Draft Report on Chesapeake Bay Watershed Climate Change Impacts

A draft report fulfilling Section 202(d) of Executive Order 13508

September 9, 2009

The charge from Executive Order 13508:
Sec. 202 -- Reports on Key Challenges to Protecting and Restoring the Chesapeake Bay. Within 120 days from the date of this order, the agencies identified in this section as the lead agencies shall prepare and submit draft reports to the Committee making recommendations for accomplishing the following steps to protect and restore the Chesapeake Bay:

> (d) assess the impacts of a changing climate on the Chesapeake Bay and develop a strategy for adapting natural resource programs and public infrastructure to the impacts of a changing climate on water quality and living resources of the Chesapeake Bay watershed;

PART 6—PROTECT CHESAPEAKE BAY AS THE CLIMATE CHANGES

> *Sec. 601.* The Secretaries of Commerce and the Interior shall, to the extent permitted by law, organize and conduct research and scientific assessments to support development of the strategy to adapt to climate change impacts on the Chesapeake Bay watershed as required in section 202 of this order and to evaluate the impacts of climate change on the Chesapeake Bay in future years. Such research should include assessment of:
>
> (a) the impacts of sea-level rise on the aquatic ecosystem of the Chesapeake Bay, including nutrient and sediment load contributions from stream banks and shorelines;
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> (b) the impacts of increasing temperature, acidity, and salinity levels of waters in the Chesapeake Bay;
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> (c) the impacts of changing rainfall levels and changes in rainfall intensity on water quality and aquatic life;
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> (d) potential impacts of climate change on fish, wildlife, and their habitats in the Chesapeake Bay and its watershed; and
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> **(e)** potential impacts of more severe storms on Chesapeake Bay resources.

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Disclaimer:

This draft document is the Department of Commerce's (DOC) and Department of the Interior's (DOI) current draft report under Section 202d of Executive Order 13508 (EO) making recommendations to the Federal Leadership Committee (FLC) for an adaptation strategy in response to climate change impacts in the Chesapeake Bay watershed. DOC and DOI intend to release this draft document to the public concurrently with its submission to the FLC. After the FLC has considered this draft, along with the other draft reports prepared pursuant to the EO, it will prepare a draft strategy to restore the Bay and publish it in the Federal Register for public comment. The current draft report includes preliminary recommendations which may change as the draft strategy is developed. Because this draft document is only intended as input into a strategy for future agency action, it is not a final agency action subject to judicial review. Nor is this draft document a rule. Nothing in this draft document is meant to, or in fact does, affect the substantive or legal rights of third parties or bind DOC or DOI. While this draft document reflects DOC and DOI's current thinking regarding recommendations to protect and restore the Bay, the agencies reserve the discretion to modify the report as it works with the FLC to develop the strategy, or act in a manner different from this report as appropriate.

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I. Executive Summary

Climate change will complicate the ability to meet Chesapeake Bay management and restoration goals. The Chesapeake Bay watershed includes six states and the District of Columbia; and has the highest land area to water volume ratio of any estuary in the world making it highly responsive to prevailing weather conditions in the watershed. Changes in climate patterns, superimposed on population growth, land use change, and other environmental management challenges, are likely to affect the region's ability to meet Chesapeake Bay Program restoration and conservation targets. Shifts in key climatic variables may significantly increase the currently projected costs and timelines for achieving water quality and living resource restoration goals. Additionally, the Chesapeake Bay region has some of the highest land subsidence rates along the Eastern Seaboard, creating extremely vulnerable shorelines. Many of the region's urban centers and particularly significant ecosystems are in low-lying areas that are particularly vulnerable to sea-level rise and storm surge. As an example, Hampton Roads, Virginia is one of the nation's population center's most at risk from sea-level rise and storm surge due to the concentration of people living in this vulnerable low-lying area. Most wetlands on Maryland's eastern shore are likely to be inundated under even moderate sea-level rise scenarios. Due to the comprehensive nature of climate change effects federal agencies must take collective action to ensure that these effects are considered in the development of regional restoration goals and conservation strategies.

The federal government must develop climate change response strategies. Federal agencies own approximately 3.2 million acres within the Chesapeake Bay watershed, representing about 8% of the total watershed land area. The federal landholdings include Department of Defense facilities, National Wildlife Refuges, National Parks, and National Forest Lands, all of which are vulnerable to climate changes. Additional landholdings, owned by state and private organizations are supported with federal funding. All federal landholders and non-federal landholders receiving federal support should implement climate change response plans to minimize impacts on their resources in light of projected changes. This report focuses on how federal agencies can and should respond to these impacts and provide guidance and support to stakeholders as they develop similar adaptation strategies.

This report responds to Section 202d of Executive Order 13508 (EO) which charges Federal agencies to make recommendations to "…assess the impacts of a changing climate on the Chesapeake Bay and develop a strategy for adapting natural resource programs and public infrastructure to the impacts of a changing climate on water quality and living resources of the Chesapeake Bay watershed." Section 601 of the EO directs the Secretaries of Commerce and Interior to organize and conduct research and scientific assessments to evaluate the impacts of climate change in future years and to support development of a strategy to adapt to climate change impacts on the Chesapeake Bay watershed. This report provides an overview of some of the anticipated impacts of climate change on Bay resources, and examples of existing federal programs that could collaborate on adaptive responses. The report is divided into six major parts: Executive Summary, Background, Overview of Impacts, Adaptive Actions, Technical Needs, and Climate Change Strategies.

This report recommends a range of technical, management and adaptation strategies across multiple timelines. It also recommends a process that continually builds upon the best available scientific information because so much of our understanding of climate change and our ability to project impacts is still developing. Many of the recommended strategies should be implemented immediately, and all adaptation efforts should be reviewed and modified as new information becomes available. The recommendations in this report are based on a review of numerous studies (see Part VII) on the impacts of climate change on coastal zones and watersheds and recent management reports on the mid-Atlantic region (including in the Chesapeake Bay). Although there is still much uncertainty surrounding climate change projections and specific impacts, available information is sufficient to begin adapting to and mitigating the most likely impact scenarios and to raise awareness among policy makers and the public. In summary, the potential significance of climate impacts to the Bay demands taking both adaptive and mitigative action now, with strategies designed to be regularly adjusted as our understanding of climate change impacts on the Bay continues to evolve.

Key recommendations in this report are to:

1. Develop a centralized Chesapeake Bay climate change coordination program to address climate adaptation activities and management decisions throughout the Chesapeake Bay watershed;
2. Integrate climate change concerns into Chesapeake Bay Program activities and strengthen legislative authority;
3. Enhance existing and/or develop new technical information and decision support tools to better understand, project, and respond to climate change and its impacts e.g., modeling, observation stations, remote sensing, etc.;
4. Establish adaptation guidance for managing federal programs, federally-managed lands, and federally financed state, local, and private lands;
5. Develop a coordinated strategy for climate change outreach and education; and
6. Develop federally coordinated plans for supporting climate change adaptations.

A complete presentation of these recommendations is provided in Part VI of this report.

II. Background

Climate change adds a new level of complexity to natural resource manager and policy decision-maker efforts to restore and protect the Chesapeake Bay and its fish, wildlife, and native plant populations. The Chesapeake Bay ecosystem is already degraded due to a long history of land clearance and development, fertilizer use, and human population increases which have resulted in reduced water quality, habitat loss, lower levels of dissolved oxygen, high turbidity, and disturbed biological communities (U.S. Geological Survey, 2007). Climate change will have additional impacts on water quality and quantity, public health, the sustainability of aquatic freshwater and marine and terrestrial living resources, as well as the quality of life and economic well-being of the watershed's 17 million residents. Managing the Chesapeake Bay and its watershed to accommodate climate change impacts will be further complicated by future population growth and associated land use decisions throughout the watershed. This is particularly true for the region's coastal areas due to the impacts of sea-level rise. Therefore, the Chesapeake Bay Program and its partners should recognize that the Bay will experience significant changes due to climatic variability, and history should not be used as the only guide for establishing future restoration targets.

The Earth's climate is changing in part due to human activities that have released unprecedented levels of heat-trapping greenhouse gases into the atmosphere in a relatively short period of time. Mitigation strategies, like those in proposed federal cap and trade legislation, seek to reduce the amount of emissions released in an effort to minimize the overall magnitude of global climate change. However, according to the Intergovernmental Panel on Climate Change (IPCC), regardless of mitigation actions taken to limit emissions, the level of greenhouse gases already in our atmosphere commit the Earth to significant levels of climate change (Teng et al., 2006). Therefore the federal government has a vested interest in developing adaptation strategies to plan for and respond to those changes. While we recognize that there are existing uncertainties surrounding climate change projections, we do know that the severity of the impacts, particularly by mid- and late-century, is very sensitive to the amount of greenhouse gases emitted globally over the coming decades.

According to a recent synthesis by the Chesapeake Bay Program's Scientific and Technical Advisory Committee (STAC) (Pyke et al., 2008) and by the Maryland Climate Change Commission (Boesch 2008), by the year 2100 regional warming is projected to be 4^0 to 11^0F above the historical average, relative sea level is projected to rise by 2-5 feet (60-150 cm), mean winter and spring precipitations are likely to increase (potentially up to 10%), and storm intensity may increase. Because of higher initial sea levels, even the same strength of storms will produce more coastal inundation. Over the last century, sea level in the Chesapeake Bay has risen approximately 1 foot (30 cm). Tide gauge measurements throughout the Bay show a steady increase in sea levels due to thermal expansion of the oceans, melting glaciers and ice sheets, and regional subsidence. Given the low relief topography bordering most of the Bay, sea-level rise and storm surge are serious threats to coastal communities and habitats.

Hurricane Isabel (2003) provides a compelling example of the destructive nature of coastal storms. This storm made landfall in North Carolina as a category 2 storm and resulted in more than $3 billion in damages and 50 deaths either through direct or indirect storm impacts across eight Atlantic states from North Carolina to New York (Bevin and Cobb, 2003).

Despite existing uncertainties, Virginia and Maryland have already developed climate action plans (Governor's Commission on Climate Change, 2008; Maryland Commission on Climate Change, 2008), while Delaware, Washington, D.C. and Pennsylvania are currently developing similar plans. Maryland, in particular, has adopted innovative strategies to adapt to the impacts of increasing sea-level rise. However, even though states such as Maryland and Virginia have identified their needs and recommended actions, lack of funding, political will, existing institutional frameworks, and uncertainties associated with climate change projections challenge their ability to effectively implement the full list of strategies. Given these challenges, this report recommends increased Federal and regional collaboration to address climate change impact issues, and provides recommendations to spur adaptive action in the Bay, addressing many of the existing barriers to widespread adaptation implementation.

III. Overview of Impacts

A summary of potential climate change impacts to the Bay ecosystem and watershed is provided in Table 1. This list is not meant to be comprehensive or exhaustive but does provide an overall perspective of the scope and variety of impacts that should be considered in designing adaptive strategies to climate change. The following sections discuss specific impacts on the Chesapeake Bay and its watershed resulting from sea-level rise, increases in temperature, acidity, and salinity, and changing rainfall patterns and increases in rainfall intensity. The final section on impacts focuses on public infrastructure and human health. Broad recommendations related to the federal role in adapting to climate change are discussed in Part VI of this document. It is important to keep in mind that this overview represents expected impacts from projected warming scenarios based on current knowledge. The magnitude of impacts will largely depend upon future global carbon dioxide emissions, and could be either mitigated (reduced) through global reduction strategies or enhanced by the lack of mitigation actions.

A. Rising sea level and storm surge in the Chesapeake Bay

The probability of more rapid rates of sea-level rise in the future is one of the greatest threats to the Bay and its aquatic and coastal ecosystems. It is well established that the mean rate of relative sea-level rise, accounting for land subsidence, in the Chesapeake region exceeds the rate of global sea-level rise. Regional land subsidence is caused by post-glacial rebound over the past ~ 10,000 years (Cronin et al., 2007, Larsen and Clark, 2006). In local areas, compaction of subsurface layers may also contribute to land subsidence. Although the mean long-term rate of sea-level rise has been about 1 foot (30 cm) over the past century, relative sea-level rise can vary throughout the Bay region due to different rates of land subsidence. Rates of relative sea-level rise as determined from long-term tide station records vary across the region from about 1 foot per century in the northern and central Bay to about 1.5 feet per century along the Virginia's lower southeastern shore (CCSP 2009).

