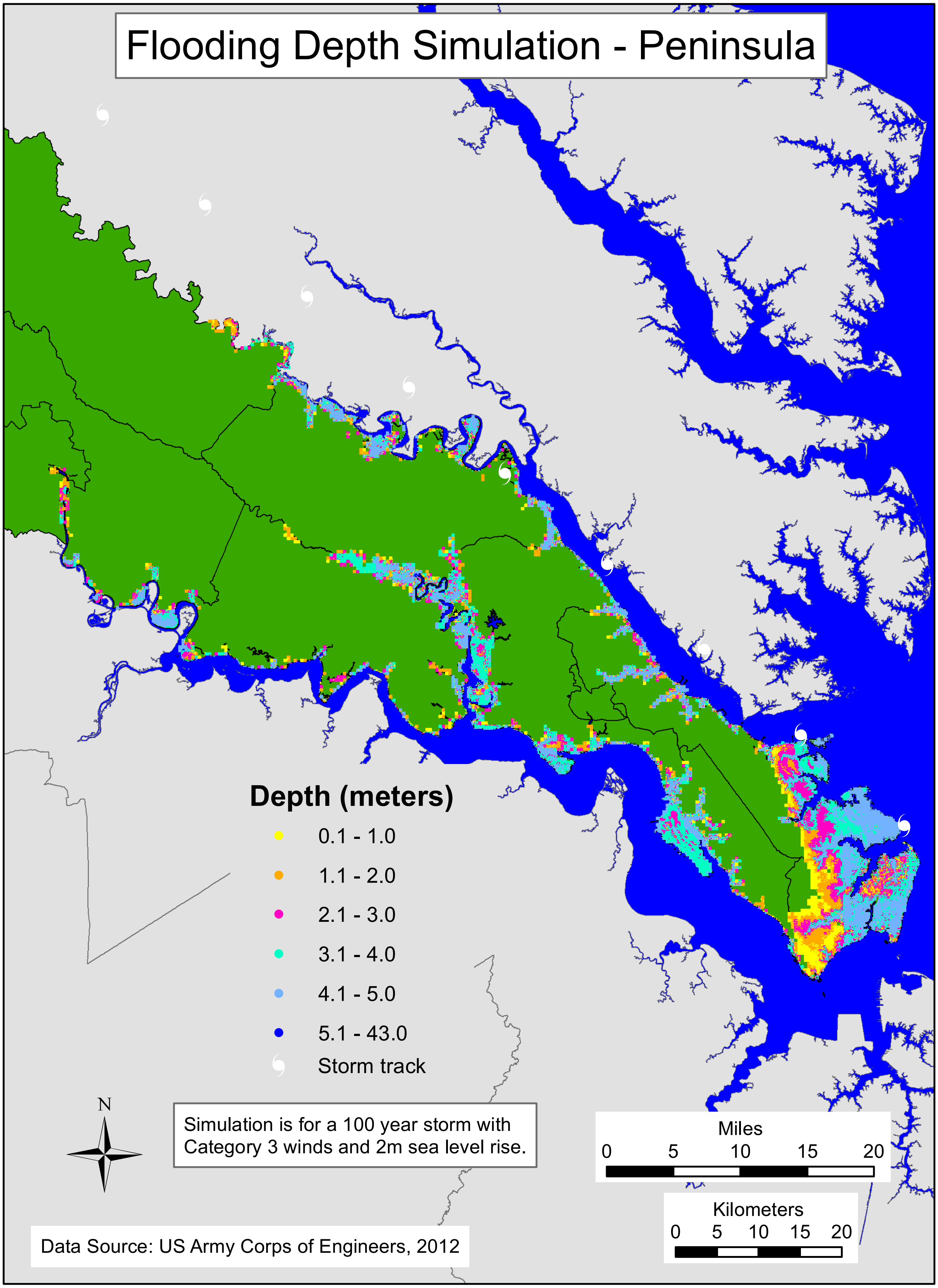
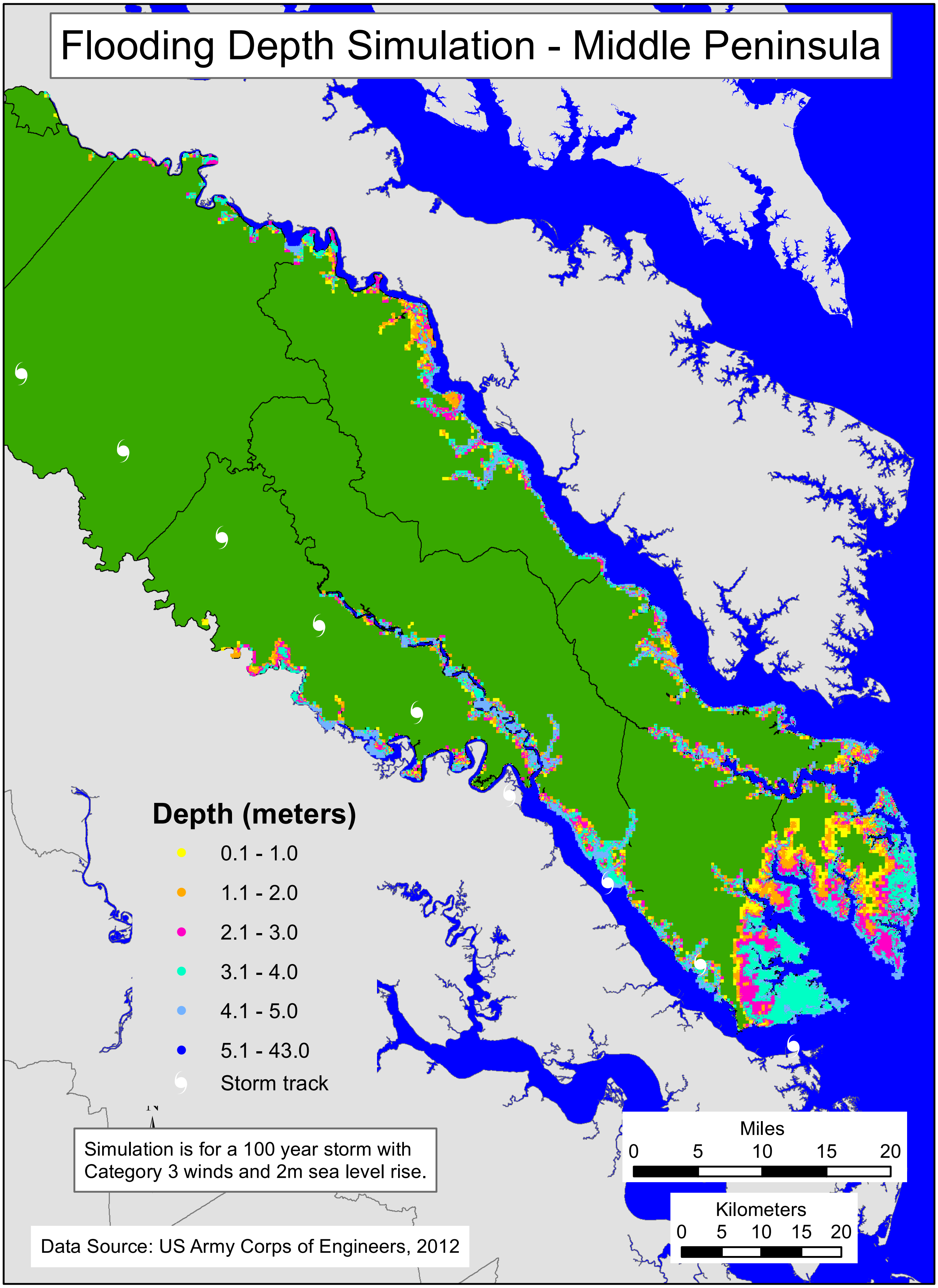
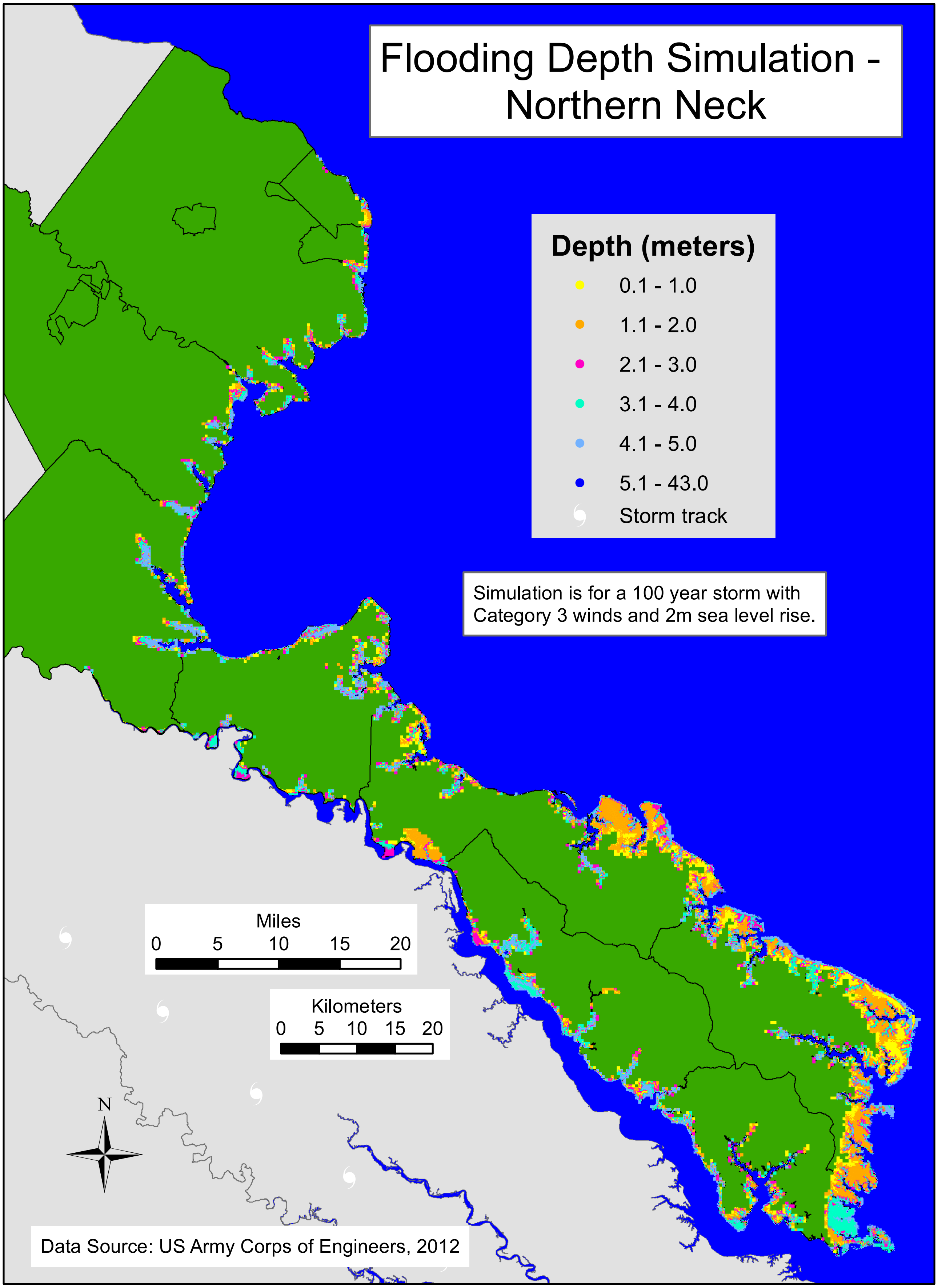

Flooding Depth Simulation - Peninsula
Depth (meters)
0.1 - 1.0
1.1 - 2.0
2.1 - 3.0
3.1 - 4.0
4.1 - 5.0
5.1 - 43.0
Storm track
N
Simulation is for a 100 year storm with Category 3 winds and 2m sea level rise.
Miles
0 5 10 15 20
Kilometers
0 5 10 15 20
Data Source: US Army Corps of Engineers, 2012

Figure 20


Flooding Depth Simulation - Middle Peninsula
Depth (meters)
0.1 - 1.0
1.1 - 2.0
2.1 - 3.0
3.1 - 4.0
4.1 - 5.0
5.1 - 43.0
Storm track
Simulation is for a 100 year storm with Category 3 winds and 2m sea level rise.
Data Source: US Army Corps of Engineers, 2012
Miles
0 5 10 15 20
Kilometers
0 5 10 15 20


Flooding Depth Simulation - Northern Neck
Depth (meters)
0.1 - 1.0
1.1 - 2.0
2.1 - 3.0
3.1 - 4.0
4.1 - 5.0
5.1 - 43.0
Storm track
Simulation is for a 100 year storm with Category 3 winds and 2m sea level rise.
Miles
0 5 10 15 20
Kilometers
0 5 10 15 20
N
Data Source: US Army Corps of Engineers, 2012

Section 4: Background Information

Section 4.1 Background on Flooding in Virginia

Effectively managing flooding requires that flood risk be a consideration at all levels of planning. The challenge for appropriate flood management planning is to reduce risks to people, property and ecosystems associated with existing development while managing or preventing new development in high risk areas (Kim and Karp 2012). This goal can be accomplished through a variety of adaptation strategies. Adaptation strategies fall into 3 main categories: Management/retreat (zoning policies and similar), Accommodation (elevation of roads and buildings, evacuation scenarios, etc.) and Protection (hard and soft engineering strategies).

Most localities have addressed flooding and flood mitigation strategies to some extent, either through zoning policies, floodplain management ordinances, comprehensive plans, floodplain management plans or hazard mitigation plans (which are typically regional plans). Only a few localities have detailed adaptation strategies, while most rely on a more general set of decision making guidance. There is little integration between state and local planning efforts, and apparently no integration between planning efforts in adjacent localities.

Flooding in coastal Virginia

Flooding in coastal Virginia includes precipitation-based flooding and tidal/storm surge flooding. The two types of flooding are driven by different factors, necessitating different adaptation strategies. At the local government level, they are frequently handled by different departments. Precipitation-based flooding is typically handled by the stormwater managers, while storm surge driven flooding is typically handled by emergency managers.

The likelihood of flooding is typically couched in terms of the size of the storm, for example the "100-year storm" is a storm with a 1% chance of occurrence in any given year. What does that mean for property owners? It means that over the lifetime of a typical mortgage (30 years), there is a 26% chance that the property will be flooded. Over a 10 year time span (a reasonable length of home ownership) there is a 10% chance that the property will be flooded. If a property is in the 10-year flood/storm zone, it is highly likely (96%) to be flooded over the lifetime of a typical mortgage.

	Flood/storm size (recurrence)			
Time Period	10-year	25-year	50-year	100-year
1 year	10%	4%	2%	1%
10 years	65%	34%	18%	10%
30 years	96%	71%	45%	26%

The table above shows the probability of a given storm or flood occurring within three different time periods. In one year, there is little chance of any of the floods occurring. However, within 10 years, there is over 50% likelihood that areas in the 10-year floodplain will incur flooding, while only a 10% chance that areas only in the 100-year floodplain will flood. This argues that in areas of low elevation (where each of these zones would be relatively wide), it might be worth mapping several flooding zones, not just the 100-year flood.

Sea Level Rise and flooding

Impacts of sea level rise on coastal communities depend greatly on the elevation of the communities and may include:

1. Exacerbation of storm surges, coastal flooding and resultant loss of property
2. Increased shoreline erosion
3. Saltwater intrusion into drinking water aquifers and septic fields
4. Reduced capacity for some stormwater systems
5. Increased potential for some wastewater system overflows
6. Reduced capacity for stormwater absorption into the groundwater system resulting in longer ponding or increased overland flows
7. Loss of ecosystems, including: tidal freshwater systems, barrier islands, bay islands, coastal dunes and shallow water habitats

Effective planning for sea level rise requires the selection of a planning window and an acceptable rate of sea level rise. Localities plan on a wide range of planning windows, and the appropriate window depends to a certain extent on what infrastructure you are planning for. Roads are relatively easy to raise and convert so a 20-year planning window may be appropriate, while city block or stormwater drainage systems may have a life of 100-years or more, necessitating a longer planning window (Titus 2003).

Storm Frequency and coastal flooding

Reports of large storm events in Virginia date back to the times of the Jamestown Settlement. Since then, they have been documented regularly. On average, a tropical storm, or its remnants, can be expected to impact Virginia yearly, with hurricanes expected once every 2.3 years (Roth and Cobb, unknown year). Understanding trends in land-falling storms is critical to future planning.

Risk Assessment

Location of Recurrent Flooding Problems in Coastal Virginia

Before any planning or consideration of adaptation strategies can occur, the extent of the problem must be determined. Precise elevation data are the most important piece of information for accurately mapping flood potential. A lack of precise elevation data was cited as one of the primary barriers to modeling sea level rise impacts in Virginia (VITA 2008). To that end, localities and other entities in Virginia have been acquiring LiDAR (Light Detection And Ranging) elevation data, accurate to at least 1.2 feet vertical resolution (RMSEz <= 0.60 and NSSDA Accuracy <= 1.2 ft). At this time, LIDAR data is available for many of Virginia's coastal localities.

Elevation data help determine the likelihood of flooding. Other components include the capacity of an area to handle stormwater runoff, the expected amounts of precipitation, tide heights, and storm surge heights.

Precipitation flooding

The Virginia Department of Transportation has a 4 year database of road closures due to flooding on state maintained roads. This database indicates areas at risk from flooding. Some cities and localities keep this information for locality maintained roads, but it must be obtained individually from localities. Areas of recurrent flooding should be targets for management. Flooding in tunnels and near bridges are priority areas, since road closures in these areas can be a hindrance to evacuation and emergency services. However, all road closures due to flooding can be problematic since they can impact economic activities. Coastal Virginia's unique geography (a series of peninsulas connected by bridges and tunnels) frequently means that there are few alternative routes, and that a closure on a main road can result in long and complicated detours.

Coastal flooding

Storm surge maps show the worst case flooding potential for a given area. For Virginia, regional and locality-specific storm surge inundation maps can be found at the Department of Emergency Management (http://www.vaemergency.gov/readyvirginia/stay-informed/hurricane/storm-surge). Maps show four categories of storm surge inundation areas, which use the same language as hurricane categories, although the two are not necessarily linked. The maps are static, providing a generalized storm surge for all storms. The data used to create these maps come from the partially-completed Virginia Hurricane Evacuation Study. The Virginia Hurricane Evacuation Study is a joint effort by VDEM, the Federal Emergency Management Agency, the U.S. Army Corps of Engineers and coastal localities.

Coastal County Snapshots, NOAA Coastal Services Center: Digital Coast

This tool allows assessment of a county's exposure and resilience to flooding, including maps of flood zones and types of infrastructure in the flood zones. It uses a "dashboard" type interface, which summarizes information for the entire county. It can be found at: http://www.csc.noaa.gov/snapshots.

