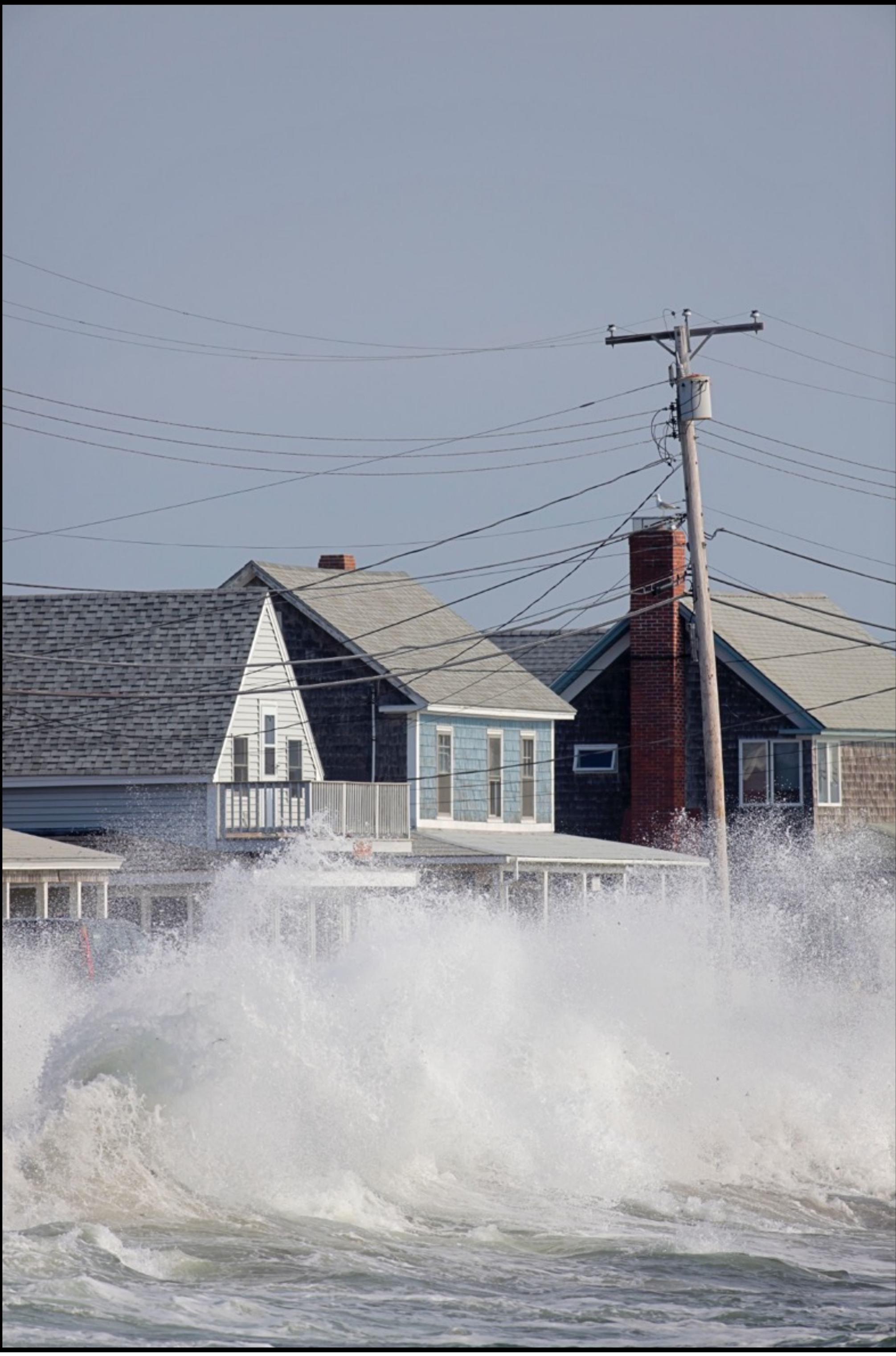

# Water & the Coasts

## Opportunity, Vulnerability, & Risk Management

American Meteorological Society
Policy Program Study
April 2017

Policy Program Study

# Water and the Coasts: Opportunity, Vulnerability, and Risk Management

American Meteorological Society

This report should be cited as:
AMS Policy Program, 2017. Water and the Coasts: Opportunity, Vulnerability, and Risk Management. An AMS Policy Program Study. The American Meteorological Society, Washington, D.C.

The American Meteorological Society's Policy Program is supported in part through a public—private partnership that brings together corporate patrons and underwriters, and Federal agencies. Supporting agencies include the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the National Science Foundation (NSF). Corporate partners include Ball Aerospace & Technologies and Lockheed Martin.

The findings, opinions, conclusions, and recommendations expressed in this report do not necessarily reflect the views of AMS or its members and supporters.

The American Meteorological Society (AMS) is a scientific and professional society of roughly 13,000 members from the United States and over 100 foreign countries.

Additional copies of this report can be found online at: http://www.ametsoc.org/studies

**Acknowledgements**: This study is based primarily on two AMS Policy Program workshops that were held at the end of 2016. We thank the speakers and participants for valuable thoughts and insights. Jennifer Sprague, Audra Luscher-Aissaoui, Carl Gouldman, Jonathan Gourley, and Peter Colohan, helped provide valuable feedback on an earlier draft. This work was supported, in part, by grants from the National Oceanic and Atmospheric Administration (grant #NA15NOS4690029) and the National Aeronautics and Space Administration (grant #NNX13AM26G).

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## About the AMS Policy Program

The AMS Policy Program has two primary goals. The first is ensuring that policy choices take full advantage of information and services relating to weather, water, and climate. The second is making sure that policy makers understand how much the broader society's welfare depends on information and services relating to weather, water, and climate. Meeting these two goals will help ensure that the scientific community receives the support and resources it needs to be able to make critical information and services available and, most importantly, will help the nation, and the world, avoid risks and realize opportunities related to the Earth system.

The Policy Program uses three primary approaches to help meet these two goals.

- We develop capacity within the AMS community for effective and constructive engagement with the broader society.
- We inform policy makers directly on established scientific understanding and the latest policy-relevant research.
- We help expand the knowledge base needed for incorporating scientific understanding into the policy process through research and analysis.

Through these activities, we create new ways to reduce society's vulnerability to weather and climate events by sharing our resources and information with policy makers and the public.

# Executive Summary

Water is simultaneously a resource and a threat. It is of central importance to our socioeconomic wellbeing and it becomes a hazard when there is too much, too little, or if the quality is poor.

Water poses challenges and opportunities throughout the country (and the world). These challenges and opportunities are often acutely evident in coastal areas, which are both incredible national resources and sites of significant vulnerability. Factors like population growth and land use change combine with high impact weather events to threaten coastal communities. Furthermore, many communities that already suffer the effects of high impact weather will face new and magnified risks over the coming decades due to ongoing changes in climate. Effective coastal risk management depends on minimizing vulnerabilities while preparing for and responding to unavoidable hazards.

In this study we identify seven key approaches for advancing coastal risk management. These seven approaches are:

1) Provide Actionable Information
2) Prepare and Empower Information Users
3) Create Decision Support Products and Services that Harness Scientific Advances for Societal Benefit
4) Build Strong Partnerships Among Stakeholders, Practitioners, and Information Providers
5) Develop the Next Generation Workforce
6) Align Roles and Responsibilities
7) Recognize Linkages and Potential Leverage

### Provide Actionable Information (observations, science, and forecasts)

Coastal risk management can be enhanced through improvements in observational capabilities, science (including research, data assimilation, and models), and computational power.

For any particular weather or climate event, sources of water may include precipitation, tides, waves, sea level rise, storm surge, and rivers. Factors that influence water's behavior include geomorphology, hydrological connectivity, land use patterns and grey or green infrastructure (e.g., marshes, wetlands, levies, seawalls, and other physical barriers). Forecasts of water quantity and quality are most useful when they account for all sources of water and all factors that influence water's behavior.

Providing accurate information along the coasts is particularly difficult, both because of observational gaps and lack of interoperability among different modeling approaches (e.g., river forecast, wave, ice, estuarine hydrodynamic, and storm surge models). In addition, it is important to understand the linkages among weather, water, and climate, and to confront the specific challenges that arise over different weather and climate timescales (i.e., minutes to two weeks; two weeks to two months; and two months and beyond).

The natural and social sciences also provide critical information relating to coastal risk assessment and management. For example, the natural sciences help reveal potential human health related impacts and responses of biological systems—including the potential to enhance or disrupt biological resources and the goods and services that they provide to coastal communities.

The social sciences help reveal the socioeconomic implications of weather events, which can disrupt social institutions and disturb biological resources upon which coastal communities often depend in complex ways. Critically, improved integration of physical, natural, and social sciences is necessary for understanding linkages among the physical climate system, biological systems, and socioeconomic wellbeing.

**Prepare and Empower Information Users**

Stakeholders, emergency managers and other practitioners, policy makers, the media, and the public need to be equipped to use information effectively. This can greatly enhance the value of information.

Formal education at all levels (pre-K through college and graduate training) and informal education are central to the development of people's capacity to take up and use information effectively.

Effective communication and stakeholder engagement are also critical in building an informed public that recognizes coastal vulnerabilities, effectively weighs options for risk management, and knows how to respond appropriately when confronting hazards. Public awareness is also a central component of effective governance in a democratic society, as policy decisions and funding priorities ultimately reflect the choices of the people.

Influxes of people and turnover among coastal populations ensure that efforts to prepare and empower information users must be ongoing. Similarly, long periods of time between the recurrence of high impact events require strategies for overcoming complacency and for ensuring that people know how to respond to threats and opportunities in a timely and constructive manner.

Finally, insights from the social sciences can improve our understanding of how to engage effectively with stakeholders, emergency managers and other practitioners, information users, policy makers, the media, and the public. Most notably, though not exclusively, through enhanced risk communication.

**Create Services and Decision Support Products that Harness Scientific Advances for Societal Benefit**

Information is necessary but not sufficient for effective coastal risk assessment and management. In order for users and stakeholders to take advantage of the information generated by the weather, water, and climate community, that information must be in forms that are easy to access and that meet users' needs. Products and services that are tailored to user needs make it easier for municipalities to integrate risk management into their decision-making.

Big data and data analytics offer increasing potential to contribute to risk management services and decision support products. To be effective, there is need for a common and straightforward data collection systems, formatting, and user-friendly access. Data (and model) interoperability among information providers and users can enhance uptake and use.

Efforts to reduce repetitive losses may be particularly promising. One option to reduce repetitive losses is to conduct National Transportation Safety Board (NTSB)-style analyses following high-impact events. Such efforts could identify factors contributing to losses and potential responses to avoid recurrence. Scenario-based exercises might extend this capability to help identify avoidable risks ahead of time and recommend response options, perhaps somewhat similar to stress tests for banks. Such efforts could inform voluntary buyouts programs and regulatory responses.

**Build Strong Partnerships Among Information Providers, Users, and Stakeholders**

Common opportunities and challenges exist in determining public, private, and academic roles across the weather, water, and climate enterprise. Understanding differing perspectives, values, and priorities is critical to successful engagement efforts and collaboration. Efforts to manage water resources have the best chance of success when all stakeholders understand and respect differing views, and work to identify shared values that can be advanced together.

There is a need for strong, sustained networks of connected partners working together across federal agencies and among local, regional, and federal organizations and stakeholders. These relationships must be built and maintained over time. That often requires investments of resources to support collaborative structures and relationships. Institutionalizing key relationships, including focusing on effective mechanisms for bringing groups together, can make them more robust in the face of personnel turnover within agencies and among experts and service providers.

## Develop the Next Generation Workforce

Future generations will be most likely to thrive if the scientists and practitioners who contribute to coastal risk management are trained in the skills and techniques that matter most. Skills of high value are likely to include expertise in probabilistic modeling, stakeholder engagement, risk communication, integrated risk assessment, data analytics, and the integration of the physical, natural, among others.

A highly skilled and capable next generation workforce combined with the public's well-developed capacity to use that information would be a powerful combination for helping to ensure that coastal communities recognize vulnerabilities and respond effectively to hazards.

## Align Roles and Responsibilities

Conflicts arise among users who are separated across local, state, and federal jurisdictions. This creates a need for aligning responsibilities and jurisdictions, and setting the appropriate spatial scales for management. Regional and national coordination is needed for issues that exceed local jurisdictions

In addition, coastal risk management will be most effective when it acknowledges and addresses the realities facing communities and local governments. This includes aligning incentives for sustainable development practices and accounting for the multiple, sometimes conflicting, priorities in water management. Suboptimal allocations of resources can occur when decision-making responsibilities are narrowly focused, and efforts to deal with a problem at one scale can create new problems at other locations or scales. Though challenging, care is needed to implement solutions that work across spatial and temporal scales and that attempt to account for the needs of all users.

Federal roles with respect to water resource management may include: setting of standards; identifying best practices; providing a repository of case studies and/or lessons learned; helping to ensure and enhance public goods; regulation; and the provision of resources to local and regional efforts. Federal efforts that apply to diverse local communities have greater chance of widespread adoption and success.

## Recognize Linkages and Potential Leverage

Connecting coastal vulnerability and risk management to other priorities, like infrastructure or jobs, can maximize the effective use of limited resources and help build interest in coastal efforts. Coastal risk management projects that achieve multiple goals may be more appealing to local communities that must meet many high priority economic and social goals. For example, green infrastructure to mitigate coastal flooding may also provide fisheries habitat and recreational assets. Similarly, coastal projects can create local jobs or provide training in new skills.

Finally, challenges and opportunities to coastal risk management are often at least partly similar throughout the world. The United States can both learn from other countries and share our resources and information with other countries (e.g., identify common needs, case studies, and lessons learned).

This AMS Policy Program study is based primarily on two workshops that occurred in 2016 along with a literature review, off-line discussions with practitioners, and additional analysis. Opportunities for further advancement abound and a sustained effort to advance the national discussion on water is needed. The American Meteorological Society's Policy Program intends a series of follow-on activities to advance an integrated consideration of water and to build a community of practice that includes public, private, and academic sectors that works to provide the information and services needed for managing risks and realizing opportunities associated with weather, water, and climate challenges.

# 1. Introduction

### A. Coastal communities: A critical and vulnerable resource

The coasts of the United States of America are both incredible national resources and sites of significant vulnerability. Although coastal counties represent a small fraction of land in the United States, they have an outsize impact on the health, sustainability, and resilience of the nation.

Coastal Watershed Counties[1] contain less than 20% of the total land in the United States but hold 52% of the nation's population – over 160 million people as of 2010. Coastal Shoreline Counties alone, representing less than 10% of the nation's land area, hold 123 million of those coastal residents. Total population and population density are both expected to increase in the coming years (NOAA 2013).

Coastal counties are also drivers of the nation's economy. In 2012, Coastal Shoreline Counties accounted for $6.9 trillion of the nation's GDP, approximately 45% of all economic activity in the United States (NOAA 2015; NOAA 2013; and NOAA n.d.).

The coasts are also exposed to a variety of risks, and the human and economic impacts of coastal hazards increase as population and infrastructure on the coasts increase. According to AIR Worldwide, the insured value of property on the coasts exceeds $13 trillion (AIR Worldwide 2016).

Maintaining and increasing the resilience of our coasts is critical to ensuring a sustainable, healthy future for the people and natural environments of the coasts.

### B. Understanding coastal vulnerability and risk management

The coasts of the United States face a complex combination of short- and long-term threats and vulnerabilities. Factors like population growth and land use change combine with climate change to challenge the resilience of coastal communities. Many communities that already suffer the effects of high impact weather will face new and magnified threats over the coming decades.

The National Ocean Service defines resilience as "the ability to adapt to changing conditions and withstand—and rapidly recover from—disruption due to emergencies. In other words, it means bouncing back after something bad happens. This ability to overcome, or bounce back, is a concept that applies to individuals, to communities large

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[1] Coastal Shoreline Counties are a subset of Coastal Watershed Counties. Coastal Shoreline Counties are directly adjacent to the open ocean, major estuaries, or the Great Lakes, while Coastal Watershed Counties have significant percentages of land intersecting coastal watersheds. See NOAA 2013 for more information.

and small, to our infrastructure, and to the environment (NOS 2016)."

Risk preparedness and response can also be used beyond the context of hazards and emergencies. Climate change may lead to changes in the amount and timing of precipitation, water temperature, and seasonal shifts, all of which affect the coastal environment, and thus fisheries, agriculture, aquaculture, and other ecosystem-dependent sectors. Coastal resilience includes the ability of ecosystems to maintain their function in the face of multiple stressors (human impacts, drought, changes in precipitation, sea level rise, etc.), whether through absorbing stress, bouncing back, or movement/migration.