Wu et al., (2009) estimated a projected total future sea-level rise of between 1.7 and 2.0 feet (528-599 mm) by the year 2100 at Annapolis, Maryland using two IPCC (Intergovernmental Panel on Climate Change) greenhouse gas emission scenarios, A2 and B2 (IPCC 2000). But this study did not take into account several important factors that suggest future rates might be higher than previously expected. For example, new studies suggest that future rates of sea-level rise given by the widely cited IPCC 2007 4th Assessment Report (AR4), similar to those used by Wu et al. (2009), are considered underestimates because they do not take into account mass balance changes in the Greenland and Antarctic ice sheets (e.g. Shepherd and Wingham, 2007). The AR4 estimates also do not account for the regional oceanographic effects due to changes in Atlantic Meridional Overturning Circulation (Hu and Meehl, 2009, Yin et al., 2009), which Yin et al. suggest could significantly increase the sea level rise in the Chesapeake Bay region, beyond that caused by global increases and regional subsidence. In addition, paleo-sea level records show mean global sea-level rise rates can exceed approximately 0.33 in/yr (8-10 mm/yr, or 3 feet/century) during periods of climatic warming and rapid ice sheet melting (Cronin et al., 2007). These values are more than twice the historical rate and should be considered within the range of potential future scenarios over the next 1-2 centuries.

According to the National Wildlife Federation (2008), by 2100 sea-level rise will lead to tremendous change along the Chesapeake Bay. They project that the region will lose more than 167,000 acres of undeveloped upland area, 161,000 acres of brackish marsh, 69% of our estuarine beaches, 58% of our ocean beaches, and more than 50% of our tidal marshes. These areas will be replaced by more than 266,000 acres of open water and 50,000 acres of saltmarsh.

Inundation:
Inundation directly threatens coastal habitats and communities. For example, Virginia's Hampton Roads region is considered to be one of our nation's populated centers most at risk from sea level and related storm damage. Other populated areas such as Alexandria, Virginia have already experienced flooding damage from water inundation and are at greater risk due to sea-level rise (Virginia's Commission on Climate Change, 2008). The amount of land inundated by a given sea-level rise is a complex function of elevation, shoreline geology, land use, wetland ecology, and the rate of sea-level rise (Pyke et al., 2008). Coastal development confines the inland migration of species and fragile coastal habitats. For portions of the southern and eastern Chesapeake Bay especially, where there are many small marsh islands and vast areas of low-lying land with very little vertical slope, gradual inundation of the land by the combination of sea-level rise and land subsidence is already an issue of great concern. These low marshes and islands are especially vulnerable to flooding during nor'easters and tropical storms, and are currently exhibiting rapid shoreline erosion (Figure 1). Since the 1930s, more than over 8,000 acres (3,000 hectares), or 12 square miles, of marsh at Blackwater National Wildlife Refuge has been lost at a rate of 150 acres (60 hectares) per year. Causes of this marsh loss include sea-level rise, erosion, subsidence, salt water intrusion, and invasive species (such as the recently extirpated nutria). Similar losses have occurred, and continue to occur, throughout the Bay region. Strategies to either abandon or protect these high risk areas must soon be developed (U.S. Fish and Wildlife Service 2008).

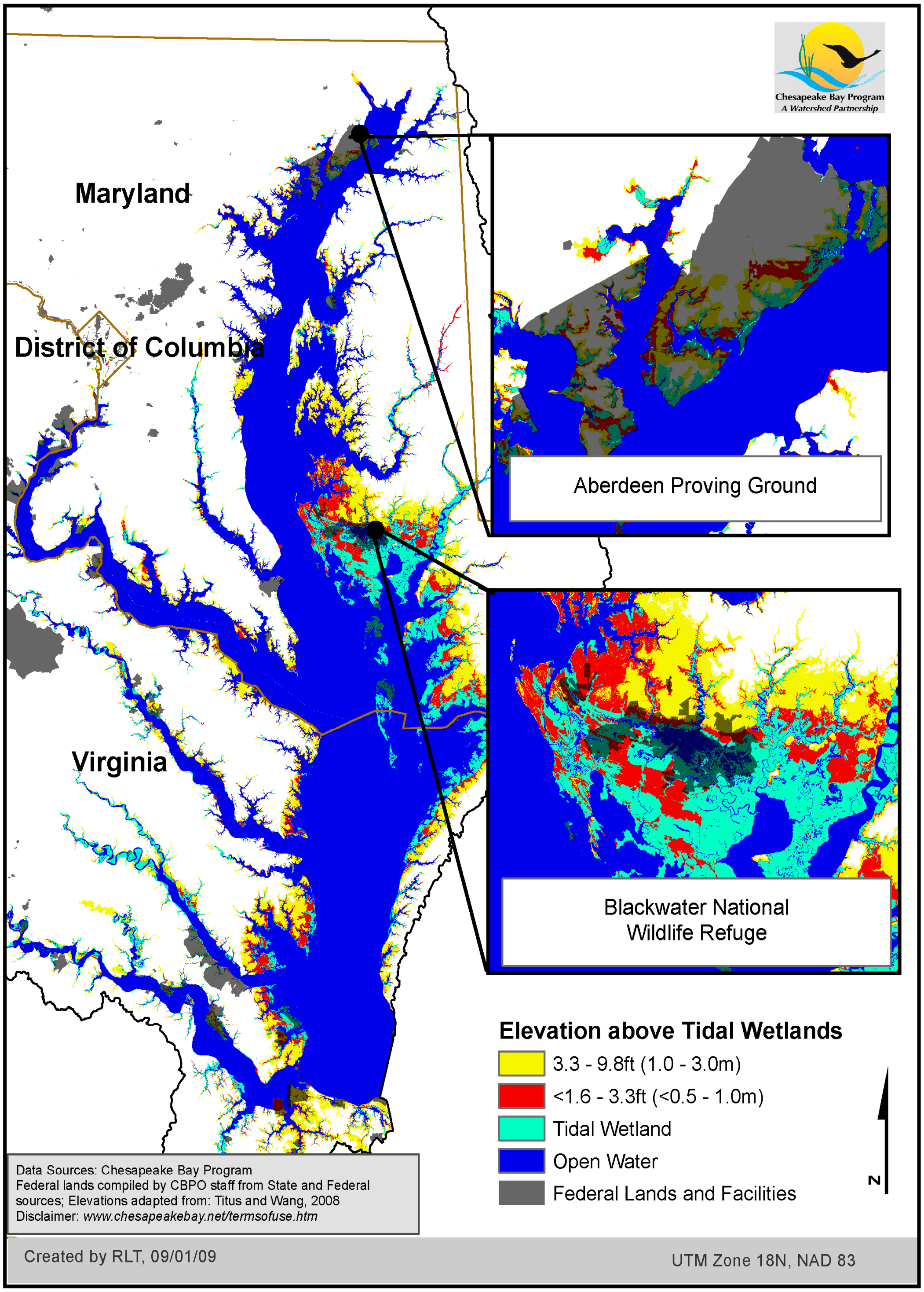

Figure 1. Federal Lands Potentially Impacted by Sea Level Rise and Storm Surge. The future extent of tidal wetlands, shown in light blue, is uncertain. Tidal wetlands may migrate landward as sea level rises. Landward migration rates and extents will be constrained by the rate of sea level rise and land subsidence and by hardened shorelines and near shore infrastructure.

Wetlands and Marshes:
Wetlands and marshes are critical habitat for many species of amphibians, reptiles, birds, fish, and plants. As these habitats decrease, so too will populations of the species dependent upon them. Rising sea level poses the largest threat to low-lying coastal *Spartina* marshes of the Chesapeake Bay. Under the most extreme circumstances, where rates exceed approximately 0.33 in/yr (10 mm/yr or 3 feet/century), tidal marshes will not be able to accrete as fast as sea-level rises resulting in marsh “drowning”. This phenomenon is well-documented in mid-latitude marshes like the Chesapeake’s for past periods of rapid sea-level rise. High losses of estuarine marsh islands have occurred in the past (Cronin, 2005) with the pace seeming to increase in the past 50 years (Leatherman et al., 1995). Although more research is needed, it appears that the ability of marsh elevations to be maintained under rates of sea-level rise exceeding 0.33 in/yr is unlikely and most coastal wetlands on Maryland’s lower eastern shore are unlikely to survive even a rate of 0.16 in/yr (5mm/yr). Sea-level rise will result in some transgression of salt marshes into upland habitats, including agricultural lands and forested margins (partially offsetting losses due to inundation in other tidal areas). This will create problems with reduced plant productivity both in agricultural lands (which may become nonfunctional for crops) and in forests, as salt water intrusion advances inland.

Habitat Loss:
Coastal wetlands, submerged aquatic vegetation, and other shoreline ecosystems provide important ecological services, including serving as nursery areas to juvenile finfish and other coastal animals and critical habitat for many other animals and plants. These ecosystems are vitally important to sustain fisheries and other coastal dependent jobs, improve water quality, and buffer the impacts from storms on upland habitats and property. Submerged aquatic vegetation, one of the primary “indicators” of Bay health, will be impacted by rising sea level through associated higher turbidity and nutrient availability and decreased light intensity. The extensive efforts and investments over the past decade to restore submerged aquatic vegetation may be compromised by increasing water depth, coastal erosion, and suspended sediment, thereby decreasing light penetration to plants.

Expected wetland losses would be accompanied by the loss of a number of highly valuable ecosystem functions, including a reduction in potential nursery areas for finfish (forage fish as well as commercially valuable species), crabs, and nesting habitat for waterfowl (e.g., American black duck, , mallards, and wood ducks), wading birds and rails. Losses of tidal wetlands will also affect a number of migratory waterbirds that depend on the Chesapeake Bay. Figure 1 shows an example of a species that will most likely be affected by climate change. Additional examples can be found in appendix 2.

The American Black Duck (*Anas rubripes*) has long been one of the high-priority species of concern for federal and state wildlife management agencies along the Atlantic Coast. It breeds in modest numbers in the Chesapeake Bay, but in winter its numbers increase dramatically with birds arriving from the northeastern states and eastern Canada. Causes for declines include hunting pressure, increases in numbers of foxes and raccoons at many marsh sites in the Bay and along the Virginia barrier region, and loss of breeding habitat, as many small islands formerly used as nesting sites have disappeared over the past 30-50 years with rising sea levels (Cronin 2005, Erwin et al. 2007, Costanzo and Hindman 2007). Encouraging more island restoration (e.g. dredge material deposition) would greatly benefit this and other waterbird species.

Figure 2: The American Black Duck

Changes in sea level will no doubt affect the ranges of many migratory and resident fish, bird, and invertebrate species as salt marshes and tides may reach farther up the major tributaries. With the loss of salt marsh area and small estuarine islands, some habitat specialists such as clapper rails and seaside sparrows may be dramatically reduced, as well as several species of nesting terns and American black ducks. Diamondback terrapins and the federally threatened Northeastern beach tiger beetle may be extirpated from the Chesapeake Bay or displaced upriver into areas with less suitable sandy-shore habitats. If the tidal marshes along the fringes of the Bay are lost over the next 100-years, feeding habitat will be reduced for more than 20 species of migratory shorebirds (plovers, sandpipers, etc.), wading birds such as herons and egrets, and wintering waterfowl. Thus, these populations will be adversely affected and overall biodiversity and ecosystem complexity will be reduced, threatening the ability of the ecosystem to be resilient to natural disturbances and seriously jeopardizing the sustainability of the Bay.

