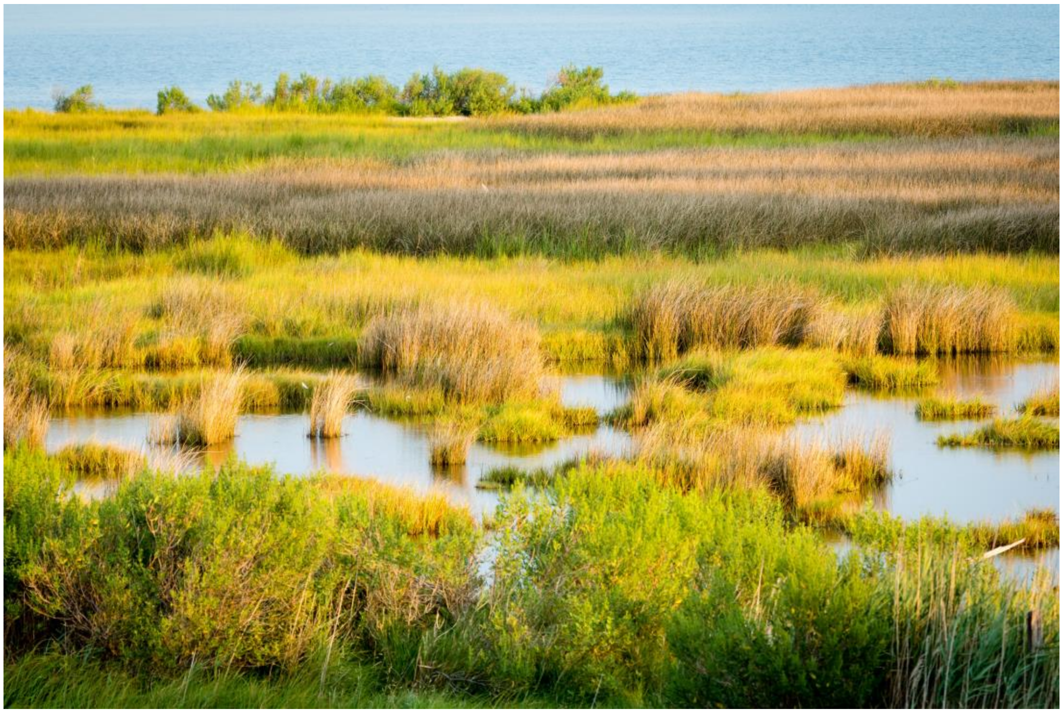
Climate Resiliency Outcomes

Management Strategy

2015–2025, v.2



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I. Introduction

All aspects of life in the Chesapeake Bay watershed—from living resources to public health, from habitat to infrastructure—are at risk from the effects of a changing climate. As one of the most vulnerable regions in the nation to the effects of climate change, the Chesapeake Bay is expected to experience major shifts in environmental conditions. Warming temperatures, rising sea levels and more extreme weather events have already been observed in the region, along with coastal flooding, eroding shorelines and changes in the abundance and migration patterns of wildlife. The stakeholders of the Chesapeake Bay watershed are large and diverse and are a critical component of any work to evaluate current and possible future conditions of the watershed. It is important that the work of the Climate Resiliency Work Group embrace the diversity of these stakeholders, which includes decision makers, and utilizes the best available science while being responsive to their needs as they deliberate and make choices about implementation of the management strategy.

Changing environmental conditions will affect not only the health of our ecosystem, but also the success of restoration and protection work across the watershed. Documenting changes in temperature, sea level and weather events allows us to plan our efforts to anticipate and withstand the threats facing our communities in order to recover and adapt to the impacts from forecasted climate change. Effective programs and policies rely on good stakeholder engagement as we facilitate the continual assessment of and adaptation to the influence climate change has on our work. Adjusting to a changing environment helps us build the resiliency[1] of the region's living resources, habitats and communities.

II. Goal, Outcomes and Baseline

This management strategy identifies approaches for achieving the following goal and outcomes:

Climate Resiliency Goal

Increase the resiliency of the Chesapeake Bay watershed, including its living resources, habitats, public infrastructure and communities, to withstand adverse impacts from changing environmental and climate conditions.

Monitoring and Assessment Outcome

Continually monitor and assess the trends and likely impacts of changing climatic and sea level conditions on the Chesapeake Bay ecosystem, including the effectiveness of restoration and protection policies, programs and projects.

Adaptation Outcome

Continually pursue, design and construct restoration and protection projects to enhance the resiliency of Bay and aquatic ecosystems from the impacts of coastal erosion, coastal flooding, more intense and more frequent storms and sea level rise.

Baseline and Current Condition

The Chesapeake Bay watershed has experienced changes in climate over the last century. Overall, the watershed is experiencing stronger and more frequent storms, an increase in heavy precipitation events, increasing Bay water temperatures and a documented rise in sea level, trends that are expected to continue over the next century. These trends, which vary both spatially and temporally throughout the watershed, are altering the ecosystems, the watershed and the human communities of the Chesapeake Bay. Changes in policies, programs and projects will be necessary to successfully achieve restoration, sustainability, conservation and protection goals for the Chesapeake Bay watershed.

The Climate Resiliency Goal and Outcomes are new additions in the most recent *Watershed Agreement* and no formal ecological condition or programmatic baseline for climate resiliency has yet been

[1] There are numerous definitions of "resiliency" in current academic and gray literature. The partnership will review the term ongoing, but the essence of the term is to ensure that the region's living resources, habitats and communities are prepared for changing conditions, are capable of withstanding impacts, where appropriate, and are able to recover and adapt to climate change impacts over time.

established. However, Chesapeake Bay Program partners have been engaged in climate change-related activities for some time. For example:

- The 2008 Scientific and Technical Advisory Committee (STAC) report "Climate Change and the Chesapeake Bay: State-of-the-Science-Review and Recommendations" synthesized the current understanding of climate change impacts on the Chesapeake Bay, identified knowledge gaps and outlined research priorities to address those gaps.
- The 2010 "Strategy for Protecting and Restoring the Chesapeake Bay Watershed" (Federal Leadership Committee for the Chesapeake Bay) noted that changing climate conditions are a significant challenge to successful restoration and protection of the Chesapeake Bay and its watershed. The report recommended a suite of actions to reduce vulnerability over time.

In addition to these two reports, Chesapeake Bay Program partners have published a number of additional documents and research related to climate science, monitoring, assessment and adaptation actions for the Bay and its watershed, as well as recommendations to drive future efforts. A compilation of these efforts that have been published in more recent years, including key documents, peer-reviewed papers and agency reports, are included in the Appendices. All of this information will be used to inform the establishment of the baseline for both climate Outcomes. Since the Climate Resiliency Goal is a new element of the *Watershed Agreement*, the development of initial baselines for the two associate outcomes will be critical to long-term monitoring and assessment of progress toward goal attainment.

III. Participating Partners

The following partners have participated in the development of this strategy. A workplan to accompany this management strategy will be completed six months after this document is finalized. It will identify specific partner commitments for implementation of the strategy.

Chesapeake Bay Watershed Agreement Signatories

Outcome	Participating Jurisdictions/CBC	Participating Agencies
Climate Resiliency Goal		
Monitoring and Assessment	MD, DC, DE, PA, VA, WV, CBC	DOI (USGS/USFWS), NOAA, EPA, NPS, USACE
Adaptation	MD, DC, DE, PA, VA, NY, WV, CBC	USACE, NOAA, FWS, EPA, DOT, DOI (USFWS/NPS/USGS)

Other Key Participants

In addition to the signatory jurisdictions and participating agencies, a broad set of stakeholders is engaged in the development of the Climate Resiliency Outcomes Management Strategy. Organizations include:

Academic Institutions:

- Virginia Institute of Marine Science
- Old Dominion University
- University of Maryland
- Penn State University

- Virginia Tech
- Christopher Newport University
- Bucknell University
- William & Mary

Non-Governmental Organizations:

- National Wildlife Federation
- Maryland Sea Grant
- The Conservation Fund
- Made Clear
- Sierra Club
- Wetlands Watch
- Alliance for the Chesapeake
- South River Federation
- Virginia Conservation Network
- Chesapeake Research Consortium

Local Government

- Metropolitan Washington Council of Governments
- Hampton Roads Planning District Commission

Other

- Bay Journal

Local Engagement

There is an important role for local governments, watershed associations, non-profits and the private sector in achieving the Climate Resiliency Outcomes. Roles include, but are not limited to, the following:

- *Local Governments*. Local governments should be prepared for a range of possible future conditions with respect to climate change impacts to better anticipate, prepare, recover and adapt to them over time. Local governments can serve as partners with state and federal regulators and funders in identifying and undertaking implementation opportunities. Local governments, school districts and other public institutions can provide locations for pilot projects that support the monitoring and assessment objectives and can serve as a venue for showcasing successful projects throughout the watershed.
- *Watershed Associations*. Local stream and watershed associations can provide leadership through member-implemented projects to restore riparian areas, which can hold, slow and cool water in streams and rivers for the benefit of adjacent and downstream communities as well as wildlife. Watershed associations are key partners as they can serve a major role in identifying opportunities, as well as implementing on-the-ground best management practices that address both climate impacts and stormwater runoff.
- *Non-Profits*. Non-profit conservation organizations can help apply downscaled climate impact information to improve the resilience of specific sites to sea level rise, storm impacts and other climate-related impacts. They can provide leadership on programs that mitigate climate effects,

such as reforestation, urban tree planting, and wetlands and floodplain restoration. As sources of information and public outreach, they can help educate and engage the public in supporting Bay Program climate resiliency objectives.

- *Private Sector*. Through voluntary leadership in adapting corporate-owned lands to the impacts of climate change (through reforestation, living shoreline or wetland restoration projects, for example), businesses can provide cost-effective, resilient models of addressing climate effects that will motivate employees and other stakeholders. Business improvement districts can provide leadership in providing more resilient infrastructure in public spaces, which can create a more attractive environment for customers and employees as well as increasing protection against climate-related business interruptions.

IV. Factors Influencing Success

The following are natural and human factors that influence the partnership's ability to attain the Climate Resiliency Outcomes:

1. Science Factors

- **Scientific Capabilities.** The scientific capabilities to estimate, project, model and monitor ecosystem changes and impacts due to climate change are just emerging. To fully understand the potential changes and anticipated impacts, the Chesapeake Bay Program and its partners must define the science and data needs at appropriate scales for the Chesapeake Bay. Data availability and accessibility at multiple scales is necessary, as is a better understanding of the methods, models and tools required to assess impacts, vulnerabilities, adaptation and management priorities.

- **Geographic Extent/Variability of Watershed.** The impacts of climate change will be varied across the watershed. It is important to not limit the focus of the management strategy to coastal issues alone—rather, to recognize the wide range of monitoring, assessment and adaptation needs throughout the region. However, the variability of the ecosystem within the Bay proper and the larger watershed presents challenges in data consistency and comparability among regions and sectors. The variability of ecosystems and ecosystem processes will also require different science and adaptation approaches.

- **Complexity of the Monitoring Program.** Developing a monitoring program to detect ecosystem change and inform program and project response is a complex undertaking and there are clear budgetary challenges associated with such long-term monitoring.

Non-climate Related and Multiple Stressors. Overall, climate change impacts are particularly difficult to monitor and assess because they can be exacerbated by existing non-climate or human-induced stressors, such as regional or localized land subsidence, land use change, growth and development. It is often difficult to differentiate climate impacts from the impacts of other stressors. An increased understanding of these interactions is necessary to successfully assess climate impacts and the effectiveness of restoration and protection policies, programs and projects.

2. Institutional Capacity, Regulatory Constraints and Stakeholder Response

- **Engaging Stakeholders and Incorporating Change.** Appropriate and accurate science and modeling are necessary for Chesapeake Bay Program partners to properly address climate impacts during policy planning and adaptation efforts. Meaningful engagement of the many and diverse stakeholder groups presents a challenge, particularly in light of the scientific uncertainties described above. Although there is acknowledgement that climate change and adaptation need to be addressed, there is a lack of understanding or agreement from stakeholders on what it means to be resilient or what constitutes resiliency, including what kind of actions support an adaptive management approach. Lack of appropriate stakeholder engagement jeopardizes acceptance of choices made about action plans and implementation strategies, introducing additional levels of social discord in an already complex environmental-economic-social landscape. If social stability is reduced, then policy effectiveness would likely be reduced.

- **Lack of Capacity.** Institutions and the private sector have a general lack of capacity to understand the science and incorporate meaningful change into plans, programs, processes or projects. Although building that capacity is paramount, it can be time consuming and costly, considering the resource constraints faced by governments and organizations.

- **Adapting to Change and Lack of Guidance.** Governments' and institutions' ability to respond to climate change is also limited by legislative, policy, regulatory and other authorities. Given the scientific uncertainties and the relatively recent emergence of the issue, there is currently a lack of clear science (models, tools and metrics) and guidance for the Chesapeake Bay Program, as well as stakeholders, to use to develop plans or to measure efficacy of response. The nature of on-the-ground implementation often requires certainties (e.g., hydrology, water quality, temperature, precipitation, sea level rise, coastal erosion rates) that are not yet available for a changing climate.

- **Lack of Collaboration.** The many and diverse stakeholders and organizations that make up the Bay Program are a strength, but this also causes collaboration challenges that must be addressed in order to leverage resources and provide consistent approaches across the watershed. Currently, there is a lack of coordination among Goal Implementation Teams (GITs), stakeholders and others that are addressing climate science and adaptation. As can be expected, there is also variability in institutional responses and the capacity to respond.

V. Current Efforts and Gaps

The findings of past assessments, such as the 2008 State-of-the-Science STAC report, provide a foundation on which to continue monitoring and assessment of changing climate conditions, while providing a knowledge base from which to pursue the design and implementation of specific adaptation action strategies for the partnership.

While the *Watershed Agreement* may be the most recent and prominent policy document to address climate resiliency, climate-related research, practices and policy development have been underway for a number of years. Partnership and Federal Agency strategies and reports include:

- *2008 STAC Report "Climate Change and the Chesapeake Bay: State-of-the-Science Review and Recommendations"*
- *2009 Presidential Executive Order 13508*
- *2010 Chesapeake Bay Total Maximum Daily Load (Bay TMDL)*
- *2010 Executive Order 13058: Strategy for Protecting and Restoring the Chesapeake Bay Watershed*
- *2011 Adapting to Climate Change in the Chesapeake Bay: STAC Workshop Report*
- *2015 North Atlantic Coast Comprehensive Study*

A summary of additional efforts and associated gaps with respect to both climate outcomes are provided below.

Environmental Monitoring

Environmental monitoring is an essential component of the Chesapeake Bay Program. The Chesapeake Bay Monitoring Program, which began in 1984, is a Bay-wide cooperative effort involving Maryland, Pennsylvania, Virginia, the District of Columbia, several federal agencies, 10 institutions and over 30 scientists. Current efforts include monitoring and modeling programs to assess ecosystem responses, with focus on the Bay TMDL and water quality. Chesapeake Bay Program partners currently monitor 19 physical, chemical and biological characteristics 16 times per year in the Bay's mainstem and many tributaries. Measured variables include: 1) freshwater inputs; 2) nutrients and sediments; 3) chemical contaminants; 4) phytoplankton; 5) soft-bottom benthos; 6) finfish and shellfish; 7) underwater Bay grasses, or submerged aquatic vegetation (SAV); and 8) water temperature, salinity, and dissolved oxygen. Many agencies have monitoring plans in place or under development, including USGS' draft *USGS Chesapeake Science Plan: Addressing USGS and DOI Priorities* and NOAA's *Chesapeake Bay Sentinel Site Cooperative Implementation Plan, FY13-FY18*.

