Monitoring and Assessing Impacts of Changes in Weather Patterns and Extreme Events on BMP Siting and Design

STAC Workshop Report
September 7-8, 2017
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About the Scientific and Technical Advisory Committee

The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program (CBP) on measures to restore and protect the Chesapeake Bay. Since its creation in December 1984, STAC has worked to enhance scientific communication and outreach throughout the Chesapeake Bay Watershed and beyond. STAC provides scientific and technical advice in various ways, including (1) technical reports and papers, (2) discussion groups, (3) assistance in organizing merit reviews of CBP programs and projects, (4) technical workshops, and (5) interaction between STAC members and the CBP. Through professional and academic contacts and organizational networks of its members, STAC ensures close cooperation among and between the various research institutions and management agencies represented in the Watershed. For additional information about STAC, please visit the STAC website at www.chesapeake.org/stac.

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Cover graphic: Coastal plain outfall: a component of a larger "treatment train" designed to accommodate for increased flow. Photo credit: Will Parson (Chesapeake Bay Program). Location: US Naval Academy, 2017

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Executive Summary

On September 7-8, 2017, the Chesapeake Bay Program's (CBP) Scientific and Technical Advisory Committee (STAC) hosted the workshop *Monitoring and Assessing Impacts of Changes in Weather Patterns and Extreme Events on BMP Siting and Design* for the purposes of: 1) assessing the state of the knowledge on the effect of anticipated changes in weather patterns and extreme events on best management practices (BMPs); 2) compiling siting and design guidelines, tools and resources to increase BMP resilience; and, 3) identifying gaps and priority needs to better inform and improve BMP development and implementation. General conclusions for each workshop objective are outlined below.

State of the Knowledge

Considering impacts associated with climate change and extreme weather during the planning, siting, design, and implementation of a water quality-related BMP can reduce vulnerability to structural failure over the practice's design life and ensure that Total Maximum Daily Load (TMDL) requirements are achieved. However, while there is a generally sound understanding of possible hydrologic and water quality changes related to changes in precipitation, temperature, runoff, sea level rise (SLR) and extreme events, further work is needed to advance the state of knowledge of the totality of these impacts on BMP structural integrity and functionality in nutrient and sediment removal.

General Best Practices and Siting and Design Principles

Due to uncertainty in future environmental conditions and the performance of BMPs under changing conditions, the primary goal in siting and designing BMPs for the future is resilience. Six key characteristics of resilient BMPs to consider in siting and design were identified at the workshop:

> *Sensitivity*. Is the BMP and its performance sensitive to the range of potential changes in climate, weather or resultant hydrologic and water quality changes? Sensitivity refers generally to system response to a change in a driver (e.g., temperature, precipitation, sea level). Future changes, such as climate and land use, will affect both BMP performance and the flows and loads that BMPs must address. For example, if precipitation increases, a BMP that may not be sized appropriately could be washed out in an extreme event, and/or biological components could be compromised.
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> *Adaptability.* Can the practice be modified to be resilient to potential changes as they emerge? BMP performance can depend on precipitation, soil moisture, temperature, and other factors. The degree to which a BMP can be modified to address changing environmental conditions, or is locked into a fixed design with respect to current conditions over a long period of time, is a measure of its adaptability. To build in flexibility and adaptability, there is a need to allow for adjustments in BMP

implementation in order to consider a wider range of potential uncertainties and a richer set of response options (e.g., load allocations, BMP selections, BMP redesign). Existing development of the jurisdictions' Watershed Implementation Plans (WIPs), implementation and reporting procedures, as well as monitoring results and local feedback on performance, could be used to guide this process.

Timeliness. How quickly can BMPs be altered or implemented to adapt to changes? BMPs with short maturation periods (e.g., riparian buffers) or lead times for implementing modifications to address changing environmental conditions will be more resilient.

Cost-effectiveness. Will the cost to modify BMPs to prevent or remove projected increases in pollutant loads be feasible and reasonable? Large capital costs should be avoided that may not be appropriate to the actual future conditions. An analysis of the benefit to cost ratio of designing to a higher standard should be assessed in the context of an excepted level of risk tolerance, over the intended design-life of a proposed practice.

Robustness. Will BMPs perform well over a range of projected future environmental conditions? Robustness refers to that ability to meet a stated goal, e.g., to remain above/below a defined threshold. "Climate-smart" principles can be used to site and design BMPs to reduce future impact of sea level rise, coastal storms, increased temperature, and extreme events.

Auxiliary or Co-Benefits. In addition to reducing pollutant loads to the Bay, will BMPs provide other co-benefits (e.g., recreational, heat amelioration, flood control)? On the flipside, maladaptive practices should be examined and avoided.

Tools, Resources and Implementation Guidance

Data, tools and resources that can assist watershed managers, planners, and restoration practitioners with integrating climate considerations into siting and design practices are increasing in availability (see Appendix E). Workshop presenters provided an overview of general best practices and in a few cases siting and design principles, however, specificity and standardization of practices and procedures for factoring impacts associated with extreme weather and climate into BMP siting and design is still acknowledged as an emerging body of work.

Areas for Future Focus

The Chesapeake Bay watershed is experiencing stronger storms, an increase in heavy precipitation events, increasing air and water temperatures, and a rise in sea level. These trends, which vary both spatially and temporally throughout the watershed, are altering the natural ecosystems and the human communities of the Chesapeake Bay and are likely to require changes in programs, projects, and practices used to successfully achieve restoration goals. Workshop participants identified seven areas for future focus:

1. **Develop design guidance to increase BMP resilience.** There is a clear need for the standard operating procedures and adoption of practices for factoring impacts associated with extreme weather and climate into BMP siting and design. Updating design storms (e.g., Rainfall Intensity Duration Frequency curves) based on projected future conditions would be a key piece of design guidance for the urban sector.
2. **Improve simulation-modeling capabilities.** Most rainfall-runoff simulation modeling applications that estimate hydrologic flows and pollutant loadings are not yet able to address a wide range of uncertainty related to climate change, extreme weather patterns, or other future changes (e.g., population, land use).
3. **Conduct targeted research to enable quantification of impacts on structural integrity as well as nutrient and sediment removal effectiveness.** While there is a generally sound understanding of possible hydrologic and water quality changes related to the direct and indirect effects of changes in precipitation, temperature, runoff, and sea level rise, further work is necessary to advance our understanding of the cumulative impacts on BMP structural integrity and functionality in nutrient and sediment removal.
4. **Develop monitoring protocols and parameters.** To learn more about the impact of climate change and extreme events on the structural integrity and effectiveness of BMPs, workshop participants identified the need to:
    - Communicate the importance of establishing baseline conditions and conducting routine site assessments;
    - Develop post-storm monitoring guidelines and data collection parameters (e.g., nutrient, sediment, toxics, thermal and benthic impacts, stream and watershed effects, and vegetation longevity);
    - Establish methods to collect accurate localized climatological data (i.e., rain gauge) to support trend and impact assessments; and
    - Include climate and extreme event impact data collection parameters into existing CBP BMP verification protocols.
5. **Advance programmatic practices, legal, and regulatory tools.** Looking beyond the Midpoint Assessment and Phase III WIPs, a roadmap for moving from science to policy to regulation should be developed. For urban BMPs, siting and design principles need to be integrated into regulations and standards. For agricultural and forestry sectors, implementation is more voluntary as climate change considerations are addressed through resource management practices. For all sectors, however, workshop participants recommended the use of programmatic or regulatory incentives to promote implementation of projects beyond minimum standards.

6. **<u>Improve communication and outreach to end-users</u>.** Communication efforts should focus on increasing understanding of planning for risk, uncertainty and likelihood of impacts as well as support the need for sharing and disseminating climate data and future projections. Exploring the use of visualization tools for comparison of historical, current conditions, and future change was recommended. Workshop participants recognized that there are numerous information end-users and recommended that communication products should be targeted to individual audiences.
7. **<u>Identify, prioritize, and fill data, research, and information needs</u>.** Workshop speakers and participants expressed a need for improved methods to evaluate siting and design considerations within the watershed context, in addition to site-level assessment needs. Additionally, there was a strong message that better tools are needed to improve understanding of cost-effectiveness (and co-benefits) of upgraded BMP design, and within that context, an assessment of the intended design life for the suite (267 Chesapeake Bay Program approved BMPs. Both of these would enable the Partnership to gain a better understanding of the cost-benefit/trade-offs of considering impacts beyond 2025. The development of a research agenda, prioritizing key information needs, potential funding sources, and collaborators, is a critical first step.

Looking beyond this STAC workshop, the CBP should monitor emerging climate science and advance the application of this information to CBP assessments and decision-making processes. In this regard, the seven areas for future focus outlined above serve as a guide for suggested near-term efforts.

Introduction

The Chesapeake Bay watershed has experienced changes in climate over the last century. On the whole, the watershed is experiencing stronger storms, an increase in heavy precipitation events, increasing air and water temperatures, and a rise in sea level. These trends, which vary both spatially and temporally throughout the watershed, are altering both the natural ecosystems and the human communities of the Chesapeake Bay, and will require changes in programs, projects and practices used to successfully achieve and maintain restoration and protection goals over time.

Examining both impacts and solutions related to climate and extreme weather on BMP performance is a very timely issue for the Chesapeake Bay Program (CBP).[1] The Partnership is in the midst of a multi-year modeling and planning effort to assess how to incorporate climate change considerations into the Chesapeake Bay jurisdictions' Phase III Watershed Implementation Plans (WIPs). To inform this process, the CBP Climate Resiliency Workgroup (CRWG) was tasked with informing the climate change projections and scenarios for input into the watershed and estuarine modeling efforts; exploring policy options for addressing climate change in the Phase III WIPs; and, developing policy implementation guidance for the Partnership's consideration.

In December 2017, the Partnership approved a suite of "Climate Resiliency Guiding Principles" for Phase III Watershed Implementation Plans and is currently considering several programmatic policy options (Figure 1). One of the policy options[2] under consideration is a qualitative approach, entitled "Optimize Phase III WIP Development and Adaptively Manage BMP Implementation." If approved by the Partnership[3], this policy would require jurisdictions to consider and prioritize BMPs that are more resilient to future climate impacts over the intended design life of the proposed practices, during the development of Phase III WIPs. The proposed policy language also specifies that within an applicable practical timeframe, the Partnership will consider new information on the performance of BMPs, including the contribution of seasonal, inter-annual climate variability, and weather extremes. Jurisdictions would then assess this information and adjust plans through the two-year milestone process to implement their Phase III WIPs to better mitigate anticipated increases in nitrogen, phosphorus, or sediment due to climate change. Additionally, jurisdictions would be tasked with providing a narrative consistent with

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[1] In addition to this workshop, STAC also hosted a more generally focused examination of BMP Performance Uncertainty in Chesapeake Bay Program implementation efforts in November 2017. See Stephenson, K., C. Hershner, B. Benham, Z. Easton, J. Hanson, S. Julius, E. Hinrichs. (2018). *Consideration of BMP Performance Uncertainty in Chesapeake Bay Program Implementation*. STAC.