Storm Surge:

Several factors converge to increase future storm surge extremes: rising sea level, increased tidal range (itself due to sea-level rise, Zhong et al. 2008), and storm intensity. Storm surges, on top of sea-level rise, have the potential to cause extreme damage to coastal communities, as was seen throughout the Bay region following Hurricane Isabel in 2003 and many other strong coastal storms. Storm surge also impacts ecosystems, and can lead to changes in large areas of vegetation from freshwater and brackish-dominant plants to salt-water tolerant communities. Large storm surges may saturate soils with salt adversely affecting large areas of salt-intolerant vegetation and allowing invasion of more salt-tolerant species.

Rising sea levels and storm surges have the potential to severely impact water supply infrastructure, including damaging treatment facilities, and interrupting electrical service needed to operate pumps and treatment equipment. Storms can also impact water quality by increasing turbidity levels in surface water, making it much more difficult to treat the water using convention al methods. Flooding can contaminate wells with bacteria and other pathogens. Flooding can also cause long-term changes to water quality in aquifers. Sea-level rise increases the rate of saltwater intrusion on drinking water supplies, presenting additional public health concerns.

B. *Increasing temperature, acidity, and salinity levels of waters*

The Chesapeake is near the southern edge of the Atlantic growing range of eelgrass (*Zostera marina*), the dominant underwater bay grass species in higher-salinity parts of the Bay. Continued warm temperatures could severely reduce the amount of eelgrass able to grow in the Bay. Eelgrass becomes stressed when water temperatures reach 86^0 F or higher for prolonged periods. Unlike other underwater bay grasses that sprout each spring, eelgrass is perennial and grows through the year. In 2005, for example, a late-summer stretch of high temperatures killed vast areas of eelgrass in the lower Bay. A large loss of eelgrass would affect a number of species, including: Post-larval and molting adult blue crabs, which hide from predators in eelgrass beds; and waterfowl and other aquatic animals that feed on eelgrass during the winter.

Figure 3: Eel grass

As noted in the Science and Technical Advisory Committee (STAC) literature review (Pyke et al., 2008), changes to air and water temperatures and water chemistry will have direct impacts on the distribution of living resources and their habitats. Many Chesapeake Bay species are currently at the geographic edge of their ranges and as conditions change, so will their distributions. Both the commercially important soft clam (*Mya arenaria*) and the ecologically important underwater eelgrass (*Zostera marinus*), are examples of Bay species at the southern edge of their ranges. Neither species can tolerate warm waters. Figure 2 provides additional information on how eelgrass may be affected by climate change. Many priority freshwater fish, such as brook trout, also require cool water. Although forested riparian buffers can provide shade to moderate stream temperatures, there are few adaptation options available for marine waters.

Temperature:
Temperature and especially salinity in the Chesapeake Bay are subject to strong seasonal, inter-annual and decadal-scale variability driven by large-scale climatic processes that can mask the long-term effects of secular warming. At present, climate models agree fairly well that by 2100 annual mean temperature will rise from 4˚ -11˚ F (2˚-6˚C) (Najjar et al., 2009). A warming trend over the past 30 years has led to the advancement of spring spawns by as much as three weeks (Austin, 2002). This warming trend causes a lag to develop between historical synchronization among seasonal temperature changes and seasonal changes in sunlight. Species use environmental cues such as length of daylight or temperature as cues for spawning. The disruption in the Bay's annual productivity cycle can be illustrated by the connection between spring phytoplankton blooms and the fishery species that depend upon them for food. If the spring blooms do not coincide with temperature driven returns of fish back into the Bay (or an end to the winter dormancy), these fish may not find adequate food supplies. Similarly, anadromous fishes (e.g., striped bass and American shad) may be ready to spawn at earlier dates but may not be in synchrony with pulses of spring food stocks in tributaries of the Bay.

Acidity:
Rising atmospheric carbon dioxide concentrations are upsetting the global ocean carbonate chemistry as carbon dioxide is dissolved and mean ocean acidity increases. This ocean acidification is expected to become more severe in the next century, and recent research suggests there may be even greater combined effects on ocean acidification from anthropogenic atmospheric nitrogen and sulfur deposition in

addition to oceanic uptake of anthropogenic carbon dioxide (Doney et al., 2007). Low-latitude calcifying organisms and even some North American coastal ecosystems may be impacted due to upwelling of water under-saturated with respect to aragonite and calcite. Upwelling is a potential concern for some continental shelf regions, but the ocean source water for Chesapeake Bay is the Mid-Atlantic Bight, which derives much of its water from the 3,100 mile (5,000 km) long southward-flowing coastal current emanating in the sub-polar North Atlantic (flowing through the Labrador Sea, Scotian Shelf, and Gulf of Maine). Consequently, while long-term acidification may eventually be a concern, the physical oceanography, circulation, and geological setting of the Chesapeake Bay do not make this problem as acute as those of rising sea level, increasing temperature and changing precipitation.

Dissolved oxygen:
Dissolved oxygen is an important parameter for maintaining aquatic ecosystems. The amount of dissolved oxygen is highly dependent on temperature. The amount of oxygen (or any gas) that can dissolve in pure water (saturation point) is inversely proportional to water temperature; therefore, the warmer the water, the less dissolved oxygen. As ambient temperatures increase with climate change, the water temperature in the Chesapeake Bay will also increase. This will cause the concentrations of dissolved oxygen in the Chesapeake Bay, its tributaries, and upland streams to decrease. These changes in the dissolved oxygen may have a significant effect on water quality and the ability of the Bay and its watershed to sustain native species.

Salinity:
Salinity in the Chesapeake Bay is primarily driven by stream flow but is also affected by sea level rise (Hilton et al., 2008). Precipitation is expected to increase slightly during the winter and spring. Increases in precipitation from January-May would increase stream flow, resulting in lower salinities during the winter and spring. Projections for summer and fall salinity levels are less certain (Pyke et al., 2008). Seasonal shifts would influence the distribution of species, habitats, and marine diseases. More research should be directed at understanding how salinity variations will shift in response to climate change, and how these shifts will affect the Bay ecosystem.

Forests:
The ecosystem services that forests provide, such as slowing flood waters, maintaining groundwater recharge, reducing erosion, and filtering water , are threatened by the effects of climate change on forests. As regional warming increases, high elevation ecosystems and species that require lower temperatures and specific forest systems will see available habitat shrink, and may eventually become locally extinct if they are unable to migrate. It is estimated that the mean latitude of suitable habitat for most tree species in the eastern United States is projected to move northeast from 250 to 500 miles (400 to 800km) (Iverson et al., 2008). Some current forest types such as spruce-fir, hemlock, mountain ash, sugar maple, and butternut are likely to disappear from the Bay watershed altogether. Limited by slow dispersal rates and habitat fragmentation that cuts off migration corridors, many tree species will not be able to naturally migrate into areas providing newly suitable habitat. In addition, with increasing temperatures come changes in the timing of recurring natural phenomena like budding, flowering, pollination and breeding which may have significant effects on the ability of plant species to regenerate. These effects compound to create stressed forests that are more susceptible to invasions by insects, disease, and invasive plant species. These factors further result in canopy and footprint fragmentation, disruption of mobility corridors for ground dwelling species, and increased exposure of leaf litter layers with potential for associated release of greenhouse gases.

Native Oysters:
The eastern oyster (*Crassostrea virginica*) is an important species within the Chesapeake Bay, prized for its habitat, water filtration, and economic value. Current population levels of oysters in the Bay are less

than 1% of historic levels due to impacts from disease, harvest, and water quality. The two primary oyster diseases, MSX and Dermo, are strongly correlated with warmer waters and increased salinity, indicating that Bay oyster populations may experience increased oyster disease stress as climate changes. A recent study also found significantly reduced calcification rates in *C. virginica* in the Chesapeake Bay under end-of-the-century projected carbon dioxide concentrations (Miller et al. 2009). Potential positive benefits of climate change on eastern oyster populations include a northerly extension of their range and increased growing seasons.

Invasive Species, Species Shifts and Diseases:
Air and water temperatures are increasing as a result of climate change. These temperature increases could alter the geographical distributions of Bay-region plants and animals. All species have certain preferences for where they live, based on local conditions, including temperature, salinity, and availability of food. When these conditions shift, plants and animals tend to shift in response. Increasing temperature and salinities will impact our ability to achieve Chesapeake Bay Program living resources restoration targets. For example, eelgrass is an important underwater grass that provides habitat and food for many Bay species. As mentioned previously, eelgrass is particularly sensitive to changes in water temperature. If water temperatures continue to rise as projected, this important species could disappear from the Bay in the coming decades. An increase in water temperature could also affect local fish populations, and cooler-water species such as striped bass may be replaced by warmer-water species such as brown shrimp and grouper.

Mawdsley et al (2009) note that an increased spread of invasive or non-native species, including plants, animals, and pathogens are expected as a result of climate change. However, there is inadequate research and monitoring on the impacts of climate change on algal blooms, aquatic diseases and invasive species. In theory, increasing water temperatures will increase the potential for harmful algal blooms and perhaps some aquatic diseases. Impacts from invasive exotics or native climate-driven migrant species are largely unknown at this time. Further research and monitoring is critical to better understand climate impacts on the Bay's living resources. . The Chesapeake Bay Program and its partners will have to assess how climate projections will impact their current restoration targets and develop a revised vision for restoration possibilities given the realities of changing climate.

C. Changing rainfall levels and changes in rainfall intensity

Precipitation is the primary factor influencing stream flow patterns and salinity in the Bay. Freshwater inflow is a dominant driver of Bay circulation, biogeochemistry, and ecology. Based on General Circulation Model (GCM) simulations, total precipitation and the intensity of precipitation events are expected to increase in the winter and spring seasons. Stream flow, largely driven by precipitation, explains 89% of the variability of annual-average Susquehanna River flow (Najjar et al., 2000). Nutrient and sediment export from the watershed to the Bay correlates directly with high runoff events. During drier seasons and years the configuration of stream and river channels can be significantly altered by increased stream flows, affecting navigation, runoff, and instream habitats. Projected increases in temperature will increase evapotranspiration rates, which may lead to decreases in stream flow.

Stream flow:
Projected increases in stream flow as a result of increased total precipitation and increased storm intensity could lead to detrimental effects on various living resources in the Chesapeake Bay watershed. Increased turbidity, anoxia, and nutrient may lead to a decrease in submerged aquatic vegetation, impacting an important food source for some bird populations and resulting in fish and shellfish distribution changes

and oyster mortality (Najjar et al., 2000). In addition, it is likely that 50-75% of fish species in small piedmont streams will be highly stressed in the future due to climate change (Nelson et al., 2009).

Erosion:
Increases in precipitation variability and intensity will directly impact nutrient and sediment loads to streams and to the Bay (Castro et al., 2003). Increased storm intensity and associated increases in stream flow will lead to an increase in erosion of the land surface and an increase in the erosion of stream banks and re-suspension and transport of sediments in stream beds. In 1972, Tropical Storm Agnes contributed to the loss of two-thirds of the underwater grasses in the Bay due to increased sediment delivery. Increases in erosion will also lead to higher phosphorus loads, particularly in areas where soils are saturated with phosphorus. Land use changes may exacerbate these effects, particularly urbanization associated with population growth leading to increases in temperature, stream flow, and nutrient and sediment loads (Pyke et al., 2008).

Water Quality:
Climate change will impact ecosystem functions related to water quality such as denitrification and sediment storage. Denitrification is a microbial process prevalent in saturated soil conditions as found in natural and converted wetlands and floodplains. Several watershed models suggest that denitrification is the greatest sink for nitrogen pollution in northeastern watersheds (van Breemen et al., 2002). While increasing temperatures facilitate denitrification in these systems, increased precipitation variability may reduce soil moisture and lower water residence times in wetlands and floodplains (Howarth, 2006). Wetlands depending primarily on precipitation for their water supply are particularly vulnerable to the effects of climate change (Winter, 2000). Channel incision due to greater stream flows during storm events could lower groundwater tables in riparian ecosystems (Groffman and Crawford, 2003) and further limit denitrification. Although denitrification rates may decrease, other water quality improvement processes that occur during flooding may be enhanced. Floodplains in the watershed store significant amounts of sediments and associated carbon, nitrogen, and phosphorus (Noe and Hupp, 2009). Greater floodplain inundation and greater sediment loads are likely to increase this contaminant retention function. The value of such services increases even more when considering the effects of urban growth and agricultural land uses on floodplain and wetland hydrology and vegetation (Brooks et al., 2004).