Ultimately, risk management is about the communities on the coasts, and their ability to manage hazards, maintain and enhance community health, and sustain economic strength in the face of all of the above stressors, including climate change and high impact weather events.

**C. The role of water in coastal vulnerability and risk management**

Water is central to many of the issues that challenge coastal risk management. Existing vulnerabilities associated with coastal inundation, floods, droughts, the impact of routine and extreme weather events, and the threat of climate change all depend, primarily or in part, on water.

*Water is central to many of the issues that challenge coastal communities. … Water is also of central importance to virtually every economic sector.*

Water is also of central importance to virtually every economic sector. Waterways contribute to the national transportation network, and overland transportation systems are vulnerable to interruption due to flooding. Agriculture relies on precipitation and water for irrigation, whether from groundwater or surface water sources; agriculture is also a major contributor of pollutants that contribute to water quality issues. Water supplies are crucial to the success and health of communities, but urbanization can compromise water quality and increase flooding impacts through stormwater runoff. Water is required to produce energy (i.e., power plant cooling and hydropower), and energy is required to divert and transport water from areas where it poses risks and to areas where it is needed. Water is inextricably bound up in the health and economic growth of our nation.

For any particular weather or climate event, sources of water may include precipitation, tides, waves, sea level rise, storm surge, and rivers. The amount and characteristics of water involved in any event also depend, in part, on factors such as geomorphology, hydrological connectivity, land use patterns, and grey or green infrastructure (e.g., marshes, wetlands, levies, seawalls, and other physical barriers). Accounting for all sources and factors is particularly critical for comprehensive risk assessment and management. In addition, we must understand the issues over a wide range of time scales (from minutes to decades), integrating short-term weather events, seasonal climate variability, and decadal climate changes.

There are also complex policy challenges relating to water, including the need to address issues at the appropriate level of government (international, federal, state, local) and to overcome boundaries among the governing water management authorities and responsible parties. These challenges arise, in part, because the scope of the water management challenge is widely distributed over individual, institutional, and governmental domains. At the same time, the focus of management attention is too often fragmented, incomplete, and focused on short-term objectives.

**D. An integrated approach**

In order to understand the ways that water affects coastal vulnerability, it is necessary to take an integrated view of both science and management. We must understand all the ways that water moves through the coastal environment and impacts individuals and communities.

For any particular weather or climate event, sources of water may include precipitation, tides, waves, sea level rise, storm surge, and rivers. Factors that influence water's behavior include geomorphology, hydrological connectivity, land use patterns and grey or green infrastructure (e.g., marshes, wetlands, levies, seawalls, and other physical barriers). Forecasts of water quantity and quality are most useful when they account for all sources of water and all factors that influence water's behavior. Such forecasts must also integrate social and environmental systems.

Providing accurate information along the coasts is particularly difficult, both because of observational gaps and lack of interoperability among different modeling approaches (e.g., river forecast, wave, ice, estuarine hydrodynamic, and storm surge models).

For example, NOAA's Operational Forecast System (OFS) integrates observational data (meteorological, oceanographic, and river flow rate) with hydrodynamic model predictions to provide both nowcasts and forecasts for water levels, waves, and water conditions in coastal environments.

Similarly, the California Department of Water Resources developed a water resources management and planning model, Integrated Water Flow Model (IWFM), that "simulates groundwater, surface water, stream-groundwater interaction, and other components of the hydrologic system," as well as including agricultural and urban water demands and water reuse (Bay Delta Office 2016). In another effort, the NOAA National Severe Storms Laboratory developed the CI-FLOW model to capture the "complex interaction between rainfall, river flows, waves, tides and storm surge, and how they will impact ocean and river water levels." A need remains for basic models that integrate the different sources and flows of water.

Other researchers are looking at the way water is integrated with other important earth systems. For example, the National Science Foundation recently launched a new program looking at the food-energy-water nexus.

Finally, experts are also developing systems to integrate our understanding of human and ecological systems. For example, researchers at Oregon State University developed the modeling platform *Envision* to examine alternative future scenarios in coupled natural and human systems. It has been applied to several different locations in the Pacific Northwest, including The Willamette Water 2100 project, which evaluates "how climate change, population growth, and economic growth will alter the availability and use of the water in the Willamette River Basin (Bolte n.d.)."

This trend towards integrated systems thinking is also reflected in operational and management organizations. NOAA, the U.S. Army Corps, and the U.S. Water Alliance all offer slightly different interpretations of the same concept.

NOAA's pursuit of the Integrated Water Resources Science and Services (IWRSS) initiative further captures the need to develop an integrated understanding of water. IWRSS is an innovative business model for interagency collaboration where different federal agencies share their resources to collectively address water resources issues across the nation. Established in 2011, IWRSS is a partnership between the USACE, USGS, NOAA, and FEMA that is guided by the following three unified goals of: 1) integrating information delivery and simplifying access to this data, 2) increasing accuracy and timeliness of water information, and 3) providing summit-to-the-sea high resolution water resources information and forecasts.

For example, coastal inundation during hurricanes results from a combination of factors, most notably storm surge and wind-generated waves. Storm surges and waves are produced through different physical processes that require separate modeling approaches each of which involves state-of-the-art physics. In response to requirements under the Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act, an effort to improve the National Flood Insurance Program, NOAA is working to couple storm surge and wave models. This will enable improvements in inundation forecasts and mapping in coastal areas.

The United States Army Corps of Engineers has advanced a philosophy of integrated water resources management (IWRM). In a 2010 report, the Army Corps defines IWRM thus:

> "IWRM aims to develop and manage water, land, and related resources while considering multiple viewpoints of how water should be managed (i.e., planned, designed and constructed, managed, evaluated, and regulated). It is a goal-directed process for controlling the development and use of river, lake, ocean, wetland, and other water assets in ways that integrate and balance stakeholder interests, objectives, and desired outcomes across levels of governance and water sectors for the sustainable use of the earth's resources (USACE 2010)."

The U.S. Water Alliance has developed a similar philosophy that calls for water to be managed holistically: "The one water approach views all water—drinking water, wastewater, stormwater, grey water and more—as resources that must be managed holistically and sustainably. Doing so builds strong economies, vibrant communities, and healthy environments."

The 2010 report on Managing One Water lays out the case for integrated water management:

> "A piecemeal approach to water management may have seemed logical at a time when the problems appeared unrelated. However, with the benefit of better science, we are beginning to understand that not only are many water problems inter-connected, but they are also connected to critical issues beyond water – such as species and habitat conservation, energy supply, air pollution deposition, urban development, transportation, housing, and the list goes on. …To continue making progress, we will have to stretch our thinking and look at things in a new way (Clean Water America Alliance 2010)."

We need to understand the complete hydrologic cycle and interface it with coastal hydrodynamics to get the whole picture of integrated water. A full picture involves accounting for: 1) rainfall and runoff flowing down the rivers and 2) what is getting pushed up through coastal forcing (wind, waves, storm surge). It is when those phenomena merge that we are getting major issues and where our prediction systems need the greatest improvements.

*An integrated understanding of systems, both natural and human, will provide policy-makers and the public with essential information for making decisions in a complex world.*

How water interacts with other natural systems, and how natural systems connect to social systems. An integrated understanding of systems, both natural and human, will provide policy-makers and the public with essential information for making decisions in a complex world. These are current frontiers of research as universities, government agencies, private companies, and nongovernmental organizations grapple with the water-related challenges of the twenty-first century.

## 2. Background

### A. Overview of challenges facing coastal communities

Water is implicated in many of the challenges facing our nation's coasts. Natural hazards, reliance on ecosystem-dependent economic sectors, and changes in water supplies can all challenge community resilience.

*Natural Hazards*

Recent flooding events bring the vulnerabilities of our coasts into clear view. Houston's April 2016 floods damaged over 1,000 homes and businesses, were responsible for eight deaths, and caused an estimated $1.2 billion in damages. South Carolina's October 2015 floods cost $2 billion, and the closure of a major transportation corridor (I-95) impacted the lives of thousands along the Eastern Seaboard (NCEI 2016). As we were preparing this report, flooding in Louisiana caused the deaths of 13 people and $10 billion in damages (NCEI 2016).

In addition to high-impact, high-cost floods, coastal communities are impacted by low-cost but frequent flooding events. Annapolis, MD had an average of 39.3 nuisance flood days between 2007 and 2013. Atlantic City, NJ and Washington, DC had an average of 24.6 and 29.7 nuisance flood days, respectively, over that same time period (Sweet et al. 2014). These floods can close roads, interrupt the supply of goods and movement of people, and cause small but cumulative costs. Miami Beach, FL has become well-known for flooding during king tides, and is planning to spend $400-500 million to help mitigate recurring flooding (Flechas and Staletovich 2015).

Many coastal regions also experience dangers related to erosion. Erosion is influenced by different factors in different regions. In the Great Lakes, changing water levels affect erosion rates; in the Mississippi River Delta, changes to sediment supply contribute to wetlands loss; on the West Coast, the El Nino cycle drives rapid increases in erosion rate. Nationwide, coastal erosion causes approximately $500 million in coastal property loss per year (U.S. Climate Resilience Toolkit n.d.). A study on coastal wetland loss in Louisiana found that storm damages from a major hurricane would increase by up to $133 billion with maximum wetland loss scenarios (Barnes et al. 2015). Erosion is also felt keenly on smaller scales. The California city of Pacifica had to pay $200,000 to demolish a 20-unit apartment building when the bluffs it sat on started to collapse (Edwards 2016).

Tsunamis also pose a threat to coastal areas. Commonly caused by earthquakes in coastal regions, tsunamis can utterly devastate communities with extreme loss of life and property damage and, depending on the magnitude, can spread destruction over thousands of miles. Tsunamis can occur anywhere, but happen frequently in the Pacific due to oceanic and continental tectonic plate activity (Bernard n.d.). Local conditions are important in mediating impacts. For example, a New York Times article calls

Crescent City, California "a Tsunami Magnet" due to a variety of factors, including an underwater offshore ridge and the rectangular shape of the harbor's inner basin (McKinley 2011).

*Water Supplies*

Drought, along with human factors like excess groundwater pumping, can lead to saltwater intrusion in coastal aquifers, threatening both municipal water supplies and local industries. For example, saltwater intrusion on the Central Coast of California impacts the multi-billion dollar crops produced there. The Pajaro Valley in Monterey County produced nearly $1 billion in artichokes, strawberries, and other high-value crops in 2013 (Walton 2015), but has also averaged 200 feet of saltwater intrusion a year over the past decades (Levy and Christian-Smith 2013; PVWMA 2010). Monterey County relies on groundwater for 99% of its urban and agricultural water supplies (Martin 2014), and this saltwater intrusion threatens the county's drinking water and irrigation.

In addition, as an example of the truly integrated nature of water in the coastal environment, groundwater depletion can lead to land subsidence, which can contribute to increased flooding. The Harris-Galveston Subsidence District (HGSD) was created in 1975 to manage groundwater pumping (HGSD n.d.). As chronicled by former General Manager of the HGSD:

> "In the early 1970's, groundwater pumpage was approaching 450 million gallons per day (mgd). Subsidence had resulted in elevation losses that threatened entire subdivisions with complete destruction from tidal flooding. The major elements of Houston's economy were at risk of significant flooding, including the Port of Houston, the Ship Channel industries, industries in Baytown and Texas City, the Port of Galveston, NASA's Johnson Space Center, the Texas Medical Center, and all the businesses located downtown (Neighbors 2003)."[2]

Virginia also suffers from subsidence that increases the relative rate of local sea level rise and thus increases flooding. Subsidence in the area is largely caused by natural forces (i.e., isostatic rebound from historic glaciers), but groundwater withdrawals also contribute. Groundwater pumping has lowered water levels by as much as 200 feet in some parts of Virginia (Ress 2016). The Hampton Roads Sanitation District is piloting a project for injecting treated wastewater into the local aquifer to help mitigate subsidence and saltwater intrusion (Mayfield 2016). The project may also help to improve water quality by diverting wastewater that would otherwise be discharged into surface waterways that lead to the Chesapeake (Ress 2016).

[2] See also the Houston Chronicle's article on Houston flooding and subsidence: http://www.houstonchronicle.com/news/houston-texas/houston/article/For-years-the-Houston-area-has-been-losing-ground-7951625.php

Socioeconomic Impacts

There are different ways to try to understand the value we gain from the oceans and coasts. At the broadest level, oceans and coasts provide food and myriad additional ecosystem services including flood and drought protection, recreational opportunities, the purification of water, air, and soil, erosion control, the provision of nutrients, and habitat and species protection. In short, oceans and coasts are of central importance to thriving communities throughout the world, both on the coasts themselves and inland. Coastal resources provide livelihoods for people that live there, of course, but they also provide socioeconomic benefits for those who visit and even those who remain inland but rely upon the goods and services that oceans and coasts provide.

Several economic studies have taken different approaches to calculating this value in monetary terms. The Integrated Ocean Observing System sponsored a study of the "ocean enterprise" – the economic activity of firms that support ocean measurement, observation, and forecasting. The study found that the ocean enterprise generated annual revenue of $7 billion, and included over 400 firms (ERISS Corp. 2016).

It is also possible to calculate the value of the economic sectors dependent on the ocean in some way. The National Ocean Economics Program, housed at the Center for the Blue Economy at the Monterey Institute of International Studies, compiles "time-series data that track economic activities, demographics, ports and cargo volume and value, natural resource production and value, non-market values, and federal expenditures (Kildow et al. 2014)." This data is broken down into three different categories: the coastal economy, the ocean economy, and non-market values.[3]

The ocean economy includes the sectors of marine-related construction, living resources, minerals, ship and boat building, tourism and recreation, and transportation. In 2010, the ocean economy provided 2.7 million jobs and generated over $258 billion in GDP. In comparison, other natural resource industries (e.g. farming, mining, and forestry) together employed 1.15 million people in 2010 (Kildow et al. 2014). Another study, using similar data and methodology, found that the ocean economy accounted for 2.9 million jobs, $113 billion in wages, and $343 billion in GDP in 2012 (NOAA 2015).

In addition, ports and waterways are essential for the global movement of goods. Water transport accounted for 75% of U.S. foreign trade in 2012 by weight, accounting for 49% of the value of U.S. foreign trade (BOTS 2013). In 2010, international trade accounted for 22% of the GDP. The share of value handled via water accounted for $1.4 trillion dollars, nearly 10 percent of the GDP that year (Wolfe and MacFarland 2013).

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[3] NOEP defines the coastal economy as the "total amount of economic activity originating in coastal regions." The ocean economy is composed of the "employment, wages, and output from 6 sectors and 21 industries whose goods and services derive in one way or another from the oceans and Great Lakes."

It is also possible to look at specific sectors and case studies to determine the economic impacts of water in the coastal zone. For example, the recreational razor clam fishery is very important to the economies of small communities along the Washington State coast. Large harmful algal blooms (HABs) can force the state to close the razor clam fishery for health and safety reasons; from 1991-2008, domoic acid concentrations in razor clams, resulting from blooms of *pseudo-nitzschia*, forced closures on 23.3% of potential fishing days. Some seasons see partial closures, while other years the entire season is shut down. Dyson and Huppert (2010) calculated that a full season shutdown of the four major beaches in Pacific and Grays Harbor counties would negatively impact 339 full-time jobs and $10.6 million in labor income. This is a significant impact on coastal communities that are largely dependent on tourism and recreation income. If you go digging in the literature, other examples and case studies are easy to find.

All of the ocean economy sectors depend on the health of the ocean and coasts, and on the products and services provided by the public, academic, and private sectors. For example, marine transportation is reliant on accurate water level forecasts to ensure navigable waters; tourism and recreation depends on coastal water quality being good enough for fishing and swimming; and commercial fisheries need ecosystems that are healthy enough to support large, resilient fish stocks.

The health of ocean and coastal communities depends on the water in their region. Drought threatens water supplies and has downstream impacts on coastal and ocean ecosystems; flooding damages infrastructure and takes lives; and water quality, whether measured by temperature, nutrients, dissolved oxygen, or other factors, impacts communities' health, both physical and economic. Coastal risk management depends on having the observations, science, and services to support decision-making that allows for mitigation of and adaptation to all these factors.

### B. Understanding the issues

Many of the issues facing our coasts are well understood. Significant work and thought has gone into identifying and characterizing the ways that water poses both a challenge and an opportunity for coastal communities. Some of these lessons can be pulled from the wider national dialogue on water. Some of these lessons are specific to the coasts.