[2] Additional policy options and revisions to this proposed language has been considered by the CBP Partnership during the Midpoint Assessment decision-making process. The proposed policy option as outlined in this workshop report is the language under consideration at the time of the workshop.

[3] Final climate change policy provisions for Phase III Watershed Implementation Plans will be taken under consideration by the Chesapeake Bay Program Partnerships' Principle Staff Committee on March 2, 2018.

the Guiding Principles that describes their programmatic commitments to address climate change in their Phase III WIPs.

WIP Development

1. *Capitalize on "co-benefits"* – select BMPs to maximize climate resiliency, flood control, carbon sequestration or socio-economic benefits.
2. *Account for existing stressors* – consider existing stressors (e.g., land-use change) in combination with climate impacts when establishing reduction targets.
3. *Align with existing plans and strategies* – align WIPs with existing greenhouse gas and climate adaptation strategies, hazard mitigation plans or floodplain mgmt. programs.
4. *Manage for risk and plan for uncertainty* – employ iterative risk management to achieve and maintain water quality standards in changing conditions.
5. *Engage local agencies and leaders* – work cooperatively with agencies, elected officials and staff to facilitate the development of WIPs to account for localized impacts.

WIP Implementation

1. *Reduce vulnerability* - site and design BMPs to reduce future impact of sea level rise, coastal storms, increased temperature, and extreme precipitation.
2. *Build in flexibility and adaptability* - allow for adjustments in BMP implementation in order to consider a wider range of potential uncertainties and a richer set of response options.
3. *Adaptively manage* - Allow for changes in BMP selection or WIP implementation as new climate and ecosystem science, research, or data becomes available and our understanding of the impact of climatic and weather conditions on the performance of watershed restoration practices improves.

Figure 1. Climate Resiliency Guiding Principles for Phase III WIPs

To support the Partnership's evaluation of these proposed policy provisions, including implementation considerations, the CBP's Scientific and Technical Advisory Committee (STAC) hosted this workshop for the purposes of:

1) Assessing the state of the knowledge on how anticipated changes in weather patterns and extreme events may affect the structural integrity of a subset of urban stormwater, agriculture, and stream restoration BMPs over time;
2) Compiling siting and design principles and resources (e.g., guidance, data and tools) to increase BMP resilience to future impact of sea level rise, coastal storms, increased temperature and extreme events; and,
3) Identifying remaining gaps and highest priority needs (i.e., research, monitoring measures, programmatic efforts, guidance, data and tools) in order to better inform and improve BMP development and implementation.

The body of this report documents the findings of the workshop, designed around answering the questions posed above. Links to workshop presentations are provided in Appendix C. All presentations and other associated materials can be found at http://www.chesapeake.org/stac/workshop.php?activity_id=280.

State of the Knowledge: Climate Science and Influence on BMPs

To assess the state of the knowledge of how anticipated changes in weather patterns and extreme events may affect the structural integrity of a subset of urban stormwater, agriculture, and stream restoration BMPs over time, one must start with a basic understanding of observed and expected changes in climate and extreme weather at the watershed scale. To set the stage, Ray Najjar (Penn State) presented an overview of climate change impacts on the Chesapeake Bay watershed. Najjar provided a thorough synopsis of the findings of the Northeast chapter of the 2014 National Climate Assessment (Horton et al. 2014), with results showing that the northeast US has warmed by 2 degrees F and has gotten wetter – by about 10% over last 100 years. Natural variability has played a large role in the precipitation changes the region has experienced over last 30 years. This trend is projected to continue into the future: the Chesapeake Bay region will have a warmer, wetter climate with more extremes. Future precipitation increases are projected for spring and winter, with summers becoming slightly drier. This may have an impact on the timing of snowmelt, resulting streamflow and the timing of seasonal runoff. With shifts in rainfall seasonality and increases in rainfall intensity, resulting changes in the amount and timing of runoff will be a factor to consider in BMP planning and implementation. For example, systems designed for summer rainfall may not be as effective in winter or spring when precipitation is projected to increase.

Runoff and consequent nonpoint water quality problems are currently addressed by specifying the type and number of BMPs placed on the landscape to reduce pollutant loads. BMPs make urban and agricultural landscapes sustainable by controlling flow and pollutant loads, and allowing water resources to regenerate and approximate natural conditions. Traditionally, the choice of BMPs selected for each jurisdictions' WIPs are based on historic conditions, observed BMP performance, and established BMP efficiency standards. Under a changing climate, however, it is important to understand how BMP performance may be effected to make more resilient decisions.

Different types of BMPs are used in different systems (agriculture, urban, forestry) for a variety of purposes (e.g., flow, sediment, nutrients, etc.). BMPs function through a variety of mechanisms, including physical retention, filtration, and biological uptake. These mechanisms determine their sensitivity to different climate drivers (i.e., rainfall volume and intensity, temperature, soil moisture, etc.). For many engineered BMPs, if precipitation statistical properties (e.g., changes in Intensity-Duration-Frequency (IDF) curves) change, then current sizing guides may not achieve desired result. "Green" BMPs (e.g., bioswales, green roofs, rain gardens) rely on biological processes that may respond to climate (heat, moisture) in complex yet poorly understood ways.

For agricultural BMPs in particular, limited detailed studies exist on the effect of climate change on performance (Liu et al. 2016). In general, studies are mostly conceptual. For example, Nearing et al. (2005), O'Neal et al. (2005), and Garbrecht et al. (2014) focused on increases in rainfall amount, intensity, and stress on agricultural BMPs. Other studies (e.g., Porter et al. 1991, Nearing et al. 2004, O'Neal et al. 2005, Nearing et al. 2005, Soil and Water Conservation Society 2006, Garbrecht et al. 2014, and Mellander et al. 2015) focus on increased pest risk and soil status.

Studies related to urban BMPs are also limited, with those available being mostly focused on increased precipitation volume and intensity. Precipitation extremes may result in direct effects (inadequate sizing of structures), as well as indirect effects (e.g., control structures being washed out or bio components inundated). Few studies look at how combined physical and biological changes effect BMP performance. However, there are several studies (Gill et al. 2007, for example) examining the co-benefits (e.g., heat island mitigation) of urban BMPs. Additionally, while the organized analysis of BMP response to climate change is limited, there is information on how different BMPs work (See Dell, Kaye in Appendix C) and how they are sensitive to weather (i.e., temperature, moisture, etc.).

Other work underway includes the development of a Climate Change and Urban Stormwater Design Guide by USEPA (Job, Appendix C). The guide will provide an analysis of the performance of green and gray stormwater controls under future climate and outline insights into how to adapt designs for future conditions. The guide will address: (1) How climate change might affect performance of conventional stormwater infrastructure and green infrastructure (GI) compared to current conditions; (2) How conventional and GI designs can be adapted so that a site under future climate conditions provides the same performance as the site under current conditions; and (3) What the results suggest regarding the adaptation of green and grey infrastructure. Preliminary results, presented by Scott Job (Tetra Tech), are informative; approaches that used a mixture of GI and gray BMPs have the lowest combined cost (i.e., current cost + cost to adapt to climate change) when compared to approaches that use only conventional BMPs or GI BMPs. However, when the future climate is projected to have a large increase in storm event intensity and volume, conventional approaches tended to have a lower combined cost.

In conclusion, while there is a fairly sound understanding of possible hydrologic and water quality changes related to the direct effects of changes in precipitation, runoff, and load, as well as the indirect effects through impacts on plant growth and soil processes in "green" practices, further work needs to be done to advance our understanding of the totality of these impacts on BMP structural integrity and functionality in nutrient and sediment removal.

General Best Practices and Siting/Design Principles

Consideration of impacts associated with climate change and extreme weather during the planning, siting, design, and implementation of a water quality-related BMP can increase effectiveness, decrease maintenance costs, and help to ensure the U.S. Environmental Protection Agency's (EPA) Total Maximum Daily Load (TMDL) requirements are met into the future. In addition to water quality benefits, hazard risk reduction (e.g., riverine and coastal flood, heat and drought) may be enhanced with several suites of BMPs – including forest buffers, urban tree canopy, stream restoration, shore erosion control, and wetland restoration. Addressing these risks in conjunction with ongoing restoration efforts will prepare communities for greater variability and may result in cost savings and reduced risks in the long term.

Workshop presenters provided an overview of the general best practices, and in a few cases, siting and design principles. However, specificity and standardization of practices and procedures for factoring impacts associated with extreme weather and climate into BMP siting and design is still an emerging body of work. Presentations on agricultural (general and cover crop-specific), forest, and urban BMPs (stormwater and green infrastructure), and coastal restoration practices (e.g., tidal outfalls and living shorelines) provided insight into good practices, but more importantly, identified critical factors to consider moving forward.

Due to uncertainty in future environmental conditions and events, and the performance of BMPs under changing conditions, the primary goal in siting and designing BMPs for the future is resilience – defined here as "the ability to compensate for or overcome the unexpected." Six key characteristics of resilient BMPs to consider in siting and design were identified:

> *Sensitivity*. Is the BMP and its performance sensitive to the range of potential changes in climate, weather, or resultant hydrologic and water quality changes? Sensitivity refers generally to system response to a change in a driver (e.g., temperature, precipitation, sea level). Future changes, such as climate and land use, will affect both BMP performance and the flows and loads that BMPs must address. For example, if precipitation increases, a BMP that may not be sized appropriately could be washed out in an extreme event, and/or biological components could be compromised.
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> *Adaptability.* Can the practice be modified to be resilient to potential changes as they emerge? BMP performance can depend on precipitation, soil moisture, temperature, and other factors. The degree to which a BMP can be modified to address changing environmental conditions, or is locked into a design that is fixed with respect to current conditions over a long period of time, is a measure of its adaptability. To build in flexibility and adaptability, there is a need to allow for adjustments in BMP implementation in order to consider a wider range of potential uncertainties and a richer set of response options (e.g., load allocations, BMP selections, and BMP redesign).

Existing WIP development, implementation and reporting procedures, as well as monitoring results and local feedback on performance, could be used to guide this process.

Timeliness. How quickly can BMPs be altered or implemented to adapt to changes? BMPs with short maturation periods (e.g., riparian buffers) or lead times for implementing modifications to address changing environmental conditions will be more resilient. Not surprisingly, incorporation of climate considerations is more pressing for BMPs with longer lifespans.