The number of short, medium, and long-term droughts in the northeast United States is expected to increase (Hayhoe et al., 2007). Drought related stress on forests increases their susceptibility to disease, insect damage, and wildfires. Higher growth rates associated with atmospheric nitrogen deposition may initially increase forest productivity but may also magnify the effects of drought by a corresponding increase in water demand. Drought stress will be more pronounced on steeper slopes where shallow soils already limit growth and productivity. Decreasing forest health and productivity have direct effects on nitrogen export from watersheds. Moreover, forests contribute the least amounts of nitrogen to the Bay compared to all other land uses.

Drought:
Extended and/or severe drought conditions would have a serious impact on water supply. Not only can drought conditions affect water availability in both surface and ground water supplies, but water usage during drought periods typically increases. This is true for public water systems, agricultural activities and other uses. Severe drought conditions could result in insufficient water supplies for some areas. In addition, extended drought conditions could result in overuse of water supplies resulting in lowering of water tables in confined aquifers below recommended management levels. Lowering of water levels in unconfined aquifers reduces base flow to streams, with potential detrimental effects on aquatic resources.

Projected variability in precipitation will have profound effects on river discharge, nutrient loadings, Bay productivity, and dissolved oxygen levels, ultimately affecting all or most ecosystems in what are now "designated use" areas within Chesapeake Bay. All of these changes depend heavily on future changes in seasonal precipitation in the watershed and the overall balance between changes in precipitation and rising air temperatures. As discussed above, the future state of precipitation inputs to the Bay remain highly uncertain, and they are likely to remain difficult to forecast for some time due to uncertainties associated with emission scenarios, large-scale climatic processes, and land cover changes. Despite these uncertainties, due to the potentially significant impacts from climate change, resource managers should err on the side of being more aggressive when establishing restoration and conservation goals.

D. Impacts to public infrastructure, health and ecosystem services

Sea-level rise and concomitant ecosystem changes will impact the built environment and the ecosystem services on which we depend, affecting basic societal needs and functions, as well as the economy (CCSP:2009). Drinking water and wastewater systems and the availability and quality of drinking water will be affected, as will transportation and commerce (especially coastal cities, ports, bridges and roads). Saltwater intrusion from over-pumping and sea-level rise poses a significant threat to water supplies for communities living along the Bay, especially because groundwater is the main source of drinking water for many of these communities. Salt water intrusion will be exacerbated by sea-level rise.

Rising Seas and Shore Protection:
Higher sea levels provide an elevated base for storm surges to build upon and diminish the rate at which low-lying areas drain, thereby increasing the severity and duration of flooding from storm events. Increases in shore erosion also contribute to greater flood damages by removing protective dunes, beaches, and wetlands. Current policies allowing hardened shore protection can encourage coastal development in vulnerable areas, putting the ecosystem, economy and homeowners at risk. "Hardened" shore protection is common along developed shores, but rare along shores managed for conservation, agriculture, and forestry. Most shore protection structures and development setbacks are designed for the current sea level and will not accommodate a significant acceleration in the rate of sea-level rise. Although shore protection and retreat both have environmental impacts, the long-term adverse impacts from hardened shore protection are likely to be greater. In the short term, retreat is more socially disruptive than shore protection. In the long term, however, shore protection may be more disruptive—especially if it fails or proves to be unsustainable.

Transportation Infrastructure:
According to a recent report, published by the Transportation Research Board, transportation infrastructure has been designed for typical weather patterns; therefore, transportation infrastructure will be affected by climate changes that cause conditions outside the range for the design of the system. All modes of transport have the potential to be affected by climate change, including land, marine, and aviation. Impacts specifically related to changes in rainfall and intensity include: flooding of coastal roads and railways, lack of capacity of culverts to accommodate increased flow and erosion, moisture level build-up behind retaining walls affecting the stability of pavement sub-grades, increased sedimentation having adverse effects on bridge foundations, rail beds and road bases (Committee on Climate Change and US Transportation, 2008).

Water and Wastewater:
Similarly, changes in rainfall intensity can increase the cost of operating water and wastewater treatment and distribution systems, could result in increased discharges of untreated sewage (e.g., bypasses and overflows) threatening downstream drinking water systems, and cause costly damage to these systems. In

addition, wastewater treatment technology efficacy may be compromised due to high precipitation rates causing more frequent periods of ineffective treatment and possible impacts to water quality. The increased surface runoff caused by intense precipitation brings higher than usual levels of suspended solids (sediment) and total organic carbon (TOC) into drinking water treatment plants using surface water. Increased sediment makes the filtration of *Cryptosporidium* more difficult and increased TOC translates to increased disinfection by-products (DBPs) and the need to reduce them to comply with federal and state drinking water safety standards.

More frequent drought conditions could alter watershed hydrology, affecting water availability within rivers and reservoirs. Current state and federal water withdrawal permitting approaches do not incorporate climate change and projections for less reliable water sources. Drought conditions can also cause lower water levels, particularly when combined with increased sedimentation, in major shipping ports requiring increase dredging (Committee on Climate Change and US Transportation, 2008).

Storm surges can clog drinking water treatment filters with sediment acquired on the trip inland if filters are not properly maintained. That may reduce the effectiveness of removing microbial pathogens like *Cryptosporidium*. Sea-level rise and storm surges may also contaminate surface and underground drinking water supplies or infiltrate drinking water distribution systems, with salt water and other contaminants e.g., septic leachate or petroleum from fishing marinas – the former could present an immediate but possibly undetected health risk. Where contamination is detected, it will reduce available water supplies or increase the cost of treating them. For those using private wells such treatment may be economically unavailable.

Warmer water increases the potential for growth of harmful algal blooms and microbial pathogens which can sicken swimmers and increase the burden for water systems to maintain compliance with health based safety standards e.g., by increasing disinfection requirements that may create more DBPs that also pose potential health threats. If drinking water treatment protocols are not adjusted accordingly, microbial pathogens or DBPs may be delivered into the distribution systems in unsafe concentrations. These treatment adjustments may increase operating expenses and, in the extreme, require new capital expenses e.g., for additional filtration. Persons using private wells drawing from shallow aquifers under the direct influence of surface water may also be affected.

Table 1. Summary of potential impacts from climate change on the Chesapeake Bay and watershed.*

Climate / Stressor	Resource Affected	Potential Impact
Sea-level rise / Storm Surge	Estuarine open water	• Increased wave driven erosion and flooding leading to shoreline retreat and loss of Bay islands • Increased salinity due to estuarine hydrodynamic change
	Wetlands and Forests	• Increased frequency and duration of coastal inundation resulting in marsh loss • Alteration of estuarine marsh islands and wildlife refuges • Loss of rare coastal edge plant communities • Transgression of salt marshes upland reducing plant productivity in forest and farm areas • Loss of submerged aquatic vegetation with increasing water depth and suspended sediment • Loss of nesting habitat for some ducks, rails, terns, and marsh sparrows • Increase frequency of invasive species invasion
	Animals	• Reduction in potential nursery areas for fish and crabs • Change in nesting habitat for some waterfowl • Changed habitat for fish, birds, amphibians and invertebrate species
	Public Infrastructure and Health	• Increased rate of saltwater intrusion on drinking water supplies • Flooding can contaminate drinking water wells with bacteria, other pathogens, and pollutants • Increased vulnerability to coastal hazards, including increased flooding of transportation infrastructure • Salt water intrusion into coastal aquifers will challenge drinking water treatment systems and may pose health risks for those using private drinking water wells. • Salt water intrusion into coastal aquifers will challenge the functioning of onsite sewage treatment systems and may pose health risks for those using private treatment systems • Salt water increases corrosion problems for submerged pipes in coastal areas (e.g., carrying electrical, telecommunications, water, sewage, etc.) • Storm surge may inundation roads/highways required for emergency efforts (e.g., evacuation, emergency services)
Increases in air and water temperature	Estuarine open water	• Strong spring blooms of diatoms may cause stratified conditions leading to seasonal oxygen depletion
	Streams	• Evapotranspiration rates increase reducing summer baseflows • Benthic and fish populations are heat stressed, particularly coldwater species (e.g., brook trout) • Increased bacterial growth and fish stress and disease
	Wetlands and Forests	• Change in wetland hydrology and denitrification functions • Potential increase in plant productivity • Species range shifts and possible extinction for some species • Potential asynchronous timing of flowering and pollination

Table 1. Summary of potential impacts from climate change on the Chesapeake Bay and watershed.*

Climate / Stressor	Resource Affected	Potential Impact
		• Increases in invasive species introductions, including plants, insects, and diseases
	Animals	• Altered physiological and life history processes of key species including crabs, striped bass • Spread of new species; range changes for many species currently limited to the Chesapeake Bay • Increased number of harmful algal blooms • Increased hypoxic conditions leading to fish and shellfish die-offs • Altered flowering times and increased missed pollination events
	Public Infrastructure and Health	• Increased bacterial counts may lead to more frequent beach closures • Warmer water fosters growth of microbial pathogens increasing the risk to swimmers and the burden on drinking water treatment systems
Changes in precipitation / storm intensity	Estuarine open water	• Changed nutrient and sediment loads • Change in salinity levels • Changes in wave erosion of shoreline and islands during coastal storms
	Streams	• Changed nutrient and sediment loads • More frequent high flow events • Periodic more intense low flow conditions
	Wetlands and Forests	• Change in wetland hydrology and denitrification functions • Increased vulnerability of forests to disease, insect damage, and wildfires due to drought stress • Stress on edge of range and globally rare species and ecosystems • Increased sedimentation • Lower water residence times • Amplification of drought stress on forests through increased water demand caused by increased carbon in the atmosphere and longer growing seasons
	Animals	• Disturbances in the abundance of certain fish, shellfish, and benthic populations • Stress on submerged aquatic vegetation affecting bird populations and other species
	Public Infrastructure and Health	• More frequent and longer periods of drought will stress public and private water supply and irrigation systems • Extended droughts could result in insufficient water supplies for many areas • Undermining of structural supports of bridges, roadways and seawalls • Overburdened culverts, detention ponds and other stormwater practices during intense storm events • Reduced flows due to drought can result in underutilization of water collection and distribution

Table 1. Summary of potential impacts from climate change on the Chesapeake Bay and watershed.*

Climate / Stressor	Resource Affected	Potential Impact
		systems, reducing quality of water and damaging infrastructure • Increased sediment and total organic carbon burden drinking water treatment systems in addressing Cryptosporidium and disinfection by-products respectively • Increases in precipitation, stormwater flow, and treatment system infiltration could overburden the capacity of treatment works, resulting in bypasses and overflows of untreated sewage into public waterways • Flooding of coastal properties and communities, which has huge societal and economic costs

*Format for Tables 1 and 2 was inspired by U.S. Environmental Protection Agency, 2009.

IV. Adaptive Actions

Adapting to climate change involves maintaining or enhancing the resiliency and reducing the vulnerability of the Chesapeake Bay and its watershed to the effects of climate change. Establishing feedback cycles in which objective targets are set, management actions are taken, and monitoring and assessment are used to evaluate progress and inform necessary changes in approach compose the core of an adaptive management approach. In many cases, adaptation will not involve entirely new approaches to conservation and resource management; rather, it will build upon existing strategies and solutions to protect and restore ecosystem resilience. As described in Part III, climate change will exacerbate many existing environmental problems as well as create new threats to ecosystem health. Therefore, adaptive actions aimed at protecting and restoring proper ecosystem function in the Chesapeake Bay and its watershed are vital for coping with climate change. The design and implementation of adaptation strategies should include careful analysis of existing decision making processes. Assumptions used in engineering and designing new infrastructure and restoration practices need to be reevaluated in recognition of climate change. It should then include systems-based analysis of options to identify alternative management strategies that reduce vulnerability while minimizing implementation costs, including through potential environmental market-based approaches. Even though model projections commonly cite changes expected by the year 2100, this date does not indicate an end to climate change nor does it mean agencies should wait to take action.