Gap: Coordination of Modeling

Ensuring that monitoring systems can reliably detect signs of climate change and differentiate these signals from restoration or degradation is a complex undertaking. Virtually all the parameters measured by the Bay Program are informative with regard to how climate change is impacting ecological and hydrological systems of the watershed. However, fully integrated modeling within Bay assessments is missing. Integrated environmental modeling consists of utilizing a variety of water quality, flow, sediment, ecological, air quality and other models that more holistically represent an environmental system where all components influence one another. We should make a coordinated effort towards integrated modeling that includes climate change.

Scientific Assessments

The 2008 STAC Report and an update of the literature review conducted in that report (Najjar et al. 2010) represent a fairly comprehensive review of the impact of climate change on the tidal Chesapeake Bay. Additionally, numerous peer-reviewed papers and agency reports related to climate change monitoring and assessment have since been published. These are summarized in Appendix A.

Numerous research institutions, such as Old Dominion University, Virginia Institute of Marine Science, University of Maryland, Pennsylvania State University and Cornell University, have active and ongoing research on climate science, including projections for the Chesapeake Bay region and the associated potential impacts on the ecology of the Bay.

There is also a growing toolbox of Climate Change Vulnerability Assessments (CCVA) being used by natural resource agencies, non-profits and other organizations to assess vulnerability of natural resources, including individual species, habitats, and places (e.g., protected areas, watersheds, and landscapes), to the effects of climate change.

Gap: Climate Science

While the efforts to date at the Chesapeake Bay Program have focused on assessing the current condition of the watershed, addressing climate change will require continued assessment and analysis as well as new approaches to fill critical science gaps. Moving forward, we will need continued efforts to develop a comprehensive understanding of the current science and management actions relevant to the goals and outcomes of the *Watershed Agreement*.

Another gap is the adequacy of downscaled climate data for the Chesapeake Bay watershed, as well as the availability of future climate projections. Although some modeling efforts have occurred (e.g. sea-level rise), standardized assessment approaches to utilize projections to identify key vulnerabilities and tradeoffs and account for uncertainty have not been developed for the watershed. Such projections could be used as inputs to a variety of hydrological and ecological models to assess potential future climate impacts on natural and human systems. There is a need for more consistent and accurate modeling to enable the consideration of climate impacts.

Assessing the effectiveness of restoration and protection policies, programs and projects, such as the Bay TMDL or BMP implementation, will require improving scientific capabilities to monitor, model and assess ecosystem impacts and response. Currently, both technical barriers (data availability, accessibility, formatting and model programming, particularly across appropriate spatial scales) and gaps in science knowledge present challenges to completing such assessments.

Adaptation Research and Planning

Chesapeake Bay Program partners are engaged in a wide array of climate change activities across the region, designed to strengthen the watershed's resilience to climate change.

Federal Efforts. The federal partners in the Bay Program are among the most prominent and active federal agencies addressing climate change. They are acting to build capacity in climate science, develop tools to assist in planning and implement informed decisions on the ground. The National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA), the Fish and Wildlife Service (USFWS), the U.S. Geological Survey (USGS), U.S. Department of Agriculture (USDA) and the Department of Defense (DOD) are among the numerous agencies actively involved in programs, planning and conducting research on climate change.

State Efforts. States and communities around the Chesapeake Bay are taking steps to prepare for climate change. The District of Columbia and most Bay states, including Delaware, Virginia, Maryland, Pennsylvania, and New York, have developed either standalone climate change adaptation plans or a sustainability plan that incorporates climate change and adaptation. Several states and the District have established advisory bodies, such as Virginia and Maryland's Climate Commissions, to guide efforts and to oversee plans, projects and future actions that can help create more resilient communities. (Source: http://www.georgetownclimate.org/adaptation/state-and-local-plans).

Local Government and Community-Based Planning. Local governments and communities have started to adapt to the impacts of climate change in new and creative ways. For instance, the city of Norfolk, Virginia, was selected in 2013 to participate in the Rockefeller Foundation's 100 Resilient Cities Challenge for the purpose of building urban resilience in the face of climate change. Non-profit organizations and academic institutions also play an important role in adaptation efforts. Examples include the *Blackwater 2100: A Strategy for Salt Marsh Persistence in an Era of Climate Change* report, where the Conservation Fund and Audubon MD-DC partnered with the USFWS, Maryland Department of Natural Resources, the Chesapeake Conservancy and other organizations to produce a salt marsh adaptation strategy for Blackwater National Wildlife Refuge.

Gaps: Adaptation

Institutional capacity. Climate change is an emerging issue that has not been fully integrated into existing Bay restoration and management efforts within the Chesapeake Bay Program. This issue is illustrated by the extent to which climate change has and has not been considered in the broader *Watershed Agreement*. To address this gap, capacity must be built among the Chesapeake Bay Program partnership to: 1) more holistically understand and address the consequences of changing climate conditions, which includes both ecosystem and societal responses; 2) support informal collaboration across organizational, jurisdictional and disciplinary boundaries; 3) coordinate data collection, tool development and communication products; 4) construct inclusive, transparent processes to inform stakeholders about policy, program and project alternatives; and 5) plan for and implement restoration and protection efforts that build community and ecosystem resilience within the Bay watershed.

Cross-cutting programmatic gaps. The *Watershed Agreement* includes 29 individual Management Strategies to be implemented by six GITs and several Work Groups. Most, if not all, of these strategies will likely include a suite of actions intended to address climate change impacts. However, in some cases, *Watershed Agreement* Outcomes may need to be revised or reconsidered to accommodate anticipated climate-related changes or impacts. For example, with respect to goals and outcomes for Vital Habitats, the outcome of creating/reestablishing 85,000 acres of wetlands and enhancing the functions of another 150,000 acres should be carefully coordinated to include climate change resilience.

Linking science to implementation. The identification of climate change cross-linkages with the *Watershed Agreement* goals and outcomes is not yet occurring because of the lack of a cohesive framework that includes science components (monitoring, modeling and assessment) as well as stakeholder deliberation, prioritization and goal-setting components. Starting with the current integrated modeling expertise at USEPA, it is possible to improve the Bay watershed assessments of current and future conditions as well as indicator development and analysis for on-the-ground projects and other implementation strategies.

Facilitated Stakeholder Engagement. While the Bay stakeholders have a long history of meeting and discussing goals and outcomes, what is missing from current efforts are facilitated discussions guided by a broad assessment framework, which links scientific and social-scientific activities needed for a cohesive Bay management strategy. Rather than seeking to educate and perform outreach at the end of the analytical process and the beginning of the implementation process, cross-disciplinary, collaborative stakeholder discussions should be initiated at the start of adaptation and management efforts. These collaborative learning approaches must include discussions of audience-appropriate climate change education and information materials during the process.

VI. Management Approach

The partnership will work together to carry out the following actions and strategies to achieve the Climate Resiliency Goal. The Management Approach seeks to address the factors affecting the ability to meet the gaps identified above.

The *Watershed Agreement* includes 29 individual strategies to be developed and implemented by six GITs and various Work Groups. In many cases the effect of climate on individual outcomes is not well understood, and in other cases it is established and moving forward. The adopted management approach will require close coordination across the GITS and with the Climate Resiliency Workgroup to ensure that efforts to include climate in the strategies are consistent and complementary in their approach. The workgroup will work closely with the GITS to prioritize which aspects of climate change have the most impact on achieving outcomes, establish a research agenda for those outcomes where the effect of climate is not well understood, and establish whether suitable monitoring exists within the Chesapeake Bay to establish baselines and assess progress related to climate change.

The Chesapeake Bay Program has had much success in developing a variety of pollutant control measures as well as implementation of restoration and protection projects and commitments. To ensure that these efforts continue and are based on the best science available as well as improving stakeholder engagement, it is important to continue to develop and maintain capabilities to evaluate, assess and forecast the effectiveness of these measures in light of simultaneous impacts from multiple pollutants and climate change. This will require consolidated efforts among scientists, practitioners and stakeholders to understand societal responses as well as limitations of the science.

To address climate resilience, it will be important to assess the relative effectiveness of proposed measures, best management practices, restoration/preservation projects and regulations. Because the ecosystem response will be holistic, it is important to develop an analytical capability to best capture both science and society. Building cross-science disciplinary knowledge and better understanding societal responses will create greater opportunities to think about the Bay watershed and ecosystem on a broader scale.

Figure 1 graphically represents the Management Approach that will be utilized to achieve the Climate Resiliency Outcomes. This approach includes a biennial reassessment of baselines, goals and priorities.

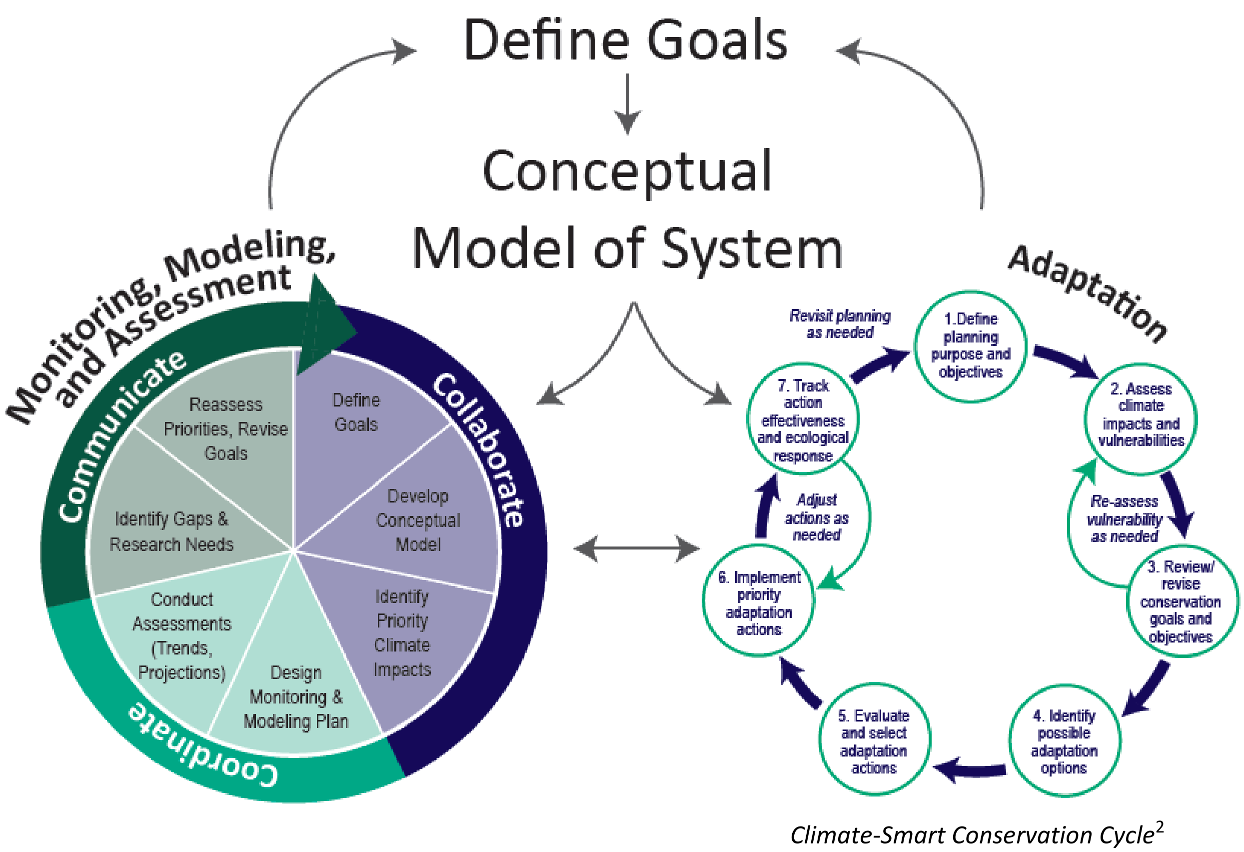

Figure 1. Climate Resiliency Outcomes Management Approach – Process Framework

The approach recognizes that multiple spatial and temporal scales are at play with regard to ecosystem impacts, responses and local vs. regional priorities. Without imposing a one-size-fits-all strategy, evaluation of ecosystem responses and stakeholder perspectives requires sensitivity to spatial and temporal scales when proposing or approving projects, control measures, best management practices or other adaptation strategies.

Monitoring and Assessment Outcome

Monitoring and assessment in conjunction with modeling, statistics and other scientific tools will be required to improve our understanding of ecosystem responses to climate change. The strategic development and maintenance of modeling, monitoring and assessment programs will allow the partnership to evaluate and compare current and alternative future scenarios constructed for different policies, programs and projects in response to the potential impacts of climate change together with anthropogenic activities.

Using the framework as illustrated in Figure 1, the following actions and steps to be undertaken in an ongoing process are proposed to achieve the Monitoring and Assessment Outcome:

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[2] *Stein, B.A et al. 2014. Climate-Smart Conservation: Putting Adaptation Principles into Practice. National Wildlife Federation, Washington, D.C.*

1. ***Define Goals and Establish Baselines*.** This action will require establishing baselines for the monitoring, modeling and assessment of different aspects of climate change as part of a core network. An evaluation of existing data, research, studies and tools, as they relate to climate and the needs for each of the management strategies, should be conducted and thoroughly documented. Available data and gaps in the monitoring network for each management outcome will need to be identified. This action will require coordination between the Climate Resiliency Workgroup and the GITs for each outcome and should utilize existing studies on past conditions by USGS, NOAA, EPA, the academic community and others for the range of climate indicators identified as critical to each outcome.
2. ***Develop Conceptual Monitoring, Modeling and Assessment Model.*** The model design will be driven by management questions, which link impacts of climate change to the ability to achieve the *Watershed Agreement* outcomes. The Partnership will develop a process to guide the Climate Resiliency Workgroup to coordinate with and among individual GITs, the larger research community and stakeholders to identify the linkages of climate to each outcome and evaluate whether those linkages are well understood or need further research.
3. ***Prioritize Climate Impacts*.** Once the gaps in available assessment tools, scientific understanding and baseline monitoring have been identified, a consultative prioritization will be performed to determine which of the gaps are most critical to outcome attainment. The highest priorities for the *Watershed Agreement* should include the identification of gaps that impact multiple outcomes.
4. ***Design Monitoring and Modeling Plan.*** This action will involve the following steps:
   - *Determine if the monitoring data being collected and the tools that are available can answer questions that fill out the assessment framework.* For outcomes where the linkages to climate are well understood, the Climate Resiliency Workgroup will coordinate with the GITs to evaluate existing monitoring data and available assessment tools to determine if they are adequate to fully explain the relationship of the future impact of climate on the outcome.
   - *Identify forecast projection models necessary to carry out the needed assessment of outcomes and for use in climate adaptation.* Standardized approaches are needed with regard to forecast projections utilized within the Bay Program for assessing the impact of climate on independent goals and outcomes. There is a wide range of projections within the scientific literature related to forecasted precipitation, storm intensity, air temperature, sea-level rise, etc. It is important that the Bay Program be consistent in how these projections are utilized as assessments are made.
   - *Outline an integrated monitoring and assessment agenda for priority aspects of climate change.* The Climate Resiliency Workgroup will work with GITs to develop a monitoring plan and research agenda for the prioritized gaps that have been identified in terms of assessment tools, scientific understanding and baseline monitoring. Costs associated with closing those gaps will need to be identified as part of that plan. That plan should also identify agencies/organizations through which commitments could be sought to achieve long-term monitoring.