Critical Facilities Flood Exposure tool, NOAA Coastal Services Center: Digital Coast

This tool provides an assessment of a community's critical facilities (schools, fire stations, etc.) and road miles within the FEMA 100-year flood zone (1% annual chance of flooding), using FEMA data for the flood zones and 2000-2001 FEMA HAZUS-MH data (see below) for the facilities. Results are presented both as maps and as tables. It can be found at: http://www.csc.noaa.gov/criticalfacilities.

Hazards U.S. Multi-Hazard (HAZUS-MH), Federal Emergency Management Agency

HAZUs-MH is a nationally applicable, standardized method for estimating losses from natural disasters, including floods. Potential loss estimates include: physical damage to buildings and infrastructure; economic losses including business interruptions; and social impacts (shelter requirements, displaced households, etc.). It maps the limits of high-risk locations, allowing users to visualize the relationship to populations. It can be used to assess the reduction in losses associated with certain adaptation strategies. One of the current limitations of HAZUS-MH is the use of old census data, which makes the analysis underestimate impacts in regions that have recently seen increased growth. However, FEMA is currently updating HAZUS-MH with 2010 census data, which should help alleviate concerns in that area. It can be obtained at: http://www.fema.gov/hazus.

Although some localities have done vulnerability analyses and prioritized areas for adaptation strategy adoption, at this time, there is no comprehensive analysis of coastal vulnerability.

It is important to note that vulnerability is not a static measure, but will change over time. As populations grow and new development continues, the magnitude of consequences from a given flood event will change. In addition, sea level is predicted to rise faster in some parts of Virginia, changing likelihood of flooding in certain areas relative to other areas. Therefore, some prediction of future conditions may help prioritize flooding adaptation efforts.

Predictions of future impacts: Changing precipitation and storm surge

Predictions of changes in precipitation are a complicated subject because they have two components, one is the number of storms that occur and the other is the intensity of the storms. In Virginia, both tropical systems (hurricanes and tropical storms) and extratropical systems (nor'easters and winter storms) can drop significant amounts of precipitation in a short time period.

Both types of storm systems also create storm surge, the primary component of coastal flooding. Storm surge is affected by storm intensity, size, speed, central pressure, angle of approach, shape of the coastline, slope of the offshore area and the complexity of the shoreline (inlets, bays, etc.) This means every storm produces a unique storm surge, making them difficult to model and predict. On the open coast, fast moving storms tend to produce a higher surge, while in bays and sounds, slower storms produce higher surges. In Virginia, nor'easters arguably have a larger storm surge impact because they tend to move slowly, raising water levels over multiple tidal cycles (Davis and Dolan 1993), while hurricanes storm surges create the most flooding when they coincide with high tide. Models suggest that for small to moderate storms, storm surge increases about 30 cm per 10mb pressure, while for large storms, storm surge increases about 40 cm per 10mb pressure (Westerrink et al. 1992).

Trends in both high intensity precipitation and storm surge are complicated by the fact that weather patterns tend to follow cycles. This means that a short dataset may show an increasing or decreasing trend in a weather pattern while a longer dataset may suggest a cyclic pattern. The best information can be gathered from datasets long enough to show multiple cycles. These datasets can be analyzed to see if the cycles themselves appear to be trending up or down. At this time, the understanding of climate controls on changing patterns of storminess and storm surge are limited, reducing confidence in future projections of coastal storm impacts (Burkett and Davidson 2012).

Precipitation

There are no clear trends in historic records of annual rainfall in Virginia, although it is predicted to increase by approximately 6% in Virginia (NCA 2012). Analyses of the 24-hour maximum rainfall frequency indicate an upward trend in coastal Virginia (Bonnin et al. 2006). However, when considering flooding from precipitation, we are more concerned with the number of high intensity rain events, rather than the total annual precipitation. High intensity rain events are typically the ones that lead to flooding. Scientists predict increasing storm intensity (leading to higher per storm precipitation), but the trend varies globally and even within the United States. Between 1948 and 2006, there appears to have been a 25% increase in the frequency of extreme precipitation events in Virginia (Madsen and Figdor 2007). Extending the dataset to 2011, there appears to have been a 33% increase in the frequency of extreme precipitation events, with the 1-year storm now occurring every 9 months (Madsen and Wilcox 2012). As the frequency of extreme events has increased, so has the amount of rain that those storms produce (i.e. the biggest storms are getting bigger), with Virginia seeing an 11% increase in precipitation from the largest storms between 1948 and 2011 (Madsen and Wilcox 2012).

This trend has implications for how we design our water management systems. Storm water drainage systems are typically designed to handle storms of a certain frequency (e.g. a 2-year storm design would handle storm water from a level of precipitation predicted to occur once every 2 years). As storm frequency increases, levels of precipitation that are currently expected only every five years will start to occur every two years. In the Virginia urban areas with combined sewer/stormwater systems, changes in storm intensity could have health and environmental impacts. The U.S. EPA estimates that sewer overflows discharge about one trillion gallons of untreated stormwater containing human sewage every year (EPA 2004). This suggests that new stormwater systems should be designed to handle larger storms than we are currently experiencing.

More research should be done on storm intensity trends in Virginia, so that we can incorporate these trends while planning our infrastructure.

Storm Surge

Nor'easters typically move rapidly to the north and northeast past the coast of Virginia, but under favorable conditions in the general atmospheric circulation they can stall and intensify with little forward motion for a couple of days (Ho et al. 1976). This can generate long lasting storm surges. Research looking directly at storm surge data for the southeastern United States found a significant increasing trend in the number of moderately large storm surges, and 44 of the top 50 storm surge events between 1923 and 2008 were related to tropical storm activity (Grinsted et al. 2012). Although tropical storms tend not to affect the system for as long as extratropical storms they should be considered equally important drivers of flooding. Therefore, it is important to understand changes in both types of storm systems to predict future flood events. However, the body of science addressing these topics is still actively growing, making it difficult to predict future trends at this time.

Tropical storms

Much recent research has been done on the question of whether tropical storm activity is increasing. Hurricane activity in the North Atlantic appears to have been increasing significantly since 1995 (Nyberg et al. 2008) although the mechanism is unclear. Research on tropical storms in the North Atlantic Basin suggest that there is an increase in storm activity in the 20th century, but not necessarily an increase in storm intensity (i.e. proportion of hurricanes to tropical storms remain constant) (Holland and Webster 2007). It is also unresolved whether the increase in tropical storm activity is part of a cycle or is a return to normal hurricane activity, following a period of anomalously low activity in the 1970's.

Tropical storm activity has been linked to sea surface temperatures, El Niño, the North Atlantic Oscillation, and the Atlantic Multidecadal Oscillation among others, all of which are predicted to change over time (as cited in: Grinsted et al. 2012). The frequency of storms differs between warm and cold years, with the warm years having more storm activity, with the strongest effect on the largest storms (Grinsted et al. 2012). Trends suggest that Hurricane Katrina-size storms are twice as frequent in warm years than in cold years (Grinsted et al. 2012). Determining trends in storm activity is hampered by the changing observational and record keeping quality over time. Additionally, an increase in tropical storm activity in the North Atlantic Basin does not necessarily correlate with an increase in storms making landfall in Virginia.

The only research found on tropical storm frequency in Virginia (making landfall) looks at data from the 1800-1990's and suggests that there is a 50-year cycle in the number of tropical storms and hurricanes, with the peak of the cycle lasting about 15 years (Roth and Cobb, unknown year). This concurs with other research suggesting that tropical storm tracks are driven by random fluctuations in atmospheric steering currents, making the data sets too "noisy" (filled with unexplained variations) to detect long-term trends in tropical storm landfall (Landsea 2005; Vecchi and Knutson 2011).

Winter Storms

Most of the storm tides with a 10-yr return period magnitude in coastal Virginia are caused by winter storms (or nor'easters) (Ho et al. 1976) making them a critical driver of the most frequent storm surges (Boon 2012). In the United States, the average loss per storm (in $$) as well as the average storm intensity (measured as numbers of states impacted by a single storm) appears to be increasing (Changnon 2007). In Virginia, winter storm occurrences between 1984 and 2003 were 130% higher than during the previous 20 year time period, potentially related to a southern shift in the Arctic front in the latter time period (Changnon 2007). Research on 50 years of data suggests that the annual frequency of the strongest nor'easters is related to the position of the southerly jet-stream, which varies on an annual basis (Davis and Dolan 1993) and may be cyclical.

Further research is needed to develop and refine storm-tide projections with a given probability of occurrence per month and year in Chesapeake Bay. These projections can be used to estimate the design life of coastal development projects (Boon et al. 2008).

Predictions of future impacts: Sea Level Rise predictions

Regional summary of locality vulnerability to sea level rise

The following information about locality vulnerability is summarized from Titus et al. (2010). It considers vulnerability to inundation by sea level rise over the next century. The area of land considered vulnerable to sea level rise is listed below, ordered from highest to lowest (note: some Tidewater localities were omitted from the study due to the poor resolution of elevation data available at the time of the study.):

Locality	Vulnerable Land (sq. miles)
Accomack	208.0
Northampton	186.4
Virginia Beach	59.8
Chesapeake	25.1
Gloucester	24.0
Mathews	16.9

James City	14.2
King William	14.2
Suffolk	12.5
Poquoson	10.7
York	8.9
Newport News	8.2
Hampton	7.6
Portsmouth	5.3
Norfolk	3.9
Others (collective)*	53.0

*Collective total for Alexandria, Arlington, Caroline, Fairfax, Fredericksburg, King George, Middlesex, Prince William, Spotsylvania, Stafford, Surry, Westmoreland, Chesterfield, Colonial Heights, Falls Church, Franklin City, Hanover, Henrico, Hopewell, Petersburg, Prince George, City of Richmond, Southampton, Sussex, and Williamsburg

Eastern Shore

Several communities in Accomack are considered vulnerable to sea level rise. The natural resource-based agriculture and seafood industries of the region are being impacted as farmlands are experiencing increased inundation and salt comtamination and local seafood industries are experiencing problems created by stormwater runoff and changing coastal dynamics. Accomack has three developed islands, Tangier, Saxis and Chincoteague. In Tangier, approximately 90% of structures are in the 100-year flood plain, the entire island is below the 5-ft contour, and severe shoreline erosion threatens the island. Saxis Island also has severe erosion problems, and the northern portion of the island is very low-lying land. The evacuation route, a causeway through the marsh, is at risk from both potential compaction of the road bed and erosion of the surrounding marshes as well as recurrent floodin and sea level rise. Chincoteague is somewhat less vulnerable to erosion, because it is located in the wave-attenuated Chincoteague Bay, but is vulnerable to recurrent flooding and sea level rise.

Overall the risk to communities in Northampton County is lower than those in Accomack County. This is due in a large part to topography; even the lowest lying town (Town of Cape Charles) is mostly above the 5-ft elevation. However, it is still vulnerable to storm surges and stormwater flooding as drainage ditches become tidal, reducing their capacity to handle stormwater. The lowest lying lands (the barrier islands) are largely undeveloped. The primary impact from sea level rise is expected to be increased shoreline erosion.

Hampton Roads

Hampton Roads includes a large number of localities which vary greatly in both elevation and extent of development. Norfolk, Newport News, Portsmouth, Poquoson and Hampton are highly developed localities, with extensive commercial and industrial development in Norfolk and Newport News. Virginia Beach and Chesapeake have both highly developed and pristine areas. The remaining localities are considered less developed.

Poquoson is considered highly vulnerable to sea level rise due to its elevation, which is entirely below 10-ft. Hampton and Norfolk both have substantial lands below the 10-ft elevation. Both Virginia Beach and Chesapeake have low land, vulnerable to sea level rise, but elevations are higher in their most developed areas. Erosion is a threat, particularly along the oceanfront. The southern shore of the James River has high bluffs along much of its length, buffering the effects of flooding from sea level rise, but still vulnerable to erosion. The northern shore tends to be lower elevation and flooding has been an issue as far up as Jamestown Island.

Middle Peninsula

Gloucester and Mathews counties have most of the low lying land in the Middle Peninsula region, and hence are the most vulnerable to sea level rise. Gloucester County is also the most developed of the Middle Peninsula localities. Most of its low lands are concentrated in a single area, Guinea Neck, where flooding on high tides is common. In Mathews County, low land is dispersed and much of it is undeveloped. However, the northern portion of Mobjack Bay is developed and is vulnerable to sea level rise. Although at relatively high elevations, Middlesex County is bayfront and therefore subject to erosion.

Northern Neck

The Northern Neck has relatively high elevations, with only a few, small areas vulnerable to sea level rise. The lowest community is Lewisetta, Northumberland County. Lewisetta is the only community vulnerable to inundation (in the next 100 years) along the Potomac River. It already experiences some tidal flooding of drainage ditches. However, portions of the Northern Neck are bayfront and subject to erosion.

Rappahannock Area

Most of the Rappahannock area has relatively high elevation, and the major risk in this area is from increased erosion. Some of the lowest lying land in this area is owned by the military and there are recreational beaches which may be vulnerable. Although the localities in this region are not highly developed, there is waterfront development along the rivers.

Northern Virginia

This region is the northern-most area, located along the upper portion of the Potomac River. This setting reduces expected wave energies thereby reducing erosion risk. Much of the

Potomac River shoreline is owned by the National Park Service, and thus, is undeveloped (although the George Washington Memorial Parkway runs along the waterfront). There are two low lying areas prone to flooding, Old Towne, Alexandria and Belle Haven, Fairfax County. These areas are the most vulnerable to sea level rise in the region.

Predictions of future impacts: Impacts of Sea Level Rise on infrastructure

There are three major threats to road systems from rising sea level: alterations to the drainage capacity, flooding of evacuation routes, increased hydraulic pressure on tunnels (Titus 2003). Most roads have some type of drainage system, and in many low-lying areas roads are built at a lower elevation than the surrounding land to drain properties. These drainage systems rely on hydraulic head (from a slope to the waterway) to drain properly. As sea level rises, that slope declines, decreasing the capacity of the drainage system. This can cause stormwater to back up or pond, causing flooding. In areas subject to storm surge flooding, rising sea level may cause the road to flood earlier, potentially cutting off evacuation routes. This requires that evacuation decisions be made earlier and can increase the risk to life. Roads and bridges can be raised as sea level rises, however, tunnels are relatively static constructions. Tunnels are used throughout Southside Virginia to ensure navigability of channels. If tunnel entrances cannot be raised, there is danger of flooding in the tunnels and a higher water table (due to sea level rise) results in increased hydraulic pressure on the tunnel structure (Titus 2003). Sea level rise is also predicted to increase coastal erosion. In coastal Virginia, many roads are adjacent to waterways. Erosion of the shoreline adjacent to these roads puts the roads at risk of collapse, potentially cutting off access to portions of the road.

Navigation is an important consideration for coastal Virginia, where port facilities and boat traffic are a key part of the economic activity. Sea level rise will make channels deeper, allowing access to deeper draft vessels but will also reduce clearance under bridges (Titus 2003). Reduced clearance under bridges is unlikely to be a major problem in coastal Virginia due to the large number of drawbridges. However, sea level rise may be a problem for some port facilities and docks and piers where structures are built at an optimum height relative to sea level (Titus 2003). How big of an issue sea level rise becomes for these structures depends on the relationship between the rate of sea level rise and the expected lifespan of the structures. If the structures require renovations or rebuilding every 20-30 years anyway, new sea level heights could be taken into account at the time.

Other transportation at risk in Virginia includes airports and railroads. Reagan National Airport (located in Arlington, VA) has runways immediately adjacent to tidal waters. They are at risk from storm surge flooding and also at risk from Potomac River flooding. Sea level rise is expected to exacerbate this problem and may shorten the runways (Titus 2003). Railroad lines in coastal Virginia are used both for transportation and freight movement (http://www.trainweb.org/varail/vamap.html). Tracks which cut across marsh, swamp or other low-lying land may be impacted by sea level rise (Titus 2003).

There are a number of utilities at risk from sea level rise in Virginia, including water supply and sewage waste. The average elevation of the Newport News water works service areas is below 30 feet and some of the water intakes have low elevations (Ramaley 2012). For example, the Chickahominy River intake is only 3 ft above current sea level, making it already vulnerable to saltwater intrusion during storm surges. It currently experiences approximately 3 saltwater incursions per year during which the pumps have to be shut down; a 3-foot sea level rise would cause the number of saltwater incursions to more than double, causing the pumps to be shut down more than half the year (Ramaley 2012). Because sewers are mostly gravity driven systems (with occasional pump stations) the outfalls area always at low elevations. This makes the systems extremely vulnerable to changes in sea level, as the capacity of the system will decline if the outfalls are partially or completely submerged ((Heberger et al. 2012). Pump stations are also vuleranble as they rely on electricity to operate and are located at the lowest elevation (Bernas 2012). Inundation from floods (in particular saltwater) could damage pumps and other equipment, and lead to untreated sewage discharges (Heberger et al. 2012).

Available tools

Coastal County Snapshots, NOAA Coastal Services Center: Digital Coast

This tool allows assessment of a county's exposure and resilience to flooding, including maps of flood zones and types of infrastructure in the flood zones. It uses a "dashboard" type interface, which summarizes information for the entire county. It can be found at: http://www.csc.noaa.gov/snapshots.

Critical Facilities Flood Exposure tool, NOAA Coastal Services Center: Digital Coast

This tool provides an assessment of a community's critical facilities (schools, fire stations, etc.) and road miles within the FEMA 100-year flood zone (1% annual chance of flooding), using FEMA data for the flood zones and 2000-2001 FEMA HAZUS-MH data (see below) for the facilities. Results are presented both as maps and as tables. It can be found at: http://www.csc.noaa.gov/criticalfacilities.