Cost-effectiveness. Will the cost to modify BMPs to prevent or remove projected increases in pollutant loads be feasible and reasonable? Large capital costs should be avoided that may not be appropriate to the actual future conditions. An analysis of the benefit to cost ratio of designing to a higher standard should be assessed in the context of an excepted level of risk tolerance, over the intended design-life of a proposed practice.

Robustness. Will BMPs perform well over a range of projected future environmental conditions? Robustness refers to that ability to meet a stated goal, e.g., to remain above/below a defined threshold. "Climate-smart" principles can be used to site and design BMPs to reduce future impacts of sea level rise, coastal storms, increased temperature, and extreme events. Vulnerability should be evaluated based on the factor of risk (i.e., consequence x probability) in combination with determined levels of risk tolerance, over the intended design-life of the proposed practice.

Auxiliary or Co-Benefits. In addition to reducing pollutant loads to the Bay, will BMPs provide other co-benefits (e.g., recreational, heat amelioration, aesthetic)? On the flipside, maladaptive practices should be examined and avoided. In 2017, the CBP commissioned a study (Tetra Tech 2017) to evaluate both positive (0 to +5) and negative (0 to -5) effects of BMPs on various CBP restoration goals and outcomes. Results of the climate adaptation benefits of select BMPs are contained in Appendix D.

Using the characteristics outlined above, the workshop highlighted a series of both general practices for siting and design, as well more tailored principles for a subset of urban stormwater, agriculture, coastal and stream restoration BMPs. General practices include: 1) considering BMPs as a system, such as a "treatment train," as a means of increasing resilience to future environmental changes; 2) incorporating "low regrets" solutions that are resilient against many potential futures; and 3) addressing compounding factors (urbanization, growth, watershed scale impacts). Other practices include recognizing the importance of maintenance in sustaining the functionality of BMPs over time, such as storm drain cleaning, vegetation management, and sediment removal in green infrastructure projects.

Drawing from workshop presentations and discussion, Table 1 below lists general principles as well as ancillary benefits for a subset of BMPs, routinely implemented within the Chesapeake Bay watershed.

Table 1. General Siting and Design Principles and Co-Benefits

Practice	***General Siting and Principles***	***Co-Benefits***
Agricultural (general)	Nutrient management practices can be adapted and adjusted to address changing conditions (e.g., optimizing timing and placement of nutrients). Annual practices have the most flexibility. Structural and vegetated buffers BMPs can add resiliency to the landscape. An increased level of effort may be needed to offset increased runoff during extreme events. Nutrient management plans should factor in the likelihood of an increase in storm intensity due to climate change.	Improve soil health (healthy soils are more resilient); carbon sequestration (e.g., tillage management, cover crops); climate adaptation (irrigation management to adapt to drought).
Agricultural (cover crops)	Climate change may produce more extreme runoff events which may be harder to control through traditional cover crops. Shifts in onset of seasons will make timing of plantings key. Winter cover crops reduce sediment but cold fall/winter temperatures can limit impact. There are about 100 different cover crop options, so it is a flexible BMP.	Cover crops protect against damage from weather events when primary crop is not growing; carbon sequestration, nitrate immobilization.
Forestry (riparian forest buffers)	Climate change may increase intensity of storm events which would reduce the infiltration provided by this practice. Plan for species diversity. Assess drainage flow patterns. Adjust practices upland to disperse flows. Manage for pest and invasive species. Larger or wider buffers may be needed to accommodate for more intense storm events or to guard against buffer loss due to sea level rise in coastal areas.	Carbon sequestration; habitat connectivity; flood control; stream shading and thermal control.
Shore Erosion Control (Living Shorelines)	Self-adapting and dynamic. Consider wetland/shoreline migration potential. Vegetation planting should maximize plant density and height. Maintain low sill for erosion control and fish access. Suitable for low-moderate energy systems. Living shorelines need low banks with little development to migrate and accrete in response to sea level rise.	Sediment and nutrients capture; Reduce storm/wave energy and associated erosion; Habitat provision; sea level rise adaptation; oyster growth promoted by dynamic waves.

Shoreline Restoration (general)	Protect the important ecological attributes of the shoreline and maintain and improve water quality. Plan for adaptive management throughout life cycle of the project.	Tourism; improve habitat; mitigate flooding; protect infrastructure and natural resources; provide public access.
Urban (stormwater)	Climate change may produce more extreme precipitation runoff events, which may be harder to control through stormwater management. Evaluate site designs from a watershed context (treatment train). Account for variability in precipitation events. Update "design storm" curves based on future climate projections. Limited space availability in urban settings may limit areas for implementation.	Mitigate urban flooding; decrease runoff water temperatures.
Urban (Green Infrastructure)	Combine practices (e.g., green roofs with bio-retention). Integrate siting and design principles into regulatory standards.	Alleviate urban heat island effects; mitigate urban flooding; reduced runoff, pollutant loads and peak flows; erosion control.
Stream Restoration	Climate change may produce more extreme runoff events, which may make stream restoration less effective at nutrient and sediment reductions. Stream restoration projects should be adaptively managed over time. Best practices include floodplain reconnections and slowing movement of water.	Mitigate flooding; restore habitat connectivity.

Data, Tools, and Resources

Data, tools, and resources are increasing in availability that can assist watershed managers, planners, and restoration practitioners with assessing and/or integrating climate considerations into siting and design practices. Workshop presenters provided information and background on a number of key resources, including readily available climate data, models, projections, and scenarios; modeling approaches and applications; vulnerability assessments; and decision-support products and tools. Two specific examples discussed (see Appendix C), data portals such as the EPA's Stormwater Calculator (Berner), and the US Army Corps of Engineers Sea Level Rise Calculator (Z. Johnson), can be used to facilitate the integration of climate information into BMP project siting and design.

A compilation of many of the tools and resources referenced during the workshop is contained in Appendix E. This compilation is intended to be a living document which will be updated periodically as new information becomes available and will be made available on the CBP Climate Resiliency Workgroup's webpage.

Climate data, models, projections and scenarios

Generally available climate data, models, projections, and scenarios were identified by workshop presenters (see Table 2) to support specific user decision-needs (e.g., modeling applications, vulnerability assessments). Products are typically tailored to national, regional, or state-levels and in limited cases, at the local-scale. For example, municipalities such as the District of Columbia are developing customized downscaled products to support specific decision needs (K. Johnson). Additionally, organizations (e.g., MARISA, CBP) are working towards customized data (Ches Wx) and summary visualizations specifically focused on the Chesapeake Bay watershed and the decision needs identified in this and other reports.

Table 2. Some common sources of climate model output and scenarios.

Name	**Description**
NOAA Climate Explorer 2	Primarily for viewing climate change projections, some ability to download spatial summaries of CMIP5 climate model output.
North American Regional Climate Change Assessment Program (NARCCAP)	Dynamically downscaled climate scenario data for the United States, Canada, and northern Mexico, using regional climate model, coupled global climate model, and time-slice experiments.
USGS Geo Data Portal (GDP)	Provides users access to downscaled climate projections and other data resources that are otherwise difficult to access and manipulate, allows user to supply their area of interest as a pre-existing GIS shapefile with one-to-many unique polygons or by drawing a single polygon using an interactive web-map.
USGS National Climate Change Viewer (NCCV)	Allows visualization of projected changes in air temperature, precipitation and key water balance terms anywhere in the United States, includes historical and future climate projections from 30 downscaled models for RCP 4.5 and RCP 8.5.
Monthly bias-correction and spatial disaggregation (BCSD)	Statistically downscaled CMIP3 and CMIP5 climate and hydrology projections for the conterminous United States, portions of Canada, and Northern Mexico developed using monthly bias-correction and spatial downscaling, at a spatial resolution of 1/8 degree (roughly 12 km × 14 km) for the period 1950−2099.
Daily bias-correction constructed analogs (BCCAv2)	Very similar to BCSD but with daily values

Multivariate Adaptive Constructed Analogs (MACA) Statistical Downscaling Method (Abatzoglou and Brown 2012)	Statistical downscaling method applied to output from 20 GCMs of the CMIP5 for the historical GCM forcings (1950-2005) and the future RCPs RCP4.5 and RCP8.5 scenarios (2006-2100) from the native resolution of the GCMs to either 4-km or approximately 6-km.
The Nature Conservancy—Climate Wizard (Girvetz et al. 2009)	A powerful, yet easy to use, web-based tool that provides non-climate specialists with simple analyses and innovative graphical depictions for conveying how climate has and is projected to change within specific geographic areas throughout the world.
Localized Constructed Analogs (LOCA)	Downscaled climate projections providing temperature and precipitation on 6 km resolution pixels for CMIP5 RCP 4.5 and 8.5, attempting to better preserve extreme hot days and heavy rain events, regional patterns of precipitation, and future climate changes predicted by GCMs. The data are daily, covering the period 1950-2100 for 32 global climate models.
USEPA Locating and Selecting Scenarios Online (LASSO) Tool	Provides a simple interface to large, complex, climate model output files, including guidance and strategies for selecting specific climate model projections from the larger ensemble.
NASA Earth Exchange Downscaled Climate Product (NEX-DCP30)	Monthly downscaled version of the CMIP5 climate models for the conterminous United States. Spatial resolution is 30 arc seconds (~1 km x 1 km).
NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP)	Global, daily downscaled version of the CMIP5 climate models. Spatial resolution is 0.25 degrees (~27.75 km x 27.75 km)
U.S. Global Change Research Program	Climate change scenario products to support the Fourth National Climate Assessment (NCA4).

Modeling applications and approaches

Workshop presenters described a range of studies that rely on simulation models. Models such as EPA's System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) can be used to help site or design BMPs, while others (e.g., EPA SWMM) are used to evaluate the potential for BMPs to reduce pollutant loadings, meet water quality standards, or achieve other public benefits. These models can typically be run for a specific design rainfall event, and/or in a continuous simulation modeling approach to estimate performance over days, months, or years. It is important to distinguish between models that enable a site-level and broader/regional analysis. Models that provide for broader analyses often include multiple objectives and can weigh benefits and costs, but are limited in their application at a site-level.

Although the workshop included a number of examples where climate or other uncertain extremes have been included in simulation modeling analysis, the consensus among presenters and participants is that most rainfall-runoff simulation modeling applications that estimate hydrologic flows and pollutant loadings are not yet able to address a wide range of uncertainty related to climate change, extreme weather patterns, or other future changes (e.g., population, land use).

Project screening checklists

Another category of tools and resources growing in availability are planning guidance documents and project screening checklists. Project planners and engineers who may not be familiar with how to factor climate considerations into the siting and design of water quality-related BMPs can benefit from several recent project planning guidance documents (e.g., Climate Smart Framework and Decision-Support Tool, Naval Facilities Engineering Command Installation Adaptation and Resilience Planning Handbook).