5. ***Assess Trends and Conduct Assessments***. Assessing changing climatic and sea level conditions and trends is a vital and essential component of the *Watershed Agreement*'s Resiliency Goal. The Climate Resiliency Workgroup will collaborate with partners to analyze trends and document observed changes in sea level, precipitation patterns, Bay temperature, and the ecosystem responses. Using the trend analysis in combination with modeling programs and interrelated socioeconomic assessments, the Climate Resiliency Workgroup will coordinate with STAC and others to conduct formal climate vulnerability assessments of the Chesapeake Bay ecosystem, including the effectiveness of existing restoration and protection policy and regulatory programs and projects. The results of these assessments will be used to inform the development and prioritization of both on-the-ground projects and programmatic management strategies.
6. ***Develop a Research Agenda.*** For those outcomes where the linkages to climate are not well understood it will be necessary to conduct research to improve that understanding. The Climate Resiliency Workgroup will work with the GITs to engage the research community in order to provide that information.
7. ***Reassess Priorities and Revise Goals.*** Progress will be reviewed on a biennial basis, with emphasis on evaluating progress toward the closing of gaps in baseline monitoring and gaps in assessment tools and scientific research. Part of this process will be to re-prioritize remaining gaps in monitoring and scientific understanding.

Approaches Targeted at Local Participation

- ***Undertake Public, Stakeholder and Local Engagement.*** Traditionally led by scientists, partners will need to build the capability to better understand and address societal responses to policies affecting pollution, climate and control measures. The 2008 STAC report concluded that climate change will change the socioeconomic and cultural environment of Bay stakeholders, particularly fishermen and those whose livelihoods are directly connected to the water. As such, it is important that the best physical science information and forecasting are utilized and interpreted in a way that is meaningful to the public and policy makers. The data collected during the monitoring and assessment component must be accessible and able to support stakeholder discussions on the socioeconomic impacts of climate change on the Bay. This can best be achieved by collaborating with stakeholders in the development of data synthesis products for their use.

Adaptation Outcome

The essence of this outcome is to facilitate, demonstrate and implement "climate smart"[3] protection and restoration planning to enhance the resilience of the Bay watershed's habitats, public infrastructure (e.g., water and waste water systems, critical transportation assets) and human communities from the impacts of coastal erosion, coastal flooding, more intense and more frequent storms and sea level rise. Adaptation strategies will need to consider a range of future conditions to appropriately address uncertainty associated with climate change and its corresponding impacts.

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[3] *Defined by Stein et al. (2014) as: "The intentional and deliberate consideration of climate change in natural resource management, realized through adopting forward-looking goals and explicitly linking strategies to key climate impacts and vulnerabilities."*

On-the-ground restoration efforts will be addressed largely through the 29 individual strategies comprising the *Watershed Agreement*. It is critical that these restoration efforts be made climate smart by considering and integrating changing climatic conditions (e.g. precipitation patterns), sea-level rise and storm surge factors in the pursuit, design, implementation and long-term maintenance of restoration components of each strategy. Climate change considerations must be designed into current agricultural, forestry, urban and wastewater Best Management Practices (BMPs) associated with the Bay TMDL/WIP goals. Additionally, the Partnership may need to use specific BMPs to address specific restoration or protection needs, such as restoring or protecting areas that may serve to facilitate inland wetland/SAV migration, or siting and designing wetland restoration efforts to optimize for accretion.

To ensure that adaptation efforts are forward-thinking and not actually maladaptive, a systematic approach to planning should be undertaken. Several systematic approaches to climate change adaptation planning exist, most of which are modifications of an adaptive management planning rubric such as the *Open Standards for the Practice of Conservation* (http://cmp-openstandards.org/). Two of the more frequently mentioned approaches to adaptation planning are the *Adaptation for Conservation Targets* (ACT) *Framework* (Cross et al. 2012)[4], and the *Climate-Smart Conservation Cycle* developed by an expert group empaneled by the National Wildlife Federation (Stein et al. 2014) (see Figure 1). The Climate-Smart Cycle features seven steps in an iterative process, to be informed by monitoring and assessment, at each step of the cycle.

Using the Climate-Smart Conservation Cycle as a guide, the following actions and steps are proposed for an ongoing process to achieve the Adaptation Outcome:

1. ***Compile and Assess Current Efforts and Lessons Learned.*** The Climate Resiliency Workgroup will develop a process to periodically compile and assess lessons learned from past and ongoing adaptation planning and programmatic efforts within the Chesapeake Bay watershed. See Appendix B, which includes an initial compilation of current efforts that the workgroup will build upon. Current efforts, including policy, tools, products and scientific understanding, should be compiled, analyzed and shared with all interested parties engaging in adaptation work or discussions. This process could be achieved through an annual STAC workshop or similar venue. For example, communities that implement coastal protection measures using living shorelines or other integrated green/gray infrastructure techniques could share information about performance, problems and solutions, and sources of expertise at an annual conference.
2. ***Assess Climate Impacts and Vulnerabilities.*** The Climate Resiliency Workgroup will coordinate with both STAR and STAC to: 1) prepare a state-of-the-science synthesis of climate change impacts, vulnerabilities and adaptation information that link explicitly to management endpoints; and 2) evaluate tools, frameworks, and other products for their applicability to the Chesapeake Bay Program. The workgroup will also work to: 1) produce or evaluate guidance on implementation of climate change science within adaptation decision making processes; 2) identify significant gaps in terms of adaptive capacity (i.e., maladaptive management strategies or legal, policy or regulatory barriers); and 3) ensure that monitoring and assessment align with

[4] *Cross et al. (2012). The Adaptation for Conservation Targets (ACT) Framework: A tool for incorporating climate change into natural resource management.* Environmental Management *50: 341-351.*

adaptive management needs. A feedback loop, to be developed, will ensure that adaptation approaches are utilizing the best available science and techniques.

3. ***Review and Revise Conservation, Restoration and Protection Goals and Objectives.*** In some cases, other Management Strategies may need to be revised or reconsidered to accommodate anticipated climate-related changes or impacts. GITs will need to coordinate with each other, and the Climate Resiliency Workgroup, as well as decision makers to ensure that climate-related impacts have been considered in a manner responsive to these stakeholders' needs. This action will involve the following step:
    - A science-based framework should be developed and used to engage one-on-one with GITs to identify, assess, evaluate and revise, as necessary, climate-related elements of individual management strategies. Actions to integrate and understand the cumulative effects of multiple climate and non-climate related stressors should accompany this effort. This requires simultaneous modeling of the multiple factors of concern. This could be accomplished through the creation of GIT Climate Liaisons, who would be instrumental in communication among their groups and stakeholders about the best available science.
4. ***Establish Adaptation Outcome Priorities.*** The Climate Resiliency Workgroup will seek to engage stakeholders (including decision makers) by considering stakeholder-driven approaches that facilitate their articulation of desired outcomes and prioritization of those outcomes. Further, once stakeholders describe and articulate those outcomes, scientists connect the best available appropriate science to those outcomes, which includes the evaluation of climate scenarios for achieving the Bay goals and resilience in light of climate change. Critical to any approach is the capability to facilitate stakeholder inclusiveness, foster coordination and collaboration with affected communities, and ensuring that the best available science is used to evaluate adaptation alternatives that they want to consider.
5. ***Increase the Institutional Capacity of the Chesapeake Bay Program to Prepare for and Respond to Climate Change.*** Working with the Goal Implementation Teams and other appropriate Bay partners, the Climate Resiliency Workgroup will help to build the capacity among the Chesapeake Bay Program partnership to understand and address the consequences of climate change. While this is likely to involve significant investments of time and resources and may be disproportionate for particularly hard-hit areas such as low-lying urban areas, the Climate Resiliency Workgroup recognizes that without such capacity building, all of these areas are likely to be in even worse condition in the future.
    - The workgroup will also develop an Adaptation Network and Collaboration Strategy focused on increasing opportunities for formal and informal communication and the exchange of ideas and formation of strategic partnerships among the Chesapeake Bay watershed's existing "adaptation planning network," as well with other key regional partners (i.e., North Atlantic and Appalachian Landscape Conservation Cooperatives). This strategy would maximize the partnership's capacity to implement intentional and effective adaptation across organizational, jurisdictional, regulatory, and disciplinary boundaries. The NOAA Chesapeake Bay Sentinel Site Cooperative serves as one example of the many partners engaged in this type of network. A comprehensive framework and list of organizations within the "Chesapeake Bay Adaptation Network" should be developed.

6. ***Implement Priority Adaptation Actions.*** The Adaptation Outcome calls for the continual pursuit, design and construction of restoration and protection projects to enhance the resilience of Bay and aquatic ecosystems from the impacts of coastal erosion, coastal flooding, more intense and more frequent storms and sea level rise. The pursuit of specific adaptation projects will be a major undertaking on the part of the partnership and an effort that will be carried out, most likely by participating partners, agencies, local government and stakeholders. Implementation will require consideration of long-term planning horizons and a range of possible future conditions to account for the uncertainty associated with climate change impacts, including sea level change. This action will involve the following components:
   - Several gaps must be addressed, including increasing the capacity of the Chesapeake Bay Program to: 1) help plan for and implement restoration and protection efforts that build community and ecosystem resilience within the Bay watershed; and 2) remove some of the institutional barriers that currently exist. The Climate Resiliency Workgroup will identify priority actions related to these factors, but in the near-term, will focus efforts on: 1) compilation of local model climate adaptation guidance; 2) development of climate-related siting and design guidance for on-the-ground protection and restoration projects; 3) identification of funding availability and needs; 4) recommendation of specific policy, programmatic and regulatory enhancements that will increase support for such efforts; and 5) analysis and exploration of new mechanisms to incentivize private landowner actions to achieve priority adaptation actions, such as but not limited to the protection of wetland migration corridors.
   - It is recognized that underrepresented communities are often geographically based in high-risk areas that may be vulnerable to the effects of climate change. When targeting and implementing specific resiliency projects and community outreach, the Environmental Protection Agency’s Environmental Justice (EJ) Screening Tool will be used as a priority targeting mechanism in the decision-making process to ensure fair distribution of Bay Program partnership resources and restoration activities across all communities in the Bay watershed.
7. ***Track Adaptation Action Effectiveness and Ecological Response.*** The Climate Resiliency Workgroup will reassess priorities following implementation of steps 1 through 6, as outlined above. The establishment of performance metrics will aid in the assessment of progress to achieve the Adaptation Outcome.

Approaches Targeted to Local Participation

- ***Increase Local Engagement.*** Information regarding climate adaptation should be incorporated into the Management Strategy and biennial workplan for the Local Leadership Outcome, as appropriate.
- ***Undertake Public and Stakeholder Engagement.*** The Climate Resiliency Workgroup will conduct targeted conversations, focus groups and other appropriate mechanisms with stakeholder groups that may help to establish and implement Adaptation Outcome priorities, including recommended changes in policy at the local, state, and regional levels. Local governments and natural resource groups should be engaged alongside the broader community. The workgroup will also strive to engage stakeholders through existing community development, economic development, floodplain management, shoreline protection, hazard and flood mitigation,

emergency management and coastal zone management programs. Since climate resilience is an interdisciplinary issue, it will have interdisciplinary solutions.

- ***Foster a Larger Discussion on the Linkage Between Climate Impacts and Diversity.*** In an effort to create resiliency across the Bay watershed, expanding the diversity of the workforce and participants in climate resiliency restoration and conservation activities is a high priority. For this effort to be successful, the Bay Program partners need to honor the culture, history and social concerns of local populations and communities and include a wide range of people of all races, income levels, faiths, gender, age, sexual orientation, and disabilities, along with other diverse groups, in our decision-making processes. The Climate Resiliency Workgroup will coordinate with the Diversity Workgroup to ensure that a diverse group of local stakeholders are engaged in discussion related to climate change and the Chesapeake Bay. There are many underrepresented and underserved communities at risk from the impacts of climate change, and such communities need to be fully engaged in the design of Adaptation Outcome priorities in their communities.
- ***Increase Regional Collaboration.*** The partnership should increase participation of regional collaborations of local governments and other stakeholders, such as the Greater Baltimore Wilderness Coalition in central Maryland and Metropolitan Washington Council of Governments. Efforts such as these will provide a mechanism for implementing and creating a broad constituency for Bay-wide goals on adaptation and resilience at the community and neighborhood level to provide effective regional solutions.
- ***Conduct Targeted Education and Outreach*****.** Both practitioners (including consultants) and the general public should be provided the opportunity to learn about adaptation science, approaches and demonstration projects and feel empowered to have a voice in the decisions being made in their communities. For example, a periodic "special issue" newsletter could be released to disseminate adaptation-related information. Additional steps could include:
  - Engage the Stewardship Workgroup in support of climate outreach and education;
  - Provide support for decision-makers and community leaders to engage on climate change adaptation planning efforts at multiple levels (county, city, state, federal);
  - Develop broad Chesapeake Bay Program climate messaging, including information on how it integrates climate science into restoration efforts and impacts of climate on restoration work in progress;
  - Identify mechanisms that can increase community engagement and provide communities and diverse stakeholders with a voice and opportunity to engage in climate adaptation planning and policy decision-making processes for their communities;
  - Explore effective formal and informal education tools to increase climate resilience literacy among multiple audiences in the Bay. These should be closely linked with management strategies to achieve the Diversity and Environmental Literacy Outcomes;
  - Engage the academic community to develop effective collaborative learning approaches for informing and empowering communities across the watershed and test and develop new communication tools that are audience specific so that climate information is accessible and understandable across multiple audiences and communities.

VII. Monitoring Progress

This management strategy is designed to address a current gap regarding the institutional capability to conduct integrated environmental modeling across the entire Bay watershed. Monitoring progress will require a cohesive and collaborative strategy that includes strategic and analytical use of monitoring and modeling information. Evaluating baseline and alternative scenarios (whether current or forecast) rely on selecting appropriate indicators. Ensuring that selected indicators adequately represent desired outcomes is critical to assessing whether those outcomes have been achieved.

One way to accomplish this is to follow a process that allows for the inclusive and transparent construction of an analysis of Bay conditions using indicators chosen by the partners, as well as stakeholders. Some of the indicators will be those already identified, but the partnership should revisit those as well as consider additional indicators that will better describe the watershed's condition and assess progress. The indicators could be estimated using monitoring data, modeling data or a combination of both.

