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Resilience to a Changing Climate in the Chesapeake Bay Watershed

Progress, Challenges, Information Gaps, and Opportunities

Neil Berg, Debra Knopman, Benjamin F. Hobbs, Klaus Keller, Robert E. Nicholas

The Mid-Atlantic Regional Integrated Sciences and Assessments (MARISA) program was established in September 2016 through a five-year grant from the National Oceanic and Atmospheric Administration (NOAA). MARISA supports integrated, flexible processes for supporting decision-making and building capacity for adaptation to climate variability and change in diverse settings in the mid-Atlantic region, with an initial focus on the Chesapeake Bay watershed (CBW). MARISA's mission is to bring the best climate science, data, and information to bear on near- and longer-term decisions (e.g., public and private investments in infrastructure, urban and residential development generally, rural and agriculture activities, ecosystem restoration, and other services vital to the economic and social well-being of the CBW) most pressing to stakeholders and end users. The CBW includes all or parts of Maryland, Virginia, Delaware, Pennsylvania, West Virginia, and the District of Columbia (D.C.).

As one of MARISA's first tasks, team members spoke with officials, experts, and other stakeholders from 29 public and private organizations operating in the region to collect their perceptions of climate-related issues that pose the challenges most significant to the stakeholders' near- and longer-term operations and plans. Organizations represented in the discussions were drawn from across the region, as summarized in Table 1. Discussions included phone conversations, in-person visits, and conference meetings that focused on the following questions:

- What decisions and investments under consideration today would most benefit from the inclusion of climate information?
- What adaptation initiatives have been accomplished, and what are proposed future adaptation options?

Table 1. Organizations Represented in the Discussions

Sector	Agency
Federal government	NOAA, U.S. Geological Survey, U.S. Department of Agriculture, and U.S. Army Corps of Engineers
State government	Maryland Department of Natural Resources, Maryland Department of Transportation, and Virginia DEQ
Local government	D.C. Department of Energy and Environment; DC Water; City of Baltimore, Maryland; Harford County, Maryland; and City of Norfolk, Virginia
Academia	West Virginia University; University of Delaware; VIMS, College of William and Mary; Virginia Sea Grant, Old Dominion University; Consortium for Climate Risk in the Urban Northeast; Northeast Climate Science Center; Georgetown Climate Center; and George Mason University
Regional governmental organizations	Metropolitan Washington Council of Governments, Washington Metropolitan Area Transit Authority, Susquehanna River Basin Commission, and Northern Virginia Regional Commission
Nongovernmental organizations	Eastern Shore Land Conservancy and Mid-Atlantic Regional Council on the Ocean
Private sector	PJM Interconnection, Baltimore Gas and Electric Company, and McCormick and Company

NOTE: Virginia DEQ = Virginia Department of Environmental Quality. DC Water = D.C. Water and Sewer Authority. VIMS = Virginia Institute of Marine Science.

- Where are the key knowledge and data gaps in climate resilience and adaptation initiatives?
- What opportunities exist to advance climate resilience efforts?
- What are the challenges to and constraints on advancing those efforts?

In the following sections, we summarize the key points elicited in these discussions related to decisions, investments, operations, or plans that organizations are facing that a changing climate might affect; progress already made toward building resilience; data and information gaps; and the key climate adaptation challenges that lie ahead. Our intent is to provide a high-level summary of these

engagements for a broad audience, with the goals of (1) providing an account of the stakeholder feedback that is helping to shape the priorities for MARISA's efforts going forward and (2) increasing awareness of stakeholder perceptions on the multiple ways in which a changing climate is already affecting or will soon affect costs and operations of public services, ecosystem services, and recreational assets in the region.

Public engagement will continue throughout the course of the MARISA program, and we acknowledge that not all geographical regions and sectors are fully sampled in this initial outreach. Notable gaps in this initial scan include state government agencies in Pennsylvania; stakeholders from urban centers outside of Washington, D.C., and Baltimore, Maryland (for example, Richmond, Virginia); and academic researchers at the University of Maryland. The MARISA team will prioritize discussions with those not initially represented in Table 1 to continually improve our understanding and support of needs in the region. Finally, we note that a subset of our discussions consisted of interviews that are more formal and more structured that we discuss in a forthcoming academic report. The future report will complement this report by providing technical details on the interview protocol, a subsequent survey of interviewees, and an analytical process of extracting and ranking meaningful insights into regional priorities and the drivers of those priorities.