In 2017, the CRWG, with the help of Tetra Tech, developed a *Climate Smart Framework and Decision-Support Tool* (Tetra Tech 2017). The projects' purpose was to develop a structured, science-based framework through which the principles of climate-smart adaptation planning can be effectively applied to Chesapeake Bay restoration activities. Development and application of the tool was piloted with the Submerged Aquatic Vegetation, Black Duck Action Team, and the Tidal Wetlands and Toxic Contaminants Workgroups of the CBP. As presented at the workshop by Z. Johnson (Appendix C), the tool's Adaptation Design Tables have broad applications for assessing the impacts of climate and weather extremes of BMP siting and design and the purposeful implementation of "climate-smart" modifications and/or enhancements to planned projects. Climate-Smart Adaptation Design Tables, along with instructional guidance, are available and online at: https://www.chesapeakebay.net/channel_files/25931/cbp_climate_smart_framework_and_decision_tool_-_final_report_2018.pdf.

From the project-specific case-studies (Smith, Becraft) presented, as well the more detailed project planning resources presented at the workshop, seven basic steps in a step-wise process were identified.

Step #1: Identify existing and future (e.g., 25, 50 75-year) climate impacts (sea level rise, storm surge, precipitation change, temperature increase) that could potentially impact the site or project location.

Step #2: Assess vulnerabilities to the proposed project (over its intended design life).

Step #3: Recommend siting (location) or design (construction) modifications to accommodate for and/or mitigate against any future climate impacts.

Step #4: Conduct a benefit-cost analysis.

Step #5: Design (with climate impact accommodations) and construct.

Step #6: Monitor (for functionality in light of extreme events or changes in climatological trends) and maintain.

Step #7: Adaptively manage.

A valuable resource that demonstrates the application of each step in more detail is the recently released white paper, *Building Resilience through Habitat Restoration* (Carlozo 2015). Designed as a living document, this paper outlines how climate impacts can be considered in various phases of a restoration project: targeting and prioritization, selection, site analysis, design, environmental review, permitting, construction, and monitoring. Best practices are outlined along with available tools and resources for integrating climate change into project management and restoration decisions. The design and monitoring phases represent key points where practitioners can best integrate climate change and promote adaptive management to build coastal resilience through habitat restoration.

Research Gaps and Implementation Needs

Workshop speakers and participants expressed a need for improved methods to evaluate siting and design considerations within the watershed context, in addition to site-level assessment needs. Additionally, there was a strong message that better tools are needed to improve understanding of cost-effectiveness (and co-benefits) of upgraded BMP design, and within that context, an assessment of the intended design life for the suite 267 Chesapeake Bay Program approved BMPs. Both of these would enable the Partnership to gain a better understanding of the cost-benefit/trade-offs of considering impacts beyond 2025. General research and implementation needs for select BMP suites, documented during the workshop, are outlined in Table 3 below.

Table 3: Research Gaps and Information Needs

Practice	***Research Gaps***	***Implementation Needs***
Agricultural (general)	Better understanding of how climate change and extreme events may affect timing (seasonality) and magnitude of nutrient flows and loads. Identify BMPs that are better at addressing potential increase in inorganic nitrogen.	Improve translation of climate data and technical information to portray how individual farms may be impacted as well as localized on-the-ground adaptation measures.
Agricultural (cover crops)	Best mix of diverse cover crops; timing of planting. Impact of drought on cover crop vs. cash crop growth. Research on whether cover crops leach water from cash crops	Provide information for farmers on cover crop varieties and planting techniques (ex, over-cropping) may be more adapted to future condition and suit farmers' needs.
Forestry (riparian forest buffers)	Updated guidance on tree species for forested buffers and urban tree plantings. Assess critical areas for forest buffers along Brook Trout streams. Improved understanding of the absorptive capacity of tree canopy and impact of conifers.	Develop outreach products that promote practices such as: leave room for streams, plant buffers with native vegetation; design tree planting for multiple benefits; conserve forests; and manage for healthy forests.
Shore Erosion Control (Living Shorelines)	Research on why plant density tends to be lower in living shorelines in comparison to natural marshes. Long-term benefits of artificial thin layer deposition of dredge materials on marshes. Monitoring of removal of nitrogen and phosphorus.	None identified.
Urban (stormwater)	Need "plug and chug" data for engineers. Update design storm curves that account for future climate change. Assess thermal impacts on stormwater. Improve understanding of how to make stormwater BMPs more resilient and adaptive to flooding. Identify ways to optimize or adaptively manage BMPs in urban settings.	Integrate siting and design principles into regulatory standards. Address public misconception that the primary purpose of urban storm water BMPs is flood control.

Urban (Green Infrastructure)	Recommend "climate-smart" vegetation guidelines for green infrastructure. Assess how well distributed green infrastructure perform for flood control. Explore existing restrictions on the use of green infrastructure practices and tree planting in floodplains. Need to account for growth when assessing climate change impacts.	Communication products should make link between the green jobs co-benefit of green infrastructure projects.
Stream Restoration	Changes in planning criteria for 100-year storms. Hydrologic response of streams to integrated controls.	None identified.

Conclusions

The Chesapeake Bay watershed is experiencing stronger storms, an increase in heavy precipitation events, increasing air and water temperatures, and a rise in sea level. These trends, which vary both spatially and temporally throughout the watershed, are altering the natural ecosystems and the human communities of the Chesapeake Bay and are likely to require changes in programs, projects, and practices used to successfully achieve restoration goals. Considering impacts associated with climate change and extreme weather during the planning, siting, design, and implementation of water quality related-BMPs can reduce vulnerability to structural failure over the practices' design life and ensure that EPA's TMDL requirements are achieved.

The workshop purpose was three-fold: 1) assess the state of the knowledge on the effect of anticipated changes in weather patterns and extreme events on BMPs over time; 2) compile siting and design guidelines, tools, and resources to increase BMP resilience; and, 3) identify gaps and priority needs to better inform and improve BMP development and implementation. Workshop participants identified seven areas for future focus:

1. **Develop design guidance to increase BMP resilience.** There is a clear need for standard operating procedures and adoption of practices for factoring impacts associated with extreme weather and climate into BMP siting and design. Updating design storms (e.g., Rainfall Intensity Duration Frequency curves) based on projected future conditions would be a key piece of design guidance for the urban sector.
2. **Improve simulation modeling capabilities.** Most rainfall-runoff simulation modeling applications that estimate hydrologic flows and pollutant loadings are not yet able to address a wide range of uncertainty related to climate change, extreme weather patterns, or other future changes (e.g., population, land use). Drawing from the presentations and discussions at the workshop, several key needs emerged as near-term priorities for simulation modeling:

- Models that can estimate the performance of a series of linked BMPs (treatment train);
- Coupled models that allow for BMP co-benefits analysis (e.g., water quality improvement and local-scale flooding);
- Scalable high-performance computing to support analysis across a broader range of climate and other uncertain projections;
- Better representation in models of how BMP performance might be maintained or degrade with long-term operations and maintenance decisions, especially in continuous simulation models;
- Models that can enable a sensitivity analysis with a goal of identifying thresholds/threshold behavior, especially where modeled values are uncertain or only rough approximations of real conditions;
- Application of models for long-term planning under uncertainty using simulation approaches such as "robust decision making" or other "decision-making under uncertainty" approaches; and
- Increased collection of monitoring data, such as continuous simulation (hourly) hydrological modeling of climate change impacts, to support modeling efforts.

3. **Conduct targeted research to enable quantification of impacts on structural integrity as well as nutrient and sediment removal effectiveness.** While there is a generally sound understanding of possible hydrologic and water quality changes related to the direct and indirect effects of changes in precipitation, temperature, runoff, and sea level rise, further work is necessary to advance our understanding of the cumulative impacts on BMP structural integrity and functionality in nutrient and sediment removal. Substantive data, research, tools, and guidance are not currently available to support Chesapeake Bay jurisdictions with implementing the proposed Phase III WIP policy element to "consider and prioritize BMPs that are more resilient to future climate impacts over the intended design life of the proposed practices."
4. **Develop monitoring protocols and parameters.** To learn more about the impact of climate change and extreme events on the structural integrity and effectiveness of BMPs, workshop participants identified the need to:

    - Communicate the importance of establishing baseline conditions and conducting routine site assessments;
    - Develop post-storm monitoring guidelines and data collection parameters (e.g., nutrient, sediment, toxics, thermal and benthic impacts, stream and watershed effects, vegetation longevity);
    - Establish methods to collect accurate localized climatological data (i.e., rain gauge) to support trend and impact assessments; and
    - Include climate and extreme event impact data collection parameters into existing CBP BMP verification protocols. This could be done on a voluntary basis to support collection of long-term data and information to further the Partnership's

understanding of climate impacts on BMP performance and to identify specific suites of BMPs that better mitigate the anticipated increases in nitrogen, phosphorus or sediment.

5. **Advance programmatic practices, legal and regulatory tools.** Looking beyond the Midpoint Assessment and Phase III WIPs, a roadmap for moving from science to policy to regulation should be developed. For urban BMPs, siting and design principles need to be integrated into regulations and standards. This could be done by adopting the use of updated design storms. For agricultural and forestry sectors, implementation is more voluntary as climate change considerations are addressed through resource management practices. For all sectors, however, workshop participants recommended the use of programmatic or regulatory incentives to promote implementation of projects beyond minimum standards.
6. **Improve communication and outreach to end-users.** Communication efforts should focus on increasing understanding of planning for risk, uncertainty, and likelihood of impacts as well as supporting the need for sharing and disseminating climate data and future projections. Exploring the use of visualization tools for comparison of historical, current conditions, and future change was recommended. Consumers of information include water utilities, agricultural producers, extension agents, local-state planners, legislators, urban stormwater managers, ecosystem restoration community, agricultural and forest management community, and floodplain managers. Workshop participants recognized that there are numerous information end-users and recommended that communication products should be targeted to individual audiences (i.e., develop a "Too Wet to Plant" factsheet for agricultural sector).
7. **Identify, prioritize and fill data, research and information needs.** Workshop speakers and participants expressed a need for improved methods to evaluate siting and design considerations within the watershed context, in addition to site-level assessment needs. Additionally, there was a strong message that better tools are needed to improve understanding of cost-effectiveness (and co-benefits) of upgraded BMP design and within that context an assessment of the intended design life for the suite 267 BMPs. Both of these would enable the Partnership to gain a better understanding of the cost-benefit/trade-offs of considering impacts beyond 2025. This workshop report outlines general, as well as sector-specific data, research, information, and communication needs (see Tables 1 and 3). The development of a research agenda, prioritizing key information needs, potential funding sources, and collaborators, is a critical first step.