For example, a review of over thirty reports from federal agencies, interagency task forces, and non-government groups (Seid-Green 2016) identified over 800 specific recommendations for how the nation should approach water issues, but those could be consolidated into a framework with just twelve categories of common recommendations:

1. Improve data collection
2. Improve data management
3. Increase scientific understanding for water resources decision making in a changing climate
4. Advance modeling capacity

5. Expand and tailor products for water resources managers
6. Support integrated approaches to water management
7. Address water rights
8. Expand and protect water supplies
9. Invest in water infrastructure
10. Establish federal coordination and planning processes
11. Invest in training and workforce development
12. Expand education and outreach

This review also highlighted six topics that are not directly covered in the national dialogue on water. We have an opportunity to improve our understanding and management of water issues by:

1. Increasing public knowledge and understanding
2. Planning for "big data"
3. Increasing public-private engagement
4. Preparing for hydrologic extremes
5. Understanding and managing surface and groundwater interactions
6. Understanding international dimensions.

In the findings and recommendations for this study that come later, we identify seven high-priority needs that more concisely capture these 18 categories. We include this expanded list here as it offers useful additional detail that generally hold for the broader range of water issues and that can be applied specifically to coastal risk management.

The NOAA Office for Coastal Management, in a presentation to the U.S. Integrated Ocean Observing System (Kuipers et al. 2016), listed six important barriers that communities face when trying to build coastal resilience. In 2016, NOAA convened a series of meetings on the topic of water information for the 21st century, with a focus on integrated information and services. Through the course of two regional meetings and a large national meeting, six priorities surfaced.

| Office for Coastal Management barriers | National Conversation on Integrated Water priorities |
| --- | --- |
| • Coastal data availability<br>• Data accessibility and integration<br>• Intergovernmental coordination<br>• Techie and non-techie tools<br>• Training<br>• Outreach and awareness | • Stakeholder engagement<br>• Research supporting region-specific water information needs<br>• Better integration of social science<br>• Improved service delivery<br>• Partnerships<br>• Business cases and risk reduction |

These lists reflect the scope of NOAA's mission, but still fit within the framework provided in Seid-Green (2016).

Numerous groups focused on specific regions have also tackled the question of coastal vulnerability. The Gulf of Mexico Alliance and West Coast Governors' Agreement on Ocean Health are examples of ocean and coastal regional planning with a strong focus on risk management. The Gulf of Mexico Alliance's Action Plan III identifies six priority areas: 1) Coastal resilience; 2) Data and monitoring; 3) Education and engagement; 4) Habitat resources; 5) Water resources; and 6) Wildlife and Fisheries. It also identifies three cross-cutting issues: 1) Ecosystem services; 2) Marine debris; and 3) Conservation, restoration, and resilience planning.

The West Coast Governors' Agreement on Ocean Health has seven priority areas: 1) Ensure clean coastal waters and beaches; 2) Protect and restore ocean and coastal habitats; 3) Promote the effective implementation of ecosystem-based management; 4) Reduce adverse impacts of offshore energy development; 5) Increase ocean awareness and literacy among citizens; 6) Expand ocean and coastal scientific information, research, and monitoring; and 7) Foster sustainable economic development.

*The focus on water allows a uniquely comprehensive look into the multiple aspects of community resilience.*

The issues and challenges facing the nation's coasts are well understood. However, very few reports and initiatives contain a focus on understanding regional needs in the context of the needs of other regions and of national priorities. And even fewer, if any, focus specifically on the role of water in coastal resilience. The focus on water allows a uniquely comprehensive look into the multiple aspects of coastal risk management.

### C. The study approach

This report is based primarily on two workshops that took place in Washington, D.C. in the fall of 2016 (agendas in Appendix A). Each workshop focused on two regions. The first workshop, Sept. 27-28, 2016, focused on the East Coast (Chesapeake Bay and Savannah River region) and Great Lakes (Lake Erie and Lake Michigan). The second workshop, Oct. 18-19, 2016, focused on the Gulf Coast (Houston-Galveston and Mississippi River Delta) and West Coast (Tillamook Bay watershed and California's central coast).

The workshops used a place-based approach to understand integrated water for coastal vulnerability and risk management. The concept of "integrated water" can seem vague and overwhelming. Building a narrative of how water affects a particular community is a way to ground that concept in the reality of communities' and individuals' lived experiences. In addition, many of the impacts of water are felt locally, and a lot of decision-making around water occurs at the local and state level.

This focus on the eight communities provided a broad snapshot of the range of issues occurring throughout the United States. They offer a broad regional distribution, including all of the coasts of the United States (East Coast, West Coast, Gulf Coast, and Great Lakes). All of the selected communities also face complicated and challenging water issues; they are communities sitting at the nexus of different water issues.

The focus regions also represent a diversity of environment and community types. For example, Savannah is a relatively small urban area, with a population of about 400,000 people. In comparison, the Chesapeake Bay watershed supports a population of over 17 million. Tillamook County, Oregon is a largely rural coastal community, whereas Lake Erie is bordered by several major urban centers. The Mississippi River Delta is fronted by an extensive landscape of marshes and estuaries, whereas Galveston directly fronts the Gulf of Mexico. Some communities have high institutional capacity, whereas others struggle to meet basic municipal needs.

In addition, these communities have received different levels of national attention. The Great Lakes have benefitted from national-level attention (i.e., Great Lakes Restoration Initiative). California water issues have dominated recent conversations, but without a lot of focus on specific coastal issues (except desalination). The Tillamook Estuary is a national estuary, as is the Galveston Estuary, but neither are commonly included in national-scale discussions. Charleston, SC is a pilot community for the National Academies' Resilient America Roundtable initiative, and the Charleston Resilience Network has been featured in national-level discussions, but Savannah, just a hundred miles south, has not benefited from this type of national attention.

It is beneficial to share the stories of communities that are not often heard on the national stage. At the same time, there is a rich set of lessons to be learned from the experiences of communities that have gone far down the road of regional collaboration for coastal risk management. This blend of communities allows for fresh information and insights to contribute to the national conversation on coastal vulnerability and risk management.

In order to maintain some consistency, and to facilitate more comparable results from the different communities, the workshop proceedings were guided by a set of common questions:

Understanding Water in the Region

- What are the top water-related challenges and opportunities facing the region?
- How well do we understand the magnitude and nature of risks we face in the coastal environment?
- In what cases is environmental intelligence sufficient and well-used, and where and why is it inadequate?

Cross-cutting Themes

- How well is water science and management integrated in the region?
- What lessons have you learned about making the following successful?
    - regional collaboration
    - data sharing and use
    - research to operations transition
    - stakeholder engagement
- What policies and regulatory structures are needed to support integrated water prediction, risk assessment, and management?

More information on each of these questions is available in the specific regional sections in Section 3.

By asking the same questions about each of the focal regions, we hoped to understand both the commonalities and differences in water-related coastal vulnerabilities across the nation. Many regional issues are held up as unique, and understanding regional differences is important. However, our goal was to identify national lessons; with a focus on federal-level policies and priorities, we need to understand where policy needs to be differentiated, versus where it can address common needs, problems, and opportunities across the different communities. In our analysis, we looked for underlying common variables in how different communities struggle with coastal risk management.

| | Ecological Forecasting | | |
|---|---|---|---|
| **Variable** | **HAB** | **Pathogen** | **Hypoxia** |
| Temperature | X | X | X |
| Salinity | X | X | X |
| Dissolved Oxygen | | X | X |
| Chlorophyll Concentration and its Anomaly | X | X | |
| Remote sensing reflectances | X | | |
| Attenuation Coefficient | | X | |
| Nutrient Concentration (NO3, PO4) | | X | X |
| River Flow | | | X |
| pH | | X | |
| Current velocity | X | | |
| Upwelling Potential | X | | |
| River plume location | X | | |
| Species counts/biomass & toxicity / virulence | X | X | |
| Forcing for Atmospheric, Hydrodynamic, or BGC models | X | X | X |

Source: Brown 2016

The Ecological Forecasting Roadmap (EFR) offers a model for considering how federal and nation-scale organizations can support the needs of particular regions. Each region deals with different types of harmful algal blooms. For example, Florida deals with "red tide" (*k. brevis*), Lake Erie with blue-gree algae (cyanobacteria), and the West Coast with *pseudo nitzchia*. Originally, people thought that the monitoring needs for the different types of HABs would be very individualized. However, many of the same basic environmental variables are needed to forecast each of the different types of HABs.

The fifth guiding principle of the EFR is that "NOAA's approach to ecological forecasting is currently national in scope but regional in application and delivery." It was our hope that this same principle could be applied more broadly to coastal risk management.

In fact, that became evident during the first workshop. Three different regions struggled with three different types of water quality problems. Salinity is a main driver determining water quality in the nearshore waters and estuaries of South Carolina and Georgia (Conrads 2016). In Lake Erie, the severity of the year's HAB is driven by sediment and nutrient loading (Reutter 2016). Dissolved oxygen levels and the Chesapeake dead zone are also driven by nutrient loading (Batiuk 2016). However, the timing and quantity of precipitation is the major driving factor in predicting and forecasting salinity, nutrient loads, and turbidity. Precipitation underlies water quality on the coasts. What seemed like very different issues can, in fact, be tractably supported by nationally consistent federal resources and information when we dig down to the underlying factors. Similarly, many of the regions struggle with issues around collaboration, stakeholder engagement, and data sharing, among others.

*Although the specific challenges facing each region are different, there are common underlying needs that would benefit from federal support and coordination, and areas where lessons learned and success stories can help communities address any challenge they face.*

Although the specific challenges facing each region are different, there are common underlying needs that would benefit from federal support and coordination, and areas where lessons learned and success stories can help communities address any challenge they face.

The following sections explore the challenges facing local coastal communities, and highlight some important lessons about coastal vulnerability and risk management. Section 3 provides information on the eight communities examined during the workshops, as well as an overview of select innovative data sharing programs. Section 4 pulls together recommendations and conclusions on how to best address coastal vulnerability and risk management.

## 3. The regions

The United States encompasses a variety of coastal regions. This section describes eight different coastal communities, two each from the Great Lakes, East Coast, Gulf Coast, and West Coast. The following sections of this report draw strongly from the proceedings of the workshops, including insights from participants during Q&A and discussion sessions. They also incorporate additional research and analysis from AMS Policy Program staff.

Each regional profile includes information on the natural and human landscape of the region; why water and the coasts are important to the local communities; major water-related vulnerabilities in the region; an overview of relevant governance structures and collaborations; and highlights and insights from the workshop discussions and presentations.

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### A. Great Lakes

**Lake Erie**

***Natural Landscape***

In comparison to the other Great Lakes, Lake Erie is both shallow and warm. It is the smallest Great Lake in terms of volume, and the average depth is just 62 feet (Great Lakes Information Network [GLIN] n.d.).

The Lake Erie watershed drains an area of about 30,000 square miles (DGESS n.d.), including parts of Indiana, Michigan, Ohio, Pennsylvania, New York, and Ontario (DGESS n.d.). The Detroit River, draining the Upper Great Lakes, accounts for eighty percent of the lake's total water inflow; precipitation accounts for eleven percent of the inflow, and other tributaries account for the remaining nine percent of inflow (EPA n.d.-a). Water levels in Lake Erie are largely influenced by the dynamics of the natural system – precipitation, evaporation, and wind direction (Jones 2009).

***Human Landscape***

The Lake Erie watershed contains approximately 12 million people – almost one third of all people in the Great Lakes basin (EPA n.d.-a). The Lake Erie watershed is highly industrialized and urbanized, but also contains very intensively used agricultural land (EPA n.d.-a). In the Lake Erie watershed in 2000, agriculture accounted for 75% of land use, forestry for 11%, and urban land for 11% (Myers et al. 2000). In 2005, land cover in the Western Lake Erie Basin was 71% cropland, 10% urban development and roads, and

8% forested (NRCS 2005). Cleveland, Buffalo, Toledo, Detroit, and Windsor, Ontario are major urban centers on the shores of the lake.

### *Importance and Impacts*

Lake Erie is an important contributor to the surrounding states' economies through tourism, fishing, and navigation. In addition, the Lake supplies water to surrounding communities.

Lake Erie is the most popular Great Lake for fishers (Michigan Sea Grant n.d.-b). In 2006, 37% of all Great Lakes recreational anglers fished in Lake Erie, and Lake Erie accounts for 40% of all Great Lakes charter boats (Winslow 2015). Ohio Sea Grant calculates that Lake Erie tourism, including direct, indirect, and induced spending, generates $12.9 billion in sales per year (Winslow 2015). The tourism industry generated $811 million in federal taxes, $510 million in state taxes, and $337 million in local taxes in 2013 (Winslow 2015). Lake Erie also accounts for 61% of the total Great Lakes commercial fishery harvests, which is remarkable given its small size relative to the other Great Lakes (Michigan Sea Grant n.d.-b).

Shipping is another important lake-dependent economic sector. The total economic impact of a particular lake is difficult to calculate, since the shipping sector relies on the entire Great Lakes-Seaway system.[4] However, Ohio's nine Lake Erie ports, handling almost 40 million tons of inbound and outbound cargoes, provide 28,081 jobs, $2.1 billion in personal income, $3 billion in business revenue, and $580 million taxes annually (GLSP 2015a).

Finally, Lake Erie is an important water supply for the region. Water is withdrawn from Lake Erie for power supply and cooling, as well as for drinking water. In 2005, 72% of all the water withdrawn from the Great Lakes was used for power plant cooling (GLEAM n.d.-a). Lake Erie provides drinking water for 11 million people in the surrounding region (EPA n.d.-a).

### *Major issues*

While different states and groups prioritize different issue areas, there is a common list of challenges facing Lake Erie. A review of the Great Lakes Restoration Initiative (GLRI) Action Plan II, Michigan's Water Strategy, New York's Interim Great Lakes Action Agenda (GLAAI), the Ohio Coastal Management Program's priority issues, the Western Lake Erie Basin Water Resources Protection Work Plan, and the Great Lakes Environmental Research Laboratory's (GLERL) summary of threats is illustrative.

*Invasive species*

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[4] For more information on the economic impact of the Great Lakes-Seaway system, the GLSP conducted an economic impact report in 2011 (Martin Associates 2011).

Invasive non-native species are a concern because of their effects on the Great Lakes' ecosystems. They can threaten the diversity or abundance of native species, and thus unbalance ecosystems and the human activities that depend on the Great Lakes' waters and habitats (Vanderploeg n.d.). Non-native species are commonly introduced to the Great Lakes through maritime commerce (mainly through discharge of ship ballast water); migration up canals and waterways, including the Mississippi River; trade; recreational activities; and aquaculture (Vanderploeg n.d.).

For example, zebra mussels and quagga mussels, both native to Eurasia, have colonized large swaths of territory (GLEAM n.d.–b). They outcompete native species of mussels, altering habitats, food webs, and nutrient dynamics (GLEAM n.d.–b). Zebra and quagga mussels accumulate on both soft (quagga) and hard substrates (zebra), often clogging and fouling infrastructure such as water intake pipes, boating facilities, and navigational lock structures. A congressional analysis estimated that quagga and zebra mussels cost the Great Lakes power industry $3.1 billion dollars from 1993-1999, with a total economic impact of over $5 billion (Idaho Aquatic Nuisance Species Taskforce 2009).

*Water quality*

Lake Erie faces several water quality challenges. Water quality impairments can damage the ecosystems and economies of Lake Erie through impacts on fisheries, beach closures, and drinking water, among others.

The issue of harmful algal blooms (HABs), largely driven by non-point source nutrient pollution, has dominated attention on the Lake since a bloom of cyanobacteria (also known as blue-green algae) forced the closure of the City of Toledo's water intakes for two days in 2014. Blue-green algae can produce microcystins, which cause illness in humans and lead to mortality in dogs and livestock (Butler et al. 2009). In addition, blooms of algae can contribute to depletion of oxygen in the water, with negative effects on fish and drinking water quality (Carmichael 2013; GLERL n.d.-b).

Lake Erie also is subject to ongoing challenges from point source pollution. There are 93 Lake Erie communities with Combined Sewer Overflow (CSO) systems, which discharged 16.4 million gallons of untreated sewer overflow in 2014 (Office of Wastewater Management 2016). Lake Erie also suffers from a legacy of industrial pollution and the threat of toxic substances and oil spills from the ships that travel its waters.

The Ohio Department of Health monitors public and semi-public beaches in the state for unsafe levels of *E. coli.*, and exceedances of safe levels forces beach closures. Ohio beaches were under advisories for 33% and 25% of the season in 2013 and 2014, respectively (Ohio Department of Health 2014). In the most extreme case, Edson Creek spent 79.05%, or 83 days, of its 2014 season under a health advisory (Ohio Department of Health 2014). Beyond the public health impacts of unsafe waters, beach closures can have negative impacts on tourism and recreation, and thus downstream effects on the economic health of coastal communities.