Hazards U.S. Multi-Hazard (HAZUS-MH), Federal Emergency Management Agency

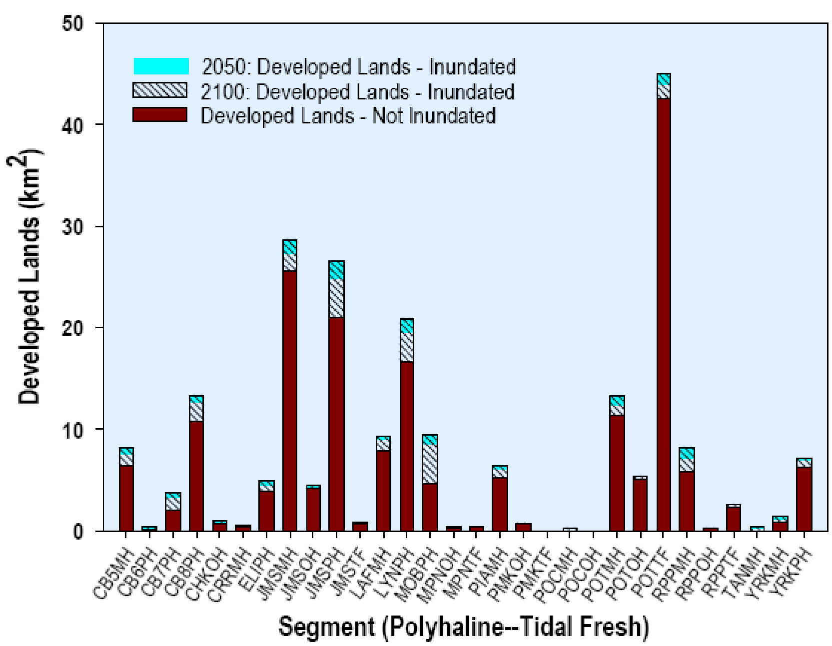
HAZUs-MH is a nationally applicable, standardized method for estimating losses from natural disasters, including floods. Potential loss estimates include: physical damage to buildings and infrastructure, economic losses including business interruptions and social impacts (shelter requirements, displaced households, etc.). It maps the limits of high-risk locations, allowing users to visualize the relationship to populations. It can be used to assess the reduction in losses associated with certain adaptation strategies. One of the current limitations of HAZUS-

MH is the use of old census data, which makes the analysis underestimate impacts in regions that have recently seen increased growth. However, FEMA is currently updating HAZUS-MH with 2010 census data, which should help alleviate concerns in that area. It can be obtained at: http://www.fema.gov/hazus.

Shallow Water Vulnerability model

The Shallow Water Vulnerability model primarily was designed to project broad-scale climate change effects on future distributions of coastal habitats. However, it also shows areas of developed lands that are vulnerable to sea level rise. The model has been run for the entirety of Tidewater Virginia. The final report is at: http://ccrm.vims.edu/research/climate_change/COASTALHABITATS_FinalReport.pdf. Maps of each locality, with current and future projected conditions can be found at: http://ccrm.vims.edu/research/climate_change/append/AppendixV_VulnerableDevelopedLands.pdf.

They report that "Many low-lying segments are in danger of losing high percentages of infrastructure and residences near the coastline in the next 50-100 years (e.g. Mobjack Bay (51%), Tangier Island (99%), and Middle York River (37%))." Most segments are in danger of losing some portion of their developed lands.



Predictions of future impacts: Impacts of Sea Level Rise on natural resources

Many of our coastal resources are critical components of a natural system to reduce coastal flooding impacts. Wide shallow water stretches break waves, reducing their energy before they strike the shore. Beaches and marshes can act in the same way, protecting upland development. Marshes can also absorb floodwaters and excess precipitation, reducing flood duration, decreasing runoff "flashiness" and promoting groundwater recharge. Dunes act as natural levees and help prevent coastal erosion. Natural resources such as these are being engineered throughout the world to reduce impacts of flood events (see Section II for more detail).

The potential value of these natural resources, and the costs associated with re-engineering them once lost, argue for the importance of their preservation. However, these resources are not only under threat from human development, but also from nature. Sea level rise and coastal erosion eat away at the extent of marshes, beaches and shallow water areas. Understanding the future distribution of these resources is critical to maintaining their services.

There are a few tools in existence that can be used to understand coastal processes and the impacts to natural resources in Virginia. Descriptions of these tools follow.

Available tools

Sea Level Affecting Marshes Model (SLAMM)

SLAMM was designed to model the effect of long-term sea level rise on wetland conversion and shoreline modifications. It uses national datasets, such as NOAA tidal data, U.S. Fish & Wildlife Service National Wetland Inventory data, as well as local data, such as erosion rates, local rates of sea level rise and elevation data. Information about SLAMM can be found at: http://www.warrenpinnacle.com/prof/SLAMM . SLAMM-View 2.0 is a web-based application which allows comparisons of maps using different sea-level rise scenarios. It will also create a report summarizing changes under different scenarios. SLAMM-View 2.0 can be found at: http://www.slammview.org.

In general, SLAMM projects are only run for small areas at a time. There are 2 projects on the SLAMM-View site that encompass parts of Virginia. These are 1) Chesapeake Bay Region (including Tangier Sound, the Eastern Shore, parts of the Lower and Middle Peninsula and Southside Hampton Roads; http://www.nwf.org/Global-Warming/Effects-on-Wildlife-and-Habitat/Estuaries-and-Coastal-Wetlands/Chesapeake-Bay.aspx) and 2) Chincoteague, Virginia Site (http://www.slammview.org/slammview2/reports/LDP_ChincoteagueFinal.pdf). The Chesapeake Bay Region model was run with LIDAR where available (however, Virginia LIDAR in 2008 was limited; new and more extensive coverage of LIDAR exists at this time.) Using a 27.2 inch sea level rise over 100 years, they reported the following results:

- Natural lands
    - Undeveloped dry land = Decrease 17-19%
- Marsh
    - Tidal fresh marsh = Decrease 3-59% (highest area of loss: Tangier Sound)
    - Tidal Swamp = Decrease 20-85% (highest areas of loss: Tangier Sound, Southside)
    - Brackish marsh = Decrease 29-95% (highest areas of loss: Tangier Sound, Eastern Shore, Middle Peninsula)
    - Transitional saltmarsh = Increase 133-1400% (highest areas of gain: Middle Peninsula, Southside)
    - Saltmarsh = Increase 162-25500%; Tangier Sound, Middle Peninsula, Southside, and Decrease 87%; Eastern Shore
- Other shoreline
    - Tidal flats = Decrease 47-96% (highest area of loss: Tangier Sound)
    - Estuarine Beach = Increase 53-800%; Tangier Sound, Middle Peninsula, Southside, and Decrease 93%; Eastern Shore
    - Ocean Beach = Decrease 82-79% (only Eastern Shore and Southside have ocean beach)

These results suggest that different resources are at risk throughout Tidewater Virginia. Areas with ocean beaches are at risk of losing large percentages of them, while for most areas, estuarine beaches should be increasing. Swamps, tidal fresh and brackish marshes will decrease as the salt wedge moves up the estuary, with a concurrent increase in transitional and saltmarshes (except on the Eastern Shore). However, this model does not incorporate shoreline hardening projects and creek constrictions (such as low bridges) which can affect the ability of habitats to migrate. Therefore, losses may be greater than predicted by this model.

Shallow Water Vulnerability model

The Shallow Water Vulnerability model projects broad-scale climate change effects on future distributions of coastal habitats. It accounts for changes in sea level rise, temperature and salinity. This model uses different rates of sea level rise from SLAMM, so results for a given year scenario will be different. However, the chosen rates bracket those used in the Chesapeake Bay Region report discussed above. In addition, this model accounts for current areas of hardened shoreline which will prevent landward migration of coastal habitats, and in particular will reduce the future extent of transitional and salt marshes. The goal of the model was to identify areas with potential to support critical coastal habitats in the future, allowing managers to target those areas for conservation and preservation. In addition, this model shows areas of developed lands that are vulnerable to sea level rise. The model has been run for the entirety of Tidewater Virginia. The final report is at:

http://ccrm.vims.edu/research/climate_change/COASTALHABITATS_FinalReport.pdf. Maps of each locality with current and future projected conditions can be found at: http://ccrm.vims.edu/research/climate_change/index.html.

They report that currently 11% of Virginia's tidal shoreline has been hardened and that 27% of riparian lands are currently developed. Shoreline hardening is primarily around areas of higher population. They predict an additional 9-18% shoreline hardening in the next 50-100 years, based on historic rates. By 2100, shallow waters are estimated to decrease by up to 51%, eelgrass habitat to decrease by 65%, estuarine beaches to decrease by 85%, tidal wetlands (marshes and flats) to decrease by 52%, and tidal marshes (a subset of tidal wetlands) to decrease by 38%.

The loss of shallow water habitat is highest in estuarine regions, while shallow water habitat is expected to increase in some freshwater areas as tidal wetland habitat is converted to shallow water areas. The loss of eelgrass beds is similar across all areas where they currently exist. Tidal marsh was reported to decrease in all areas except Mobjack Bay and the Piankatank River under most scenarios.

Chesapeake Bay Shoreline Evolution Reports

Chesapeake Bay Shoreline Evolution Reports look at changes in shoreline position overtime due to erosion, deposition and sediment transportation. These are linked to flooding in two respects. First, as shorelines erode, the water line comes closer to upland structures; flooding happens sooner and more frequently. Second, as sea level rises, shorelines that are susceptible to erosion may experience increased rates of erosion.

Shoreline Evolution Reports are done on a county-wide scale and are available for the following localities: Accomack County, Gloucester County, City of Hampton, Isle of Wight, James City County, King George County, Lancaster County, Mathews County, Middlesex County, City of Newport News, City of Norfolk, Northumberland County, Northampton County, City of Poquoson, City of Portsmouth, Prince William County, Richmond County, City of Suffolk, Surry County, City of Virginia Beach, Westmoreland County, York County. The reports can be found here: http://web.vims.edu/physical/research/shoreline/Publications-Evolution.htm. The reports contain analyses of historic rates of shoreline change as well as some discussion of future predictions (in the next 10-20 years) of shoreline change.

Predictions of future impacts: Predictions of Population and development changes

Currently, approximately a third of Virginia coastal shoreline within 1m above high water is highly developed, with another 22% of lands with intermediate levels of development (Titus et al. 2009). In addition to high populations in many coastal localities, commuters must also be considered. Impassable roads can affect both local and nearby communities.

Shoreline Protection/Hardening
Protecting developed coastal lands from erosion and other coastal hazards is frequently accomplished through shoreline protection or hardening. As development continues, it is expected that shoreline hardening will increase. While shoreline hardening is done to protect property, it prevents natural resources (wetlands, shallow water, etc.) from migrating landward in response to sea level rise. Since these natural systems play a role in reducing the impacts of storm surge and storm waters, continued loss of these systems could negatively impact efforts to protect uplands from floods.

Throughout Virginia, over 75 percent of shorelines are considered at risk of shoreline hardening; this translates to more than 4600 miles of shoreline (Titus et al. 2010). Future shore protection is considered unlikely along most of the Atlantic Coast on the Eastern Shore (where there are large conservation areas) and along the upper reaches of many tributaries and creeks feeding to those tributaries (Titus et al. 2009). Future shore protection is likely near the mouths of creeks and tributaries, on most bayfront lands and throughout much of Hampton Roads (Hampton, Norfolk, Portsmouth, Virginia Beach, Suffolk, Isle of Wight, York and parts of James City County) (Titus et al. 2009). Overall, nearly a third of Hampton Roads shoreline is "Almost certain" to be hardened, while an additional 8 percent is "Likely" to be hardened (Titus et al. 2010).

Coastal Change Analysis Program (C-CAP) Regional Land Cover
The Coastal Change Analysis Program is a national standardized dataset of land cover and land use changes. The dataset was developed through remotely sensed imagery and is mapped with a 30m resolution. The data available for Virginia includes 1996, 2001 and 2006. Data can be downloaded at: http://www.csc.noaa.gov/digitalcoast/data/ccapregional/download, or viewed in the land cover atlas at: http://www.csc.noaa.gov/ccapatlas/. The land cover atlas will also summarize land use data on a locality scale.

In 2006, the areas with the highest percent of developed lands in Tidewater Virginia were primarily located in the Northern Virginia region, although a large percent of the city of Richmond is also developed (http://www.csc.noaa.gov/ccapatlas/). This analysis does not look at population, but rather the percent of available lands within a locality. Therefore, it is likely that smaller localities/cities will have higher percentages of developed lands. Because of the high percentage of land that is already developed, these localities will have a reduced suite of practical adaptation options.

Localities with the largest percent change in developed lands tended to be more rural localities (e.g. Northampton, New Kent, Charles City, Isle of Wight) (http://www.csc.noaa.gov/ccapatlas/). Although overall developed area in these localities was low, the percent increases suggest that they are growing. Localities in this category are in a prime position to incorporate flood and sea level rise in to every stage of planning and they have the flexibility to consider most available adaptation options. With proper planning, these localities may be able to "future-proof" their communities at relatively little cost.

Localities with the percent change in impervious surface greater than 20% include localities with the largest percent change in developed lands and additional localities (e.g. York, James City, Chesterfield, Suffolk) (http://www.csc.noaa.gov/ccapatlas/). This suggests that these localities are also seeing a fair amount of growth. Since increases in impervious surface contribute to increased rates of stormwater runoff, and are therefore related to flooding issues; localities with high increasing impervious area are in a prime position to prevent future flood issues through careful management of stormwater on new development.

Predictions of population changes

The largest populations in Tidewater Virginia are currently found in the following localities (in order of population): Fairfax County, Prince William County, Virginia Beach, Chesterfield County, Henrico County and Norfolk (U.S. Census Bureau 2012). Projections for populations in 2030 are primarily the same, with populations in Chesapeake slightly surpassing those of Norfolk (Virginia Employment Commission 2007). Virginia Beach and Chesapeake are both within the top five localities with the most land vulnerable to sea level rise (see Regional summary of locality vulnerability to sea level rise, above). Localities predicted to see the highest percent growth in population are (in order of highest growth): Suffolk, Spotsylvania County, Prince George County, Stafford County, New Kent County and King George County (Virginia Employment Commission 2007). Gloucester County (the locality with the fifth most land vulnerable to sea level rise (see Regional summary of locality vulnerability to sea level rise, above) is predicted to see a 40% increase in population by 2030.

County Name	2011 Pop (US Census Bureau 2012)	2020 Projection (VEC 2007)	2030 Projection (VEC 2007)	Percent Change by 2030
Accomack County	33,336	42,185	44,249	33%
Alexandria	144,301	153,174	165,572	15%
Arlington County	216,004	212,816	225,163	4%
Caroline County	28,674	36,058	43,662	52%
Chesapeake	225,050	272,381	308,736	37%

Chesterfield County	320,277	372,532	430,266	34%
Essex County	11,205	11,960	12,974	16%
Fairfax	22,549	24,193	25,561	13%
Fairfax County	1,100,692	1,101,144	1,165,525	6%
Falls Church	12,751	11,517	12,100	-5%
Fredericksburg	25,691	25,116	28,518	11%
Gloucester County	36,901	46,013	51,824	40%
Hampton	136,401	144,655	144,650	6%
Hanover County	100,342	124,097	143,959	43%
Henrico County	310,445	339,703	379,041	22%
Hopewell	22,580	23,298	23,993	6%
Isle of Wight County	35,356	44,083	51,629	46%
James City County	68,200	82,781	100,294	47%
King and Queen County	6,997	7,187	7,564	8%
King George County	24,161	30,126	37,365	55%
King William County	15,981	19,119	22,227	39%
Lancaster County	11,282	11,477	11,478	2%
Manassas	39,300	43,654	48,181	23%
Manassas Park	15,332	15,171	17,707	15%
Mathews County	8,962	9,077	9,068	1%
Middlesex County	10,854	12,055	13,181	21%
New Kent County	18,822	23,671	29,496	57%
Newport News city	179,611	182,415	183,372	2%

Norfolk	242,628	237,448	238,927	-2%
Northampton County	12,377	14,932	15,931	29%
Northumberland County	12,461	14,587	15,821	27%
Petersburg	32,326	30,734	30,730	-5%
Poquoson	12,000	12,281	12,782	7%
Portsmouth	95,684	100,429	101,071	6%
Prince George County	36,555	53,061	63,420	73%
Prince William County	419,006	515,235	609,953	46%
Richmond	205,533	187,066	187,066	-9%
Richmond County	9,220	9,900	10,512	14%
Spotsylvania County	124,327	175,402	217,797	75%
Stafford County	132,133	176,710	218,772	66%
Suffolk	84,930	122,482	151,427	78%
Surry County	6,931	7,585	8,156	18%
Virginia Beach city	442,707	470,288	493,095	11%
Westmoreland County	17,595	18,336	19,261	9%
Williamsburg	14,444	13,866	14,159	-2%
York County	66,134	76,376	86,823	31%

Current efforts and on-going actions

Review of locality efforts and plans

In October 2000, the United States Congress passed an amendment to the Stafford Act called the Disaster Mitigation Act of 2000. Based on this act, FEMA wrote regulations requiring local governments to complete a Hazard Mitigation Plan (HMP) in order to continue to receive certain types of disaster assistance (Eastern Shore Hazard Mitigation Planning Committee and the Accomack-Northampton Planning District Commission (2011). Hazard Mitigation Plan--The Eastern Shore of Virginia. http://www.a-npdc.org/hazardplan.pdf). A typical regional hazard mitigation plan includes a hazard analysis, a vulnerability risk assessment, and a capability assessment. A few localities such as Chesapeake and Poquoson have their own plans but for the most part the HMPs are regionally focused.

The IPCC (1990) recommendations for National Coastal Planning include four goals for local governments' coastal planning efforts. First, coastal localities should implement comprehensive coastal zone management plans. Most of the hazard mitigation plans fail to address adverse effects on the coastal zone due to land subsidence and sea level rise. Even far reaching plans such as the City of Hampton's Comprehensive Waterways Management Plan lack a comprehensive study of current and probable future tidal flooding impacts in the city's flood prone areas. Still comprehensive coastal management plans need to extend beyond the borders of one locality and look at an entire watershed or region. In addition to the HMP, many localities have comprehensive planning, disaster recovery plans, emergency operations plans, floodplain management plans, stormwater management plans, green infrastructure plans, open space management plans, and water supply plans, which hopefully will further the mitigation goals.

Second, the IPCC recommends local governments identify coastal areas at risk. All of the hazard mitigation plans do a thorough job identifying areas at risk, inventorying structures at risk and recognizing changing coastal hazards. IPCC also recommends localities should ensure that coastal development does not increase vulnerability to flooding. The National Flood Insurance Program's main goal is to reduce flood damages and protect people and their property from unwise floodplain development through floodplain management regulations, which is reiterated in every hazard mitigation plan but some localities have passed more conservative regulations to restrict new development in vulnerable areas. Finally, according to IPCC's recommendations, emergency preparedness and coastal zone response mechanisms should be reviewed and strengthened. The hazard mitigation plans definitely focus on emergency preparedness mechanisms by addressing emergency alert systems, evacuation protocols and operations plans.

The hazard mitigation plans predominately focus on risk assessments, which usually includes an inventory of critical facilities, chronology of storm hazard events, and repetitive loss estimates by locality but the exact methodology tends to vary by region. A typical risk assessment, such as in Poquoson, evaluates the probability of occurrence, location, extent, magnitude and likelihood of a hazard for a given community. Whereas a vulnerability assessment estimates the extent of injury and damage that may result from a hazard event of a given intensity. Vulnerability assessments adjust for the fact that a hazard event that occurs in a highly populated area will have a much higher impact than a comparable event that occurs in a remote, unpopulated area. Chesapeake performed the vulnerability assessment in two ways – first by estimating the potential impacts on structures in a given planning area in the event of a 100 year flood and then by estimating the per capita planning area damage. The Eastern Shore prioritized hazards based on the probability of past events, number of structures damaged, primary impacts, secondary impacts and potential mitigation options. Whereas the George Washington Regional Comission completed community specific and regional hazard analyses as well as community specific and regional vulnerability assessments. The Middle Peninsula created a series of maps for each locality showing the location of structures, on-site sewage disposal systems, census block groups data and evacuation routes in Flood Zone A and in Flood Zone AE for the 100-year floodplain as well as the 500-year floodplain.

