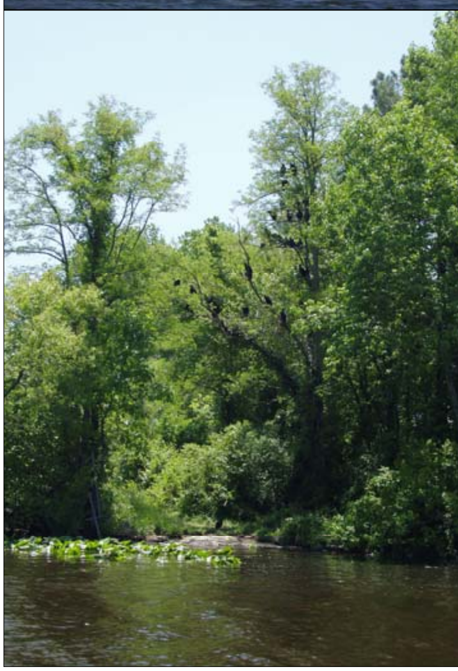
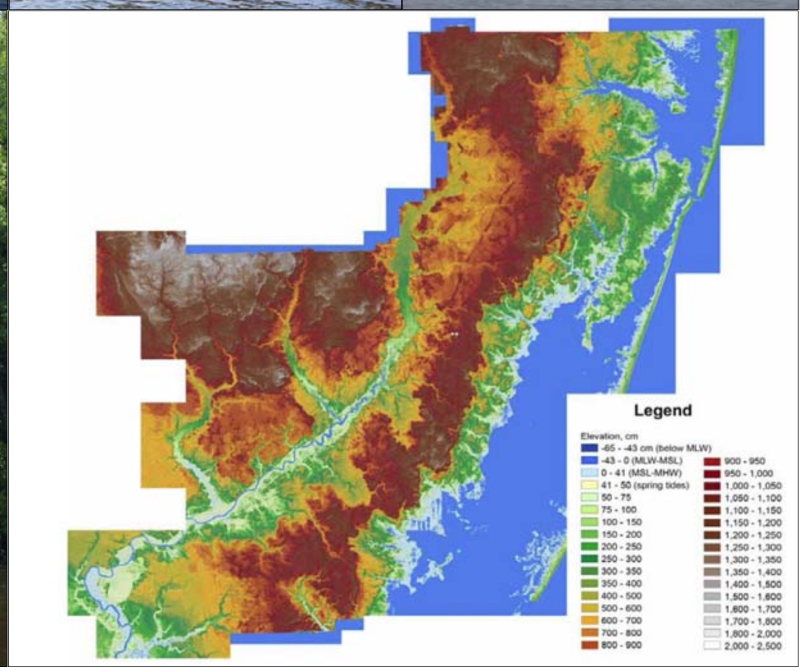
Sea Level Rise Response Strategy
Worcester County, Maryland

September 2008



Worcester County, Maryland
Department of Comprehensive Planning
1 West Market Street
Snow Hill, Maryland 21863-1249

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Prepared for:

Worcester County, Maryland
Department of Comprehensive Planning
1 West Market Street
Snow Hill, Maryland 21863
Telephone: (410) 632-5651

Prepared by:

CSA International, Inc.
8502 SW Kansas Avenue
Stuart, Florida 34997
Telephone: (772) 219-3000

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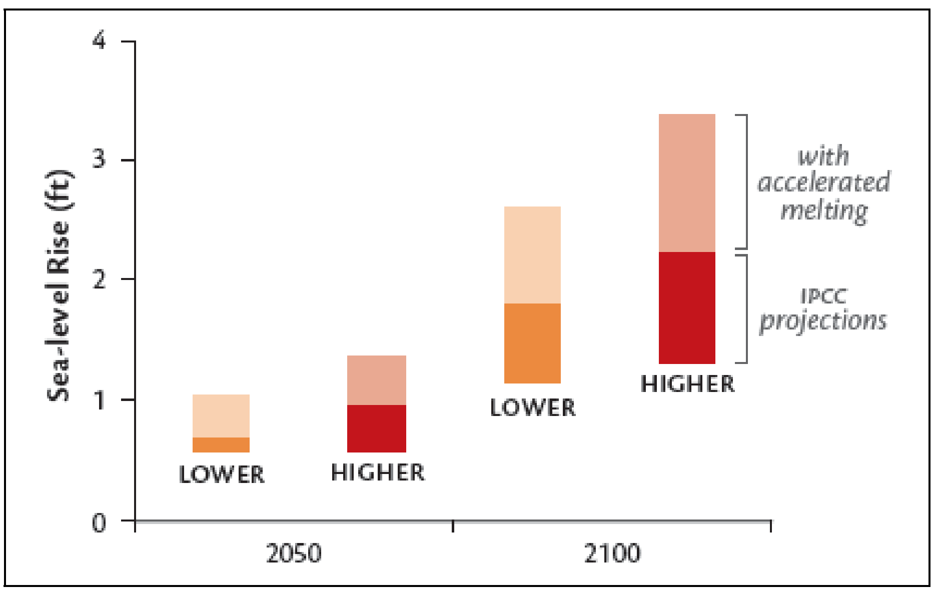
1 Sea Level Rise Scenarios

The purpose of this study is to develop and assess response options for the expected impacts of accelerated sea level rise caused by climate change. To be able to plan responses to sea level rise impacts on the local communities and ecosystems within Worcester County, some assumptions of the rate and range of sea level rise must be made. Although great progress has been made in our understanding of climate change and modeling impacts, results of these models are still inconclusive regarding the exact extent of sea level rise and when it will occur. To account for this uncertainty, this report presents several scenarios to assess the impacts of sea level rise on Worcester County over the next century. Also, the prioritization of the response options considers which options would be useful despite uncertainties in the rate and range of sea level rise.

Current rates of sea level rise in Maryland, 3 to 4 mm per year or approximately 1 ft per century, are higher than many other coastal states due to land subsidence (Johnson, 2000). The land subsidence of this area is expected to continue at much the same rate and, therefore, approximately half of the observed sea level rise is a known factor (Maryland Commission on Climate Change, 2008).

The degree to which sea level rise accelerates due to climate change could vary based on future global efforts to reduce greenhouse gas emissions. The Intergovernmental Panel on Climate Change (IPCC) accounts for this variability by using low and high emission scenarios in its sea level rise projections. The most recent IPCC projections are considered conservative by most experts because they do not include rapid ice sheet melting, which could greatly increase sea level rise as seen in **Figure 1.1** (Maryland Commission on Climate Change, 2008).



(Maryland Commission on Climate Change, 2008)

Figure 1.1. Projected relative sea level rise in Maryland in 2050 and 2100.

It is commonly accepted that regardless of actions taken today or in the immediate future to reduce greenhouse emissions, there will still be some degree of acceleration in sea level rise due to the level of greenhouse gases currently in the atmosphere. This, combined with the fact that Worcester County is already affected by current sea level rise impacts, such as erosion and coastal flooding, means that taking action now despite uncertainties as to the exact extent of sea level rise at the end of the century is extremely important for the county's well being and will be further discussed in later sections of this report. For more on sources of information, see **Sidebar 1.1**.

Sidebar 1.1 For more information

More information on the causes and projections of sea level rise, especially in Maryland, can be found in the recently published *Maryland Climate Change Commission's Climate Action Plan*. Other useful sources of information on sea level rise due to climate change can be found on the U.S. Environmental Protection Agency's website and in IPCC reports.

1.1 WORCESTER COUNTY SEA LEVEL RISE INUNDATION MODEL

The Maryland Department of Natural Resources (DNR) and the U.S. Geological Survey (USGS) modeled sea level rise for Worcester County for three future dates: 2025, 2050, and 2100. They also used three scenarios of sea level rise rates: Steady State, Average Accelerated, and Worst Case. These scenarios are summarized below (Maryland Department of Natural Resources et al., 2006) and shown in **Figure 1.2**. In addition, the model depicted the increase in hurricane storm surge for the steady state and average accelerated models. More detail can be found in the *Worcester County Sea Level Rise Inundation Model Technical Report.*

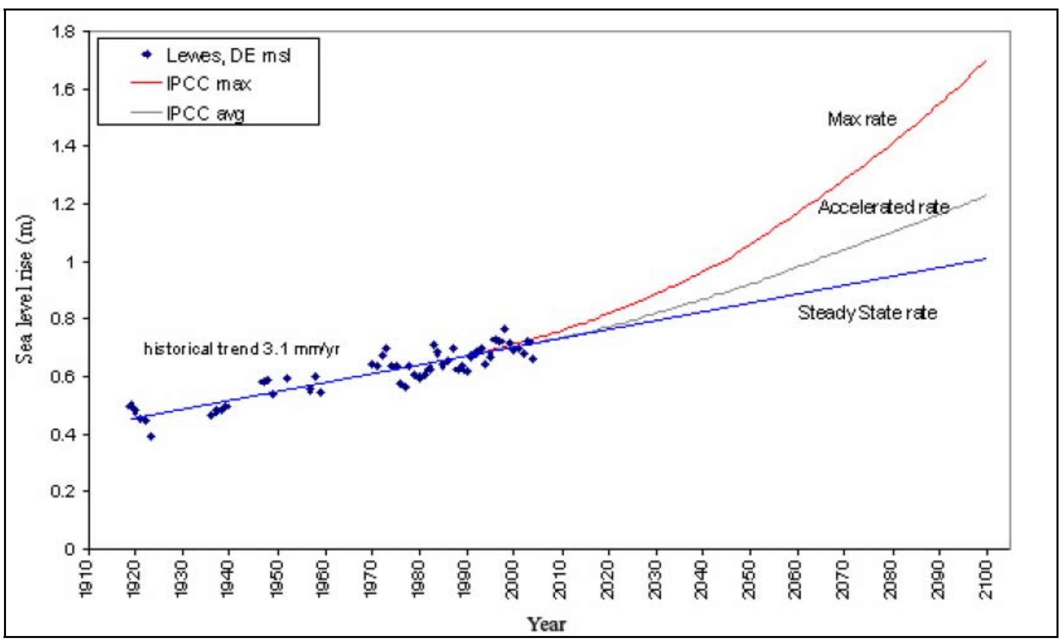


Figure 1.2. Sea level rise scenarios used in Worcester County Inundation Model (From: Maryland Department of Natural Resources et al., 2006).

Steady State Model – Based on the long-term historic rate of sea level rise of the area, approximately 3.1 mm/yr or 0.57 m by 2025 at spring high tide.

Average Accelerated Model – Estimated by averaging the IPCC projections. Annual rates were increased by 1 mm/10 yr to reach this projection, resulting in a 1 m sea level rise by 2100 at spring high tide.

Worst Case Model or Max Rate – Uses the max range of all IPCC models, 85 to 90 cm by 2100. The annual rates were increased by 1 mm/10 yr through 2050 and then more rapid increases were used to reach an annual rate of 15 cm for the period 2090 to 2100. This resulted in spring high tides of 0.63 m in 2025, 0.83 m in 2050, and 1.47 m in 2100.

1.2 SCENARIOS USED IN ANALYSIS

The impact analysis in **Section 2** used modeled inundation zones from the Worcester County Sea Level Rise Inundation Model. For the purposes of this analysis, the scenarios shown in **Table 1.1** were used in combination with local land use, infrastructure, and ecosystem data to address the range of projected impacts for the county. The spring high tide was used as the landward boundary of each inundation zone except for those scenarios including storm surge. A full methodology for the analysis can be found in the **Appendix**.

Table 1.1. Sea level rise scenarios used in analysis.

Scenario	2025	2050	2100
Steady State	x		
Average Accelerated			
Worst Case	x	x	x
Steady State and Category 3 Storm Surge	x		
Average Accelerated and Category 3 Storm Surge	x	x	x

Due to the uncertainties and range of sea level rise projections, the Worst Case scenario (**Figure 1.3**) was chosen as a precautionary inundation zone for pre-planning in Worcester County. While sea level rise may never reach 1.47 m at spring high tide in 2100, it could be close and the area up to 1.47 m inland could flood frequently or be subject to erosion. If possible without unacceptable opportunity costs, limiting development within this worst case inundation zone is a wise decision for the overall good of the community and environment.

In 2003, Hurricane Isabel caused a larger storm surge by about 1 ft than a similar storm in 1933 because of the higher sea level (Maryland Department of Natural Resources et al., 2006).

The Steady State 2025 scenario was chosen to present almost certain, near-term impacts that the county will face from sea level rise. This scenario simply shows a trend that has been occurring for over the past 50 years in the Worcester County area, and there is little reason to doubt this will not continue over the next 16 years.

The addition of the Category 3 hurricane storm surge zone with the steady state and average accelerated scenarios allows the county to see which increased impacts from a major disaster flooding event could occur (see **Figure 1.4**). Category 3 hurricane storm surge was chosen to present the probable maximum extent of storm surge for the county. Worcester County has experienced three indirect hits from Category 3 hurricanes since 1940. It also has experienced two direct hurricane hits since 1851 (a Category 1 and a Category 2). Globally, we are experiencing a period of increased hurricane activity. In addition, many scientists believe that the intensity of tropical storms will also increase with climate change, mostly due to the warmer sea temperatures. In addition, it is believed that non-tropical storms, such as Nor'easters, will increase in intensity and frequency (Maryland Department of Natural Resources et al., 2006). Using a Category 3 storm surge with the less severe sea level rise scenarios provides a very possible future flood scenario for hazard mitigation planning purposes.

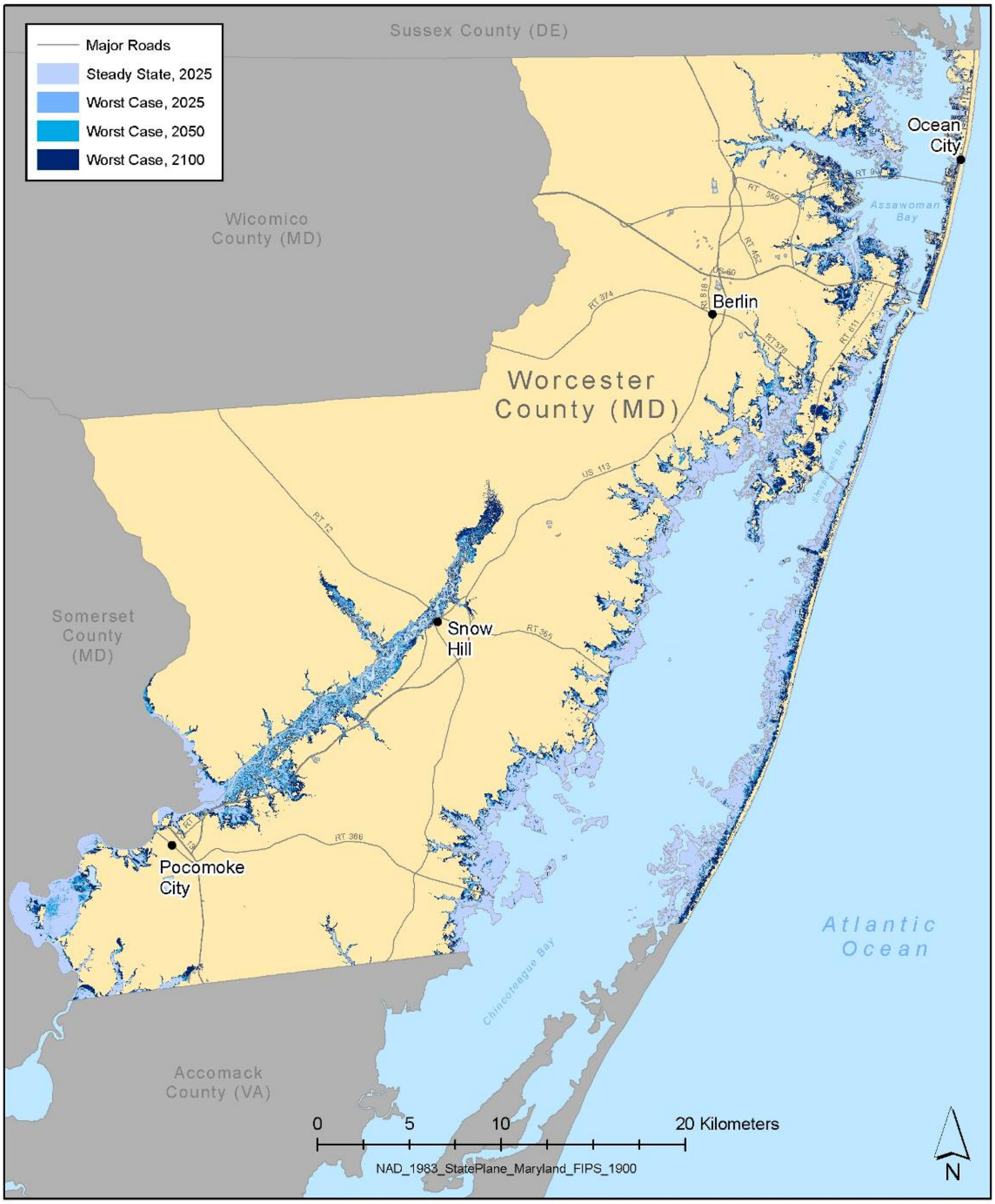


Figure 1.3. Steady State 2025 zone and Worst Case scenario for 2025, 2050, and 2100 zones for sea level rise.

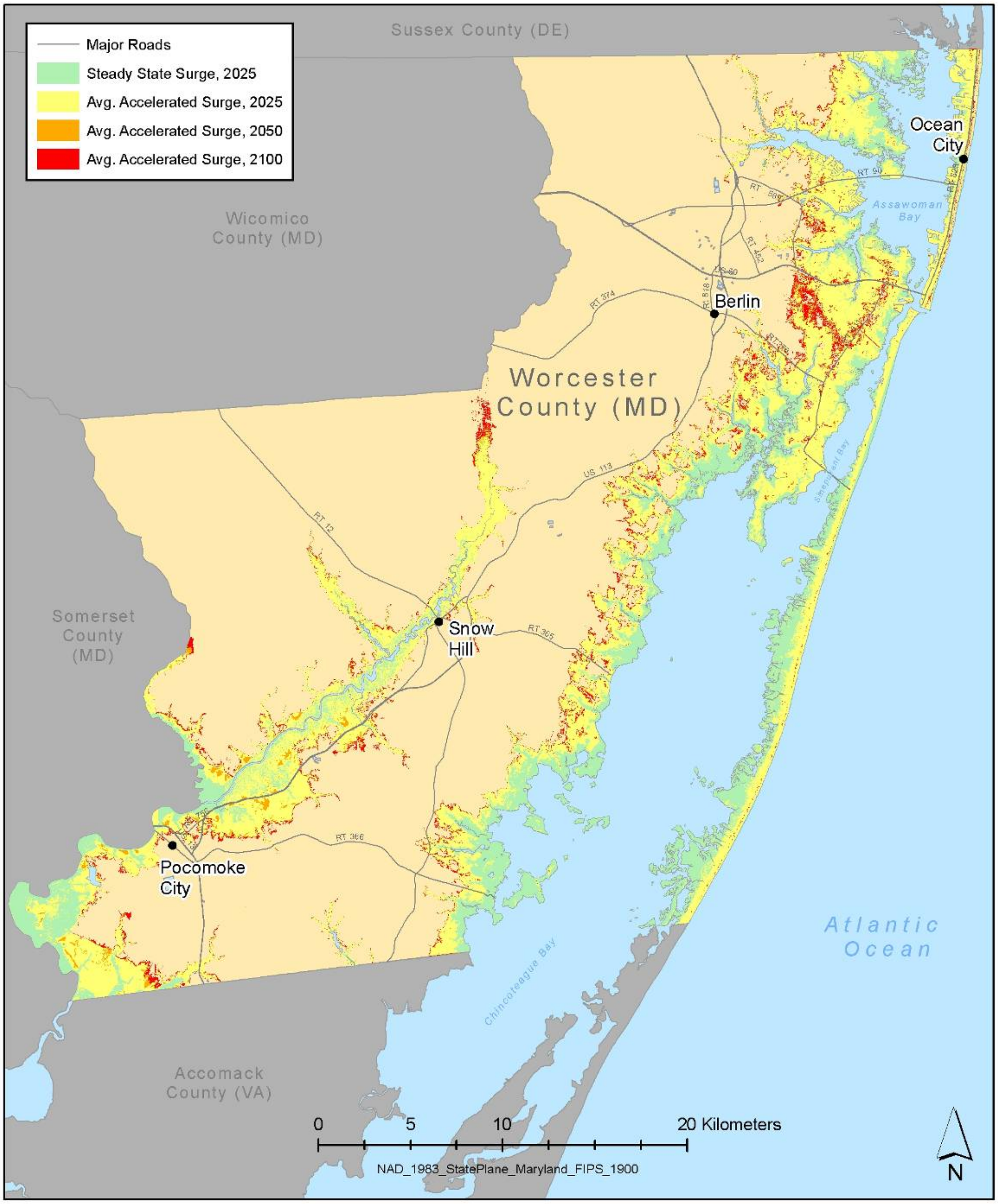


Figure 1.4. Steady State 2025 zone and Worst Case scenario for 2025, 2050, and 2100 zones for surge.

2 Projected Sea Level Rise Impacts

The direct impacts of sea level rise in Worcester County include inundation of wetlands and lowlands; accelerated coastal erosion; increased flooding; raised water tables; and increased salinity of bays, rivers, and aquifers (Worcester County Department of Comprehensive Planning, 2006). These direct impacts also create many environmental and socioeconomic implications that will need to be addressed through various response or adaptation strategies. This vulnerability analysis is organized by the potential impacts sea level rise will have on current and future development as well as ecosystem health. The economic implications of these impacts were beyond the capabilities of this study, but can be conjectured from impacts to different types of community development and those potentially affecting the county's thriving tourism industry.

The vulnerability analysis was preformed by county staff using the Worcester County Sea Level Rise Inundation Model data and local geographic information system (GIS) data, including property parcels, land use, infrastructure, and environmental inventories. A full methodology is available in the **Appendix**. This analysis is meant for use in assessing the appropriateness of sea level rise response options and gaining an understanding of the level of vulnerability of the county only (see **Sidebar 2.1** for a definition of vulnerability). Due to limitations in data as well as broad assumptions that had to be made when modeling the sea level rise scenarios, it is not recommended that the analysis output be used to declare specific property parcels or structures that will be inundated without field verification of the GIS results. The numbers of parcels, structures, and infrastructure reported as vulnerable to sea level rise impacts is to be used to gauge the degree of importance for response options and the numbers should not be mistaken as exact predictions.

Sidebar 2.1 Definition of Vulnerability

"The IPCC defines vulnerability as ''the extent to which a natural or social system is susceptible to sustaining damage from climate change''. It is a function of the exposure of the system to climatic hazards, the sensitivity of the system to changes in climate, and the adaptive capacity of the system to moderate or offset the potential damages of climate change" (Kleinosky, 2006).

2.1 INCREASED VULNERABILITY OF PRIVATE DEVELOPMENT

A major concern for Worcester County is the impact of sea level rise on existing private development and the ability to develop future coastal private property without incurring avoidable financial and environmental losses. By examining how private development vulnerability will be affected with sea level rise scenarios, response options can be tailored to the particular needs of Worcester County to meet its vision, as described in its Comprehensive Plan.

Inundation from Sea Level Rise

Inundation, the primary impact of sea level rise, is the gradual and permanent submergence of land by water determined by the gradient of the local topography. The result is a retreat of the shoreline, which also is exacerbated by erosion and flooding. Along the sand beaches of Fenwick and Assateague Islands, the extent of shoreline recession will be a function of both inundation and erosion. Along the protected shores of Worcester County's bays, where the natural shoreline consists primarily of salt marshes, the shoreline will likely recede more slowly than along the sandy beaches of the Atlantic Ocean due to less erosion. Erosion will be more limited because of lower wave energy, more cohesive sediments, and the presence of dense wetland vegetation. Intermediate levels of recession are likely along the sandy beaches fronting the bays where sediments are more susceptible to erosion than wetland substrates and wave energy is less intense than on the open ocean. The impacts of erosion are discussed in more detail in **Section 2.3**.

Because of Worcester County's low elevation and gradual slope, large geographic areas are inundated as the sea level rises. The projected inundation, as described in this section, will permanently encompass many large, rural property parcels entirely and hundreds to thousands of subdivided, developed parcels.

Existing and Currently Zoned Development

There are several heavily developed areas of Worcester County already vulnerable to flooding and erosion that will be the first areas impacted by current rates of sea level rise if no action is taken. Ocean City has already had to battle serious erosion and flood risk for decades in order to continue as an intensely developed barrier island community. It is currently committed to a long-term beach nourishment program to keep the ocean at bay. Ocean Pines was built on filled wetlands and has approximately 15,000 year-round residents (Worcester County Department of Comprehensive Planning, 2006). The Snug Harbor neighborhood, pictured to the right, has 17 repetitive flood loss properties that, with future sea level rise, will be permanently inundated without protection measures (Worcester County Department of Comprehensive Planning, 2006).

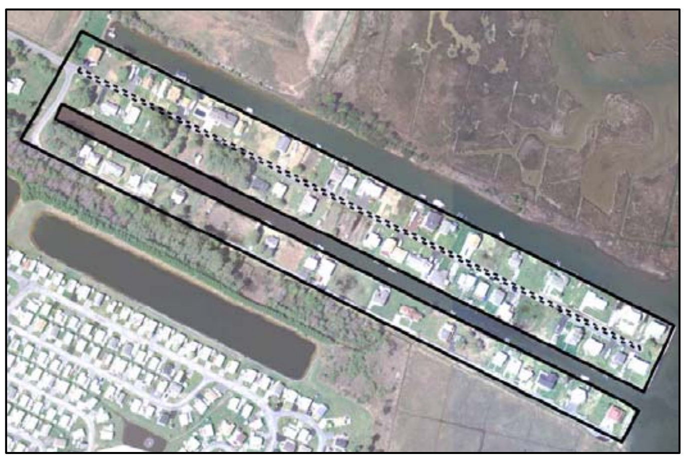


Table 2.1 provides estimates of the number of property parcels that would be completely inundated as well as those that would be partially inundated 50% or more for each sea level rise scenario. Residentially zoned property makes up the majority of parcels projected to be inundated because this is the most common existing land use in the county. The number of parcels expected to be inundated more than 50% by 2025 under the Steady State scenario is a major concern. In just 16 years without any increase in current rates of sea level rise (or assuming no acceleration of sea level rise due to climate change), 173 residential properties will be completely inundated if no protection measures are taken. Another 490 residential parcels will be more than 50% inundated, making living on those properties impossible, a major safety risk, or requiring a large number of structural protection features or flood mitigation retrofits to keep the water out. Of the total number of residential parcels projected to be inundated by the Worst Case scenario in 2100, 10.5% are in the Steady State scenario projections and are, therefore, a very likely and immediate planning problem that could impact many of the county's citizens, tourism, and tax base.