Looking beyond this STAC workshop, the CBP should monitor emerging climate science and advance the application of this information to CBP assessments and decision-making processes. The seven areas for future focus outlined above serve as a guide for near-term efforts in this regard.

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Appendix A: Workshop Agenda

A STAC Workshop:
Monitoring and Assessing Impacts of Changes in Weather Patterns and Extreme Events on BMP Siting and Design

September 7-8, 2017
Crowne Plaza Hotel, Annapolis, MD
http://www.chesapeake.org/stac/workshop.php?activity_id=280

Workshop Goals

The two-day workshop is planned for the purposes of: 1) assessing the state of the knowledge on how anticipated changes in weather patterns and extreme events may affect the structural integrity of a subset of urban stormwater, agriculture, and stream restoration Best Management Practices (BMPs) over time; 2) compiling siting and design guidelines, tools and resources to increase BMP resilience; and, 3) identifying remaining gaps and highest priority needs (i.e., research, monitoring measures, programmatic efforts, data and information) to better inform and improve BMP development and implementation.

Agenda

Day 1:

8:30 Registration, light breakfast (provided)

Session I: Introduction - General Siting and Design Principles

9:00 Introduction and Purpose of Workshop – Mark Bennett, USGS; Zoe Johnson, NOAA

9:30 State of the Science: Climate Change Impacts on the Chesapeake Bay – Ray Najjar, Penn State (*Remote*)

10:15 BMP Performance under a Changing Climate – Evaluating Resilience - Jon Butcher, Tetra Tech

11:00 DISCUSSION (ALL) – Facilitator: Susan Julius (EPA) and Mark Bennett (USGS)
What can we draw from literature review about siting and design principles?

11:30 LUNCH (provided)

Session II: Characteristics of Resilient BMPs - Case Studies

12:30 - 3:30 Case Study Presentations (20 mins each)

Agricultural BMP's

- *Climate Adaptation for Maryland Forests and Stream Buffers* – Anne Hairston-Strang, MD Forest Service
- *Co-Benefits and Adaptability of Agricultural BMPs in the Chesapeake Bay Watershed* - Curtis Dell, USDA - ARS
- *Using Cover Crops to Adapt to Climate Change* - Jason Kaye, Penn State

Coastal/Riverine BMP's

- *Adapting Living Shorelines: Siting and Design for Climate Impacts* - Molly Mitchell, VIMS (*Remote*)
- *Resiliency through Restoration* - Kevin Smith, Maryland DNR and Chris Becraft, Underwood and Associates

Urban BMP's

- *Patuxent/Illinois BMP Analysis* - Jordan Fischbach, RAND Corp.
- *GreenPhilly Case Study* - Art McGarity, Swarthmore College
- *Difficult Run Modeling Study: Lessons Learned for Improved BMP Design* - David Sample, Virginia Tech
- *Urban Tools and Resources: Stormwater Calculator* – Jason Berner, EPA (*Remote*)

3:30 Break

3:45 DISCUSSION (ALL) – Facilitator: Jordan Fischbach (RAND) and David Sample (VT)
What are specific characteristics (flexibility, adaptability, robustness) of BMP design that address extreme events and provide co-benefits?

4:45 Wrap-up

5:00 Adjourn

Day 2:

8:15 Registration, light breakfast (provided)

8:45 Welcome, Summary of Day 1, and Comments from Workshop Participants

Session III: Tools & Resources

9:00 Resilient BMPs: Tools and Resources - Zoe Johnson, NOAA Chesapeake Bay Office

9:30 An Overview: Available Tools and Resources (20 mins each)

- *MARISA Climate Data Portal (ChesWx Historical Climate Datasets)* - Rob Nicholas/ Jared Oyler, Penn State
- *Climate Ready DC* - Kate Johnson, DOEE
- *Guidance for Building Climate Resilience into Habitat Restoration* - Nicole Carlozo, MD DNR
- *Modeling BMP Design under a Changing Climate* – Scott Job, Tetra Tech
- *Green Infrastructure for Chesapeake Stormwater Management: Legal Tools for Climate Resilient Siting* - Jim McElfish, ELI

11:15 Break

11:30 DISCUSSION (ALL) – Facilitator: Susan Julius (EPA) and Jordan Fischbach (RAND)
What are the remaining gaps and highest priority needs (tools and resources) to better inform BMP development and implementation?

12:30 LUNCH (provided)

Session IV: Wrap-Up - Research and Monitoring Needs

1:30 DISCUSSION (ALL) – Facilitator: Jeremy Hanson (VT) and Zoe Johnson (NOAA)
What are the remaining gaps and highest priority needs (i.e., research, monitoring measures, programmatic efforts) to address in order to better inform and improve BMP development and implementation?

2:30 Wrap-Up

3:00 Adjourn; Convene Steering Committee for Workshop Documentation

Appendix B: Workshop Participants

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Appendix C: Links to Workshop Presentations and Selected Abstracts

Introduction and Purpose of Workshop – Mark Bennett, USGS; Zoe Johnson, NOAA
http://www.chesapeake.org/stac/presentations/280_ZJohnson_STAC%20CC%20BMP%20Workshop%20Intro.pdf

State of the Science: Climate Change Impacts on the Chesapeake Bay – Ray Najjar, Penn State (Remote)
http://www.chesapeake.org/stac/presentations/280_Najjar%20Climate%20Mid-Atlantic_FINAL.pdf

BMP Performance under a Changing Climate – Evaluating Resilience
http://www.chesapeake.org/stac/presentations/280_Butcher_BMPsOverview.pdf
Dr. Jonathan B. Butcher, P.H., Tetra Tech, Research Triangle Park, NC

Diffuse sources of land-based pollutants, whether urban or rural, are addressed through a variety of best management practices (BMPs). Estimates of water quality benefits of BMPs and the associated cost of achieving a desired level of load reduction typically assume that future conditions will resemble the historic record. That assumption is questionable under a changing climate in which average air temperatures are expected to rise and the future precipitation regime is subject to deep uncertainty. How would potential changes in climate affect BMP performance? We examine the connections between climate and BMP performance, which range from simple (e.g., more intense precipitation may require larger detention ponds) to complex (e.g., increased rates of organic matter decomposition could change the C and N cycles in soil and alter the predicted nutrient reduction benefits of cropping practices). Many BMP types, including popular urban practices such as bioretention, are based on vegetative processes and must be analyzed from both a physical engineering and an ecosystem process perspective. Climate interactions with both physical and ecosystem responses need to be evaluated. For instance, performance of a riparian grass buffer is sensitive to precipitation intensity (which shortens flow residence time and reduces filtration capacity) and to the temperature and moisture balance that affects vegetation density. To develop resilient management plans that rely on BMPs we need to understand the sensitivity of practices to climate, their adaptation potential to perform under a changed climate, and their flexibility to allow timely and cost-effective refinement as climate regime shifts are observed. Our research combines evidence from BMP performance literature and conceptual descriptions of how BMPs function with a series of simulation modeling experiments on urban and agricultural BMPs. We examine a variety of engineering and ecosystem responses to changes in the temperature and moisture regime. A better understanding of the climate adaptation potential and flexibility of specific BMP types will assist practitioners to develop management plans that minimize regrets and are robust across a range of plausible future climate conditions.

Climate Adaptation Issues for Maryland Forests and Stream Buffers
http://www.chesapeake.org/stac/presentations/280_Hairston-Strang_MDForestsandClimateAdaptation.pdf

Anne Hairston-Strang, Ph.D. Maryland DNR Forest Service, 9/7/17

Forests are the natural land cover in the Mid-Atlantic region, and forested watersheds support healthy streams, clean water, wildlife, and clean air. For climate adaptation and watershed restoration, several forest-related best management practices take advantage of that natural function: riparian forest buffers, other tree planting, and forest harvesting sediment and erosion control practices. Opportunities for improvement in these BMPs include addressing concentrated flow issues, invasive species, and deer browse through planning and management, emphasizing species diversity and income-producing options, and focusing attention on stream crossings where sediment is most likely to enter waters.

Managing forests to adapt to climate change means creating conditions where the forests resist disturbances (diversity in species, age, forest structure) and are resilient following major storms (potential to regenerate trees, multiple canopy layers). Forest characteristics that contribute to greater function in nutrient retention and stormwater infiltration include deep rooting and macropores from old root channels that increase infiltration, a spongy litter layer that supports the microbial community and adds organic matter to the soil, interception from tree canopy, and evapotranspiration that increases soil storage capacity. Other BMPs can infiltrate runoff but do not replace evapotranspiration, leaving more water to runoff or leach into waterways. Expected changes in forests with climate change are portrayed in the USFS Climate Change Atlas (Prasad et al. 2007. http://www.nrs.fs.fed.us/atlas/tree). The Mid-Atlantic expects to lose some northern species like red spruce and see range increases for southern species like loblolly pine and southern red oak, with shifts mitigated by the long-lived nature of trees, greater tolerance of varying conditions by mature trees than by seedlings, and topographic variability. Changes in climate may exacerbate risks to forest health, especially for invasive species shifts (e.g., warmer winters with greater pest survival, longer growing seasons with potential for multiple generations of pests). Suggestions for improving resilience to climate changes include: prioritizing room for naturally vegetated and forested buffers; designing tree planting for multiple benefits like shade and community livability; conserving priority forests, more cost-effective than restoration, better for rare species; and managing for healthy forests, including pest and vine control, encouraging native diversity adapted to projected future condition.

Co-Benefits and Adaptability of Agricultural BMPs in the Chesapeake Bay Watershed
http://www.chesapeake.org/stac/presentations/280_Dell%20STAC%20Sept%207-revised%20FINAL.pdf
Curtis Dell, USDA-ARS-PSWMRU, University Park, PA

Agricultural practices comprise the largest group of BMPs which states can utilize to meet Chesapeake Bay water quality mitigation goals. These practices include long-term structural practices and vegetative buffers, but the largest number of agricultural BMPs are annual management practices or management plans. While criteria for structural practices should be carefully reviewed to determine that if specifications are sufficient to meet expected impacts of climate change, the annual nature of most agricultural BMPs provides flexibility to adjust management practices to address changing weather conditions. An example of flexibility in annual agricultural practices are the cover crop BMPs. A very wide range of approved cover crop practices (103) allows farmers the ability to alter plant species grown, and method and timing of both planting and termination. Numerous agricultural BMPs also provide the co-benefit of climate change mitigation and adaptation. For example, conservation tillage and vegetative buffers can lead to carbon sequestration. Additionally, nutrient management and precision livestock feeding BMPs aim to optimize nitrogen additions to crops and animals, reducing quantities of excess nitrogen in soils and manures that could be converted to nitrous oxide. Nutrient management also incorporations many adaptive approaches that allow farmers to alter amount and timing of nutrient additions within a growing season, providing the ability react to weather variability. However, some agricultural BMPs, such as no-till planting and manure injection, do have the potential to increase nitrous oxide emissions. In conclusion, the large dependence on annual management practices indicates that the Bay Program's agricultural BMPs appear to largely have the flexibility needed adjust to expected weather changes.