*Coastal hazards*

Although the Lake Erie coastline is not subject to the same forces as ocean coastlines, communities along Lake Erie still face significant threats from erosion and flooding. Wave force, groundwater seepage, freeze-thaw cycles, water levels, and sediment transport all affect erosion rates (DGS 2011; OCM n.d.-a). Erosion can occur suddenly or over time, and can have catastrophic effects on infrastructure (OCM n.d.-a). The Ohio Department of Natural Resources (DNR) monitors erosion on the Ohio coasts of Lake Erie, and has documented erosion rates varying from .4 to 2.7 feet per year (DGS 2011). Analysis of the economic impacts of coastal erosion in Lake Erie is not readily available, but the Ohio DNR asserts: "The economic losses caused by coastal erosion can exceed tens of millions of dollars (DGS 2011)." In addition, sudden erosion can result in human fatalities (DGS 2011).

Lake Erie is affected by both major and minor flooding events. On August 12, 2014, the metro-Detroit area experienced a historical flooding event as a result of over 6 inches of rainfall in one storm event, leading to a state of emergency declaration by the Governor of Michigan. In another example, a seiche (a change in water levels driven by wind) on November 13, 2015 caused water levels in Buffalo to rise 7.5 feet over the course of ten hours, causing local flooding (Tunison 2015). The City of Toledo is subject to frequent, minor floods due to intense rainfall events (Great Lakes Coastal Resilience Planning Guide 2013).

*Habitats*

Habitat conservation and restoration is a cornerstone of many other areas of concern. Coastal wetlands and other shoreline ecosystems help filter nutrients before they reach the waters of Lake Erie, provide habitat for fish and other species, and provide a degree of protection from flooding. Forest, shrub, and grass buffers along waterways can entrap nutrients and pollutants, and decrease erosion and sediment. Approximately 95% of Lake Erie's original 307,000 acres of wetlands have been lost, leaving less than 30,000 acres intact (Doran and Kahl 2014; Markey 2016).

### Governance and collaboration

Lake Erie is part of the many different Great Lakes-wide collaborative efforts. As part of the Great Lakes Water Quality Agreement, binational partners developed a Lake Erie Management Plan (LAMP), and subsequently developed the Lake Erie Binational Nutrient Management Strategy. Lake Erie has also benefited from funding from the Great Lakes Restoration Initiative (GLRI).

However, Lake Erie is also the subject of additional, geographically focused collaborative initiatives. The Western Lake Erie Basin Partnership was formed in 2005 as a partnership between the USDA Natural Resources Conservation Service (NRCS) and the U.S. Army Corps of Engineers, and now has fourteen different partners, including the Governors of Indiana, Michigan, and Ohio, the Maumee River Basin Partnership of Local Governments, and the USGS Ohio Water Science Center, among others. The Western Lake Erie Basin Conservation Effects Assessment Project (WLEB CEAP) is a collaboration between many NGOs, government agencies, and universities that focuses on understanding the sources, destinations, and effects on nutrients and sediments and examining effective prevention strategies.

### ***Highlights and insights***

*Phosphorous reduction is necessary for water quality improvements*

Both nitrogen and phosphorous contribute to water quality problems in Lake Erie. However, phosphorous is normally the limiting nutrient in freshwater systems. While reducing both phosphorous and nitrogen is important, reducing phosphorous alone would significantly solve HAB problems (Reutter 2016). Moreover, it is important for policies to target specific types of phosphorous. Particulate phosphorous (PP) is only about 25% bioavailable, but dissolved reactive phosphorous (DRP) is 100% bioavailable, and DRP has significantly increased in recent years. PP largely enters waterways through soil erosion, while DRP often enters waterways through drainage tile systems.

*Field-level practices and conditions are significant factors for water quality*

DRP loading has increased 150% in recent years due to changes in farming practices, but recommended best management practices have focused solely on PP (Reutter 2016). Moreover, effective reduction strategies will require identification of problem fields. 42% of acres are responsible for 78% of phosphorous and sediment loss, including legacy phosphorous that has built up in fields that habitually apply too much phosphorous. Targeting these problem fields will also maintain the good will of farmers who voluntarily take action to manage their nutrient applications to minimize runoff.

*Nutrient reduction strategies need better information at smaller scales*

As shown above, it is important to have accurate information at the field level. It is also important to have accurate information on individual channels and tributaries. This is a more granular scale of information than has historically been available to scientists, regulators, and policy-makers. Workshop participants discussed a wish list of information needs and opportunities, including: accurate information on each agricultural field, accurate load information from connecting channels and the atmosphere, annual nutrient soil tests on individual fields, monitoring around animal operations, tributary transport models, and, as an overarching imperative, funding for long-term monitoring.

*Annual variation in nutrient loading depends on rainfall*

Predicting the severity of water quality impairments in Lake Erie, including the size of the expected HAB, depends heavily on the timing and quantity of precipitation. This is because phosphorous discharges from sewage treatment plants vary little from year to year but phosphorous discharges from agricultural tributaries vary greatly from year to year depending on rainfall. The vast majority of phosphorous loading occurs during storm events, and the timing of rainfall (on frozen ground, before fertilizer applications, after planting, etc.) matters a great deal. Moreover, climate change is increasing the frequency of severe rainfall events; Reutter estimated that the frequency of severe storms over Lake Erie is up 37-53% (2016).

*Field trips are helpful learning tools*

Field trips can be very helpful learning tools for targeted groups of participants. For example, The Ohio State University's Stone Laboratory hosts groups of farmers to discuss water quality issues and how conservation measures on the field can benefit the Lake (Buehler 2014). Field days are an opportunity for farmers to learn from other farmers already implementing conservation practices (Burlew 2016). Field trips can also be valuable for policymakers to get an on-the-ground view of the challenges facing farmers and better understand how to tailor policies to those realities (Reutter 2016; see also Yeager 2016). These are fairly expensive and intensive programs, which limits how many people can be reached, but has a correspondingly higher impact than more general outreach strategies.

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## Lake Michigan

### *Natural Landscape*

Lake Michigan, the only Great Lake located entirely in the United States, is the second large largest of the group by volume – almost 1200 cubic miles – and the third largest by surface area (EPA 2016e). Lake Michigan has a shoreline of 1,640 miles and a drainage basin area of 45,600 square miles. It is directly connected to Lake Huron by the Straits of Mackinac (NOAA 2000). It is often divided into a northern and southern basin. Through the connecting channels (the St. Clair River, Detroit River, Niagara River, St. Lawrence River, and the Ottawa river), waters from Lake Michigan eventually flow to the Atlantic Ocean (NOAA 2000). Water also leaves the system through evaporation, transpiration, groundwater outflow, consumptive use, and diversions. (Watershed Council 2016)

There is a diversion into the Mississippi River basin at the Chicago River as well as a much smaller diversion in Waukesha, Wisconsin. (Wisconsin Department of Natural Resources 2016). The latter, though small, is thought to be a precedent for future diversion requests as it was the first to be granted after the adoption of the Great Lakes Compact (Davey 2015).

### *Human Landscape*

Bordering Indiana, Illinois, Michigan, and Wisconsin, Lake Michigan boasts a surrounding population of approximately 12 million people. The largest population centers include Chicago, IL and Milwaukee, WI, accounting for 8 million people - 20% of the total Great Lakes basin population (NOAA 2000). There are numerous other small cities on the lake in all four states. The Lake Michigan Basin is also home to numerous Native American tribes, the original inhabitants of the region.

The lower basin of Lake Michigan has seen some of the highest development in the Great Lakes due to the vicinity of large population centers. Conversely, the northern basin is largely undeveloped (excluding the Fox River Valley) and is covered with mixed wood forest (Lakewide Action and Management Plan 2015).

### *Importance and Impacts*

Lake Michigan is used as a major source of drinking water, and contributes to the fishing, tourism, shipping, industrial, and agricultural sectors in multiple states. Its contributions to surrounding economies are vast, accounting for billions of dollars in annual revenue.

The Michigan Sea Grant found that there are over 1.5 million jobs related to the Great Lakes, generating $62 billion in wages each year (Michigan Sea Grant n.d.-b). Lake Michigan alone provides 15% of jobs in Michigan (Michigan Sea Grant n.d.-a). In addition, the Great Lakes are a vast maritime transportation network for shipping, and tourism and recreation also generate tens of billions in revenue for bordering states (GLC 2015). The Great Lakes fisheries are collectively worth more than $7 billion annually (Great Lakes Fishery Commission n.d.). Recreational fishing on Lake Michigan is the most prevalent, though commercial and tribal fishing take place as well (Michigan Department of Natural Resources 2016).

Lake Michigan is the largest public drinking water supply in the state of Illinois and provides drinking water to over 10 million people (Illinois Environmental Protection Agency 2015). It also provides freshwater for surrounding agriculture and industry, namely for power plant cooling, steel, and automobiles (Illinois Environmental Protection Agency 2015; GLC 2016).

### *Major Issues*

Through the review of several group priorities and action plans, issues for Lake Michigan can be categorized by coastal erosion, invasive species, water quality, and habitat destruction. Plans and groups reviewed include the Lakewide Action Management Plan, The Great Lakes Restoration Initiative, The Great Lakes Commission, state-specific Sea Grants and environmental departments, and NOAA's Great Lakes Environmental Research Laboratory. Though different states experience different facets of these issues, they are shared threats for all areas. Lake Michigan currently has 9 geographical areas deemed Areas of Concern (AOCs) under the Great

Lakes Water Quality Agreement. These are areas where "significant impairment of beneficial use has occurred as a result of human activities at the local level (EPA 2016c)."

*Coastal Erosion*

Coastal erosion occurring on the shores of Lake Michigan is caused mainly by land use and water level changes. Due to climate change and temperature increases of approximately 2-4 degrees Celsius in the region, average lake levels will likely experience prolonged drops due to increased evaporation and reduced runoff (NOAA 2000). Though water levels fluctuate naturally, climate change will impact the duration and magnitude of such drops. Drops in water level can have harmful effects on coastal erosion as it can expose new surfaces. Shipping and industry face consequences from this erosion, including increased need for harbor dredging and losses in hydroelectric power output (NOAA 2000).

*Invasive species*

There are over 180 nonindigenous plant and animal species in the Great Lakes, including destructive invasive species, such as zebra mussels. These species can deeply harm ecosystems and native fish populations and cause damage to commercial fisheries and infrastructure (EPA 2016d). Invasive species in the region are difficult to control once they have entered into the system and become established, thus making prevention the most effective method dealing with this threat (NOAA 2000). These measures include ballast water regulation, close ecosystem monitoring, and electric barriers (EPA 2015).

*Water Quality*

Lake Michigan suffers from a range of water quality issues. First, harmful algal blooms (HABs) can create nuisance and/or health problems depending on species type. For example, HABs of blue-green algae can contain multiple toxins dangerous to both humans and animals. Occurring mostly in the Green Bay portion of Lake Michigan, they are caused by phosphate products and runoff, and potentially by invasive mussel species (Michigan Sea Grant n.d.-a). Second, pollution and contaminated sediments are still an ongoing threat (EPA 2015). Lake Michigan contains a range of pollutants that can adversely impact drinking water, fish populations, and recreational activities. Industrial discharge, oil spills, and agricultural runoff lead to chemical contamination while atmospheric deposition leads to high mercury levels in fish. In addition, microplastics are a more recent concern originating from a range of consumer products. Namely made out of polyethylene or polypropylene, they can potentially be toxic to many animals and may have harmful effects on ecosystems (Watershed Council 2016).

*Habitat Destruction*

The Lake Michigan basin contains a wide range of natural habitats, including forests, wetlands, and the world's largest freshwater dune system (Michigan DNR 2016; Michigan Sea Grant n.d.-b), but suffers from habitat destruction, degradation, and fragmentation. Continually increasing urbanization near Lake Michigan, as well as dams and barriers to species migration, leads to high habitat loss and destruction (NOAA 2000). This increased urbanization also leads to higher runoff and discharge of improperly treated sewage (LAMP 2015). Habitat degradation can also result in loss of invaluable ecosystems services, such as the natural groundwater filtration and flood control provided by wetlands (Watershed Council 2016).

### *Governance and collaboration*

There are many programs, collaborations, and groups working towards managing issues in the Great Lakes. There are both public and nonprofit groups working towards progressing the science as well as protecting the environment.

The Great Lakes Environmental Research Laboratory (GLERL), run by NOAA, conducts integrated research on ecosystem dynamics, modeling and forecasting, and more. Examples of their efforts include a HAB tracker and the Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS). In addition, their Great Lakes Forecasting System delivers both nowcasts and forecasts (Buan 2016). The state Sea Grant Programs, including Michigan, Wisconsin, and Illinois-Indiana, also conduct research focused on pressing issues in Lake Michigan.

An additional successful program is the Great Lakes Observing System (GLOS), a regional association of the U.S. Integrated Ocean Observing System (GLOS 2016). GLOS coordinates federal, state, private, and academic institutions to enable better collection, delivery and use of data specific to the Great Lakes (GLOS 2016). Serving as a data assembly center, it helps to better meet stakeholder needs and improve efficiency (IOOS).

There are also many different Lake-wide programs to coordinate work. For example, the Great Lakes Restoration Initiative (GLRI) is a taskforce of many federal agencies and state governments; the Great Lakes Commission (GLC) is an interstate agency that promotes integrated development and conservation of the Great Lakes; and a series of public-private partnerships created Lakewide Action and Management Plans (LAMPs) to both monitor and protect the Great Lakes. The GLC also created the Lake Michigan Monitoring Coordination Council in 1999 to support water quality monitoring.

### *Highlights and insights*

*Balancing multiple stakeholder needs is difficult*

Scientists, managers, and policy makers must balance the multiple, sometimes conflicting, needs of different stakeholders. In Lake Michigan, low lake levels benefit some stakeholder groups, whereas high lake levels benefit others. For example, high water levels can decrease beach recreation but increase boating recreation. As another example, water withdrawals from the lakes can benefit the energy sector, cities, and industry, but also harm commercial and recreational fishing. Providing information and policy solutions that acknowledge and grapple with these contradictory costs and benefits is an ongoing challenge.

*Coordinating multiple jurisdictions takes deliberate effort*

Lake Michigan is surrounded by multiple jurisdictions (state, city, county) and enmeshed in the complex Great Lakes management structure. Coordinating the work of these multiple jurisdictions can be quite difficult and time-consuming. However, coordination is possible. For example, the Great Lakes Blue Accounting initiative, run by the Great Lakes Commission and The Nature Conservancy (GLC 2014), provides the structure for comprehensive, coordinated water monitoring. Recommendations for monitoring address aquatic ecosystems, human uses, and social values, and the project subsequently identified actions and metrics for evaluation (GLC 2014).

*Environmental intelligence gaps remain*

Despite the great funding and research that the Great Lakes have enjoyed, there remain gaps in environmental intelligence for crucial lake processes and sectors. Beach and drinking water managers need better water quality forecasting. Emergency managers need better predictions of the location and magnitude of extreme rainfall events. Farmers need better rainfall predictions to help manage their fertilizer applications to reduce runoff (Buan 2016).

*Environmental intelligence depends on adequate observations*

In order to address these remaining environmental intelligence gaps, maintenance and expansion of certain observations is necessary. While river discharge and river water quality observations are currently good, better coverage would be helpful. Terrestrial observation of meteorological variables is quite good, due to substantial investments in radars and mesonets. However, over-lake observation remains lacking. In particular, evaporation observations are extremely limited, and over-lake precipitation observations need improvement (Buan 2016).

*Understanding river-lake connections is difficult*

Given the importance of the coastal zone, it is important for scientists and researchers to increase our understanding of the complex interactions along the coastal zone. Modeling the interface between the Lake and its tributaries remains difficult. River forecasts are currently limited to gaged locations, often many miles from the coasts, and connecting river models with the Great Lakes Operational Forecast System is difficult (Buan 2016). We also need to understand how "variations in flows, lake levels, and climate control the ecology of the coastal zone and how coastal ecology relates to both inland and deep-water ecosystems (Reeves 2016)."

## B. East Coast

### Chesapeake Bay

#### *Natural Landscape*

The Chesapeake Bay is a vast system of coastal waterways on the Atlantic Coast of the United States. It is the largest estuary in the United States, stretching 64,000 square miles, about 195 miles in length and between 4 to 30 miles in width at different intervals (Phillips 2006). According the Chesapeake Bay Program (2012b), the Bay and its tidal tributaries comprise 11,684 miles of shoreline.

The Chesapeake Bay watershed comprises portions of six states: Maryland, Virginia, Delaware, New York, Pennsylvania, West Virginia and the entire District of Columbia (Washington D.C.). Five major rivers empty into the Chesapeake Bay (the York, Rappahannock, Susquehanna, James and Potomac rivers). The latter three rivers supply a combined 80% of freshwater distributed to the Bay (Chesapeake Bay Program 2012b). Over 150 major rivers and streams and thousands of smaller creeks, brooks, and tributary streams flow into this great basin.