Table 2.1. Property parcels by zoning projected to be inundated by observed sea level rise rates and Worst Case scenario.

Property Parcels Projected to be Inundated	Development Zoning				
	Residential	**Commercial**	**Industrial**	**Agricultural**	**Institutional**
Steady State Sea Level Rise, 2025					
Parcels inundated <100% and ≥50%	490	44	0	38	1
Parcels 100% inundated	173	25	0	11	0
Worst Case Sea Level Rise, 2025					
Parcels inundated <100% and ≥50%	613	56	1	57	2
Parcels 100% inundated	206	28	0	11	0
Worst Case Sea Level Rise, 2050					
Parcels inundated <100% and ≥50%	1,157	103	1	85	2
Parcels 100% inundated	353	40	0	15	0
Worst Case Sea Level Rise, 2100					
Parcels inundated <100% and ≥50%	3,162	274	11	252	17
Parcels 100% inundated	3,087	267	2	113	11

There are also many commercial and agricultural properties in projected inundation zones. Agricultural properties are generally very large, so even a small number of parcels becoming completely inundated could have a major impact on this industry and way of life. Partial inundation of agricultural properties could prevent the owners from being able to meet a profitable level of production due to lost acres. In addition, salt water intrusion, discussed in later sections for its impact on potable water and the environment, could further impair farming activities on properties that are even slightly inundated or have irrigation canals within the inundation zone due to certain crops' intolerance to increased salinity levels. Commercial property inundation could greatly impact the local economy, and there are many commercial entities located on coastal property due to their water dependent activities.

Table 2.2 presents the number of structures that may any land inundated for each sea level rise scenario. It also shows how many of those land parcels are within currently designated FEMA flood zones (defined in **Sidebar 2.2**). Most of the structures are residential, with a much smaller portion in commercial and agricultural zones. Notably, a majority of the structures fall within the current 100-year floodplain as designated on FEMA Flood Insurance Rate Maps. These zones are tied to the Worcester County Floodplain Law and, therefore, are already subject to some regulations for flood protection that would come into effect if any of the structures become substantially damaged. More about this will be discussed in **Section 3**.

Sidebar 2.2 Flood Zone Definitions

V zones are areas closest to the shoreline and subject to wave action, high-velocity flow, and erosion during the 100-year floodplain.

A zones are subject to flooding during the 100-year floodplain, but where flood conditions are less severe than in V zones.

An "E" next to a V or A zone designates that a base flood elevation (BFE) has been defined for those zones.

Table 2.2. Structures by existing land use projected to be at least partially inundated by observed sea level rise rates and Worst Case scenario.

Structures Projected to be Inundated	Zoning				
	Residential	Commercial	Industrial	Agricultural	Institutional
Steady State Sea Level Rise, 2025					
Structures inundated	719	66	0	27	9
Structures inundated and in Flood Zone A, AE, or VE	701	65	0	27	9
Percent already in flood zone	97.5%	98.5%	NA	100.0%	100.0%
Worst Case Sea Level Rise, 2025					
Structures inundated	932	82	0	41	11
Structures inundated and in Flood Zone A, AE, or VE	905	81	0	41	11
Percent already in flood zone	97.1%	98.8%	NA	100.0%	100.0%
Worst Case Sea Level Rise, 2050					
Structures inundated	1,992	156	2	108	20
Structures inundated and in Flood Zone A, AE, or VE	1,903	151	2	107	20
Percent already in flood zone	95.5%	96.8%	100.0%	99.1%	100.0%
Worst Case Sea Level Rise, 2100					
Structures inundated	8,232	696	14	891	72
Structures inundated and in Flood Zone A, AE, or VE	7,399	554	13	848	58
Percent already in flood zone	89.9%	79.6%	92.9%	95.2%	80.6%

Table 2.3 presents the same information on structure vulnerability to inundation by jurisdictional location. It shows that the unincorporated portions of the county have the most structures projected to be inundated under each scenario followed closely by Ocean City. Berlin is entirely outside of the projected inundation zones. Snow Hill and Pocomoke City have extremely manageable numbers of structures projected to be inundated, and these are within existing flood zones for the most part, except for in the 2100 Worst Case scenario for Snow Hill. This is far enough in the future, though, that it could be easily avoided if action is taken in the near future. Though Ocean City has a large number of structures projected to be inundated even in the 2025 Steady State scenario, most of its vulnerable structures are in existing flood zones. This means that there is already a perceived risk and, coupled with floodplain regulations and the beach nourishment project, gives Ocean City a head start in dealing with future structural inundation. The unincorporated portions of the county may be more of a challenge because there are quite a few structures under each scenario that are outside of the current 100-year floodplain. Also, the sheer number of structures that could be inundated as soon as 2025 and the lack of a protection already in place will require a major county effort.

Table 2.3. Structures by jurisdiction projected to be at least partially inundated by observed sea level rise rates and Worst Case scenario.

Structures Projected to be Inundated	Structure Location				
	Unincorporated	**Ocean City**	**Snow Hill**	**Pocomoke City**	**Berlin**
Steady State Sea Level Rise, 2025					
Structures inundated	427	385	5	4	0
Structures inundated and in Flood Zone A, AE, or VE	408	385	5	4	0
Percent already in flood zone	95.6%	100.0%	100.0%	100.0%	NA
Worst Case Sea Level Rise, 2025					
Structures inundated	596	461	5	4	0
Structures inundated and in Flood Zone A, AE, or VE	568	461	5	4	0
Percent already in flood zone	95.3%	100.0%	100.0%	100.0%	NA
Worst Case Sea Level Rise, 2050					
Structures inundated	1,472	777	16	13	0
Structures inundated and in Flood Zone A, AE, or VE	1,379	776	15	13	0
Percent already in flood zone	93.7%	99.9%	93.8%	100.0%	NA
Worst Case Sea Level Rise, 2100					
Structures inundated	5,889	3835	94	87	0
Structures inundated and in Flood Zone A, AE, or VE	5,124	3622	46	80	0
Percent already in flood zone	87.0%	94.4%	48.9%	92.0%	NA

Part of the existing development in Worcester County has been around for over 100 years and is an important component of the community's character and atmosphere that the Worcester County Comprehensive Plan and other local regulations are trying to protect. Sea level rise is a major threat to historic structures and resources because these sites cannot simply be abandoned or compensated for. **Table 2.4** presents the number of mapped historic resource sites within each jurisdiction that would be within projected sea level rise scenarios. Fortunately, the number of sites is not high, although several of the sites are large historic districts encompassing many structures, some of which may fall within the inundation projections. Under current sea level rise rates, it is projected that 12 historic sites throughout the county would be at least partially inundated by 2025 if no protection measures are taken. Four of these sites are shown in **Figures 2.1** and **2.2**. These 2025 vulnerable historic sites will require immediate attention as planning the most appropriate and least harmful measures to protect these resources and locating funding for implementation could take many years. The historic resources at risk only increase by three sites until the 2100 Worst Case scenario, although a more detailed field assessment of risk to historic structures should be done on a regular basis as these dates become closer. The 2100 Worst Case scenario shows a total of 48 historic sites that could be inundated.

Table 2.4. Historic resources by jurisdiction projected to be inundated by observed sea level rise rates and Worst Case scenario.

Historic Resources Projected to be Inundated	Historic Resource Location				
	Unincorporated	Ocean City	Pocomoke City	Snow Hill	Berlin
Steady State Sea Level Rise, 2025					
Historic resources inundated	6	1	2	3	0
Worst Case Sea Level Rise, 2025					
Historic resources inundated	7	2	2	4	0
Worst Case Sea Level Rise, 2050					
Historic resources inundated	7	2	2	4	0
Worst Case Sea Level Rise, 2100					
Historic resources inundated	12	21	6	9	0

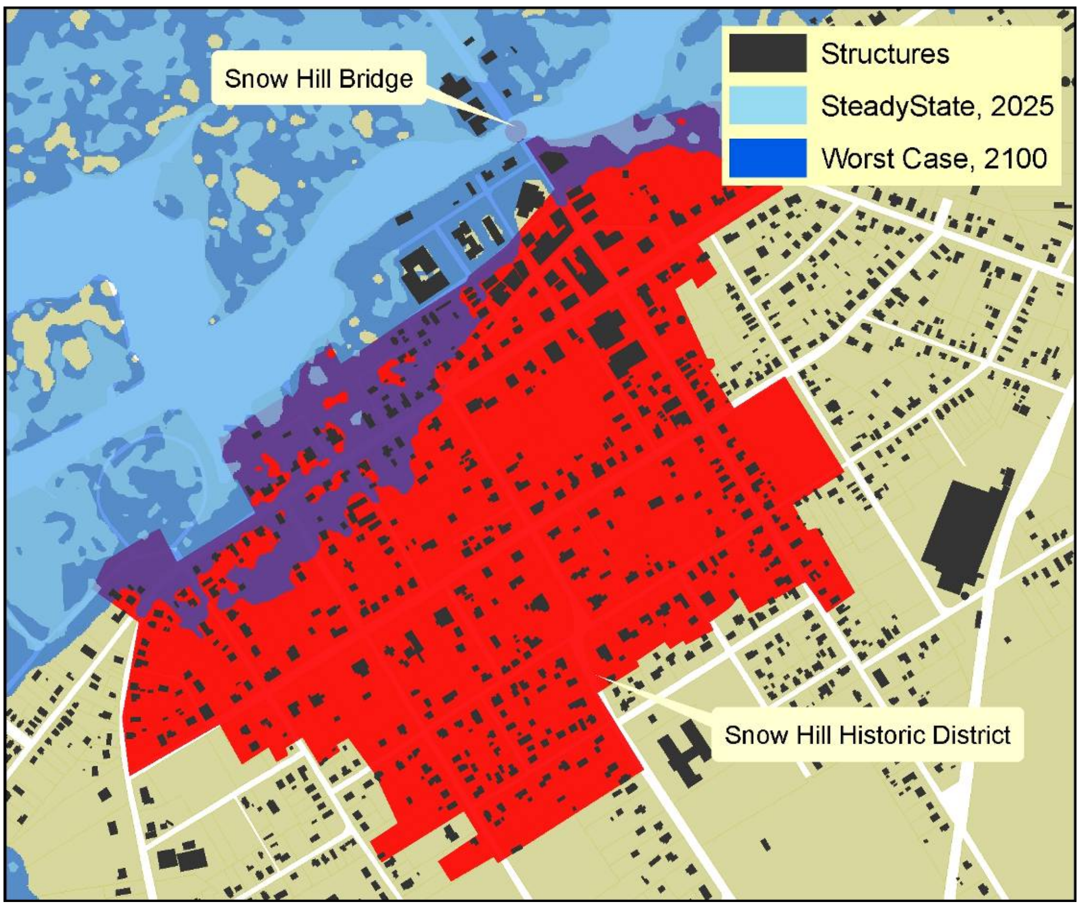


Figure 2.1. Snow Hill historic resources projected to be partially or completely inundated.

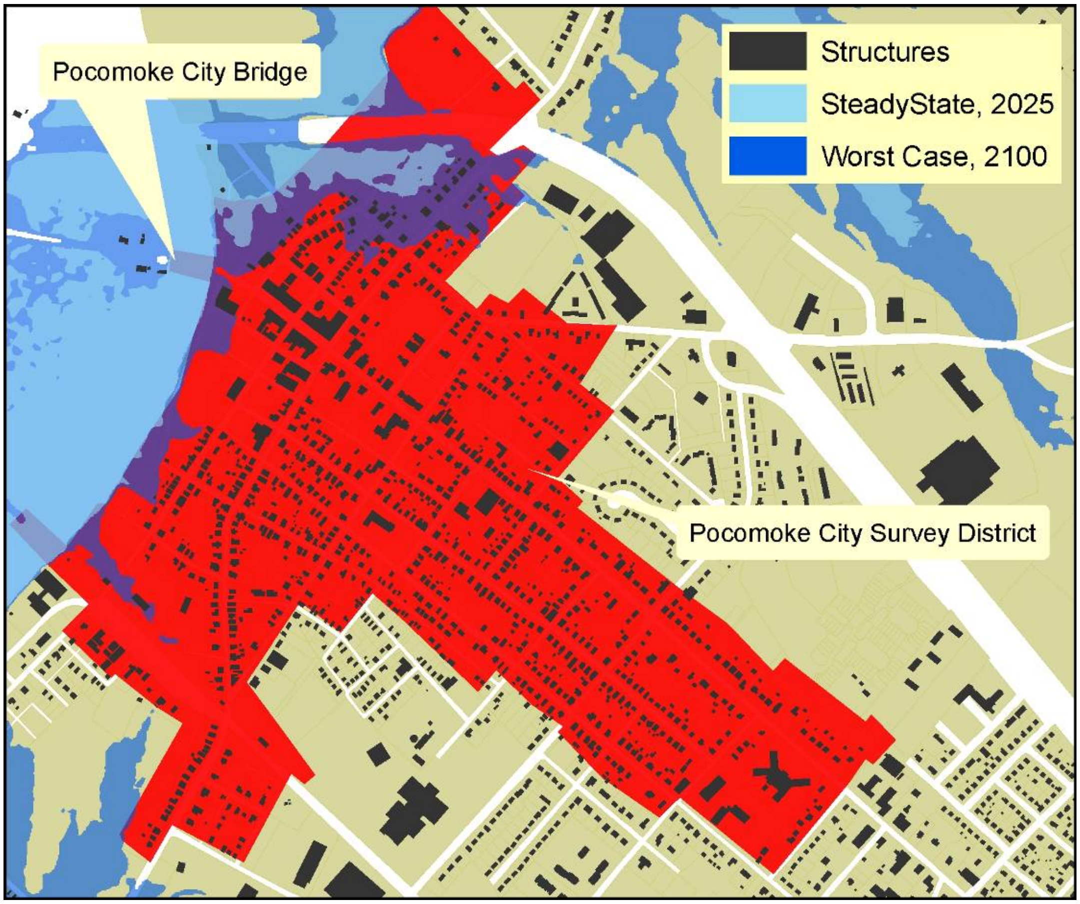


Figure 2.2. Pocomoke City historic resources projected to be partially or completely inundated.

Future Development

The Worcester County Comprehensive Plan lays out a vision of preserving the rural and coastal character of the county that includes designating large connected tracts of land as conservation. The Future Land Use Map limits sprawl by creating compact towns surrounded by agricultural and natural lands. If this vision is implemented, then it would mean many of the parcels zoned for development would actually be used for conservation. The potential for this as a response option is discussed in **Section 3**.

Of the residential parcels projected to be 100% inundated by 2025 under the Steady State scenario, 18% are at least partially within an area designated for conservation on the Future Land Use Map. For the agricultural parcels inundated at least 50% under this scenario in 2025, approximately 66% are located in conservation use areas.

Only about 5% of the residential parcels projected to be inundated in 2100 by the Worst Case scenario are in areas designated for conservation. The remainder of the parcels would be allowed or possibly encouraged for development if the potential for inundation is not made known to the public. For agricultural parcels projected to be at least 50% inundated by 2100 under the Worst Case scenario, 51% are at least partially within conservation designated areas.

The ideal way to decrease vulnerability of inundation for private development is to retreat development or not develop in the projected inundation zones at all. Worcester County has a great opportunity in this regard because 30% of the property parcels projected to be 100% inundated by the Worst Case scenario in 2100 do not currently house any structures. Another important factor for limiting future development in these projected inundation zones is to address the placement of infrastructure. This subject will be discussed in **Section 2.2**.

Increased Vulnerability from Storm Surge Flooding

A major impact of sea level rise is an increase in the land area at risk from storm surge-related flooding and an increase in the depth of flooding in areas already at risk from storm surge (defined in **Sidebar 2.3**). As sea level rises, the return frequencies of coastal floods of a given elevation will increase (i.e., higher floods will happen more often, and the boundaries of flood zones for floods of a given return frequency will move higher and further landward). Shoreline recession due to erosion will shift flood zones further landward, as discussed in **Section 2.3**.

In this section, storm surge flooding from a Category 3 hurricane, as it will occur under the steady state and average accelerated scenarios, is analyzed. This would be the most probable maximum extent of flooding. It can be inferred from these projections that impacts from smaller storm events such as Nor'easters and tropical storms would also be increased under the sea level rise scenarios as compared to their impacts today, but to a lesser degree than described in the following tables.

Sidebar 2.3 Definition of Storm Surge

A rise above the normal water level along a shore caused by strong onshore winds and/or reduced atmospheric pressure. The surge height is the difference of the observed water level and the predicted tide (Weatherbug, n.d.).

Existing and Currently Zoned Development

Areas of the county's 100-year tidal floodplain are highly developed as well as the projected 100-year tidal floodplain associated with expected sea level rise. While property in the current floodplain (see **Table 2.5**) has a high probability of becoming permanently inundated with sea level rise, the concern with increased storm surge due to sea level rise is that land previously not at risk of flooding previously will be in the future. This could greatly influence development patterns or result in large financial losses and possibly the loss of life. Worcester County already has $1.75 million in repetitive flood loss claims, with 44 repetitive flood loss properties (Worcester County Department of Comprehensive Planning, 2006).

Table 2.5. Structures located in the current 100-year floodplain.

Structures	Count	Improvement Value	
		Average	Total
Boat Slips and Docks	456	20,805	8,024,000
Single Family Homes	4,361	614,793	623,881,770
Mobile Homes	873	44,451	38,805,850
Condominiums	488	927,422	70,568,180
Commercial, Industrial, Institutional	179	1,085,720	53,384,330
Agricultural	15	78,032	1,170,480
Total	**6,372**	**2,771,224**	**795,834,610**

Sea level rise is a slow-moving hazard that is not a human safety concern in itself; however, increased storm surge from sea level rise is a major public safety issue. The increase in property at risk from storm surge also will increase the population at risk and the need for emergency management preparedness in order to evacuate larger areas of the county.

As with the inundation projections, a majority of the properties at risk of increased storm surge are residentially zoned (**Table 2.6**). The increases between the escalating scenarios are minimal, meaning that if any action is going to be taken it needs to be before 2025 to make the most difference. Not counting the parcels inundated under the 2025 Steady State scenario as reported in **Table 2.1**, there are 16,930 residentially zoned parcels at risk from Category 3 storm surge in just the next 16 years. There are also 2,487 commercial properties and 2,183 agricultural properties that will not be permanently inundated, but will be within the increased Category 3 surge risk zone. Increased storm surge flooding could, therefore, have a major impact on homes and businesses in the county and require a long-term recovery effort if a major storm should hit.

Table 2.6. Property parcels by existing land use projected to be at risk from increased Hurricane Category 3 storm surge due to sea level rise.

Property Parcels Projected to Flood	Zoning				
	Residential	Commercial	Industrial	Agricultural	Institutional
Hurricane Category 3 Storm Surge and Steady State Sea Level Rise, 2025					
Parcels at risk	17,923	2,564	88	2,219	65
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2025					
Parcels at risk	17,947	2,579	88	2,232	65
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2050					
Parcels at risk	18,228	2,634	93	2,298	65
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2100					
Parcels at risk	18,880	2,725	101	2,468	65

As **Table 2.7** presents, there are 20,522 structures countywide that are at risk of Category 3 storm surge respective to Steady State sea level rise in 2025, which is 42% of all structures in the county. In Ocean City, 89% of the structures are at risk of increased surge from the Steady State 2025 scenario. The numbers of structures at risk increase slightly with each scenario. In 2100 with Average Accelerated sea level rise, storm surge will put all but 518 structures at risk in Ocean City.

Table 2.7. Structures by jurisdiction projected to be at risk from Hurricane Category 3 storm surge with observed sea level rise rates and average accelerated sea level rise.

Structures Projected to Flood	Structure Location				
	Unincorporated	**Ocean City**	**Snow Hill**	**Pocomoke City**	**Berlin**
Hurricane Category 3 Storm Surge and Steady State Sea Level Rise, 2025					
Structures at risk	13,220	6,699	199	404	0
Structures at risk and in Flood Zone A, AE, or VE	8,023	6,278	58	142	0
Percent already in flood zone	60.7%	93.7%	29.1%	35.1%	NA
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2025					
Structures at risk	13,266	6,711	200	407	0
Structures at risk and in Flood Zone A, AE, or VE	8,028	6,289	58	142	0
Percent already in flood zone	60.5%	93.7%	29.0%	34.9%	NA
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2050					
Structures at risk	13,913	6,785	213	462	0
Structures at risk and in Flood Zone A, AE, or VE	8,112	6,359	58	142	0
Percent already in flood zone	58.3%	93.7%	27.2%	30.7%	NA
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2100					
Structures at risk	15,031	6,914	278	579	0
Structures at risk and in Flood Zone A, AE, or VE	8,161	6,486	58	142	0
Percent already in flood zone	54.3%	93.8%	20.9%	24.5%	NA

Snow Hill and Pocomoke City have relatively lower percentages of structures at risk, but they still have enough to be a concern. At the maximum surge estimates in 2100, 18% of Snow Hill structures are at risk. Pocomoke City has a higher risk, with 28% of structures within the increased surge zone in 2100. Berlin has no structures within the increased surge zones.

The unincorporated county, Snow Hill, and Pocomoke City each have a large number of structures at risk from increased surge that are not within the current 100-year floodplain. Only 58 of Snow Hill's 199 structures at risk from increased surge from the 2025 Steady State scenario are currently within a designated FEMA flood zone and, therefore, have a perception of flood risk. Unless flood and surge zones are remapped and the public is educated of these future increased risks, owners of these structures cannot realize the need to purchase increased flood insurance in the future or mitigate the structures to protect from flooding.

Mitigating or recovering from historic structure flood damage is particularly difficult because modifications to the building may make it ineligible for the National Register of Historic Places. Worcester County has a multitude of historic sites (some of which are currently listed on the National Register) within the projected Category 3 storm surge zones after sea level rise, as shown in **Table 2.8**. There are 89 historic sites at least partially within the surge zone in 2025 with the Steady State scenario. This increases to 115 sites, or 26% of all historic sites in the county, under the 2100 Average Accelerated scenario storm surge. Despite its small size, Snow Hill has the largest number of historic sites at risk – 48% of all historic sites within the city boundaries in 2100 with Average Accelerated increased storm surge. Examples of the sites at risk are show in **Figures 2.3** and **2.4**.

Table 2.8. Historic resources by jurisdiction at risk from Hurricane Category 3 storm surge with observed sea level rise rates and average accelerated sea level rise.

Historic Resources Projected to Flood	**Historic Resource Location**				
	Unincorporated	**Ocean City**	**Pocomoke City**	**Snow Hill**	**Berlin**
Hurricane Category 3 Storm Surge and Steady State Sea Level Rise, 2025					
Historic resources at risk	24	25	15	25	0
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2025					
Historic resources at risk	25	25	15	25	0
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2050					
Historic resources at risk	26	29	18	28	0
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2100					
Historic resources at risk	29	29	18	39	0

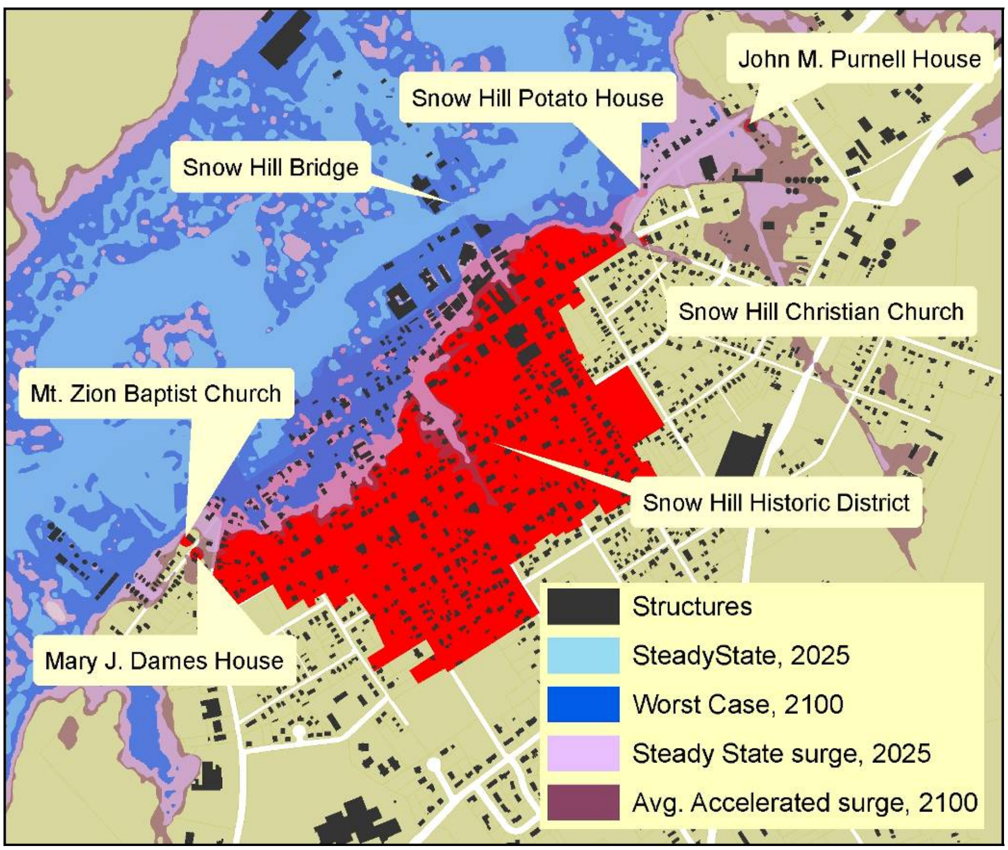


Figure 2.3. Snow Hill historic resources projected to be inundated or at risk of increased storm surge from sea level rise.