All of the regions except the Eastern Shore, which calculated the loss estimation in-house, utilized FEMA's loss estimating software, Hazards U.S. Multi-Hazard (HAZUS-MH) for their vulnerability assessment. The George Washington Region lists and maps all the critical facilities in the 100-year floodplain for each locality. While very few plans show a digital overlay of the FEMA floodplain maps in relation to critical facilities, most quantified repetitive loss properties using the HAZUS flood model total annualized loss. HAZUS-MH was used to perform an elevated structures analysis for Poquoson which found a total of $64,228,000 dollars could be saved during a 100-year coastal flood as a result of elevating 567 structures; a 16-percent reduction in loss (City of Poquoson and AMEC Earth and Environmental (2009). City of Poquoson Multi-Hazard Mitigation Plan. http://www.ci.poquoson.va.us/sites/default/files/City%20of%20Poquoson%20FINAL%20to%20FEMA%20RIII%20091409.pdf). The problem with HAZUS-MH is that it uses census data from 2000 which likely underestimates the amount of development in the coastal zone for all localities.

In addition to HAZUS, Southside Hampton Roads and Northern Virginia used a qualitative assessment based on a Priority Risk Index tool to measure the degree of risk for identified hazards in local communities. For Northern Virginia and Northern Neck, the Virginia Tech Center for Geospatial Information and Technology and VDEM developed a standardized methodology to compare different hazards' risk on a jurisdictional basis including parameters such as history of occurrence, vulnerability of people in the hazard area, probable geographic extent of the hazard area, and historical impact in terms of human lives and property. Northern Virginia overlaid digital flood data with local parcel data and used it to perform a GIS-based risk assessment for critical facilities. In the future, all the localities that have GIS data layers such as digital flood data, tax parcel records and building footprint data, could begin to estimate total building exposure in the 100-year floodplain.

Limitations

Virginia is still in the process of acquiring comprehensive light detection and ranging (LIDAR) data. These data will allow for more precise estimations of elevation, therefore improving the predictive capability of models. All of Coastal Virginia could greatly benefit from the availability of LiDAR elevation data because LiDAR data will provide the resolution needed to map and analyze storm water flooding issues in more detail.

In general structural-loss estimates are based on best available data such as tax parcel, structural characteristics of facilities, hazardous storage classifications, E911 building structures, digital tax maps, census block information and construction type. but since this information varies by locality, it limits the effectiveness of the regional hazard assessments. Each locality provided local critical facility and infrastructure data in some format but a comprehensive inventory consistent across jurisdictions does not exist because there is not a universally accepted definition of what constitutes a critical facility. Structural inventories with elevation, high water marks and flood frequency data from all the localities could be very helpful in preparing more accurate cost-benefit analyses but there continues to be a data gap in many of the regions. Some plans underestimated the losses by treating all structures equally while some plans over estimate losses, by not taking into account which structures have been elevated or have had flood-proofing measures installed.

The Commonwealth of Virginia's 2010 hazard mitigation plan ranking was based on the National Climate Data Center (NCDC) database. A few regions used this same framework to establish a common system for evaluating and ranking hazards. The majority of the data on historical weather-related events is from the Storm Event Database available from NCDC, whereas the numerical damage data and qualitative analysis are based on the collection of information reported by local offices of the NWS, as well as other local, State and Federal agencies. Uncertainties are inherent in any loss estimation methodology, arising in part from incomplete scientific knowledge concerning specific hazards and their effects on the built environments, as well as incomplete datasets, approximations and simplifications of datasets and relatively short time periods of records. As a result, inadequate information poses a problem for developing accurate loss estimates.

Hazards

Coastal flooding is the predominate threat throughout Tidewater Virginia; all regions stated flooding as a top priority. The majority of the flooding in all the regions is tidal flooding, which primarily occurs in conjunction with coastal storms such as hurricanes, northeasters, and tropical storms but many regions are also subject to inland or riverine flooding. Most HMPs distinguish between flooding caused by precipitation and coastal flooding hazards associated with hurricanes, tropical storms and nor'easters. Some plans such as Chesapeake, Richmond-

Crater and Poquoson analyze wind events (including tornadoes, hurricanes, nor'easters) as a separate hazard. Poquoson listed all the historical tropical storms and differentiated whether the historic event was caused by flooding, high winds or both. Shoreline erosion (which is driven by a number of natural influences such as sea level rise and land subsidence, large storms, storm surge, and flooding) is typically incorporated into the flood section.

Not all plans identified sea level rise as a hazard but certain regions such as Southside Hampton Roads, Northern Virginia, and Middle Peninsula have more information on the topic and explain why the hazard will pose a greater threat in the future. For the plans that acknowledge sea level rise, it is generally accepted that increased flooding damage will result from sea level rise.

After the Virginia Department of Emergency Management (VDEM) created new hurricane storm surge maps for the coast of Virginia in 2007, the Northern Neck PDC created the Northern Neck Regional Coastal Storm Surge Hazard Assessment to quantify the monetary impact to real estate improvements of a category 1 hurricane storm surge throughout a county's coastline. There are many assumptions inherent in this analysis that have mostly to do with limitations with the GIS datasets but it is still helpful in identifying storm surge problem areas for Northern Neck localities. The analysis looked at the total assessed value of all improvements that have at least some area within the storm surge area as well as the percentage of the total value for only those portions of buildings within the storm surge area.

Middle Peninsula Storm Surge Hazard Maps were developed by the U.S. Corp of Engineers in conjunction with the VDEM as part of their 2008 Virginia Hurricane Evacuation Study. VDOT and County officials in the Middle Peninsula region identified specific flood prone roads in the 100-year and 500-year floodplain maps. The storm surge maps overlaid the evacuation route with tidal storm surge impacts for a few coastal counties in the Middle Peninsula. The data only reflect salt water flooding even though freshwater flooding may also occur with hurricane events from heavy rainfall runoff. The storm surge hazard maps identify areas that can be expected as the result of Category 1, 2, 3 and 4 hurricanes, based on the Sea, Lake and Overland Surge from Hurricanes (SLOSH) model. The SLOSH model is best used for defining the “worst case scenario” of potential maximum surge for particular locations as opposed to the regional impact of one singular storm surge event (Salter’s Creek Consulting (2011). Southside Hampton Roads Hazard Mitigation Plan. http://remtac.org/LinkClick.aspx?fileticket=Fdy2DLERy44%3d&tabid=346&mid=1709).

Capability and Mitigation

A few regions completed a capability assessment of each jurisdiction's fiscal, administrative, and technical capabilities. A review of existing plans, policies, programs, ordinances and staff expertise was completed to identify existing gaps within government activities that could exacerbate a locality's vulnerability or hinder its ability to implement the hazard mitigation actions. By only looking at the local level, it becomes difficult to highlight the gaps that exist in the region as a whole but it tends to be easier for communities to review locality specific strategies and determine their own mitigation activities than it is to implement multi-jurisdictional planning. Many localities developed individual actions plans without holistically developing cross-jurisdictional mitigation goals. Several of the plans such as George Washington, Northern Virginia and Southside include the same list of mitigation techniques, sorted by prevention, property protection, natural resource protection, structural projects, emergency services and public education, without customizing the strategies to be specific to the region. Both regions included the individual locality action plans and identified several themes but only had a few overarching general goals.

Most of the HMPs generally aim to identify existing flood-prone structures that may benefit from mitigation measures and encourage the incorporation of such techniques into new and pre-existing development. The plans also support mitigation of priority flood-prone structures using FEMA HMA programs but in general different regions prioritized mitigation strategies in different ways and had different geographic scales. The City of Poquoson Municipal Code includes the Floodplain Management Overlay District which prohibits new manufactured homes in the Special Flood Hazard Areas. The ordinance requires the minimum height of the lowest floor of any new or substantially improved buildings built in the floodplain to be at least one foot above BFE (City of Poquoson and AMEC Earth and Environmental (2009)). Poquoson's development standards require all new roads to be built at least 4.5 feet above mean sea level, all new pump stations to be built above the 100-year flood elevation and all new utilities below the 100-year flood elevation are required to have watertight manhole lids.

Planning District Efforts

Under a grant from the Virginia Coastal Zone Management Program, several of the Planning District Commissions (PDC) have looked at the impacts of climate change on their localities. One of the impacts considered is sea level rise. These reports are geospatially explicit and provide local information about potential sea level rise impacts. Links to the reports can be found on the Virginia Coastal Zone Management Program's website, at: http://www.deq.virginia.gov/Programs/CoastalZoneManagement/CZMIssuesInitiatives/ClimateChange.aspx

Section 4.2 GIS methodology

Existing state-wide models of elevation (or topographic) surfaces use DEMs (Digital Elevation Models) developed from the Virginia Base Mapping Program (VBMP). DEMs have less vertical and horizontal resolution than newer techniques, which can result in over-estimating areas of potential inundation. More accurate LiDAR (Light Detection and Ranging) data are still being collected for portions of the Tidewater Virginia region. Therefore, we built a new surface for Tidewater Virginia, consisting of LiDAR data where available and DEMs in the few localities where LiDAR are not yet available. The surface we created has the most recent, highest resolution elevation data currently existing. Onto the newly created surface, we projected a sea level rise of 1.5 feet and a storm surge of 4.5 feet (3 feet above sea level rise, considered a reasonable surge for a large, but typical storm).

Figure 10 shows the distribution of data type by locality. Most of the LiDAR data layers came referenced to North American Vertical Datum 1988 (NAVD88), a standard geodetic vertical datum. Any data layers that were in a different vertical datum were converted to NAVD88 before using. A geographic information system (ArcGIS) was used to combine the data layers into seamless elevation surfaces for five regions: Northern Neck, Middle Peninsula, Peninsula, Southside, and Eastern Shore. These highly detailed surfaces resulted in very large files, between 50 and 150 gigabytes for each dataset. This meant processing times were considerable, as much as 24 hours for each step in the procedure, with a minimum of 16 steps per region.

In order to determine what land areas would flood, the elevation surfaces needed to be referenced to a tidal datum. We chose to reference our surfaces to present mean higher high water (MHHW), so our sea level rise and storm surge values represent water levels above this reference. Using this adjustment, sea level rise is calculated from the highest point typically inundated daily. Adjusting from NAVD88 to MHHW involved using software developed by NOAA called VDatum, whose primary purpose is to convert elevation data between different vertical reference systems. The basic concept involves many elevation points along the shoreline being converted from NAVD88 to MHHW, and then extrapolated inland. The adjusted surface used in this analysis was provided by NOAA's Coastal Services Center. This adjusted surface was subtracted from the NAVD88-referenced elevation surface to create a MHHW-referenced elevation surface.

Using the MHHW-referenced elevation surfaces for each region, all elevations less than or equal to 1.5 feet were extracted to represent the area flooded by this potential sea level rise. Next all elevations greater than 1.5 and less than or equal to 4.5 feet were extracted to represent the area flooded by a 3 foot storm surge on top of the 1.5 foot sea level rise. The areal extents of these two scenarios were overlain on three different elements: land use, wetlands, and roads. The land use layer is from the Coastal Change Analysis Program (CCAP) and was grouped into three major categories for this study: developed, agricultural, and forested. The wetlands layer is from the National Wetlands Inventory (NWI), and the roads layer is from TIGER/Line data from the US Census Bureau. The land use, wetlands, and roads data were apportioned to each coastal locality for both scenarios, and are presented in the Table of Coastal Vulerability to Predicted Sea Level Rise and Storm Surge (see Section I).

Section 4.3 Sea Level Rise in Virginia

From: Hershner, C. and M. Mitchell. 2012. Rising Tides, Sinking Coast: How Virginia's coastal communities can adapt to surging sea levels. Virginia Issues and Answers 17(2):22-27.

Sea level rise in Virginia is a documented fact. Water levels in Hampton Roads have risen more than one foot over the past 80 years. The causes of this rise are well understood and current analyses suggest the rate of rise is increasing (Boon 2012; Ezer & Corlett 2012; Sallenger et al. 2012). The consequence of higher sea level is evident in the increased frequency of significant flooding events in coastal Virginia communities. In the face of increasing risks, adaptation is essential, and need to act is immediate.

Sea level in Virginia is affected by three general factors: the volume of water in the ocean, the elevation of the Virginia shoreline, and the movement of water in the ocean. All three things have been changing in recent times. The result for coastal Virginia has been a long-term and recently accelerating rise in the level of tidal waters in the Commonwealth.

The first factor – the volume of water in the ocean - is simple to understand. Increasing the volume of water in the ocean will unavoidably raise the water level at the shoreline. Two things are currently causing the volume of ocean water to increase. Glaciers, ice caps, and ice sheets in Greenland and Antarctica are melting, adding water that was stored on land surfaces to the ocean basins. At the same time, the water in the oceans is warming causing it to expand. Together these processes are believed to have added over half a foot to ocean levels in the past century. Both of these processes have increased recently, and now are adding to the oceans' volume at about twice the former rate. Depending on how much the earth's atmosphere warms, these rates are anticipated to increase even further.

The second factor – the elevation of Virginia's shoreline – is surprising for many people living here. It turns out that Virginia's coast is sinking. Again there are a number of things causing this. The primary cause is the continuing adjustment of the earth's crust to the melting of glaciers from the last ice age. About 25,000 years ago, huge ice sheets extended from the North Pole all the way south to what is now northern Pennsylvania and New Jersey. These ice sheets were estimated to be over a mile thick, exerting tremendous pressure on the earth's crust, actually causing it to bulge up in the region of Virginia. As the ice sheet melted and retreated northward, that pressure was released and the earth's crust has been slowly readjusting ever since. The result is a slow sinking of the mid-Atlantic coastal region.

In addition to the general subsidence of the region, there are two other more local processes that are adding to the general sinking of our land area. The first is the continuing compaction of the materials that were blasted apart when a meteor struck the area near Cape Charles about 35 million years ago. Materials in the impact crater, which extends from the mouth of the Rappahannock River to Virginia Beach, continue to settle and compact to this day. The other process is even more localized, but adds significantly to the slow sinking of land in a number of areas. This is pumping of large volumes of deep groundwater. Two examples of the impact can be found in West Point and Franklin where paper mills extract groundwater as part of their manufacturing process. Much like the pumping of oil along the Gulf Coast, removal of liquids from deep in the earth causes the overlying areas to settle as sediments compact.

Together the responses to retreat of the glaciers, the meteor impact, and groundwater pumping, have caused subsidence in our region that almost doubles the effect of increasing ocean volume. At present sea level in southeastern Virginia is rising at a rate slightly greater than 1.5 feet per century, and it appears to be accelerating.

The third factor – the movement of water in the ocean – may explain some of the increasing rate of rise. As anyone who has spent time at sea knows, there are many large currents that circulate ocean waters around the globe. Some are driven by winds; others are driven by the cooling of sea water near the poles. Just as warming sea water causes it to expand, cooling causes it to contract and become denser. When surface waters near the poles are cooled they tend to sink and flow south, being replaced by warmer waters from the tropics that is drawn north to replace the sinking polar waters. In the north Atlantic this process drives a major circulation pattern scientists call the Atlantic Meridional Overturning Circulation, or AMOC for short. It is perhaps better known locally as the Gulf Stream. One of the things we have learned studying the world's oceans, is that moving water is affected by the earth's rotation. In the northern hemisphere it is diverted slightly to the right, a fact that causes the typical counter clockwise spiral of water moving down a drain. At the very large scale of the Atlantic Ocean, the northward flow of the AMOC, tends to move water away from the U.S. coast (to the right of the northward flowing surface water). Some of the recent rapid rise in local sea levels may be explained by a slowing of the Gulf Stream as the polar region warms. Slower moving water means less pressure to move water away from the coast, and the result is higher water levels here in the mid-Atlantic.

Looking forward, sea level rise is anticipated to continue. We do not anticipate the subsidence rate for the Virginia coastal region will change, so it should remain a constant factor. Current understandings of global atmospheric processes indicate temperatures will continue to rise for at least the rest of the century. The uncertainty that exists is in how high they may go. At a minimum this will sustain current trends in glacier and ice cap melting, as well as thermal expansion of ocean water. Indeed several independent recent analyses have detected acceleration in the rate of sea level rise from the mid-Atlantic to New England. What all this means is that we will see higher sea levels in the future, they will probably rise more rapidly than they have in the last century, and potentially they will rise much more rapidly.

The long range, end-of-the-century forecasts have significant uncertainty, with projections for our region of a sea level rise anywhere between 1.5 and 7.5 feet. These projections are based on the U.S. National Climate Assessment which has generated four scenarios of global sea level for its 2013 report to Congress (Parris et al. 2012). By adding what we know about land subsidence in the Virginia coastal region, we are able to develop regional scenarios to inform planning and adaptation efforts. The scenarios are shown in Figure 16. They all begin with the documented sea levels in 1992. The lowest curve (labeled "current") represents a simple extrapolation of the historic average rate of rise. The top curve (labeled "highest") represents the physically possible circumstance that would occur with rapid melting of all the earth's glaciers and ice caps, essentially a worst case scenario. The middle two curves are based on models of the global system's response to either significant efforts by the world's nations to reduce greenhouse gases (the "low" curve), or business as usual (the "high" curve). Recent trends in Virginia sea levels suggest we are on the "high" curve. Whether this rate of increase will be sustained is uncertain, but it does inform thinking about the Commonwealth's future.

Given what is currently known, it seems reasonable to anticipate that sea level in Virginia will be 1.5 feet higher than it is presently sometime in the next 20 to 50 years. This is a time frame that makes consideration of potential impacts relevant for home mortgages and most public infrastructure (e.g. roads, schools, fire stations).

Section 4.4 Storm surge inundation modeling

Data and analysis for the following maps are courtesy of the Strategic Environmental Research and Development Program's (SERDP) RC-1701 project led by Ms. Kelly Burks-Copes and Dr. Edmond J. Russo (US Army Engineer Research and Development Center (ERDC-EL), Vicksburg, MS). Storm analyses conducted by Dr. Jane Smith (ERDC-CHL) and Dr. Jay Ratcliff (ERDC-CHL). Funding for this effort was jointly provided by the SERDP program (http://www.serdp.org/) and ERDC (http://www.erdc.usace.army.mil/) in support of FEMA.