The development of adaptation strategies should be an inter-disciplinary effort that considers the social, economic, and environmental factors required to reduce the vulnerability of cultural and socio-economic systems to climate-related disruption. Adaptation strategies should recognize that impacts resulting from climate change will coincide with and possibly amplify other impacts such as those from land use change, pollution, and invasive species management. Adaptation strategies are typically developed to identify opportunities to reduce vulnerability and increase the likelihood of achieving societal goals under changing conditions (Pyke et al., 2008).

To cope with climate change effectively, all levels of government must develop sound and cost-effective mitigation and adaptation strategies. A clear scientific understanding of the rates at which conditions are changing, the controlling factors, and the likely consequences for resources and communities, will improve the efficacy of adaptation actions and avoid unnecessary costs. An adaptive management approach will enable managers to respond to critical climate change threats even while there is uncertainty in the models. The keys to a successful adaptive management approach are to provide the public and decision makers with the most current scientific information available while also advancing our understanding of climate change and its effects on the Bay ecosystem through research, monitoring, and modeling.

Due to the historic and forecasted rates of sea-level rise and the long anticipated performance period of many structures, adaptation is required immediately and enhanced observation systems are required for the future. Generally, an adaptation strategy to sea-level rise should focus on reducing future growth in areas forecasted to be inundated by sea-level rise over the next 50-100 years, mitigating erosion rates, allowing for landward retreat of tidal wetlands through land acquisition and growth management, protecting existing forests and wetlands near the shore, and adapting public infrastructure by removing, relocating, or raising the elevation of important roads and structures.

Adaptation measures to increases in temperature and precipitation variability involve minimizing impervious surfaces, managing increasing amounts of stormwater, maintaining and restoring tree canopy along streams and other water bodies, protecting groundwater recharge and discharge areas, and ensuring water supply management plans account for the potential increased frequency and duration of droughts, as well as more variable stream flows. In order to protect water quality, particular attention must be given to maintaining ecologically sustainable stream flows in light of increased temperatures, evapotranspiration, and more variable and intense precipitation events.

More specific examples of adaptive options are listed in Table 2. While many of these actions fall under the jurisdiction of state and local governments, federal agencies provide much of the data, research and regulatory context that serve as incentives for implementing such actions. Broad recommendations related to the federal role in adapting to climate change are discussed in Part VI of this document.

Table 2. Options to adapt to climate change impacts.

Climate / Stressor	Example Adaptive Options
Sea-level rise / Storm Surge	• Create regional dredge material management plans to mitigate loss of wetlands, islands, beaches and dunes.. • Acquire land, rolling easements, or traditional conservation easements surrounding National Wildlife Refuges, National Estuarine Research Reserves, National Parklands, and critical tidal marsh habitats to enable wetland migration as sea-level rises. • Inventory and monitor globally rare and listed edge species, such as the Northeastern beach tiger beetle • Revise shoreline management efforts to account for climate change impacts (e.g., transition hardened/engineered shorelines to nonstructural shore protection or living shorelines in low-energy environments) • Map areas appropriate for armoring nonstructural protection, living shorelines, or retreat to support shoreline management policies • Local jurisdictions should adopt a "reduce, retreat, protect, abandon" strategy • Reduce potential future impacts to infrastructure by expanding development setbacks and use restrictions in shoreline buffer areas • Promote sustainable shoreline and buffer management practices, including cliff retreat policies similar to the Calvert County, MD policy • Explore feasibility of altering federal and local permitting requirements to remove incentives for shoreline hardening • Revisit federal subsidies for development and/or management of on vulnerable property (e.g. loans, insurance) • Implement strategies to reduce, retreat, protect, or abandon public and private infrastructure vulnerable to sea-level rise, storm surge, and saltwater intrusion. Such infrastructure includes: drinking water wells, groundwater recharge areas, drinking and wastewater treatment plants, and agricultural manure management sites, septic drainfields and onsite treatment systems. • Assess potential increased vulnerability to corrosion or other structural breakdown and increased infiltration-influx in drinking water and wastewater treatment plants; develop and implement a long term management plan to reduce damage and discharges. • Create long-term plans for relocating federal facilities vulnerable to sea-level rise and storm surge, and develop policies for "climate ready" use of abandoned lands. • Evaluate risk to transportation infrastructure from increased flooding and long-term inundation. • Develop economic incentives to allow abandonment of private lands (e.g., agricultural) in coastal margins vulnerable to sea-level rise • Determine what lands should be protected in face of projected SLR and where wetlands are able to transgress. • Determine drivers of land subsidence that can be changed (e.g. water withdrawal) and limit development in those

Table 2. Options to adapt to climate change impacts.

Climate / Stressor	Example Adaptive Options
	areas.
Increases in air temperature	• Protect, restore, and extend riparian forest buffers, particularly along coldwater streams, to allow lateral and altitudinal movements of species • Plant urban trees for shade benefits and expand use of stormwater "green infrastructure" that provides cooling and water retention co-benefits • Limit increases in impervious surfaces, particularly in the floodplain, groundwater recharge and discharge areas, near wetlands, and in watersheds supporting coldwater fish species (e.g., brook trout) • Evaluate risk to native plant and animal species utilizing models such as NatureServe's Climate Change Vulnerability Index • Protect and restore flow from coldwater springs
Changes in precipitation / storm intensity	• Create regional sediment management plans with more stringent requirements near critical habitats. • Encourage stricter nutrient management and increase implementation of nutrient management plans • Limit increases in impervious surfaces, particularly in the floodplain, groundwater recharge and discharge areas, and near wetlands. • Protect and restore wetlands, floodplains, and forests and hydrology, particularly along headwater streams. • Incorporate wetland, floodplain, and forest protection into stormwater management plans. • Prepare for drought through establishing water resource management plans, implementing water conservation strategies, conducting detailed assessment of water availability and demand for all sectors including aquatic habitats, and managing development over groundwater recharge areas. • Enhance management of or restore prior converted wetlands for ecosystem services, relying more on natural systems to mitigate and adapt to climate change. • Conduct research to project the effects of sea level rise on habitats of species of concern. Where appropriate to an organism's mobility and size, find ways to connect important habitat with corridors to facilitate migration. • Manage stormwater by mimicking predevelopment hydrologic conditions on-site, utilizing low impact development on new and existing sites and upgrading Combined Sewer Overflow systems • Limit development in floodplains and incorporate forecasted changes in hydrology into floodplain maps, planning for new infrastructure, codes and ordinances and land use planning • Improve accuracy and precision of storm surge and coastal flooding predictions.

V. Technical Needs

A. Analysis of decision making processes

Information about decision making processes provides the foundation to support effective action to reduce vulnerability and increase resilience to climate change. The development of effective decision support requires the systematic assessment of existing decision making processes. It is essential to understand the factors influencing resource management decisions, including climatic assumptions and their consequences for current practices, such as Total Maximum Daily Load assessments, tributary strategies, and the design of both shoreline and stormwater management practices. Understanding these factors guides how scientific information can be best communicated to inform the decision-making process.

B. Modeling

Modeled forecasts of climate change are highly variable. Different models yield different forecasts of when and how regional temperature, precipitation and sea level will change, and on what impacts these processes will have. There are three primary reasons for this. First, climate models cannot yet simulate regional scale responses to elevated greenhouse gas concentrations with a high degree of certainty and projections of future concentrations of greenhouse gases vary widely with assumptions about policy and technology adoption. Second, our knowledge of the Bay's ecosystem response to rapidly changing environmental conditions is incomplete; consequently, ecosystem models cannot yet project responses to climate changes. While our knowledge of the Bays ecosystem response will always be incomplete, with increased real time information to put into modeling efforts we will be able to make better predictions that will feed into adaptive management strategies. These models should also include risk and vulnerability as part of the picture. Third, how future climate changes affect the Bay ecosystem will depend upon how resource managers and policy makers prepare for climate change and sea-level rise including the large uncertainties. Despite these challenges, it is critically important to assess and communicate the level of uncertainty associated with models while also committing to use the best available science to implement adaptation strategies and pursue new avenues of research with the most up to date information the downscaled climate models provide.

The Chesapeake Bay restoration effort is currently informed by a variety of loosely coupled models that simulate processes such as atmospheric deposition (Community Multiscale Air Quality, CMAQ, model), land use change (Chesapeake Bay Land Change Model, CBLCM), nutrient and sediment generation and transport (Chesapeake Bay Watershed Model, CBWM), estuarine water quality (Chesapeake Bay Water Quality and Sediment Transport Model, CBWQSTM), sea-level rise (Sea Level Affecting Marshes Model, SLAMM) and fisheries ecological interactions (Ecopath with Ecosim, EwE). These models serve to synthesize and integrate monitoring data, increase scientific understanding of system processes, and simulate the effects of management actions. However, for the reasons listed above many of these models are still in their infancy in terms of incorporating climate impacts and feedbacks as forcing functions. Forcing functions are applications of these physicochemical models, such as GCMs and model outputs to biological models.

While General Circulation Models (GCMs) cannot yet simulate regional scale response to elevated greenhouse gas concentrations with a high degree of certainty, data from multiple models under different socio-economic scenarios provide a range of plausible forecasts. The Chesapeake Bay Program is assessing flows and associated nutrient and sediment loads to the Bay consistent with three benchmark climate change scenarios reflecting a range of potential changes in temperature and precipitation through the year 2030. The three scenarios were derived from a larger set of 42 climate change scenarios that were evaluated from seven GCMs, two scenarios (A2 and B2 from IPCC, 2000), and three assumptions about precipitation intensity in the largest events. The Consortium for Atlantic Regional Assessment (CARA) developed downscaled GCM temperature and precipitation datasets that are being used to guide modifications to a historical (1984 to 2000) dataset of precipitation and temperature. These data combined with future forecasts of land use change from the CBLCM will be incorporated into Phase 5.3 of the CBWM to discern future nutrient and sediment loads from climate change (L. Linker, pers. comm., August 3, 2009). The estimated tidal Bay response to climate change in dissolved oxygen, chlorophyll, and clarity can be further assessed through linkage with the CBWQSTM and the Chesapeake Bay Inundation Prediction System. As part of an adaptive management strategy, model runs should be continually updated based on the best available science, input data, and downscaled GCM output.

The changing climate compounds the natural variability of the estuarine environment to create a complex set of factors that impact populations and ecosystems. These types of complex interactions are often characterized by non-linear responses and threshold-type behavior. Given this complexity, some factors that may be minor for a particular species may have profound repercussions for the ecosystem. Existing ecosystem models (such as the Chesapeake Bay Fisheries Ecosystem Model) and models under development (i.e., Chesapeake Atlantis Model) can be used to explore the ecosystem response to climate change. To do this, some basic research, monitoring and climate model outputs are needed to develop forcing functions. Forcing functions can be applied to ecosystem models to estimate the impacts of different climate scenarios on the whole ecosystem. In addition, understanding changes to the physical environment such as localized rates of relative sea-level rise is essential, and the geospatial infrastructure and observations required for those analyses are critical inputs to the decision making process. The output from multi-model scenarios can be used to help actively plan for mechanisms to compensate to the extent possible for climate-induced ecosystem change.