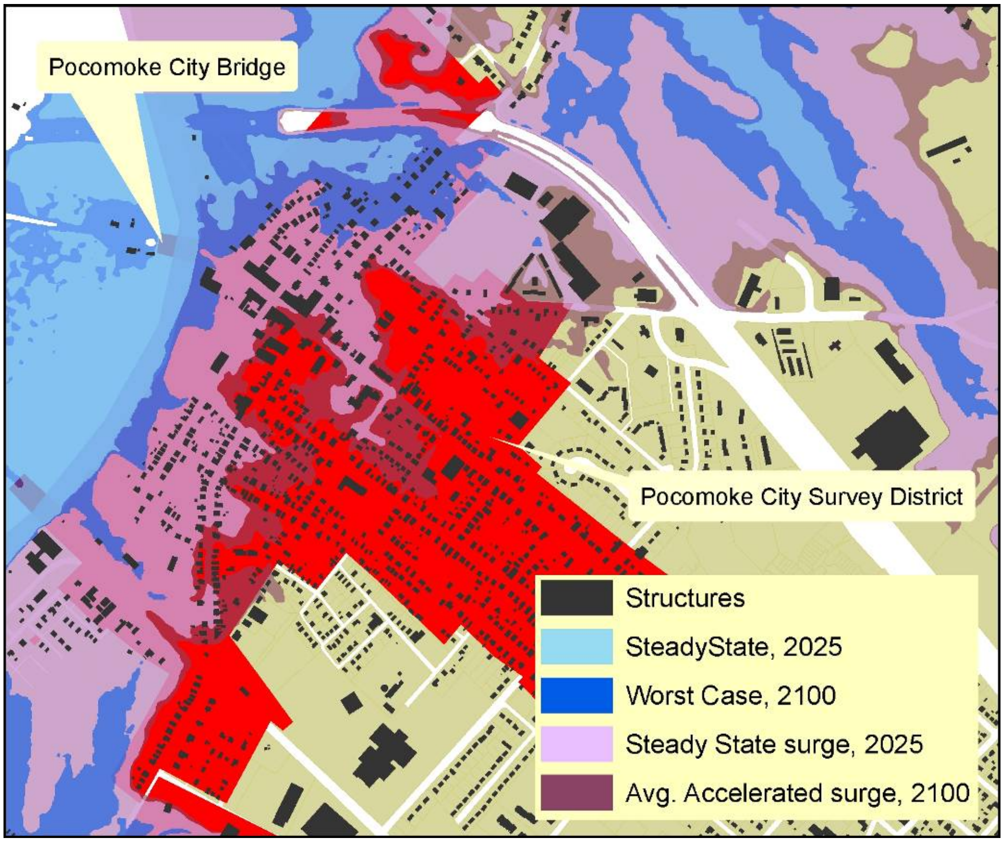


Figure 2.4. Pocomoke City historic resources projected to be inundated or at risk of increased storm surge from sea level rise.

Future Development

Approximately 38% of the parcels within the inundation and increased surge zones for Steady State sea level rise in 2025 are undeveloped but designated for some type of development. Also, 36% of the parcels are undeveloped in the 2100 Average Accelerated surge scenario. The distribution of those undeveloped parcels by future land use designation is presented in **Table 2.9**. The majority is designated for residential use; however, there also are many undeveloped commercial and agricultural properties at risk from increased storm surge. If these properties are allowed to develop, it will greatly increase the values at risk from increased storm surge since because as undeveloped, there is already $1.1 billion in property value at risk. As seen in **Table 2.7**, many of these properties outside of Ocean City are not in current FEMA flood zones and would most likely not obtain flood insurance. To acquire even a portion of these properties most at risk by 2025 would be major undertaking – just one third of the undeveloped residential homes at risk from Steady State surge in 2025 would cost $238 million.

Table 2.9. Currently undeveloped property parcels by future land use projected to be at risk from Hurricane Category 3 storm surge with observed sea level rise rates and average accelerated sea level rise.

Undeveloped Property Parcels Projected to Flood	Future Land Use of Undeveloped Parcels at Risk from Storm Surge				
	Residential	Commercial	Industrial	Agricultural	Institutional
Hurricane Category 3 Storm Surge and Steady State Sea Level Rise, 2025					
Parcels at risk	6,314	718	9	733	12
Estimated value	$794,647,440	$280,680,870	$621,470	$48,165,780	$1,277,880
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2025					
Parcels at risk	6,326	719	9	741	12
Estimated value	$794,892,650	$280,839,830	$621,470	$48,524,120	$1,277,880
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2050					
Parcels at risk	6,369	719	9	759	12
Estimated value	$803,575,590	$280,839,830	$621,470	$49,599,830	$1,277,880
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2100					
Parcels at risk	6,572	728	9	814	14
Estimated value	$835,776,730	$281,991,330	$621,470	$52,625,280	$1,336,210

2.2 INCREASED VULNERABILITY OF INFRASTRUCTURE AND PUBLIC FACILITIES

Potential sea level rise impacts are described here for roads, potable water supply distribution lines and treatment facilities, and wastewater management facilities. GIS data were not obtained for storm water management facilities or for other critical public facilities. Potential vulnerabilities to which these facilities might be subject are briefly described below.

Transportation Infrastructure

Table 2.10 presents the number of miles of roads of different classes that may be directly inundated as a result of sea level rise under the Steady State 2025 scenario and the Worst Case scenarios for 2025, 2050, and 2100 based on the local elevation of the terrain in which they are located. It is important to note, however, that actual vulnerability is a function of road surface elevations that may be higher than the surrounding terrain. The most vulnerable roads in the county include those in the Pocomoke River floodplain, including portions of Pokomoke City and Snow Hill; roads that provide access to the western shores of Chincoteague Bay and Sinepuxent Bay, especially portions of South Point Road, Eagles Nest Road, and Airport Road as well as roads within the Assateague Point and The Landings subdivisions; many of the roads in the subdivisions along Sinepuxent Bay and Isle of Wight Bay in West Ocean City; many of the roads in Ocean Pines and other areas along the St. Martins River, including Piney Island Drive, Dixie Drive, Salt Grass Point Road, and St. Martin's Neck Road; roads along Grey's Creek and within Edgewater Acres on the north shore of Assawoman Bay; and many of the bayside roads in Ocean City. As shown in **Table 2.10**, the mileage of vulnerable roads increases by a factor of four between 2050 and 2100 for the Worst Case sea level rise scenario (from approximately 32 to 130 mi).

Table 2.10. Road miles projected to be inundated by steady and worst case sea level rise scenarios.

Location	Miles of Road Class Inundated				
	Major	**Collector**	**Minor**	**Local**	**Alley**
Steady State Sea Level Rise, 2025					
Unincorporated County	3.0	1.3	1.3	7.9	0.0
Municipality	0.1	0.0	0.0	1.1	0.0
Worst Case Sea Level Rise, 2025					
Unincorporated County	3.0	1.6	1.3	9.7	0.0
Municipality	0.1	0.0	0.0	1.8	0.0
Worst Case Sea Level Rise, 2050					
Unincorporated County	3.1	2.9	1.5	18.0	0.0
Municipality	0.7	0.0	0.1	5.8	0.3
Worst Case Sea Level Rise, 2100					
Unincorporated County	4.6	9.3	2.9	68.5	0.0
Municipality	7.3	5.4	0.4	28.7	2.0

Inundation impacts will be exacerbated where transportation infrastructure lies in the path of shoreline recession due to elevated sea level rise and erosion. As the mean high tide line moves landward in these areas, roads and bridge approaches will initially be subject to more frequent intermittent flooding from spring high tides. Shoreline recession due to erosion may eventually result in the scouring and undermining of road bases and bridge abutments.

Table 2.11 presents the mileage of roads that will be vulnerable to inundation and storm surge flooding associated with a Category 3 hurricane under Steady State sea level rise for 2025 and Average Accelerated sea level rise for 2025, 2050, and 2100. These values are substantially higher than those reported in **Table 2.10** for simple inundation due to sea level rise. Storm surge impacts may be limited to flooding. However, storm surge also can undermine and destroy the road bed, as shown in **Figure 2.5** as well as damage bridges and causeways, as illustrated in **Figure 2.6**. Roads of particular concern are those used for evacuation of coastal residential areas. As sea level rises, these will be subject to storm wave overwash sooner. As a result, evacuation clearance time windows will be reduced. The causeway approaches to the Harry W. Kelley draw bridge (US 50) and the approaches to the MD 90 bridges over the St. Martins River and Assawoman Bay appear to be the most vulnerable of the potential evacuation routes in Worcester County.

Table 2.11. Road miles at risk from storm surge flooding with observed sea level rise rates and average accelerated sea level rise.

Location	Miles of Road Class at Risk of Flooding				
	Major	**Collector**	**Minor**	**Local**	**Alley**
Hurricane Category 3 Storm Surge and Steady State Sea Level Rise, 2025					
Unincorporated County	13.9	22.7	12.1	166.2	0.0
Municipality	18.8	11.6	2.0	58.2	3.3
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2025					
Unincorporated County	13.9	22.8	12.2	166.6	0.0
Municipality	18.8	12.1	2.0	58.5	3.3
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2050					
Unincorporated County	17.6	24.2	13.6	172.7	0.0
Municipality	19.1	12.2	2.2	60.1	3.3
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2100					
Unincorporated County	18.5	26.6	17.0	185.0	0.0
Municipality	19.1	12.3	2.7	62.5	3.4

Figure 2.5. Storm surge damage to State Road 128 in Orange Beach, Alabama from Hurricane Ivan in 2004 (Source: Hurricane Ivan, 2004).

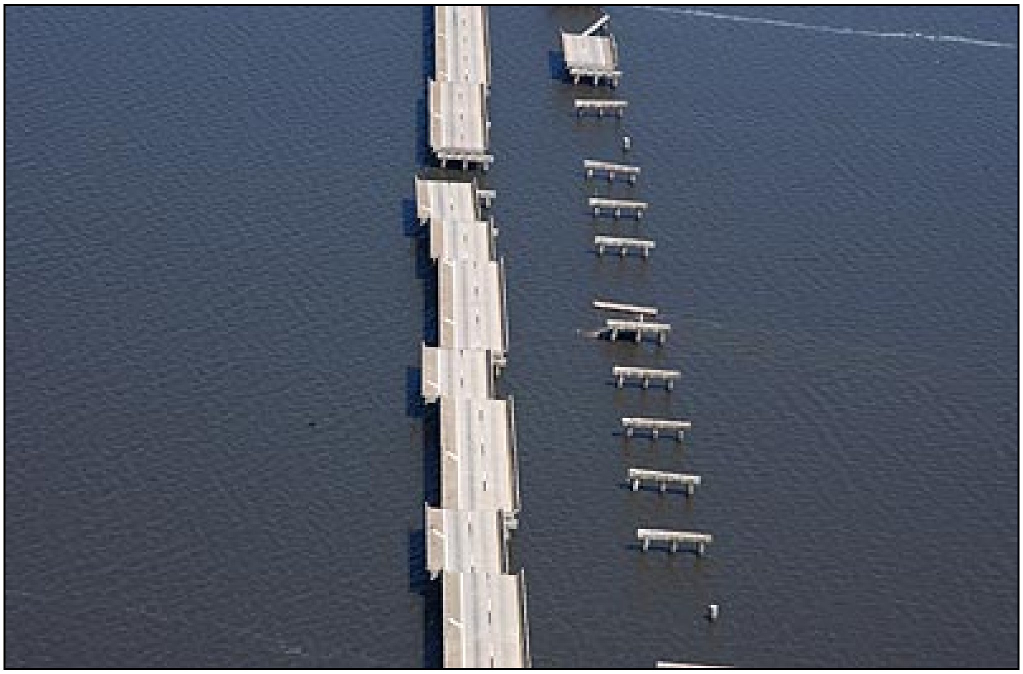


Figure 2.6. I-10 Bridge over Escambia Bay, Florida after Hurricane Ivan in 2004 (Source: Hurricane Ivan, 2004).

Higher water tables can lead to a reduction in the bearing capacity of some soils because of friction loss between soil particles, which may affect the structural stability of road bases and require more frequent resurfacing. Such impacts are likely to occur at the margins of advancing sea level in areas with hydric soils (e.g., sands, sandy loams, silt loams, mucks, and peats) that are hydrologically influenced by adjacent coastal water levels. Such conditions are likely to already be common throughout much of Worcester County where more than 58% of the soils are very limited for road building (USDA NRCS, 2007). Roads in some areas of Worcester County have been constructed on fill. In these cases, the vulnerability of the road to rising ground water will be a function of the nature of the fill substrate and the native soils within which it has been placed.

Sea level rise also may interfere with navigation under bridges by diminishing the above-water clearance. This will not be a major issue for the movable-span bridges in Worcester County, although these bridges will need to be opened more frequently as sea level rises (Maryland Department of Transportation, State Highway Administration, 2007). These bridges include the following:

- The Harry W. Kelley draw bridge (US 50) over Sinepuxent Bay (clearance in closed position is15 ft above mean high tide)[1];
- The Snow Hill bridge (MD 19) on the Pocomoke River (closed position clearance is 5 ft); and
- The Pocomoke City draw bridge (MD 675) on the Pocomoke River (closed position clearance is 4 ft).

[1] An article in the *Baltimore Daily Record* on March 2, 2004 reported that state officials that the Kelley bridge may be replaced in 2019.

Reduced clearance may be an issue at some point for high-clearance vessel traffic under fixed-span bridges such as the US 13 bridge over the Pocomoke River at Pocomoke City (vertical clearance is 35 ft), the MD 90 bridges over the St. Martins River and Assawoman Bay (vertical clearances are 37 ft), and the MD 611 bridge over Sinepuxent Bay (vertical clearance is 35 ft) (Maryland Department of Transportation, State Highway Administration, 2008).

Bridges over non-navigable, freshwater are typically designed with a "drift clearance" of approximately 2 ft. Where sea level rise affects these streams, vulnerability to blockage and structural damage from floating debris will increase. An inventory of bridges maintained by Worcester County and its municipalities was not obtained for this analysis.

Potable Water Systems

Direct inundation poses a threat both to water supply lines as well as the wells and water supply treatment and storage facilities. **Table 2.12** presents the numbers of miles of potable water supply mains, within water service areas operated by Worcester County and its municipalities, that may be directly inundated as a result of sea level rise under the Steady State 2025 scenario and the Worst Case scenarios for 2025, 2050, and 2100. No GIS water line data were obtained for the towns of Snow Hill or Ocean City. Affected water lines were approximated on the basis of the local street network. The mileage of vulnerable water supply lines increases significantly for the 2050 and 2100 Worst Case sea level rise scenarios. The most vulnerable areas include the bay side of Ocean City, portions of Ocean Pines and West Ocean City, the Assateague Point and The Landings service areas along Sinepuxent Bay, the Edgewater Acres service area on Nantucket Point, and areas of Snow Hill closest to the Pocomoke River. In Pocomoke City, only a small fraction of the water lines closest to the river would be affected under the 2100 Worst Case scenario. No water lines in Berlin are vulnerable to sea level rise inundation.

Table 2.12. Potable water supply lines projected to be inundated by observed and worst case sea level rise scenarios.

Potable Water Line Miles at Risk of Flooding	Water Line Miles by Jurisdictional Location				
	Unincorporated	**Ocean City***	**Pocomoke City**	**Snow Hill***	**Berlin**
Steady State Sea Level Rise, 2025					
Water lines (miles)	1.0	0.8	0.0	0.3	0.0
Worst Case Sea Level Rise, 2025					
Water lines (miles)	4.5	1.5	0.0	0.4	0.0
Worst Case Sea Level Rise, 2050					
Water lines (miles)	11.2	5.8	0.0	0.8	0.0
Worst Case Sea Level Rise, 2100					
Water lines (miles)	42.0	40.5	1.8	1.9	0.0

***** Values for Ocean City and Snow Hill approximated from local road network.

Table 2.13 lists the numbers of water supply wells, pumping stations, and treatment facilities, within water service areas operated by Worcester County and its municipalities that are projected to be inundated by sea level rise under the Steady State 2025 scenario and the Worst Case scenarios for 2025, 2050, and 2100. The GIS data we obtained lacked information for the towns of Berlin, Ocean City, and Snow Hill as well as the Oyster Harbor and Sunset Village service areas. The GIS data for Ocean Pines, Pocomoke City, and the Riddle farm service area lacked a portion of the facilities listed in a data base provided by the county. Thus, **Table 2.13** may be an under-estimate of water supply facility vulnerability.

None of the potable water supply facilities is projected to be inundated by 2025 under either the Steady State or Worst Case sea level rise scenarios (**Table 2.13**). One well in the West Ocean City area will most likely be inundated under the 2050 Worst Case scenario. One additional well as well as a treatment facility in that area may be inundated under the 2100 Worst Case scenario along with both wells and one treatment facility in the Edgewater Acres service area on Nantucket Point.

Table 2.13. Public potable water supply facilities projected to be inundated by current and worst case sea level rise scenarios.

Public Water Supply Service Area[†]	**Public Water Supply Facilities**		
	Wells	**Water Pumping Stations**	**Water Supply Treatment Facilities**
Steady State Sea Level Rise, 2025			
Assateague Point	0	0	0
Berlin*	n/a	n/a	n/a
Briddletown	0	0	0
Edgewater Acres–Nantucket Point	0	0	0
Landings (Bayside)	0	0	0
Mystic Harbour	0	0	0
Newark	0	0	0
Ocean City*	n/a	n/a	n/a
Ocean Pines[†††]	0	0	0
Oyster Harbor*	n/a	n/a	n/a
Pocomoke City[††]	0	0	0
Riddle Farm[††††]	0	0	0
Snow Hill*	n/a	n/a	n/a
Sunset Village*	n/a	n/a	n/a
West Ocean City**	0	0	0
Worst Case Sea Level Rise, 2025			
Assateague Point	0	0	0
Berlin*	n/a	n/a	n/a
Briddletown	0	0	0
Edgewater Acres–Nantucket Point	0	0	0
Landings (Bayside)	0	0	0

Public Water Supply Service Area†	Public Water Supply Facilities		
	Wells	Water Pumping Stations	Water Supply Treatment Facilities
Mystic Harbour	0	0	0
Newark	0	0	0
Ocean City*	n/a	n/a	n/a
Ocean Pines†††	0	0	0
Oyster Harbor*	n/a	n/a	n/a
Pocomoke City††	0	0	0
Riddle Farm††††	0	0	0
Snow Hill*	n/a	n/a	n/a
Sunset Village*	n/a	n/a	n/a
West Ocean City**	0	0	0
Worst Case Sea Level Rise, 2050			
Assateague Point	0	0	0
Berlin*	n/a	n/a	n/a
Briddletown	0	0	0
Edgewater Acres–Nantucket Point	0	0	0
Landings (Bayside)	0	0	0
Mystic Harbour	0	0	0
Newark	0	0	0
Ocean City*	n/a	n/a	n/a
Ocean Pines†††	0	0	0
Oyster Harbor*	n/a	n/a	n/a
Pocomoke City††	0	0	0
Riddle Farm††††	0	0	0
Snow Hill*	n/a	n/a	n/a
Sunset Village*	n/a	n/a	n/a
West Ocean City**	1	0	0
Worst Case Sea Level Rise, 2100			
Assateague Point	0	0	0
Berlin*	n/a	n/a	n/a
Briddletown	0	0	0
Edgewater Acres–Nantucket Point	2	0	1
Landings (Bayside)	0	0	0
Mystic Harbour	0	0	0
Newark	0	0	0
Ocean City*	n/a	n/a	n/a
Ocean Pines†††	0	0	0
Oyster Harbor*	n/a	n/a	n/a
Pocomoke City††	0	0	0
Riddle Farm††††	0	0	0
Snow Hill*	n/a	n/a	n/a

Public Water Supply Service Area[†]	Public Water Supply Facilities		
	Wells	Water Pumping Stations	Water Supply Treatment Facilities
Sunset Village*	n/a	n/a	n/a
West Ocean City**	2	0	1

† Only service areas operated by municipalities and Worcester County with wells or other facilities located within the service area are included in this table.

†† The county database lists six wells and two treatment plants for the Pocomoke City service area. The GIS database includes only a single well and no treatment facilities.

††† The GIS data include only five wells for the Ocean Pines service area and do not include any treatment facility locations. The county database, however, indicates that treatment facilities are associated with each of a total of 14 wells, some of which are "standby wells."

†††† The GIS data include only the treatment facility for the Riddle Farm service area. The county database includes three wells. Some or all of these wells may be exposed to category 3 storm surge under one or more of the sea level rise scenarios.

* No GIS data were provided for five service areas included in the county database: Berlin, Ocean City, Oyster Harbor, Snow Hill, and Sunset Village. Coordinate data for facilities in these areas are being prepared by county staff.

** West Ocean City is not listed as a water or sewer service area in the database provided by the county. However two wells (Center Drive and Ocean gateway) and three water supply treatment facilities (Center Drive, Golf Course Road, and Whisper Trace Drive) included in the GIS file provided by the county are listed as being within West Ocean City and are not readily matched to any of the service areas in the county database.

Shoreline recession in areas along bay and ocean coasts may cause physical damage from direct exposure to water and waves that result from shore erosion. Water lines and potentially some wells and treatment facilities in Ocean City are likely to be the most vulnerable to these impacts where they are not protected by sea walls or other structures.

Enhanced storm surge flooding does not represent a significant threat to water supply lines except where it is accompanied by shore erosion. Wells, pumping stations, and water supply treatment facilities may, however, be impaired or damaged by storm surge flooding if they are not adequately flood-proofed. **Table 2.14** reveals substantially larger numbers of water supply facilities at risk from Category 3 storm surge flooding combined with sea level rise. Nine wells and six water treatment facilities are subject to such flooding associated with the 2025 Steady State and Average Accelerated sea level rise scenarios. Two additional wells are at risk of Category 3 storm surge flooding under the 2050 and 2100 Average Accelerated sea level rise scenarios, and two water supply treatment facilities are additionally at risk under the 2100 Average Accelerated sea level rise scenario.

Table 2.14. Public potable water supply facilities at risk from storm surge flooding with observed sea level rise rates and average accelerated sea level rise.

Public Water Supply Service Area[†]	**Public Water Supply Facilities**		
	Wells	**Water Pumping Stations**	**Water Supply Treatment Facilities**
Hurricane Category 3 Storm Surge and Steady State Sea Level Rise, 2025			
Assateague Point	2	0	0
Berlin*	n/a	n/a	n/a
Briddletown	0	0	0
Edgewater Acres–Nantucket Point	2	0	1
Landings (Bayside)	0	0	1
Mystic Harbour	1	0	0
Newark	0	0	0
Ocean City*	n/a	n/a	n/a
Ocean Pines[†††]	1	0	1
Oyster Harbor*	n/a	n/a	n/a
Pocomoke City[††]	1	0	0
Riddle Farm[††††]	0	0	0
Snow Hill*	n/a	n/a	n/a
Sunset Village*	n/a	n/a	n/a
West Ocean City**	2	0	3
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2025			
Assateague Point	2	0	1
Berlin*	n/a	n/a	n/a
Briddletown	0	0	0
Edgewater Acres–Nantucket Point	2	0	1
Landings (Bayside)	0	0	1
Mystic Harbour	1	0	0
Newark	0	0	0
Ocean City*	n/a	n/a	n/a
Ocean Pines[†††]	1	0	0
Oyster Harbor*	n/a	n/a	n/a
Pocomoke City[††]	1	0	0
Riddle Farm[††††]	0	0	0
Snow Hill*	n/a	n/a	n/a
Sunset Village*	n/a	n/a	n/a
West Ocean City**	2	0	3
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2050			
Assateague Point	2	0	1
Berlin*	n/a	n/a	n/a
Briddletown	0	0	0
Edgewater Acres–Nantucket Point	2	0	1
Landings (Bayside)	0	0	1

Public Water Supply Service Area†	Public Water Supply Facilities		
	Wells	Water Pumping Stations	Water Supply Treatment Facilities
Mystic Harbour	3	0	0
Newark	0	0	0
Ocean City*	n/a	n/a	n/a
Ocean Pines†††	1	0	0
Oyster Harbor*	n/a	n/a	n/a
Pocomoke City††	1	0	0
Riddle Farm††††	0	0	0
Snow Hill*	n/a	n/a	n/a
Sunset Village*	n/a	n/a	n/a
West Ocean City**	2	0	3
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2100			
Assateague Point	2	0	1
Berlin*	n/a	n/a	n/a
Briddletown	0	0	0
Edgewater Acres–Nantucket Point	2	0	1
Landings (Bayside)	0	0	1
Mystic Harbour	3	0	1
Newark	0	0	0
Ocean City*	n/a	n/a	n/a
Ocean Pines†††	1	0	0
Oyster Harbor*	n/a	n/a	n/a
Pocomoke City††	1	0	0
Riddle Farm††††	0	0	1
Snow Hill*	n/a	n/a	n/a
Sunset Village*	n/a	n/a	n/a
West Ocean City**	2	0	3

† Only service areas operated by municipalities and Worcester County with wells or other facilities located within the service area are included in this table.

†† The county database lists six wells and two treatment plants for the Pocomoke City service area. The GIS database includes only a single well and no treatment facilities.

††† The GIS data include only five wells for the Ocean Pines service area and do not include any treatment facility locations. The county database, however, indicates that treatment facilities are associated with each of a total of 14 wells, some of which are "standby wells."

†††† The GIS data include only the treatment facility for the Riddle Farm service area. The county database includes three wells. Some or all of these wells may be exposed to category three storm surge under one or more of the sea level rise scenarios.

* No GIS data were provided for five service areas included in the county database: Berlin, Ocean City, Oyster Harbor, Snow Hill, and Sunset Village. Coordinate data for facilities in these areas are being prepared by county staff.

** West Ocean City is not listed as a water or sewer service area in the database provided by the county. However two wells (Center Drive and Ocean gateway) and three water supply treatment facilities (Center Drive, Golf Course Road, and Whisper Trace Drive) included in the GIS file provided by the county are listed as being within West Ocean City and are not readily matched to any of the service areas in the county database.

Saltwater contamination of ground water aquifers due to rising sea level is most likely to occur in areas of Worcester County proximate to the Atlantic Ocean or the interior bays where water is drawn from the surficial, unconfined Pleistocene aquifer. Such areas include the Mystic Harbour, Ocean Pines, and River Run water supply service areas. It is very likely that a number of semi-public water supplies, serving campgrounds, small subdivisions, etc., and private wells, which also tap this aquifer but were not analyzed in this study, will similarly be at risk of saltwater intrusion as sea level rises. Long-term studies of chloride levels in water supply wells serving Ocean City suggest that wells drawing from the confined Ocean City or Manokin aquifers are unlikely to be vulnerable to saltwater intrusion from rising sea levels because of the overlying confining beds (Phelan, 1987 and 2008; U.S. Geological Survey, 2008).[2] While an increase in chloride levels has been recorded at the 44th Street well, which taps the Ocean City aquifer (U.S. Geological Survey, 2008), the cause has been attributed to leakage from the underlying Manokin aquifer rather than saltwater intrusion from the ocean. Some saltwater intrusion has been documented in the unconfined Pleistocene aquifer on the Ocean City barrier island (Town of Ocean City, 2007), but this aquifer is not used for public potable supply in this area.