Using Cover Crops to Adapt to Climate Change
http://www.chesapeake.org/stac/presentations/280_Kaye_STACCoverCropsAdaptation.pdf
Jason Kaye, Penn State University

Cover cropping is the practice of maintaining plant cover even when cash crops are not growing in an agricultural field. In Chesapeake Bay watersheds, cover crop adoption is expanding and thoughtful management of cover crops could increase adaptation to climate change. With future warming it will be easier to establish a wider array of cover crop species in autumn. However, higher soil temperatures could increase soil net N mineralization and inorganic N leaching. Cover crops with high fall growth rates are likely to be a reliable adaptation strategy to reduce warming-induced nitrogen losses. The precipitation record in the region shows that the frequency of intense precipitation events is increasing in autumn. Cover crops can help reduce sediment and phosphorus losses from these intense events if they achieve high cover prior to large events.

Research is needed to define reliable strategies for establishing cover crops earlier in autumn so that they can be used to adapt to increased frequencies of intense rain events in autumn.

Drought may also become more common in the region. Cover crop management can help adapt to drought by killing cover crops to reduce water use, or by mulching soils with cover crop residues to reduce evaporation. For all three climate changes mentioned here, research is needed on how cover crop species selection impacts the value of cover crops for adaptation. Traits such as fall growth potential, winter hardiness, nitrogen fixation, rooting depth, and residue decomposition rates can all affect the role a cover crop species may play in adaptation. Mixtures of cover crop species planted together may provide some insurance that cover crops will reduce nutrient pollution across an array of climate and soil conditions, but there are trade-offs in using mixtures, including increased seed expense and management complexity. Overall, cover crops should be an important tool to reduce nutrient pollution in a changing climate, but research is still needed on management strategies and species that will be most effective for adaptation.

Reference:
Kaye, J.P., and M. Quemada. 2017. Using cover crops to mitigate and adapt to climate change: A review. Agronomy for Sustainable Development 37. DOI 10.1007/s13593-016-0410-x

Adapting Living Shorelines: Siting and Design for Climate Impacts
http://www.chesapeake.org/stac/presentations/280_Mitchell_Adapting%20Living%20Shorelines_STAC%20Workshop.pdf
Molly Mitchell & Donna Marie Bilkovic
Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, VA

Living shorelines are nature-based shoreline stabilization techniques that also function as coastal BMPs due to their ability to remove sediments and nutrients from precipitation runoff and tidal waters, resulting in improved water quality and their ability to reduce wave energy, which can help protect upland areas. Both functions are related to marsh width and vegetation, making those characteristics critical for continued function. Like any biotic system, living shorelines are susceptible to climate shifts that impact their width and vegetative characteristic, which will impact their ability to perform as BMPs in the short term, and their persistence on longer time frames. The biggest threat to living shorelines in the Chesapeake Bay region under climate change are sea level rise and increased storminess.

Marshes are dynamic systems, with some natural resilience to sea level rise built in through feedback loops involving vegetation, sediment capture and migration into adjacent areas. These are qualities which could be engineered into living shorelines, but are not currently the focus of most living shoreline design. To enhance the longevity of BMP functions, living shoreline design must capture the dynamics of the natural marsh systems, particularly their ability to migrate and accrete sediment. This can be accomplished through both careful siting of the projects and engineered characteristics.

Appropriate siting can enhance the ability of the marsh to maintain elevation and/or migrate with sea level rise. Migration potential is linked to the elevations of surrounding lands and also to their land uses. Living shorelines built along low elevations shorelines have room to migrate and will persist regardless of their ability to accrete sediment. Living shorelines built in front of high bluffs may persist through accretion but will be unable to migrate. The ability of a marsh to accrete is related to the sediment supply and the relative sea level rise rates. Areas with high sediment supply and low relative sea level rise will be the most resilient.

Both planting plans and sill design can be used to maximize sediment accretion (increasing resilience). Sediment trapping potential is related to plant characteristics, so vegetation should be planted to maximize height and density. Adding sills to living shorelines may enhance sediment accretion (Currin et al. 2010), but should be balanced against the need for aquatic animal access to the marshes. Incorporating living organisms like oysters into their design would add a dynamic component to living shorelines that can increase sill resilience under sea level rise (Hall et al. 2017). It is also possible that living shoreline elevation can be artificially enhanced through thin layer deposition (e.g., Ford et al. 1999).

References:

Currin, Carolyn A., W. Scott Chappell, and Anne Deaton. 2010. Developing alternative shoreline armoring strategies: the living shoreline approach in North Carolina, in Shipman, H., Dethier, M.N., Gelfenbaum, G., Fresh, K.L., and Dinicola, R.S., eds., 2010, Puget Sound Shorelines and the Impacts of Armoring—Proceedings of a State of the Science Workshop, May 2009: U.S. Geological Survey Scientific Investigations Report 2010-5254, p. 91-102.

Ford, Mark A., Donald R. Cahoon, and James C. Lynch. 1999. Restoring marsh elevation in a rapidly subsiding salt marsh by thin-layer deposition of dredged material. Ecological Engineering 12(3): 189-205.

Hall, S. G., R. Beine, M. Campbell, T. Ortego, and J. Risinger. 2017 Growing Living Shorelines and Ecological Services via Coastal Bioengineering. In Bilkovic, D.M., Mitchell, M.M., La Peyre, M.K. and Toft, J.D. eds., 2017. Living shorelines: the science and management of nature-based coastal protection. CRC Press.

Resiliency through Restoration - Kevin Smith, Maryland DNR and Chris Becraft, Underwood and Associates

http://www.chesapeake.org/stac/presentations/280_Smith_Becraft_Resiliency%20through%20Restoration.pdf

Patuxent/Illinois BMP Analysis - Jordan Fischbach, RAND Corp.

http://www.chesapeake.org/stac/presentations/280_Fischbach_WQ_Uncertainty.pdf

Performance and Effectiveness of Urban Green Infrastructure: Maximizing Benefits at the Subwatershed Scale through Measurement, Modeling, and Community-Based Implementation
http://www.chesapeake.org/stac/presentations/280_McGarity_PDF_y17m08_STAC_Workshop.pdf
Arthur E. McGarity, Ph.D., Prof. of Engineering, Swarthmore College
Investigator, EPA STAR Research Project: Green Infrastructure for Reducing CSOs in Philadelphia:

Summarized are the goals and progress through year 5 of Philadelphia's 25-year program to improve water quality through reductions in combined sewer overflows (CSOs) through implementation of green stormwater infrastructure (GSI). Recent results from Swarthmore College's EPA STAR funded research, which includes co-PIs at Johns Hopkins, Temple, and UMBC, are presented. Groundwater monitoring and 3-D hydrological modeling at Philadelphia GSI sites shows the potential for significant increases in subsurface storage under a green infrastructure scenario. Annual CSO flow reductions resulting from widespread deployment of specific GSI technologies are modeled using EPA's SWMM model using Philadelphia's largest CSO sewershed (Wingohocking) as a case study. Results show that in this Piedmont watershed, the magnitude of CSO reductions depends primarily on the total number of "greened acres" deployed and less on the types of GSI used and where in the watershed they are deployed. The StormWISE model is used to incorporate these simulation results in an optimization study that shows how prioritization of GSI technologies is necessary to minimize cost while achieving specified CSO reduction goals. Methodology is discussed to enable inclusion of future changes in weather patterns and extreme events in the analysis. Previously presented results using this methodology are reviewed including a case study of nutrient and sediment runoff management in a suburban Philadelphia watershed under scenarios that include land-use change and climate change. For more information, visit: http://www.greenphilly.net.

Difficult Run Modeling Study: Lessons Learned for Improved BMP Design - David Sample, Virginia Tech
http://www.chesapeake.org/stac/presentations/280_Sample_DifficultRun.pdf

U.S. EPA National Stormwater Calculator
http://www.chesapeake.org/stac/presentations/280_Berner_StormwaterCalc.pdf
Jason Berner, EPA

Stormwater discharges continue to cause impairment of our Nation's waterbodies. In order to help reduce impairment, EPA developed the National Stormwater Calculator (SWC) to help support local, state, and national stormwater management objectives and regulatory efforts to reduce runoff through infiltration and retention using green infrastructure practices as low impact development controls. It can be used for small- to medium-sized (less than 1 acre to 12 acres) sites within the United States, including Puerto Rico, and is designed to be used by anyone interested in reducing runoff from a property.

The SWC is now available as a mobile web application that can be used on desktop devices and mobile devices, such as smartphones and tablets, and is compatible with all operating systems with an internet connection. A cost estimation module that allows planners and managers to evaluate green infrastructure practices based on comparison of regional and national project planning level cost estimates and predicted performance has also been added. This includes whether the project is being applied as part of new development or redevelopment and if there are existing site constraints. An application of how the SWC was used for a technical assistance workshop in Baltimore, MD in 2017 is covered during this presentation; focusing on the climate change and cost estimation modules.

References:
Climate Resilience Evaluation and Awareness Tool (CREAT): https://creat.epa.gov/creat/

MD DNR. Over 4800,000 Announced to Support Local Green Infrastructure Projects to Improve Communities and Provide Jobs: http://news.maryland.gov/dnr/2017/06/29/over-800000-announced-to-support-local-green-infrastructure-projects-to-improve-communities-and-provide-jobs/

U.S. Climate Resilience Toolkit. Improving Water Quality by Dealing with the First Inch of Rain. http://toolkit.climate.gov/case-studies/improving-water-quality-dealing-first-inch-rain

Resilient BMPs: Tools and Resources - Zoe Johnson, NOAA Chesapeake Bay Office
http://www.chesapeake.org/stac/presentations/280_ZJohnson_Tools%20Resources%20for%20Resilient%20BMPs.pdf

ChesWx: Gridded Daily Weather Observations for the Chesapeake Bay Watershed
http://www.chesapeake.org/stac/presentations/280_ChesWx_Overview.Oyler_and_Nicholas.CBP_STAC_Workshop.FINAL.pdf
Jared Oyler and Robert Nicholas, Earth and Environmental Systems Institute
Penn State University

Interactions with stakeholders and decision-makers through the NOAA Mid-Atlantic RISA (MARISA, http://MidAtlanticRISA.org) have identified a growing concern over issues such as stormwater management, efficacy of urban and agricultural best management practices (BMPs), and riverine flooding. Understanding these issues and mitigating the risks associated with them both rely upon a clear characterization of historical and expected future precipitation extremes.