Decisions Most Affected by a Changing Climate

MARISA's overarching goal behind engaging stakeholders was to better understand firsthand perspectives on how climate variability and change are affecting or might affect decisions, investments, plans, operations, and other issues, including social equity facing a wide range of organizations and communities around the CBW (Table 1). Participants discussed impacts on numerous sectors, although responses to our discussion questions tended to center on transportation and the management of land and water. Each of the following sections summarizes responses to the questions in our stakeholder discussions, while also providing some reference to known efforts or background material for each topic area.

Transportation

One sector that the climate is likely to affect in terms of costs and long-term investment decisions is transportation. The Maryland Department of Transportation is already examining anticipated impacts from future coastal flooding.[1] Along the coast, nuisance flooding[2]—when high tides encroach on the shoreline and cause public inconveniences, such as disrupting the mobility and connectivity in the region—is already a major problem in some of the state's low-lying and subsiding Eastern Shore communities. Similar hazards are also plaguing coastal communities in Hampton Roads,

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Virginia, where residents have to navigate around regularly flooded roads during high tides.[3]

Adapting to nuisance flooding events that are more frequent and more severe under higher sea levels includes such options as raising the height of affected roadbeds, installing culverts to divert water from roadbeds, and using surface materials that are more permeable. Measures that are more drastic in the longer term, such as managed retreat away from persistently inundated roadways or at least diverting government funds from the maintenance of those roads, might need to be considered.

Although the Maryland Department of Transportation has initially focused on flooding impacts on the road network, rising temperatures could also affect the performance of highway and local road surfaces. Surface materials that are more heat tolerant might be necessary under future climates with longer periods of extremely hot temperatures.

As a more urban example, decisions and investments within the Washington Metropolitan Area Transit Authority system also are likely to be influenced by climate change. Increased extreme heat could exacerbate the occurrence of kinked rail,[4] requiring more maintenance or the installation of new materials that can better withstand higher temperatures. It also places additional strain on the heating and cooling demands within the railcars and the stations. Rising temperatures also influence the timing and scheduling of maintenance repairs; crews will have to work around increased occurrences of "no-labor-time work rules" regarding harmful heat conditions both inside and outside of the railway tunnels.

Indirect temperature impacts to the Metro system are also of concern. Increased precipitation and other synergistic effects of a warmer atmosphere could increase the occurrence of extreme snowfall events during winter months.[5] This could disrupt transit services because, to ensure safe train operations, aboveground rail service is suspended when eight or more inches of snow falls. Moreover, Metro station entrances might need to be raised or hardened to protect them and the system's occupants from expected increases in flash floods and other extreme rainfall events in a warmer climate.[6]

Land Management

Coastal and interior land management in the CBW makes up another set of decisions and investments that climate change could affect. For instance, the Maryland Department of Natural Resources has a program to rank and acquire lands for conservation or recreational purposes.[7] One key objective of the organization is to avoid purchasing land now that could be inundated in the near future; otherwise, significant state-based fiscal resources could be wasted. Therefore, the organization reduces the score of coastal land parcels that it expects 2050 sea levels to inundate. However, there is significant uncertainty in sea level rise projections, and the Maryland Department of Natural Resources recognizes that additional data sets and tools could help its decisionmaking process for land acquisitions.

Naturally occurring tidal fluctuations superimposed on higher water levels due to rising seas might also increase the frequency or severity of tidal flooding, which implicates decisions to control coastal erosion. Living shorelines are an increasingly popular ecosystem-based adaptation response in the region[8] employed by the Maryland Department of Natural Resources and the Virginia DEQ and researched by VIMS.[9] Living shorelines represent portions of the coast that are lined with native trees and shrubs, often

in conjunction with other natural materials to reduce soil erosion. Additionally, the natural features help reduce sediment loading to the bay and improve water quality and can help absorb wave energy during storm surges that can mitigate inland damage. Although this technique is attractive for its emphasis on using natural materials, whether these living shorelines can withstand significant sea level rise and increased severity of flooding hazards remains an area of active research.