The Climate Resiliency workgroup has developed a suite of climate indicators that will be used to track and analyze trends, impacts, and progress toward advancing the climate resiliency goal and outcomes. There are three categories of climate indicators: physical climate trends based on measurements of physical or chemical attributes of the environment; indicators of ecological and societal impact that measure a) attributes of ecological systems, particularly attributes that may be influenced by physical climate trends, or b) impacts on society, such as health or economic outcomes; or indicators of programmatic progress toward resiliency that quantify resilience or show evidence of learning or adaptation over time.

Lessons Learned

The Climate Resiliency Workgroup (CRWG) is on target to meet the goals of both outcomes. While the CRWG management strategy outcomes lack a qualitative endpoint, we continue to make considerable progress

The Climate Resiliency workgroup has developed a suite of climate indicators that will be used to track and analyze trends, impacts, and progress toward advancing the climate resiliency goal and outcomes. There are three categories of climate indicators: physical climate trends based on measurements of physical or chemical attributes of the environment; indicators of ecological and societal impact that measure a) attributes of ecological systems, particularly attributes that may be influenced by physical climate trends, or b) impacts on society, such as health or economic outcomes; or indicators of programmatic progress toward resiliency that quantify resilience or show evidence of learning or adaptation over time.

Consistent incorporation of climate into jurisdiction efforts, indicators to inform decision making and impact of climate on BMPs can help explain the existing gaps between actual progress and anticipated trajectory of the climate outcomes. After going through the SRS, the CRWG noted that the following developments will influence our ability to achieve both outcomes: fiscal challenges associated with monitoring recommendations, uncertainty of climate science and lack of a qualitative endpoint.

Monitoring that is designed for climate change adaptation must include an element of flexibility and adaptability to account for: 1) uncertainty regarding how the climate system will change over time and how those changes will impact resources; 2) changing priorities resulting from an increased understanding of the impacts of climate change on resources; 3) developing new and innovative adaptation approaches that act on systems or resources in ways not accounted for; and 4) other factors such as threshold events and abrupt changes that are revealed to be specific to particular areas or affect certain species.

The Climate Resiliency Workgroup will develop a comprehensive inventory of planned or ongoing adaptation activities supported by Chesapeake Bay Program partners. These projects will be tracked to monitor the adaptation goal, status, and outcome of each effort. Adaptive management, which emphasizes management based on observation and continuous learning, provides a means to effectively address uncertainty in our knowledge of climate change impacts and system responses to adaptation actions. It is necessary to use this approach to reassess and update approaches to restoration, and possible reengineering of existing restoration projects as the understanding of changing climate conditions and impacts to communities and ecosystems increases.

VIII. Assessing Progress

Progress will be assessed every two years. Based on improved institutional modeling, monitoring and assessment capabilities, updated science information (including inventories, monitoring and modeling assessments) and improved information about social and cultural responses to climate change, the basis for the iterative stakeholder discussions could result in reassessing baselines, goals and priorities. Part of the process will be improving the current indicators used to track progress, which could result in identifying and constructing new metrics that better reflect stakeholders' goals and priorities. Facilitated stakeholder discussions will be important in identifying and constructing better indicators.

IX. Adaptively Manage

The Bay Program's commitment to adaptive management means that periodic reassessments of the science, stakeholder interests and policy alternatives are necessary. Adaptive management requires information, analysis and stakeholder engagement at multiple spatial (local, state, federal) and temporal (understanding historical trends, current conditions and forecasts into a variety of future time periods) scales. The management strategy describes the relationship among the various science and social science components that will be needed to successfully and adaptively manage the Bay watershed to meet its climate resiliency and other goals. As described here, monitoring, modeling, assessment and stakeholder engagement (at all levels) are not independent activities but are part of a broad assessment and adaptation framework.

Climate adaptation is not a "one-size-fits-all" effort. It will involve the utilization of multiple approaches to achieve the Adaptation Outcome. To that end, based on an improved understanding of the entire Bay watershed, targeted demonstration projects should be selected, monitored and assessed to inform adaptive management to ensure that on-the-ground projects are not maladaptive (providing benefits in one area but resulting in degradation in another). Understanding tradeoffs when evaluating on-the-ground projects allows stakeholders to use the best information generated by physical and social scientists in light of other stakeholder goals related to current agricultural practices, forestry, urban, wastewater, BMPs and the Bay TMDL. It must also be noted that the adaptive management convention of implementation and subsequent monitoring is problematic for long-lived infrastructure (natural or built) because of the large capital, operation and maintenance costs, and the timeframes that are involved, and therefore must be approached differently.

The Bay Program will continue to examine the following questions to address implementation challenges and opportunities, incorporate new climate related data and scientific understandings, and refine decision support tools and management strategies toward the achievement of the Climate Resiliency Outcomes in the *Watershed Agreement*:

- What progress had been made in implementing the Climate Resiliency Goal?
- How is climate change affecting the effectiveness and feasibility of achieving overall Bay restoration goals?
- What improvements are needed in modeling, monitoring, or science?
- Are specific changes to water quality standards or BMP efficiencies needed to address climate change and its water quality implications (i.e., modifications and/or changes to the Bay TMDL) and permit requirements? What are we learning about implementing better practices and adaptation strategies to build climate resiliency?

X. Biennial Workplan

The Climate Resiliency Workplan includes the following information:

- Key actions
- Expected outcome
- Partners responsible for each action
- Estimated resources

Appendix A.
Summary of Recent Research on Effects of Climate Change on the Chesapeake Bay

A1. Introduction

Najjar et al. (2010) summarized research on historical and projected impacts of climate projections for the Chesapeake Bay region and the associated potential impacts on the circulation, biogeochemistry, and ecology of the Chesapeake Bay. The study concluded that climate change has the potential to dramatically alter the Bay with likely changes being: “(1) an increase in coastal flooding and submergence of estuarine wetlands; (2) an increase in salinity variability on many time scales; (3) an increase in harmful algae; (4) an increase in hypoxia; (5) a reduction of eelgrass, the dominant submerged aquatic vegetation in the Bay; and (6) altered interactions among trophic levels, with subtropical fish and shellfish species ultimately being favored in the Bay.” The main purpose of this appendix is to review research published over the past five years on the historical and projected effects of climate change on the Chesapeake Bay.

A2. Climate and hydrological processes affecting the Bay

A2.1. Atmospheric composition

Najjar et al. (2010) utilized climate projections based on the Special Report on Emissions Scenarios (SRES), which were produced by the Intergovernmental Panel on Climate Change (IPCC) 15 years ago (Nakićenović and Swart, 2000). For the most recent IPCC climate assessment, a new family of greenhouse gas emissions scenarios, known as Representative Concentration Pathways (RCPs), was prepared (Moss et al., 2010; van Vuuren et al., 2011). Four RCPs have been developed—RCP8.5, RCP6.0, RCP4.5, and RCP2.6—where the numbers refer to the anthropogenic radiative forcing at 2100 in watts per square meter (Figure A1). Compared to the A2 and B1 SRES scenarios, which were in most common use, the RCP family captures a wider range in the forcing and the resulting simulated climate (Figure A2). The projected amount of total (natural plus anthropogenic) radiative forcing in terms of CO_2 equivalents is about 400 to 1200 ppm, which can be compared to the preindustrial CO_2 level of 280 ppm. Surface open-ocean average pH declines from the late 20th century to the late 21st century are between 0.06 and 0.32 pH units (Ciais et al., 2013).

A2.2. Water temperature

A new historical air and stream temperature analysis was conducted for the Chesapeake Bay watershed by Rice and Jastram (2014). Statistically significant trends over the 1960-2010 period of 0.23 and 0.28 °C per decade were found for air and stream temperature, respectively. Land use changes were found to explain differences in air and stream temperature trends.

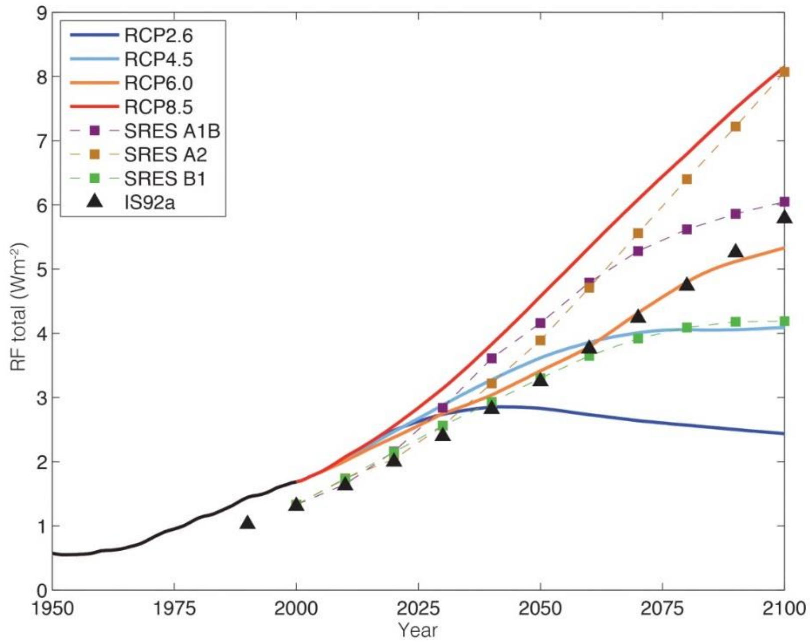

Figure A1. Anthropogenic radiative forcing from the Representative Concentration Pathways (RCPs) and the Special Report on Emissions Scenarios (SRES). Reproduced from Cubasch et al. (2013).

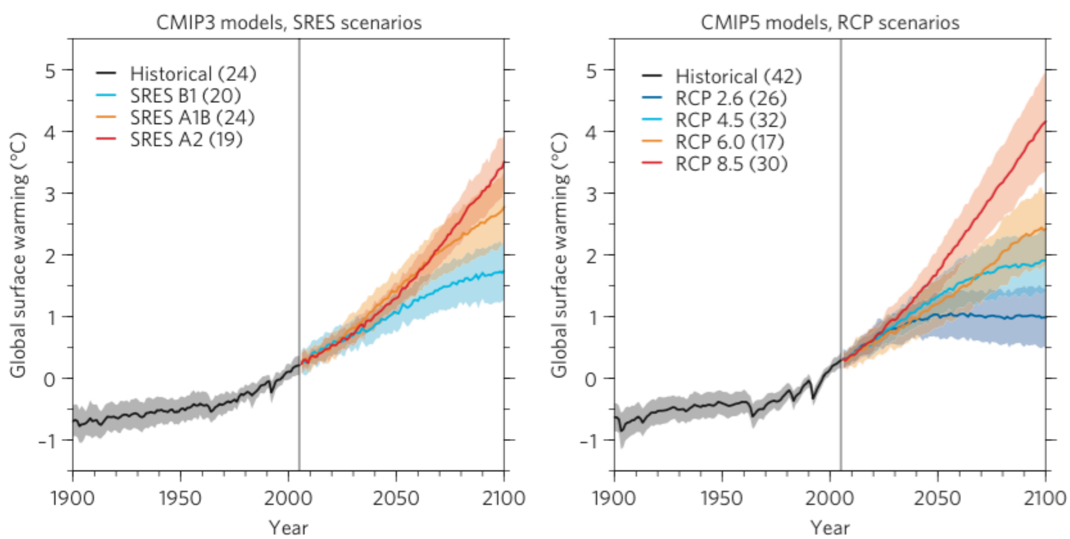

Figure A2. Historical and future simulations of global-mean surface temperature anomaly from the Coupled Model Intercomparison Project (CMIP). Left panel shows CMIP3 global climate models under the SRES emissions scenarios and right panel shows CMIP5 global climate models under the RCP emissions scenarios. Reproduced from Knutti & Sedláček (2013).

Projected changes in water temperature are expected to follow projected changes in air temperature (Najjar et al. 2010). Many new climate model simulations have been conducted over the past five years, which provide new estimates of air temperature change. Compared with previous work, these models may: (1) have higher spatial resolution, (2) utilize different emissions scenarios (Section A2.1), and (3) have been processed using statistical and dynamical downscaling techniques that provide projections on a finer spatial scale. One set of climate model simulations, known as the North American Regional Climate Change Assessment Program (NARRCAP; Mearns et al., 2012; Mearns et al., 2009), uses regional climate models of relatively high spatial resolution (50 km) embedded in Global Climate Models (GCMs) of coarser resolution. One study of Pennsylvania, which is representative of the northern part of the Chesapeake Bay watershed, showed that NARCCAP simulations were quite similar to global climate model simulations in terms of temperature (Shortle et al., 2013); Kunkel et al. (2013) came to a similar conclusion for the Northeast U.S. in an analysis conducted for the National Climate Assessment.

Climate model projections for the Chesapeake Bay watershed have more confidence than they did five years ago because climate models can now successfully simulate the observed warming of the Northeast U.S. over the 20th century (Kunkel et al., 2013).

There has been great interest in winter climate over the past five years, with numerous studies suggesting a linkage between reductions in Arctic sea ice and increases severe winters over land in mid-latitudes (e.g., Francis and Vavrus, 2012; 2015; Liu et al., 2012). Winter temperature trends over the past 50 years were positive everywhere over land in the Northern Hemisphere, but for the past 20 years were actually negative over much of North America and Asia. In a recent review article, Cohen et al. (2014) conclude that “it is possible, in principle, for sea ice and snow cover to jointly influence mid-latitude weather” but “because of incomplete knowledge of how high-latitude climate change influences these phenomena, combined with sparse and short data records, and imperfect models, large uncertainties regarding the magnitude of such an influence remain.” To emphasize this uncertainty, one recent study shows that Arctic amplification (greater warming in the Arctic than elsewhere) has actually led to a decline in sub-seasonal cold-season temperature variability (Screen, 2014). Despite these uncertainties, GCMs show a reduction in cold-air outbreaks over North America under enhanced levels of greenhouse gases (Gao et al., 2015). However, the reduction is about 20% smaller in a band that extends from Alaska to the Northeastern U.S. Thus, while winters are expected to become less severe in the future over the Chesapeake Region, the reduction in severity may be less than projections of mean temperature would suggest.

A2.3. Precipitation

Unlike mean temperature, there have been significant changes in projected mean precipitation for the Northeast U.S. Though models still project, on average, increases in annual precipitation, the higher-resolution models from NARCCAP show two important differences (Kunkel et al., 2013): (1) there is increasing consensus that summer precipitation will decline and (2) winter projections of increased precipitation are larger. Therefore, compared with earlier research, there is now a greater seasonality in the projected precipitation change. Increases in precipitation intensity, which are projected by GCMs, are also supported by the NARCCAP models (Kunkel et al., 2013).

A2.4. Streamflow

Whereas historical analysis of annual streamflow in the Chesapeake Bay watershed clearly indicates increasing trends, the question as to whether streamflow is becoming more extreme remains unresolved. An analysis in the Chesapeake Bay watershed for the 1930-2010 period by Rice and Hirsch (2012) used the annual seven-day low flow and one-day high flow as metrics of extreme flow. Low flows were found to have increased whereas high flows generally remained the same, meaning that flows have become less extreme with time. This is in contrast to previous work that suggested that high flows had increased in the Northeast U.S. (Groisman et al., 2001; 2004). Most recently, however, Armstrong and Collins (2014) found that annual maximum instantaneous discharge generally showed increasing trends throughout the Northeast U.S., including the Chesapeake Bay watershed. Similar results were found for another high-flow metric: the number of flow peaks exceeding a USGS-designated, station-specific threshold. The different conclusions among the studies may reflect the different metrics used for extreme flow and the choice of stations analyzed. For example, Armstrong et al. (2014) argue that the use of gauges in regulated watersheds compromised previous results.