#### *Human Landscape*

The Chesapeake watershed currently supports an estimated population of 17.7 million people, and is expected to increase to 20 million by the year 2030 (Chesapeake Bay Program 2012c). From 1980 to 2000, population growth in the Chesapeake Bay area was greater than in any other watershed region in the United States (Crossett et al. 2004). According to Sprague et al. (2006), 60% of the region's land cover is forestland, 21% is used for agricultural practices, and 9% has been converted to urban development.

The major population center of the region is the District of Columbia, with a population of 672,228 and a resident density of 11,000 people per square mile (U.S. Census Bureau n.d.). Major metropolitan centers in the state of Maryland include: Baltimore with a population size of 620,961; Columbia - 99,615; Germantown – 86,395 and Silver Spring - 71,452 (Maryland State Archives 2015). In the Commonwealth of Virginia, the top four population centers are: Virginia Beach – 437,994; Norfolk – 242,803, Chesapeake – 222,209 and Arlington – 207,627 (GeoNames n.d.-b).

#### *Importance and Impacts*

Economists estimate the value of the Chesapeake Bay at more than one trillion dollars, including fishing, tourism, real estate, and shipping industries (Chesapeake Bay

Foundation 2012a). The Bay is famously known for its seafood industry with the primary fisheries being oysters, shellfish, soft-shell clams, and blue crabs. The Chesapeake Bay Foundation (2017) reports that the commercial seafood industry in Maryland and Virginia contributes $3.39 billion in sales, $890 million in income, and almost 34,000 jobs to the local economy.

Tourism is a huge contributor to the region's economic development. Annually, $1.6 billion dollars is generated from fishing in Pennsylvania, $2.03 billion from recreational boating in Maryland, and $960 million from wildlife activities in Virginia (U.S. Fish and Wildlife Service n.d.). The Bay is also contributes to property values: according to the EPA (1973), the value of a single family home 4,000 feet or closer to the shoreline can increase by up to 25 percent.

The Bay contains two of the United States' five largest ports, the Port of Baltimore and the Hampton Roads/Norfolk Complex, both of which transport large quantities of tobacco, food, clothing, automobiles, and raw materials such as coal and lumber. The Port of Baltimore generates almost $2.9 billion in annual wages and salary, and supports over 127,600 direct, indirect and induced jobs connected to Port work (Martin Associates 2015).

### ***Major Issues***

*Natural hazards*

The region is prone to hurricanes, coastal flooding, shoreline erosion, and severe winter storms. Sea level rise is also an issue in many low-lying areas, and many areas along the Bay have seen a one-foot increase in sea level rise - six inches due to climate change, and another six inches due to naturally subsiding coastal lands (National Wildlife Federation 2008). In coastal Virginia, the southern Chesapeake Bay Region has experienced the highest rate of relative sea level rise on the Atlantic coast (Zervas 2009), with increases of more than 14 inches since 1930 in the Hampton Roads region (Old Dominion University Center for Sea Level Rise 2017). Many of the bay's coastal marshes and small islands have been inundated, and the National Wildlife Federation asserts that at least 13 islands in the Bay have completely disappeared. Sea level rise also increases the impacts of both tidal and event-driven flooding.

*Saltwater intrusion*

Saltwater intrusion, driven by sea-level rise, storm surge, and groundwater pumping, is another threat to the region. As sea water intrudes into freshwater aquifers this alters the composition of natural ecosystems and contaminates municipal and agricultural water supplies. Ress and Bogues (2015) reported that in some parts of eastern Virginia including the Hampton Roads area, groundwater levels have decreased 200 feet or more over the past century. This decline was attributed to increased withdrawals from coastal plain aquifers beginning after World War II (Heywood and Pope 2009).

A significant portion of the population in southeastern Virginia relies on private wells to supply water for household consumption. Private well withdrawals for domestic use in the Coastal Plain was about 40 million gallons per day, or about 28% of all ground-water withdrawals in the area (USGS 2007). Although groundwater tables continue to drop, there have been some recent increases due to reductions in withdrawals.

*Habitat loss and degradation*

Wetlands provide vital ecological services such as natural habitats for wildlife, plant, and aquatic species. They also aid in protecting water quality by filtering out sediments and pollutants, and act as buffers for adjacent upland areas, minimizing erosion and thereby guarding against floods and storm surges. Changes in sea level could increase shoreline erosion rates and create more turbid waters, impacting submerged vegetation by creating conditions unsuitable for their survival.

Coastal habitats have dramatically been altered over several decades as 22% of forests and wetlands have been converted to agricultural land and 9% to suburban and urban uses. Between 1990 and 2005, roughly 100 acres of forest habitat land was lost daily to development (National Wildlife Federation 2016). Moreover, over the past 150 years 10,500 acres of island habitat were lost in the Middle Eastern portion of the Chesapeake Bay region alone, displacing fish species, migratory birds, and other wildlife populations (Mueller 2008).

*Water quality*

Decades of land use conversion, agricultural and urban runoff, and excessive nutrient and sediment inputs have contributed to water quality problems in the Bay. The largest source of pollution to the Chesapeake Bay is agricultural runoff, followed by the sewage/ industrial sector. The fourth leading source is storm-water runoff or polluted runoff, which is also the fastest growing source of nutrient inputs (specifically nitrogen) to the Bay (Chesapeake Bay Foundation 2012b). Various pollutants, such as animal waste, oils and automotive fluids, chemical waste products, nutrients, and sediments enter the Bay through multiple pathways, including direct surface runoff, seepage through soil, and percolation into wells and groundwater.

These pollutants facilitate the increased production of harmful algae blooms and red tides, which can lead to increased hypoxia, increased turbidity, massive fish kills, and loss of native species. In addition, excess sediments that settle at the bottom of water bodies can smother vegetation and organisms, such as oysters and clams. If suspended in the water column, excess sediments will cause surface waters to become cloudy, thus limiting the availability of sunlight for underwater species. Furthermore, high temperatures can also damage beds of underwater grasses, such as *eelgrass*, the Bay's dominant submerged aquatic vegetation, and negatively impact wetlands.

Drinking and municipal water supplies can also be affected by to nutrient and sediment pollution in groundwater. Since groundwater tends to move very slowly and with little turbulence, dilution, or mixing, once the pollutants reach groundwater a concentrated plume may form. Impaired water quality also disrupts tourism and recreational activities, results in job reduction, and a decline in economic revenue from the fisheries and shipping industries. Other negative impacts include a decrease in real estate and property values located closer to the shoreline. Bacteria also poses a water quality problem in the Bay. For example, in the summer of 2011 there was an outbreak of the deadly bacteria *Vibrio*.

### *Governance and collaboration*

Multiple organizations work on Chesapeake Bay issues and governance, including the Chesapeake Bay Commission and the Chesapeake Bay Program. Federal, state and local governments, businesses, non-governmental organizations, interests groups, and citizens collectively seek to protect and restore the Chesapeake Bay watershed.

In September 1985, the Chesapeake Bay Commission developed the *Chesapeake Bay Restoration and Protection Plan,* which resulted in the implementation of management and control strategies to reduce nutrients and runoff from agricultural, forested and urban areas, and to improve water quality, habitats and fisheries in the Chesapeake Bay watershed. Five main categories became the central focus of the Chesapeake Bay Program: 1) Reducing Pollution, 2) Restoring Habitats, 3) Managing Fisheries, 4) Protecting Watersheds and 5) Fostering Stewardship (Chesapeake Bay Program 2008).

#### *Total Maximum Daily Load*

Most of the Chesapeake Bay and its tidal waters are regarded as impaired because of excess nitrogen, phosphorus and sediments. As a result, in 2010, the United States Environmental Protection Agency established the *Chesapeake Bay Total Daily Maximum Load (TDML)*, which was required under the federal *Clean Water Act*. The TDML establishes pollution limits required to meet water quality standards (EPA 2016a).

Although TDMLs are quite costly and necessitate significant input and resources from all stakeholders, they can be effective in restoring the health of water bodies and returning them to their designated use. The TDML sets pollution limits for the Chesapeake Bay watershed at 185.9 million pounds of nitrogen, 12.5 million pounds of phosphorus and 6.45 billion pounds of sediment per year (EPA 2015). These limits equate to a 25 percent reduction in nitrogen, 24 percent reduction in phosphorus and 20 percent reduction in sediment. The six states surrounding the Bay, as well as the District of Columbia, created Watershed Implementation Plans (WIPs) that describe what measures the states will employ to meet pollution allotments in specific time frames.

#### *Hampton Roads Pilot Project*

A major concern for Hampton Roads and surrounding areas is land subsidence and rising water levels due to global sea level rise. According to Eggleston and Pope (2013), since the 1940s land subsidence has been occurring in the southern Chesapeake Bay region at rates of 1.1 to 4.8 millimeters per year (mm/yr). Along with rising water levels, land subsidence combines to cause relative sea-level rise at rates higher in this region than anywhere else on the Atlantic Coast of the United States. The region is prone to extreme weather events and, with its relatively flat topography, small decreases in land elevations and small increases in sea levels can increase the likelihood of flooding.

The Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Pilot Project was created to develop practical solutions to manage the impacts of climate change and sea level rise, with a focus on the region's urban coasts (Steinhilber et al. 2015). The project is a framework for collaborative strategic planning, bringing together local stakeholders and other risk management initiatives in the region (Steinhilber et al. 2015). The project addresses: 1) Permanent inundation, 2) Increased tidal flooding, 3) Increased storm surge, both frequency and magnitude, and 4) Combined impact of sea level rise, precipitation and groundwater elevation on storm water drainage.

Since its inception the project has achieved significant milestones. For example, the Department of Defense officially acknowledged the project as one of its three national pilots in the Fall of 2014. The project also collaborated with water management specialists from the Netherlands and conducted dialogues locally in Norfolk and in other regions throughout the country, including New Orleans (Steinhilber et al. 2015). The success of this template is a useful model that other coastal communities experiencing similar threats to shorelines and national security can emulate.

### ***Highlights and insights***

*Market-based strategies hold promise*

Market-based strategies are a relatively new approach to environmental protection and restoration. Several market-based programs have been developed and implemented in the Chesapeake Bay. For example, in 2013 the Department of the Environment in the District of Columbia (DDOE) implemented a Storm-water Retention Credit (SRC) trading program, which allows individuals or groups that voluntarily implement storm-water control measures to sell their credits in an open market to others needing to meet retention standards.

Organizations have also expressed interest in a pollution credits market for the entire Chesapeake Bay, where entities would purchase credits that represent an equivalent or greater amount of environmental improvement from the provider of the improvement in question. The Federal Leadership Committee (2010) noted that opportunities exist in the Chesapeake Bay watershed to add to current state trading programs and for deeper federal supervision to expand the nutrient and sediment trading market. Although preliminary projects have shown evidence of the usefulness of such concepts, the infrastructure required for effective functioning in the Chesapeake Bay region is still lacking.

*Habitats and fisheries can recover*

The Susquehanna Flats experienced declines in sea grass for over 30 years and virtually disappeared after Hurricane Agnes in 1972. Since the early 2000s, however, the flats have begun to thrive once more. Steady reductions in nutrient inputs created baseline healthy conditions for sea grass, and a four-year drought lowered turbidity enough to create excellent conditions for rapid regrowth (Blankenship 2014). Furthermore, as the sea grass began to regrow, this created other positive effects, such as reducing the flow of water, weakening waves, and trapping dirt and substrate in the grass bed, thus creating even more favorable growing conditions.

Another area that has experienced some success is the blue crab fishing industry. Overfishing and pollution severely hampered the fishery, leading to a decline in fish populations and economic revenue for the region. In 2007, the industry suffered the worst fish harvest since 1945, and Maryland and Virginia have endured $640 million dollars in losses over the last decade (Chesapeake Bay Foundation 2008). However, since 2008 both states have lowered the limit on the number of female crabs that could be harvested and, along with water quality improvements, underwater grass restoration, proper harvest management, and industry regulations, the industry will be able to maintain this valuable resource.

*National programs can support state-level collaboration*

The U.S. Army Corps of Engineers runs the national Silver Jackets program, helping individual states create interagency teams to address natural hazards. These teams comprise multiple federal, state, tribal, and local agencies whose efforts are directed towards hazard mitigation, emergency management, floodplain management, and natural resources management (U.S. Army Corps of Engineers n.d.). The Army Corps provides both national and regional logistical and personnel support, and each team addresses issues of particular priority to their state.

In the state of Maryland, outreach activities by the Silver Jackets team consist of educating residents on the differences between the storm surge inundation maps contained in hurricane evacuation studies, and the flood insurance rate maps developed for the National Flood Insurance Program. In the District of Columbia, the Silver Jackets assist local communities by leveraging resources to identify and implement comprehensive and sustainable solutions to reduce flood risk. Although Silver Jackets teams are unique and differ from state to state, the underlying goal is delivering viable solutions to flood-hazard challenges by evaluating flood risks, providing assistance to implement projects, and educating stakeholders and residents about flood risks.

*Assessment of healthy watersheds is lacking*

Suitable assessments of watersheds are essential for maintaining and restoring the health of the Bay. Though the six states surrounding the Bay work together to preserve area watersheds, they often have varying goals, definitions, and approaches. This can lead to inconsistencies and gaps in information. Furthermore, most of the activity regarding the collection and use of data regarding the condition of watersheds is used to characterize impaired watersheds for restoration, rather than to identify and protect healthy watersheds (Chesapeake Bay Program 2014a). As a result, there is a lack of information for assessing "health" as opposed to "degradation." Thus, baseline knowledge about the actual status of healthy waters/watersheds may be inadequate, which in turn may influence the reliability of information needed to guide the regulatory process. This may create additional challenges since the status and importance of healthy watersheds are not always conveyed to local decision-makers and other organizations across all the Chesapeake Bay jurisdictions.

*Baseline monitoring of the regional nutrient budget is difficult*

If water quality goals are to be achieved, creating a balance in the regional nutrient budget is an important but difficult task. Many watersheds are not monitored or assessed by managers unless there is some activity regarding a change in status (e.g. a development proposal, a new wastewater plant, or dredge/fill permit application). Furthermore, new pollution associated with future growth in the watershed is difficult for resource managers to account for.

In addition, accurate monitoring of non-point source pollution is expensive, and it is difficult to identify the responsible party. Added complications arise when attempting to measure and assign partial degrees of responsibility for water quality impairments to individual parties.

*It is important to understand farm-level conditions*

In the agricultural industry, best management practices for nutrient reduction must take farm-level conditions into account. For example, best management practices that focus only on fertilizer application on cropland make it difficult for enterprises that combine cropland with confined feeding animal operations (CAFOs) to achieve farm-level balance of nutrients. These operations produce more manure than their farms' cropland can use, leading to a tendency to over-apply manure nutrients to cropland. Best management practices must take into account issues of farm-level nutrient management, integrating animal operations and cropland nutrient strategies (Ribaudo et al. 2014).

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## Savannah River Region

### *Natural Landscape*

The Savannah River, 300 miles long, drains a watershed of 10,577 square miles. Its headwaters originate in the Blue Ridge Mountains of Georgia and the Carolinas. It demarcates the state boundary between Georgia and South Carolina, and flows into the Atlantic Ocean near Savannah, Georgia. The Savannah River Basin receives roughly 40 to 80 inches of precipitation annually (SCDHEC 2010).

The diverse basin is home to everything from forests to swamps and marshes. This makes it the home of a large variety of wildlife, including a number of protected species. The Savannah River has several large dams, including those forming Lakes Hartwell, Russell, Clark Hill, and Thurmond. These reservoirs provide power generation, flood control, recreation, fisheries, and biological ecosystems.

### *Human Landscape*

The river basin includes all 27 counties in Georgia, with 10 entirely in the basin (SCDHEC 2010). Augusta (population 195,844) and Savannah (population 379,199) are major metropolitan centers in the watershed. Additionally, the Savannah Harbor is a significant shipping port, and a project to expand the Harbor is currently underway.

### *Importance and Impacts*

Before railroad expansion redefined America's transportation landscape, the Savannah River served as a major transportation corridor. Today it provides drinking water, industrial utility, and waste disposal. Various dams in the Savannah River watershed are used for hydropower generation, providing energy to the surrounding area (Savannah Riverkeeper n.d.), including the metropolitan centers of Augusta and Savannah. Additionally, the Savannah Harbor continues to hold economic significance as a major shipping port in the region (SCDHEC 2010).

The Savannah River region is also home to diverse ecosystems, and much of the region's economic fabric is dependent on those ecosystems. Forestry and fisheries are both important parts of the regional economy. Some commonly recognized fish populations found in the Savannah include bass and catfish, as well as various trout species (SCDHEC 2010).