Interior land management policies and practices, particularly in rural and agricultural regions in the mid-Atlantic, also are expected to be affected by climate change. Here, sea level rise is of less concern, but the possibility of increased extreme rainfall events (and changes in temperature) poses a major threat to efforts to control stormwater runoff and pollutant deposition into bay tributaries through the use of current or planned best management practices (BMPs). In this context, BMPs are techniques to improve water quality, usually by reducing runoff volumes through more pervious landscapes or by installing barriers and filters that help remove pollutants from the runoff.[10] Modifying land use patterns or implementing new BMPs often requires the exercise of local regulatory authority and can be costly for landowners and local government. Nonetheless, effective interior land management decisions will be needed in the future to protect ecosystems, water quality, and agricultural economies in the CBW.

Water Management

Investment and operational decisions to ensure the adequacy of freshwater supplies and maintain water quality standards in the CBW are likely to be highly affected by climate change. DC Water, a water and wastewater utility servicing the District of Columbia

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and parts of Maryland and Virginia, has taken progressive steps to increase resilience of its facilities along the banks of the Potomac River. The organization has begun installing a $13 million, 17-foot-high sea wall to help protect its Blue Plains Advanced Wastewater Treatment Plant from rising seas and increased storm surge hazards.[11] Like many mid-Atlantic cities, Washington, D.C., has a combined stormwater and sewer system. To help limit sewer overflows, DC Water has undertaken several green infrastructure projects—including green roofs, pervious pavement, and bioretention zones—at its facilities and other locations in the city to reduce the amount of stormwater entering the combined system.[12]

Further upstream in the CBW, the Susquehanna River Basin Commission (SRBC), an interstate federal agency responsible for managing water resources along the Susquehanna River, is also beginning to plan for the effects of climate change on its dam management and operational decisions and investments. For instance, the Federal Energy Regulatory Commission license to Exelon Corporation (through its Susquehanna Electric Company subsidiary) to operate the Conowingo Dam, a 548-megawatt hydroelectric dam in the lower Susquehanna River, has recently expired.[13] Exelon is seeking a 40-year license renewal, and part of this licensing process requires environmental impact reviews. Currently, the reviews

consider only historical streamflows and sediment deposition, but, given the 40-year time horizon of the desired license, SRBC is aware that future precipitation changes could significantly alter streamflow patterns, operations, and environmental impacts related to the dam relicensing.

Alongside water quantity issues, climate change is also expected to affect water quality in the CBW. Coastal communities that withdraw groundwater from regional aquifers might need to shift pumping wells inland to avoid the encroachment of saltwater intrusion under higher sea levels. Similarly, coastal marshes and ecosystems might be affected by a larger inland extent of saline waters. Recent efforts (and successes[14]) by CBW states to reduce harmful nutrient and sediment deposits (i.e., through the federal Clean Water Act's total maximum daily load program[15]) to the bay might be challenged by rainfall events that are more extreme. As a result, the Chesapeake Bay Program has undertaken major efforts to develop and incorporate climate change information into its planning processes for total maximum daily load.[16]

Summary of Climate Impacts

Our initial public engagement revealed a myriad of decisions, investments, plans, and operations across the CBW that are sensitive to changes in the climate. Table 2 summarizes stakeholder views on some of the issues of most importance that were raised in our discussions. Addressing them will require extensive research and, in some cases, the development of new data sets to fill major data and information gaps, which we discuss further in the next section.

Table 2. Summary of Stakeholder Views of Decisions Dependent on Changes in Sea Level, Temperature, and Precipitation

Subject Area	Dependent Decisions
Sea level rise	Protecting transportation networks, electrical substations, homes, and buildings from coastal flooding; purchasing noninundated coastal land and easements; managing water quality through erosion control; and ensuring freshwater availability via groundwater withdrawals
Extreme temperature	Maintaining performance of railway and road materials; planning underground labor tasks around hazardous heat conditions; managing electricity demand for cooling needs; and ensuring safe air quality, particularly in urban heat islands
Extreme precipitation	Protecting transportation networks and the built environment from inland flooding; managing urban stormwater and rural, agricultural runoff; and managing hydroelectric power generation and dam regulations

Data and Information Gaps

The mid-Atlantic region is expected to experience changes in temperature, precipitation, and sea levels. Consequently, questions being asked now by end users and stakeholders of climate information include the following:

- How much will temperature rise across different seasons and between urban and rural areas?
- How will precipitation extremes, not just average amounts, shift in a warmer world?
- How should infrastructure and other development plans be forged around a range of plausible sea level rise scenarios?
- How do changes in precipitation and sea level rise jointly influence coastal and inland flooding hazards?
- What data visualization and decision-support tools incorporating climate information are available to help inform stakeholders and decisionmakers?