Elevated water tables can impair the structural stability of water supply lines and the foundations of water treatment and storage facilities, and the influx of salty ground water can expose buried pipelines to corrosion, especially where cast iron or concrete pipe is exposed to saltwater (NRC, 1987). The areas most vulnerable to such impacts are those where water lines are closest to current shorelines (i.e., the bay side of Ocean City, portions of Ocean Pines and West Ocean City, the Assateague Point and The Landings service areas along Sinepuxent Bay, and the Edgewater Acres service area on Nantucket Point).

Wastewater Management Systems

As is the case with water supply infrastructure, direct inundation poses a threat to both wastewater treatment facilities and the wastewater collection system, including sanitary sewer lines, wet wells, lift stations, pump stations, vacuum collection stations, and storage tanks. **Table 2.15** reports the number of miles of sewer mains within sanitary service areas operated by Worcester County and its municipalities that may be directly inundated as a result of sea level rise under the Steady State 2025 scenario and the Worst Case scenarios for 2025, 2050, and 2100. No GIS sewer main data were obtained for the town of Ocean City. Affected water lines were approximated on the basis of the local street network. The mileage of vulnerable sewer mains increases dramatically for the 2100 Worst Case sea level rise scenario. The most vulnerable areas include the bay side of Ocean City, portions of Ocean Pines and West Ocean City, the Assateague Point and The Landings service areas along Sinepuxent Bay, the Edgewater Acres service area on Nantucket Point, the Lighthouse Sound subdivision along St. Martins Neck Road, and areas of Snow Hill and Pocomoke City closest to the Pocomoke River. No sewer mains in Berlin are vulnerable to sea level rise inundation.

[2] Freshwater aquifers in Worcester County include the following, from top to bottom: Pleistocene (70 to 180 ft thick), Pocomoke (30 to 80 ft), Ocean City (3 to 120 ft), and the Manokin (50 to 150 ft) (Phelan, 1987).

Table 2.15. Sewer mains projected to be inundated by current and worst case sea level rise scenarios.

Potable Water Line Miles at Risk of Flooding	Sewer Main Miles by Jurisdictional Location				
	Unincorporated	Ocean City*	Pocomoke City	Snow Hill	Berlin
Steady State Sea Level Rise, 2025					
Sewer mains (miles)	4.0	0.8	0.0	<0.1	0.0
Worst Case Sea Level Rise, 2025					
Sewer mains (miles)	4.9	1.5	0.0	<0.1	0.0
Worst Case Sea Level Rise, 2050					
Sewer mains (miles)	9.6	5.8	0.0	0.3	0.0
Worst Case Sea Level Rise, 2100					
Sewer mains (miles)	46.7	40.5	1.1	1.5	0.0

***** Values for Ocean City approximated from local road network.

Table 2.16 lists the number of wastewater treatment and collection facilities within wastewater management service areas operated by Worcester County and its municipalities that are projected to be inundated by sea level rise under the Steady State 2025 scenario and the Worst Case scenarios for 2025, 2050, and 2100. The GIS data obtained lacked information for the town of Ocean City. No wastewater treatment facilities and few collection facilities are threatened by impending sea level rise. A pump station on Center Drive is likely to be inundated under the 2050 Worst Case scenario. With the 2100 Worst Case scenario, eight additional wastewater collection facilities are likely to be vulnerable to inundation, including a wet well on Center Drive, a pump station and wet well on Golf Course Road, pump stations on Madison Avenue, Ocean Parkway, and Yacht Club Drive and a pump station and wet well on Torquay Road.

Table 2.16. Wastewater management facilities projected to be inundated by current and worst case sea level rise scenarios

Jurisdiction	Wastewater Management Facilities		
	Wastewater Treatment Facilities	Wastewater Collection Facilities*	Wastewater Storage Tanks
Steady State Sea Level Rise, 2025			
Unincorporated Worcester County	0	0	0
Ocean City	n/a	n/a	n/a
Pocomoke City	0	0	0
Snow Hill	0	0	0
Berlin	0	0	0
Worst Case Sea Level Rise, 2025			
Unincorporated Worcester County	0	0	0
Ocean City	n/a	n/a	n/a
Pocomoke City	0	0	0
Snow Hill	0	0	0
Berlin	0	0	0

Jurisdiction	Wastewater Management Facilities		
	Wastewater Treatment Facilities	Wastewater Collection Facilities*	Wastewater Storage Tanks
Worst Case Sea Level Rise, 2050			
Unincorporated Worcester County	0	2	0
Ocean City	n/a	n/a	n/a
Pocomoke City	0	0	0
Snow Hill	0	0	0
Berlin	0	0	0
Worst Case Sea Level Rise, 2100			
Unincorporated Worcester County	0	9	0
Ocean City	n/a	n/a	n/a
Pocomoke City	0	0	0
Snow Hill	0	0	0
Berlin	0	0	0

* Wastewater collection facilities include wet wells, lift stations, pump stations, vacuum collection stations, and storage tanks.

Physical damage may result to sewer mains and wastewater management facilities in areas along bay and ocean coasts as a result of shoreline recession. Sewer mains and collection facilities in Ocean City are likely to be the most vulnerable to these impacts where they are not protected by sea walls or other structures.

Enhanced storm surge flooding can cause problems for sewer mains where manholes are not sealed to prevent the inflow of flood waters and sediments. Wastewater treatment and collection facilities may be impaired or damaged by storm surge flooding if they are not adequately flood-proofed. **Table 2.17** indicates that a substantial number of wastewater treatment and collection facilities are susceptible to Category 3 storm surge flooding under the best case scenario of steady state sea level rise: four treatment facilities and 46 collection facilities (two in Pocomoke City and the remainder in unincorporated areas of the county). The number of affected treatment facilities increases to five under the 2050 accelerated sea level rise scenario and to six under the 2100 accelerated sea level rise scenario. Only under the latter case does the number of vulnerable wastewater management facilities increase, from 46 to 52. The most vulnerable areas are similar to those noted above for sewer mains.

Elevated water tables can impair the structural stability of sewer mains and the foundations of wastewater treatment and collection facilities, while the influx of salty ground water can expose buried pipelines to corrosion, especially where cast iron or concrete pipe is exposed to saltwater (NRC, 1987). The areas most vulnerable to such impacts are those where sewer mains are closest to current shorelines as listed above.

Table 2.17. Wastewater management facilities at risk from storm surge flooding with observed sea level rise rates and average accelerated sea level rise.

Jurisdiction	Wastewater Management Facilities		
	Wastewater Treatment Facilities	Wastewater Collection Facilities*	Wastewater Storage Tanks
Hurricane Category 3 Storm Surge and Steady State Sea Level Rise, 2025			
Unincorporated Worcester County	4	44	1
Ocean City	n/a	n/a	n/a
Pocomoke City	0	2	0
Snow Hill	0	0	0
Berlin	0	0	0
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2025			
Unincorporated Worcester County	4	44	1
Ocean City	n/a	n/a	n/a
Pocomoke City	0	2	0
Snow Hill	0	0	0
Berlin	0	0	0
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2050			
Unincorporated Worcester County	5	44	1
Ocean City	n/a	n/a	n/a
Pocomoke City	0	2	0
Snow Hill	0	0	0
Berlin	0	0	0
Hurricane Category 3 Storm Surge and Average Accelerated Sea Level Rise, 2100			
Unincorporated Worcester County	6	50	1
Ocean City	n/a	n/a	n/a
Pocomoke City	0	2	0
Snow Hill	0	0	0
Berlin	0	0	0

* Wastewater collection facilities include wet wells, lift stations, pump stations, vacuum collection stations, and storage tanks.

Storm Water Management Systems

GIS data for storm water management facilities in Worcester County were not able to be obtained. The following discussion, therefore, describes generic impacts likely to befall storm water management facilities located in areas exposed to sea level rise.

As is the case for sanitary sewers and water supply lines, buried storm water sewers may be damaged along sedimentary coasts where resultant shoreline erosion and recession expose them to currents and wave forces (NRC, 1987). As sea level rises, some storm water sewer drains, ditches, and canals will be inundated as well as detention/retention facilities in low-lying coastal areas. Discharge rates from gravity-flow storm sewers, ditches, and canals will be reduced because of the decreased hydraulic head of higher tailwater levels where outfalls become partially submerged (Titus et al., 1987). The capacity of such systems will be further reduced due to increased siltation at lower flow velocities. The effectiveness of tide gates in storm water drainage canals and mosquito control ditches also may be compromised by small increases in sea level (NRC, 1987).

Storm surge flooding impacts on storm water drainage facilities, including surcharged storm sewers and over-topping of open ditches, canals, and detention/retention facilities, will extend further landward as storm surge impact zones shift with rising sea level.

Elevated water tables may impair the structural stability of storm sewers and detention/retention facilities, while the influx of salty ground water can expose buried pipelines to corrosion, especially where cast iron or concrete pipe is exposed to saltwater (NRC, 1987).

Other Public Facilities

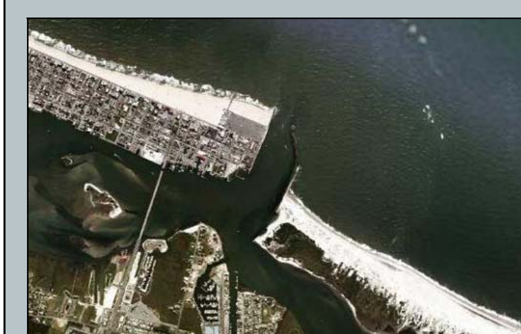
GIS data for other critical public facilities such as hospitals, police stations, fire stations, emergency operation centers, and designated shelters were not able to be obtained. The impacts of rising sea levels on such facilities are likely to be comparable to those affecting other structures in areas likely to be inundated or proximate to such areas (i.e., inundation and shoreline recession, increased exposure to storm surge flooding, and structural undermining from rising ground water levels).

2.3 INCREASED STRESS ON COASTAL ENVIRONMENTS

Sea level rise impacts to the coastal ecosystem of Worcester County could be severe depending on the speed of the rise and the extent of human barriers to natural adaptation. The primary impacts of sea level rise on the county's natural resources will be shoreline erosion and barrier island morphological changes, the drowning of some wetlands and submerged aquatic vegetation, and saltwater intrusion into freshwater habitats. Impacts to the natural coastal environment also are intertwined with impacts to the built environment. Erosion is as much a human hazard as a stress on the beach habitats because the beach and dune systems protect the built environment from inundation and flooding. Most of the impacts listed will greatly impact the county's tourism industry, which employs 60% of the county's labor force (Worcester County, 2006). Loss of wetlands and aquatic vegetation will impact water quality of the bays and subsequently the fisheries. Saltwater intrusion will change habitat suitability for many species.

Sidebar 2.4 Barrier Island Migration

Barrier islands are dynamic landforms that can migrate landward through overwash processes as sea level rises if they are in their natural state. Fenwick Island and Assateague Island were split during a storm in 1933 and the inlet has been artificially maintained. This has caused severe erosion to northern Assateague Island and accelerated movement landward.



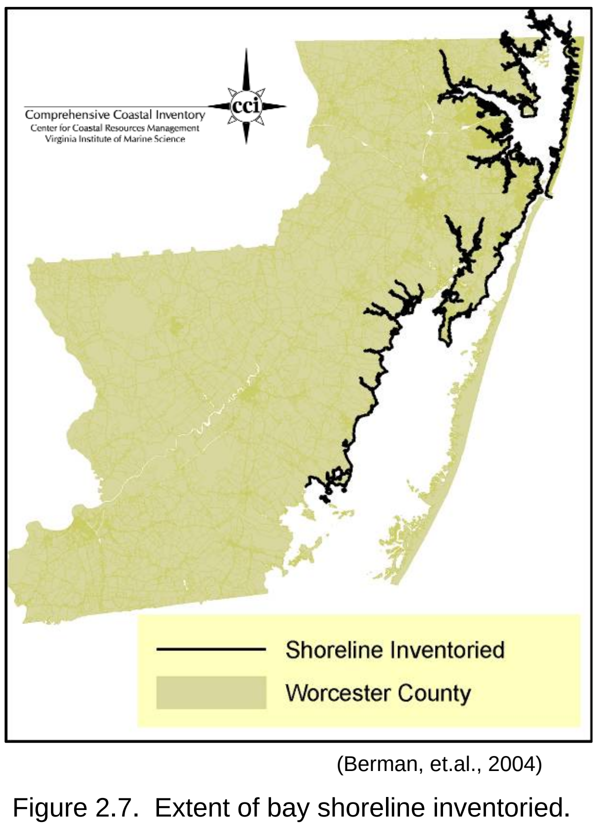
Shoreline Erosion

Worcester County, especially its barrier islands, has been grappling with shoreline erosion for decades (**Sidebar 2.4**). Sea level rise does not directly cause erosion, but the increased tide and storm surge from sea level rise allows wave action to reach further up the beach profile and carry sediment offshore (Cooper, 2005). While much of the erosion problems encountered by Fenwick and Assateague Islands have resulted from human interference (most notably the inlet), there is evidence that sea level rise is contributing to widespread beach erosion worldwide (Cooper, 2005). The commonly used Brunn Rule states that for every 1 ft in sea level rise, the coastline will retreat 50 to 100 ft depending on the slope of the beach profile. With the Ocean City beach replenishment program and the unnatural effects of the inlet on Assateague's erosion rates, this rule cannot be applied easily to Worcester County's barrier beaches. **Table 2.18** presents the current extent of shoreline recession throughout the county.

Table 2.18. Current miles of coastal accretion and erosion in Worcester County (From: Worcester County Department of Comprehensive Planning, 2006).

Rate of Change	Shoreline Length	
	Miles	%
Accretion	299	43
No change	6	1
Slight erosion (0 to -2 ft/year)	314	45
Low erosion (2 to -4 ft/year)	51	7
Moderate erosion (-4 to -8 ft/year)	12	2
High erosion (over -8 ft/year)	15	2
Total	**697**	**100**

Approximately 56% of the county's shoreline is receding, with 4% eroding at over 4 ft per year (**Table 2.18**). With accelerated sea level rise, these percentages will most likely increase. If sea level rise accelerated to 5 mm/year, as projected under the higher emissions scenario sometime during the middle of the century, it is very likely that northern Assateague Island, south of Ocean City, would fragment with one or more new inlets opening to the Coastal Bays. This would dramatically impact the National Seashore as well as the Coastal Bays through increased exposure to waves and storm surge (Maryland Commission on Climate Change, 2008).



(Berman, et.al., 2004)

Figure 2.7. Extent of bay shoreline inventoried.

The Virginia Institute of Marine Science has an inventory of shoreline use for a large portion of Worcester County's bays (see **Figure 2.7** for the extent of the shoreline inventory). From this inventoried area, 26% of the shoreline is armored or has some type of erosion control structure in place. The types of erosion control structures found include bulkhead, riprap, breakwater, debris (e.g., tires, bricks, etc. tossed haphazardly along the shoreline), unconventional (e.g., concrete blocks or other miscellaneous material placed neatly along the shoreline for stabilization), groin field, jetty, wharf, dilapidated bulkhead, and marina. An example of these erosion control structures with projected sea level rise can be found in **Figure 2.8**. Current placement and elevation of most erosion control structures in place today will not stop future sea level rise inundation without modifications and further armoring of neighboring shorelines. In fact, the bulkheads at Ocean Pines have most likely caused erosion to nearby beaches; approximately 292 m of beach on either side of the bulkheads are eroding. The inlet armoring between Fenwick and Assateague Islands is an obvious example of how stabilizing one shore can cause erosion to nearby unarmored shores.

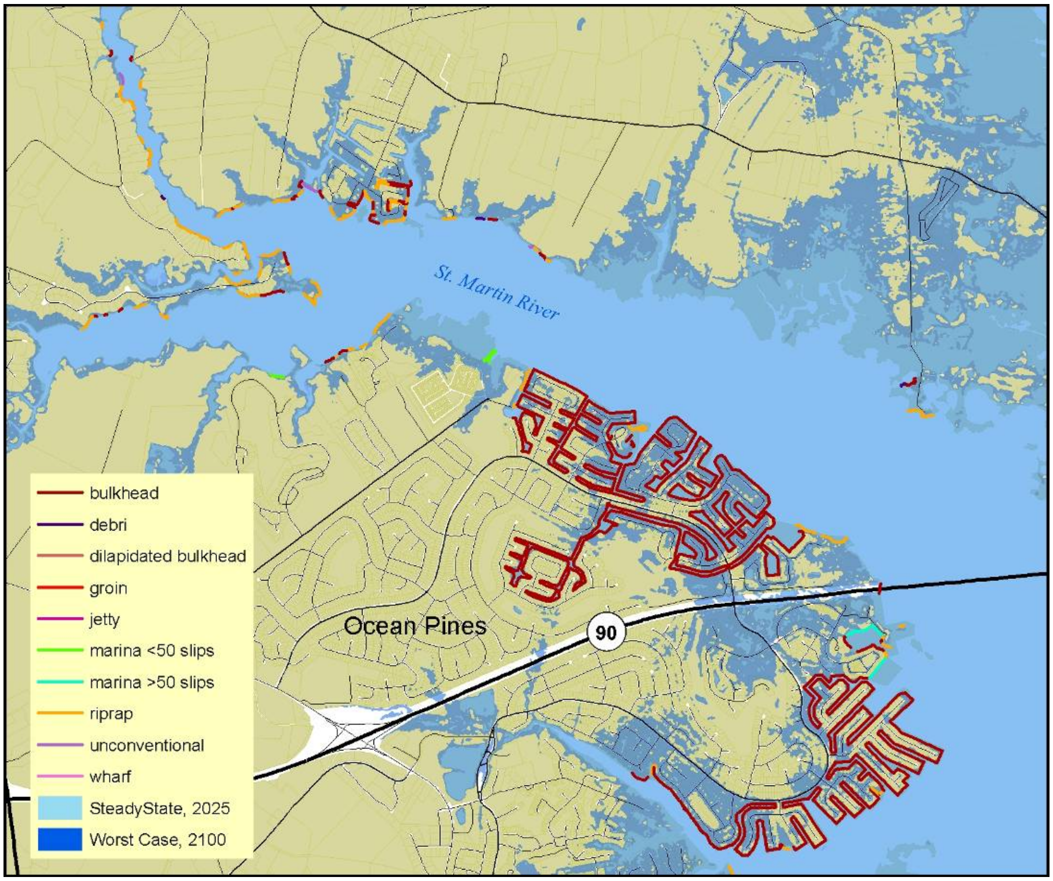


Figure 2.8. Erosion control structures in use in the Ocean Pines area with projected sea level rise scenarios (From: Berman et al., 2004).

Beaches on the coastal bays are a rare natural resource that provide habitat for many species and some recreational access for people. Of the 394 mi of shoreline inventoried, only 6 mi includes beach. For these beaches to not be quickly inundated by sea level rise, they need the ability to erode and have new beach emerge landward, which depends on the slope, sediments, and landward barriers in each beach location. Of the 6 mi of bay beach inventoried, 2.9 mi have one or more buildings within 100 ft, greatly reducing the opportunity for the beach to migrate with sea level rise.

Drowning of Wetlands

Wetlands are a source of basic ecological "services," providing wildlife habitat, food chain support, floodwater storage, erosion control, groundwater recharge, nutrient cycling, nutrient storage, and pollutant removal (Worcester County, 2006). They are critical to the tourism and commercial fishing industries as well as to the general environmental integrity of the county. Wetlands have historically been lost to development, although federal and state laws have slowed these losses. Development in wetlands has not been stopped altogether though, as 78.6 acres of wetland were filled between 1991 and 2003 – 89.6% of the acres requested for filling (Worcester County, 2006). Increased stress and potential for massive wetland losses will result from sea level rise, and tidal wetlands will be inundated from sea level rise. With sea level rise scenarios that project a gradual inundation, wetlands may have the ability to migrate landward as water levels rise, depending on the slope, sediment availability and composition, and the presence of inland barriers to migration. If this occurs, some undeveloped coastal uplands will be converted to wetlands, high marsh will become low marsh, and tidal flats will be converted to open water (see **Figure 2.9**). It is currently thought that any sea level rise over 1 m by 2100 may be too rapid for wetlands to keep pace, but much more research needs to be made on this topic and should not preclude attempts to assist wetlands in adapting to sea level rise. The ability of wetlands to migrate also is location specific because it is directly related to the accretion rate. Wetland accretion processes in the mid-Atlantic region have mostly stagnated (Cooper et al., 2005). Accelerated sea level rise may drown vegetation, which reduces sedimentation entrapment and exacerbates substrate erosion (Klarin, 1990). Erosion to the barrier islands also could affect the bays' wetlands if fragmentation of Assateague Island occurs and cause increased wave action. Shoreline armoring, which could increase with the threat of erosion, also can increase wave action to nearby wetlands.

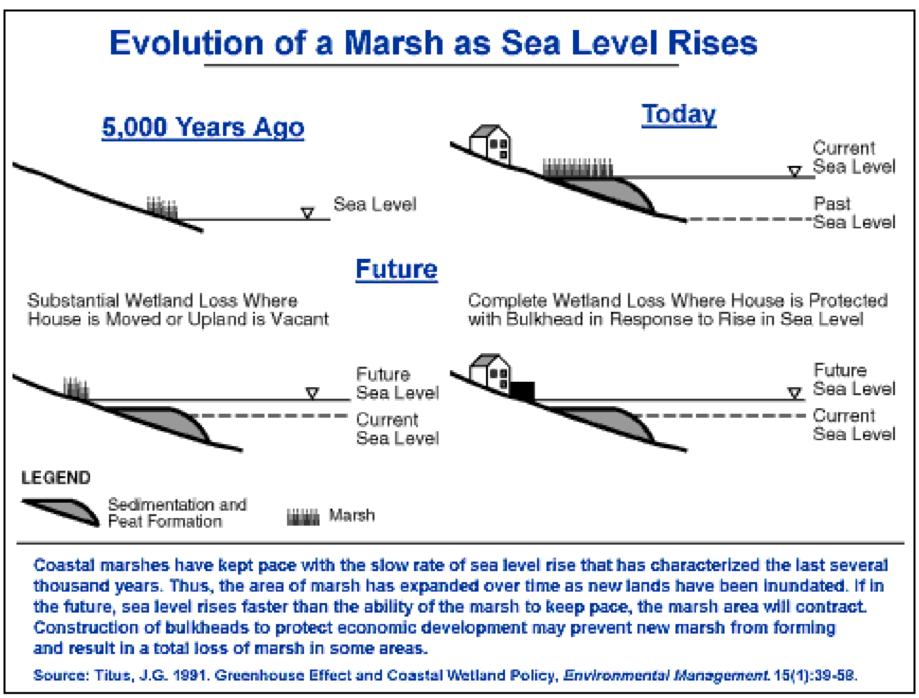


Figure 2.9. Evolution of a marsh as sea level rises.

It is estimated using GIS that there are 42,283.7 acres (55% of all county wetlands) of connected wetlands within Worcester County that intersect the Worst Case sea level rise inundation zone for 2100. Of the wetlands projected to be within the 2100 Worst Case inundation zone, 268.2 acres are within 100 ft of a building. See **Figure 2.10** for an area near Ocean Pines of wetlands with barriers. These acres of wetlands will not be able to migrate and, thus, will be the first loss. There may be additional acres of wetlands with other types of barriers to migration (i.e., roads, erosion control structures, ditches or even maintained lawns or agricultural land). Also, 100 ft is an arbitrary distance and as sea level rises wetlands may be squeezed by barriers 300 ft or more inland.

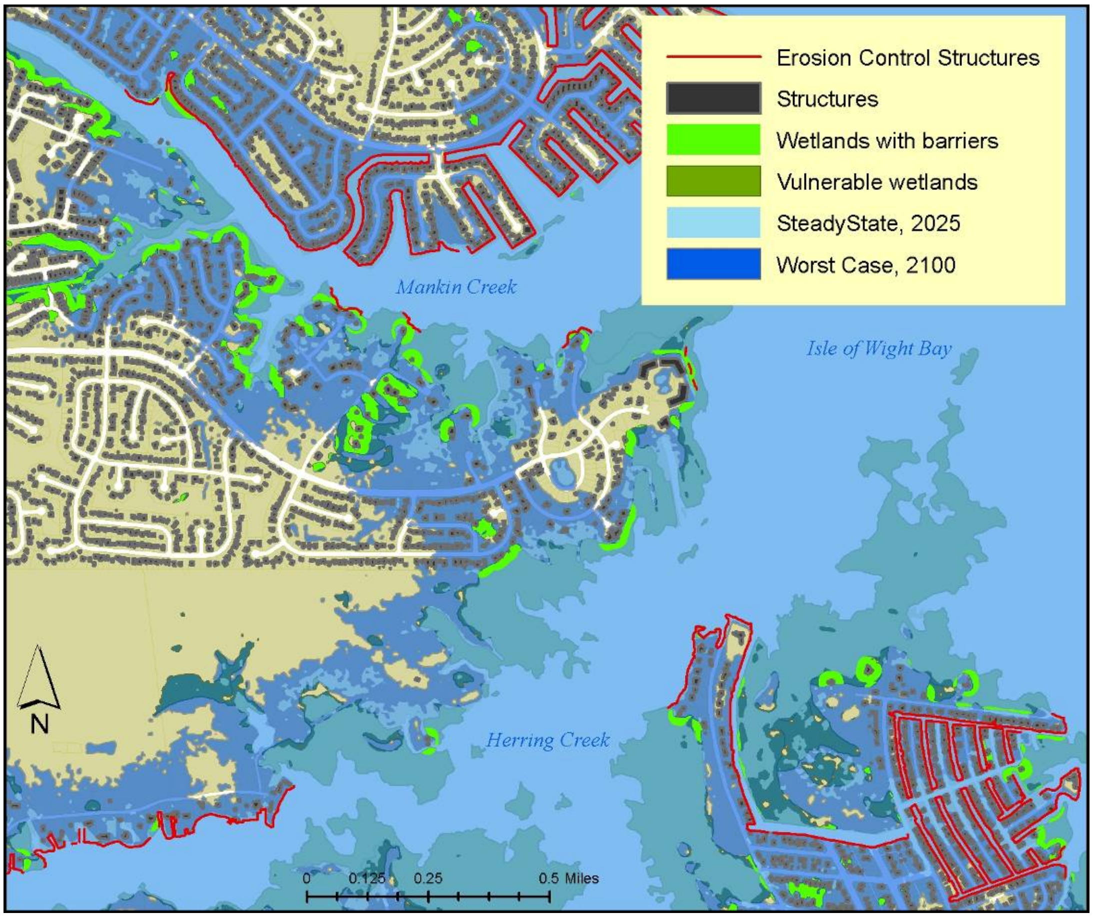


Figure 2.10. Wetlands within projected 2100 Worst Case scenario sea level rise and wetlands with barriers to migration.