Najjar et al. (2010) concluded that future changes in streamflow to the Chesapeake Bay, particularly the annual average, were highly uncertain because of the opposing effects of increases in temperature and precipitation. Major new work in this area was done by Johnson et al. (2012) and U.S. EPA (2013), who simulated changes in the hydrology of the Susquehanna River Basin using two watershed models and multiple sources of climate change projections, including GCMs, statistical downscaling, and dynamical downscaling (NARCCAP). Results in Table A1 are shown for one of the watershed models and six of the NARCCAP models for the middle of the 21st century under the A2 emissions scenario. In general, flow increases, as do peak flows, with median increases of 7% and 18%, respectively. The change in the magnitude of the lowest flows is equivocal. Global model results from Schewe et al. (2013), who used five watershed models in combination with 11 GCMs, indicate that warming will have very modest effects on mean streamflow in the Chesapeake region, with the projected change between -10 and +10% for a 2 °C warming. Modeling results from HiraBayashi et al. (2013) show an increased frequency of the 100-year flood in the lower Chesapeake watershed but a decreased frequency in the upper watershed.

Table A1. Results of Hydrological Model Simulations under Future Climate Change (US EPA, 2013).

	CRCM _ cgcm3	HRM3 _ hadcm3	RCM3_ gfdl	GFDL_ slice	RCM3 _ cgcm3	WRF _ ccsm	Median
Total streamflow	109	106	106	108	111	90	107
7-day low flow	91	120	104	89	107	86	98
100-year peak flow	107	130	106	128	172	100	118
Flashiness index	107	111	107	110	112	103	109
Sediment load	117	108	108	115	118	84	112
Phosphorus load	128	106	111	127	115	109	113
Nitrogen load	162	147	147	156	150	132	149

Results are reported for the time period 2041-2070 as a percent of the time period 1971-2000. Values greater than 100% represent an increase in the quantity being simulated. Results are shown for six different climate model configurations run under the A2 emissions scenario. The watershed model is SWAT (Soil Water Assessment Tool).

A2.5. Sea level

Numerous studies of sea-level rise at the global scale have been published over the past five years. There is strong consensus now that global-mean sea level is accelerating. Church and White (2011) found an acceleration of global-mean sea level consistent with numerous earlier studies. Problems closing the sea level budget before 1990 have been resolved by a reanalysis that indicates a mean sea-level rise of 1.2 ± 0.2 mm yr^{-1} for the 1901-1990 period, a rate substantially lower than previous estimates (Hay et al., 2015). For the 1993-2010 period, the same reanalysis estimated a global mean sea-level rise of 3.0 ± 0.7 mm yr^{-1}, similar to previous estimates, which indicates that sea level is accelerating more than previously thought.

Significant contributions have been made to our understanding of sea-level rise in the Chesapeake Bay region over the past five years. Despite initial indications of no acceleration of sea-level in the Chesapeake Bay (Boon et al., 2010), further study indicated acceleration larger than the global average and much of the U.S. east coast, which is possibly a result of changing ocean circulation (Boon, 2012; Ezer et al., 2013; Kopp, 2013; Sallenger et al., 2012). Global climate model simulations suggest that the Gulf Stream will weaken in the future, which will weaken the downward slope of the sea surface towards the east coast of the U.S., potentially adding another 0.2 m of sea-level rise to the Chesapeake Bay region by the end of the 21st century (Yin et al., 2009). Global sea-level rise projections that attempt to account for changes in global ice volume have not dramatically changed over the past five years, with typical projections by the end of the century between 0.3 and 1.3 m (Walsh et al., 2014). Boesch et al. (2013) suggest sea-level rise by 2100 of 0.5-1.4 m (best estimate 0.8 m) for the global mean and 0.7-1.7 m (best estimate 1.1 m) for Maryland.

The high rates of sea-level rise in the Chesapeake Bay are also due to land subsidence, caused by isostatic adjustment in response to the retreat of ice sheets as well as aquifer-system compaction resulting from groundwater withdrawals. Eggleston and Pope (2013) conclude that, in the southern Chesapeake Bay region, land subsidence currently contributes to approximately half of the relative sea-level rise and aquifer-system compaction contributes to about half of the land subsidence.

Rising sea level has increased the shoreward energy delivered to Chesapeake Bay's shorelines. Along the upper tidal shorelines of the lower Chesapeake Bay, the average shoreward energy flux for 1982-2010 was twice that for 1948-1981 (Varnell, 2014).

Rising sea level has dramatically increased flooding as well, including nuisance flooding, which is defined using a sea-level criterion determined by the local National Weather Service office (Sweet et al., 2014). For example, in Annapolis, Maryland, nuisance flooding occurred during only a few hours per year before 1940 whereas it is not uncommon over the past 10 years for it to occur for more than 200 hours per year.

Often ignored in historical sea-level rise analyses and projections is natural variability. Cronin et al. (2012, 2014) using a temperature-based reconstruction of sea-level for the Chesapeake Bay over the last 2000 years, notes that short-term rates of sea-level change have been frequently as large as they are now. These authors thus caution that the current acceleration in sea level may not be unusual or representative of a long-term average.

A2.6. Storms

Significant storms that impact the Chesapeake Bay are North Atlantic tropical storms and winter extratropical cyclones (including nor'easters). The most recent National Climate Assessment (Walsh et al., 2014) concluded that there is "high confidence that the intensity, frequency, and duration of North Atlantic hurricanes, as well as the frequency of the strongest (Category 4 and 5) hurricanes, have increased substantially since the early 1980s; low confidence in relative contributions of human and natural causes in the increases; and medium confidence that hurricane intensity and rainfall rates are projected to increase as the climate continues to warm." These conclusions are generally similar to the state of the science five years ago. Continued research on winter extratropical cyclone changes indicates little consensus on changes in the Northern Hemisphere, especially in the North Atlantic basin (Collins et al., 2013).

A3. Fluxes of nutrients and sediments from the watershed

Flow-adjusted concentrations of total nitrogen and total phosphorus at the mouths of the three largest rivers emptying into the Chesapeake Bay (Susquehanna, Potomac, and James Rivers) declined from 1985 to 2013 (Langland et al. 2012; Blomquist et al., 2014), with the exception of total phosphorus in the Susquehanna River, which showed no trend. Suspended sediment concentration trends for 1985-2013 were not significant, except for a decreasing trend in the Potomac. More recent trends (2003-2013) are negative for nitrogen (except for the James, which showed no trend), and not significant for phosphorus and sediment, except for an increasing phosphorus trend in the Susquehanna River.

High-flow events and their effect on the Conowingo Dam appear to play a disproportionate role in the delivery of nutrients and sediments from the Susquehanna River to the Chesapeake Bay. Hirsch (2012) analyzed the 1996-2011 period and found that flow-adjusted concentrations of nitrogen declined by 3% and those of total phosphorus and sediment increased by 55% and 97%, respectively. Upstream of the dam, however, concentrations declined for all constituents. Remarkably, Tropical Storm Lee, which contributed only 2% of the freshwater flow from the Susquehanna River to the Chesapeake Bay during 2002-2011, contributed 5%, 22%, and 39% of the nitrogen, phosphorus, and sediment loads. Zhang et al. (2013) reached similar overall conclusions. Both studies suggest that the Conowingo Dam is close to reaching its capacity to store particulate material and that increases in extreme flow events will pose significant management challenges.

The fraction of net anthropogenic nitrogen inputs (NANI) to a watershed that is exported from that watershed is a function of the watershed's climate, with some studies showing that this fraction increases with streamflow (e.g., Howarth et al., 2006) and others showing a decrease with temperature (Schaefer and Alber, 2007). In a recent analysis of a very large number of watersheds in the U.S. and Europe, it was found that the fraction of NANI exported varied significantly with temperature, precipitation, and streamflow, but the latter had by far the most predictive power (Howarth et al., 2012).

Modeling of future nutrient and sediment loads in the Susquehanna River Basin show increases in all quantities by mid-century under the A2 emissions scenario (Table A1). Median increases in sediment, phosphorus, and nitrogen loads are 12%, 13%, and 49%, respectively (Johnson et al., 2012; U.S. EPA, 2013).

A4. Bay physical response

Two modeling studies have been conducted over the past five years to estimate potential changes in the circulation and salinity of the Chesapeake Bay in response to sea-level rise. Rice et al. (2012) investigated changes in salinity in the James and Chickahominy Rivers resulting from sea-level increases between 0.3 and 1 m. They found that salinity was more sensitive to sea level during dry years, with salinity increases as large as 4 ppt for a 1-m rise in sea level. They also found that a local drinking water supply will be affected by saltwater intrusion resulting from sea-level rise. Hong and Shen (2012) explored similar sea-level scenarios for the whole of the Chesapeake Bay and found salinity and stratification to increase. In addition, they found an increased exchange flow, weaker downstream transport of fresh water, increased residence time, and increased vertical transport time. In addition, tidal currents were found to increase with sea-level rise, but not enough to negate the weakened vertical exchange associated with the stratification increase.

A5. Estuarine biogeochemistry

A5.1. Plankton

Harding et al. (2015) investigated historical changes in plankton composition in the Chesapeake Bay from 1985 to 2007. They found diatoms to be the predominant taxonomic group. Diatom abundance tended to be higher in wet years. Furthermore, flow-adjusted diatom abundance decreased towards the end of the time series, which was suggested to be a result of nutrient reductions; this suggests that future nutrient reductions could result in a more diverse phytoplankton population.

A5.2. Pathogens

We were unable to identify recent research on the impact of future climate change on estuarine biogeochemistry and plankton, with one exception: Urquhart et al. (2014) studied current models of ***Vibrio vulnificus*** and argued that these models are inadequate for predicting the effects of warming on this microbe.

A5.3. Dissolved oxygen

The processes driving interannual variations in summertime hypoxic volume in the Chesapeake Bay have been investigated in numerous studies over the past five years. Scully (2010a) found a correlation between observed wind direction and hypoxic volume, which was supported by numerical modeling results (Scully, 2010b). Murphy et al. (2011) found trends in the timing of summertime hypoxia, which were attributed to changes in stratification and nutrient loads. Testa and Kemp (2014) determined that higher Susquehanna River flows resulted in an earlier onset of hypoxia. Zhou et al. (2014) were able to account for 85% of the interannual variability in hypoxic volume using January-May total nitrogen load, April-August winds, and April-May precipitation as predictors. A numerical modeling study by Li et al. (2015) suggested that vertical mixing, vertical advection, and lateral advection are all important sources of dissolved oxygen to bottom waters. Hypoxic volume was surprisingly insensitive to river flow in this modeling study; this resulted from compensating changes in the lateral and vertical supply of dissolved oxygen to bottom waters. Li et al. (2015) also found that wind speed affected the timing and magnitude of hypoxic volume.

A6. Vascular plants

A6.1. Submerged aquatic vegetation

Orth et al. (2010) analyzed submerged aquatic vegetation (SAV) distributions in the Chesapeake and found support for the assertion that increases in nitrogen pollution reduce SAV abundance.

Jarvis et al. (2014) developed a model of *Zostera marina* and examined impacts of temperature and light stress. They found high sensitivity of established beds to consecutive years of stress and negative effects of multiple stressors on *Z. marina* resilience and recovery.

A6.2. Estuarine wetlands

Recent research suggests that sea-level rise continues to pose an uncertain but potentially significant threat to estuarine wetlands. Kirwan et al. (2013) used mesocosms to evaluate the hypothesis that sea-level rise would reduce organic matter decay rates, thereby providing a negative feedback loop that would help to reduce submergence. However, they found no effect of sea-level rise on decay rates, and concluded that enhanced organic matter production or mineral sediment supply would be needed in order for marshes to keep pace with accelerated sea level. Furthermore, temperature increases are expected to reduce net ecosystem production (Drake, 2014). However, elevated CO_2 was shown to enhance net ecosystem production of C3- and, to a lesser extent, C4-dominated communities in a Chesapeake Bay tidal wetland (Erickson et al., 2013).

A7. Fish and shellfish

A meta-analysis by Vaquer-Sunyer and Duarte (2011) showed that "ocean warming is expected to increase the vulnerability of benthic macrofauna to reduced oxygen concentrations and expand the area of coastal ecosystems affected by hypoxia."

A study of blue crabs along the east coast of the U.S. (Hines et al., 2010) concluded that warming may have positive and negative effects. The reduced severity of winters associated with global warming will increase winter survival and promote rapid growth and brood production. Warming, however, may increase juvenile mortality and size at maturity.

New research has been conducted on the impact of environmental factors on oysters. Levinton et al. (2011) found in a modeling study that projected increases in precipitation may lower salinities enough to be harmful to oysters. Kimmel et al. (2012) found that long-term variability in Eastern oysters in the Chesapeake Bay was related to salinity.

Waldbusser et al. (2011a), in laboratory studies of juvenile eastern oysters, found that biocalcification declined significantly with a reduction of ~0.5 pH units, but that increases in temperature and salinity reduced the sensitivity to pH. A related study using a flow-through control system found that pH declines increased shell dissolution rates (Waldbusser et al., 2011b).

Through a literature review, Jones (2013) examined the potential impact of climate change on finfish in the Chesapeake Bay through changes in seagrass and concluded that the uncertainty is too large to make reliable projections.

A8. Human systems

Some new research has been conducted on the human response to climate change in the Chesapeake region and in coastal areas in general. Paolisso et al. (2012) studied two African-American communities on the eastern shore of the Chesapeake Bay and found that community members recognize potential impacts and are organized through their churches to address some of those impacts. More generally, Moser et al. (2012) underscore multiple stressors that coastal systems face and the need for transformative changes in the science and management to address what appears to be an overwhelming challenge.