As part of a project to develop a model that quantitatively evaluates risks to critical military assets (i.e., infrastructure) and mission capabilities threatened by a range of SLR, tidal fluctuation, and storm surge-frequency hazards, ERDC carried out extensive modeling efforts for the coastline of Virginia.   To see more about the project, go to: http://www.serdp.org/Program-Areas/Resource-Conservation-and-Climate-Change/Climate-Change/Vulnerability-and-Impact-Assessment/RC-1701/RC-1701/(language)/eng-US

The project resulted in detailed sea level rise and storm surge models, including 5 sea level rise scenarios (0.0m, 0.5m, 1.0m, 1.5m, 2.0m) and 17 tropical storms, 3 nor'easters and the 1-year and 10-year storms.   In total, they intensively assessed risks for 25 scenarios (SLR X Storm intensity = 1 scenario; for 5 SLR ranges and 5 storm intensities – 100-yr, 5-yr, 10-yr, 1-yr, and 1 nor'easter). Below we present maps (Figures 17, 18, 19, 20, 21) using data from one of the storms, placed on a 2m sea level rise.

For the maps below, the models used ADCIRC's unstructured mesh with varying grid cell sizes ranging from 30m to 4 km (smaller as they move inland) and FEMA's new topo/bathy surface(downscaled to 10m). It does not model the effects of hydrologic connectivity to groundwater and flooding (although this was done on one military installation and the capability exists within the models).

For more details, please see the report:
Copes, K. A., and E. J. Russo. (In press). *Risk Quantification for Sustaining Coastal Military Installation Assets and Mission Capabilities*, *Final Technical Report*. Prepared by the U.S. Army Engineer Research and Development Center (ERDC), Environmental Laboratory (EL), Vicksburg, MS for the Strategic Environmental Research and Development Program (SERDP) under project #RC-1701.

Section 4.5 Emergency Manager Survey Responses

We obtained responses to our questions from 19 localities and 25 participants (note that City of Chesapeake, Suffolk, and Virginia Beach had more than one respondent representing their locality). Localities are list below; the ones with asterisks had at least one participant who responded to the survey, the number of respondents is in parentheses. Responses are graphed below. Response should be considered the viewpoint of the respondent, since respondents from the same localities did not always respond in the same way. Responses from the *Northern Neck and Middle Peninsula Regional Emergency Manager Meeting* (NN/MP) and the *Regional Emergency Management Technical Advisory Committee Meeting* (REMTAC) are included in "ALL" responses, but have also been graphed separately to highlight any operational differences between the approaches of predominantly low development localities (NN/MP) with predominantly high development localities (REMTAC).

Meetings attended:

Northern Neck and Middle Peninsula Regional Emergency Manager Meeting

Mathews

* Middlesex (2)

King and Queen County

King William County

* Essex County (1)

* Lancaster County (1)

* Richmond County (1)

Westmoreland County

Northumberland County

Gloucester

* The Town of West Point (1)

Regional Emergency Management Technical Advisory Committee

* Hampton City (1)

* Norfolk City (1)

* Chesapeake City (2)

* Suffolk (3)

* Newport News City (1)

* Virginia Beach City (2)

* Isle of Wight County (1)

* Portsmouth City (1)

* Poquoson City (1)

* City of Williamsburg (1)

Franklin City

Suffolk City

Gloucester

James City

Southampton

Surry

York

Other regional groups, surveys mailed or emailed:

Northern Virginia Emergency Managers

* Alexandria City (1)

Arlington County

Prince William County

Fairfax County

Stafford County

Manassas City

Manassas Park City

Rappahannock River Area Emergency Managers

* King George County (1)

* Spotsylvania County (1)

Caroline County

Fredericksburg City

Parts of Stafford

Eastern Shore Emergency Managers

* Accomack County (1)

Chincoteague Town

Northampton County

Region 1 Emergency Managers

Charles City County

Chesterfield County

Hanover County

Henrico County

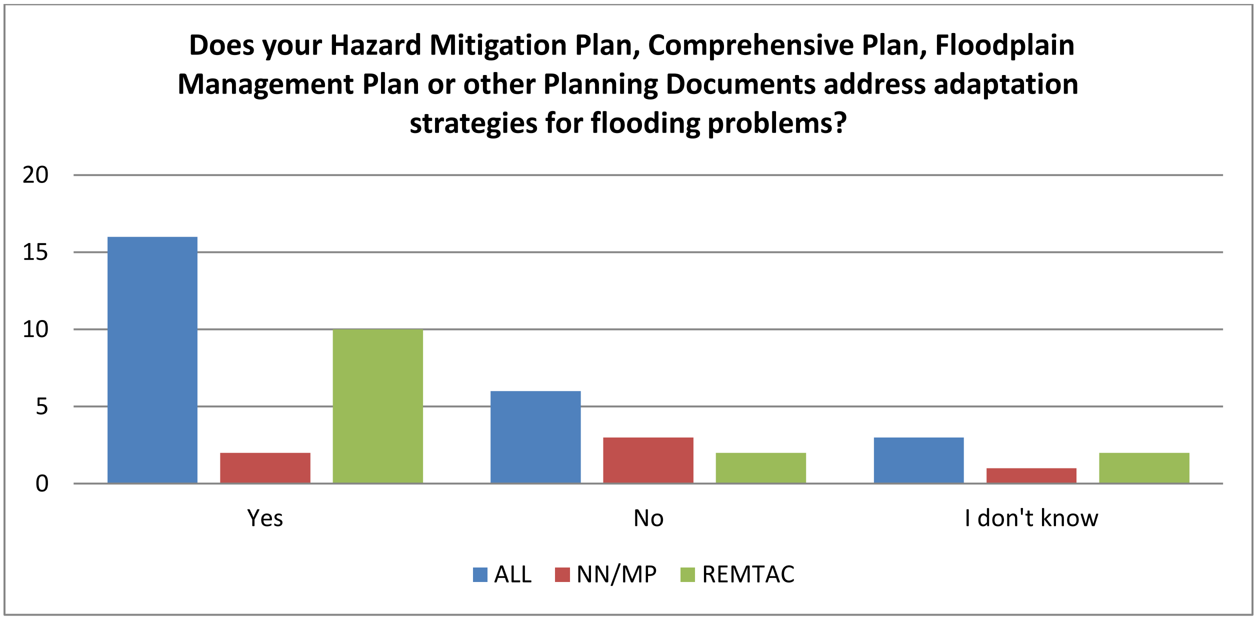
Hopewell City

New Kent County

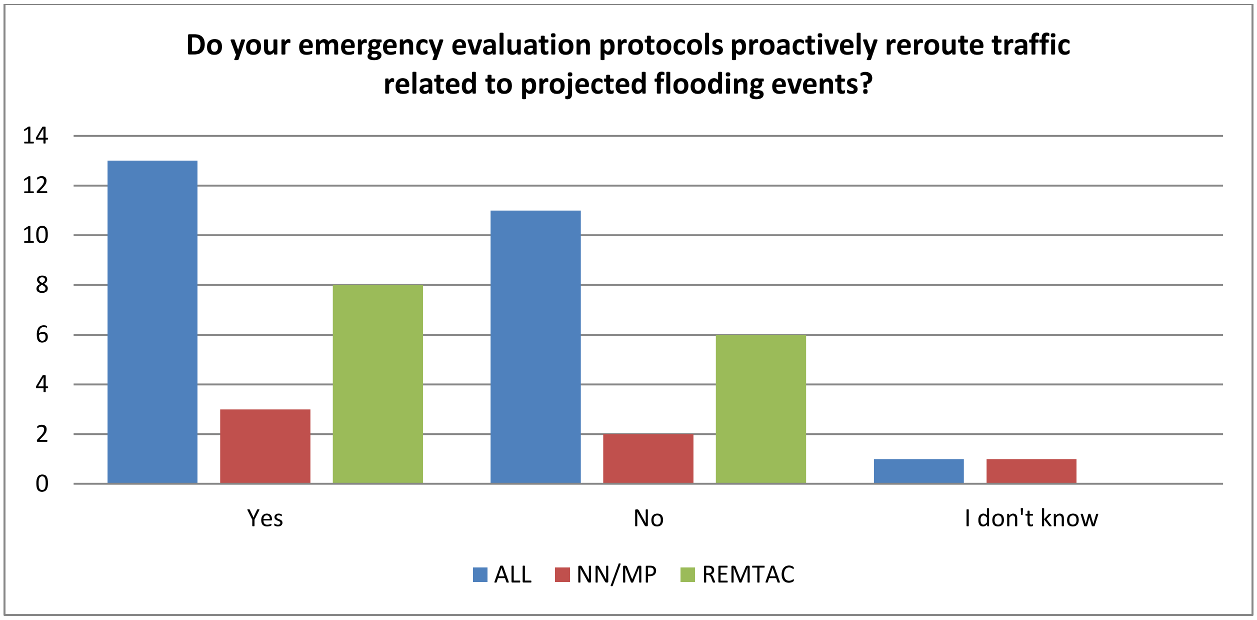
Prince George County

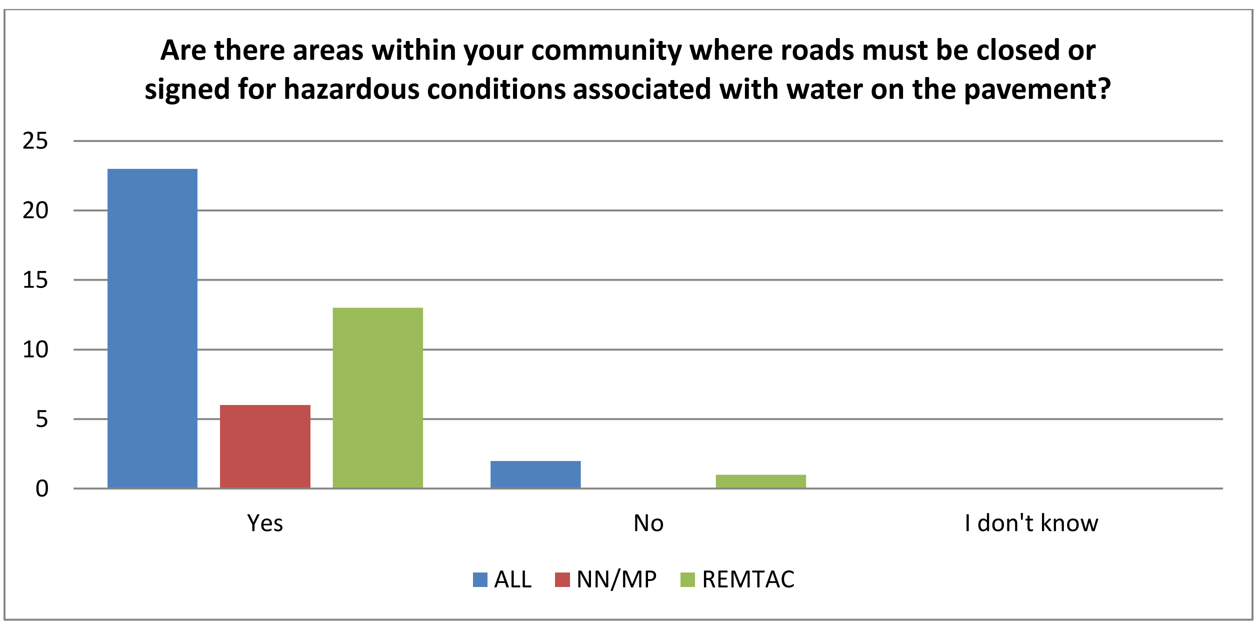
Richmond City

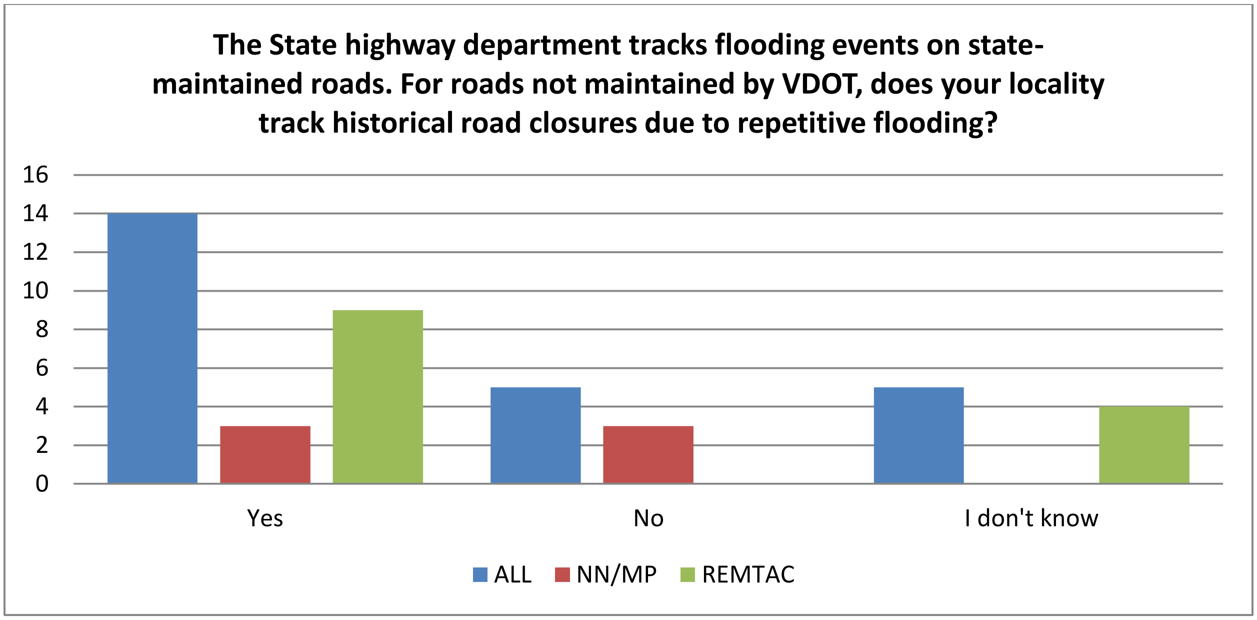
Survey Responses

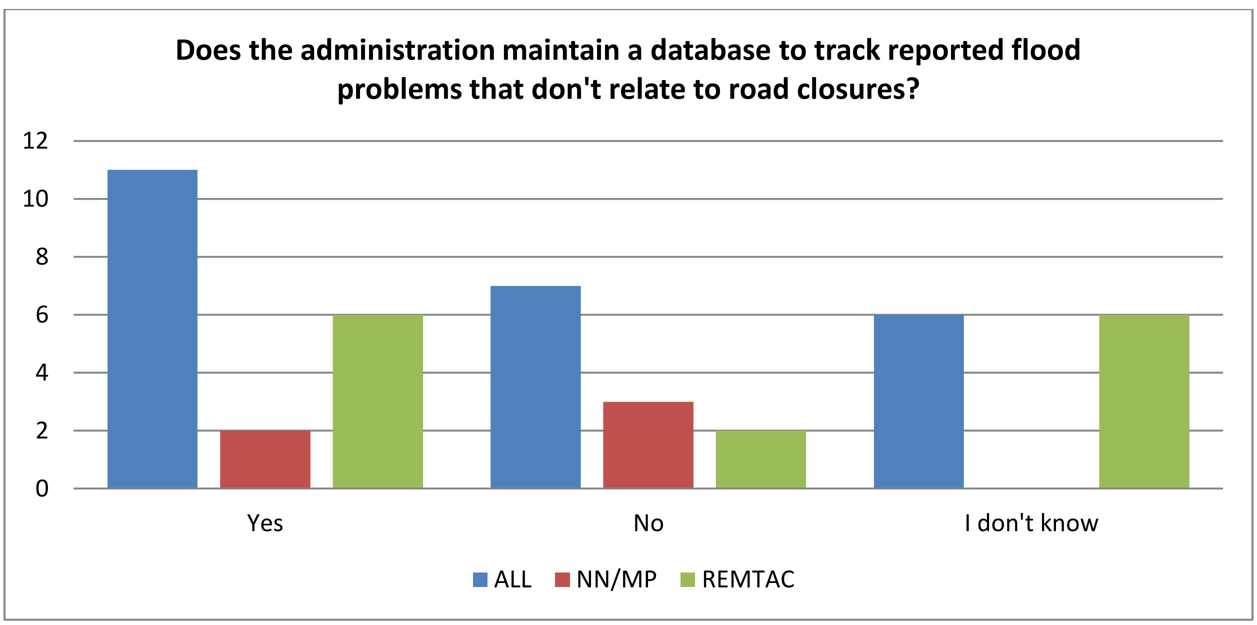


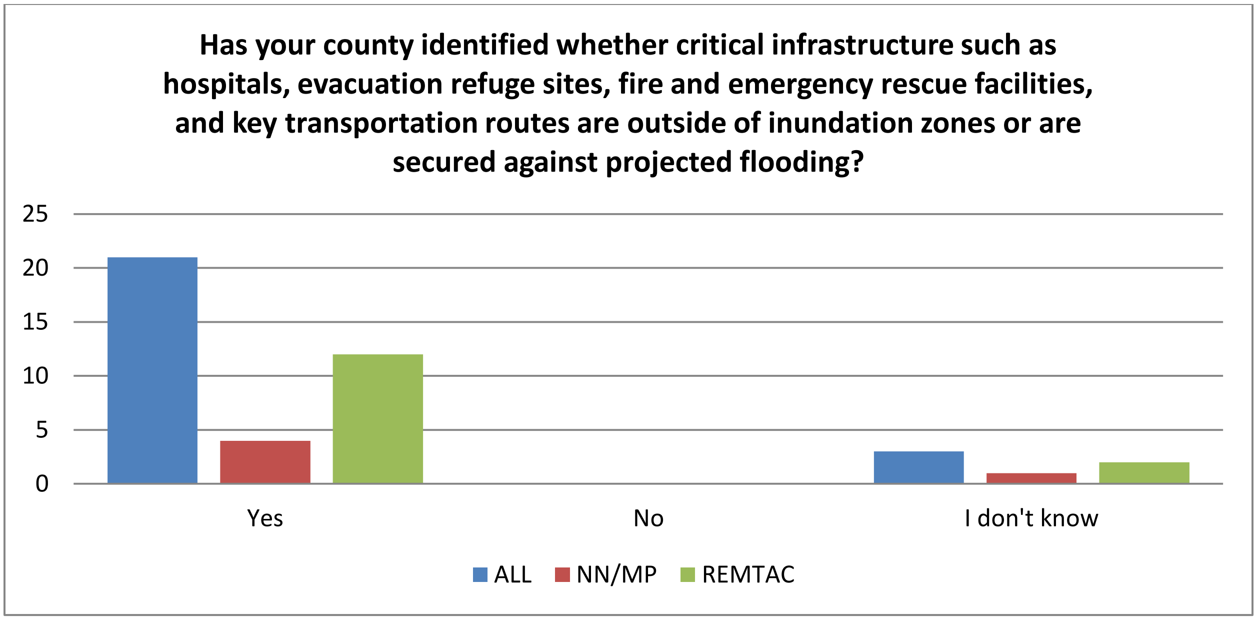
Although we asked this question, we also did our own survey of locality plans related to flooding (see previous section: Review of locality efforts and plans). Therefore, this question serves more to gauge the perception of emergency managers about actions in their locality regarding flooding. It is likely related to how well localities have “advertised” their flood planning efforts. It is interesting to note that when localities had multiple respondents, they tended to answer this question differently, suggesting that flooding planning efforts may only be familiar to the people directly involved in the planning efforts and may not be well “advertised” to others within the locality.