Drowning of Submerged Aquatic Vegetation

The abundance and distribution of submerged aquatic vegetation, or seagrasses, are an important part of coastal bay ecosystems. Seagrasses are used as nursery for many species and improve water quality as well as provide food and shelter for waterfowl, fishes, and shellfishes. These benefits have economic value for tourism and commercial fishing; for instance, the density of juvenile blue crabs is 30 times greater in grass beds than in unvegetated areas (Wazniak et al., n.d.). Efforts have been made to increase the abundance of seagrasses in coastal bays, and successful results have been seen in recent years. Unfortunately, sea level rise and other climate change impacts, such as warmer ocean temperatures, will add increased stress to these submerged vegetation beds. Of particular concern are the northern bays where conditions for seagrasses are less than optimal due to polluted waters. As sea level rises, it will increase the water depth in which the beds are currently located and, at some point, depending on water visibility, light attenuation will not be sufficient to support seagrasses in those locations. The beds could migrate toward land as sea level rises; however, as shown in **Figure 2.11**, the bayside of Ocean City is mostly armored shoreline. Seagrasses also are vulnerable to wave action; for example, grasses have not been able to take hold at survey sites near the inlet. If more inlets in Assateague Island are formed from erosion, the healthy seagrass beds that line its bayside also will become vulnerable. Sea level rise also could increase tidal currents in the bays, resulting in more scour and diminished seagrass beds (California Coastal Commission, 2001).

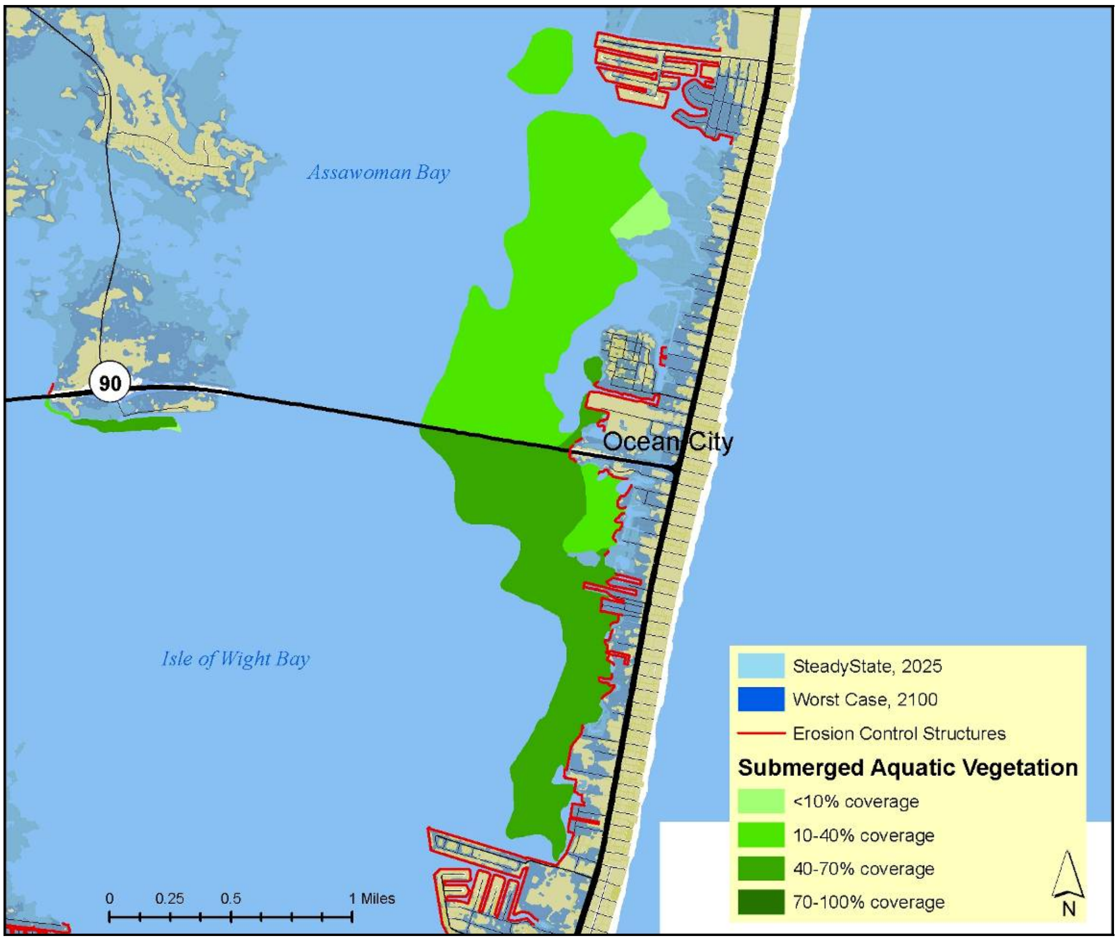


Figure 2.11. Vulnerable submerged aquatic vegetation bayside of Ocean City.

Saltwater Intrusion

Another impact of sea level rise is the inland and upstream movement of the saltwater-freshwater interface, or brackish water zone. Species diversity varies with salinity, duration of inundation, and disturbance; the most diverse marshes occupy more elevated surfaces in strictly freshwater regimes (Virginia Department of Conservation & Recreation, n.d.). Tidal freshwater wetlands are an important habitat for birds and rare plant species. Sea level rise is advancing the salinity gradient upstream in rivers, leading to shifts in vegetation composition and the conversion of some tidal freshwater marshes into oligohaline marshes (Virginia Department of Conservation & Recreation, n.d.). This can change fish and wildlife populations that are adapted to specific plant associations (Cooper et al., 2005). There also is a potential for elevated water tables from sea level rise that could increase salinity levels in freshwater wetlands near the coast that are not inundated. Storm surge can bring saltwater intrusion as well; however, the duration of that impact would not entirely alter the species composition. While nature may be able to adapt to these changes, human development barriers to habitat migration could result in diminished populations and environmental quality. Beyond the intrinsic value at stake, the economic impacts to the tourism and fishing industries also could be impacted.

The State of Maryland has designated certain nontidal wetlands as Wetlands of Special State Concern and required 100-ft buffer areas around these important preservation sites. In Worcester County, there are approximately 5,588 acres of Special State Concern nontidal wetlands within the 2100 Worst Case inundation zone. Of these, 2,860.4 acres are on the upper reaches of the Pocomoke River and would most likely be inundated but not be impacted by excessive saltwater intrusion. The other 49%, however, would be directly impacted by coastal bay water intrusion, which would raise salinity levels of those wetlands. Examples of some nontidal wetlands of Special State Concern that would be impacted are shown in **Figure 2.12**. The acres presented here are only those that fall within the boundary of the inundation zone. The salinity levels also would be increased throughout any connected wetlands.

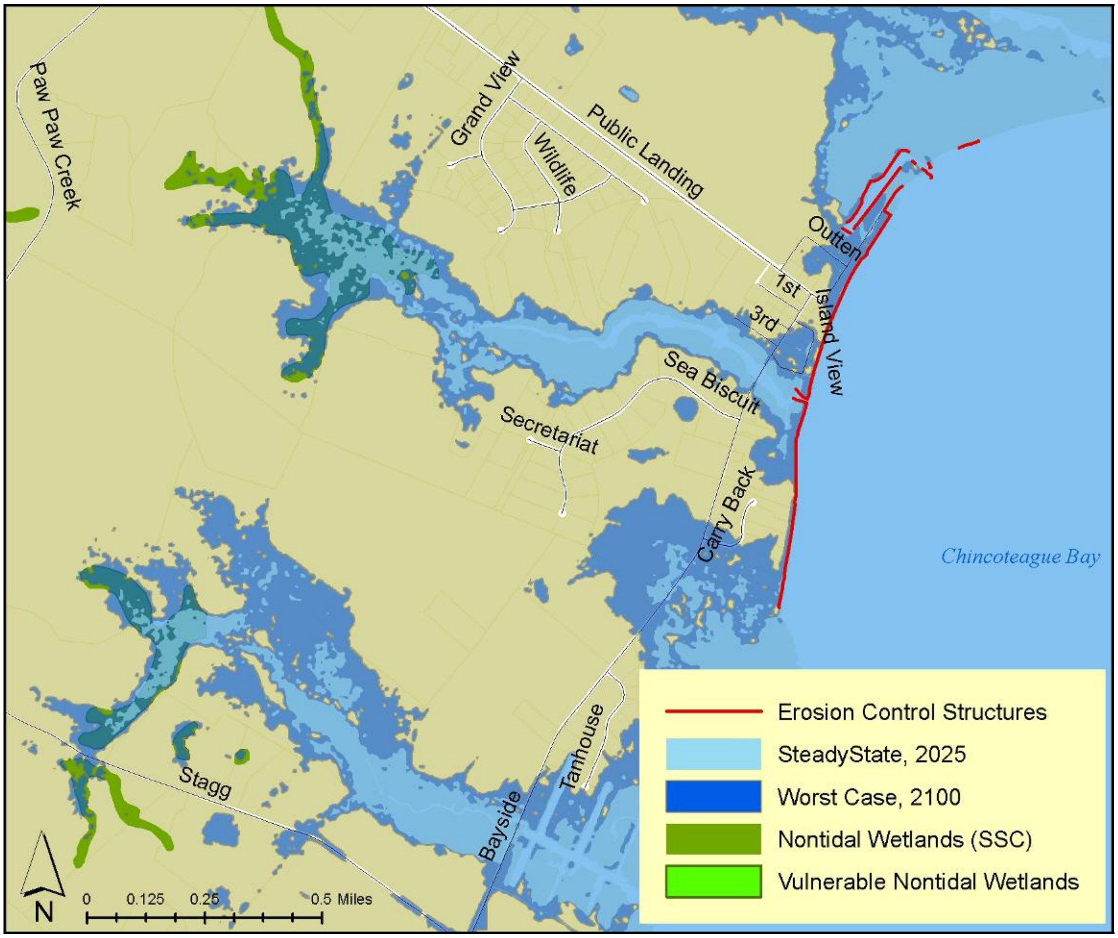


Figure 2.12. Nontidal Wetlands of Special State Concern (SSC) vulnerable to saltwater intrusion.

3 Potential Response Options

Impacts from sea level rise are several of the more avoidable consequences of climate change. While there is still uncertainty in the exact measurement of future sea level rise, it is certain that accelerated sea level rise will occur (see **Sidebar 3.1**). Efforts to mitigate greenhouse gases are gaining momentum, but unfortunately these efforts will have little impact on sea level rise rates over the next 50 years (Cooper et al., 2005; U.S. Environmental Protection Agency, 1995). In addition, as **Section 2** illustrates, even the current rate of sea level rise will have major adverse impacts on Worcester County's development and environment. Action should be taken to respond to this anticipated hazard in order to reduce health and safety, financial, and quality of life damages that will be incurred. Opportunities to avoid sea level rise impacts will require acting now (U.S. Environmental Protection Agency, 1995).

Sidebar 3.1 Responding Now
"Meaningful preparations can take place now, despite scientific uncertainty, by building upon current research, utilizing adaptive planning frameworks, and evaluating a range of sea level rise scenarios" (Johnson, 2000).

The four major categories of response options to sea level rise are no action, protection, retreat, and accommodation. This report does not explore the no-action response option because the outcome of this is explained in **Section 2**. Options for protection, retreat, and accommodation are presented for existing development, future development, infrastructure, and the natural environment, where applicable. The advantages and disadvantages of each option use are described for the prioritization and selection of a set of options to codify and implement in Worcester County. This section focuses on response options be appropriate for implementation at the local level or those that could be recommended by the county for other entities to pursue. The criteria by which these response options should be judged are presented in **Section 4,** as are recommendations for implementation.

3.1 ADAPTION OPTIONS FOR EXISTING DEVELOPMENT

A major component of the Worcester County Sea Level Rise Response Strategy is the adaptation of existing development to future sea level rise scenarios. Ocean City, West Ocean City, and Ocean Pines are all nearing build out and water-oriented development is complete (Worcester County, 2006). **Section 2.1** concluded that there is extensive development in Worcester County that will be vulnerable to inundation and increased storm surge.

Protection Options

Protection of areas currently developed can be accomplished by structural or non-structural means of holding back the sea. The timeframes for planning, designing, and constructing such projects are likely to run to several decades. The choices will have significant impacts on future investment and development patterns as well as the other adaptive response options that are considered for areas that will not be protected. Therefore, if any of the following protection options are considered now or in the future, it is important to first designate which areas of the county should be protected from sea level rise. It is also important to establish standards now for the protection level that will be needed for these areas (i.e., building bulkheads to today's sea levels will not protect those areas in the future unless the bulkheads are heightened and strengthened later).

Identifying protection areas will require an assessment of the costs and benefits of protection options. The benefits of protecting historic districts, for instance, will probably outweigh the costs. One important element of such calculations will be identifying the existing capital improvements, both privately and publicly owned, vulnerable to encroaching sea level (see **Section 3.3** regarding identification of vulnerable infrastructure and public facilities). Further criteria for making these decisions on whether to protect existing developed areas and prioritizing which ones to protect can be found in **Section 4.1**.

<u>General Advantages of Protection for Existing Development</u>

- Making decisions on what and where to protect sooner will allow long timeframes needed to plan, design, and construct protection structures to meet the future sea level requirements. It is very likely that there will be a shortage of materials as the rest of the world begins to take similar adaptive response initiatives. Advanced planning may facilitate securing necessary materials at prices less affected by high demand.
- Property in areas designated for protection will increase in value.
- Established communities will remain intact.

<u>General Disadvantages of Protection for Existing Development</u>

- Structural protection initiatives will be extremely expensive (Titus et al., 1991; Watson et al., 1996), yet available cost estimates are very likely significantly under-priced.
- Property in vulnerable areas not designated for protection will lose value.
- Protected property may still be at high risk from storm surge flooding.
- Adverse environmental impacts may be great.

Structural Protection

Structural protection, or shoreline armoring, includes any attempt to stabilize the shore through "hard" erosion control techniques. Structural engineering techniques, such as bulkheads, seawalls, riprap, dikes, breakwaters, sills, and revetments, can successfully hold back the sea to the level of protection for which they are designed, but with major environmental degradation. **Figure 3.1** presents the preferred order of erosion control techniques in the State of Maryland, beginning with a "soft" technique of revegetation and favoring hybrid soft/hard techniques that more closely resemble living shorelines, discussed under *Non-Structural Protection*. The last resort techniques are the structural erosion control projects that squeeze out beach and wetland habitat, such as bulkheads and seawalls. Erosion control in Maryland is considered a statutory right of every property owner and can typically be conducted in most locations with a permit (Titus, 1998). Attitudes toward structural protection have changed, and consideration of the extent of structural protection that may occur with sea level rise and the impact it will have on neighboring unprotected shores may make designating only certain areas for structural protection an encouraged endeavor.

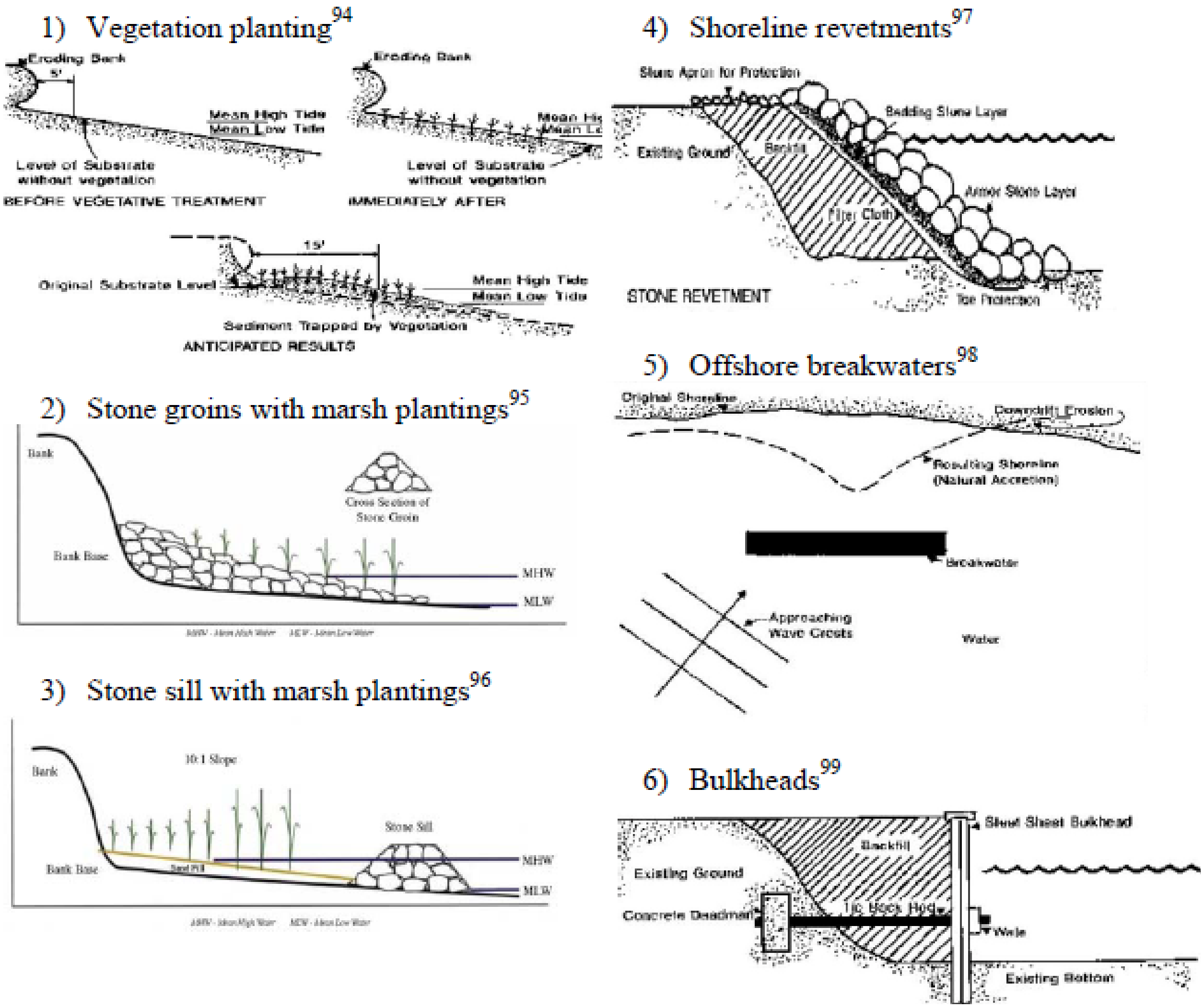


Figure 3.1 Maryland's preferred order of erosion control techniques

Advantages of Structural Protection

- Will be well accepted by coastal property owners because structural protection is currently allowed and the ability to protect property is an expectation of coastal property owners.
- The construction of stabilization structures can effectively protect coastal property in the short-term (Cooper, 2005).
- Can be carried out in smaller parcel–by-parcel projects or can be large, publicly constructed features.
- Loss of land will be minimized benefiting property owners and the tax base.
- Water-dependent uses can continue to be located at the water's edge without relocating as sea level rises.

<u>Disadvantages of Structural Protection</u>

- Erosion control structures will need to be reinforced to withstand the greater forces, or a lower level of protection will have to be accepted for the property protected by the structure (California Coastal Commission, 2001).
- May give residents a false sense of security becasue large storms often breach these devices (Klarin, 1990).
- Environmental degradation will occur; typically involving the loss of on-site beach or wetland and possibly impacting nearby natural shoreline habitats through increased erosion or wave action. Extensive shoreline armoring could lead to a massive loss of wetland habitat and pollution of the coastal bays.
- Structural protection will lead to a loss of public access, especially to the bay shoreline, if access easements are not a requirement of construction (Titus, 1998).
- The negative impact of many of these structures on local and neighboring sediment transport and beach profiles has been well documented (Cooper, 2005).
- The expense of maintaining an acceptable level of protection as sea level rises over the next century will be a very large burden on property owners and/or government funds.

<u>Implementation Considerations</u>

- Clear designation of structural protection zones, perhaps with incentives for first using non-structural protection if suitable for the location.
- Streamlined permitting in protection zones in exchange for public access easement dedications along water's edge.
- Creation of a special district to tax properties that benefit from large-scale, publically-erected protection structures, such as a breakwater or beach nourishment, as is done in Ocean City.
- Property owner preference through private investment and permitting procedures already in place. Property owners could be notified upon purchase of the property that it is in a designated protection zone and the property could be subject to substantial erosion and flooding should they choose to not invest in protection structures.
- Subsidized protection construction through state grants and local revenue funding. This may be needed in a limited way to deal with issues of equity where those who cannot afford to protect their property are forced out of structural protection zones.
- Wetland mitigation for every linear foot of wetland shoreline being lost through construction of structural protection could be required as impact fees to be used outside of structural protection zone.

Non-Structural Protection

Non-structural protection techniques include beach nourishment and the building of sand dunes and marshes. Inn this report, hybrid or "living shorelines" erosion control is considered non-structural due to its decreased impact on the environment. Beach nourishment is the most effective "soft" technique for dealing with sea level rise, although none of these techniques are long-term solutions. Non-structural protection techniques work best in low to moderate erosion settings, which will not be the case with accelerated sea level rise as shown in **Section 2** (Dean et al., n.d.). The designation of protection areas could differentiate areas for structural and non-structural techniques based on suitability and whether the area should be protected indefinitely or only until a certain rise in sea level makes it no longer cost beneficial.

Beach nourishment is a popular erosion control method that is already the major method of stabilization for Ocean City's beaches. It can also be used in combination with structural protection to create pocket or perch beaches, and sand dune building can be done in tandem to provide further protection and habitat restoration. Beach nourishment is really only the appropriate option for Worcester County's barrier islands.

Typically, beach nourishment projects require huge volumes of sand; at least several hundred thousand cubic meters. In addition to the volume requirements, certain specifications of sediment composition, color, and texture must be met; all natural beach areas have a specific set of characteristics (Dean et al., n.d.). The location of available volume is also an important factor because the transportation costs associated with placing the borrow material on the beach often are the biggest cost in a nourishment project (Dean et al., n.d.). Sand sources also must undergo extensive environmental reviews by State and Federal agencies. Sand sources will become more expensive and less available over time as more beaches need nourishment due to sea level rise.

According to the Maryland Geological Survey, sand resources within state waters could be depleted after the scheduled 2010 Ocean City nourishment cycle. From 2014 to 2044, at least 7.6 million cubic meters of sand will be required to maintain Ocean City beaches. New sand sources are needed outside state waters to meet increased demand (Maryland Geological Survey, n.d.).

Hybrid or living shoreline erosion control techniques utilize restoration and revegetation with limited hard structures, typically stones, to increase sedimentation or reduce water action and thereby reduce erosion (**Figure 3.2**). Living shoreline treatments are designed with the intention of minimally disrupting normal coastal processes, such as sediment movement along the shoreline, and protecting wetlands (Jefferson Patterson Park and Museum, n.d.).

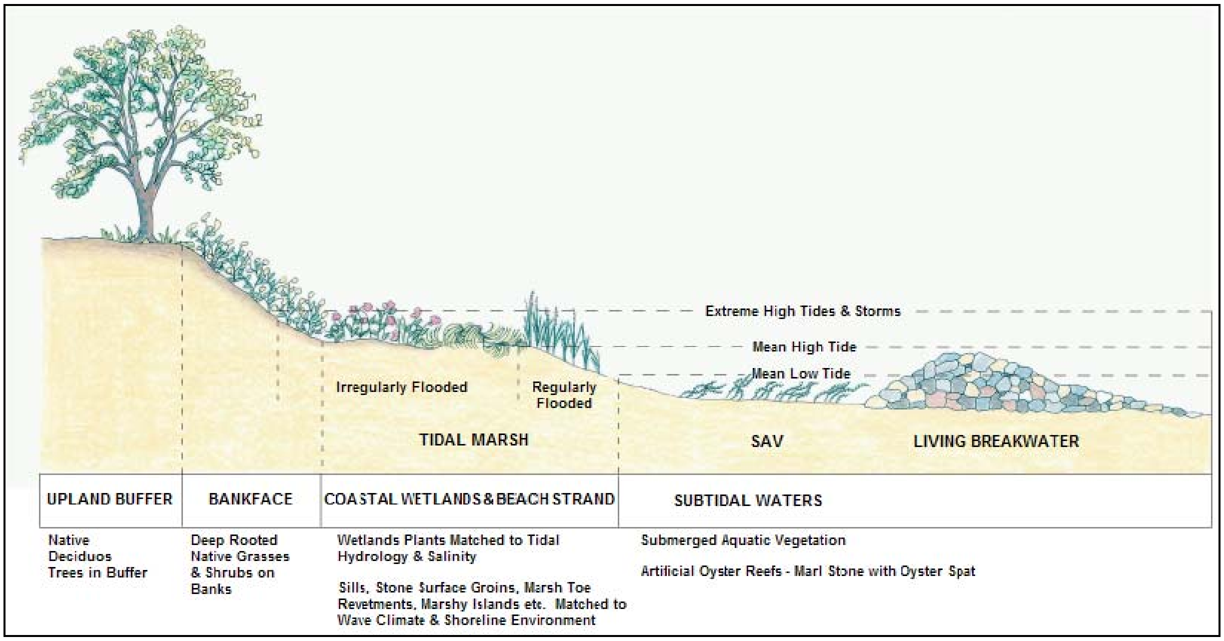


Figure 3.2. Example of a living shoreline project (From: Jefferson Patterson Park and Museum).

In Louisiana, ideas for wetland restoration include marsh building, which basically entails the reuse of dredge materials to supplement sediment supplies to wetlands. The dredge material can be sprayed on the marsh to raise its elevation. There is a lack of available information on this technique in order to judge its effectiveness without further research. In theory, this would be the equivalent of beach nourishment for the bay’s wetland areas and act as a buffer between rising seas and coastal development.

<u>Advantages of Non-Structural Protection</u>

- Storm damage reduction through the nourished beach or dune or living shoreline acting as a buffer between storm surge and upland development.
- Recreation and tourism protection by providing natural-looking beaches and marsh areas.
- Habitat protection/restoration for beach and wetland species. This also can protect the ecotourism industry. Living shoreline treatments utilizing vegetation provide water quality benefits that structural protection does not.
- Enhanced property values through stabilizing the shore and via an aesthetically pleasing method.
- Effective as a short-term option that maintains opportunities for other protection, retreat, or accommodation options. In fact, non-structural protection can be used in combination with most accommodation options for existing development. As conditions change, non-structural protection projects can be periodically reviewed for effectiveness to determine whether it continues to be the most appropriate sea level rise response.