The simulation of the Bay ecosystem response to climate should be enhanced by coupling and incorporating feedbacks between marsh dynamic models and water quality, quantity and fisheries ecological models. For example, SLAMM is being used to simulate the wetland habitat responses to inundation patterns but it lacks biological feedbacks (e.g., vegetation responses to relative sea-level rise) and does not account for uncertainty in data inputs (Kirwan and Guntenspergen, 2009). In general, dynamic feedbacks between the entire suite of models, particularly the atmospheric and watershed models will better represent system processes and address a broader array of stakeholder questions related to the effects of actions to mitigate and adapt to climate change. To further simulate processes and address and inform local land management decisions, models also need better spatial resolution, more accurate elevation, bathymetry, and water level input data, and to be capable of simulating local manipulations of the environment (e.g., addition or removal of barriers to species movement, freshwater flow, saltwater intrusion and sediment movement). Future models should also focus on the impacts of climate change stressors on public infrastructure, water availability and the impacts of water withdrawals on public health and aquatic resources. Modeling approaches must also be tailored to address the relevant parameters in actual decision making processes. For example, changes in air temperature might be expressed in changes in annual heating and cooling degree days, rather than variation in annual mean temperature. These considerations are essential to making modeling relevant to resource management.

Ecologists view the fundamental ecosystem structure and function as shaped by the species present, genetic diversity, and external physical and chemical factors. Many of these factors can be described statistically and mathematically in models. The more we understand the effect of climate on physicochemical factors, and the more we understand the effect of the physicochemical factors on living resources, the better we can understand the potential impacts of climate change on living resources. To achieve this improved understanding, we need a steady stream of monitoring and focused research.

C. Monitoring

While current environmental monitoring programs in the Chesapeake region can contribute significantly toward deciphering the effects of climate change, they were not designed to measure the complex ecosystem interactions described above. The great challenge facing the region is to effectively use and enhance existing observation and research capabilities to meet the climate challenge. Most importantly, long-term (multi-decadal) environmental monitoring stations must continue to be supported and data from different programs must follow standardized protocols, so that long-term trends in ecological and socio-economic response can be assessed to inform science-based mitigation or adaptation strategies.

Previous efforts at organizing environmental information to address resource management issues provide a road map for initiating the Nation's response to this new climate challenge. In 1996, the White House National Science and Technology Council charged the Committee on Environment and Natural Resources to develop a framework for integrating the Nation's environmental monitoring and research programs to support ecosystem management of Federal lands (Committee on Environment and Natural Resources of the National Science and Technology Council, 1997). More recently, the National Oceanic and Atmospheric Administration (NOAA) created the National Integrated Drought Information System (NIDIS), providing a dynamic and easily accessible drought information system for the nation. NIDIS could be utilized to develope tools or information specific to the Chesapeake Bay. NOAA also provides real time water level data through their Tides and Currents program and the National Weather Service's River Forecast center provides data on inland river levels to predict flooding. NOAA, the U.S. Army Corps of Engineers, and the U.S. Geological Survey (USGS) in collaboration with other organizations have also formed the Integrated Water Resources Science and Services (IWRSS) partnership for providing a seamless suite of water resources information across scales ranging from small hill slopes to large watersheds, from droughts to floods, and from historical analyses to long-range prediction. The U.S. Forest Service Northern and Southern Research Stations work to monitor climate change impacts and responses. Their "Eastern Climate Tower Network" provides a network of flux and meteorological monitoring towers. NOAA could utilize the capabilities of the Regional Integrated Sciences & Assessments (RISA) program in the Chesapeake Bay and the USGS, in collaboration with other agencies, is organizing a Collaborative Climate Impacts Monitoring program (CCIM). The purpose of the CCIM is to provide a framework for linking different types of environmental data to assess current data-collection capabilities, identify gaps in information for addressing climate change, analyze the uncertainty in the data, and structure enhancements of programs as necessary to fill data and research gaps. The CCIM program is envisioned as a "network of networks" that builds upon existing data collection programs, with an investment in additional data collection and research activity where needed, to establish a comprehensive climate effects observation and research strategy. Creating a Chesapeake Bay regional network for monitoring climate effects as part of ongoing USGS or NOAA initiatives or as regional component of the National Science Foundation's National Ecological Observatory Network (Schimel et al., 2009) would help to coordinate research efforts and provide an early warning system for detecting and anticipating the environmental consequences of climate and land-use change and support sound policy and management decisions. A Chesapeake Bay regional monitoring framework for climate information could organize data collection into four categories:

1) Collaborative Observation and Research (CORe) focus sites where inter-disciplinary studies and long-term monitoring would be aligned to determine and track the key processes controlling resource or ecosystem response to changes in climate, and to test possible adaptation or mitigation strategies;
2) Climate gradient study regions where changes in climate from north to south or from the mountains to the coast can be used to make projections of potential climate change effects through time;
3) Regional surveys of common environmental indicators to link the understanding developed at the focus and gradient study areas to the broader landscape; and
4) Ground, aircraft, and satellite based remote sensing data that would be verified with data from the surveys, gradient studies, and CORe sites and then used to track environmental change across the entire Bay and watershed. These approaches should be used to enhance the ability to detect and differentiate climate and non-climate stressors on critical Bay performance metrics.

D. Research Coordination and Leadership

As stated in the STAC report (Pyke et al., 2008), there is no institutional focal point for climate change related research in the Chesapeake Bay. Such a research program is necessary to improve our existing knowledge of ecosystem responses to climate change drivers. Several of the recommendations contained in Section VI of this report address increased Federal leadership on climate research within the Bay region. This leadership is necessary to inform public policy and implement consistent regional adaptation strategies. Several other regions in the U.S. have established climate focal points that depend upon strong partnerships between federal agencies, academic institutions, state, and local partners. For example, the Climate Impacts Group (CIG) at the University of Washington focuses on understanding climate change impacts and responses in the Pacific Northwest. This group, funded through a variety of federal, state, and non-profit programs, has provided leadership on developing public policy including the development of the innovative 2007 King County, Washington Climate Plan. Another example is provided through NOAA's Regional Integrated Sciences and Assessments (RISA) program. The RISA program supports research that addresses complex climate sensitive issues of concern to decision-makers and policy planners at a regional level. The RISA research team members are primarily based at universities though some of the team members are based at government research facilities, non-profit organizations or private sector entities.

Although research needs are discussed throughout this document, it is not intended to provide a comprehensive review of research needs. The major recommendations discussed in Part VI include an overview of several research needs that were consistently identified throughout the process. A comprehensive inventory and prioritization of research needs related to climate change and its effects should be part of an interagency adaptive management process. This inventory would build on available information from this report, the Scientific and Technical Advisory Committee's Climate Change and the Chesapeake Bay review, and input from relevant federal, state, local, and NGO agencies.

V. Climate Change Strategies for Federal Policies and Programs

As called for in the EO, greater federal leadership is required to restore the health of the Chesapeake Bay. In regards to climate change, federal agencies that actively manage and restore lands such as the National Park Service (NPS), Department of Defense (DOD), Fish and Wildlife Service (FWS), Army Corps of Engineers (ACE), and Federal Highway Administration (FHWA) can lead by example through implementing climate change adaptation strategies on the properties they manage. Federal agencies that have an emphasis in conducting research, monitoring, or modeling the environment, such as USGS, NOAA, and the Environmental Protection Agency (EPA) can lead by developing guidance and by collaborating and coordinating their research, monitoring, and modeling activities with each other and with state and local governments, academia, and the private sector. Significant overlap exists in the roles of federal agencies participating in the Bay restoration effort. Such overlap is unavoidable in a broad-scale estuarine restoration project because of the complex and interrelated processes affecting estuarine conditions. Overlapping roles, however, can also lead to inefficiencies and inconsistencies among approaches and messages which led to our recommendation for a centralized coordination body.

To complement the activities of the proposed program, we recommend a series of actions to enhance and focus federal climate activities in the Bay through increased and strategic cooperation and partnerships. State, local, and academic institutions and decision makers are critical to current and future efforts to understand and address climate change and variability in the region; they should be active partners in developing and implementing adaptive strategies for the Chesapeake Bay and its watershed.

While all of the following recommendations are important, the first recommendation, A, and recommendations B1, B2, and B3 are viewed as "mission critical" and should be addressed as quickly as possible. For all other recommendations, we note whether the recommendation should be implemented in the next 1-2 years (short-term) or within the next 3-5 years (medium term).

A. Develop a centralized Chesapeake Bay climate change coordination program to address climate adaptation activities and management decisions throughout the Bay watershed.

Working closely with state and local government agencies, academia, non-profit organizations, and the private sector, the proposed program would assume the following functions:

- Provide specific, reliable, and consistent guidance to state and local governments and other institutions on climate change projections and adaptation strategies based on the best available science, while remaining consistent with information delivered through national efforts;
- Identify priority climate change-related research needs in consultation with state and localities;
- Coordinate and develop consistent adaptation strategies among federal agencies with land management responsibilities;
- Evaluate and suggest changes to existing environmental monitoring programs for their ability to detect and differentiate climate change drivers;
- Develop a collaborative climate change communication strategy to effectively discuss global climate change, projected impacts for the Chesapeake Bay watershed, adaptation options and the communication of uncertainty and risk to the public;
- Inform the development of decision-relevant and decision-ready science information through examining state and local decision making processes related to the implementation of adaptive strategies to climate change;

- Ensure a coordinated and unified federal climate change sea-level rise monitoring and reporting system implemented through the existing, enhanced, and new observation systems;
- Identify or compile information on geographic areas of the Chesapeake Bay watershed at high risk of contributing to water quality degradation as a result of changing climate conditions;
- Assess climate impacts on water quality restoration program priorities (e.g., Total Maximum Daily Load assessments and Tributary Strategies);
- Assess climate impacts on key coastal habitats (e.g., wetlands, underwater grass, riparian forests, maritime forests, and beaches) and inland habitats (e.g., bogs and other non-tidal wetlands, floodplain and high elevation forests);
- Identify key coastal and aquatic plant and animal species at risk from inundation, warming waters, increased storm severity, salinity changes, and other climate change impacts, and develop a plan for mitigating these influences through restoration, conservation, policy changes, or additional means;
- Review existing state and federal programs (e.g., NIDIS, IOOS/CBOS, CELCP, etc.) to identify opportunities to implement adaptation strategies that address the recommendations in this report.

This proposal could take the form of a physical or virtual research and assessment center (Center), which would be a regional Chesapeake Bay component of national scale efforts to address climate change. National efforts are underway or being considered, such as the creation of a National Climate Data Center, National Climate Service, NOAA Regional Integrated Sciences & Assessment Center and a USGS National Climate Change and Wildlife Research Center. Comprised of representatives of individual agencies, a Center would provide the institutional framework to coordinate climate related activities among federal, state, and local agencies within the watershed and provide specific and reliable guidance on climate change based on the best available science, consistent with information delivered through national efforts. A Center would be driven by stakeholder needs and utilize existing and developing capabilities to develop consensus based projection data and guidance, identify priority climate change-related research needs, and develop communication materials. Developing partnerships with state agencies and research institutions would be vital to the success of the Center. This effort is meant to complement, not compete with, the work being done by states, localities, NGO's, and academia.

A Center would develop and disseminate consistent information on climate drivers, such as planning targets for rates of sea-level rise, temperature increases, and precipitation changes. As previously discussed in our report, there is still much uncertainty regarding temporal and spatial climate change projections. This uncertainty can paralyze planning decisions at the state and local level. Increasing certainty and consistency will be an important function.

Based on gaps identified by an interactive dialogue among scientists, stakeholders and the relevant local, state and national institutions, a Center would develop specific collaborative research activities designed to advance understanding of the linkages between climate and the priority resources of the Bay region. A Center would not compete with existing programs and resources, but rather utilize and complement the capabilities of these programs, to focus on particular research and policy gaps, and coordinate with regional efforts on climate change adaptation.