### *Major Issues*

*Water quality*

Pollution is one of the biggest issues facing the Savannah River. Pollution comes from a variety of sources. Nitrate compounds, which are commonly found in fertilizers, make up roughly 88% of water contamination in the state of Georgia (EPA 2014), indicating a problem with excessive agricultural runoff. The issue is exacerbated by stormwater runoff, which washes oil residues and contaminants from industry and urban development, and soil into the river.

These problems threaten the region's ecosystems and the populations that depend on the basin as a water resource. Dredging also depletes oxygen levels in the water – an additional threat to aquatic wildlife, and a complicating factor when it comes to other water quality challenges (Savannah Riverkeeper n.d.).

*Saltwater Intrusion*

Saltwater intrusion, which can be caused by channel construction and the pumping of groundwater, also contaminates water resources in the Savannah River area. Saltwater intrusion could cause serious harm to the freshwater environment and jeopardize drinking water availability.

Currently, a major channel-building endeavor called the Savannah Harbor Expansion Project (SHEP) is under way. SHEP will deepen the 18.5-mile outer harbor from 42 feet to roughly 49 feet, with the goal of accommodating larger vessels expected to follow the expansion of the Panama Canal. SHEP may impact the hydrology and hydraulics of the Harbor, and significant work is being done to understand those impacts.

*Sea Level Rise*

Sea level rise is another major water-related challenge. Sea level rise exacerbates flood risks from storm surges and coastal erosion. Increased frequency of tidal flooding in low-lying areas like Beaufort and Port Royal poses critical danger to property, infrastructure, water quality, and public safety (Beaufort and Port Royal Sea Level Rise Taskforce 2014). A study of the Georgia coast projected a 1-meter rise in water level by the year 2110. While sea level rise occurs over a long time frame, experts stress the need for planning and preparation in order to build sustainable communities (Georgia Conservancy 2016).

*Coastal Drought*

Coastal ecosystems in the Carolinas, especially tidal marshes, freshwater marshes, and forested wetlands, are vulnerable to drought impacts. These include changes in water quality, habitat integrity, nutrient-loading, food web dynamics, and overall ecosystem health. Prolonged drought in the region also exacerbates problems related to salinity. These impacts, in turn, can be compounded by water management-related practices, such as dam building and dredging (Gilbert et al. 2012).

### ***Governance and collaboration***

Several local initiatives have formed to tackle coastal vulnerabilities. The municipalities of Beaufort and Port Royal in South Carolina formed a joint task force to deal with the local impacts of sea level rise on public property, crucial infrastructure, and citizen safety. The membership includes a diverse cross-section of local officials, academics and experts, and local residents.

The Carolina Integrated Sciences Assessment (CISA), a NOAA RISA team, has sponsored and supported collaborative work in the Carolinas. In September 2016, the CISA led the Carolinas Climate Resilience Conference which focused on providing actionable tools and information to on-the-ground practitioners. The Georgia Department of Natural Resources Coastal Resources Division sponsored a similar conference in November 2016 titled "Prepare, Respond, and Adapt: Is Georgia Climate Ready?," the first climate change-focused conference for Georgia practitioners.

Chatham County, Georgia (city of Savannah) has also been chosen as a pilot community for the American Planning Association (APA) and Association of State Floodplain Managers (ASFPM)'s Building Coastal Resilience project. Recipients of a 2015 NOAA Regional Coastal Resilience Grant Award, the project will focus on best practices for incorporating climate change into capital improvement planning.

### *Highlights and insights*

*Coastal drought is unique*

Research done at the Carolinas Integrated Sciences and Assessments (CISA) and USGS South Atlantic Water Science Center has developed an understanding of the unique character of coastal drought. The primary mechanism for drought impacts on the coasts is through salinity changes; during times of drought, streamflow decreases, allowing for the intrusion of saltwater up rivers, creeks, estuaries, and other water bodies (Gilbert et al. 2012). This affects tidal marshes and ecosystems, fisheries, and the transport of pathogens like vibrio.

Experts have worked to develop a Coastal Drought Index, using salinity as a key variable (Conrads 2016). Ultimately, this will allow for adaptive management measures, including salinity alert systems, development of infrastructure to deal with short-term salinity intrusions (e.g., drinking water intake systems), changing the timing of regulated water storage releases to control salinity, and understanding projected changes to fresh- and saltwater estuaries to plan effective ecosystem preservation work.

*It can be effective to integrate risk management into existing municipal frameworks*

Since the closure of oyster beds due to contamination in the 1990s, Beaufort County has been working to address water quality and stormwater management issues. The County pursued land use policies that could mitigate pollution runoff, including riparian buffer areas, property set backs, land preservation efforts, and stormwater best management practices. These were institutionalized in the County's Comprehensive plan, zoning ordinances, and utility regulations and guidelines (Merchant 2016).

As the County recently began to face the challenges of sea level rise and climate change, they discovered that many of the projects and initiatives aimed at water quality improvements also increased the community's resilience to short- and long-term weather and climate impacts. In addition, framing the impacts of climate change as a nuisance issue, and a costly nuisance at that, was particularly productive in helping local offices understand the problems and how to address them.

Nearby Tybee Island, GA is dealing with significant nuisance flooding from sea level rise. An initiative facilitated by Georgia Sea Grant allowed the community to identify the issues, assess the magnitude of threats, and consider options for adaptation. As a result of that work, the community realized that it is important to incorporate sea level rise planning into the Department of Transportation's planned modernization of Highway 80 and the re-authorization of the Army Corps' Tybee Island Shoreline Protection Project, both of which are significant, ongoing infrastructure projects.

These initiatives in Beaufort County and Tybee Island demonstrate the importance of framing risk management in a way that is relevant to the day-to-day work of the municipality and the need to integrate preparedness planning into existing municipal plans and projects.

*Stakeholder outreach is crucial*

The Tybee Island Sea Level Rise Adaptation Plan demonstrates the importance of significant stakeholder outreach early in the project. The outreach efforts of Georgia Sea Grant reached over 4,000 people, which is remarkable given the small population of the Island. The sea level rise plan was presented to the City Council in mid-April 2016 and was unanimously approved, becoming the first sea level rise plan in Georgia. The project has also led to additional research efforts, including considering a living shoreline on the island, studying voluntary buyouts for reducing repetitive losses, and piloting a mobile app. The unanimous acceptance, community buy-in, and follow-on use of the project data demonstrate the importance of early and extensive community outreach (Gambill 2016).

*Visualizations are an effective tool for communicating risk*

Common wisdom asserts that a picture is worth a thousand words, and Georgia Sea Grant discovered that simulated pictures are also an effective way to meaningfully communicate the risk of sea level rise. Georgia Sea Grant took an existing picture of a bridge and dock on the coast and simulated pictures of the same location with different levels of sea level rise. These visualizations were very helpful for communicating the actual impact of different future scenarios to local residents (Gambill 2016).

*Immediate benefits drive long-term work*

It is crucial to note that the Tybee Island Sea Level Rise Adaptation Plan allowed the community to participate in FEMA's Community Rating System and lower their flood insurance costs by $725,639. This direct financial benefit to property owners was a significant driver of participation in the program, and an important incentive for other communities to participate in additional projects with Georgia Sea Grant. Together with other state Sea Grant programs and academic partners, Georgia Sea Grant is working with seven additional communities in the Southeast on sea level rise and climate adaptation planning.

*Large projects drive research and monitoring needs*

The Savannah Harbor Extension Project is driving significant work to address science and data gaps in the region. For example, the project includes an oxygen injection system whose effectiveness is still unknown. The system will be installed in 2018, and significant studies will be in place to measure dissolved oxygen in the Savannah River. In addition, the harbor deepening will have an impact on saltwater intrusion. The Savannah National Wildlife Refuge, one of the last extensive freshwater tidal marshes, and the City of Savannah's water intake may both be impacted by changes in salinity, and will thus require extensive monitoring. The Army Corps is also working with the South Carolina Department of Natural Resources to conduct fishing surveys, in particular to understand the state of the sturgeon population. Finally, the Army Corps needed to be certain that the deepening would not cut into the confining unit of the aquifer, and thus needed to conduct research to better understand and locate the aquifer confines. Building adaptive management into big projects can improve the state of science and monitoring in the region and help to inform larger coastal vulnerability and risk management questions, not just the issues specific to the project.

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## C. Gulf Coast

### Houston/Galveston Area

#### *Natural Landscape*

Galveston Bay is the largest of seven estuaries in Texas (Texas A&M University 2016). With 232 miles of shoreline, the Bay's combined area is over 600 square miles (Galveston Bay Estuary Program 2013). The Galveston Bay watershed extends inland up to the Dallas-Forth Worth Metroplex, covering 24,000 square miles with 120,000 acres of wetland (Galveston Bay Keeper; Galveston Bay Estuary Program 2013).

Multiple rivers and bayous, including the Trinity and San Jacinto Rivers, discharge into Galveston Bay estuary. Galveston Bay is composed of four sub-bays: the Galveston, Trinity, East, and West bays. The estuary is varied with both aquatic and terrestrial habitats: wetlands, uplands, oyster reefs, intertidal mudflats, seagrass meadows, coastal prairie, and riparian forest (Galveston Bay Estuary Program 2013).

The estuary is connected to the Gulf of Mexico, though separated by Pelican Island, Galveston Island, and the Bolivar Peninsula (Coplin and Galloway n.d.). The climate in the area is subtropical and averages 47 inches of rain annually (United States Geological Survey). The Texas coast experiences a hurricane or tropical storm once every two years, on average (Coplin and Galloway n.d.).

### *Human Landscape*

Galveston Bay is contained within the Houston-Galveston metropolitan area, which boasts a total population of approximately 6.5 million people. The region contains over 75% of the coastal population in Texas (Houston-Galveston Area Council 2016; Galveston Bay Estuary Program 2013). The region is growing rapidly; the population rose 12% from 2010 to 2015 (Houston-Galveston Area Council 2016). The western side of the bay is heavily populated while the eastern side is largely undeveloped and rural (Galveston Bay Estuary Program 2013).

### *Importance and Impacts*

Named an "estuary of national significance" by the U.S. Congress, Galveston Bay provides both economic and ecosystem services to the surrounding areas (Galveston Bay Foundation 2016). Galveston Bay is the most biologically productive ecosystem in the state (Galveston Bay Estuary Program 2013).

Economically, it provides for the shipping, industrial, agricultural, fishing, and recreational sectors. Through these sectors, Galveston Bay supports the employment of tens of thousands of people and contributes billions to the regional economy (Galveston Bay Estuary Program 2013). The Port of Houston, connected to Galveston Bay via the Buffalo Bayou and San Jacinto River, is the largest port in the United States for waterborne commerce and the second largest port by tonnage of shipment (Galveston Bay Foundation 2016). Commercial seafood harvesting is also a large part of the local economy, with a focus on shrimp and blue crab (Galveston Bay Estuary Program 2013). Galveston Bay provides one third of commercial fishing income in Texas and half the state's recreational fishing (Galveston Bay Estuary Program 2013).

### *Major Issues*

Galveston Bay faces numerous threats, both natural and anthropogenic. Through the review of several group priorities and action plans, including the Galveston Bay Estuary Program (GBEP), The Galveston Bay Foundation, and the Houston Area Research Council (HARC), the issues facing the region can be categorized by coastal subsidence and erosion, storms and flooding, water quality, and habitat destruction.

#### *Coastal Subsidence and Erosion*

A portion of the Galveston Bay shoreline is prone to higher rates of erosion due to past subsidence issues and rising sea levels from climate change (Galveston Bay Estuary

Program 2013). Past subsidence was caused largely by high levels of groundwater pumping as well as oil and gas extraction, leading to flooding, shifting coastlines, and wetland loss (Coplin and Galloway n.d.). While the region has worked to reduce its dependency on groundwater, subsidence continues to cause issues for the area.

*Storms & Flooding*

Storms are a continuing issue for the Houston-Galveston area. The region is susceptible to tropical storms and hurricanes in the Gulf of Mexico, which is experiencing faster than predicted rates of sea level rise due to both global climate change and coastal subsidence (Melillo et al. 2014). Galveston has seen a sea level increase of 3 feet since 1880 (Melillo et al. 2014). Though seawalls were built in Galveston decades ago, Hurricane Ike caused approximately $28 billion in damages and caused 20 fatalities in the Houston-Galveston area in 2008. Storm surges and flooding associated with such events are a major threat, with surges reaching between 15-20 feet in Chambers County in Galveston Bay during Hurricane Ike (Climate Central 2012).

*Water Quality*

Water quality remains an ongoing issue in Galveston Bay. Major pollutants of concern include pathogenic bacteria, nutrients, mercury, pesticides, suspended solids, oil, and solid waste (GBEP 2014). The region has seen improving trends in non-point source pollutants, but whether these trends will be maintained is a remaining question (Gonzales 2016).

One of the main priority pollutants is bacteria, with 32 bacteria impaired water bodies in the Houston-Galveston area (National Estuary Program 2009). Population growth is an additional contributor, through non-point source pollution and failing septic systems. Oil spills are another recurring issue, with an average of 285 spills per year since 1998 with an average size of 103 gallons (Tresaugue 2014). The 14-acre San Jacinto River Waste Pits Superfund site is another major threat to water quality. In September 2016, the U.S Environmental Protection Agency proposed to remove the toxic waste that is currently buried and submerged (Environmental Protection Agency 2016f).

*Habitat destruction*

The Galveston Bay Watershed has extremely diverse habitats, including wetlands, seagrass meadows, and oyster reefs (Houston Advanced Research Center 2016). The Bay is losing approximately 1,200 acres of wetlands per year due to sea-level rise, land-use change, and dredge-and-fill activities (Galveston Bay Estuary Program 2013). Though saltwater wetlands are protected by the Clean Water Act, freshwater wetlands are unprotected (HARC 2016). These areas have been adversely affected by salinity changes, sea level rise, and low water clarity. Oyster reefs, which improve water quality and are an important part of the commercial seafood industry, are also under stress. Due to storm surges, over harvesting, drought, and fishing pressure, the habitat is quickly declining (HARC 2016). In addition, future population growth and its related development represent the greatest future impact on water quality, water use and flooding in Galveston Bay (Gonzales 2016).

### ***Governance and collaboration***

There are an array of programs and initiatives working towards managing issues in the region, including both public and nonprofit groups. These organizations include the Houston Advanced Research Center, The Galveston Bay Foundation, and the Galveston Bay Estuary Program. Each of these organizations contributes to an array of different activities. For example, the GBEP produces the State of the Bay report, a regular update on Galveston Bay ecosystem and its management actions (GBEP 2011). One of the main focuses of The Galveston Bay Foundation is on improving and promoting water conservation as well as the potential for water re-use as a water management strategy (Paciorek 2016).

### ***Highlights and insights***

*Report cards are a valuable public communication strategy*

One of the major successes in the region was the use of report cards and scorecards as a means of communicating the issues the Bay faces to the public. The Galveston Bay report card, an effort of the Galveston Bay Foundation and HARC, is the "first easy to understand grading system that communicates the health of the Bay to the public (Gonzales 2016)." Similarly, the Texas Water Conservation scorecard is an effort by the Sierra Club-Lone Star Chapter, the National Wildlife Federation, and Galveston Bay Foundation, all partners in the Texas Living Waters Project. The effort is "an evaluation of what utilities are doing to save water through ongoing conservation measures (Paciorek 2016)."

*Coastal communities are always changing and require constant outreach*

Population growth, along with turnover of residents, makes communication and outreach difficult. It is necessary for non-governmental organizations, experts, and government offices to maintain a vigilant approach to outreach, both to understand the needs and issues of a changing community and to ensure citizen awareness and education on environmental issues in the region (Paciorek 2016).

*Some data gaps remain*

While the Galveston Bay report card highlights excellent long-term data sets from federal, state, and local partnerships, it also indicates that gaps still remain. These gaps are namely for seagrass and oyster reef acreage, litter issues, and legacy pollutants in sediments and the food web. These remain in large part due to a lack of both funding and focus (Gonzales 2016).

*Additional funding is needed*

Workshop presentations reiterated that while climate change mitigation may be difficult to pursue aggressively in the current political climate, community preparedness planning efforts are taking place and merit additional resources. Local conservation, restoration and research efforts require intense leveraging of funds when state funds can be scarce (Gonzales 2016). The Galveston Bay Report Card provides an accessible way for stakeholders to understand the areas where additional resources could be heavily leveraged.

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**Mississippi River Delta**

***Natural Landscape***

The Mississippi River Delta is an ecologically diverse and biologically productive region stretching nearly 3 million acres (Couvillion et al. 2011). It is one of the largest areas of coastal wetlands in the United States. The delta ranges from interior forested wetlands to barrier islands on the Gulf of Mexico, with numerous interconnected habitats including freshwater, brackish and salt marshes.

The Mississippi River watershed is the fourth largest in the world, extending from the Allegheny Mountains in the east to the Rocky Mountains in the west, and measures approximately 1.2 million square miles (National Park Service n.d.). The Mississippi River is the second longest river in the United States with a length of 2,320 miles (National Park Service n.d.).