Many of the existing gridded observational products employ methodologies that minimize the error variance of their estimates, an approach that achieves a high level of local accuracy for precipitation amount but also tends to result in reduced spatiotemporal variability relative to station observations. These datasets are also often ambiguous in terms of whether they represent point values or areal averages. In light of this, we have undertaken development of a new 1948-to-present high-resolution gridded daily precipitation dataset that seeks to provide accurate estimates of all precipitation components (amount, intensity, and frequency) while also improving the representation of extremes. To achieve this, we apply a new approach that combines station observation homogenization, time-of-observation adjustments, missing value infilling, and geostatistical simulation. The new dataset (ChesWx, for ``Chesapeake Weather'') covers the Chesapeake Bay watershed and greater Mid-Atlantic region at 4 km, daily resolution and is explicitly designed to be interpreted as a set of gridded point values, not areal averages. Compared with similar, existing datasets, ChexWx shows reduced biases in precipitation frequency, average intensity, dry spell length, spatial decorrelation, return interval, and intensity of extremes while retaining similar spatial patterns for mean precipitation and sacrificing relatively little in terms of local accuracy. An initial version of the dataset has been completed and can be downloaded from from the MARISA data portal (http://marisa.psu.edu/data/).

Climate Ready DC
http://www.chesapeake.org/stac/presentations/280_KJohnson_ClimateReadyDC.pdf
Kate Johnson, District of Columbia, Department of Energy and Environment

This presentation provided an overview of Climate Ready DC, the District of Columbia’s climate adaptation and preparedness plan adopted in 2016. The plan includes an analysis of the potential impacts of climate change on the District, a citywide risk and vulnerability assessment, and 77 adaptation strategies that the District will take. The climate change projections used to inform the plan were created using statistical downscaling and provided changes in temperature and precipitation, including extreme events, from now until 2080s. For example, the projections showed that the number of extreme heat events, defined as days when the heat index exceeds 95 degrees Fahrenheit, could more than double by the 2050s and triple by the 2080s. The vulnerability and risk assessment mapped the increase in flood risks and led to the District to identify five priority planning areas for the implementation of Climate Ready DC. Two areas, Buzzard Point and Watts Branch, are now the subject of more detailed flood risks assessments being conducted by the Department of Energy & Environment and partners. The presentation concluded with a discussion of some of the challenges of integrating climate change considerations into the District’s stormwater management policies and programs. All the material reference is from the District’s Climate Ready DC plan and is available at doee.dc.gov/climateready.

Guidance for Building Climate Resilience into Habitat Restoration
http://www.chesapeake.org/stac/presentations/280_Carlozo_Guidance%20for%20Building%20Climate%20Resilience%20into%20Habitat%20Restoration.pdf
Nicole Carlozo, Maryland Department of Natural Resources

The Maryland Department of Natural Resources' *Building Resilience to Climate Change Policy* directs the Department to proactively pursue, design and construct habitat restoration projects to enhance the resiliency of the Bay, aquatic and terrestrial ecosystems to the impacts of climate change, while increasing carbon sequestration. In response to this policy, the Department developed the white paper *Building Resilience through Habitat Restoration*. Designed as a living document, this paper outlines how climate change can be considered in various phases of a restoration project. Recommendations are provided for future enhancements as refined climate change data and monitoring data becomes available. The various project phases addressed in this resource include targeting and prioritization, selection, site analysis, design, environmental review, permitting, construction, and monitoring. Best practices are outlined along with available tools and resources for integrating climate change into project management and restoration decisions. The design and monitoring phases represent key points where practitioners can best integrate climate change and promote adaptive management to build coastal resilience through habitat restoration. In Fiscal Year 2018, the Department launched a new Coastal Resiliency Program to fund design, construction and adaptive management of coastal resiliency restoration projects. Monitoring, communication and outreach will be integrated into the project lifecycles, and staff will update the white paper as lessons are learned through these initial demonstration projects.

References:
Maryland Department of Natural Resources. 2010. Building Resilience to Climate Change. http://dnr.maryland.gov/climateresilience/Documents/climate_change.pdf
Maryland Department of Natural Resources, Chesapeake & Coastal Service. CCS Habitat Restoration & Conservation Division: Building Resilience through Habitat Restoration. http://dnr.maryland.gov/ccs/Documents/NF_CCS-HRC_Climate_2015.pdf

Modeling BMP Design under a Changing Climate
http://www.chesapeake.org/stac/presentations/280_Job_Modeling%20BMP%20Design.pdf
Scott Job, Tetra Tech, Research Triangle Park, NC

The USEPA is developing a Climate Change and Urban Stormwater Design Guide. The guide will provide an analysis of the performance of green and gray stormwater controls under future climate and offers insights into how designs could be adapted in the future. The principal questions addressed by the guide include: (1) How might climate change affect performance of conventional stormwater infrastructure and green infrastructure (GI) compared to current conditions, (2) How can conventional designs and GI designs be adapted so that a site under future climate conditions provides the same performance as the site under current conditions, and (3) What do the results suggest regarding the adaptation of green and grey infrastructure?

Simulation modeling is being used to provide examples demonstrating principles from the guide and to show how stormwater infrastructure could respond to a changing climate. A number of conceptual site and stormwater management scenarios are being developed and simulated using the SUSTAIN (System for Urban Stormwater Treatment and Analysis INtegration) model, a decision support system and modeling tool.

The stormwater management scenarios cover five types of development in five geographic locations representing different hydroclimatic regimes throughout the US. HSPF model simulations driven by current and potential mid-century climate scenarios was used as input for the SUSTAIN simulation. A variety of stormwater best management practices are represented ranging from conventional gray infrastructure to GI designs using local design standards and guidance. Using existing requirements and stormwater goals to drive the site infrastructure and practice designs allowed for projecting how real-world stormwater programs might be affected by climate change.

Each practice-based scenario was modeled under existing and future climate conditions. In an additional model run, the site's practices were modified under future climate conditions to achieve the same performance as the existing climate scenario using SUSTAIN's optimization function. Modifications targeted resizing the water quality treatment and peak flow control BMPs. Comparisons of water quantity and quality performance and costs of the site practices were evaluated.

Summary results were presented for the Atlanta, GA ultra-urban site. Two stormwater management approaches were simulated - a conventional approach, and a mixed GI/gray approach. The up-front cost of the mixed GI/gray approach was higher than for the conventional approach, but the incremental additional cost for adapting the site to climate change was substantially lower for the mixed GI/gray approach than for the conventional approach.

Results were then presented for all sites to show trends in costs across locations and stormwater management approaches. Generally speaking, approaches that used a mixture of GI and gray BMPs have the lowest combined cost (i.e., current cost + cost to adapt to climate change) when compared to approaches that use only conventional BMPs or GI BMPs. However, when the future climate is projected to have a large increase in storm event intensity and volume, conventional approaches tended to have a lower combined cost. The reason is that gray infrastructure with detention storage is more effective for mitigating extreme event volume increases. GI on the other hand has greater flexibility for addressing multiple objectives.

Green Infrastructure for Chesapeake Stormwater Management: Legal Tools for Climate Resilient Siting
http://www.chesapeake.org/stac/presentations/280_McElfish_Chesapeake%20climate%20resilient%20GI%20PowerPoint_FINAL.pdf
Jim McElfish, Environmental Law Institute

The current legal framework in Maryland and Virginia offers state and local officials opportunities to establish green infrastructure siting guidelines for stormwater management. In Green Infrastructure for Chesapeake Stormwater Management: Legal Tools for Climate Resilient Siting, the Environmental Law Institute (ELI) explains how stakeholders in both states can use existing laws and regulations to site green infrastructure projects in locations that maximize their resilience to a changing climate while expanding communities' capacity to handle projected increases in stormwater runoff. The report notes that one of the greatest impacts of climate change on the Chesapeake Bay watershed will be stormwater management. The report, funded by the Chesapeake Bay Trust, examines and addresses the potential legal obstacles and describes the most promising pathways within the existing legal framework. For state and municipal leaders looking to go even further, the report recommends specific actions that legislative and regulatory bodies can take to modify the current stormwater management regime so as to more easily incorporate pragmatic consideration of climate change impacts. The report is available at https://www.eli.org/research-report/green-infrastructure-chesapeake-stormwater-management-legal-tools-climate-resilient-siting. A fact sheet provides additional detail on key findings of the report.

Appendix D: Climate-Related Co-Benefits of Chesapeake Bay Program Best Management Practices

Source: Estimation of Best Management Practice Impact on Chesapeake Bay Program Management Strategies (Tetra Tech, 2017)				
Description: The report scores BMPs based on their ability to positively (0 to +5) or negatively (0 to -5) impact climate related objectives of (i.e., climate adaptation, flood control and energy efficiency) of Chesapeake Bay Program's management strategies.				
Sector	**BMP Name**	**Climate Adaptation**	**Energy Efficiency**	**Flood Control/ Mitigation**
Agriculture	Ag Forest Buffer	2.5	0.5	3.5
Agriculture	Ag Shoreline Management	0.0	0.0	4.0
Agriculture	Ag Stream Restoration	2.0	0.0	0.0
Agriculture	Ag Tree Planting	2.0	1.5	2.0
Agriculture	Agricultural Ditch BMPs	0.0	1.0	-1.0
Agriculture	Alternative Crops and Alternative Crop/Switchgrass	0.0	0.0	1.0
Agriculture	Cover Crops	0.0	3.0	1.0
Agriculture	Barnyard Clean Water Diversion	1.0	0.0	0.0
Agriculture	Barnyard Runoff Controls	1.0	0.0	0.0
Agriculture	Commodity Cover Crop Barley, Rye, Wheat	0.0	3.0	1.0
Agriculture	Conservation Tillage	0.0	1.0	1.0
Agriculture	Continuous High Residue Till	0.0	1.0	1.0
Agriculture	Conversion to Hayland	0.0	0.0	1.0
Agriculture	Conversion to Pasture	0.0	0.0	1.0
Agriculture	Cropland Irrigation Management	0.0	3.0	1.0
Agriculture	Dairy Precision Feeding and/or Forage Management	0.0	1.0	0.0
Agriculture	Dirt & Gravel Road E&SC	0.0	1.0	-1.0
Agriculture	Dry Waste Storage Structure	0.0	3.0	1.0
Agriculture	Grass Buffer on Watercourse	1.0	0.0	1.0
Agriculture	Grass Buffers	1.0	0.0	1.0
Agriculture	Grass Nutrient Exclusion Area on Watercourse	1.0	0.0	1.0
Agriculture	Heavy Use Poultry Area Concrete Pads	0.0	0.0	-1.0
Agriculture	Horse Pasture Management	0.0	0.0	-1.0
Agriculture	Irrigation Water Capture Reuse	0.0	3.0	1.0
Agriculture	Lagoon Covers	0.0	0.0	-1.0
Agriculture	Land Retirement to Hay without nutrients	0.0	0.0	1.0