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Appendix B.
Current Adaptation Efforts

B1. Policy and Plans

B1.1. State of Delaware

Executive Order Number Forty-One: Preparing Delaware for Emerging Climate Impacts and Seizing Economic Opportunities from Reducing Emissions (2013) – The Executive Order establishes the Governor's Committee on Climate Change and Resiliency. It charges the Committee with overseeing the development of an implementation plan to continue reducing emissions and develop agency-specific actionable recommendations for improving Delaware's preparedness and resiliency to climate impacts.
http://governor.delaware.gov/orders/EO41.pdf

Delaware Climate Change Impact Assessment (2014) – In addition to providing a summary of the potential impacts of climate change to Delaware, the assessment lends strong scientific foundation for the development of the state's mitigation and adaptation planning and strategies.
http://www.dnrec.delaware.gov/energy/Pages/The-Delaware-Climate-Impact-Assessment.aspx

Climate Change Projections and Indicators for Delaware (2013) – This report documents how global changes are expected to affect Delaware and supports the state's Assessment.
http://www.dnrec.delaware.gov/energy/Documents/Climate%20Change%202013-2014/ARC_Final_Climate_Report_Dec2013.pdf

Preparing for Tomorrow's High Tide: Recommendations for Adapting to Sea Level Rise in Delaware (2013) – Delaware's Sea Level Rise Advisory Committee approved recommendations for adapting to sea level rise. Public comment, investigation and discussion helped to formulate the recommendations.
http://www.dnrec.delaware.gov/coastal/Documents/SeaLevelRise/SLR%20Final%20Draft%20for%20Publication%20082013.pdf

B1.2. District of Columbia

Sustainable DC Omnibus Amendment Act of 2014 – The amendment includes provisions that support climate adaptation. These include more public access to energy and water use data and protections for urban forests.
http://sustainable.dc.gov/page/sustainable-dc-act

Sustainable DC Act of 2012 – The Act is intended to promote various energy-related programs including energy efficiency, renewable energy, and financing. It supports a robust sustainability plan for the District, Sustainable DC.
http://dcclims1.dccouncil.us/images/00001/20130124112432.pdf

National Capital Region Climate Change Report (2008) – The report reflects the work of representatives from the District, Maryland, Virginia and other regional organizations. It presents a regional climate change strategy to meet the regional greenhouse gas reduction goals.
http://www.mwcog.org/uploads/pub-documents/zldXXg20081203113034.pdf

2013-2016 Climate, Energy, and Environment Policy Committee Action Plan and Resource Guide – The Committee drafted an Action Plan and Resource Guide - The Plan identifies goals and implementation actions for sectors such as greenhouse gas reduction, infrastructure, and transportation. The Guide provides descriptions, best practice examples, and resources needed for implementing the Plan.

ACTION PLAN
https://www.mwcog.org/environment/climate/Documents/2013-4-22%20CEEPC%20Action%20Plan%20Resource%20Guide_Working%20Final.pdf

RESOURCE GUIDE
https://www.mwcog.org/environment/climate/Documents/2013-5-22%20Final%202013-2016%20CEEPC%20Action%20Plan.pdf

B1.3. State of Maryland

Climate Action Plan (2008) - The plan addresses strategies to reduce the state's vulnerability to climate change by considering impacts, mitigation, and other concerns. The Plan includes a report to the Maryland Commission on Climate Change from the Scientific and Technical Working Group on the impacts and recommended actions to protect Maryland's property and people from the effects of climate change.
http://climatechange.maryland.gov/publications/global-warming-and-the-free-state-report/

Comprehensive Strategy for the Reducing Maryland's Vulnerability to Climate Change, Phase 1: Sea-level Rise and Coastal Storms (2008) – A report by state agencies that lays out policy recommendations and identifies implementation targets with respect to sea level rise and coastal hazards.
http://dnr.maryland.gov/coastsmart/pdfs/comprehensive_strategy.pdf

Comprehensive Strategy for the Reducing Maryland's Vulnerability to Climate Change, Phase 11: Building Societal, Economic, and Ecological Resilience (2011) – The strategy lays out policy recommendations and identifies implementation targets including aquatic and terrestrial ecosystems and water resources.
http://www.dnr.state.md.us/climatechange/climatechange_phase2_adaptation_strategy.pdf

Building Resilience to Climate Change, MDNR – Policy applied to MDNR that provides direction and guidance in the management of land, resources, and assets in facing climate change impacts. In addition, MDNR lists as a resource a report published by Restore America's Estuaries provides extensive recommendations on adaptation through the restoration of coastal habitat.
http://www.dnr.state.md.us/dnrnews/pdfs/climate_change.pdf

Greenhouse Gas Reduction Act Plan (2013) - The Plan advances strategies to: reduce greenhouse gas emissions, transition to new energy sources, and stimulate technological development.
http://climatechange.maryland.gov/publications/maryland-s-greenhouse-gas-reduction-plan-executive-summary/

Climate Change Impact Area Mapper - The mapper is an online map service which shows land areas in Maryland that are projected to be the most sensitive to anticipated changes in climate.
http://www.dnr.maryland.gov/climatechange/mapper.asp

Coastal Atlas - The Atlas is an online interactive mapping tool, developed by Maryland DNR to access and assess sea level rise, coastal hazard data and imagery.
http://www.dnr.state.md.us/ccp/coastalatlas/index.asp

CoastSmart Communities Scorecard - The Scorecard provides planning guidance in five major sectors: Risk and Vulnerability Assessment; People and Property; Infrastructure and Critical Facilities; Natural Resources; and Societal and Economic Impacts, and can be used to develop a custom made strategic planning and response guide.
http://dnr.maryland.gov/coastsmart/

Updated Sea Level Rise Projections - Dr. Donald F. Boesch, UMCES President, convened a panel of highly qualified scientific experts on sea level rise drawn from Maryland and the Mid-Atlantic region (VA, DE, NJ, PA). A report detailing best estimates for MD was issued in June 2013. The "Best" estimate of mean sea level rise along Maryland's shorelines by 2050 (over the mean level in the year 2000) is 1.4 feet; based on present scientific understanding. It is unlikely to be less than 0.9 foot or greater than 2.1 feet. The "Best" estimate for mean sea level rise by 2100 is 3.7 feet; it is unlikely to be less than 2.1 feet or greater than 5.7 feet.
http://climatechange.maryland.gov/publications/updating-marylands-sea-level-rise-projections/

Climate Change and Conservation Practices - DNR has developed new conservation criteria and easement provisions to identify coastal habitats that may help Maryland proactively adapt to sea level rise and increased storm events associated with climate change. Climate change targeting criteria was used to develop new conservation areas for "GreenPrint" and a parcel-level scorecard used to review land acquisition projects.
http://dnr.maryland.gov/ccs/habitats_slr.asp

Plan Maryland: Climate Change Impact Areas - Climate Change Impact Areas are included as one of Plan Maryland's Areas of Special Designation. Climate Change Impact Areas include: projected 50 and 100-year Sea Level Rise Inundation Zones, 50-Year Erosion Vulnerable Zones, Category 2 Storm Surge Inundation Zones, Marsh Transition Zones, Temperature Sensitive Streams, Drought Hazard, and Wildfire Risk Areas. Climate Change Impact Areas are currently being used by state agencies and local governments to identify vulnerable areas, as well as areas to target for implementation of climate change and sea level rise resilience measures.
http://www.plan.maryland.gov/

Greenhouse Gas Reduction Plan: Adaptation Update - The 2012 Greenhouse Gas Emissions Reduction Act (GGRA) Plan was released by the Governor on July 25, 2013. Chapter 8 of the Plan details the strategies underway within State Government to address the impacts of climate change, including sea level rise.
http://climatechange.maryland.gov/publications/greenhouse-gas-reduction-plan-chapter-8-adaptation/

Coast Smart Construction Executive Order - EO 01.01.2012.29, issued in December 2012, enacts a number of policy directives, including directing all State agencies to consider the risk of coastal flooding and sea level rise when they design capital budget projects and charging the Department of General

Services with updating its architecture and engineering guidelines to require new and rebuilt State structures be elevated two or more feet above the 100-year base flood level.

Climate Change and Coast Smart Construction - Infrastructure Siting and Design Guidelines (2014): The report (issued in response to directives outlined in executive order) recommends specific siting and design guidelines for State construction projects to protect against the impacts of climate change. The report recommends that *Coast Smart* practices also be applied to non-state buildings and infrastructure projects if partially or fully funded by the State, as well as projects on state lands. Recommended practices include: increasing the elevation requirements for State buildings, and critical and essential facilities, such as 911 centers and fire stations; increasing the setback requirements for State structures to avoid areas likely to be impacted by sea level rise within the next 50 years; and protecting natural storm surge buffers on construction sites.
http://climatechange.maryland.gov/publications/state-of-maryland-climate-change-and-coast-smart-construction-infrastructure-siting-and-design-guidelines/

Coast Smart Council (House Bill 0615) - House Bill 615 codifies into law and builds on key provisions of Executive Order 01.01.2012.29 by creating a Coast Smart Council chaired by the head or designee of DNR, with membership comprised of the head or designee of DBM, MDE, DGS, MDP, MDOT, DBED, MEMA, Critical Area Commission, University of Maryland, and 5 members appointed by the Governor to represent local government, environmental, and business interests.
http://www.dnr.state.md.us/climatechange/CSCouncil/index.asp

Bay Acidification Task Force **-** House Bill 118 required the State to devise a team, or Task Force, of State leaders, and water quality, fishery and climate experts, to address how changing Bay chemistry negatively impacts Maryland’s coast and shellfish industry. The Task Force studied and assessed water quality in Maryland’s Chesapeake and coastal Bays, and review ocean acidification studies and findings from other states. The group presented recommendations for monitoring and addressing acidification, and its effects on Maryland’s commercial fishery and aquaculture industry in January, 2015. The Task Force included State agency representatives, along with representatives from the State’s aquaculture industry, the Maryland Watermen’s Association, the National Aquarium in Baltimore, the University of Maryland Center for Environmental Science, and the Chesapeake Bay Foundation.
http://msa.maryland.gov/megafile/msa/speccol/sc5300/sc5339/000113/020000/020856/unrestricted/20150253e.pdf

B1.4. State of New York

New York State Climate Action Interim Report (2010) – The interim report focuses on achieving the goal of reducing greenhouse gas emissions by 80 percent below the levels emitted in 1990 by the year 2050. Adaptation policy options and relevant financial aspects are identified and examined.
http://www.dec.ny.gov/energy/80930.html

Responding to Climate Change in New York Synthesis Report (2011) – This state level assessment of climate change impacts is intended to assist with developing adaptation strategies.
http://www.nyserda.ny.gov/Cleantech-and-Innovation/Environment/Environmental-Research-and-Development-Technical-Reports/Response-to-Climate-Change-in-New-York

B1.5. Commonwealth of Pennsylvania

Pennsylvania Climate Adaptation Planning Report: Risks and Practical Recommendations (2014) – The report provides climate adaptation information to government agencies, businesses, researchers, other stakeholders and the public. Statewide planning efforts cover infrastructure, public health, natural resources and tourism sectors.
http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-103584/2700-RE-DEP4303%20Combined.pdf

The Pennsylvania DEP has produced two climate impact assessments for the commonwealth and is in the process of publishing a third report. The two published reports are:

Shortle, J., Abler, D., Blumsack, S., Crane, R., Kaufman, Z., McDill, M., Najjar, R., Ready, R., Wagener, T., Wardrop, D., 2009. Pennsylvania Climate Impact Assessment, Report to the Pennsylvania Department of Environmental Protection, Environment and Natural Resources Institute, The Pennsylvania State University, 350 pp.

Shortle, J., Abler, D., Blumsack, S., McDill, M., Najjar, R., Ready, R., Ross, A., Rydzik, M., Wagener, T., Wardrop, D., 2013. Pennsylvania Climate Impacts Assessment Update, Report to the Pennsylvania Department of Environmental Protection. Environment and Natural Resources Institute, The Pennsylvania State University, University Park, Pennsylvania, 155 pp.

B1.6. Commonwealth of Virginia

Climate Change Final Report: A Climate Change Action Plan (2008) - The report presents recommendations to meet the state greenhouse gas reduction target of 30 percent below the business-as-usual projection by 2025. It includes findings and recommendations for effects on the built environment and insurance, natural systems, human health; general strategies; and greenhouse gas reduction goals.
http://www.sealevelrisevirginia.net/docs/homepage/CCC_Final_Report-Final_12152008.pdf

In 2014 the Governor convened the Climate Change and Resiliency Update Commission to review, update, and prioritize the recommendations of the 2008 Climate Change Action Plan. Moreover, the updated report will work to identify sources of revenue to fund the implementation of these recommendations.

Recommendations to the Secure the Commonwealth Panel on the Issue of Sea Level Rise and Recurrent Flooding in Coastal Virginia (2014) – In addition to recurrent flooding issues and future flooding challenges, the report evaluates adaptation strategies for reducing the impact of flood events.
http://ccrm.vims.edu/SCPRecommendationsReport_Sept2014.pdf

Virginia's Strategy for Safeguarding Species of Greatest Conservation Need from the Effects of Climate Change (2009) - A climate change strategy for the Virginia's Wildlife Action Plan. This strategy outlines the importance of considering a changing climate in developing and implementing successful wildlife conservation practices, particularly for those species already experiencing stressors that threaten their long-term viability and persistence in Virginia.
http://www.vcnva.org/index.php/our-work/green-communities/wildlife

B1.7. Metropolitan Washington Council of Governments

In 2008, the Metropolitan Washington Council of Governments (COG) Board adopted the National Capital Region (NCR) Climate Change Report, which established regional greenhouse gas (GHG) reduction goals and identified over 100 actions, including adaptation measures. A key focus of COG's adaptation initiatives has been to build the capacity of regional leaders to understand and address the unavoidable impacts of climate change. In order to help facilitate COG's initiatives, COG applied for and received technical assistance through the U.S. Environmental Protection Agency's Smart Growth Implementation Assistance Program (EPA SGIA). EPA published Using Smart Growth Strategies to Create More Resilient Communities in the Washington, D.C., Region, a guidebook that provides an overview of general climate adaptation approaches that pulls most of its case studies from the NCR. In addition, COG staff has written a report that is a synopsis of lessons learned during the project called Summary of Potential Climate Change Impacts, Vulnerabilities, and Adaptation Strategies in the Metropolitan Washington Region. For more information and additional resources on MWCOG climate resilience and adaptation efforts, visit:
http://www.mwcog.org/environment/climate/resilience.asp

B2. Programs

B2.1. Environmental Protection Agency (EPA)

EPA National Center for Environmental Assessment (NCEA) Global Impacts and Adaptation Program within the Office of Research and Development (ORD)/National Center for Environmental Assessment (NCEA) - NCEA's Global Change Impacts and Adaptation program, as part of the ORD Air, Climate and Energy Program, assesses the potential vulnerability to climate change (and other global change stressors such as land-use change) of EPA's air, water, ecosystems, and human health protection efforts at the federal, regional, state, municipal, and tribal levels, as well as adaptation options to build resilience in the face of these vulnerabilities. The focus is on interdisciplinary syntheses across newly emerging scientific findings to identify potential impacts, and characterize and communicate the uncertainty in the science, to provide support for decision makers and managers.
http://www.epa.gov/global-adaptation/

EPA Office of Research and Development Science Inventory - Catalogue of ORD Research relevant to climate change.
http://cfpub.epa.gov/si/si_lab_search_results.cfm?subject=Air%20Research&showCriteria=0&searchAll=Climate%20and%20Adaptation&actType=Product&TIMSType=PUBLISHED+REPORT&sortBy=revisionDate

B2.2. National Oceanic and Atmospheric Administration (NOAA)

Regional Climate Trends and Scenarios for U.S. National Climate Assessment – NOAA has developed regional climate change descriptions that can be used to develop regional reports for the National Climate Assessment.
http://www.nesdis.noaa.gov/technical_reports/142_Climate_Scenarios.html

National Climatic Data Center (NCDC) – The Center provides access to climate and historical weather data and information that scientists need to understand climate change, e.g., paleoclimatology data which is data derived from natural sources such as ice cores.
http://www.ncdc.noaa.gov/

NOAA Technical Report NOS CO-OPS 073: Sea Level Rise and Nuisance Flood Frequency Changes around the United States – This report discusses results of measuring water levels around the United States. It shows exceedances above minor coastal flooding impacts have been increasing in time and frequency and regional patterns are changing and how those changes effect coastal communities.
http://tidesandcurrents.noaa.gov/publications/NOAA_Technical_Report_NOS_COOPS_073.pdf

NOAA National Ocean Service - NOAA scientists engaged in and support research that supports resiliency goals, e.g. a project to assess the influence of changes to the shoreline on Chesapeake Bay and Delmarva ecosystems.
http://www.coastalscience.noaa.gov/projects/region

NOAA National Data Buoy Center – NDBC designs, develops, operates, and maintains a network of data collecting buoys and coastal stations in U.S. waters, including in the Mid-Atlantic region.
http://www.ndbc.noaa.gov/

2013 Highlights of progress: Responses to Climate Change by the National Water Program – This is a joint EPA-NOAA report on incorporating climate change considerations into stormwater planning efforts.
http://water.epa.gov/scitech/climatechange/upload/Final-2013-NWP-Climate-Highlights-Report.pdf

NOAA Chesapeake Bay Office - NOAA has been working on the Chesapeake Atlantis Model, a full system ecosystem model designed for identification of the cumulative effects of system changes, like climate. The office also operates the Chesapeake Bay Interpretive Buoy System, a network of observing platforms in the Bay that provide real-time data on weather and water conditions.
http://chesapeakeBay.noaa.gov/ecosystem-modeling/chesapeake-atlantis-model
http://buoyBay.noaa.gov

NOAA Coastal Storms Program - The Coastal Storms Program is a nationwide effort to make communities safer by reducing the loss of life and negative impacts caused by coastal storms. This work is accomplished by bringing together organizations from all sectors. Each funded project lasts three to five years and brings additional manpower, focus, and funding to a specific region. In 2015, the program will be focusing on the Mid-Atlantic/Chesapeake Bay area and will have a coordinator working in the region. The results often include new data and predictive tools, new ways of keeping the public informed and enlightened, and new partnerships that strengthen existing resilience efforts.