The Mississippi discharges at an annual average rate of between 200,000 and 700,000 cubic feet per second and releases about 400 million yards of mud, sand, and gravel per year. Flat terrains and poor drainage is typical throughout the region, creating conditions suitable for wetlands (Stroud 2015).

***Human Landscape***

The Mississippi River Delta is surrounded primarily by the states of Louisiana and Mississippi. Almost half of the population of Louisiana lives near the coast, including in the city of New Orleans. The coast's unique culture is made up of people whose lifestyle is tied to the bayous, including Acadians (Cajuns), American Indians, and other non-indigenous populations. The major population centers in the state of Mississippi include: Jackson – 173,514; West Gulfport – 71,329; and Gulfport – 67, 793. In the state of Louisiana: New Orleans - 343,829; Baton Rouge - 229,493; and Shreveport - 199,311 (GeoNames n.d.-a).

***Importance and Impacts:***

Much of the region's economy is dependent on the coast and wetlands, home to shipping ports, several highly productive commercial fisheries, and offshore oil fields and refineries. The economy also relies heavily on tourism and recreational activities such as fishing, hunting and wildlife watching. The Mississippi River Delta contains seven of the top 50 seafood landing ports in the United States, with Louisiana's commercial fisheries the source of more than 30% of the nation's commercial catch (Dardis 2010). Commercial fishing is a $2.4 billion industry in the Gulf of Mexico with about 75% of the fish arriving through Louisiana ports. Louisiana has the second largest commercial fishery in the United States by weight, and is first in annual seafood produce including oysters, shrimp, crabs, crawfish, red snapper, wild catfish, sea trout and mullet (Lowe et al. 2011).

Three of the United States' largest ports are located in Louisiana: the Port of Baton Rouge, the Port of New Orleans, and the Port of South Louisiana. Louisiana's river ports support about 270,000 jobs and generate over $32.9 billion annually to the state's economy (Vasey 2012). Louisiana's ports are a huge contributor to the United States' domestic and international shipping industry, sending and receiving over $100 billion dollars per year in agricultural goods, machinery and other products. Altogether, the Mississippi River moves about 500 million tons of cargo each year, including over 60% of the nation's grain exports (Vasey 2012).

The region also depends on the Mississippi River as a source of freshwater and to discharge its industrial and municipal waste. Close to 18 million people rely on the Mississippi River or its tributaries for drinking water, and more than 50 cities rely on it for daily water supply (NRCS n.d.).

### *Major Issues*

*Erosion and Habitat Loss*

Land use alterations have posed significant challenges for the Mississippi Delta region. Infrastructure, including flood protection levees, canals, offshore rigs, and onshore wells, have altered wetlands, modified coastal hydrology, and accelerated coastal erosion. For example, dams constructed upstream have reduced the amount of sediments in the lower Mississippi and prevent remaining sediments from spreading across the coastal floodplain. In addition, levee structures along the Mississippi River interrupt the natural replenishing flow of sediments and freshwater, thus causing the land to subside and making wetlands more vulnerable to erosion and saltwater intrusion.

*Saltwater Intrusion*

The dredging of canals for improved access and navigation can accelerate saltwater intrusion. Oil and gas pipeline ditches and navigation canals act as conduits which allow saltwater to enter interior marshes, destroying freshwater vegetation and causing them to become submerged underwater.

*Oil Spills*

Oil spills have devastating effects on coastal communities, economies and natural ecosystems. For example, the 206 million gallon BP oil spill in 2010 produced ripple effects on marine plants and animals by disrupting food webs, reducing dissolved oxygen levels, and increasing turbidity in ocean waters. Other negative impacts include the altering of natural habitats, the disruption of beaches and coastal waters for both recreational and economic activities, and the disturbance of thousands of acres of coastal marshes and shorelines that serve as a nursery for migratory birds and other wildlife.

*Storm surge and flooding*

The region is prone to storm surges, flash flooding, hurricanes, coastal flooding, and shoreline erosion. The thinning of oyster reefs and barrier islands diminishes their natural protection, while loss of wetlands results in fewer natural defenses against hurricanes and other natural disasters. The destructive impact of Hurricane Katrina and Rita produced overwhelming effects throughout the Gulf Coast region, with damages totaling $150 billion (Plyer 2016). Flood waters displaced over 770,000 people in the Gulf Coast and caused property damage to over 1 million housing units. In New Orleans alone, an estimated 300,000 homes were destroyed or otherwise made uninhabitable (Plyer 2016). Together the two storms resulted in almost two thousand deaths

*Sea level rise*

According to Karl et al. (2009), Louisiana has experienced local relative sea-level rise and the loss of 1,900 square miles of coastal wetlands. This stemmed mostly from the sinking of local lands due to the construction of levees and the extraction of fluids and sediment during oil and gas drilling. A combination of increasing surface water temperatures and sea-level rise can lead to fragmentation of barrier islands, soil loss, degradation of natural resources such as mangroves, and the destruction of homes and other infrastructure.

*Water Quality*

Water quality issues have plagued the Mississippi region for decades due to the combined effects of agricultural development and an expanding industrial river complex. With fewer wetlands to filter the river's flow, excess run-off of nutrients and sediments have contributed to the diminished quality of water resources. Excessive quantities of nitrates and phosphates routinely enter the river from agricultural fields, runoff from suburban lawns, and discharges from waste treatment systems and industrial facilities.

These nutrients lead to massive increases in algae populations (eutrophication), which facilitates the growth of harmful algal blooms (HABs). When the algae blooms eventually die, the ensuing decomposition reduces the amount of oxygen available in the water (hypoxia) for other forms of aquatic life. This creates dead zones and leads to high mortality and population decline in marine species. NOAA estimates that between 1987 and 2000 these dead zones cost seafood and tourism industries in the United States, including the Gulf of Mexico, about $82 million a year in economic losses (Andreatta et al. 2012). In 2015, the Gulf of Mexico dead zone was ranked as the second largest human-caused hypoxic area in the world, with an area size of 6,474 square miles (NOAA OCM 2015).

*Invasive Species*

The presence of invasive species, such as *Nutria,* has had severe effects on coastal wetlands. Through aggressive foraging, these fast breeding, voracious rodents consume the roots of marsh plants and devour cypress seedlings.

### ***Governance and collaboration***

There are several organizations working to coordinate the efforts of various states, non-profits, and federal agencies along the Mississippi River. The Upper Mississippi River Basin Association (UMRBA) is a regional interstate organization formed by the five upper river states (Illinois, Iowa, Minnesota, Missouri, and Wisconsin) to help coordinate their river-related programs and to work with federal agencies on river issues. The Lower Mississippi River Conservation Committee (LMRCC) is a multi-state coalition of twelve state natural resource conservation and environmental quality agencies.

The Mississippi River Collaborative (MRC) is a partnership of various environmental organizations and legal centers from states bordering the Mississippi River, as well as regional and national groups working on issues affecting the Mississippi River and its tributaries. It comprises thirteen organizations from Minnesota, Wisconsin, Iowa, Illinois, Missouri, Kentucky, Tennessee, Arkansas, Louisiana, and Washington D.C.

Established in 2004 by the Governors of the five Gulf States – Alabama, Florida, Louisiana, Mississippi and Texas – the Gulf of Mexico Alliance (GOMA) is a regional ocean partnership between these five Gulf States and federal agencies, academic organizations, businesses, and other non-profit groups in the region. The Alliance exists to increase regional collaboration and enhance the environmental and economic health of the Gulf of Mexico (GOMA 2016). Through their collaborative actions, the alliance actively addresses the region’s priority issues, including: enhancing coastal risk management; improving water quality and water quantity issues; increasing habitat resources; and improving data access and monitoring coordination, among others (GOMA 2016).

### ***Highlights and insights***

*Multiple strategies exist for restoring wetlands*

Different strategies for coastal restoration are suited for different types of landscape features, such as barrier islands, land bridges, natural ridges and levees.

River diversions imitate natural processes, using the energy of the Mississippi River to capture and push sediments, nutrients and water into wetlands in order to build new land (Plaquemines Parish 2011). According to Roberts et al. (1992), controlled sediment diversion and freshwater diversion would be effective methods for restoring wetlands. In addition, short, intense spurts of water and sediments through releases simulating flooding can provide similar benefits to permanent diversions. Robert Twilley, Director of Louisiana Sea Grant, proposed that restoring the delta's sediment supply with controlled floods could be the key to reducing coastal land loss (Twilley 2016).

However, some habitats are not well-suited to sediment diversion strategies. Barrier islands provide protection against tropical storms and erosion from tides for the habitats and structures behind them. The restoration of natural ridges through dredging, sediment placement, and vegetative plantings can effectively re-establish natural ridge functions.

*Academic institutions have a role to play in risk management*

Academic institutions play a key role in tackling environmental issues that continue to plague coastal regions across the nation, and the LSU Coastal Sustainability Studio (CSS) is a good example. The studio is a collaboration between faculty, research fellows, undergraduates, and graduate students in the School of the Coast and Environment, the College of Engineering, and the College of Art and Design at Louisiana State University in Baton Rouge, Louisiana. The CSS brings together disciplines that often work independently, such as designers, scientists, engineers, and planners. These transdisciplinary teams work to solve such problems through an integrated design and systems-thinking approach (Looney 2012). Also, each summer the CSS hires students from across the country for full-time, paid summer internships to collaborate on a variety of projects ranging from visualizations, exhibit design, and design competitions to policy initiatives and communications to address the myriad of environmental challenges facing vulnerable communities in the Gulf Coast region (Looney 2012).

*Regional harmonization of water quality standards and monitoring is a challenge*

Efforts to reduce non-point source pollution are hampered by inconsistencies among the Mississippi River corridor states in their water quality standards and monitoring programs. State-level water quality monitoring programs along the river have different levels of resources and have not been well coordinated, thus creating discrepancies. In the north, the Upper Mississippi River Basin Association (UMRBA) has promoted many cooperative water quality studies and other initiatives; however, there is no similar organization for the lower river states.

A systematic approach for monitoring water quality, including a system for sharing water quality data for the entire Mississippi River, is still needed. Although federal agencies such as NOAA, the Army Corps of Engineers, and the USGS collect various water quality data for different stretches of the river and into the Gulf, there is no single federal program for water quality monitoring and data collection for the river as a whole. Coordination between the EPA and the Mississippi River states would help ensure the collection of data necessary to develop water quality standards for nutrients in the Mississippi River and the northern Gulf of Mexico (National Research Council 2008).

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## D. West Coast

### Central California Coast

#### *Natural Landscape*

California's Central Coast, roughly 300 miles, runs between Santa Cruz in the north and Ventura in the south. The hydrologic region covers about 11,300 square miles of central California. These valleys and aquifers rely primarily on rainfall and streamflow for recharge. Valleys, including Salinas, Pajaro, Carmel, Santa Ynez, Santa Maria, and Cuyama, demarcate the area's geography, while Santa Barbara makes up a coastal plain (California Department of Water Resources 2003).

The region has 50 groundwater basins, which play a key role in the geography and water use landscape throughout the Central California Coast. Groundwater basins make up roughly a third of the hydrologic region, and groundwater itself makes up over 80% of the water supply. The size and scope of aquifers in the area vary widely. Some valleys boast extensive systems of aquifers, while other inland valleys and coastal terraces make up smaller resource concentrations (California Department of Water Resources 2003). The San Andreas Fault delineates the region's inner border.

#### *Human Landscape*

The area incorporates many population centers, including Santa Cruz, Monterey, San Luis Obispo and Santa Barbara counties in their entireties, as well as parts of San Benito, San Mateo, and Santa Clara counties -- home to approximately 4 percent of the state's population.

California relies on groundwater for about 40 percent of its supply, but in the Central Coast this number jumps to somewhere around 80% (Martin 2014). Furthermore, groundwater in this region makes up over 8 percent of the entire state's groundwater supply. Central California is a major agricultural center, home to large and diverse farming operations that are significant on state, national, and even global scales.

### ***Major Issues***

*Drought*

Many of the water issues in the Central California coast region have to do with supply. For example, how can water management reconcile extended periods of drought with population growth and a corresponding increase in demand, and how should water be allocated among sectors? Where should we source water for a given area, and how can it be most effectively transported and protected from contamination?

Perhaps the most obvious factor with regard to water scarcity is the ongoing drought, which complicates water management in the Central coast. Difficult decisions of how to allocate water resources between urban and agricultural sectors reflect the conundrum of maintaining growing city populations as well as the large farming operations that feed them – and much of the rest of the country.

The Central Coast region relies on groundwater for 80 percent of its supply. Exacerbated in times of drought, many areas in California experience overdraft, which occurs when water gets pumped out of basins faster than it can be recharged. Along the Central coast, the Salinas and Pajaro basins among others suffer from saltwater intrusion, a result of chronic overdraft (Hanak et al. 2011). This threatens the quality of drinking water and water used to irrigate agricultural land.

Drought can also increase the potential for flood damage in the region. Dried rivers can become more "flashy" following precipitation events, meaning the flow and level can rise quickly, leading to flooding. In fact, 7 million Californians live in a floodplain (California Natural Resources Agency 2016). The state has a long history of significant droughts and floods, with many notable high-impact events occurring in the central coast region. For example, 1969 saw record flooding that killed 60 people and caused $400 million in damages. In the following decade, drought impacted the whole state, including those central coast areas that had been flooded (Paulson et al. 1991). Changing precipitation patterns and a greater amount of precipitation falling as rain rather than snow contributes to this flood risk (The Nature Conservancy 2016).

*Sea Level Rise*

Sea levels along the coast have risen 8 inches over the past century. Researchers predict sea level rise from 1 meter to 1.4 meters by the year 2100 (Heberger et al. 2009). Sea level rise leads to beach erosion, cliff erosion, infrastructure and property damage, ecosystem harm, and population endangerment along the central coast (Griggs et al. 2005). Coastal population and development growth continues as sea level rises, and so the risks only increase. The projected increase to 1.4 meters would put hundreds of thousands of people and a wide array of critical infrastructures at heightened risk in the event of a 100-year flood (California Climate Change Center 2009). The narrowing of beaches, degradation of infrastructure, and erosion of natural protective barriers make prediction accuracy and coastal community risk management a critical issue in the region.

In addition, El Nino and La Nina events compound SLR-related impacts along the Pacific Coast. El Nino storms themselves induce temporary sea level rise, and the most severe damage to California's coast over the past half century resulted from El Nino events. For example, a major event in 1983 wreaked millions of dollars worth of damage in Santa Cruz and Monterey Bay (Russel and Griggs 2012).

Sea level rise also exacerbates saltwater intrusion in coastal aquifers already subject to excessive pumping (California Climate Change Center 2009).

### ***Governance and collaboration***

*Legislation*

State legislation dealing with surface water passed in 1913, but it did not address groundwater. As a result, the next one hundred years saw groundwater treated as a common resource – accessible to be pumped by anyone so long as it was put to beneficial use. In 2014, the legislature amended the water code to regulate for "sustainable" use of groundwater. The Sustainable Groundwater Management Act (SGMA) applies to high and medium priority basins. It operates on a foundation of localized control and regulation. That is, water management takes a bottom-up approach, and only when local governments fail does the state step in (Faunt 2016). The following year, Governor Jerry Brown issued an executive order mandating a 25% cut in urban water use statewide. In May of 2016, a mandated "stress test" based on assuring that water suppliers can provide a three-year supply of water replaced the percentage-based benchmarks that had been in place since February. The new regulatory frameworks continue a strategy of localized responsibility and management (State of California 2015).

*Partnerships and Collaborative Efforts*

In September of 2006, the Governors of California, Oregon, and Washington launched the West Coast Governors' Agreement on Ocean Health, forming an Alliance to promote goals such as clean coastal waters, healthy oceans, ocean awareness among the public, the expansion of coastal science, best ecosystem management practices, and the sustainability of coastal communities (West Coast Ocean Partnership 2016).

California's State Water Resources Control Board is another important governance entity. The State Water board exists to "ensure the highest reasonable quality for waters of the state, while allocating those waters to achieve the optimum balance of beneficial use (State Water Resources Control Board 2012)." Additional groups, like the California Water Partnership, work towards a sustainable, equitable water future for the state, and provide guidelines and recommendations to the State Water Board (Bothwell and Odefey 2015)

### *Highlights and Insights*

*Models are valuable tools for decision-making*

In a region where supply reliability is a significant concern, understanding water systems and developing reliable predictive models can play a key role in water management. Many different groups have developed models, both specific to certain locations and more widely applicable, that can be used to assist in decision-making and planning for the future.