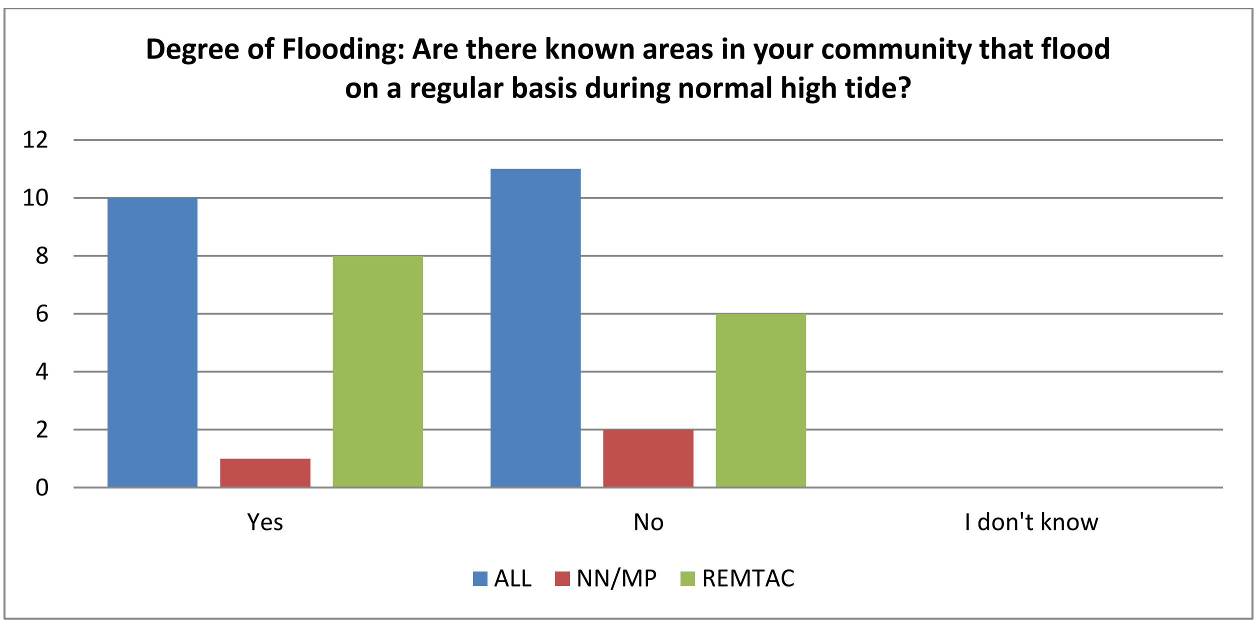

Do your emergency evaluation protocols proactively reroute traffic related to projected flooding events?
14
12
10
8
6
4
2
0
Yes
No
I don't know
ALL
NN/MP
REMTAC

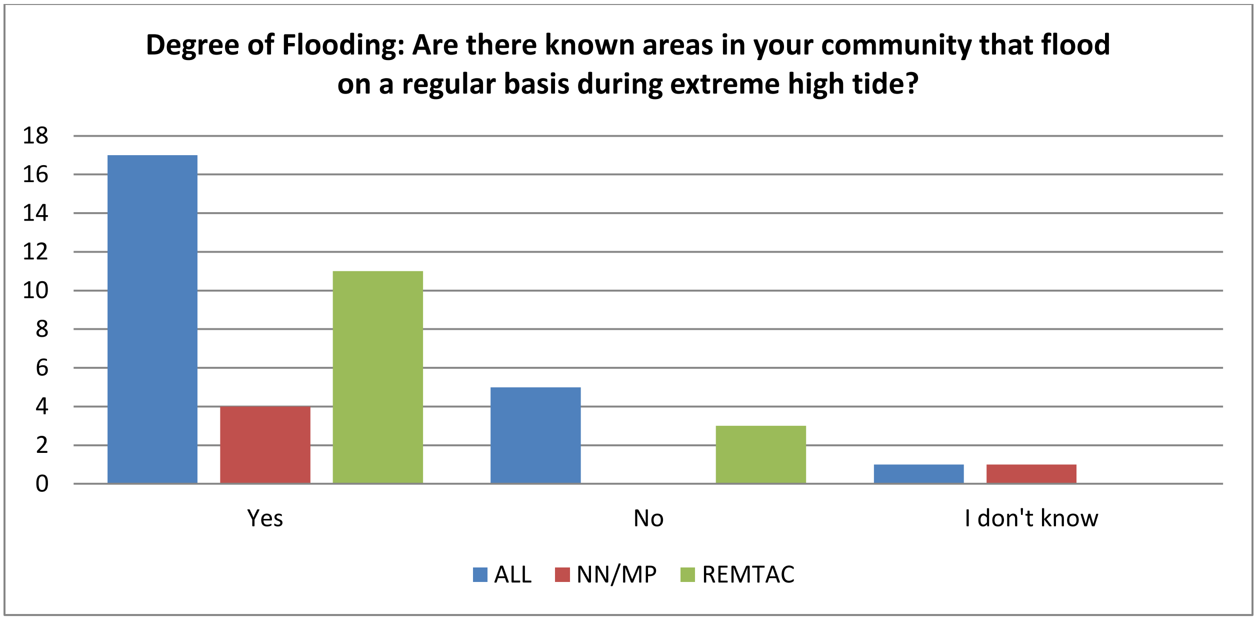

Are there areas within your community where roads must be closed or signed for hazardous conditions associated with water on the pavement?
25
20
15
10
5
0
Yes
No
I don't know
ALL
NN/MP
REMTAC

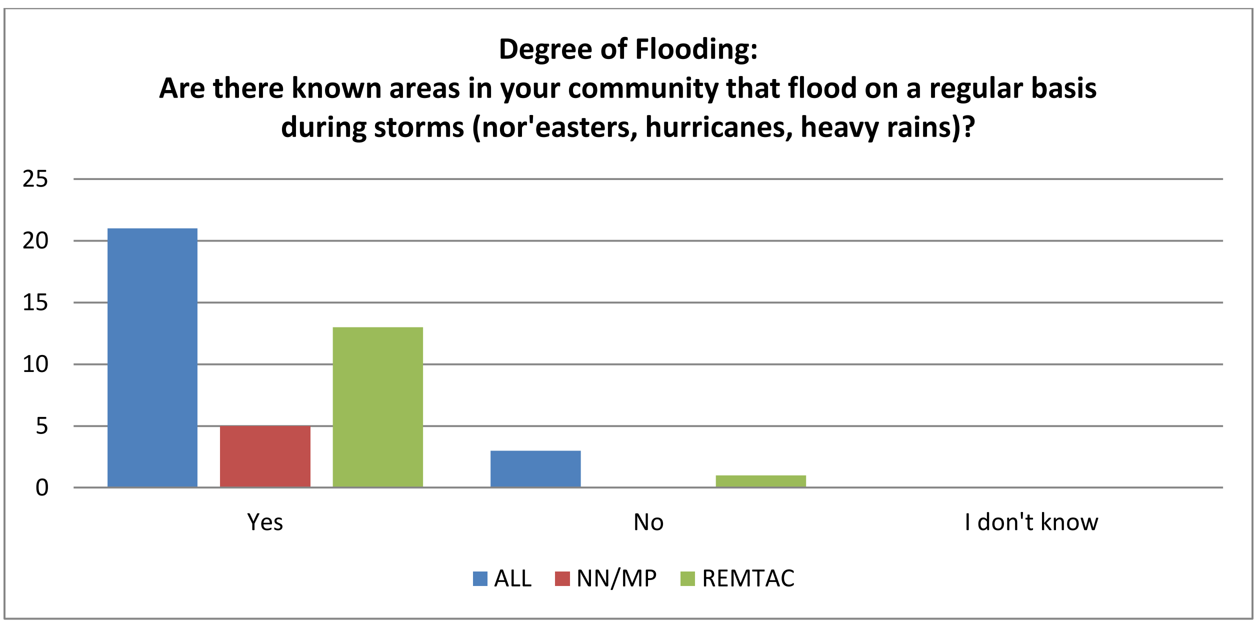

The State highway department tracks flooding events on state-maintained roads. For roads not maintained by VDOT, does your locality track historical road closures due to repetitive flooding?
16
14
12
10
8
6
4
2
0
Yes
No
I don't know
ALL
NN/MP
REMTAC

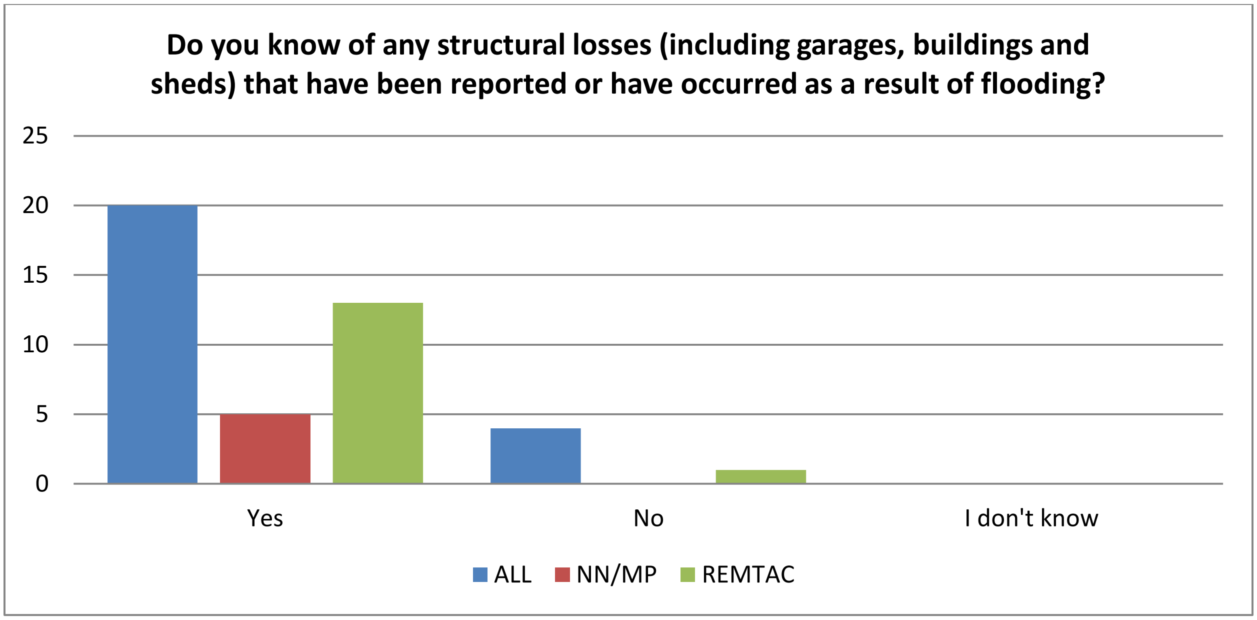

Does the administration maintain a database to track reported flood problems that don't relate to road closures?
12
10
8
6
4
2
0
Yes
No
I don't know
ALL
NN/MP
REMTAC

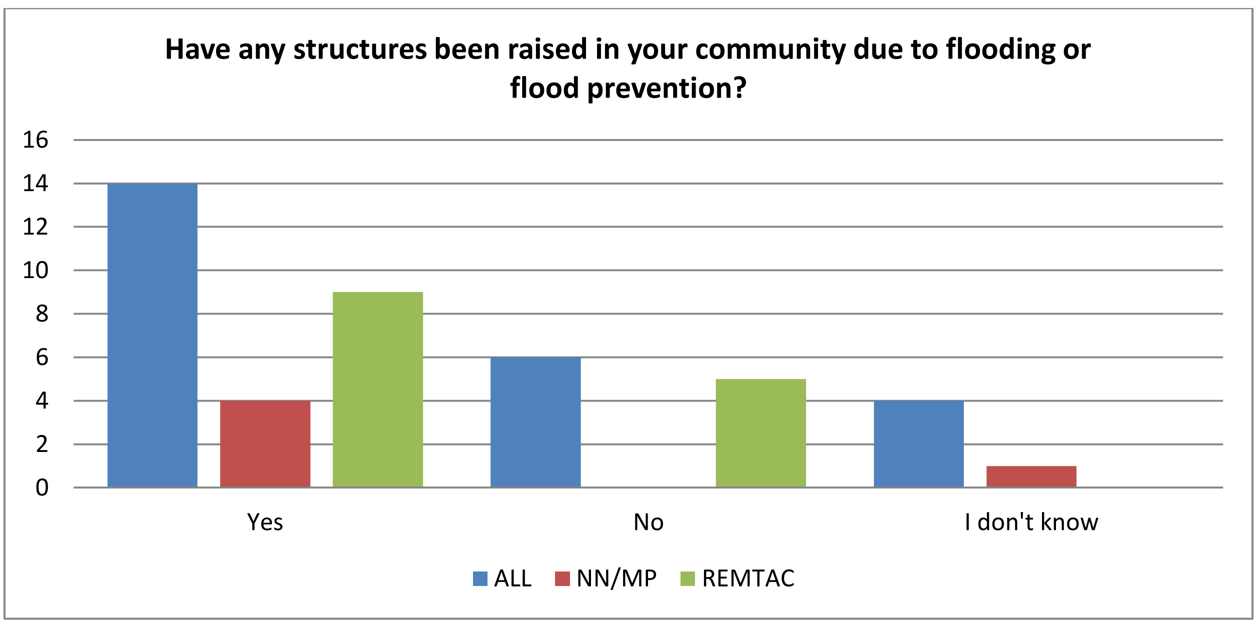

Has your county identified whether critical infrastructure such as hospitals, evacuation refuge sites, fire and emergency rescue facilities, and key transportation routes are outside of inundation zones or are secured against projected flooding?
25
20
15
10
5
0
Yes
No
I don't know
ALL
NN/MP
REMTAC


Degree of Flooding: Are there known areas in your community that flood on a regular basis during normal high tide?
12
10
8
6
4
2
0
Yes
No
I don't know
ALL
NN/MP
REMTAC

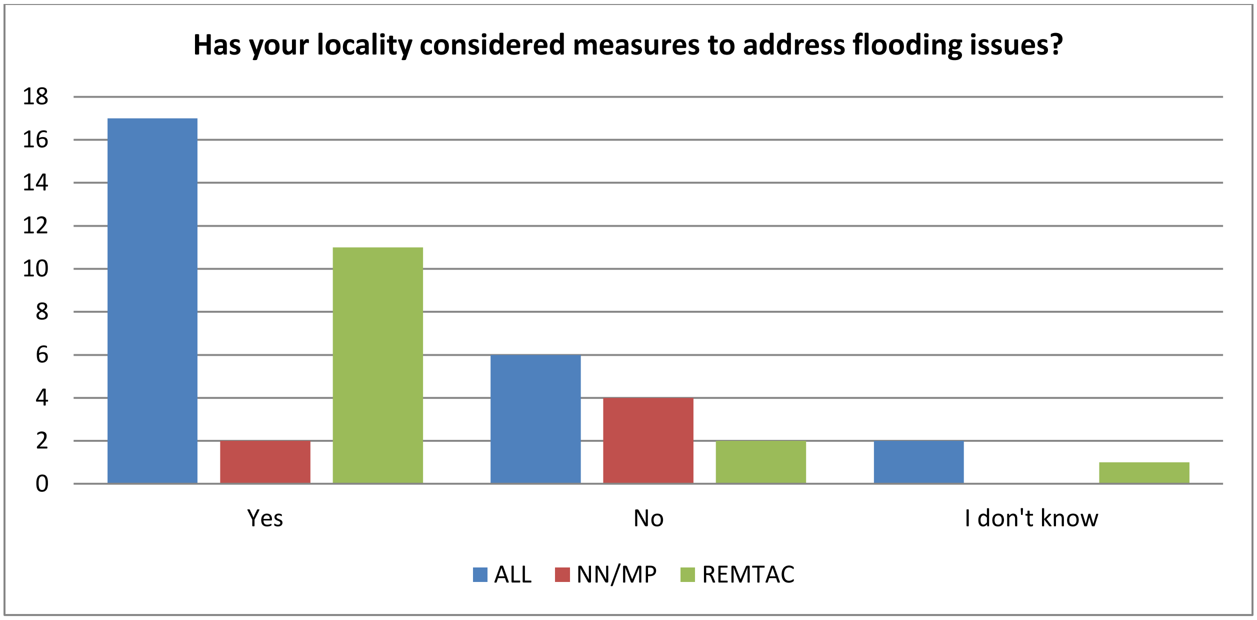

Degree of Flooding: Are there known areas in your community that flood on a regular basis during extreme high tide?
18
16
14
12
10
8
6
4
2
0
Yes
No
I don't know
ALL
NN/MP
REMTAC


Degree of Flooding:
Are there known areas in your community that flood on a regular basis during storms (nor'easters, hurricanes, heavy rains)?
25
20
15
10
5
0
Yes
No
I don't know
ALL
NN/MP
REMTAC