NOAA Habitat Focus Area – Delmarva/Choptank River Complex – NOAA is concentrating its resources to improve and sustain the ecological health of the Delmarva/Choptank River Complex, located on Maryland's Eastern Shore. Climate change and sea level rise, combined with land subsidence, further threaten losses of nearshore marshes and coastal environments. This is an ideal location to see how habitat can be a part of increased coastal resilience. One key objective for the Choptank Habitat Focus area is to improve the decision-making and resilience of coastal communities by improving the delivery of NOAA's habitat and climate science.

NOAA Coastal Mapping - National Oceanic and Atmospheric Administration (NOAA's) National Geodetic Survey (NGS) is surveying coastal regions to provide the Nation with accurate, consistent, up-to-date national shoreline. The national shoreline provides the critical baseline data for demarcating America's

marine territorial limits, including its Exclusive Economic Zone, and for the geographic reference needed to manage coastal resources and many other uses.
http://www.ngs.noaa.gov/RSD/cmp.shtml

NOAA's Coastal Zone Management Program – A voluntary partnership between the federal government and U.S. coastal and Great Lakes states and territories authorized by the Coastal Zone Management Act (CZMA) of 1972 to address national coastal issues. The program is administered by NOAA. The act provides the basis for protecting, restoring, and responsibly developing our nation's diverse coastal communities and resources. To meet the goals of the CZMA, the national program takes a comprehensive approach to coastal resource management-balancing the often competing and occasionally conflicting demands of coastal resource use, economic development, and conservation. A wide range of issues are addressed through the program, including coastal development, water quality, public access, habitat protection, energy facility siting, ocean governance and planning, coastal hazards, and climate change.
http://coast.noaa.gov/czm/about/

NOAA National Center for Coastal Ocean Science (Cooperative Oxford Lab) - Oxford Lab helps local decision-makers understand the pressures on the Chesapeake Bay watershed, among them: climate change, urbanization, and pollution. Developing a model to forecast striped bass recruitment in the Chesapeake Bay: Unlike other models, this one accounts for weather and climate variability, as well as fishing pressure.

Chesapeake Bay Climate Sensitivity Assessment: using weather, water, biological, and climate data from a variety of sources and a state of the art biophysical model (the Chesapeake Bay Ecological Prediction System) to address the needs and goals of the Chesapeake Bay NERRS, the Chesapeake Bay Program, and NOAA's Chesapeake Bay Sentinel Site Cooperative.
http://coastalscience.noaa.gov/about/centers/col

National Estuarine Research Reserve System - NOAA and the Reserve System have identified climate change and its impacts as strategic priorities. Currently, the Reserve System is developing an initiative with key actions to address climate change adaptation, mitigation, and promotes resilience of estuary ecosystems. As one of three 2011-2016 priority areas for the Reserve System, reserves are supporting both the Climate Adaptation and Mitigation goal as well as the Resilient Coastal Communities and Economies goal in NOAA's Next Generation Strategic Plan.
http://www.nerrs.noaa.gov/BGDefault.aspx?ID=470http://www.vims.edu/cbnerr/

Chesapeake Bay NERRS Contribution to Climate Change (Stewardship) - National Estuarine Research Reserves will contribute to scientific understanding of climate change and monitor ecosystem changes. National Estuarine Research Reserves will assess climate change impacts on human and estuarine ecosystem communities, vulnerability of these communities, and their capacity for adaptation and mitigation. The National Estuarine Research Reserve System will provide educational opportunities and training related to effects of climate change on human and estuarine systems to increase public awareness and foster behavior change.
http://nerrs.noaa.gov/DOC/PDF/Background/NERRSClimateChange.pdf

NOAA's Coastal Zone Management Program – A voluntary partnership between the federal government and U.S. coastal and Great Lakes states and territories authorized by the Coastal Zone Management Act (CZMA) of 1972 to address national coastal issues. The program is administered by NOAA. The act provides the basis for protecting, restoring, and responsibly developing our nation's diverse coastal communities and resources. To meet the goals of the CZMA, the national program takes a comprehensive approach to coastal resource management-balancing the often competing and occasionally conflicting demands of coastal resource use, economic development, and conservation. A wide range of issues are addressed through the program, including coastal development, water quality, public access, habitat protection, energy facility siting, ocean governance and planning, coastal hazards, and climate change.
http://coast.noaa.gov/czm/about/

National Oceanic and Atmospheric Administration (NOAA) initiated a Sentinel Site Program (SSP) to encourage federal, state and local partners to cooperatively address impacts of climate change, with an initial emphasis placed on rising sea levels. In 2011, NOAA selected the Chesapeake Bay as one of five initial regional Sentinel Site Cooperatives to demonstrate the value of using a place-based approach to address issues of local, regional and national significance. The Cooperative provides integrated observations across a host of environmental monitoring programs within the Bay area. The goal of the cooperative is to provide information to Chesapeake Bay communities and managers who need to address challenges such as storm flooding, long term, local sea level rise, barrier island movement, degraded water quality, and wetland loss.
http://oceanservice.noaa.gov/sentinelsites/
http://www.vims.edu/cbnerr/ChesapeakeBay_SentinelSiteCooperative_IP_FY13FY17_FINAL.pdf

NOAA Coastal Blue Carbon
NOAA is working to advance awareness of coastal blue carbon, the carbon captured by living coastal and marine organisms and stored in coastal ecosystems. Salt marshes, mangroves, and seagrass beds absorb large quantities of the greenhouse gas carbon dioxide from the atmosphere and store it, thus decreasing the effects of global warming.
http://www.habitat.noaa.gov/noaabluecarbonefforts.html

B2.3. US Fish and Wildlife Service (FWS)

Fish and Wildlife Service Landscape Conservation Cooperatives (LCC)
Landscape Conservation Cooperatives are partnerships between federal agencies, states, tribes, non-governmental organizations, universities, and other entities to collaboratively define science needs and jointly address broad-scale conservation issues, such as climate change in a defined geographic area.

Climate Change Vulnerability Index for Northeast species - Collaborators in the Northeast Regional Vulnerability Assessment have developed a Climate Change Vulnerability Index (CCVI) to provide a rapid, scientifically defensible assessment of species' vulnerability to climate change.
http://northatlanticlcc.org/projects/completing-northeast-regional-vulnerability-assessment-incorporating-the-natureserve-climate-change-vulnerability-index/completing-northeast-regional-vulnerability-assessment-incorporating-the-natureserve-climate-change-vulnerability-index

North Atlantic Landscape Conservation Cooperative works with a number of potentially relevant data layers related to climate and resilience. The Chesapeake Conservancy and its partners use these layers to develop conservation projects that will protect the Susquehanna's ecological and cultural resources. A project entitled “Envisioning the Susquehanna: Incorporating Landscape Science into Large Landscape Conservation”, may be related and tied into work done by Mid-Atlantic Regional Ocean Agreement Climate Resiliency Workgroup. http://lccprojects.org/?action=showone&gid=5476

Support for Understanding Land Use and Climate Change in the Appalachian Landscape - This research will compile climate change vulnerability assessments and other relevant information on vulnerable species and habitats, discern the various methodologies and criteria used in these assessments, and use a team of exert peer reviewers to recommend the most efficient, effective, and appropriate methods for adoption by the Appalachian LCC for conservation and adaptation planning.
http://applcc.org/research/climate-change-vulnerability-group

B2.4. U.S. Geological Survey (USGS)

USGS/US DOI: Land Subsidence and Relative Sea-Level Rise in the Southern Chesapeake Bay Region (2013) – Land subsidence has been shown to be a good indicator of sea-level rise.
http://pubs.usgs.gov/circ/1392/pdf/circ1392.pdf

Research to examine North Atlantic Oscillation (NAO)-type climate variability, provided supporting evidence of climate variability in the Chesapeake Bay during the Holocene era. The large contrast between early and late Holocene regional climate conditions, multidecadal salinity and temperature variability is similar to those observed during the twentieth century.
https://fds.duke.edu/db/attachment/1774

Cronin, T. M., R. Thunell, G. S. Dwyer, C. Saenger, M. E. Mann, C. Vann, and R. R. Seal II (2005), Multiproxy evidence of Holocene climate variability from estuarine sediments, eastern North America, Paleoceanography, 20, PA4006, doi:10.1029/2005PA001145.

Late Holocene sea level variability and Atlantic Meridional Overturning Circulation: A report examined sea level and Atlantic Meridional Overturning Circulation variability along the eastern United States over the last 2000 years, using a sea level curve constructed from proxy sea surface temperature records from the Chesapeake Bay, and twentieth century sea level-sea surface temperature relations derived from tide gauges and instrumental sea surface temperatures.

Cronin, T. M., J. Farmer, R. E. Marzen, E. Thomas, and J. C. Varekamp (2014), Late Holocene sea level variability and Atlantic Meridional Overturning Circulation, Paleoceanography, 29, 765–777, doi:10.1002/2014PA002632.

Rapid sea level rise and ice sheet response to 8,200-year climate event: Report on the largest abrupt climate reversal of the Holocene which slowed Atlantic meridonal overturning circulation and cooled global climate.

Cronin, T. M., P. R. Vogt, D. A. Willard, R. Thunell, J. Halka, M. Berke, and J. Pohlman (2007), Rapid sea level rise and ice sheet response to 8,200-year climate event, Geophys. Res. Lett., 34, L20603, doi:10.1029/2007GL031318.

Invited Review: Rapid sea-level rise by Thomas M. Cronin. Global processes include changes in ocean mass (glacio-eustasy from ice melt), ocean volume (steric effects), viscoelastic land movements (glacioisostatic adjustment GIA), and changes in terrestrial water storage. The practical difficulties of assessing regional sea-level patterns at submillennial timescales is discussed using an example from the eastern United States.
http://www.sciencedirect.com/science/article/pii/S0277379112003344

B2.5. U.S. Army Corps of Engineers (Corps)

Climate Change Adaptation Plan (2014) - The Corps' Plan mainstreams climate change adaptation and increased preparedness and resiliency into its missions and operations including constructed and natural water-resources infrastructure. Four strategies, e.g., focus on priority areas and external collaboration, are employed to integrate and incorporate considerations of climate change and variability in all phases of project lifecycle.
http://www.usace.army.mil/Portals/2/docs/Sustainability/Performance_Plans/2014_USACE_Climate_Change_Adaptation_Plan.pdf

Engineering Technical Letter NO. 1100-2-1 (2014) Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation – Coastal climate change effects vary depending on project type, planning horizon, and other factors. Guidance is provided to promote understanding direct and indirect physical and ecological effects of projected future sea level change on USACE operations, missions, programs and projects.
http://www.publications.usace.army.mil/Portals/76/Publications/EngineerTechnicalLetters/ETL_1100-2-1.pdf

North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk (2015). USACE recently released the North Atlantic Coast Comprehensive Study (NACCS): Resilient Adaptation to Increasing Risk, a two-year study to address coastal storm and flood risk to vulnerable populations, property, ecosystems and infrastructure in the North Atlantic region of the United States affected by Hurricane Sandy in October 2012. The study, authorized by Congress in January 2013 in the Disaster Relief Appropriations Act of 2013 (Public Law 113-2), brought together experts from Federal, state, and local agencies, as well as non-governmental organizations and academia, to assess the flood risks facing coastal communities and ecosystems, and collaboratively develop a coastal storm and flood risk management framework to address increasing risks, which are driven in part by climate and sea level change. The full report and study products are available online at:
http://www.nad.usace.army.mil/CompStudy.aspx.