Key data and information gaps for temperature, precipitation, and sea level rise are slowing progress toward answering these questions, according to those with whom we spoke and relevant literature. The following sections provide a summary of stakeholder views on these primary data and information gaps.

Temperature

According to current observational trends and a wide range of global climate models,[17] increased temperatures are widely expected in the region and understood by most decisionmakers in the watershed. Numerous public observational data sets and projections (both observations and projections are hereafter referred to as *data*) from credible scientific bodies, accompanied by user-friendly tools and visualizations, are available, a sampling of which is presented in Table 3 and discussed later in this report. Many of these data products focus, however, on longer-term or larger regional average values. In our interviews, numerous stakeholders expressed interest in having more data and supporting tools that examine changes in short-term extremes. In general, though, it is a challenge (not just for end users) to understand how temperature changes will directly or indirectly affect their decisionmaking and to gather and interpret the relevant data. For instance, rising temperatures will alter the frequency and duration of no-work times because of an increase in hazardous work conditions, an issue particularly relevant to maintenance schedules in the water and transportation sectors. Electricity generators also lack temperature projections for different seasons, which limits a comprehensive understanding of how peak demands might shift under future climate scenarios.

Precipitation

Highlighted by the devastating flood in 2016 in Ellicott City, Maryland,[18] urban residents and decisionmakers are increasingly aware of the confluence between projected increases in rainfall extremes and outdated stormwater infrastructure in many mid-

Most available data sets on future changes in precipitation tend to focus on average values and at spatial and temporal scales larger than those necessary for stormwater modeling efforts for individual towns and cities.

Table 3. Temperature Data Sets and Display Tools for Use in the Chesapeake Bay Watershed

Organization	Data Set or Tool	Access
NOAA	Global Climate Dashboard	NOAA, "Global Climate Dashboard," undated (b)
U.S. Climate Resilience Toolkit	Climate Explorer	U.S. Climate Resilience Toolkit, "The Climate Explorer," undated
NOAA National Centers for Environmental Information	Local climatological data	National Centers for Environmental Information, NOAA, "Data Tools: Local Climatological Data (LCD)," undated
Northeast Regional Climate Center	Monthly maps	Northeast Regional Climate Center, "Monthly Maps," undated
2014 National Climate Assessment	Northeast report	Radley Horton, Gary Yohe, William Easterling, Robert Kates, Matthias Ruth, Edna Sussman, Adam Whelchel, David Wolfe, and Fredric Lipschultz, "Northeast," in Jerry M. Melillo, Terese Richmond, and Gary W. Yohe, eds., *Climate Change Impacts in the United States: The Third National Climate Assessment*, U.S. Global Change Research Program, 2014, pp. 371–395
D.C. Department of Energy and Environment	Climate projections	D.C. Department of Energy and Environment, "Climate Projections and Scenario Development," September 10, 2015
Office of the Delaware State Climatologist	University of Delaware climate projections	Office of the Delaware State Climatologist, "Delaware Climate Projections Portal," undated
Center for Coastal Resources Management	VIMS climate database	Center for Coastal Resources Management, VIMS, "Climate Change Impacts in Virginia: A Natural Resource Database," undated (a)

Atlantic towns. Most available data sets on future changes in precipitation tend to focus on average values and at spatial and temporal scales larger than those necessary for stormwater modeling efforts for individual towns and cities. To guide the sound design of stormwater storage and conveyance structures, precipitation data sets are needed on subdaily time scales and on finer-resolution grids.[19] Concurrently, tools and guidance documents need to be crafted that help translate observed precipitation data to electronic data formats accessible and useful to local governments and planning departments for downstream analyses.

Rural communities could also benefit from new precipitation data sets for decisions concerning runoff and land management

practices. For instance, discussions with the Virginia DEQ revealed a need to better understand how extreme rainfall currently influences, and how future changes in this variable might further influence, the performance of agricultural BMPs. Existing precipitation data sets currently limit an undertaking of these analyses. Regionally averaged precipitation trends in the latest National Climate Assessment (see Table 3), for example, are too coarse for county- or even state-specific analyses. Conversely, point-based historical measurements or future projections of precipitation (for instance, those developed by the D.C. Department of Energy and Environment in Table 3) are too narrow in space for applications across larger land areas.