Priority level: Mission Critical. Potential Leads: NOAA, USGS, and EPA

B. Integrate climate change concerns into Chesapeake Bay Program activities and strengthen legislative authority.

B1. Establish a Climate Change Coordinator position within the Chesapeake Bay Program structure. This senior level staff position would be responsible for coordinating the incorporation of climate adaptation strategies into the Chesapeake Bay restoration and conservation strategies. This position would work closely with the Climate Science and Assessment Center recommended above, as well as with state climate coordinators, a wide-range of scientists, and all relevant federal agencies. The Coordinator should be directed to conduct a systematic assessment of the vulnerability of key Bay Program restoration and conservation goals to climate variability and change; as well as an assessment of the use of climatic data in Chesapeake Bay Program decision making and a prioritization of decisions based on the potential for changing climatic conditions to jeopardize mandates and goals. The Coordinator should also develop climate-related funding priorities for the Chesapeake Bay Program. The Coordinator would be the lead for incorporating climate change into the Chesapeake Bay Program's Goal Implementation Teams (see B2). Priority level: Mission Critical; Potential lead: EPA or NOAA

B2. Incorporate climate change technical advisory functions into the existing Technical Support and Services group supporting the Chesapeake Bay Program's Goal Implementation Teams (GITs). There are currently six GITs addressing the restoration goals set forth in the Chesapeake Action Plan. While various states and stakeholder groups in the Bay region recognize that climate change will continue to impact our ability to meet our restoration goals for fisheries, aquatic habitats, water quality, and healthy watersheds, and several have initiated activities to better understand and address climate change, none of the six teams explicitly address climate change considerations. This group should also provide guidance on developing new or modifying existing Bay Program restoration goals and Tributary Strategies based on projected climate impacts. Priority level: Mission Critical; Potential lead: EPA or NOAA

B3. Use the newly formed Federal Leadership Committee to champion adaptation actions and needed legislation already identified in state climate action plans and Federal climate change and sea-level rise guidance documents (e.g,, CCSP 2009), as well as those developed under ongoing and future planning processes. Examples of existing recommendations include the reauthorization of the CZMA and amending the National Flood Insurance Program. Priority level: Mission Critical; Potential lead: EPA, FWS, USACE, DOT, and NOAA

B4. Review existing authorities to identify opportunities to incorporate climate change impacts. Known examples include the Clean Water Act, reauthorization of the Coastal Zone Management Act with strengthened authorities for climate change related activities; including revising state Bay buffer distance requirements and enforcement, support for the development and implementation of coastal adaptation plans at state and local scales within the Chesapeake Bay watershed. Another significant opportunity includes addressing climate change projections under the Magnuson Stevens Act and related fishery management programs. Priority level: Short-term; Potential lead: NOAA (advisory)

C. Enhance existing and/or develop new technical information and decision support tools to better understand, project, and respond to climate change and its impacts.

C1. Conduct an integrated regional assessment of near-term and long-term landscape change due to climate change, sea-level rise, population growth, and policies related to future changes in agricultural and forestry practices, expanding on existing work by the USGS. Products developed should illustrate likely habitat composition changes across the landscape and enable partners to better identify and target critical conservation areas. Federal agencies, states, non-profits, and local governments should coordinate where feasible to address coastal lands and habitat targeting to develop consistent messaging. Priority level: Short-term; Potential lead: USGS and NOAA

C2. Develop coordinated monitoring, research, and control programs for invasive species and disease concerns exacerbated by changing climate conditions. As climate changes, invasive species will expand their ranges, taking advantage of changing ecosystem conditions to move into new territories and potentially displace native species. This effort should be coordinated with the National Invasive Species Council, and other existing efforts through federal and state agencies.
Priority level: Short-term; Potential leads: FWS, Smithsonian Institution

C3. Inventory and prioritize critical migratory corridors within the Chesapeake Bay and its watershed to facilitate habitat shifts as climate changes. High priority projects would be elevated by all federal agencies for approval of funding and/or technical assistance. Priority level: Medium-term; Potential leads: FWS and NOAA in consultation with state agencies and non-profit organizations.

C4. Develop a coordinated monitoring and research program for species vulnerable to severe decline or extirpation due to climate change. The initial focus should be on the potential loss of vulnerable key ecological or key economic species. Priority: Short-term; Potential Lead: NOAA, NPS, and FWS with state Wildlife Action Plans and Natural Heritage Programs

C5. Initiate targeted research on the abilities of soils and vegetation to sequester carbon under different management and hydrologic regimes (e.g., oak-hickory forests, pine plantations, wooded wetlands, corn/soy rotations, etc.). Estimates of sequestration rates will vary across land use types, with seasonality, and by the maturity of systems. These ranges should be considered and included in adaptive responses to climate change. Priority level: Medium-term; Potential leads: USDA and USGS

C6. Conduct Bay-wide research on vegetation responses to inundation and elevated nitrogen levels in salt, brackish, and freshwater marshes. A major unknown in marsh dynamics modeling is the degree to which marsh vegetation will respond to changing conditions of water levels, salinities, and elevated carbon dioxide and nitrogen levels. These bio-feedback inputs are essential to simulate marsh dynamics over long time periods and better understand sea-level rise impacts. The potential loss of wetlands could dramatically impact water quality. Priority level: Medium-term; Potential lead: NOAA, USGS, and EPA

C7. Ensure that state and federal water withdrawal permitting approaches incorporate climate change projections for water availability and saltwater intrusion. Evaluate saltwater intrusion rates related to public water supplies. Priority level: Medium-term; Potential lead: USGS and state agencies

C8. Monitor vulnerability of water and wastewater treatment facilities to sea-level rise and coastal inundation. Develop policy, guidance, and tools to support adaptation planning to maintain resilience and sustainability for water and wastewater infrastructure. Establish climate change protocols for water supply planning and permit approvals to be shared and coordinated with state and federal permitting, grant and loan-making agencies. Ensure that minimum flows needed to sustain aquatic resources under future climate projections are taken into account. Priority level: Medium-term; Potential lead: EPA, USACE , NOAA

C9. Establish enhanced sediment and erosion control measure guidance to adapt to changing precipitation patterns and rising sea level. The guidance would be proposed for adoption by states and localities within the Chesapeake Bay watershed. Priority level: Medium-term; Potential lead: NRCS and EPA

C10. Provide the infrastructure to collect, analyze, and disseminate high-resolution shallow water bathymetric and topographic (LiDAR) data sufficient for deriving biomass and elevation datasets and Interferometric Synthetic Aperture Radar (InSAR) for measuring subsidence for the entire Chesapeake Bay watershed and for improving coastal inundation, flooding and local sea-level rise models. Lead agency should work with Department of Defense and other agencies to ensure existing bathymetric , InSAR, and LiDAR data is made available to states and localities. Priority level: Short-term; Potential lead: USGS, FEMA, and NOAA

C11. Develop more stringent floodplain management guidelines accounting for climate change projections. In anticipation of increased storm intensity, ecosystem services provided by floodplains will need to be protected and development in the floodplain will need to be more aggressively regulated. Additionally, protecting and restoring riparian stream habitat will be critical to mitigating stream bank erosion. Comprehensive planning and zoning regulations for residential and commercial buildings in floodplains will need to be reevaluated to ensure long-term sustainability, anticipating conditions for the actual performance life of structures. Update National Flood Insurance Program maps to account for sea-level rise and precipitation variability. Priority level: Short-term; Potential lead: FEMA

D. Establish adaptation guidance for federal programs, federally-managed lands, and federally financed state, local, and private lands.

The federal government is the largest single landholder in the Bay watershed and federal resource management responsibilities even extend beyond these lands to include migratory pathways. Among such lands are national wildlife refuges, national parks, national forests, and Department of Defense installations. Adaptation actions on federal lands can serve as test cases and as models for other stakeholders, increasing confidence regarding effectiveness and economic risks. Many federal agencies have begun adopting adaptation strategies but there has been little coordination among agencies, which must include policy and program collaborations along with sharing of both successes and failures. Agencies within the Chesapeake Bay region should be used as a test-case for developing this coordination.

D1. Regularly update existing acquisition, infrastructure construction, and management plans for federal properties to incorporate climate change projections and land management adaptations. Priority level: Medium-term; Potential lead: All Federal

D2. Federal agencies should lead by example through modifying stormwater management plans to handle increases in the number and intensity of storm events. Federal agencies should develop stormwater management guidance to be shared with state and local government agencies. Priority level: Short-term; Potential lead: EPA

D3. Update or develop drought preparedness plans for federal facilities to consider restrictions necessary to adjust to prolonged, intermittent drought conditions resulting from climate change. Serve as a model for water conservation and controlling development in groundwater recharge areas. Share planning documents with states and localities. Priority level: Short-term; Potential lead: DOD

D4. Develop comprehensive protocols for incorporating sea level rise and other climate change impacts into federal engineering design criteria for dredged material islands, storm water systems, shoreline stabilization, weirs to abate saltwater intrusion, building codes, bridges, roads, and other new or existing infrastructure in coastal zones. Adopt these criteria for use on federal lands and facilities, and share them as guidance with state and local partners. Priority level: Short-term; Potential lead: USACE, DOD and NPS

E. Develop a coordinated strategy for climate change outreach and education.

The keys to a successful adaptive management approach are to provide the public and decision makers with the most current scientific information available while also advancing our understanding of climate change and its effects on the Bay ecosystem through research, monitoring, and modeling. What we have learned from past efforts, is that stakeholders should help drive development of products and tools. Federal agencies engaged in regional climate change activities should collaborate on the development of consistent messaging products and tools.

E1. Inventory existing regional climate related programs and capabilities to ensure coordination and the ability to leverage agency strengths. Priority level: Short-term; Potential lead: NOAA, USGS, and EPA

E2. Provide federal assistance to states to support climate change extension agents that can serve as advisors to localities on climate change planning. Priority level: Short-term; Potential lead: EPA or NOAA (Sea Grant)

E3. Establish sea-level rise transects with interpretive signage and easy access on federal lands as an outreach tool to demonstrate past and future coastline changes for the visiting public. Priority level: Medium-term; Potential lead: NPS, FWS, and NERRS

E4. Advance environmental literacy on climate change issues by providing educational materials and guidance on climate change to K-12 and higher education institutions. Priority level: Short-term; Potential lead: NOAA.

F. Develop federally coordinated plans for supporting climate change adaptations.

F1. Environmental markets are necessary to provide the funding needed to support adaptive strategies for climate change. Working with partners (e.g., Chesapeake Bay Bank), formulate a comprehensive strategic vision for designing and implementing an integrated environmental marketplace for the Chesapeake Bay watershed that maximizes overall efficiency and effectiveness of meeting climate and water quality goals. This vision should include a common understanding of how greenhouse gas markets and nutrient, sediment and other environmental markets (e.g, wetlands mitigation, habitat, flood mitigation, etc.) should be designed and implemented, and how the resources and expertise of the federal agencies can be used most effectively to meet these overall goals. Federal agencies should collaborate on three related components of an integrated system of market governance:

a. Design of a market-based policy framework;
b. Design of a performance measurement, reporting, and accountability system for government agencies and programs, and for pollution sources and producers of ecosystem services; and
c. Develop an ecosystem services-based information system that uses ambient data and fate-and-transport modeling to calculate the impact of the policy framework design and its implementation on the quality of land, air, water, and climate-based ecosystem services.

Priority level: Short-term; Potential lead: USDA and EPA

F2. Draw on or expand upon existing spatial targeting frameworks (e.g., Maryland's Green Infrastructure, Targeted Ecological Areas, Chesapeake Bay Program restoration targets, etc.) to direct federal funding and grants towards maintaining and enhancing watershed resilience. Further develop the Chesapeake Online Adaptive Support Toolkit (COAST) framework to support a wider range of federal support activities such as priority habitat and species conservation; protecting carbon sequestration sources (wetlands and forests); utilizing living/soft shoreline stabilization methods; controlling exotic species; and minimizing nutrient pollution and storm water runoff into Bay waterways.
Priority level: Short-term; Potential lead: USGS, USDA, and Federal Highway Administration

F3. Federal policies for land acquisition and conservation and federal programs supporting state and local land acquisition and conservation should consider the impacts of climate change. For example, allowing acquisition of lands outside current refuge or park boundaries to account for species shifts or inundation from sea level rise. Priority level: Short-term; Potential lead: NOAA, NPS, FWS, and FEMA, with states

F4. Review federal restoration and conservation grant programs to ensure that the best available and consistent climate change projections inform funding approval decisions. Codify this intent by requiring establishment of a separate ranking criterion for climate change issues (e.g. North American Wetlands Conservation Fund, Coastal and Estuarine Land Conservation Program, National Coastal Wetlands Program). Priority level: Short-term; Potential lead: FWS and NOAA

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VII. Appendix A. Survey of State Needs

The drafting team for this report contacted several state managers to inquire as the progress of their climate change plans as well as the challenges and needs associated with climate change issues. Below is a summary of the responses received from state representatives. No information was submitted for the state of New York.