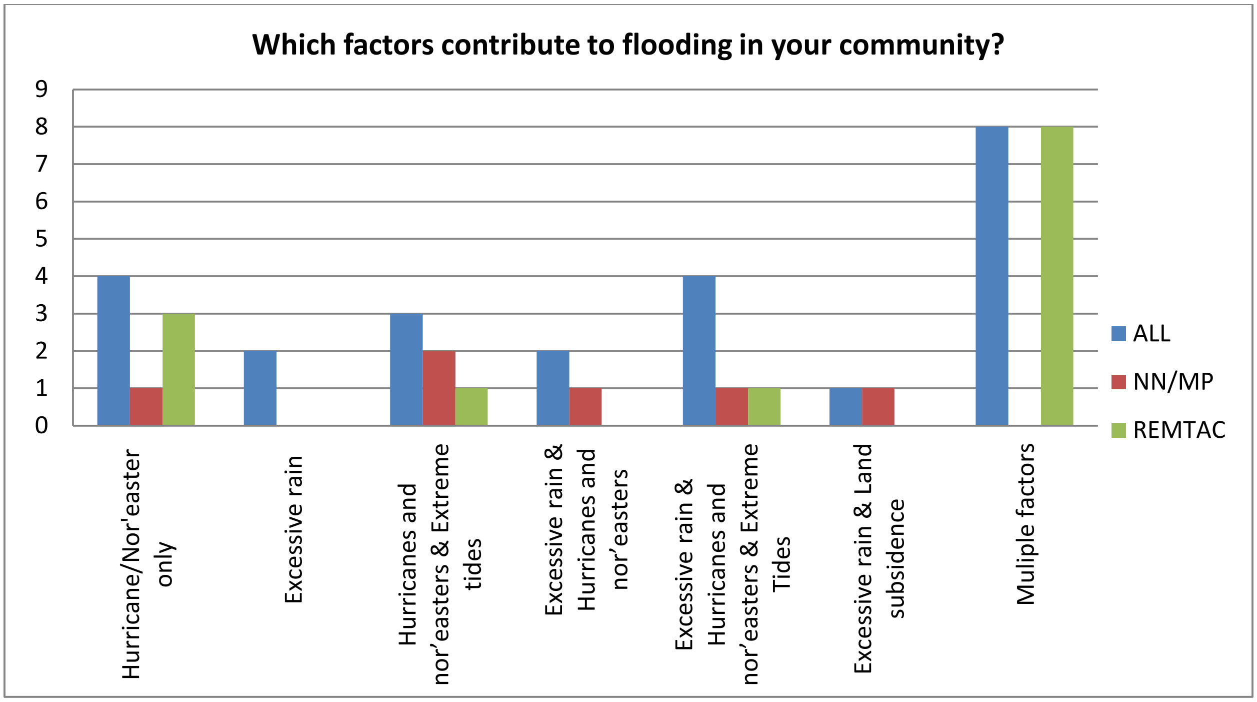


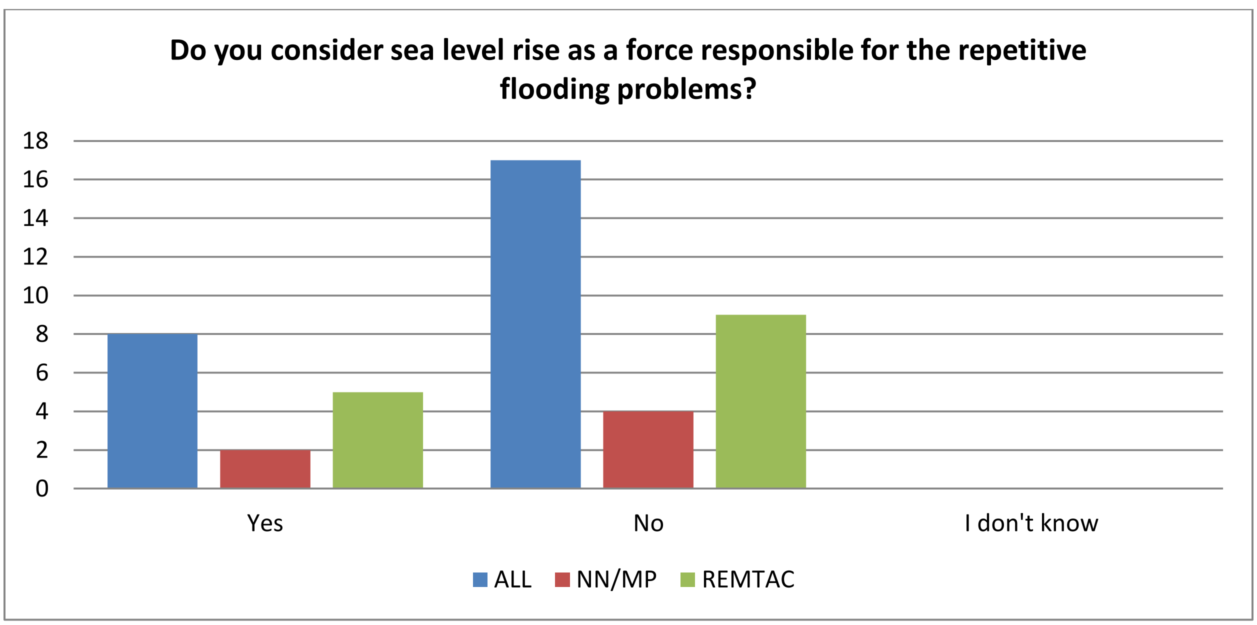


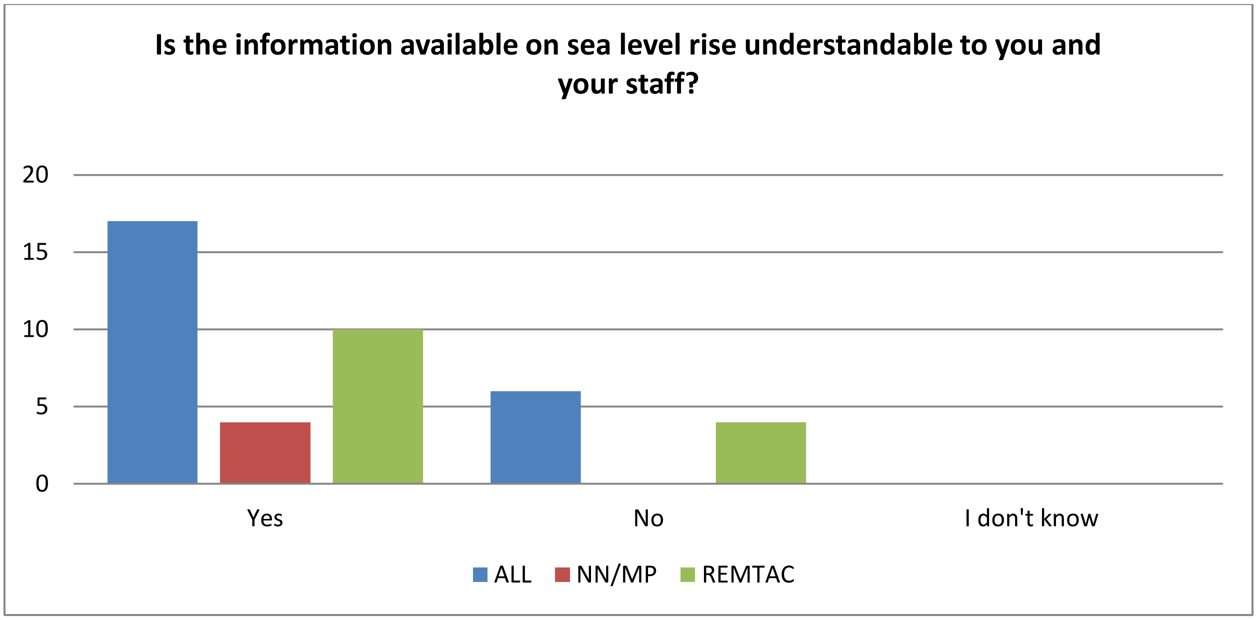
As a follow-up question, we asked "Who paid to raise the structure?" In almost all cases, the response was some combination of the private property owner and FEMA.



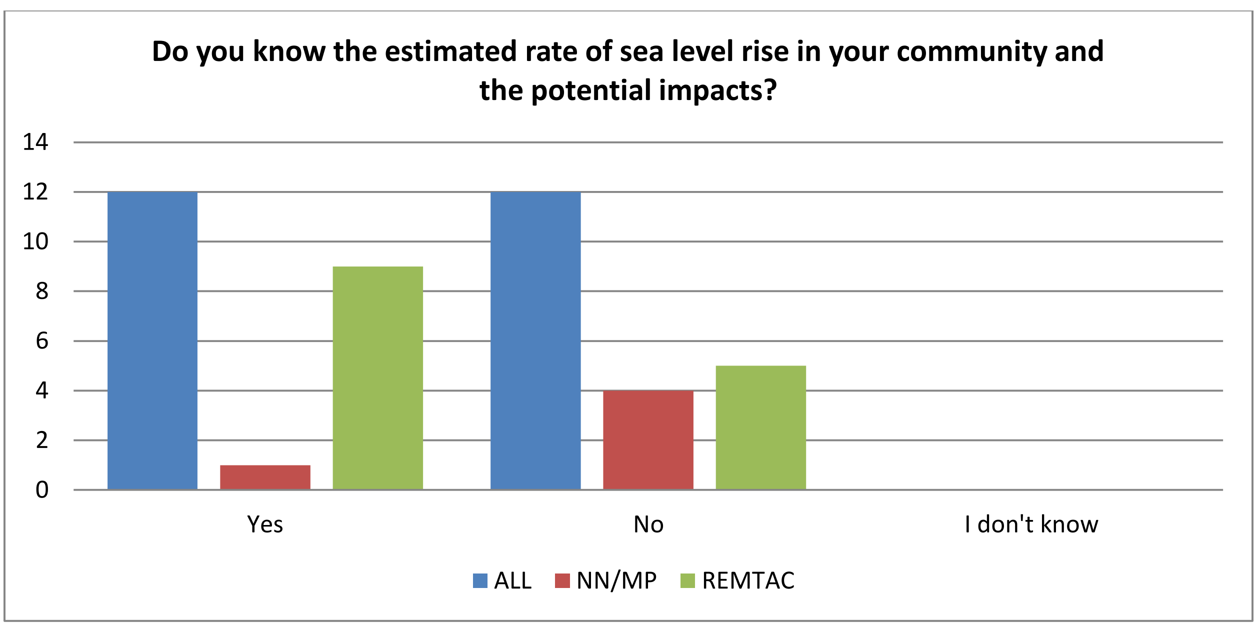
As a follow-up question, we asked "What measures have been considered a viable option to address flooding?" NN/MP localities responded: elevating road surfaces and raising structures, with one locality also considering sand bags, sea walls and relocating people. REMTAC localities responded (in order of popularity): raising structures, relocating people, elevating road surfaces and sea walls, and pumping stations/dams/levees. In general, elevating road surfaces was considered more in the less developed localities. This is likely because rural roads typically have less associated infrastructure (storm water drainage systems), making them easier and cheaper to elevate than city streets. Also, lots are typically larger, so elevating a road without elevating the surrounding property is less likely to negatively impact private property. Pumping stations/dams/and levees have been considered in some developed localities. These are expensive engineering strategies and therefore are most likely to be considered in areas where high development allows for each structure to protect a large number of properties, bringing the cost per property down.

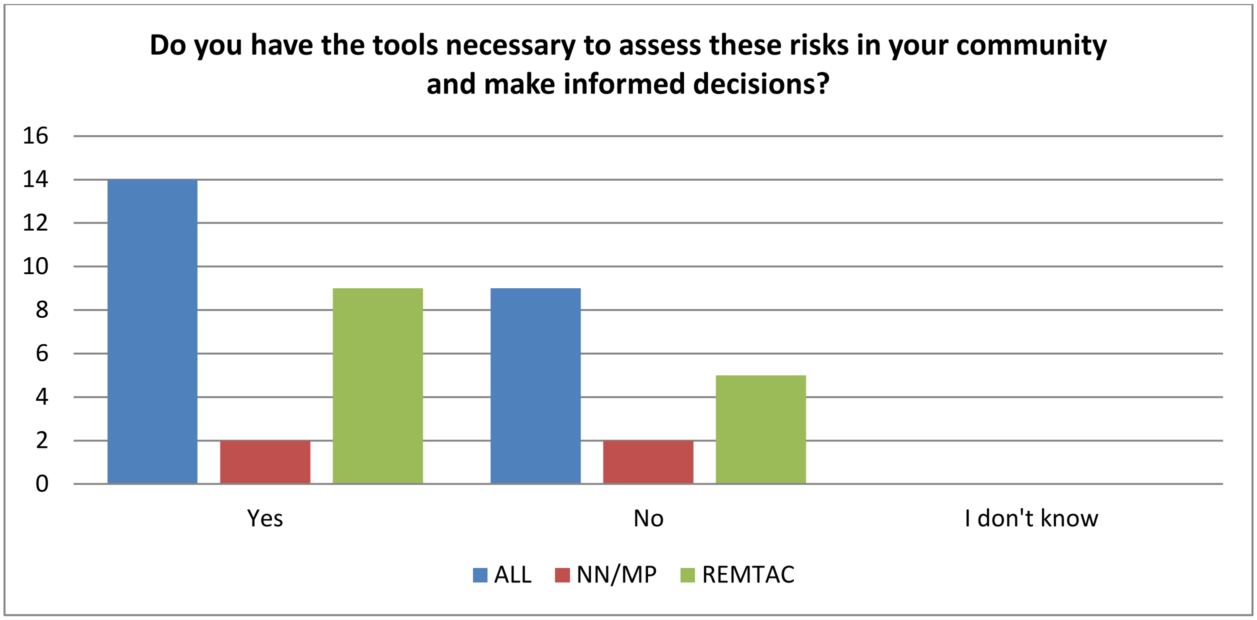

Which factors contribute to flooding in your community?
9
8
7
6
5
4
3
2
1
0
Hurricane/Nor'easter only
Excessive rain
Hurricanes and nor'easters & Extreme tides
Excessive rain & Hurricanes and nor'easters
Excessive rain & Hurricanes and nor'easters & Extreme Tides
Excessive rain & Land subsidence
Muliple factors
ALL
NN/MP
REMTAC

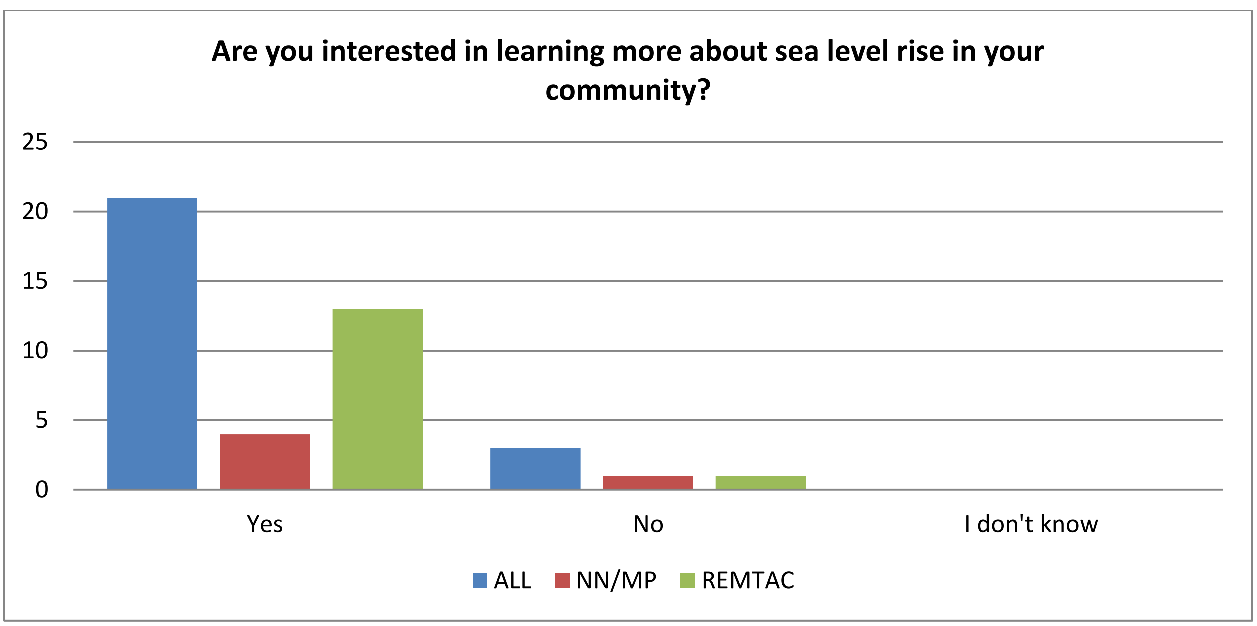

Do you consider sea level rise as a force responsible for the repetitive flooding problems?
18
16
14
12
10
8
6
4
2
0
Yes
No
I don't know
ALL
NN/MP
REMTAC

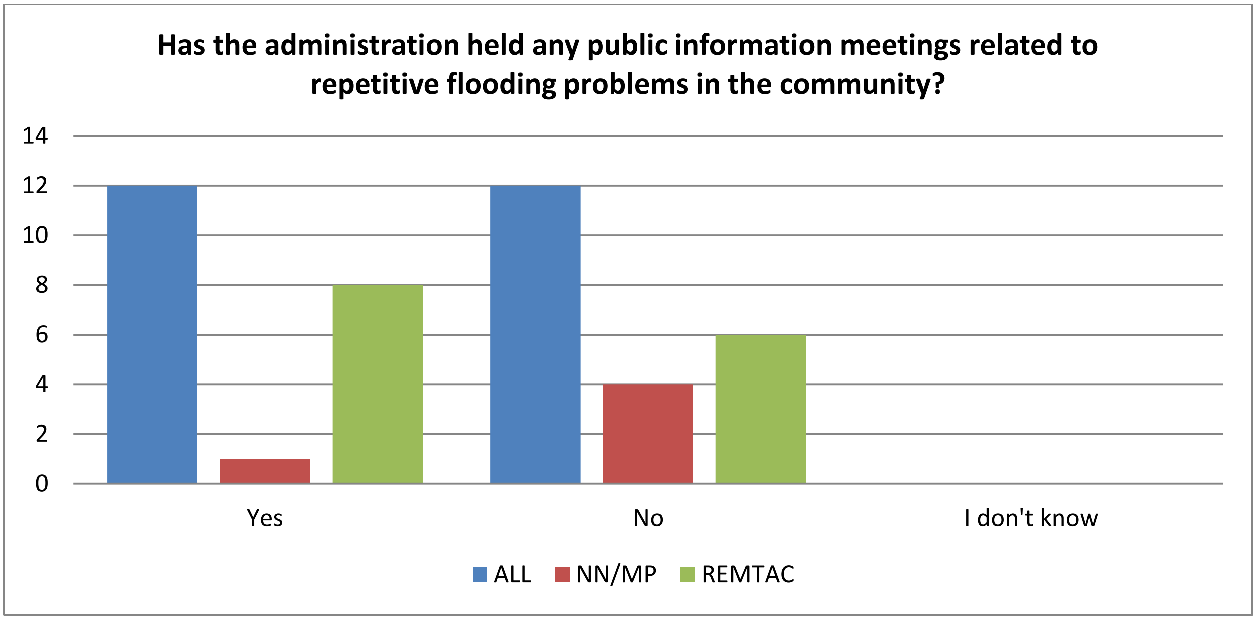


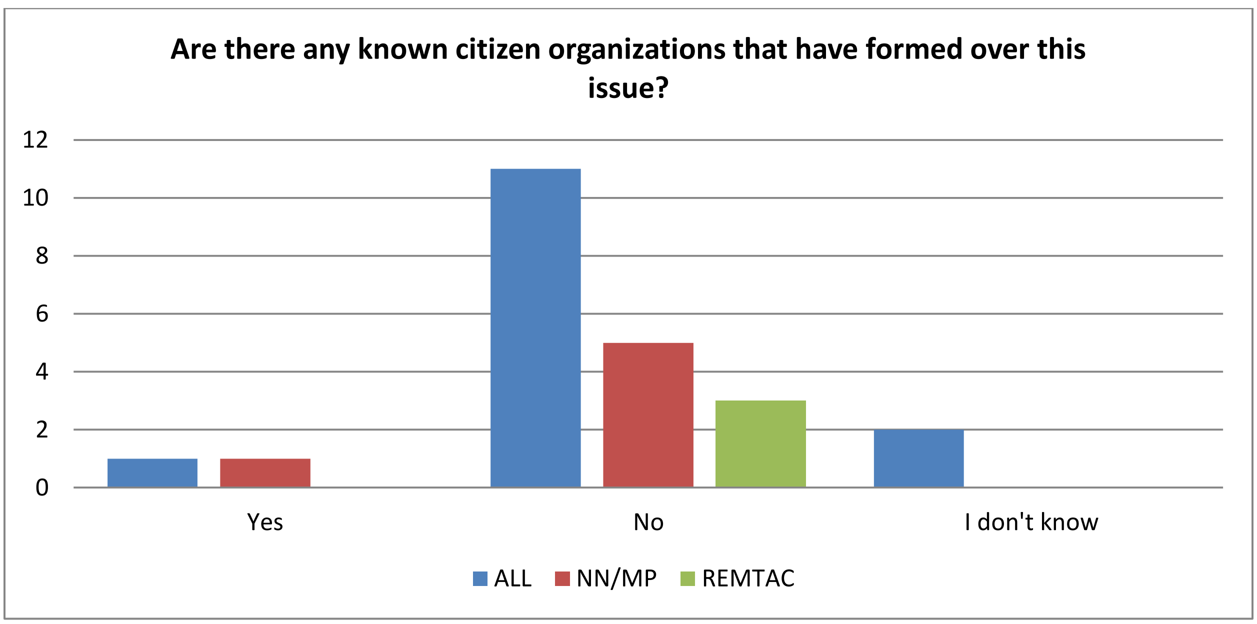
As a follow-up question, we asked "What concerns do you have regarding the repetitive flooding problem in your locality?" Almost all localities responded that public safety was their primary concern. The next top concerns were health risks associated with flooding and the use tax payer's dollars, followed by economic losses from flooding and mitigation costs. Only 2 localities had no concerns associated with flooding.