Water resource planners also struggle with incorporating precipitation changes into their decisions relating to the management and operations of dams in the region. Because of current limitations in both forecasting changes in precipitation and translating those changes to surface flows, managers in the SRBC rely solely on historical time series of rainfall and streamflow when thinking through long-term operations and permitting of dams, even though changes in precipitation patterns (timing, duration, and spatial distribution) are anticipated to occur.

Sea Level Rise

Currently, relative sea level rise is occurring twice as fast in the bay region than the global average.[20] Because of this sobering finding, coastal communities in the CBW are keenly aware of the need to understand the potential height range of sea level rise in the coming decades. The states of Maryland, Delaware, and Virginia have access to regional sea level rise scenarios and data visualization tools, ranging from static images to interactive inundation maps.[21] In light of new research and data on the dynamics driving sea level rise, NOAA has also recently updated sea level rise trends and scenarios for regions along the mid-Atlantic coast.[22]

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Although these data sets and tools provide a wealth of information, end users often have difficulty learning the techniques and approaches to structure analysis of long-term decisions under uncertainty. Policy guidance on how to plan under a range of plausible futures is also lacking. For example, discussions with the D.C. Silver Jackets, consisting of technical staff from the U.S. Army Corps of Engineers and technical experts from local government agencies, have highlighted the challenges of incorporating multiple scenarios of sea level rise in their decisionmaking processes to develop or upgrade infrastructure that often rely on the standard engineering practice of designing around a single expected value (e.g., the 100-year tidal stage).

Local Effects of a Changing Climate

Climate impacts and related adaptation strategies throughout the Chesapeake Bay are as varied as the residents and ecosystems in its watershed. Our conversations overwhelmingly demonstrated that state-, county-, and community-level agencies and organizations are rising to the challenging tasks of preparing for and adapting to a

changing climate. It is on these smaller spatial scales at which local residents and decisionmakers will jointly experience the impacts of climate in their lives and can co-develop strategies that safeguard their communities to climate variability and change. Former Speaker of the House Tip O'Neill's popular phrase "all politics is local" can aptly be modified to "all climate is local" to motivate understanding of and response to climate change in cities, towns, counties, individual states, and multistate regions within the CBW. Although our discussions overwhelmingly revealed that climate adaptation is based on local attitudes, knowledge, budgets, and politics, we do wish to emphasize that a regional and national perspective is obviously needed. The federal government has many ways to enable and constrain adaptation at the state and local levels.

Progress Is Visible

Chesapeake Bay states and communities are taking diverse and forward-thinking steps to strengthen their resilience to climate change. Virginia; Maryland; Washington, D.C.; Pennsylvania; Delaware; and New York have all developed state-level climate action plans.[23] Supporting these plans and related research efforts, projections of future temperature and precipitation have been developed for locations in Washington, D.C., and Delaware (see Table 2), alongside region-specific sea level rise scenarios for coastlines in Virginia, Maryland, and Delaware.[24] Studies have examined the impacts that sea level rise can have on aspects of Maryland's transportation system,[25] that ocean acidification can have on Chesapeake Bay ecologies and aquatic economies,[26] and that rainfall changes can have on urban stormwater drainage systems.[27]

Individual counties and smaller localities have gone beyond identifying vulnerabilities by developing plans or actions to prepare for expected changes in the climate. For instance, green infrastructure plans have been crafted for Harford County, Maryland,[28] and a climate adaptation plan has been finalized in Washington, D.C., with specific action items to increase the city's transportation, utility, and community resilience under a changing climate.[29] Throughout the entire CBW, progress toward understanding and adapting to climate change is visible.

Challenges Remain

Although clear efforts have been made to incorporate a changing climate into local decisionmaking processes and adaptation measures, communities continue to face considerable challenges to analyze and implement actions to strengthen their climate resilience.[30] Differing views of the shorter- and longer-term effects of rising greenhouse gas concentrations in the atmosphere affect research plans and funding and public communication about the issue. Neighboring counties often hold contradictory views on the causes and trends of a changing climate that are limiting consideration of larger, regional-scale adaptation strategies, according to some we interviewed.