Disadvantages of Non-Structural Protection

- Sand sources will become more expensive and less available over time as more beaches need nourishment due to sea level rise.
- Not a permanent response for excessive erosion conditions. Beach nourishment and dune/marsh building must be maintained on a regular basis. Living shorelines will only slow erosion and, to be effective, would need to be used in combination with a retreat or accommodation strategy whereby the living shoreline features are periodically replaced further inland.
- Public perception of non-structural erosion control projects may increase investment in high-risk storm surge areas and areas that will become inundated if the projects cannot be maintained over time due to increased costs or lack of resources. This could lead to takings challenges should the county decide to abandon protection and switch to a retreat strategy in the future due to property owners' expectations. Public education and clear disclosure on property vulnerability to flooding and erosion could abate this issue.

Implementation Considerations

These would be much the same as for structural protection implementation considerations. More emphasis may be placed on subsidizing non-structural protection as it is a preferred technique. If wetland mitigation was included as a requirement, on-site restoration and maintenance could be used *in lieu* of fees for off-site restoration.

Tidal Barriers

Tidal barriers have been employed in Europe, such as on the Thames River pictured right, to control flooding. With sea level rise awareness, many other large cities are considering these massive engineering projects as well. This protection option is very unlikely for Worcester County because of the severe environmental impacts and the low-density development in most of the county's bay area. Tidal barriers do have some advantages, such as controlling salinity intrusion and some having been designed for energy creation. Smaller tidal barriers or dams may be considered for tidally-influenced rivers and tributaries in the future for the control of salinity intrusion. This is mentioned in **Section 3.4** because the purpose would be to preserve current ecosystems.

Accommodation Options

Accommodation is a response strategy recognizing retreat from sea level rise inundation zones as inevitable, but works to prolong the life of existing development and set rules for eventual retreat. Accommodation areas should be identified where structural protection is not considered cost-effective, but where efforts will be made to maintain existing private development and public facilities and infrastructure up to the point where inundation is imminent. In these areas, the following accommodation options can be used alone or in combination with non-structural protection options.

General Advantages of Accommodation for Existing Development

- While similar to a no-action stance, accommodation is a more responsible government policy because it can consider public health and safety as well as plan for a fair retreat that could potentially include compensation.
- Property values decrease but do not become entirely without value until inundation occurs. A plan for compensation could be used in conjunction with accommodation options.
- Opportunity costs are lowered because more of the useful part of the structure or infrastructure lifespan can be enjoyed.
- Investment into properties that will most likely have to eventually be abandoned to the sea is reduced (Titus, 1998).

General Disadvantages of Accommodation for Existing Development

- Eventual enforcement of retreat may be difficult.
- Structural protection would have to be prohibited in these areas and not allowed as inundation begins to occur despite public protest.
- Homes and other development will be at high risk from storm surge. Repairs to infrastructure would have to be made despite the recognition that it will be abandoned at a later date because residents and businesses would be allowed to remain in the area.
- Investments will be made to elevate homes and floodproof businesses and infrastructure so that they can be used for a longer period up to inundation. This could result in houses on stilts in the bay if enforcement of development removal from public lands is lax.
- If hazard mitigation, such as elevation and floodproofing is not invested in, flood losses in the county could skyrocket as flooding becomes more frequent and severe.

Rolling Easement

Sidebar 3.2 Definition of a Rolling Easement

"A rolling easement allows construction near to the shore, but requires the property owner to recognize nature's right of way to advance inland as sea level rises" (Titus, 1998).

In Maryland, the public owns the area below mean high water. A rolling easement (defined in **Sidebar 3.2** and presented in **Figure 3.3**) enforces this common law interest by forcing the removal of private structures or charging a temporary rent once the private structure rests on public land. Use of this accommodation option for existing development may be more difficult because property owners built without knowing that they might need to one day relinquish their home or infrastructure to erosion without being able to protect their investment. Compensation methods can be coupled with a rolling easement policy, though this would require the county or State to make some assumptions on the most likely sea level rise scenario and calculate probabilities of inundation over time to determine values of the property for which they are providing compensation (Titus, 1998).

Rolling easements can be part of a multifaceted response strategy and are especially useful in combination with other options that may have undesirable side effects. For instance, elevating homes, especially if other hazard mitigation is included, can allow persons to continue occupying the the structure even if it is obstructing the beach or is in the tidal zone. It may not be acceptable to the community, however, to have structures on stilts in the bay or tidal creeks (Titus, 1998). Including a rolling easement policy means that there is clear and advanced notice that even if the structure can withstand the impacts of sea level rise temporarily, it must be removed after a set length of time of being below mean high tide. Rolling easements also can be used in conjunction with setbacks, which is further discussed in **Section 3.2**.

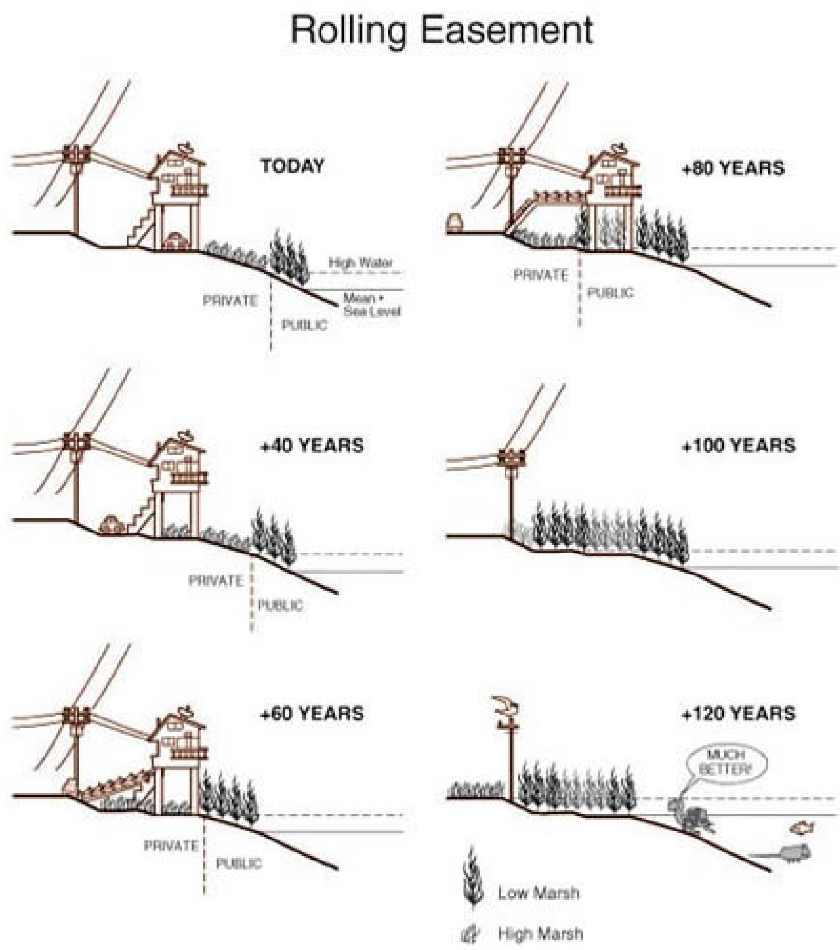


Figure 3.3 Example of how a rolling easement works.

In **Figure 3.3**, the high marsh reaches the footprint of the house in approximately 40 years. Because the house is on pilings, it can still be occupied (assuming that it is hooked to a sewerage treatment plant as a flooded septic system would most likey fail). After 60 years, the marsh has advanced enough to require the owner to park the car along the street and construct a catwalk across the front yard. After 80 years, the marsh has taken over the entire yard; moreover, the footprint of the house is now seaward of mean high water and, thus, on public property. At this point, additional reinvestment in the property is unlikely, and the State might charge rent for continued occupation of the home. Approximately 20 years later, the particular house has been removed, although other houses on the same street may still be occupied. Eventually, however, the entire area returns to nature (Titus, 1998).

Advantages of Rolling Easements

- Future sea level rise rates are uncertain, and local, relative sea level rise can vary within the county due to erosion and other factors. Because of this, determining a setback line to distinguish public shoreline that must be left natural is difficult, but a rolling easement adjusts with relative sea level rise and is not tied to a specific scenario. If sea level does not rise as expected, there is little cost.
- A rolling easement provides advanced notice to property owners that their property will be subject to erosion, flooding, and inundation (Titus, 1998).
- Eventually the shore will retreat to any setback that is established, even if a long time period and maximum scenario are chosen. A rolling easement is dynamic and will continue to move back as sea level rises, allowing for land within a distant future projected inundation zone to be used until the sea reaches that area, lowering lost opportunity costs. Property owners can determine the best use of their land based on knowledge that it will eventually erode and be inundated.
- The impact on current property values would generally be less than 1% (Titus, 1998). This would either impose a minor burden to property owners or the county could determine a process for compensation because the costs would be small and could potentially be paid in increments as the impact occurs. According to Titus (1998), "rolling easements would rarely be takings."
- During a set period of time of a structure being on public land, the government can charge rent and no one has to be forced out if the structure is still safe (Titus, 1998).
- A rolling easement does not require the public to accept accelerated sea level rise. If they do not believe the sea is rising, they will have no problem agreeing to a rolling easement that only comes into effect when the sea rises.

Disadvantages of Rolling Easements

- Rolling easements only work if shoreline protection, or at least structural protection, is prohibited. Since many current property owners have erosion control structures, it would be difficult to equitably implement a rolling easement without designating zones in which natural shorelines are the only areas subject to the rolling easement. This may still be viewed as unfair because there would be many property owners who would have built erosion control features if they had known that they would not be allowed in the future.
- Property values would be negatively impacted in areas subject to rolling easements.
- For existing development in particular, the assumption and expectation of the right to hold back the sea could result in legal challenges. Although the case has been made that no one has the right to increase their property at the expense of a neighbor due to laws of erosion (Titus, 1998).
- Monitoring and enforcement may be difficult. Accurate property use inventories would need to be kept, and field checks and surveying would be needed to enforce any private obstructions onto public land. When the time came to remove structures from public land, it could become very controversial. This would especially be the case if there was no compensation.

<u>Implementation Considerations</u>

- Rolling easement zoning districts could be specified on the Worcester County and municipal zoning maps. A public education campaign could accompany this action.
- For existing development, implementation will most likely require compensation. The county or State could buy purchase options for the easement or a reversionary interest (Titus, 1998).
- Structures could be moved landward if there is room on the lot and the structure is capable of being moved. Variances for yard setbacks and other landscape requirements could be granted, and final assistance could be provided.

Elevation and Floodproofing Retrofits

As the date of inundation nears for a particular property, it will be more and more at risk from temporary flooding due to storm surge. At some point, the safety hazard of the structure may be too great for it to remain occupied or it may receive substantial damage from a flood. To further accommodate use of the structure, it will need to be elevated or floodproofed, depending on whether it is a residence or business. These hazard mitigation techniques are proven to work and be cost-effective.

Homes in a storm surge zone, or FEMA V Zone, are typically elevated. Worcester County recently amended its Floodplain Law to require a 2-ft above base flood elevation requirement for the lowest horizontal structural member of the structure. In velocity flood zones, which areas projected for sea level rise inundation would be, the homes must be elevated on an open foundation consisting of piers, posts, columns, or pilings. This kind of elevation can be done on frame; masonry veneer; and masonry homes on basement, crawlspace, or slab-on-grade foundations. Houses already elevated also can be raised higher if necessary in order to meet increased base flood elevations. Not all homes will be able to be elevated. Larger homes are more difficult and expensive; for instance, multistory homes can be difficult to stabilize during lifting (FEMA, 1998).

Floodproofing is another available flood mitigation method, but is solely for non-residential structures. Although, it can occasionally be used for accessory components of a house, such as a garage. There are two types of floodproofing – wet and dry. Wet floodproofing allows water to enter the structure but not damage structural components or service equipment. Dry floodproofing prevents water from entering the structure and is only effective where flood levels are low (i.e., below 3 ft) and there is little flow velocity (FEMA, 1998).

If a structure is in a FEMA flood zone and receives substantial damage (i.e., 50% or more of the value of the structure), then it will be required to retrofit before rebuilding. There also are grant funding opportunities for hazard mitigation retrofit projects after a presidentially-declared disaster in the community (FEMA Hazard Mitigation Grant Program) as well as pre-disaster grant funding (FEMA Flood Mitigation Assistance and Pre-Disaster Mitigation Grant Programs). For those covered by an NFIP Standard Flood

Insurance Policy, they also would be eligible for Increased Cost of Compliance after substantial damage, which can help pay for retrofits, including elevation and floodproofing.

Advantages of Elevation and Floodproofing Retrofits

- Reduces the flood risk to the structure and, consequently, the damages. It also can reduce flood insurance premiums.
- These techniques are well known, and qualified contractors and necessary resources are readily available.
- The time required for elevating or floodproofing a structure would be a few months to 1 year, at most, for planning and construction. Property owners could wait until the flood probability increases to an unacceptable level before making the investment.
- While structural protection methods such as seawalls or levees also could extend the length of time a coastal property can withstand sea level rise, elevating and floodproofing allow the shoreline to remain natural. Structural protection measures also can fail or not offer the necessary level of protection for a flood event, and the same damages would occur as if there were no protection. If a home is elevated to the correct base flood elevation or a non-residential structure is properly floodproofed, it should withstand coastal flooding events.
- Many structures would already be required to make these retrofits after substantial damage from a flood event.

Disadvantages of Elevation and Floodproofing Retrofits

- The cost of these retrofits may be prohibitive for widespread use without financial assistance. Elevation costs include the actual lifting of the house as well as the elevation of plumbing and electrical systems and construction of access. Floodproofing costs are less prohibitive, but may still be costly if extensive floodproofing is needed for the entire structure.
- The use of floodproofing in storm surge zones is very limited and would not be an option for many non-residential structures in projected sea level rise inundation zones. It does nothing to strengthen the structure to withstand high-velocity flow or wave action (FEMA, 1998).
- The appearance of elevated structures may not meet current community ideals.
- Access to elevated structures would be adversely affected, although it can typically be accommodated.
- The structures would need to be evacuated during flood events for public safety. As inundation nears, this could become a frequent occurrence. Enforcing evacuations could be an added strain on local government emergency management.
- Erosion as well as wind from coastal storms could still impact the structures if other hazard mitigation retrofits are not pursued.

Implementation Considerations

- If implemented through current Worcester County Floodplain Law requirements, the designated floodplain would require increased periodic remapping to meet new flood risk as sea level rises. To meet current NFIP substantial damage requirements, these would need to be map amendments to the official FEMA flood maps.

- Could develop a new ordinance specific to increased flood probabilities due to sea level rise that designates an overlay zoning district for sea level rise-related elevation and floo proofing retrofit requirements. The requirements could include non-conforming structure specifications of what would require a retrofitting.
- While public education should be a component of any implementation strategy, a voluntary implementation that included persistent public education based on continued remapping of flood probabilities could be effective. Voluntary compliance would be most plausible with financial assistance or incentives. This approach would be most effective coupled with rolling easements or stringent rebuild policies.
- A post-disaster redevelopment ordinance or plan could include rebuild policies that require flood retrofits in areas projected for sea level rise inundation or even increased surge from sea level rise.
- The Worcester County Hazard Mitigation Plan can include elevation and floodproofing projects on its mitigation project list in order to qualify for grant opportunities through the Federal government to assist property owners with retrofitting costs.

Restrictions on Septic Tank and Hazardous Materials Storage

Inundation due to sea level rise and increased flooding could result in pollution of county coastal waterbodies if septic tanks and hazardous materials storage is allowed to remain in inundation and flood-risk areas. Requiring removal of these potential pollutants in areas as flood probability increases due to sea level rise will allow existing development to remain, in most circumstances, without putting the health and safety of the community at risk or imperiling environmental quality. Water quality improvement has been a major effort in Maryland, and restrictions on potential pollutants (including septic tanks) are already common. These restrictions would need to be reviewed periodically based on the latest sea level rise projections and flood probabilities and expanded as necessary.

<u>Advantages of Restrictions on Septic Tank and Hazardous Materials Storage</u>

- Maintains coastal water quality as sea level rise impacts occur.
- Allows for existing development to remain in projected inundation zones longer while decreasing environmental damage.

<u>Disadvantages of Restrictions on Septic Tank and Hazardous Materials Storage</u>

- In areas where septic tanks are restricted and no sewer utility is available, this could act as a retreat strategy rather than accommodation if the County or municipality does not extend service.
- Restrictions could preclude some businesses from operating if alternatives to the removal of hazardous materials, such as flood mitigation methods, are not available.

<u>Implementation Considerations</u>

- The overlay zoning district could designate where septic tanks and hazardous materials must be removed. A progression of this district based on sea level rise rates in conjunction with a grace period could be used to give property owners advance notice of the requirement.
- Require removal of old tanks as a condition of property transfer or utility hook up (Klarin 1990).

- Financial assistance could be offered.
- Fees for extension of sewer infrastructure into an area that may be abandoned at a later date would make this option more of a retreat strategy by making continued use of the property less cost-effective.

Retreat Options

Retreat involves allowing sea level rise to take its natural course and avoiding impacts. This strategy requires the least investment over the long-term, but may have the highest short-term costs for compensation and relocation/demolition as well as very large opportunity costs by removing so much development. In Worcester County, the extent of land that will be inundated by even modest rates of sea level rise is extremely large, as discussed in **Section 2**. To adopt retreat as the only response strategy, especially for existing development, would be improbable considering the current legal framework of property rights in Maryland. Many of the following retreat options, however, could be used in combination with other response options or may be appropriate in particular areas. Areas should be identified where neither structural protection nor accommodation strategies are cost-effective and/or where the environmental impacts of protection or accommodation strategies are not acceptable to the community. See **Section 4.2** for more criteria to identify these areas.

General Advantages of Retreat for Existing Development

- Allows the environment to naturally adapt to accelerated sea level rise.
- Removes development from flooding and erosion hazards, resulting in increased public safety and decreased disaster damages.

General Disadvantages of Retreat for Existing Development

- Large potential loss of valuable coastal property and development, depending on the area designated for retreat. Large opportunity costs associated with inability to redevelop or intensely develop the area in the future.
- Very expensive property compensation, relocation, and demolition responsibility for the government if done on a large scale. Coupled with the massive cut in property tax revenues, the county and any municipalities that adopted a large retreat strategy would be incapable of affording this and would need State and Federal assistance.

Property Acquisition and Relocation Programs

Property acquisition is a straightforward response option, albeit a costly one. The typical property acquisition strategy would be for the local government to determine the most vulnerable properties and raise funds through grants from State or Federal government and local budget allocations to purchase the property and assist the previous owners relocate if necessary. The property could then be kept in public ownership for conservation or recreation purposes or turned over to a private conservancy to maintain.

Advantages of Property Acquisition and Relocation Programs

- Fee-simple purchase guarantees the removal of existing development and prevention of future development in projected sea level rise inundation zones.

Disadvantages of Property Acquisition and Relocation Programs

- Too expensive to be used in a widespread manner. At best, the county could afford a few properties each year; however, this would probably be insufficient to abate even the current sea level rise trends by 2025 (see **Section 2.1**).

Implementation Considerations

- The county could determine the most vulnerable developed properties to 2025 Steady State sea level rise that also are targeted for conservation according to the Worcester County Land Preservation, Parks, and Recreation Plan.
- Funding resources can be identified, including private organizations, so the county can act if a property acquisition deal becomes available. Including property acquisition for sea level rise response as a project in the Hazard Mitigation Plan will also qualify the county for funding through FEMA should a disaster occur.

Relocation

There are several types of relocation that could occur as a retreat response. One is the relocation that would occur through the above-mentioned property acquisition option where structures are moved off the property or demolished and residents are relocated onto other property. There also is the possibility that a property parcel may be large enough or located far enough from the coast to have enough space to move the structure(s) landward of the inundation zone being avoided (i.e., Worst Case scenario in 2050 or 2100, etc.). Another relocation option is for public infrastructure. If public infrastructure is relocated or removed, such as abandonment of a road or relocation of power lines, then private development has a major incentive to relocate as well or, at the very least, to not redevelop. The most reasonable relocation strategy for public infrastructure would be *in lieu* of repairs, as discussed in **Section 3.3**.

Advantages of Relocation

- Relocation as a response option may be most useful in moving historic structures out of harm's way as abandonment of these structures would be unacceptable.
- Relocating public infrastructure from projected inundation zones precludes public subsidization of continued occupation of high-risk coastal properties.

Disadvantages of Relocation

- Relocation can be an expensive undertaking. The actual movement of structures could be a large burden for property owners or public entities. Relocating infrastructure requires the purchase of new property and large construction costs in most cases.
- Relocating public infrastructure can leave property owners without basic services.

Implementation Considerations

- For private development, relocation would be a voluntary option or part of an acquisition deal.
- For historic structures, the county could identify funding sources to relocate the structures before they are damaged by a major flooding event.
- Relocating infrastructure could be a policy of the county to consider before any costly repairs are done to infrastructure in projected inundation zones.

Restrictions on Shoreline Protection

An underpinning of a retreat strategy for an area would be that existing development is removed so that sea level rise can take its course on the natural shoreline. It would, therefore, be necessary to prohibit structural protection measures and to reduce non-structural measures to those that are beneficial to maintaining the natural shoreline (e.g., marsh vegetation). If these restrictions are not going to be countywide, the areas subject to shoreline protection restrictions would need to be mapped and notifications on property deeds should be added to subdivisions in these areas. For example, South Carolina, North Carolina, Maine, Rhode Island, and Texas all forbid shoreline armoring.

Advantages of Restrictions on Shoreline Protection

- Allows natural retreat of the shoreline and decreases environmental degradation that would result from structural protection measures.

Disadvantages of Restrictions on Shoreline Protection

- Loss of land to erosion will force many developed parcels to be abandoned if the owners are not allowed to stabilize the shoreline. This will result in decreased property values and tax revenues.

Implementation Considerations

- Can be included in zoning regulations. Public awareness efforts will be necessary such that the regulations of further investment in existing development are clearly understood in advance.
- If included as deed restrictions, there is no chance of backing down from the regulations in the future.

Redevelopment Restrictions

The most practical means of eventual retreat for existing development is through restrictions or conditions on rebuilding. Since it is known that areas projected for inundation will first be more susceptible to flooding, one approach may be to adopt policies for rebuilding after a disaster. Rebuild conditions are currently in use through the Worcester County Floodplain Law, which requires structures in flood zones to be relocated or rebuilt to new standards if substantially damaged. In Florida, governments include a rebuild policy in their local comprehensive plans that require that structures in any location be brought up to current building codes after substantial damage.

Rebuilding restrictions also can be applied to the improvement of structures. For instance, the Worcester County Floodplain Law does not allow substantial improvement to structures in the floodplain except through variance if the structures meet all the development requirements. Whether through substantial damage or improvement, rebuilding conditions would make increased use of the property limited via disincentives or outright denial, decreasing flood losses since less investment would have been made had the rebuild policies not been in place.

Worcester County already has an admirable amount of land dedicated to conservation, agriculture, and low-density development on its Zoning Map (see **Figure 3.4**). Considerable amounts of the northern part of the county's coasts, though, are densely developed. To encourage retreat, some of these areas that are not going to be in protection zones could be down-zoned so that any redevelopment would be less dense. Non-conforming uses could be restricted from expanding or rebuilding.

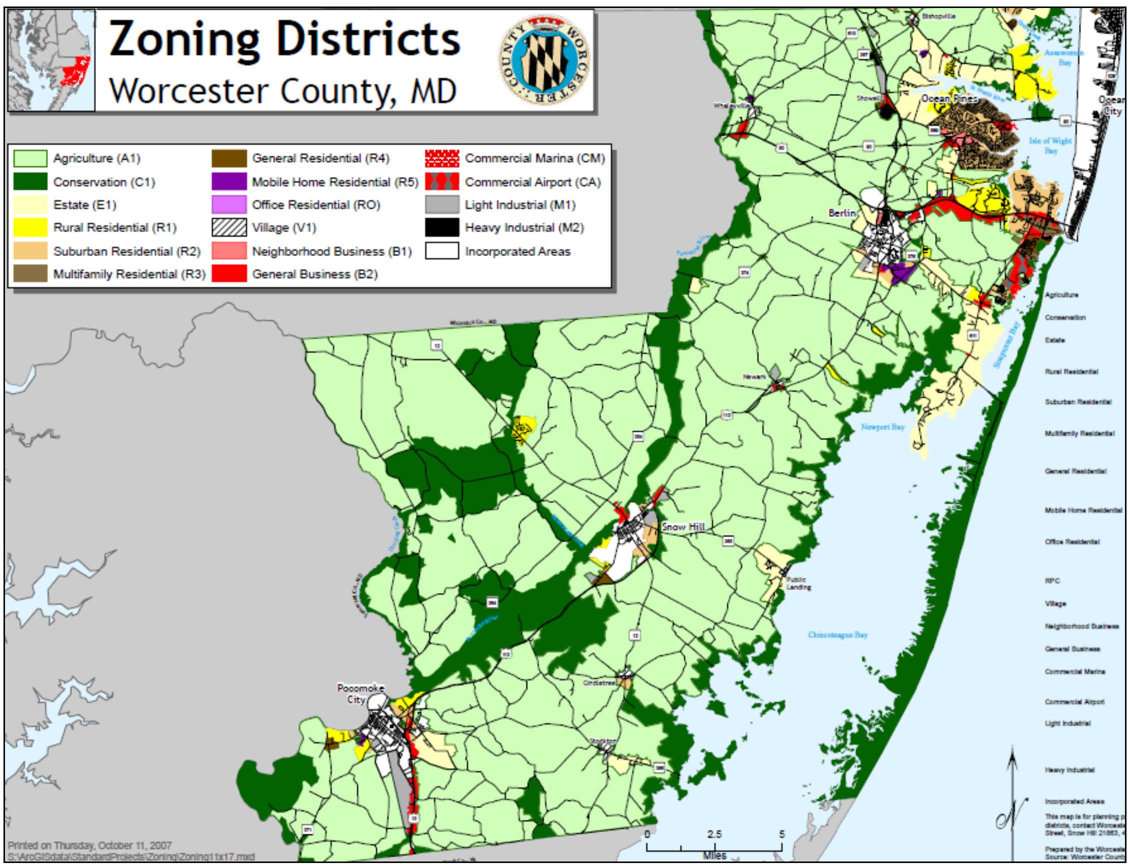


Figure 3.4. Worcester County Zoning Map.

<u>Advantages of Redevelopment Restrictions</u>

- Allows development to remain as is, but forces relinquishment or downgraded use for any substantial change, meaning that retreat is imposed when it is most cost-effective.
- If applied in areas that also are prohibited from constructing structural shoreline protection, eventual retreat will be result from a large flooding event.