Do you have the tools necessary to assess these risks in your community and make informed decisions?
16
14
12
10
8
6
4
2
0
Yes
No
I don't know
ALL
NN/MP
REMTAC


Are you interested in learning more about sea level rise in your community?
25
20
15
10
5
0
Yes
No
I don't know
ALL
NN/MP
REMTAC


Has the administration held any public information meetings related to repetitive flooding problems in the community?
14
12
10
8
6
4
2
0
Yes
No
I don't know
ALL
NN/MP
REMTAC


Are there any known citizen organizations that have formed over this issue?
12
10
8
6
4
2
0
Yes
No
I don't know
ALL
NN/MP
REMTAC

Section 4.6 IEN strategy list

The following lists are presented courtesy of the University of Virginia Institute for Environmental Negotiation.

Local Government Tools for Addressing Sea Level Rise in Virginia
DRAFT
Planning Tools To Be Considered for Discussion at Focus Groups
Compiled by the University of Virginia Institute for Environmental Negotiation
Sources cited below
January 2012

LAND USE: Examples of tools relating to land use concerns

1. Update the local Comprehensive Plan to:
    a. Establish the rate of estimated sea level rise and time period over which it may occur.
    b. Designate areas vulnerable to sea level rise.
    c. Site future public infrastructure and capital improvements out of harm's way.
    d. Provide the scientific basis to justify changes in land use decision-making, including an analysis of likely sea level rise hazards (inundation, flooding, erosion), and vulnerabilities (to specific areas, populations, structures and infrastructure).
    e. Plan responses to sea level rise.[1]
2. Using data gathered on potential sea level rise and predicted flooding, update existing or designate new inundation zones or flood plain areas.[2]
3. Integrate vulnerability assessments and sea level rise considerations into the locality's existing Wetlands Ordinance.[3]
4. Revise local zoning and permitting ordinances to require that projected sea level rise impacts be addressed to minimize threats to life, property, and public infrastructure and ensure consistency with state and local climate change adaptation plans.[4]
5. Use overlay zoning to protect shorelines and other vulnerable areas. Overlay districts could prohibit shoreline protection structures, implement shoreline setbacks, restrict

[1] Georgetown Climate Center, Stemming the Tide: How Local Governments Can Manage Rising Flood Risks – Review Draft 3 11 (May 2010), on file with author.
[2] *See id*. at 9-10.
[3] Virginia Polytechnic Institute and State University ("Virginia Tech"), Building Resilience to Change: Developing Climate Adaptation Strategies for Virginia's Middle Peninsula – DRAFT 16 (October 2011), on file with author.
[4] L. Preston Bryant, Jr., Governor's Commission on Climate Change, Final Report: A Climate Change Action Plan 35 (Dec. 15, 2008), on file with author.

future development, lower non-conforming use thresholds, or raise "free board" building code requirements. Shoreline overlay districts could take the form of either:

   a. A fixed-distance zone along the shoreline that would extend across all existing shoreline zoning districts; or
   b. A variable, resource-based zone, based on a scientific inventory of existing shoreline resources. The zone would vary in distance from the water line according to the identified resources.[5]

6. Designate specific thresholds of land disturbance in square footage or acres that trigger a Water Quality Inventory Assessment.[6]
7. Under section 15.2-2286 of the Virginia Code, offer tax credits to landowners who agree to voluntarily "downzone" their property.[7]
8. Offer Use Value Assessments for owners who preserve shoreline property as open space or Wetlands Tax Exemptions to owners who agree to preserve wetlands and riparian buffers. These strategies are authorized under Virginia Code sections 58.1-3230 and 58.1-3666, respectively.[8]
9. Enter into voluntary agreements with landowners to establish "rolling easements" with boundaries that shift as the mean low sea level rises. These would allow landowners to continue with their current land uses until sea level rise actually occurs. At this time, the concept of "rolling easements" is still relatively new.[9]
10. Extend Resource Protection Area and Resource Management Areas under the Chesapeake Bay Preservation Act (CBPA) ordinance. These areas can be extended if specific performance criteria that contribute to the stated goals of the CBPA (pollution reduction, erosion and sediment control, stormwater management) are established.[10]

NATURAL RESOURCES: Examples of tools relating to concerns

1. Prevent the erosion of storm water canals and shoreline by regularly removing trash, vegetation, sands, and other debris.[11]
2. Restore prior-converted wetlands to provide storage and filtration and mitigate storm flows and nutrient loading.[12]

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[5] Virginia Tech, *supra* note 2 at 13, 32, 43.
[6] *Id*. at 16.
[7] Georgetown Climate Center, *supra* note 1 at 18.
[8] Virginia Tech, *supra* note 3 at 43.
[9] *Id.* at 36, 43; *see also* Georgetown Climate Center, *supra* note 1 at 19-23.
[10] Virginia Tech, *supra* note 1 at 43.
[11] Institute for Environmental Negotiation ("IEN"), Sea Level Rise in Hampton Roads: Findings from the Virginia Beach Listening Sessions, March 30-31, 2011, Final Report 61, available at http://www.virginia.edu/ien/docs/Sea_Level_Rise%20final%20report%207-19.pdf.
[12] Virginia Tech, *supra* note 3 at 27.

3. Require new landscaping to incorporate flood and salt-water tolerant species and focus on creating buffers and living shorelines to reduce erosion.[13]
4. Continue implementing beach replenishment and nourishment efforts.[14]
5. Where possible, adopt shoreline protection policies that encourage the use of living shorelines rather than shoreline hardening.[15] Where this is not feasible, protect land and buildings from erosion and flood damage using dikes, seawalls, bulkheads, and other hard structures.[16]
6. Encourage shoreline property owners to implement shoreline management practices, including managing marshland and constructing stone sills, breakwater systems, revetments, and spurs.[17]
7. Expand the adoption of accepted soil-conservation agricultural management practices to reduce erosion and polluted runoff.[18]
8. Institute engineering strategies to mitigate saltwater intrusion into freshwater aquifers, including the construction of subsurface barriers, tide control gates, and artificially recharging aquifers.[19]
9. Establish and maintain corridors of contiguous habitat along natural environmental corridors to provide for the migration and local adaptation of species to new environmental conditions.[20]
10. Develop a price-based accounting system for ecosystem services.[21]
11. Provide local businesses with information on the importance of maintaining the health of shorelines.[22] (good voluntary approach if the case can be made "why do this"
12. Remain aware of the effects that flood mitigation strategies, such as beach replenishment, have on wildlife.[23]

SAFETY AND WELFARE: Examples of tools relating to safety and welfare concerns

1. Develop sea level rise action plans for critical local infrastructure. If existing transportation infrastructure is at risk, "develop plans to minimize risks, move

[13] IEN, *supra* note 11 at 57.
[14] *Id*. at 59, 65.
[15] *See* Bryant, *supra* note 4 at 36.
[16] Virginia Tech, *supra* note 3 at 35.
[17] *Id*. at 42.
[18] *Id*. at 28.
[19] *Id*. at 13.
[20] IEN, *supra* note 11 at 64.
[21] Virginia Tech, *supra* note 3 at 21.
[22] IEN, *supra* note 11 at 61.
[23] *Id*. at 64.

infrastructure from vulnerable areas when necessary and feasible, or otherwise reduce vulnerabilities."[24]

2. Implement an early warning system for flooding that would monitor rainfall and water levels and notify relevant government agencies and the general public in the event of an emergency.[25]
3. Improve the ability of local infrastructure to efficiently handle drainage in the event of increased flooding. This could involve minimizing the construction of new impervious surfaces in flood-prone areas.[26]
4. Amend existing zoning ordinances to require increased building elevations and setbacks, flood-proofing, and reduced density for new construction within flood zones.[27]
5. Improve and enhance traffic rerouting and emergency evacuation protocols related to flooding events.[28] (First responders love this stuff)
6. Ensure that hospitals, evacuation refuge sites, fire and emergency rescue facilities, and key transportation routes are outside of inundation zones or are secured against projected flooding.[29]
7. Redirect new infrastructure development away from low-lying neighborhoods and other at-risk areas, and elevate and armor existing critical infrastructure.[30]
8. Require private sector owners of infrastructure to conduct sea level rise vulnerability assessments and develop their own sea level rise adaptation plans as a condition for permit approval.[31]
9. Encourage the graduated repurposing of structures that are rendered unsuitable for their current use by sea level rise.[32] [33]
10. Gradually withdraw public services in flooded areas.[34] [35]

QUALITY OF LIFE: Examples of tools to address quality of life concerns

1. Involve businesses in the planning process to prevent the loss of shoreline business and to mitigate the impacts of increased flooding and sea level rise.[36] (could be a good voluntary strategy for public awareness.)

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[24] Bryant, *supra* note 4 at 35; *see also* IEN, *supra* note 2 at 64-65.
[25] *See* Virginia Tech, *supra* note 3 at 22.
[26] IEN, *supra* note 11 at 57, 61.
[27] *Id.* at 43; Georgetown Climate Center, *supra* note 1 at 11.
[28] William A. Stiles, "A 'Toolkit' for Sea Level Rise Adaptation in Virginia" 4.1.3, on file with author.
[29] *Id*.
[30] *Id*. at 3.1.
[31] Bryant, *supra* note 4 at 35.
[32] IEN, *supra* note 11 at 60.
[33] Bryant, *supra* note 4 at 35.
[34] *Id*. at 81.
[35] Bryant, *supra* note 4 at 35.

2. Establish a Transfer of Development Rights program to allow the owners of at-risk shoreline properties to sell development rights to upland landowners.[37]
3. Permit the use of Onsite Density Transfers, which allow developers to subdivide lots into smaller and denser parcels if they preserve a portion of the lot as open space and cluster the subdivided parcels.[38]
4. Purchase flooded property from landowners.[39]
5. Organize coastal businesses and homeowners to appeal to insurance companies for affordable rates and deductibles.[40]
6. Organize coastal businesses and homeowners to petition local, state, and federal politicians to address sea level rise.[41]
7. Require realtors to disclose the threat of sea level rise and the responsibilities of shoreline owners to potential purchasers of shoreline properties.[42]
8. Implement special taxing districts that cover the real, life-cycle costs of providing government services in high-risk flood zones, resulting in higher taxes for property-owners in those zones.[43]
9. Use a financial regulatory program to discourage increasingly risky investments along the shoreline. Examples of existing programs with similar aims include:
    a. The state regulation of the property loss insurance sector to reflect higher risk from sea level rise, and
    b. Placing conditions on economic development to require the completion of a long-range vision and plan that addresses sea level rise and flood risk.[44]
10. Hold a series of meetings with stakeholder groups to discuss and gauge potential sea level rise impacts to the region or locality.[45]
11. Educate local elected officials on sea level rise, and the predicted impacts to the region or locality.[46]
12. Present data in easily-understood terms, such as X acres will be flooded, X homes lost, and X impacts to wildlife.[47]

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[36] *Id*. at 27.
[37] Georgetown Climate Center, *supra* note 1 at 17.
[38] Virginia Tech, *supra* note 3 at 40.
[39] IEN, *supra* note 11 at 81.
[40] *Id*. at 58-59.
[41] *Id*. at 60.
[42] *Id*. at 63.
[43] Stiles, *supra* note 24 at 4.1.2.
[44] *Id*. at 4.1.4.
[45] Virginia Tech, *supra* note 3 at 7-8.
[46] *Id*. at 9. For specific training and funding opportunities, *see id*. at 44-45; *see also* IEN, *supra* note 11 at 67.
[47] IEN, *supra* note 11 at 64.

13. Extend media coverage to issues related to sea level rise to increase public awareness and to help citizens prepare for emergencies. This can include the use of social media, such as Facebook, as well as traditional media, including radio, television, and newspapers.[48]
14. Increase public outreach, including press conferences, information sessions, community events, public meetings, and exhibits on sea level rise at libraries, aquariums, and museums.[49]
15. Using modern technologies such as GIS mapping software, develop education programs for residents as well as students in local and regional schools.[50]
16. Educate residents about the role that fertilizing, vegetation removal, and litter play in increasing flooding, erosion, and property damage.[51]
17. Provide landowners with accurate data on the current and future vulnerability of their property to sea level rise as well as best managing practices for mitigating the effects of increased flooding.[52]
18. Raise public awareness of areas prone to flooding through increased signage.[53]

OTHER TOOLS to consider

1. Craft a "Community Resilience" policy statement emphasizing the need for science-based vulnerability assessments, adaptation planning, education and public engagement, and the development of flexible regulatory and non-regulatory strategies for addressing sea level rise.[54]
2. Compile a sea level rise impact assessment. This is often a long-term, multi-phase effort. Steps can include:
    a. Assembling an advisory workgroup.[55]
    b. Identifying flood zones and at-risk populations.
    c. Mapping regional and county sea level rise predictions to show impacts to existing development and natural areas; and
    d. Assessing and prioritizing economic and ecological vulnerabilities to sea level rise.[56]

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[48] *Id*. at 66, 68.
[49] *See id*. at 62-63, 66-67.
[50] *See* Virginia Tech, *supra* note 3 at 45.
[51] IEN, *supra* note 11 at 63.
[52] *Id.* at 59; Bryant, *supra* note 4 at 37.
[53] IEN, *supra* note 11 at 57.
[54] Virginia Tech, *supra* note 3 at 34.
[55] IEN, *supra* note 11 at 57.

3. Create adaptation plans for areas at early risk from sea level rise.[57] This could involve an evaluation of adaptation strategies implemented by other U.S. jurisdictions and by foreign governments.[58]
4. Investigate how to address sea level rise in other planning strategies, including transportation plans, regional economic development plans, and regional hazard mitigation.[59]
5. Identify the financial resources needed to meet adaptation needs.[60]

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[56] Stiles, *supra* note 24 at 3.1.; Virginia Tech, *supra* note 3 at 8.
[57] *See generally* Stiles, *supra* note 24; Virginia Tech, *supra* note 3 at 2.
[58] IEN, *supra* note 11 at 57.
[59] *See* Stiles, *supra* note 24 at 4.1.1.
[60] *Id*. at 3.2.

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Appendix A. Copy of SENATE JOINT RESOLUTION NO. 76

2012 SESSION

ENROLLED

SENATE JOINT RESOLUTION NO. 76

Requesting the Virginia Institute of Marine Science to study strategies for adaptation to prevent recurrent flooding in Tidewater and Eastern Shore Virginia localities. Report.

Agreed to by the Senate, February 28, 2012
Agreed to by the House of Delegates, February 24, 2012

WHEREAS, relative sea-level rise has been identified as a threat to coastal Virginia, and relative sea level measured at Sewells Point, Norfolk, has risen by 14.5 inches since 1930; and

WHEREAS, scientists predict an additional 2.3 to 5.2 feet of relative sea-level rise in the Chesapeake Bay region by 2100; and

WHEREAS, the Norfolk-Virginia Beach Metropolitan Statistical Area ranks tenth globally in the value of assets exposed to increased flooding from sea-level rise; and

WHEREAS, many areas of Hampton Roads already experience extreme flooding from routine weather events, causing extensive damage to private property and public infrastructure; and

WHEREAS, the Port of Hampton Roads is a major driver of the regional and state economy, and must be protected; and

WHEREAS, Naval Station Norfolk and Hampton Roads' other military bases are vital to our national security, and their operational capabilities must not be limited by increased flooding; and

WHEREAS, the costs of adapting to relative sea-level rise far exceed the capacity of local governments and residents to bear alone; and

WHEREAS, there are many local, regional, state, and federal partners who have a stake in coordinating their efforts to address the problems associated with relative sea-level rise; now, therefore, be it

RESOLVED by the Senate, the House of Delegates concurring, That the Virginia Institute of Marine Science be requested to study strategies for adaptation to prevent recurrent flooding in Tidewater and Eastern Shore Virginia localities.

In conducting its study, the Virginia Institute of Marine Science shall (i) review and develop a comprehensive list of ideas and examples of strategies used in similar settings around the United States and the world; (ii) convene a stakeholder advisory panel for the purpose of discussing and assessing the feasibility of employing these strategies in Tidewater and Eastern Shore Virginia; and (iii) offer specific recommendations for the detailed investigation of preferred options for adapting to relative sea-level rise.

The study shall include the participation of the Hampton Roads Planning District Commission and its member localities and Old Dominion University. All agencies of the Commonwealth shall provide assistance to the Virginia Institute of Marine Science for this study, upon request.

The Virginia Institute of Marine Science shall complete its meetings by November 30, 2012, and shall submit to the Governor and the General Assembly an executive summary and a report of its findings and recommendations for publication as a House or Senate document. The executive summary and report shall be submitted as provided in the procedures of the Division of Legislative Automated Systems for the processing of legislative documents and reports no later than the first day of the 2013 Regular Session of the General Assembly and shall be posted on the General Assembly's website.

ENROLLED

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