Agencies facing decisions affected by a changing climate will need to allocate resources to help reduce uncertainty surrounding future climates at the relevant scales, train and staff organizations with scientific and technical experts, develop effective and feasible adaptation strategies, and enhance communication and knowledge transfer across climate-affected stakeholders throughout the region. Year-to-year financial structures of many organizations, such as the Washington Metropolitan Area Transit Authority, also limit the incorporation of new climate information into longer-term investments and decisions.

The large presence of military and other federally managed lands throughout the region further complicates garnering funds for local adaptation projects around the bay. For instance, Hampton Roads, Virginia, already experiences problematic nuisance floods, an issue that is expected to worsen under rising sea levels and potential intensification of storm surges. Local governments and the private sector need to coordinate plans and funding with federal partners to support local adaptation projects.

Poor data accessibility and lack of guidance on how to appropriately use climate data are common concerns voiced by the state and local government officials with whom we spoke. These officials generally lack sufficient technical and human resources to fully understand and apply the typically academically developed climate information to their needs. Our discussions with water resource managers and a regional power distributor revealed that future climate projections are typically not included in their modeling or planning efforts. Instead, these entities base their decisions solely on historical conditions, assumptions that might not hold under many plausible future climate scenarios.[31]

Going beyond local issues in the CBW, it is also important to examine larger-scale climate effects on transportation corridors, water and electrical networks, and public health that span the greater mid-Atlantic and adjacent regions. Although there is strong interest in performing regional studies—for instance, the coupling of watershed-scale water quality and flood models—they remain an underexplored area of research because of strong coordination requirements; challenges associated with integrating complex local models together into a regional system; and a lack of unified, regional climate data sets required for such efforts. Our discussions with NOAA partners in New York City and Boston confirmed that work remains to understand climate impacts in the mid-Atlantic and Northeast, for instance, to transit networks along the Interstate 95 corridor in those regions.

Scientists and other researchers will need to work closely with local officials and an inclusive set of diverse community members to co-develop workable strategies that address the growing threats of a changing climate throughout the bay region.

How MARISA Can Help Strengthen Regional Resilience to a Changing Climate

The Chesapeake Bay region has many governmental agencies, academic institutions, nonprofits, and other community organizations seeking to improve environmental conditions along the bay and strengthen climate resilience in populations around the bay. For reference, consider that the Chesapeake Bay Program has partnerships with more than 90 different entities related to restoration activities.[32] Such a large and diverse set of organizations has yielded a large pool of informed and climate-savvy decisionmakers and a multitude of high-quality data sets and tools to support resilience efforts in the region.

However, no centralized entity serves as a portal for all of these disparate tranches of data or provides a one-stop shop for guidance documents and tools for use by nonexperts. An advantage of this decentralized landscape of climate information is that it provides for a high degree of flexibility for individual sectors to develop and

apply tailored data sets and tools for their specific objectives. A disadvantage is that it can lead to inconsistencies in impact studies across sectors and prevent analyses that are more comprehensive and more unified from being conducted. Local officials in particular are struggling with this decentralized approach. In our interviews, many expressed frustration with data overload, confusion, and lack of guidance to help them execute their duties. Therefore, MARISA will seek to develop new and compile existing data sets that can be more consistently applied to analyze climate-affected decisions throughout the CBW.

After decades of foundational research that has produced many high-quality data products, the next step to advance region-wide climate resilience is to make these products more easily accessible and user-friendly for nonexperts to quickly obtain and apply in their work. Because MARISA recognizes this issue, climate products that it develops or maintains will be transformed into useful formats, metrics, and interactive displays based on end-user feedback.

Going forward, local and state governments will have an even greater need to set priorities for project implementation and funding to make meaningful progress on climate adaptation. Scientists and other researchers will need to work closely with local officials and an inclusive set of diverse community members to co-develop workable strategies that address the growing threats of a changing climate throughout the bay region. Building on this initial round of public engagement, MARISA will regularly elicit stakeholder views on climate resilience activities to ensure that the program's efforts remain responsive and impactful in the region.