- Down-zoning would not take away all economically-beneficial uses before inundation occurs, but would disinvest the property to make way for eventual abandonment.

Disadvantages of Redevelopment Restrictions

- Recovery after a disaster could be inhibited through enforcement of rebuilding restrictions for substantially-damaged homes and businesses, causing many residents or business owners to relocate, possibly out of the county.
- Fragmented retreat could occur, affecting the provision of public services to those who are left in the retreat area.
- Prior to a rebuild policy coming into effect, damage could be done to the natural shoreline by impeding the beach or wetlands' ability to migrate inland with sea level rise.
- Rebuild and zoning regulations can be amended in the future. Public will could persuade future commissioners to change the rules and allow redevelopment in areas projected for sea level rise inundation.
- Down-zoning small lots could result in takings challenges if the density requirements are too low to allow for redevelopment.

Implementation Considerations

- Redevelopment restrictions could be included in a post-disaster redevelopment ordinance or plan.
- Conditional permitting procedures could allow rebuilding if it meets some accommodation options for new development, as presented in **Section 3.2**.
- Overlay zoning districts could be established that prohibit rebuilding in projected sea level rise inundation areas that have been designated for retreat. The zoning regulations could include a non-conforming structure rule that limits substantial improvements and that go into effect after receiving substantial damage.
- Down-zoning would need to be combined with non-conforming use regulations.

3.2 ADAPTATION OPTIONS FOR FUTURE DEVELOPMENT

The supply of available waterfront property in Worcester County has been limited due to land use policies for the Atlantic Coastal Bays Critical Area Program (Worcester County, 2006). In addition, growth area suitability in the current Future Land Use Map has been based on limiting environmental damage and minimizing negative impacts on natural, economic, and social resources (Worcester County, 2006). This has already decreased the future vulnerability of the county; however, these actions, while beneficial to adapting to sea level rise, have not specifically taken projected sea level rise scenarios into consideration in determining where future development should occur. The Worcester County Comprehensive Plan (2006) notes that Snow Hill has increased development pressure and that Pocomoke City has plans for an increased waterfront development. As described in **Section 2**, these towns will experience inundation from swelling of the Pocomoke River and be impacted by increased tidal surges in the river as well. The Snow Hill Growth Area "avoids the river's floodplain," but may need to be adjusted to avoid the river's floodplain under future scenarios of sea level rise or require accommodation measures for new development in those areas (Worcester County, 2006).

Determining which response options to implement for future development is one of the most important first steps for a sea level rise response strategy. Planning where future development will be protected, accommodated, and prohibited (retreat areas) set the stage for public facilities and infrastructure, environmental concerns, and existing development response options. The sooner regulatory options for future development are adopted, the earlier the public is aware that sea level is rising and the rate is expected to accelerate as well as the county's policy on adapting to this hazard. Property in retreat or accommodation areas purchased after regulations are in place will be bought subject to the expectation that development is restricted due to sea level rise (U.S. Environmental Protection Agency, 1995).

Protection Options

The same protection options apply to future development as to existing development. See **Section 3.1** for more detail on the following:

- Structural Protection (i.e., sea walls, bulkheads, revetments, etc.);
- Non-Structural Protection (i.e., beach nourishment and living shoreline hybrid erosion techniques); and
- Tidal Barriers.

Accommodation Options

In areas designated for accommodation, there will be pressure for future development or redevelopment, especially by those who are unconcerned about future sea level rise. There are many options for allowing development to occur with conditions that limit future flood damages and prepare the community for eventual retreat. Some of these options also apply to existing development and have been discussed in more detail in **Section 3.1**. The discussion in this section focuses on the aspects pertaining to future development.

<u>General Advantages of Accommodation for Future Development</u>

- Sets the rules of eventual retreat up front so there will be less backlash later. Decreased expectations also will decrease the perception of unfairness.
- Allows development and thereby reduces opportunity costs, but also includes conditions that will decrease future losses as sea level rises.
- Maintains a more natural shoreline than a protection strategy.
- Reduces public safety risks through conditions that prepare for future flood events in the accommodation area.
- "Policies that prevent development in areas vulnerable to erosion have generally been implemented through regulations that do not compensate landowners" (Titus 1998).

<u>General Disadvantages of Accommodation for Future Development</u>

- Allows investment in areas that will eventually need to retreat.
- Will require investments in public facilities and infrastructure to serve new development in accommodation areas.
- Depending on options chosen, may not provide as many opportunities for natural systems to migrate inland as a retreat strategy would.

Rolling Easements

Rolling easements are described in detail in **Section 3.1** for existing development. Implementing rolling easements for future development is less complicated and will be more acceptable to the public because it provides warning that structural shoreline protection will not be an option before development investments are made. There will be some issues with those who have vested rights in a property or bought with the expectation of being able to stabilize the shoreline.

Implementation Considerations

- Pass an ordinance declaring all future development is subject to the rolling easement and prohibit structural shoreline protection measures. Or, declare accommodation and retreat zones where all future development is subject to the rolling easement and structural shoreline protection is prohibited.
- Require individual structures to be subject to rolling easement as condition for building permit. Require entire development to be subject to rolling easement as a condition for subdivision or for activities that require wetlands to be filled, as is done under the Texas Open Beaches Act (Titus, 1998).
- Deed to property could specify that the boundary between publicly-owned tidelands and the privately-owned uplands will migrate inland to the natural high water mark, regardless of whether human activities artificially prevent the water from intruding. This decreases the chances of backsliding and discourages structural protection (Titus, 1998).
- Hybrid retreat/accommodation approach – use set backs for new structures for expected erosion over several decades and use rolling easement to ensure future generations do not build bulkheads at the setback line (Titus, 1998).

Temporary or Moveable Structures

A response that could work in tandem with rolling easements for future development is to require that all structures built within the projected sea level rise inundation zone (i.e., Worst Case 2100) be either temporary structures that can be removed as sea level rises or be small, moveable structures that can be relocated easily as sea level rises. The Sand Dune Law for the State of Maine uses this approach of conditional permitting for moveable structures and prohibits structural protection such as bulkheads. It also adds the requirement that the structures be moved when they reach public land as with the rolling easement and also if they are interfering with natural systems migration.

Elevation and Floodproofing Requirements

Elevation and floodproofing as an accommodation option for future development are essentially the same as applied to existing development (discussed in detail in **Section 3.1**), except for the following:

- For existing development, elevation and floodproofing are more expensive because it is considered a retrofit. For new development, requiring hazard mitigation techniques like elevation and floodproofing has been proven to be cost-effective and is not an inhibiting factor to development.

Cluster Development

Cluster development is a tool used in permitting development in any environmentally-sensitive location where variances for a typical subdivision requirement are waived so that larger areas of the property can be preserved. This is often used for property that has wetlands such that a buffer can be accommodated around the area without decreasing the density of allowed development. For areas in which development will be accommodated until inundation occurs, clustering development could further delay retreat.

<u>Implementation Considerations</u>

- This conditional permitting technique would be most useful in combination with rolling easements and/or setbacks.

Subdivision control

An ideal way of accommodating future development is at the time of subdivision. The size and shape of the subdivided parcels can be based on projected sea level rise such that development can potentially be accommodated, even with setbacks and other conditions. Setbacks are less costly and less likely to be takings when the coastal lot is relatively deep. Even in areas where shorelines will eventually be armored, a deeper lot will lengthen the life of the natural shoreline environment.

Subdivision is also the time to add deed restrictions such as shoreline protection prohibitions or rolling easement requirements.

Restrict Septic Tanks and Hazardous Materials Storage

See **Section 3.1** for further details.

Lowered Subsidies

Future development also can be accommodated in projected inundation zones by ensuring the costs of such temporary and high risk development fall on the property owner and not the taxpayers. The public costs of providing infrastructure to these areas where flooding damage and eventual removal makes investment less responsible, as discussed in **Section 3.3**, could be shifted more towards those that require the service in these areas through fees or increased taxes. The imbalanced costs of emergency management provision also could be adjusted through taxes.

<u>Implementation Considerations</u>

- Special taxing districts could be created to shift the burden of supporting accommodation areas to future development there.

Retreat Options

Any retreat strategy will be easiest to accomplish by preventing future development. The same advantages and disadvantages of a retreat strategy apply to future development as described for existing development in **Section 3.1**. The main difference is that restricting development before it occurs will cost much less than removing existing development. Also, the environmental benefits of preventing development are much greater.

Setbacks and Buffers

A major retreat strategy would be to create setbacks and/or buffers from the shoreline based on a future inundation scenario (i.e., Worst Case 2100) or a set sea level rise or erosion rate (i.e., 30 times the current rate of erosion). Setbacks can be static or dynamic and remapped on a regular basis. Setbacks will be most successful if there is enough land above the setback line to still develop property or use in some economically beneficial way (see *Subdivision Control*). This would be difficult to achieve in Worcester County, however, due to the low elevations that will cause a rise in sea level to inundate far inland (see **Section 2**).

<u>Advantages of Setbacks and Buffers</u>

- Provide a clear demarcation of where development will be restricted.
- Can allow for buffer areas for wetland migration.

<u>Disadvantages of Setbacks and Buffers</u>

- Property owners will want to dispute any scientific projections, and it may become a politically-influenced arbitrary line that does not serve its purpose (Titus, 1998).
- Eventually, the shore will erode up to line and the natural shoreline will be lost regardless if not coupled with structural protection prohibition.
- Assumption of development rights may lead to some subdivided property having no economically-productive use and could be a takings.

<u>Implementation Considerations</u>

- Can be used in conjunction with rolling easements and shoreline protection prohibition to prevent the setback line becoming a bulkhead in the future.

Down-Zoning and Transfer of Development Rights

A discussion of down-zoning can be found in **Section 3.1**. For future development, down-zoning can be used in combination with a Transfer of Development Rights Program as compensation for any vested development rights.

Implementation Considerations:

- Transfer of Development Rights Programs utilize sending and receiving zones. Designated retreat areas could act as the sending zones and inland growth areas or designated protection areas could act as the receiving zones.
- Development rights granted in the receiving zones may need to be greater than those that were vested in the sending zone because coastal development is more highly valued.

Property and Easement Acquisition

See **Section 3.1** for more details. For future development, purchasing easements to protect the inundation zone or a buffer area for wetland migration also may be an option. This would be particularly useful for agricultural lands. Developers could be encouraged to make voluntary easements to conservancies through permitting incentives (Titus, 1998).

Restrict Public Facilities and Infrastructure

See **Sections 3.1** and **3.3** for more information on this option.

3.3 ADAPTATION OPTIONS FOR INFRASTRUCTURE AND PUBLIC FACILITIES

While uncertainty remains about the magnitude and timing of sea level rise, it is clear that some existing infrastructure and public facilities are likely to be affected within their remaining design lives. In addition, development decisions being made today are committing new public and private capital to land use patterns and associated infrastructure and facilities with design lives that reach well the future when the impacts of sea level rise will be felt (Deyle et al., 2008). The street and highway rights-of-way laid out for new development have expected operating lives of more than 100 years. Underlying water distribution and wastewater and storm water collection systems have design lives of between 30 and 50 years or more. Water supply and wastewater treatment facilities as well as water detention and retention facilities have design lives close to 50 years. New bridges are built to last 75 years. Adaptive response planning should, therefore, address existing infrastructure and public facilities and decisions about where to site new facilities.

While **Section 2** discusses some of the infrastructure and public facilities vulnerability, there were many areas where more data were necessary to fully assess the threat of sea level rise impacts or they were beyond the capabilities of this study report. The following are, therefore, required to further develop response options for infrastructure and public facilities in Worcester County:

- Conduct Detailed Vulnerability Assessments for Threatened Above-Ground Facilities

  Detailed vulnerability analyses are needed to assess appropriate response options for specific segments of linear infrastructure and individual public facilities. Such assessments should include the following elements:

  1. Compile detailed lists of the specific road segments; the individual water supply, wastewater management, and storm water management facilities; and other critical public facilities likely to be inundated under Worst Case 2050 and 2100 sea level rise scenarios.
  2. Compile an additional list for those infrastructure elements and facilities that would be subject to storm surge flooding associated with the Average Accelerated 2050 and 2100 sea level rise scenarios.
  3. Compile elevation data for roads, sanitary sewer manhole covers, storm sewer intakes, storm water ditches, and canals to assist in more precisely determining the vulnerability of facilities identified through GIS analysis as being located within likely sea level inundation and increased storm surge flooding areas.

4. Determine flood elevation vulnerabilities for individual public facilities that would result in damage to the facility or other impediments to its continued operation (e.g., loss of access from increased storm surge flooding).

- Conduct Detailed Vulnerability Assessments for Threatened Buried Infrastructure

  Detailed vulnerability analyses are needed to assess appropriate response options for specific segments of buried linear infrastructure. Such assessments should include the following elements:

  1. Compile detailed lists of the specific buried infrastructure segments that are in or proximate to areas likely to be inundated under the Worst Case 2050 and 2100 sea level rise scenarios.
  2. Determine the potential for elevated ground water levels to compromise the structural stability or integrity of buried infrastructure in such areas as a function of (a) the soils within which the infrastructure is buried and their susceptibility to rising ground water levels and (b) the materials of which the infrastructure is constructed and their susceptibility to corrosion from the influx of saline ground water.

Advantages of Additional Vulnerability Assessments

- Doing so is essential to devising spatially explicit response strategies for individual public facilities as well as for deciding which areas should be structurally protected from encroaching sea level rise.
- The GIS data employed for this project can be used to compile such lists if they are supplemented with missing facility information that was not obtained in time for this analysis.

Disadvantages of Additional Vulnerability Assessments

- This will require additional time and resources.
- Detailed assessments of those segments of infrastructure found to be potentially vulnerable may require expert analysis by engineers or other specialists to determine the best course of action.

Protection Options

The same protection options available for private development also would protect infrastructure from impending sea level rise. Critical public facilities that cannot be relocated should be identified, and a determination should be made if structural or non-structural protection measures would allow the facility to continue operation. In addition, it can be assumed that infrastructure and facilities located in areas designated for protection, as discussed in **Section 3.1**, will be protected and can be less of a priority for vulnerability assessments and implementation of response options.

Accommodation Options

Accommodation options for public facilities and infrastructure would result in these facilities being able to provide services for a longer period of time before inundation and flooding impacts force a retreat. Some of the same accommodation options discussed in earlier section also apply here; they are discussed again here with details on how they relate to public facilities and infrastructure. Additional accommodation options specific to public facilities and infrastructure are also included in the following discussion.

General Advantages of Accommodation Options for Public Facilities and Infrastructure

- Where existing and future development is protected or accommodated, public facilities and infrastructure will be necessary. Accommodation limits the impacts to these facilities that must remain in high risk areas.

General Disadvantages of Accommodation Options for Public Facilities and Infrastructure

- Costs may be considerable both for conducting facility-specific assessments and for designing and implementing accommodation measures. The relative costs and benefits of alternative strategies will be largely site- and facility-specific. It is important, therefore, to initially identify those facilities most likely to be at greatest risk of more imminent impairment and focus assessment and planning activities on these facilities first.

Elevation and Floodproofing

In areas designated for sea level rise accommodation over a given planning horizon, the principal impact that must be accommodated is periodic flooding associated with hurricane storm surge and, perhaps, spring high tides. Facility-specific capital improvement plans should be developed for elevating and/or floodproofing buildings such as wastewater treatment and water supply treatment facilities and other critical facilities. Other options that may be appropriate include sealing sanitary sewer manhole covers to prevent inflow of flood waters; raising sanitary sewer wet wells; floodproofing sanitary sewer pump, lift, and vacuum collection stations and water supply wells and pump stations; elevating road beds; and installing enhanced drainage structures to capture and divert storm surge flood waters. Accommodation strategies for increased infiltration and other impacts on underground sanitary and storm sewers associated with higher water tables include complete replacement of the sewer pipe, replacement of sewer bedding material, grouting of pipe cracks and/or surrounding soil, and lining with a smaller-diameter polyethylene plastic pipe (Corbitt, 1990).

Advantages of Elevation and Floodproofing for Public Facilities and Infrastructure

- Timely elevation and floodproofing measures will reduce the costs associated with chronic flooding, including both service interruption and damage to facilities.

Disadvantages of Elevation and Floodproofing for Public Facilities and Infrastructure

- All of these elevation and floodproofing methods will be expensive and may need to be designed on a site-specific basis.
- Replacement of buried infrastructure typically is more expensive and time-consuming, resulting in service disruptions and often interfering with surface transportation along utility rights-of-way.

Storm Water System Enhancements

Titus et al. (1987) identified three major accommodation strategies for storm water drainage systems in coastal areas aside from the option of tolerating more frequent flooding:

1. Enhancement of gravity drainage through installation of large diameter pipes and widened drainage ditches to counteract the reduced head that results from higher tailwater elevations;
2. Installation of forced drainage systems in low-lying areas where gravity drainage is no longer possible and for increased pumping capacity for existing forced drainage systems to counteract higher tailwater elevations; and
3. Delay of peak discharges and reduction of peak discharge volumes by enhancing storm water detention at upstream locations within drainage basins and incorporating other measures that enhance on-site detention and retention and infiltration of runoff, such as use of porous pavements, roof-top detention, grassed waterways, etc.

<u>Advantages of Storm Water System Enhancements</u>

- These techniques could assist in dealing with more frequent flooding in developed areas by either decreasing the flood waters or more quickly removing them for more rapid recovery after a disaster. This is especially important for adapting roads to more frequent and amplified flooding associated with increased storm surge from sea level rise.

<u>Disadvantages of Storm Water System Enhancements</u>

- This would involve large capital improvements for areas that may need to retreat in the future. Ideally, enhanced storm water systems only would be constructed in protected areas as a second line of defense against storm surge. Depending on the density of development in areas designated for accommodation, some storm water system enhancements may prove to be cost effective.

Siting and Design Criteria

For future necessary public facilities and infrastructure in protection or accommodation designated areas of the county (see Retreat Options below for discussion of placement in retreat areas), siting and design criteria should be modified to consider impacts from sea level rise. Even in areas with structural protection, facilities should be designed to withstand flooding with limited damages or be able to be rapidly restored because structural protection features can fail, as learned from recent hurricane disasters.

Alternative Water Sources and/or Treatment

Saltwater intrusion into the aquifers that supply Worcester County with its drinking water could be a major impact of sea level rise. The county should hire hydrologists to begin assessing the probability of future intrusion that would result in a shortage of potable water. Alternative sources of water, such as surface water, could be identified. Alternative treatment technologies for saline aquifer water, or desalination, also can be assessed for its appropriateness for Worcester County water systems. Florida has examples of advanced alternative water planning and implementation that can be drawn from for information. Many communities use desalination for brackish aquifer water supplies in Florida, and surface water supplies are now being analyzed to ensure any supply that is diverted will not have adverse impacts on the environment.

Road and Bridge Elevation

An obvious accommodation measure for transportation systems is to elevate road beds and low sections of bridges to meet rising base flood elevations.

Retreat Options

Some of the same retreat options that are discussed in **Sections 3.1** and **3.2** also are possibilities for public facilities and infrastructure. These include relocation and a variation on redevelopment restrictions, as described below. There is an additional need to change the technology used in certain circumstances to enable retreat.

Public Investment Restrictions

Areas designated for retreat should be off limits for new public infrastructure investments. No new public infrastructure or facilities should be built in these areas, and threatened existing systems should be decommissioned and removed when specified thresholds are crossed (e.g., inundation or shoreline recession is anticipated within the next 5 to 10 years). This, of course, will be difficult to do if the areas designated for disinvestment in infrastructure are different from the areas designated for development retreat and/or if retreat options for development are not implemented and enforced.

Currently, the county has many Priority Funding Areas (see **Figure 3.5**) within projected sea level rise inundation zones. A first step in determining areas where infrastructure retreat can occur would be in reviewing these funding areas.

A practical retreat option may be to devise criteria for each facility in the projected inundation zone for Worst Case 2100 in order to determine if repairs should be made or if the area should be decommissioned and removed/relocated. It could even be determined ahead of time which emergency repairs would be allowed in order to create a transition or advance notice for those whose service would be cut. In some instances, residents reliant on a service could opt to pay larger fees for continuation of service to recoup the costs of further investment into a system that must eventually be decommissioned.

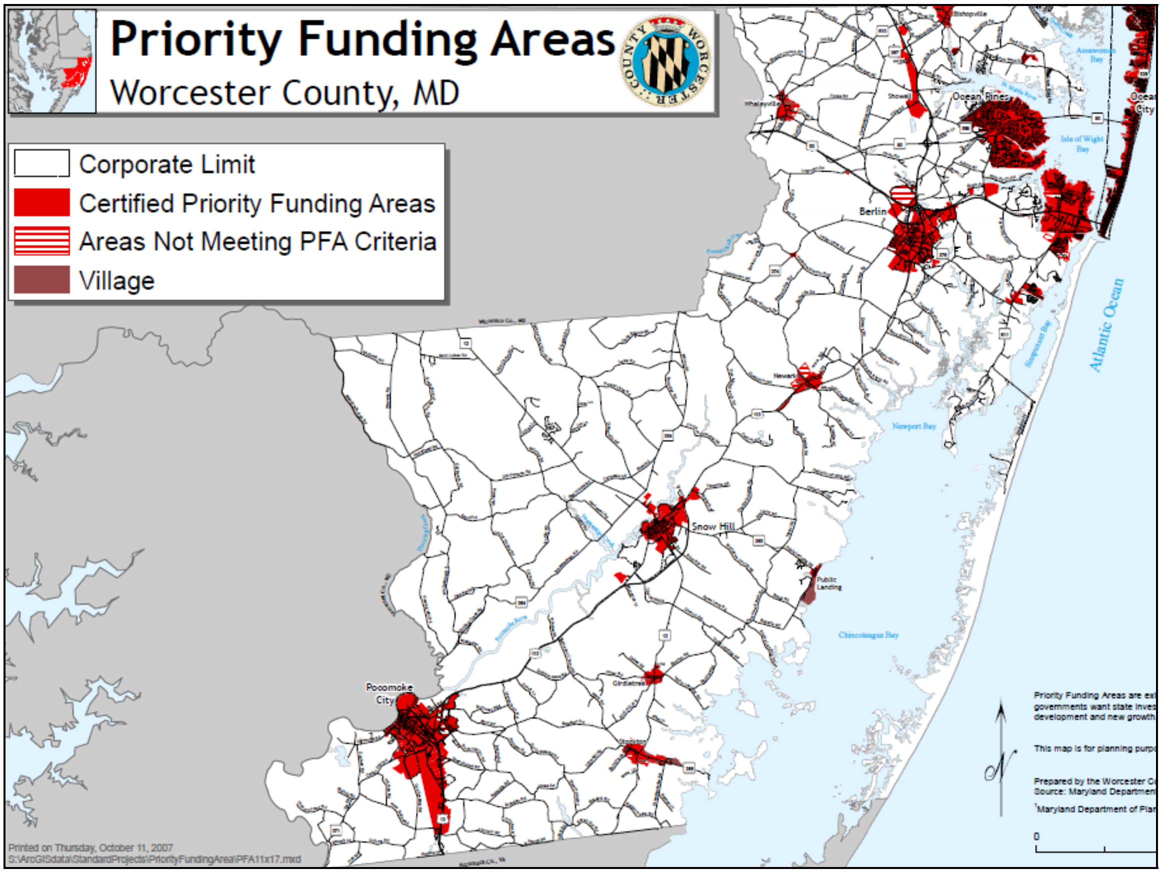


Figure 3.5. Priority Funding Areas In Worcester County.

<u>Advantages of Public Investment Restrictions</u>

- A responsible use of taxpayer dollars.
- Further advances a retreat strategy for private development.

<u>Disadvantages of Public Investment Restrictions</u>

- May be an extreme burden for residents remaining in areas where public investment is discontinued.
- Could be extremely politically unfavorable to make these drastic decisions and to enforce them when the time comes. Future elected officials could change the rules for public investment in facilities and infrastructure within areas designated for retreat.

Implementation Considerations

- Measures for determining public facility and infrastructure relocation/removal could be included in a post-disaster redevelopment ordinance so that decisions made after a disaster followed the retreat strategy.
- Public investment could be discontinued. But to ease impacts to residents remaining in accommodation or retreat areas, they could be given options for private funding.
- Priority Funding Areas should be modified to be consistent with decisions made about designation of protection, accommodation, and retreat areas.

Transfer of Ocean Outfalls to Land Application/ Water Recycling Facilities

Worcester County has several ocean outfalls that will be flooded with rising sea levels. For the coastal bay water quality as well as sea level rise adaptation, these outfalls should be converted to land application or water recycling facilities.

3.4 ADAPTATION OPTIONS FOR NATURAL SYSTEMS

The environment of Worcester County, particularly the coastal environment, is an integral component of this place. The Comprehensive Plan (2006) states that natural resources, such as islands, beaches, and marshes, are “vital to the county’s continued social and economic well-being and should be protected” (pg 31). Titus (1998) believes that “Maryland’s current coastal zone and environmental protection policies, statutes, and regulations would ensure almost complete elimination of the state’s bay beaches and coastal wetlands in developed areas” with sea level rise (pg 1,306). The main reason for this dire projection is the State’s recognition of a right to protect shore with hard structures. This will prevent tidal ecosystems from migrating inland and, if enough of the coastal wetlands are lost, could cause the entire bays ecosystem to collapse. Worcester County must, therefore, take action to protect the natural environment from the impacts of sea level rise combined with human barriers to adaptation.

Protection Options

There is no way to protect the natural environment from the impacts of sea level rise. Protection options listed in the previous sections for development would, in fact, damage natural systems in most cases. Living shorelines and beach nourishment provide some natural benefits, but are more of an accommodation strategy and are listed below.

Accommodation Options

Accommodation options for natural systems are those responses that provide some assistance in maintaining the natural shoreline or reduce barriers to natural adaptation. All retreat and accommodation options for development would be considered accommodation options for natural systems in the sense that they reduce human barriers. The following are additional options for accommodating sea level rise for natural systems.

Beach Nourishment, Marsh Building, and Living Shorelines

These non-structural protection measures are discussed in detail in **Section 3.1**. The following describes how they accommodate natural systems:

- Beach nourishment does have negative environmental impacts, but where it is a choice between the beach being squeezed out from sea level rise on one side and development on the other, beach nourishment is extremely beneficial for maintaining a natural shoreline and habitat for beach species.
- Living shoreline treatments try to mimic natural processes of reducing erosion, which can give wetlands that are struggling to keep pace with increased sea level rise rates a chance to adapt.
- Marsh building attempts to preserve wetland habitat by elevating it as sea level rises.