WASHINGTON, D.C.
Climate Plan

- GHG emissions inventory nearly complete
- Climate Action Plan -completion anticipated in early 2010

(focus on adaptation and alleviating the impact of stormwater on area waters)

Challenges to Implementation

- Government and private sector resources (financial and human)
- Political and public support
- Regional Commitment to collaboration

Federal Agency Support Needed (State Level)
DC is home to a large amount of federally managed property and federal workforce

- Need support to reduce Vehicle Miles Traveled (VMT) of commuters
- Increase fuel efficiency of federal vehicle fleet
- Increase energy efficiency of federal buildings

Federal Agency Support Needed (Local Level)
Facilitate development of strategies that support regional and/or state climate action strategies

Monitoring, Research or Technical Needs
Climate change impact studies of the District are needed, at micro (10-25 meter) and macro (regional) scales

DELAWARE
Climate Plan
In development. In addition, the Delaware is working on a Sea-level rise Adaptation Plan.

Challenges to Implementation

- Lack accurate data to determine impacts, local coastal communities do not and will not have the capacity to react in a quick manner.
- Need an updated policy on merging strategic retreat, land acquisition, places for the water to go and the wetlands to move into

Federal Agency Support Needed (State Level)

- Federal agencies need to be flexible and understand differences between states
- A national policy is needed that embraces this diversity, is flexible and allows managers to examine and adopt new issues and priorities over time
- Federal agencies need to be actively involved and to provide technical, financial and scientific support

- A National policy must embrace action and not result in overly complex and burdensome structure and process.

Monitoring, Research or Technical Needs

Lidar corrected for marsh vegetation

Mechanism to transfer planning guidance from federal level to local level
- DE coastal management program and NEPs, Delaware Estuary Program and the Delaware Inland Bays
- State planning office and planners in DNREC

MARYLAND
Climate Plan
Maryland Climate Action Plan (2008) complete (priority policy actions selected based on feasibility)

Challenges to Implementation
Staff and fiscal resource limitations

Federal Agency Support Needed (State Level)
- A clear strategy for intergovernmental coordination on coastal adaptation
- Identify roles and responsibilities at all levels of government
- Develop a coordinated research and data exchange
- Allocate funding to assisted states in research, data acquisition, monitoring and adaptation planning
- Serve as the primary provider for Relative Sea-level rise data (2025, 2050, 2100)

Federal Agency Support Needed (Local Level)
- Consistent and comprehensive data and models at the appropriate scale and detail for decisions being made at the local level.
- Incorporation of climate change and sea-level rise into FEMA programs (CRS, NFIP, floodplain mapping program)
- Incentive programs to implement adaptive responses -- both for public and private sectors.
- More stringent minimum requirements from the International Code Council, specifically related to the building requirements

Monitoring, Research or Technical Needs
- Regional land subsidence monitoring data
- More recent land-use/land cover data to better assess impact of precipitation changes on the Bay
- Support for continuous, long-term fishery independent monitoring that provides data for fish stock assessments and ecosystem-based modeling efforts
- Enhanced monitoring and modeling of precipitation patterns and impacts on Bay

Mechanism to transfer planning guidance from federal level to local level
Coast-Smart Communities initiative (In development)
- Provides technical and financial assistance to local governments on coastal hazards and climate change impacts

- Offers a variety of mechanisms to engage local government leaders, including: outreach and education through a simulation exercise and workshops, written guidance and other technical assistance for planning, data and mapping tools, etc.

PENNSYLVANIA
Climate Plan
Climate change action plan under development

Federal Agency Support Needed (State Level)
Design and development of infrastructure to accommodate increased storm flow and inundation

Monitoring, Research or Technical Needs
Monitoring ecosystem response to climate variations to aid in designing adaptation strategies for the management of ecosystems

VIRGINIA
Climate Plan
A Climate Change Action Plan (2008)
Challenges to Implementation
- Economic (immediate needs of dollars elsewhere)
- Administrative and political (nothing in the Plan was codified by the GA in 2009).
- Scale related challenges (some elements require local implementation, whereas others require state and/or federal level)

Federal Agency Support Needed (State Level)
- Assistance in defining the spatial and temporal magnitude of the changes to date and development of projections of changes to come
- Need to unearth and assemble diverse data sets, then make them publicly available through a user friendly clearing house
- Support state based vegetation classification and mapping, and rare and invasive species inventories, and NatureServe's efforts to coordinate development of national datasets on ecological systems, rare species, observation data, and targeting of species and ecosystems most at risk from climate change via the Climate Change Vulnerability Index.
- Regional Conservation Lands Needs Assessment (Green Infrastructure) for the entire bay watershed, modeled after the work of Virginia and Maryland, conducted by individual states using common methods.
- Determine if (and how) we may need to modify these Clean Water Act processes to account for climate change and whether and how states may need to be modifying or adding permit conditions for NPDES permits to reflect these changes
- Help states understand the potential equipment and operational changes and impacts of changes to water and wastewater utilities as a result of climate change
- Sponsor independent research evaluating the trade-offs of various renewable or energy efficiency technologies on water consumption
- Direct issue-specific enabling authority

Federal Agency Support Needed (Local Level)
- Direct issue-specific enabling authority

Monitoring, Research or Technical Needs
Biological monitoring
- The influence of increasing atmospheric CO_2 on the acidity of both freshwater and marine systems
- Increased focus on pH sensitive (sentinel) organisms,

Physical monitoring and mapping
- Expand tide gage networks throughout the Chesapeake Bay and it sub-estuaries
- LIDAR mapping of the coastal region

Groundwater
- Network of groundwater monitoring wells

Assistance with specific efforts needed, including:
- Support to expand the Virginia Conservation Lands Needs Assessment (VCLNA) and maintain the Conservation Lands Database on all protected lands in Virginia
- An ecological and infrastructure assessment needs to be conducted for existing Natural Area preserves

The Department of Game and Inland Fisheries'
- Public attitude information to inform outreach efforts related to wildlife conservation and climate change
- Enhanced and updated existing relevant databases
- Expanded invasive species monitoring
- Expanded use of captive breeding and reintroductions to augment populations and expand the distributions of species of greatest conservation need.
- Techniques for successful captive breeding of wildlife need to be researched in many instances

Department of Forestry
- More precise and current elevation data (LIDAR)
- Better definition and estimation techniques for ecosystem services
- Greater understanding of the role of soil carbon and natural and agricultural systems.
- Better monitoring of invasive exotic species (prevention and control, as well)
- Support for identifying and maintaining tree genotypes suitable for reforestation under climate change scenarios

Mechanism to transfer planning guidance from federal level to local level
- The Virginia Planning District Commissions
- Virginia Nonpoint Education for Municipal Officials Program (VA NEMO) is currently working with the Northern Virginia Regional Commission on a project to develop climate change communication and education information for local officials
- To a limited and just evolving extent, the state assessment and resources strategy process under the U.S. Forest Service's State & Private Forestry Program transfers planning guidance to local governments

WEST VIRGINIA
Climate Plan
Not in development at this time

Federal Agency Support Needed (State Level)
- Building capacity for accessing information at a variety of levels e.g. research, having access to climate info. (data, publications, external technical expertise), modeling capabilities that integrate climate change and data collection on related climate concerns

- Completion of development of a new CAIR rule to further regulate NOX & SO2 as higher temperatures may exacerbate ground level ozone and fine particulate formation

Federal Agency Support Needed (Local Level)
Educational assistance/outreach/guidance on:

- Changing rainfall patterns as well as support for flood management minimization/prevention
- Designing storm water management structures/controls/preventative measures
- Allowing communities resiliency thru green infrastructure investment
- Increasing periods of drought affecting water supplies
- Possible risks to drinking water infrastructure
- Support to develop climate change vulnerability assessments for native species and natural communities and monitoring of rare species and natural communities with high vulnerability to climate change as per NatureServe's assessment methodology,
- Support to conduct a state-wide conservation lands needs assessment (green infrastructure) using regionally-coordinated methods,
- Support for monitoring of CO2 impacts on forests and aquatic systems
- Support for invasive species monitoring and control.

Monitoring, Research or Technical Needs
Determine habitat adaptation shifts and changing forest cover and the resulting impacts to water quality and quantity

Mechanism to transfer planning guidance from federal level to local level
Regional Planning Councils, office of Emergency Services, various program areas within Department of Environmental Protection and the Department of Health and Human Services

VIII. Appendix B. Examples of Species Impacts from Climate Change

Greater Scaup

The Greater Scaup, also known as the bluebill, is a migratory diving duck that visits the Chesapeake in late autumn and again in March and April, where it feeds on mollusks and aquatic plants. Loss of eelgrass beds due to rising water temperatures in the Chesapeake Bay will deplete important feeding sites for Scaup and other diving ducks.

Photo source: USFWS National Digital Library "Greater Scaup Drake", accessed August 9, 2009 < http://www.fws.gov/digitalmedia/FullRes/natdiglib/0AEB5A7D-65BF-03E7-2F835BB1F6A5B0E1.jpg>

Northeastern Beach Tiger Beetle

Impacts of sea-level rise and storm surge on Chesapeake Bay beach habitats may cause the extinction of the Federally endangered Northeastern beach tiger beetle. Rising seas will also affect the endangered tiger beetles that depend on the sandy fringes, unless cliffs are allowed to erode.

Photo provided by the USFWS

Striped bass

Striped bass, also known as rockfish or stripers, are one of the most valuable recreational and commercial species in the Chesapeake Bay. More intense precipitation events will increase sediment and pollution run-off in the Chesapeake Bay watershed, exacerbating existing water quality challenges. Increasing Bay water temperatures will shrink available cool-water habitat, while also decreasing levels of dissolved oxygen.

Photo source: USFWS National Digital Library "Striped bass", accessed August 9, 2009 < http://www.fws.gov/digitalmedia/FullRes/natdiglib/DE09EAA4-75E9-4526-92B8B553F1BE74F6.jpg>

Sensitive joint vetch

The Sensitive joint-vetch inhabits the intertidal zone of fresh to slightly salty (brackish) tidal river segments, typically in areas where sediments accumulate and extensive marshes are formed. As salinity and tidal influence move farther upstream within major rivers draining to the Chesapeake Bay, suitable brackish wetland habitat for this Federally listed plant will also shift upstream.

Photo Source: USFWFS New Jersey Fiel Office, Accessed August 9, 2009 <http://www.fws.gov/northeast/njfieldoffice/Endangered/jointvetch2.html>

Baltimore Oriole

With increasing temperatures, the Baltimore Oriole, Maryland's State bird may have to shift its range northward.

Photo Source: Photo source: USFWS National Digital Library "Baltimore Oriole on a branch", accessed August 9, 2009 <http://www.fws.gov/digitalmedia/FullRes/nctcdiglib/WO_2186_DBrezinskiCD.jpg

American Eel

To be inserted in next version

Delmarva Fox Squirrel

The Delmarva Fox Squirrel (*Sciurus niger cinereus)* was listed at a federally endangered species in 1967. Although once found throughout the Delmarva peninsula and southern portions of Pennsylvania and New Jersey, the remaining populations can only be found along the eastern shore of Maryland. Causes for decline include habitat fragmentation from timber harvesting, forest to farm conversion, and development. With sea level rise, inundation by seawater of low lying habitats further threatens this species.

Photo provided by the USFWS