Related Readings and Links

Delaware Department of Natural Resources and Environmental Control Division of Energy and Climate, *Climate Action in Delaware: 2016 Progress Report*, December 2016. As of September 8, 2017: http://www.dnrec.delaware.gov/energy/Documents/2016%20Climate%20Action%20Progress%20Report/Climate%20Action%20in%20Delaware%202016%20Progress%20Report.pdf

District of Columbia Department of Energy and Environment, *Climate Ready DC: The District of Columbia's Plan to Adapt to a Changing Climate*, undated. As of September 8, 2017: https://doee.dc.gov/sites/default/files/dc/sites/ddoe/service_content/attachments/CRDC-Report-FINAL-Web.pdf

Maryland Commission on Climate Change Adaptation and Response Working Group, *Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change, Phase I: Sea-Level Rise and Coastal Storms*, August 2008. As of September 8, 2017: http://dnr.maryland.gov/ccs/Publication/Comprehensive_Strategy.pdf

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New York State Climate Action Council, *Climate Action Plan: Interim Report*, November 2010. As of September 8, 2017: http://www.dec.ny.gov/docs/administration_pdf/irpart1.pdf

Pennsylvania Department of Environmental Protection, *Pennsylvania Climate Adaptation Planning Report: Risks and Practical Recommendations*, 2011. As of September 8, 2017: http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-103584/2700-RE-DEP4303%20Combined.pdf

Virginia Governor's Commission on Climate Change, *Governor's Commission on Climate Change: Final Report—A Climate Change Action Plan*, December 15, 2008. As of September 8, 2017: http://www.sealevelrisevirginia.net/docs/homepage/CCC_Final_Report-Final_12152008.pdf

Notes

[1] The Maryland State Highway Administration recently examined the vulnerability of the organization's assets to future sea level rise and other climate changes (Elizabeth Habic, Maryland State Highway Administration, Office of Planning and Preliminary Engineering, *Maryland Adaptation and Vulnerability Assessment*, briefing, July 8, 2015).

[2] National Ocean Service, National Oceanic and Atmospheric Administration, "What Is Nuisance Flooding?" revised July 6, 2017.

[3] VIMS recently detailed this phenomenon and related adaptation strategies in Center for Coastal Resources Management, Virginia Institute of Marine Science, *Recurrent Flooding Study for Tidewater Virginia*, January 2013.

[4] *Kinked rail* refers to tracks that have buckled in extreme heat. They can cause derailments.

[5] This phenomenon might already be occurring: Events producing at least 16 inches of snow in the District of Columbia are occurring nine times more often now than in years before 1979. Additional data and information can be found in Jason Samenow, "Is Global Warming Behind D.C.'s New Era of Great Snowstorms?" *Washington Post*, February 3, 2016. Additional research on this topic can be found in Jay Lawrimore, Thomas R. Karl, Mike Squires, David A. Robinson, and Kenneth E. Kunkel, "Trends and Variability in Severe Snowstorms East of the Rocky Mountains," *Journal of Hydrometeorology*, Vol. 15, No. 5, October 2014.

[6] D.C. Metro stations are already vulnerable to flooding, as highlighted by the June 2016 flash flood that inundated the Cleveland Park station and temporarily disrupted rail service there. Pictures and more information are available in Faiz Siddiqui, "Cleveland Park Metro Station Reopens After Flooding Turns It into a Waterfall," *Washington Post*, June 22, 2016.

[7] Additional details on this program can be found at Maryland Department of Natural Resources, "Land Acquisition and Planning," undated; referenced April 28, 2017.

[8] A review of ecosystem-based adaptation strategies can be found in Richard Munang, Ibrahim Thiaw, Keith Alverson, Musonda Mumba, Jian Liu, and Mike Rivington, "Climate Change and Ecosystem-Based Adaptation: A New Pragmatic Approach to Buffering Climate Change Impacts," *Current Opinion in Environmental Sustainability*, Vol. 5, No. 1, March 2013, pp. 67–71.

[9] For instance, the Virginia DEQ recently developed guidelines for a Living Shorelines Loan Program for the State Water Control Board, accessible at Virginia DEQ, "Guidelines for New Living Shoreline Loan Program," undated.

[10] U.S. Environmental Protection Agency, *Guidance for Developing Best Management Practices (BMP)*, Washington, D.C., EPA 833-B-93-004, October 1993.

[11] Additional details can be found at U.S. Environmental Protection Agency, "Blue Plains Wastewater Facility in Washington DC Reinforces Facility Against Floods," last updated March 6, 2017.

[12] Additional details and examples can be found at DC Water, "Green Infrastructure Projects at DC Water Facilities," undated.

[13] Conowingo Dam Facts, "Relicensing Conowingo Dam," undated.

[14] The Chesapeake Bay Foundation's *2016 State of the Bay Report* (Chesapeake Bay Foundation, "2016 State of the Bay Report," undated) finds recent bay-wide water quality improvements.