Restoration

Worcester County has already made great strides in wetland restoration. Continued restoration efforts will replace those wetlands that are lost through impacts from sea level rise. The goal should be for no net loss. As mentioned in **Section 3.1**, wetland mitigation can be a requirement of any new shoreline armoring that is allowed. Established restoration programs and funding can assist in battling sea level rise losses.

Assess Waste Disposal Sites for Leaching

An impact of sea level rise that is uncertain in magnitude is elevated water tables. This could cause increased water pollution if not monitored. Waste disposal sites should be assessed for vulnerability to leaching on a regular basis as sea level rises.

Retreat Options

For natural systems, retreat options include any options that remove human barriers to the natural adaptation to sea level rise. The same retreat option as listed in **Sections 3.1** to **3.3** would apply here as well, as they all remove development and allow the natural shoreline to retreat. Some additional options specific to natural systems include the following.

Prohibition of Shoreline Armoring

The most important retreat option for the natural environment is the prohibition of shoreline armoring, which is also discussed in the previous section. South Carolina, North Carolina, Maine, Rhode Island, and Texas all forbid armoring due to its adverse environmental impacts.

Incentives or Green Payments for Migration Buffers

This is a variation on setbacks and buffers or purchasing easements. Property owners could be encouraged to retreat for environmental purposes by providing incentives. These could be in the form of reduced taxes for not developing in wetland migration buffers or a system of “green payments” could be developed. This is a fairly new idea being used for other environmental preservation concerns, such as aquifer recharge areas, where property owners are paid for leaving land open and undeveloped for a set length of time. This differs from a conservation easement in that the green payments can be revoked if the property is put into use. Farmers tend to like this option, and it would most likely be sufficient enticement for those that are unconvinced of projected sea level rise rates.

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4 Priorities for Sea Level Rise Response

4.1 CRITERIA FOR PRIORITIZING RESPONSE OPTIONS

The ultimate purpose of the Sea Level Rise Response Strategy Report is to provide the information necessary for Worcester County decisionmakers to evaluate and prioritize response options for future implementation. Based on a literature review of sea level rise planning documents and experience in prioritizing hazard mitigation and post-disaster redevelopment initiatives, the following criteria are recommended as a useful framework for determining which response options will be most appropriate for adoption and implementation in Worcester County:

- **Legal Authority** – Does Worcester County have the legal authority to implement the response option? If not, does the response option fall under the authority of another jurisdiction that the county can request consider the option?
- **Institutional Feasibility** – Can the response option be implemented through existing county management systems?
- **Consistency with Community Vision** – Does the response option support existing community goals and policies?
- **Political Feasibility** – Is the option likely to be accepted by the public? Will concern over public costs, property rights infringement, or other issues make this option politically difficult to support? Some response options may initially be politically sensitive, but could be made palatable with a public outreach program that eases concerns through a better understanding of the potential impacts of sea level rise and the options for adaptive response.
- **Estimated Benefits Outweigh Estimated Costs** – Are the costs (monetary and other) of implementing the response option less than the benefits the community stands to gain? Benefits to consider include the following:
    - Health and safety;
    - Unique or critical resources;
    - Economic impacts; and
    - Environmental impacts.
- **Minimize Opportunity Costs** – Will taking action now foreclose other options that would generate near-term benefits to the citizens of Worcester County? As part of the cost-benefit discussion, the potential for loss of opportunity by preparing for future hazards should be specifically examined. This involves weighing the opportunity costs of expending capital or removing land from the market now versus the somewhat uncertain future costs of not taking any adaptive measures. Ideally, response options would be beneficial regardless of the uncertainties of the future (i.e., if sea level rises as predicted or higher the community would benefit, but also some benefits would be realized if the rate of sea level rise turns out to be slower than expected). Few response options will meet this criterion; however, some may be closer to a no-regrets strategy than others. For example, some measures to adapt to sea level rise also will provide protection from flooding associated with coastal storms.
- **Urgency Considerations** – Would the response option need to be implemented immediately to be effective or would it be equally effective if implemented at a later

date, such as 10 or 20 years from now? If the response option meets the other criteria and is deemed a valuable solution but is time sensitive, it should be given a higher priority.

- **Positive or Neutral Environmental Impact** – What will the environmental impacts of the response option be? Actions that improve or do not harm the environmental integrity of the bays or terrestrial ecosystems are preferred over those that have the potential to degrade the environment.
- **Equity** – Does the response option avoid the problem of unfairly helping some at the expense of other communities, generations, or socioeconomic groups?
- **Demonstrated Effectiveness** – Has the response option been implemented elsewhere previously, and has it been proven effective? Many response options for sea level rise have been used for flooding, erosion, and environmental protection. Those that have a proven record of performance may help meet the political feasibility criterion.
- **Potential Resource Availability** – Are the resources required to implement the option reasonable to obtain either locally or through federal, state, or private assistance?

Sea Level Rise Response Strategies Based on Land Use

In addition to the above criteria for overall prioritization, there also is a rationale for choosing distinct response options for different land use conditions in the county. Below are recommended functional categories for applying sea level rise response options based on a literature review of land classification for sea level rise response and a review of the current and future land use patterns in Worcester County. As the response options are reviewed, they can be paired with the functional categories within which they would be most feasible to implement. For example, wetland migration would be easily implemented within #1 but also may be feasible in #4 to #6 with forward-thinking policies in place and could even be a possibility for #3 and #7. The choice of which categories to apply a wetland migration response option would depend in part on the number of acres of wetlands the county is willing to lose in the future. The actual locations to which these functional categories could be applied can be based on the county's Comprehensive Plan land use categories as depicted on the existing and future land use maps in the plan. Response options for each functional category can then be tailored to complement existing policies in each area.

The Functional Categories include the following:

1. Public or private land designated for current or future use as conservation areas;
2. Public or private property that provides a community service (i.e., infrastructure or critical facilities);
3. Land designated for future use for community services;
4. Rural private land designated for current and future agriculture or forestry;
5. Vacant land designated for future low-density residential development;
6. Vacant land designated for future commercial or industrial development;
7. Areas with existing low-density residential development; and
8. Areas with existing high-density residential, commercial, or industrial development.

Where land is currently vacant or in low-intensity use (e.g., for agriculture or forestry), the choice of response option will be influenced in part by the following:

- Potential for development that can be undertaken without compromising the natural adaptive capacity of natural features (e.g., coastal wetlands, beach-dune systems);
- Potential for development that can be protected from sea level rise impacts; and
- Potential for providing community services with facilities and infrastructure that can be protected from sea level rise impacts.

Where land is already developed, the choice of response option will be influenced in part by the following:

- Potential for relocation, including location-dependency;
- Relative costs of relocation versus accommodation or protection;
- Size of tax base affected;
- Concentration of public and private capital investment;
- Development density; and
- Quality and natural adaptive capacity of natural features (e.g., coastal wetlands, beach-dune systems).

4.2 RESPONSE OPTION RANKING MATRIX

To be completed after input from Worcester County Planning Commission and other key stakeholders has been received.

Other stakeholders who may be requested to comment on the response options include the following:

- County government department representatives, including Comprehensive Planning, Development Review and Permitting, Environmental Programs, Public Works, and Emergency Services;
- Municipal government representatives; Ocean City may want to send similar departmental representation as the county;
- Municipal and private utilities representatives (particularly water and sewer);
- Chambers of Commerce;
- MPO or other transportation planning representative;
- Homeowner associations or other community groups of areas near the water Assateague Park representative;
- Environmental protection group, especially any concerned about the health of the bays, wetlands, or species dependent on the estuaries;
- Maryland Department of Natural Resources;
- United States Geological Survey;
- National Oceanic and Atmospheric Administration; and
- Federal Emergency Management Agency.

4.3 RECOMMENDATIONS FOR IMPLEMENTATION OF PRIORITY RESPONSE OPTIONS

Complete recommendations for codification and implementation will be provided after response options have been prioritized by the Worcester County Planning Commission. A brief strategy for implementation is provided below for consideration by the Planning Commission and staff.

1. Identify protection, accommodation, and retreat zones based on impacts projected for the 2100 Worst Case scenario. This conscious choice needs to be made, first understanding the long-term implications of decisions of whether to protect particular areas. It is recommended that a visioning charette or other public input method be utilized prior to these decisions being adopted so that there is higher degree of public acceptance of the response strategy. These zones may be able to be adapted to fit current land use planning categories or critical areas designations once the initial decisions based on projected sea level rise impacts have been made.
2. Using the list of prioritized response options and the areas designated for protection, accommodation, and retreat begin assessing the options that should be used in each area. For instance, in accommodation zones, a combination of limited non-structural protection, rolling easements, property acquisition, elevation and floodproofing, setbacks for future development, and post-disaster redevelopment restrictions may provide a solid approach.
3. Begin a public education campaign!
4. Identify chosen response options that will address Steady State 2025 impacts that can be implemented quickly. Addressing these more time-critical impacts of sea level rise first will help gain acceptance for the response strategy and momentum in implementing it. Addressing Steady State 2025 impacts should be a no-regrets action as this scenario is based on current rates of sea level rise and could resolve some of the current flooding and erosion problems in the county. Options that can be incorporated in existing plans and codes will be the easiest to implement first.
5. Adopt the response strategy chosen. Begin codification of the options chosen in Step 2, starting first with those that can be implemented through existing programs or through the modification of existing codes and plans. Identify funding sources.

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Appendix: Methodology of GIS Analysis

Section 2 of this report presents a multitude of data on the vulnerability of Worcester County to sea level rise impacts. This Appendix contains a detailed methodology of how that data were derived. The analysis process began with conversion of the Worcester County Sea Level Rise Technical Model scenarios (described in **Section 1**) to polygons for use in spatial analysis techniques using ESRI ArcView 9 software. Other geographic information systems (GIS) data used are listed in **Table A.1**.

Table A-1. Other information systems (GIS) data used.

Common File Name	GIS data Source	Type	Author	Description	Process	Date
DEM-digital elevation model	wco_med7	raster	USGS--Sea level rise project completed 2006	digital elevation model	DEM was produced from the LiDAR-derived bare earth mass points representing true ground elevations with above-ground features. The DEM data is stored in a raster format with grid spacing of 2 meters in NAD83 State Plane coordinates. Elevations are given in centimeters.	2002-2003
Steady State 2025	dem_2025	Layer file; symbology for DEM	USGS--Sea level rise project completed 2006	Contains elevation symbology for the digital elevation model (DEM) of the Worcester County, MD. It incorporates projection of sea level rise for the year 2025 at a constant rate of rise 3.1 mm/yr. Elevations are given in centimeters.	1. Reclass DEM based on symbology elevation ranges. 2. Convert to polygon. 3. Select grid values 1-3 corresponding to Mean Low Water - Mean Sea Level, Mean Sea Level - Mean High Water, and spring tides (durng reclass, the first three ranges in the symbology correspond to MLW-MSL, MSL-MHW, spring tides). 4. Dissolve.	2006
Worst Case 2025	dem_max2025	Layer file; symbology for DEM	USGS--Sea level rise project completed 2006	Contains elevation symbology for the digital elevation model (DEM) of the Worcester County, MD. It incorporates projection of sea level rise for the year 2025. Rate of rise was calculated based on the maximum acceleration in the sea level rise over the next 100 years as presented by the IPCC. Elevations are given in centimeters.	1. Reclass DEM based on symbology elevation ranges. 2. Convert to polygon. 3. Select grid values 1-3 corresponding to Mean Low Water - Mean Sea Level, Mean Sea Level - Mean High Water, and spring tides (durng reclass, the first three ranges in the symbology correspond to MLW-MSL, MSL-MHW, spring tides). 4. Dissolve.	2006
Worst Case 2050	dem_max2050	Layer file; symbology for DEM	USGS--Sea level rise project completed 2006	Contains elevation symbology for the digital elevation model (DEM) of the Worcester County, MD. It incorporates projection of sea level rise for the year 2050. Rate of rise was calculated based on the maximum acceleration in the sea level rise over the next 100 years as presented by the IPCC. Elevations are given in centimeters.	1. Reclass DEM based on symbology elevation ranges. 2. Convert to polygon. 3. Select grid values 1-3 corresponding to Mean Low Water - Mean Sea Level, Mean Sea Level - Mean High Water, and spring tides (durng reclass, the first three ranges in the symbology correspond to MLW-MSL, MSL-MHW, spring tides). 4. Dissolve.	2006
Worst Case 2100	dem_max2100	Layer file; symbology for DEM	USGS--Sea level rise project completed 2006	Contains elevation symbology for the digital elevation model (DEM) of the Worcester County, MD. It incorporates projection of sea level rise for the year 2100. Rate of rise was calculated based on the maximum acceleration in the sea level rise over the next 100 years as presented by the IPCC. Elevations are given in centimeters.	1. Reclass DEM based on symbology elevation ranges. 2. Convert to polygon. 3. Select grid values 1-3 corresponding to Mean Low Water - Mean Sea Level, Mean Sea Level - Mean High Water, and spring tides (durng reclass, the first three ranges in the symbology correspond to MLW-MSL, MSL-MHW, spring tides). 4. Dissolve.	2006

Common File Name	GIS data Source	Type	Author	Description	Process	Date
Surge Steady State 2025	con2025_cat3	Line feature	USGS--Sea level rise project completed 2006	Presents storm surge contour lines for category 3 hurricane for the year 2025 with the projected sea level rise rate equal to the historic rate of 3.1 mm/yr.	polyline to polygon tool	2006
Surge Average Acceleration 2025	avg2025_cat3	Line feature	USGS--Sea level rise project completed 2006	Presents storm surge contour lines for category 3 hurricane for the year 2025 with the projected sea level rise rate calculated for the average Intergovernmental Panel on Climate Change (IPCC) scenario.	polyline to polygon tool	2006
Surge Average Acceleration 2050	avg2050_cat3	Line feature	USGS--Sea level rise project completed 2006	Presents storm surge contour lines for category 3 hurricane for the year 2050 with the projected sea level rise rate calculated for the average Intergovernmental Panel on Climate Change (IPCC) scenario.	polyline to polygon tool	2006
Surge Average Acceleration 2100	avg2100_cat3	Line feature	USGS--Sea level rise project completed 2006	Presents storm surge contour lines for category 3 hurricane for the year 2100 with the projected sea level rise rate calculated for the average Intergovernmental Panel on Climate Change (IPCC) scenario.	polyline to polygon tool	2006
Current land use--Ocean City	OceanCity_Landuse_080906_SLRcategories	polygon	Ocean City	Parcel based land use	Sea level rise (SLR) categories: Residential, Commercial, Agriculture, Institutional, Industrial;calculate GIS acres	2006
Current zoning--Worcester County (includes Snow Hill and Pocomoke)	Wor_zoning_SLR_category	polygon	County	current zoning districts for Worcester County. Includes zoning/landuse for Snow Hill and Pocomoke with guidance from town staff.	Sea level rise (SLR) categories: Residential, Commercial, Agriculture, Institutional, Industrial	ongoing
Tax polygon	tax_ply	polygon	Spatial Systems	developed by Spatial Systems through E911 project	Calculate GIS acres	2007
Building footprints	building_ftprints	polygon	Spatial Systems and Ocean City	developed by Spatial Systems through E911 project	2004	
Corporate Limits	corp_limits	polygon	County	developed by Spatial Systems through E911 project and maintained by county	ongoing	
Proposed landuse--Ocean City	OceanCity_Proposed_Landuse_080906_SLLRcategories	polygon	County	generalized areas provided by Ocean City	2006	
Future landuse--Snow Hill	SnowHill_future_landuse_SLR_category	polygon	County and Snow Hill	generalized areas digitized by county approved by Snow Hill	Sea level rise (SLR) categories: Residential, Commercial, Agriculture, Institutional, Industrial	2007
Future landuse--Worcester County (Pocomoke n/a)	wor_future_landuse_SLR_category	polygon	County	Comprehensive Plan Land Use Plan Map	Sea level rise (SLR) categories: Residential, Commercial, Agriculture, Institutional, Industrial	2006

Common File Name	GIS data Source	Type	Author	Description	Process	Date
MD Property View Centroids 2007	worc2007	point	Maryland Department of Planning	Tax assessments data	Vacant=improvement value <=20,000	2007
Centerline	cline	Line feature	County	road centerline	Calculate GIS miles	ongoing
Waterlines	sde database	Line feature	Spatial Systems	water lines digitized by Spatial Systems. Berlin and snow Hill provided water lines. Excludes much of Ocean City	separate line features merged into one file	2007
Sewerlines	sde database	Line feature	Spatial Systems	sewer lines digitized by Spatial Systems. Berline provided sewer lines. Excludes Snow Hill and much of Ocean City	separate line features merged into one file	2007
Floodzone	Floodplain_A_AE_VE	polygon	Federal Emergency Management Agency	flood insurance rate maps	select floodzone = A, AE, VE and export to new file	1995
Historic_Places	HistoricPlaces_jurisdiction	polygon	National Register of Historic Places and ?		Create field indicating name of jurisdiction	unknown

The following describes the step-by-step process used to obtain the data output for each table in **Section 2** that was done as an original analysis for this report. The methodology is organized by the output tables as numbered in **Section 2**.

Methodology for Table 2.1.

Part 1

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Merge	a. Worcester County Step 8 output file b. Ocean City Step 8 output file	Merge files into one feature class
2.	Select	Expression equals Inundation = 1	Extracts features from an input feature class or input feature layer and stores them in a new output feature class
3.	Delete Field	Link to Step 2 file output	Remove "fluff from step 1 file output
4.	Frequency	Frequency Fields: ACCTID_OC_WC	dbase; List all unique ACCTID's and its frequency
5.	Select	Expression equals Inundation = 2	Extracts features from an input feature class or input feature layer and stores them in a new output feature class
6.	Delete Field	Attach to Step 4 file output	Remove "fluff from Step 1 file output
7.	Frequency	Frequency Fields: ACCTID_OC_WC	dbase; List all unique ACCTID's and its frequency

Next step: Frequency table. Check for duplicate records against 2004 aerial photography. Sort field. Merge duplicate records.

Part 2.

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Select layer by location	a. Ocean City current landuse b. Steady State 2025	Notes: a. Ocean City current landuse: Add field "GISacres_Parcel" and calculate GIS acres b. Selects Ocean City current landuse that INTERSECTS with SS2025 scenario
2.	Feature class to feature class	n/a	Creates feature class of selected Ocean City current landuse
3.	Union	a. SteadyState2025 b. Step 2 File Output	Unionizes Step 2 file output with steady state 2025 scenario
4.	Add field		Adds field named "GISacres_SLR2025_ParcelsInundated"
5.	Calculate field	Expression = [shape_area]/4046.873	Calculate Step 5 field
6.	Add field		Adds field named "PercentInundated"
7.	Calculate field	Expression = [GISacres_SLR2025_ParcelsInundated]/[GISacres_Parcel]*100	Calculate Step 6 field
8.	Select	Query Builder = "FID_SteadyState_2025" = 1 AND "PercentInundated" >= 50.00729 AND "SLR_category" IN('Agriculture', 'Commercial', 'Industrial', 'Institutional' 'Residential', 'Town of Ocean City')	Extract selected input selected features to new output feature class
9.	Add field		Adds field named "Inundation"
10.	Make feature layer		Temporary file
11.	Delete Field	Link to Step 10 output	Delete "fluff" from Step 8 file
12.	Select layer by attribute	"PercentInundated" > 99.00943; Link to step 10 output	
13.	Calculate Value	Field name = Inundation Expression = 1	
14.	Select layer by attribute	"PercentInundated" <= 99.00943; Link to Step 10 output	
15.	Calculate Value	Field name = Inundation Expression = 2	

Similar processes taken for Worst Case 2025, 2050, 2100 and Worcester County. Next step: mergefiles.

Methodology for Table 2.2.

Part 1

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Select layer by location	a. Building footprints b. Steady State 2025	Selects all buildings that INTERSECT with steady state 2025 scenario
2.	Feature class to feature		Exports selected buildings to feature class

Apply processes to other scenarios 2025, 2050, 2100.

Part 2

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Intersect	a. Step 2 above file output b. Worcester County landuse	Attributes of buildings should contain Worcester County zoning or Ocean City landuse
2.	Select	Expression: "SLR_category" IN('Agriculture', 'Commercial', 'Institutional', 'Residential')	Saves selected to feature class
3.	Delete field	Link to select output	Remove "fluff"
4.	Make feature layer	Link to select output	Temporary file
5.	Select layer by location	a. Step 4 file output b. Floodplain_A_AE_VE	
6.	Feature class to feature class		Creates feature class of Step 5 file output

Apply process to Ocean City landuse.

Part 3

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Merge	Step 6 file out a. Worcester County b. Ocean City	Creates feature class containing Ocean City and Worcester county buildings
2.	Frequency	Attach to Step 1 output; Frequency fields: Jurisdiction	Dbase; List all unique Jurisdiction and their frequency
3.	Frequency	Attach to Step 1 output; Frequency fields: Jurisdiction	Dbase; List all unique Jurisdiction and their frequency

Methodology for Table 2.3.

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Select layer by location	a. Building footprints b. Worst case 2100	Select all buildings that intersect with the worst case 2100 scenario
2.	Feature class to feature class	n/a	Extracts selected buildings and saves them as a feature class

Methodology for Table 2.4.

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Select layer by location	a. Historic Places_jurisdiction b. Worst Case 2025	
2.	Feature class to feature class	n/a	Creates feature class of selected historic places
3.	Frequency	Frequency Fields: Name	Creates a list of the unique jurisdictions and their frequency

Methodology for Table 2.6.

Part 1

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Select layer by location	a. Ocean City current Landuse b. Average Acceleration Surge 2025	
2.	Feature class to feature class		Creates feature class of selected Ocean City current Landuse

Next Steps: Apply Worcester County zoning to methodology and surge scenarios.

Part 2

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Append	Input datasets: Ocean City final layer (Step 2 file output above) Target dataset: Worcester County final layer (Step 2 file output above) Schema type: NO_TEST	Appends Ocean City final layer to an existing layer—Worcester County final layer (determined by Step 2 above)
2.	Make Feature Layer	Expression: "SLR_category" IN ('Agriculture', 'Commercial', 'Industrial', 'Institutional', 'Residential')	Temporary file
3.	Feature Class to Feature Class	Step 4 file output	Create feature class
4.	Frequency	Frequency Fields: SLR_category	dbase; Lists unique sea level rise (SLR) categories and their frequency

Next steps: apply surge scenarios.

Methodology for Table 2.7.

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Select layer by location	a. building_ftprint b. Polygon_2025_Steady_State_Surge	Selects building footprints that INTERSECT polygon 2025 steady state surge
2.	Intersect	a. Step 1 file output b. Worcester zoning with sea level rise categories	Creates feature class of building footprints with zoning attributes
3.	Frequency	Notes: a. Attach to Step 2 file output b. Creates a list of the unique jurisdictions and their frequency Frequency Fields: Jurisdiction	dbase; List unique sea level rise (SLR) categories and their frequency
4.	Make Feature Layer	Notes: Attach to Step 2 file output	Temporary file
5.	Select Layer by Location	a. Step 4 File output b. Floodplain_A_AE_VE	INTERSECT
6.	Feature Class to Feature	Step 5 file output	Creates feature class
7.	Frequency	Frequency Fields: Jurisdiction	dbase; Select unique jurisdictions and calculate their frequency

Methodology for Table 2.8.

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Select layer by location	a. HistoricPlaces_jurisdiction b. Surge Average Acceleration 2025	Select all historic places that INTERSECT with surge avg. acceleration 2025 scenario
2.	Feature class to feature class		Create feature class from selected Step 1 file output
3.	Frequency	Frequency Field: Name	dbase; Creates list of unique jurisdictions and their frequency

Methodology for Table 2.9.

Part 1

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Select by layer by location	a. Tax poly b. Surge Average acceleration 2025	Selects all tax polygons that INTERSECT with surge avg accel 2025 scenario
2.	Feature class to feature class	Step 1 file output	Creates a feature class
3.	Make feature layer		Temporary file of Step 2 file output
4.	Make feature layer	Attach to step 5: intersect	Creates a temporary file of Worcester future landuse
5.	Intersect	a. Step 3 file output b. Step 4 file output: Worcester County future landuse plan	Attaches Worcester county future landuse plan to attributes of selected tax polygons
6.	Erase	a. Step 5 file output b. Corporate limits	Erases all polygons within corporate limits
7.	Select layer by location	a. Maryland property view points less than 20000 (vacant) b. Step 6 file output	Selects all points that INTERSECT Step 6 file output
8.	Feature class to feature class		Saves Step 7 file output to feature class
9.	Spatial join	a. Step 8 file output b. Worcester county landuse plan (future)	Attaches attributes from Worcester County landuse plant (future) to Step 8 file output

Apply process to other scenarios to include Snow Hill and Ocean City.
Next step: append

Part 2

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Append	Final results, Surge Average Acceleration 2025 a. Ocean City b. Snow Hill c. Worcester County Drop down menu: Select “No Test”	Appends all features into one feature class
2.	Summary Statistics	a. Statistics field: NFMTTLVL, SUM b. Case field: SLR_Category	dbase

Methodology for Table 2.10.

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Clip	a. Cline b. SteadyState_2025	Notes: a. Add field "GIS miles" b. Centerlines within steady state 2025 scenario
2.	Add field		Add field name "GISmiles_SteadyState2025"
3.	Calculate field	Expression: [Shape_Length]*0.000621371192	
4.	Delete Field		Delete "fluff"
5.	Make feature layer		Temporary file
6.	Feature Class to Feature Class	Expression: "JURIS" = 'Worcester'; Link to Step 5 file output	
7.	Make feature layer		Temporary file
8.	Summary statistics	Statistics: GISmiles_SteadyState2025, SUM Case field: Road_Class	Dbase file
9.	Feature Class to Feature Class	Expression: "JURIS" IN ('Ocean City', 'Pocomoke City', 'Snow Hill'); Link to Step 5 file output	
10.	Make feature layer		Temporary file
11.	Summary statistics	Statistics: GISmiles_SteadyState2025, SUM Case field: Road_Class	Dbase file

Methodology for Table 2.12.

Step	Model Application	File(s) Input and/or Field Input	File Output
1.	Clip	a. Waterlines b. Worst Case 2100	
2.	Add Field		Add field name "GISmiles_AvgAccel2100"
3.	Calculate Field	Expression: [Shape_Length]*0.0006213712	
4.	Summary Statistics	Statistics Field: GISmiles_AvgAccel2100, SUM Case field: Jurisdiction	dbase

Next steps: apply sewer lines to methodology.