B2.6. US Department of Agriculture

USDA Climate Change Program Office - The office coordinates USDA's responses to climate change, focusing on implications of climate change on agriculture, forests, grazing lands, and rural communities.
http://www.usda.gov/oce/climate_change/

USDA Climate Change Hubs (Forest Service, NRCS, ARS) - The Bay falls into 2 hubs, the Northeastern and Southeastern Hub
http://www.nrs.fs.fed.us/niacs/

USDA Forest Service - The Service has various inter-related programs to help mitigate and adapt to global climate change.
http://www.fs.fed.us/climatechange/

USDA-ARS Crop Systems and Global Change Laboratory investigate plant response to climate change related environmental variables (temperature, CO_2).
http://www.ars.usda.gov/ba/csgcl

B2.7. Department of the Navy

In 2010 the Vice Chief of naval Operations prepared a Navy Climate Change Roadmap which provides a list of Navy actions to assess, predict, and adapt to global climate change from 2010-2014 and assigns responsibility for implementation.
http://greenfleet.dodlive.mil/files/2010/08/US-Navy-Climate-Change-Roadmap-21-05-10.pdf

B2.8. Chesapeake Bay Program (CBP)

CBP Climate Resiliency Workgroup – The Work Group compiled a list of current climate change research and resiliency efforts, gaps, and resources (2014).
http://www.chesapeakeBay.net/channel_files/22260/current_efforts__resources_-_december_2015.pdf

B2.9. National Aeronautics and Space Administration (NASA)

Adapting to a Changing Climate – A report for Federal Agencies in the Washington, DC Metro Area
http://www.mwcog.org/environment/climate/adaptation/building/NASA_DCmetroClimCg%20FINAL%20NOV%202012.pdf

B3. Consortiums

B3.1. Climate Communication Consortium of Maryland (Public Engagement)

The Consortium's mission is to broaden and deepen public engagement in climate change and energy issues across all of Maryland's communities and sectors by encouraging and facilitating collaboration in the communication efforts of government agencies and elected officials, businesses, non-profit organizations, advocates and citizens.
http://www.climatemaryland.org/monthly-social-media-graphics/2014-september-smg/rising-waters-7/

B3.2. Creating Green Infrastructure Resiliency in Greater Baltimore and Annapolis Watersheds

(Planning)– 2014-2016 project led by The Conservation Fund and American Planning Association on behalf of the Greater Baltimore Wilderness Coalition (local governments, DNR, regional federal agencies

and NGOs) to identify green infrastructure network and key opportunities for increasing regional resiliency to impacts of coastal storms and climate change.
http://www.conservationfund.org/what-we-do/strategic-conservation-planning/our-projects

B3.3. The Conservation Fund

Increasing Salt Marsh Acreage and Resiliency for Blackwater National Wildlife Refuge (Maryland) - Funded by the National Fish and Wildlife Foundation, The Conservation Fund in cooperation with USFWS, Audubon MD-DC, USGS and USACE, is leading a set of projects to increase the resiliency of the Atlantic Coast's largest salt marsh ecosystem centered on the Blackwater NWR and Fishing Bay Wildlife Management Area to the effects of sea level rise and other climate factors. Project mechanisms include 1) thin-layer marsh elevation, 2) tidal exchange system modeling, 3) invasive plant mapping and control in marsh migration corridor, and 4) invasive animal eradication in regional watersheds.
http://www.conservationfund.org/projects/blackwater-national-wildlife-refuge

Blackwater 2100: A Strategy for Salt Marsh Persistence in an Era of Climate Change - Working with Audubon MD-DC and US Fish and Wildlife, The Conservation Fund developed a comprehensive set of strategies for ensuring the continued presence of healthy, productive high salt marsh in Dorchester County (MD) world-class Blackwater NWR. Integrated strategies include slowing rates of loss of existing salt marsh, improving in the transition of upland fields and forests into high quality salt marsh, and protecting targeted marsh migration "corridors" from disruptive development and uses. MD DNR and Chesapeake Conservancy assisted in assessment of sea level rise projections with other land use characteristics in identifying high-promise migration corridors. Summary of strategy and underlying models and research is available at:
http://www.conservationfund.org/images/projects/files/Blackwater-2100-report_email.pdf

B4. Projects

Virginia's Climate Modeling and Species Vulnerability Assessment: How Climate Data Can Inform Management and Conservation - Recognizing the need to use more regionally explicit, or "downscaled," set of climate models Virginia's vulnerability assessment can provide more detailed and locally relevant climate projections to better inform the species threat assessments. This report includes a summary of the findings from the modeling effort and assessment as well as highlights management concerns and implications based on the assessment results. The information developed through this project and included in this document will help inform the update of Virginia's Wildlife Action Plan.
http://www.bewildvirginia.org/climate-change/virginias-climate-vulnerability-assessment.pdf

Coastal SEES: Chesapeake Bay Sustainability: Implications Of Changing Climate And Shifting Management Objectives - A National Science Foundation funded collaborative project lead by VIMS that aims to develop an advanced modeling framework that integrates the physical, biogeochemical, and human components needed to simulate and select climate change adaptation strategies that will support a sustainable system. The National Science Foundation - Science, Engineering and Education for Sustainability (SEES) Program provides a funding mechanism to advance science, engineering, and education to inform the societal actions needed for environmental and economic sustainability and sustainable human well-being.
http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504816

Climate Change Effects on Stream and River Biological Indicators: A Preliminary Analysis - A preliminary assessment that describes how biological indicators are likely to respond to climate change, how well current sampling schemes may detect climate-driven changes, and how likely it is that these sampling schemes will continue to detect impairment.
http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=190304&simpleSearch=1&searchAll=climate

The Potential Impacts of Climate Change on the Mid-Atlantic Coastal Region - Paper assesses the potential impacts of climate change on the Mid-Atlantic Coastal (MAC) region of the United States. In order of increasing uncertainty, it is projected that sea level, temperature and streamflow will increase in the MAC region in response to higher levels of atmospheric CO2
http://www.cara.psu.edu/about/publications/Najjar_et_al_2000.pdf

Hampton Roads Intergovernmental Pilot Project - The Hampton Roads Pilot Project The Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Planning Pilot Project is a two-year project that seeks to develop adaptive planning for sea level rise by combining the efforts of federal, state and local agencies with private industries and researchers.
http://www.centerforsealevelrise.org/

Using Robust Decision Making to Manage Climate and Other Uncertainties in EPA's National Water Program: Framework for Analysis and Water Quality Case Studies - Robust decision making (RDM) is an approach that shifts focus from uncertainty quantification to uncertainty management. This method examines management strategies across a full range of climate changes and other key uncertainties to identify those that are effective across the full range of uncertainties. EPA applied RDM in two pilot case studies—Patuxent River, MD and North Farm Creek, Ill.

EPA Climate Change and Urban Stormwater Guide - EPA is developing a climate change design guide for stormwater management practices to inform on how climate change will affect stormwater control performance of gray and green infrastructure. The guide will provide information on factors affecting urban stormwater controls due to climatic changes in order to support adaptation in the stormwater community.

Implications of Climate Change for State Bioassessment Programs and Approaches to Account for Effects - The study investigates the potential to identify biological response signals to climate change within existing bioassessment data sets; analyzes how biological responses can be categorized and interpreted; and assesses how they may influence decision-making processes. The analyses suggest that several biological indicators may be used to detect climate change effects and such indicators can be used by state bioassessment programs to document changes at high-quality reference sites.
http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=239585

Rockefeller 100 Resilient Cities - The city of Norfolk Virginia was selected in 2013 to participate in the Rockefeller Foundation's 100 Resilient Cities (100RC) Challenge for the purpose of building the practice of urban resilience in the face of climate change.
http://www.100resilientcities.org/cities/entry/norfolks-resilience-challenge#/-_/

SAGE Initiative (Systems Approach to Geomorphic Engineering) - Collaborative effort between the Army Corps of Engineers, the National Oceanic and Atmospheric Administration, Federal Emergency Management Agency, the Nature Conservancy, the Conservation Fund, and the Virginia Institute for Marine Sciences, SAGE is an initiative that brings together technical experts and field practitioners from the government, academic, non-profit and private sectors to advance a comprehensive view of shoreline change that seeks to reduce impacts to coastal communities from the consequences of land cover and climate change through prevention, mitigation and/or adaptation.
http://www.ccrm.vims.edu/sage/info/mission.html
http://www.iwr.usace.army.mil/Missions/Coasts/ProgramsandInitiatives.aspx

Development of strategies to improve conservation of Virginia headwater wetland ecosystems in the face of climate change - Researchers at the Virginia Institute of Marine Science received a 3-year grant (2014-2017) from the Environmental Protection Agency to identify the streams and wetlands most vulnerable to sea-level rise, and to develop tools to help local governments and citizens conserve these important ecosystems. The project team will analyze climate-induced changes in downstream marshes, evaluate the connections between these marshes and the headwater wetlands that feed them, refine the protocol used to identify the headwater wetlands at greatest risk, and identify management options for sustaining headwater acreage and function. These outcomes will inform strategies for long-term protection of headwater resources in Virginia.

Framework and Inventory of Relative Wetland Vulnerabilities to Inform EPA Office of Water Programs - EPA Office of Research and Development project to develop a framework and inventory of relative wetland vulnerabilities to climate change at multiple scales based on integration of information on vulnerability assessment methods and wetlands classification systems.

Case Study Application of the Basins Climate Assessment Tool, And Development of a Framework for Assessing Climate Change Impacts on Water Quality in the Chesapeake Bay Watershed - The EPA Global Change Research Program (GCRP) recently supported the development of a Climate Assessment Tool (CAT) for the Office of Water's BASINS water quality modeling system. The BASINS CAT provides users with the ability to modify historical climate, generate synthetic weather time series, and conduct systematic sensitivity analyses of specific hydrologic and water quality end-points to changes in climate using the BASINS models (e.g. HSPF). This project will demonstrate the use and capabilities of the BASINS CAT, as well as support on-going efforts to achieve Bay-wide integrated climate and land use change scenarios for 2030 and, ultimately, 2100.
http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=158295&simpleSearch=1&searchAll=climate

National Wildlife Federation Vulnerability Assessment for the Middle Patuxent Subwatershed - NWF and NOAA partnered to produce a report examining the anticipated climate change impacts as they relate to conservation and restoration actions that benefit vulnerable species and habitats in the watershed.

A Framework for Assessing Climate Change Impacts on Water and Watershed Systems - Article presents a framework for assessing climate change impacts on water and watershed systems to support management decision-making. The framework addresses three issues complicating assessments of climate change impacts—linkages across spatial scales, linkages across temporal scales, and linkages across scientific and management disciplines.

VA Sea Grant Adaptation Efforts – Wetlands Watch awarded a grant to help a Hampton Roads neighborhood design a sea level rise/flooding adaptation approach. This project also incorporates ecosystem services while protecting against flooding.

Maryland Coastal Resiliency Assessment, MDNR and TNC - Maryland DNR's Chesapeake and Coastal Service, in collaboration with The Nature Conservancy, will undertake a year-long project to establish priorities for natural infrastructure solutions within tidal regions of Maryland's coastal zone. The goal of this project is to enhance coastal community resiliency by evaluating risk reduction benefits of existing natural infrastructure and providing Maryland with the means of integrating risk-reduction values into statewide conservation and restoration targeting efforts.

B5. Non-Governmental Organizations

Wetlands Watch - Wetlands Watch is a non-profit environmental group dedicated to protecting and conserving Virginia's wetlands using grass roots education and activism to influence local government land use and regulatory decisions. They are currently collaborating with state and local organizations to develop innovative land-use models that can be used by Virginia tidewater communities in coming years to protect our wetland resources as the sea rises. Wetlands Watch is conducting education and advocacy programs at the local level to educate and motivate citizens to press our state and local governments to take sea level rise into account in wetlands regulation and conservation.
http://www.wetlandswatch.org/WetlandScience/SeaLevelRise.aspx

B6. Academic

B6.1. Old Dominion University (ODU)

The Mitigation and Adaptation Research Institute (MARI) at Old Dominion University engages in research that produces the practice-relevant knowledge needed to cope with the impacts of climate change and sea level rise on the coastal zone and the urban coast in particular. In doing so, MARI responds to the knowledge needs of a wide range of community stakeholders, including government, military, private sector, and citizens.
http://www.mari.odu.edu/

The mission of the Pilot Project is to develop a regional "whole of government" and "whole of community" approach to sea level rise preparedness and resilience planning in Hampton Roads that also can be used as a template for other regions.
http://www.centerforsealevelrise.org/

B6.2. Pennsylvania State University (PSU)

Founded within the College of Earth and Mineral Sciences in 1986, the Earth System Science Center (ESSC) maintains a mission to describe, model, and understand the Earth's climate system. ESSC is one of seven centers supported by the Earth & Environmental Systems Institute.
http://www.essc.psu.edu/

Penn State is establishing a new Center: The Center for Solutions to Weather and Climate Risk (CSWCR). CSWCR's vision is to create the knowledge, training and solutions to enable the optimal outcome for every decision where weather and climate matter. Achieving this vision will extract the maximum value out of every forecast, best serve the public and private sectors, and highlight Penn State's skill and relevance in creating significant additional value to the Weather and Climate Enterprise. CSWCR's Mission is to leverage and integrate the capabilities of the University, in particular those found in Meteorology, Engineering, Statistics, e-Education and Communications, along with external partners, to advance the science of exploiting environmental opportunities and understanding environmental impacts to manage risk.
http://solutions2wxrisk.psu.edu/about-us/

The main goals of the Center for Climate Risk Management (CLIMA) are:

- To develop a new Penn State integrated assessment model of climate change that improves the representation of potential climate threshold responses and the uncertainty about ethical frameworks.
- To use this new integrated assessment model to analyze two questions.
    1. How does the uncertainty about potential climate threshold responses and future ethical value judgments affect the choice of efficient climate risk management strategies?
    2. How can we improve probabilistic climate change projections to better inform decision-making about climate change mitigation and adaptation strategies?
- To promote interaction among faculty, students, and staff in the growing interdisciplinary field of climate risk management (e.g., through seminars series and the support of the integrated assessment model).
  http://www.clima.psu.edu/

B6.3. University of Maryland (UMD)

There are efforts dedicated to widening the understanding and mitigating the effects of climate change that are being undertaken by UMCES (University of Maryland Center for Environmental Science) and UMERC (University of Maryland Energy Research Center).
http://www.umces.edu/research-discovery/climate-change
http://www.umerc.umd.edu/research/environment

The Joint Global Change Research Institute (JGCRI) houses an interdisciplinary team dedicated to understanding the problems of global climate change and their potential solutions. Joint Institute staff bring decades of experience and expertise to bear in science, technology, economics, and policy. One of the strengths of the Joint Institute is a network of domestic and international collaborators that encourages the development of global and equitable solutions to the climate change problem.
http://www.globalchange.umd.edu

Climate Information Responding to User Needs (CIRUN) seeks to form a partnership among climate scientists, experts from disciplines such as agriculture, engineering, public health, and risk management, companies which deliver specialized information, and decision makers in the private and public sectors.

CIRUN was created with the vision of developing and piloting effective ways to provide such actionable information: the environmental analogue of the “translational research” or “bench to the bedside” approach in medical research. It will focus on building links among the communities above through the following activities:

- Pilot projects to deliver actionable information.
- A program of workshops.
- A public lecture series: Living with a Changing Planet.
- Support for interdisciplinary proposals to federal agencies relevant to environmental change where connections to decision makers are important.
- An active website.
- Development of a database of potential collaborators in all the components of the information supply chain.
  http://www.climateneeds.umd.edu/

B6.4. VIMS Coastal Climate Change Research (IC^{3}R)

The Virginia Institute of Marine Science (VIMS) is committed to conducting state-of-the-art scientific research on issues related to climate change, particularly in the world's coastal zones, where half of humanity lives and where climate-change impacts are expected to be felt most acutely. VIMS' Initiative for Coastal Climate Change Research (IC^{3}R): encourages further collaboration among the many research programs at VIMS that are engaged in issues of climate and global change, serves as a central source of knowledge concerning the effects of climate change on our environment, society, and economy, and provides recommendations concerning the most effective responses to sea-level rise and other climate-change impacts.
http://www.vims.edu/research/units/programs/icccr/index.php

Virginia Coastal Policy Clinic, W&M Law School/VIMS
http://law.wm.edu/academics/programs/jd/electives/clinics/vacoastal/index.php

B6.5. Virginia Polytechnic Institute and State University (Virginia Tech)

Scientists at Virginia Tech were awarded $2 Million to study climate change effects on Chesapeake Bay.
http://www.vtnews.vt.edu/articles/2014/07/072214-cals-nsfwater.html

B6.6. University of Delaware

Participates in the MADE CLEAR Initiative: http://www.madeclear.org/. Through the University of Delaware Cooperative Extension research on climate variability and change is being conducted with partners such as: USDA, USGS, and Delaware Environmental Monitoring & Analysis Center (http://demac.udel.edu/data/satellite-imagery) which maintains real-time feeds of satellite imagery for the Delaware region.
http://extension.udel.edu/ag/climate-variability-and-change/