[15] Public Law 80-845, Federal Water Pollution Control Act, June 30, 1948, as amended.

[16] Z. Johnson, M. Bennett, L. Linker, S. Julius, R. Najjar, M. Mitchell, D. Montali, and R. Dixon, *The Development of Climate Projections for Use in Chesapeake Bay Program Assessments*, Edgewater, Md., Scientific and Technical Advisory Committee, Publication 16-006, October 2016.

[17] A summary of current and future temperature trends for the United States can be found in John Walsh, Donald Wuebbles, Katharine Hayhoe, James Kossin, Kenneth Kunkel, Graeme Stephens, Peter Thorne, Russell Vose, Michael Wehner, Josh Willis, David Anderson, Scott Doney, Richard Feely, Paula Hennon, Viatcheslav Kharin, Thomas Knutson, Felix Landerer, Tim Lenton, John Kennedy, and Richard Somerville, "Our Changing Climate," in J. M. Melillo, Terese (T. C.) Richmond, and G. W. Yohe, eds., *Climate Change Impacts in the United States: The Third National Climate Assessment*, U.S. Global Change Research Program, 2014, pp. 19–67. Corresponding interactive visualizations can be found at Jerry M. Melillo, Terese Richmond, and Gary W. Yohe, eds., *Climate Change Impacts in the United States: The Third National Climate Assessment*, U.S. Global Change Research Program, 2014.

[18] National Weather Service, National Oceanic and Atmospheric Administration, "Ellicott City Historic Rain and Flash Flood: July 30, 2016," updated September 1, 2016.

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Acknowledgments

We thank Kelly Klima and Lora Harris for their helpful feedback on this manuscript. Research was supported by the National Oceanic and Atmospheric Administration, Climate Program Office, under grant NA16OAR4310179.

About the Authors

Neil Berg is an associate physical scientist at RAND.

Debra Knopman is a principal researcher at RAND and professor at the Pardee RAND Graduate School.

Benjamin F. Hobbs is the Theodore M. and Kay W. Schad Professor of Environmental Management in the Department of Environmental Health and Engineering at Johns Hopkins University.

Klaus Keller is a professor of geosciences in the Department of Geosciences at Pennsylvania State University.

Robert E. Nicholas is an assistant research professor at the Earth and Environmental Systems Institute at Pennsylvania State University.

All the authors are members of the Mid-Atlantic Regional Integrated Sciences and Assessments (MARISA) team.

About This Perspective

The Mid-Atlantic Regional Integrated Sciences and Assessments (MARISA) program was established in September 2016 through a five-year grant from the National Oceanic and Atmospheric Administration (NOAA). MARISA supports integrated, flexible processes for building capacity to adapt to climate variability and change in diverse settings in the mid-Atlantic region, with an initial focus on the Chesapeake Bay watershed.

MARISA is led by the nonprofit RAND Corporation, in partnership with researchers in the Earth and Environmental Systems Institute at Pennsylvania State University and the Environment, Energy, Sustainability and Health Institute at Johns Hopkins University, along with support from researchers in the Department of Earth and Atmospheric Sciences at Cornell University.

This perspective is the first written, published product of MARISA and is intended to synthesize the interests and priorities that emerged from our initial round of interviews and meetings with public officials, technical experts, and stakeholders throughout the region.

RAND Infrastructure Resilience and Environmental Policy

The research reported here was conducted in the RAND Infrastructure Resilience and Environmental Policy program, which performs analyses on urbanization and other stresses. This includes research on infrastructure development; infrastructure financing; energy policy; urban planning and the role of public–private partnerships; transportation policy; climate response, mitigation, and adaptation; environmental sustainability; and water resource management and coastal protection. Program research is supported by government agencies, foundations, and the private sector.

This program is part of RAND Justice, Infrastructure, and Environment, a division of the RAND Corporation dedicated to improving policy- and decisionmaking in a wide range of policy domains, including civil and criminal justice, infrastructure protection and homeland security, transportation and energy policy, and environmental and natural resource policy.

Questions or comments about this report should be sent to the project leader, Debra Knopman (knopman@rand.org). For more information about RAND Infrastructure Resilience and Environmental Policy, see www.rand.org/jie/irep or contact the director at irep@rand.org.

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PE-243-NOAA (2017)