Agriculture	Land Retirement to Pasture	0.0	0.0	1.0
Agriculture	Loafing Lot Management	0.0	0.0	-1.0
Agriculture	Narrow Forest Buffer	1.0	0.0	2.0
Agriculture	Narrow Grass Buffer	1.0	0.0	1.0
Agriculture	Phase 6 Conservation Tillage	0.0	1.0	1.0
Agriculture	Phase 6 High Residue Tillage	0.0	1.0	1.0
Agriculture	Stream Access Control with Fencing	1.0	0.0	1.0
Agriculture	Streamside Forest Buffers	1.0	0.0	2.5
Agriculture	Streamside Grass Buffers	1.0	0.0	1.0
Agriculture	Water Control Structure	1.0	0.0	3.0
Agriculture	Watercourse Access Control	1.0	0.0	1.0
Forestry	Dirt & Gravel Road Erosion & Sediment Control	2.5	0.0	1.5
Forestry	Forest Conservation	3.5	3.0	3.5
Forestry	Forest Harvesting Practices	3.0	0.5	2.5
Septics	Constructed Wetland Elevated Mound	-0.5	-3.0	-1.0
Septics	Constructed Wetland Septic	-0.5	-1.5	-1.0
Septics	Constructed Wetland Shallow Pressure	-0.5	-3.0	-1.0
Septics	IFAS	-0.5	-3.5	0.0
Septics	IFAS Elevated Mound	-0.5	-4.5	0.0
Septics	IFAS Shallow Pressure	-0.5	-4.5	0.0
Septics	IMF	-0.5	-1.5	0.0
Septics	IMF Elevated Mound	-0.5	-3.0	0.0
Septics	IMF Shallow Pressure	-0.5	-3.0	0.0
Septics	NSF 40	-0.5	-3.5	0.0
Septics	Proporietary Ex Situ	-0.5	-3.5	0.0
Septics	RMF	-0.5	-3.0	0.0
Septics	RMF Elevated Mound	-0.5	-3.5	0.0
Septics	RMF Shallow Pressure	-0.5	-3.5	0.0
Septics	Septic Connections	-0.5	-3.0	-2.0
Septics	Septic Denitrification	-0.5	-3.5	0.0
Septics	Septic Tank Pumpout	0.0	-1.0	0.0
Urban	Abandoned Mine Reclamation	1.0	3.0	3.0
Urban	Advanced Grey Infrastructure Nutrient Discovery Program	1.0	1.0	0.0
Urban	Bioswale, Bioretention/raingardens	2.0	3.0	3.5
Urban	Dirt & Gravel Road Erosion & Sediment Control	2.5	0.0	1.5
Urban	Dry Detention Ponds and Hydrodynamic Structures	1.0	0.0	2.5
Urban	Erosion and Sediment Control	1.0	0.0	1.5
Urban	Filter Strip	1.0	0.0	3.0
Urban	Filtering Practices	1.0	1.0	1.0
Urban	Impervious Surface Reduction	2.0	1.0	3.0

Urban	Infiltration Practices	1.0	1.0	3.0
Urban	Nutrient Management	0.0	0.0	0.5
Urban	Permeable Pavement	1.0	1.0	3.0
Urban	Urban Forest Buffers	3.5	4.0	3.5
Urban	Urban Grass Buffers	2.0	1.0	2.0
Urban	Urban Growth Reduction	2.0	1.0	3.0
Urban	Urban Shoreline Management	4.0	0.5	1.0
Urban	Urban Stream Restoration	2.5	2.5	3.5
Urban	Urban Tree Planting	2.0	4.5	2.0
Urban	Vegetated Open Channels	1.0	1.0	3.0
Urban	Wet Ponds	2.0	1.0	3.0
Urban	Wetlands	2.0	1.0	3.5

Appendix E: Resilient BMP Planning Tools and Resources

General Resources

- CBP Climate Smart Framework and Decision Support Tool *Tetra Tech*
  A decision-support tool for tailoring "Climate Smart" decision-making processes to the implementation of Chesapeake Bay Program restoration goals, outcomes and action strategies.
- Estimation of Best Management Practice Impact on Chesapeake Bay Program Management Strategies *Tetra Tech*
  The report scores BMPs based on their ability to positively impact (i.e., climate adaptation, flood control and energy efficiency) Chesapeake Bay Program's management strategies.
- Climate Data for the Mid Atlantic – *MARISA Climate Data Portal*
- Access to the *ChesWx* gridded climate datasets contain daily interpolations of precipitation and temperature observations for the Chesapeake Bay watershed.
- National Climate Assessment *U.S. Global Change Research Program*
  An interactive, online report on the impact of climate change on the United States, with detailed regional information.
- Climate Resilience Toolkit – *NOAA*
  A compilation of tools, resources, data and projections, as well as case studies to help increase understanding of how to address climate risks across many sectors.
- Managing Water Quality in the Face of Uncertainty *RAND Corporation*
  A report describing how to use Robust Decision Making (RDM) when managing future uncertainties such as climate change and evolving land use patterns. A case study on the Patuxent River in Maryland is included.
- Better Assessment Science Integrating Point & Non-point Sources with Climate Assessment Tool (BASINS CAT) *EPA*
  BASINS CAT combines GIS, national watershed data, and watershed modeling tools to model potential climate change scenarios.
- Tools for Water Related Climate Change Adaptation *EPA*
  A database of climate change adaptation tools for communities on water utilities, water quality, and ecosystem protection.
- Best Management Practices: Preserving Clean Water in a Changing Climate *Maryland DNR*
  A fact sheet with information on climate risks and solutions for implementation of water quality related BMPs.

Coastal and Riverine

- Climate Change Installation Adaptation and Resiliency: Planning Handbook *NAVFAC*
  An analytical framework and methodology to help planners understand how to consider climate change in plans and projects.
- Coastal Flood Exposure Mapper *NOAA*
- A collection of visualization tools and maps to assess vulnerability to sea level rise and other coastal flood hazards.
- Building Resilience through Habitat Restoration *Maryland DNR*

Recommendations on how to incorporate climate change considerations into restoration decision-making processes.

Agriculture and Forestry

- USDA Climate Hubs - A collection of resources for farm and forest managers to make climate informed decisions.
- Implementation of BMP Strategies for Adaptation to Climate Change and Land Use in a Pasture-Dominated Watershed *Chiang et al.*
  Paper predicts the impact of climate change on 171 pastural BMP combinations and recommends those that are the most resilient.
- Using Cover Crops to Mitigate and Adapt to Climate Change *Kaye, Jason P. and Miguel Quemada*
  Paper on the use of cover crops to mitigate climate change with information on a case study in Pennsylvania.
- Assessment of Agricultural BMPs Using Models: Current Issues and Future Perspectives *Xie et. al.*
  The paper suggests model strategies, such as simplified tools and climate integration to better represent agricultural BMPs.
- Agricultural Policy/Environmental eXtender Model (APEX) *Texas A&M*
  A watershed simulation model with climate change capabilities, including assessing increased CO_2 impacts on crop yields.
- Sustaining Forests in a Changing Environment *US Forest Service* – Resources on managing forests in the face of climate change.

Urban/Infrastructure

- Assessment of Climate Change Impacts on Stormwater BMPs and Recommended Design Considerations in Coastal Communities *Horsely Witten Group*
  Report outlines recommendations for improving the selection, siting, design, construction, and operation and maintenance of coastal BMPs to ensure their adaptability and continued performance in the face of climate change.
- National Stormwater Calculator *EPA*
  The calculator uses a selection of low impact development controls to estimate local area annual rainwater and runoff frequency.
- Flood Resilience Guide: A Basic Guide To Water and Wastewater Utilities *EPA*
  The guide includes videos and flood maps to help protect small to medium water and wastewater utilities from flooding.
- Stormwater Management in Response to Climate Change Impacts: Lessons from the Chesapeake Bay and Great Lakes Regions *EPA* A report on strategies and tools to incorporate climate resiliency into community planning.
- Creating Resilient Water Utilities (CRWU) - *EPA*
  Tools to help make drinking water, wastewater, and stormwater utilities more resilient.
- Storm Water Management Model with Climate Assessment Tool (SWMM-CAT) *EPA*
- A management tool to model stormwater runoff and incorporate green infrastructure BMPs, like rain gardens.
- Climate Resilience Evaluation and Awareness Tool (CREAT) *EPA*

Current and long-term weather conditions within the risk assessment tool help utilities plan for extreme weather events.

State-Specific Resources

- Maryland Coastal Atlas *Maryland DNR*
  An interactive GIS tool with access to spatial data to help communities identify areas vulnerable to sea level rise, flooding, and erosion.
- Climate Change Preparedness in NJ: Best Practices for Watershed Management *NJ Climate Adaptation Alliance*
  A list of techniques and Best Management Practices to help local governments adapt to future changes in climate.
- DC Climate Projections and Stormwater Applications *DC Department of Energy and Environment*
  A presentation showing how DC heat index, heat wave, and precipitation projections will influence design storm events.
- AdaptVA *VIMS*
  Data, information and tools for individuals, local programs, and agencies engaged in climate adaptation.
- Delaware Climate Projection Portal *DE Division of Energy and Climate*
  Provides data on Delaware's climate indicators like temperature, precipitation, and length of growing season.
- Community Risk and Resiliency Act (CRRA) *NY Dept. of Environment and Conservation*
  Provisions, resources and implementation guidance for the ACT's requirements for mainstreaming consideration of climate change in state programs.
- Pennsylvania Climate Impacts Assessment *PA DEP*
  Report provides scientific predictions regarding changes in temperature and precipitation in Pennsylvania and a summary of the potential impact of climate change on human health, the economy and other sectors.
- Robust Stormwater Management in the Pittsburgh Region: A Pilot Study *Fischbach et al.*
  The report offers an improved decision making framework for better stormwater management in Pittsburgh.
- West Virginia State Climate Summary *NOAA*
  A summary of observed annual average and extreme temperature and precipitation records for the State of Virginia.
- Fact Sheet: Legal Tools for Climate Resilient Siting *Environmental Law Institute*
  Suggests legal strategies for implementing climate resilient green infrastructure in Virginia and Maryland.