Developed by USGS, the Coastal Storm Monitoring System (CoSMoS) makes detailed predictions of coastal flooding and cliff erosion over wide geographic areas. The system generates hindcasts, nowcasts and forecasts, and projects future climate ramifications such as sea level rise (USGS 2015). Originally developed and tested in Southern California, CoSMoS is now applied statewide and could potentially be used towards risk management in coastal areas around the world (USGS 2015). CoSMoS provides a useful database, and includes socio-economic information. CoSMoS is an example of a widely-applicable tool for place-based solutions.

The Pajaro Valley Water Management Agency employs a groundwater computer model of the Pajaro Valley Aquifer system. The agency uses four basin-wide models, three of which use code from the Integrated Surface Groundwater Model (PVWMA n.d.), while the fourth uses code from Modflow 1988. The model uses recharge from rainfall, stream seepage, and water and groundwater flow into the basin as inputs, and generates pumping, groundwater flow out of the basin, seepage from aquifers into streams, and evapotranspiration as outputs (PVWMA n.d.). This helps inform water management decision-making.

USGS's California Water Science Center developed the Central Valley Hydrologic Model (CVHM), a 3D computer model used to predict water supply scenarios and show the flow of groundwater across the landscape. Such tools are a part of a water management arsenal for addressing conjunctive water use, landscape change, and climate change (USGS 2016).

*Small interventions early can avoid large losses later*

Pacifica is a coastal city in San Mateo County, built-up and developed due to its close proximity to San Francisco. Twenty years ago, residents of apartment complexes close to the ocean enjoyed the sea view at a safe distance from the cliff's edge. This year, those same buildings were demolished as the eroded cliff crumbled from beneath them (Garcia 2016).

However, much of this damage could have been prevented, or at least made less severe. A series of photos taken of the location over several decades shows that areas of the cliff base that had been reinforced with boulders eroded far less than the parts that had not – unfortunately, most of the cliff was not reinforced. A major takeaway lesson here is the importance of prompt response. For instance, in Pacifica this may have meant implementing total boulder reinforcement upon noticing the first signs of erosion, and the subsequent difference between protected and unprotected sections of the cliff base. However, a broader lesson is the critical advantage of being proactive, rather than reactive in bolstering coastal resilience (Garcia 2016). Building resilience depends on understanding the climatic future, predicting changes in the landscape, and actively planning ahead.

*Wealthy communities have made progress on tackling vulnerability issues*

An ongoing success story in coastal risk management can be found in the Marin Bay Waterfront Adaptation Vulnerability Evaluation program (BayWAVE). BayWAVE's overarching purpose is to raise awareness and prepare for sea level rise impacts for the year 2100 through "coordinated, multi-jurisdictional assessment (County of Marin 2016)." The program evaluates the extent of impacted assets and their adaptability, working with local communities to develop adaptation plans. The project, which began in 2014, is already in its first phase of vulnerability assessment. The second phase will use information from the vulnerability assessment to make plans (County of Marin 2016). The efficient clip at which BayWAVE has progressed and the dedicated commitment of elected officials, professionals, county staff and Marin's citizens make this proactive effort a model program.

However, many communities do not have the same level of financial resources as Marin County, nor are their populations as informed or made aware of climate challenges to come (Garcia 2016). Many communities lack the money and support to implement effective strategies for long-term conservation and risk management. Resource availability is an ongoing challenge in developing sustainable water management efforts.

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## Tillamook, Oregon

### *Natural Landscape*

Tillamook County, OR is a small, largely rural county on Oregon's central coast. Nestled between the Pacific Ocean and the Oregon Coast Range mountains, it spreads across 1,125 square miles (Tillamook County 2011). The region contains five different bays. Tillamook Bay, at 13 square miles, is the largest. Other watersheds include Nehalem Bay, Netarts Bay, Sand Lake Estuary, and Nestucca Bay (TEP 2015).

The region is classified as temperate rainforest: temperature fluctuates in a very narrow range, and annual precipitation is high (Risley 2016). Average annual precipitation is 87.9 inches in Tillamook, OR and over 100 inches in the nearby Coast Range Mountains (Risley 2016).

### *Human Landscape*

Tillamook County has a population of roughly 25,800 people (Tillamook County 2011). Land cover is predominantly forested or mixed forest/agricultural. A significant percentage of that is incorporated in the 364,000 acres Tillamook State Forest. The Tillamook County Comprehensive Plan has successfully controlled land use conversion and urban sprawl: according to Pearson (2011), "approximately 70% of all new structures are constructed within urban growth boundaries," and "since the early 1970s the county has converted less than one percent of its wildland forest and mixed forest/ agricultural land to other uses."

Unlike most of the western United States, Tillamook County does not rely on significant amounts of summer runoff from snowpack or large reservoirs for water supply. Streamflow west of the Coast Range largely relies on rain, with most rainfall between October and March. Most water supplies come from surface diversions, and some shallow wells (Hendricks 2016).

### *Importance and Impacts*

The economy is largely dependent on agriculture, forestry, fishing, and tourism. Dairy is one of the largest local industries – the Tillamook Cheese Factory is the largest private employer, and drives a significant percentage of tourism to the county, with more than 1.3 million visitors each year (Jackson-Glidden 2016). In addition, dairy products accounted for 89.9% of all agriculture sales in 2010 (Pearson 2011). Tillamook County has over 40,000 dairy cows, nearly double the human population (Pearson 2011).

In 2014, tourists spent $221.1 million in the county, contributing to $66.1 million in earnings, 2,150 jobs, and $1.3 million in local tax revenue (Dean Runyan Associates 2016). A large portion of tourism is driven by Tillamook's close proximity to the urban population center of Portland, about an hour's drive away; $90.4 million of all visitor spending was for day travel, rather than overnight travel (Dean Runyan Associates 2016). The summer population in Tillamook can increase to more than double the winter population (Phipps 2016). Tillamook County is also under development pressure from retirees and second home owners (Pearson 2011).

Outdoor recreation is a strong driver of Tillamook County tourism. In 2008, fishing accounted for $34.7 million of Tillamook County's $63.4 million of travel-generated expenditures. Freshwater fishing generated $13.94 million in travel-related expenditures; saltwater fishing generated $20.78 million. Shellfishing added another $7.69 million, and hunting $2.48 million (Dean Runyan Associates 2009). Commercial fishing is a modest contributor to the economy – lack of a deep-water port limited the development of a significant commercial fishery (Pearson 2011).

In the early 20th century, logging was a major industry in Tillamook County and in Oregon more broadly. However, a series of devastating fires, in 1933, 1939, and 1945 utterly destroyed a large swath of forest, collectively known as the Tillamook Burn. The damage stretched over 300,000 acres, with such extensive damage that natural regeneration was "all but impossible (Hoadley 2001)." Salvage logging did further damage to the terrain (Hoadley 2001). However, the Tillamook Burn was the focus of a massive, concerted reforestation effort, and was later incorporated as the Tillamook State Forest.

### *Major Issues*

#### *Natural Hazards*

The Tillamook County Multi-Jurisdiction Hazard Mitigation Plan 2011 provides a wealth of information on the challenges facing Tillamook County. The four highest scoring hazards, all tied at 240 points in the FEMA scoring system, are flood, winter storm, wind storm, and land slide. Close runners up are hazardous materials, 216 points; earthquake, 212 points, and tsunami, 209 points.

Flooding in Tillamook County is driven both by rainfall and tides. Recent flooding events have washed out railways and bridges, caused landslides, and flooded roads (Phipps 2016). These flooding events can have high costs. For example, a severe storm in late 2007, with associated flooding, landslides, and mudslides, led to a Presidential Disaster Declaration, with $56.12 million in public assistance to affected counties and $6.40 million in individual assistance (Pearson 2011). Recurring flooding is also a challenge. For example, the hospital's helicopter landing pad is often under water during high tide (Pearson 2011).

Tsunami also presents a unique, possibly catastrophic natural hazard, with the potential to displace and kill thousands of people in Oregon. The 2011 Japan tsunami focused public attention on tsunami risk and, with help from a federal grant, the Oregon Department of Geology and Mineral Industries finished mapping tsunami evacuation zones along the coast in 2013 (Tillamook Headlight Herald 2013). Nearly all of the Tillamook County's coastal development is in a hazard area (NANOOS 2016). A tsunami from a local earthquake could arrive too quickly for any official warnings or instructions (Rizzo 2014).

#### *Water Quality*

Water quality poses a multifaceted challenge in Tillamook County. Threats to water quality in the region include bacteria, pesticides, and sediment contamination as well as temperature abnormalities and hypoxia. Aging infrastructure in both agricultural and urban areas exacerbates water quality issues (Phipps 2016). Contamination can spread disease, harm drinking water resources, and damage the watershed's ecological health. For example, high sediment levels harm the area's salmon population by making the environment unsuitable for both their eggs and their food sources. Low oxygen levels and high water temperatures also disturb salmon (Tillamook Estuaries Partnership 2017).

*Ocean acidification*

Ocean acidification related to climate change is an emerging issue on the West Coast. In 2006 and 2007, the Whiskey Creek Shellfish Hatchery in Netarts Bay suffered from very high mortality in their larvae production (Geiling 2015). The culprit was originally thought to be a known bacterial problem, but research led by Oregon State University pinpointed ocean acidification as the underlying cause of the mortality (Grove Oliver 2015). Ocean acidification affects the chemistry of the ocean, making it more difficult for organisms, like oysters, to form their carbon-based shells.

Commercial oyster production, a significant industry on the West Coast, relies on hatcheries for their seed supplies (Floyd 2012). There are growing efforts to monitor and mitigate ocean acidification, including efforts by the Pacific Coast Shellfish Growers Association, the Pacific Shellfish Institute, the Northwest Association of Networked Ocean Observing Systems (NANOOS), and the Pacific Marine Environmental Laboratory. In addition, the West Coast Ocean Acidification and Hypoxia Science Panel pulls together experts from California, Oregon, Washington, and British Columbia.

*Erosion*

Erosion is already a significant problem in Tillamook County, and sea level rise and increases in the frequency of major El Nino-related events may increase erosion rates and impacts. A single storm can cause up to 25 meters of dune retreat, and a series of severe winter storms over the past decades have already caused extensive damage to the Tillamook shorelines (Ruggiero et al. 2012). Erosion threatens homes and property, and may decrease beach access, both because erosion actually decreases the area of beaches and because the construction of shoreline hardening structures decreases public accessibility (Chan 2016).

*Climate change*

Climate change will compound and complicate many of the challenges already facing Tillamook County. Projected changes include decreased spring and summer streamflow, increased air temperature, and slight increases in early winter streamflow and peak flow variability. Changes in streamflow quantity and timing may affect water supply; sea level rise will impact both groundwater and surface water; coastal erosion may increase, both with sea level rise and with changes to the severity and timing of storms and El Nino-related events; and warmer temperatures and drier summers may lead to more frequent and intense wildfires (Risley 2016). In fact, the Tillamook Estuary Partnership identifies five priority climate risks: sea-level rise and coastal erosion; increased flooding; changes in hydrology; increased forest fires; and increased average temperatures (Weber n.d.).

### *Governance and collaboration*

The Tillamook Estuaries Partnership (TEP) is currently working on a number of projects to explore contamination sources, monitor pollution, and collect data. TEP partners with a number of organizations in these projects, including studies on suspended water discharge, bacterial contamination, and North Coast toxins and pesticides, among others (Tillamook Estuaries Partnership 2017).

The Tillamook Coastal Futures Project is another example of ongoing work in the region. The product of a partnership between OSU, Sea Grant, NOAA, and NSF, the goal of the project is to expand the capacity to envision future scenarios, assess impacts pertaining to erosion and flood hazards, and come up with adaptation strategies by illuminating trade-offs in different scenarios (Chan 2016). The Willamette Project 2100 ENVISION Project, funded by NSF, looks at future scenarios for the region's water system in order to inform decision-making (Chan 2016).

The State of Oregon's Water Resource Department has also taken initiative towards preparedness and more sustainable water management. The Integrated Water Resources Strategy is a five-year work plan for 2009 to 2012. The strategy is designed to integrate issues of quality, quantity, and ecology in Oregon, and prepare to meet the state's water needs. The plan's development overview stresses the importance of public engagement and productive partnerships when formulating water management and water law (Oregon Water Resources Department 2010).

### *Highlights and insights*

*Long-term, effective citizen science monitoring is possible*

Since it was established in 1995, a small, dedicated crew of volunteers has participated in the Tillamook Estuary Partnership's Bacteria Monitoring Program. These dedicated volunteers, usually six to eight people participating at any given time, sample 75 sites twice a month, 12 months a year. From 1997 to 2014, they have collected 22,000 bacteria results, which contributed to the first status and trend analysis in 2006. The Tillamook Estuaries Partnership, and its agency partners, uses this data to make decisions and document improvements (Phipps 2016).

*Water supply will be a challenge under climate change*

Because the population of Tillamook County increases in the summer, when stream flows are naturally lowest, it stresses availability of drinking water. Many drinking water streams are over-allocated for summertime flows (Phipps 2016). Coastal aquifers in the region are very shallow, which limits their ability to function as reservoirs during high demand periods. In addition, Tillamook County has the potential for significant seismic activity, which limits the viability of dams and reservoirs. The Oregon Water Resources Department considers off channel storage and increasing recharge potential in headwaters and higher aquifers as the most feasible ways to increase water supply (Hendricks 2016).

*Public awareness is crucial and requires resources*

Tillamook County, like many other regions, struggles with a lack of public awareness of water conditions and challenges. For example, a significant percentage of the workload of the region's Watermaster is dedicated to helping the public be in compliance with water laws and obtain legal water sources, which is often an issue of simple ignorance rather than intentional malfeasance (Hendricks 2016). Moreover, issues can vary significantly among different, localized watersheds, which then requires targeted outreach. One of the priority goals of Oregon Water Resource Department's District 1 is to expand education and outreach.

*Stream gages are an important resource*

Stream gages are important for successfully implementing the work of the Oregon Water Resources Department. In-stream water flows are a legislatively mandated component of maintaining salmon health, and stream gages are required to inform those environmental needs. The USGS operates some stream gages in the area, but the Oregon Water Resources Department also maintains its own network of stream gages, mostly on smaller streams and reaches (Hendricks 2016). However, there are still unmet monitoring needs. For example, the Miami, Tillamook, and Kilchis rivers are un-gaged (Risley 2016). Stream gages are also important sources of data for scientific studies and long-term records. It is helpful if monitoring is well planned and coordinated to meet the different objectives of the assorted organizations and projects in the area.

*Models can help meet current and future information needs*

Several organizations have developed models relevant to understanding challenges and making decisions in the region. For example, the Precipitation-Runoff Modeling System uses daily precipitation along with maximum and minimum daily air temperatures to predict basin streamflow and energy budget storage and fluxes (Risley 2016). The model can be used to evaluate the watershed hydrology outcomes of various climate and land use combinations (USGS). In addition, calibrated watershed modeling has the potential to simulate the effects of land-surface disturbances (such as nearby logging) and climate change on the watershed (Risley 2016).

Models can also fill information gaps with respect to water quality. CE-Qual-W2 is a water quality model developed by the Army Corps of Engineers. It has the capacity to simulate water quality given conditions of flow, nutrient content, sediments, dissolved oxygen, bacteria, and more (Risley 2016). Estuary water-quality modeling has significant utility for water management in Tillamook and beyond. In addition, USGS's

Coastal Storm Modeling System (CoSMoS) predicts coastal storms and their impacts in Oregon and on the rest of the Pacific Coast; this has important potential in terms of planning for safety, sustainability, and water management in general (Risley 2016).

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## E. Spotlight on data sharing

Data sharing and access was a high priority concern expressed by many workshop participants. While there are challenges to making data sharing and interoperability successful, several programs have made progress and can serve as examples.

### *Water Quality Exchange*

Up until 2007, the EPA collected water quality data through its STORET system. The EPA would provide a database system to partners, who would subsequently send a filled out copy of that database back to EPA. However, that model did not work well: partners did not like using the EPA database; it was hard to build one system that met the diverse needs of EPA's many partners; and it required significant resources to maintain and update the databases. Moreover, the USGS also collected water quality data in its National Water Information Service (NWIS), and it was very difficult for STORET and NWIS to share and integrate data (Young 2016).

Given these challenges, the EPA developed a new standards-based approach to data sharing. The Water Quality Exchange (WQX) was shaped to the fundamental aspects of water quality science, the "core data elements that [are] needed for someone to communicate water quality monitoring data (Young 2016)." Instead of developing a technological system, the WQX instead defines what metadata needs to be collected and how to share the information collected. This approach is more stable in the face of technological change. In addition, it allows partners the freedom to choose and run their own software and data management systems, as long as they use the same standards as WQX (Young 2016).

The WQX standards require that each piece of data contain information on the who, what, when, where, why, and how: who collected the sample, what did they sample, when was the sample taken, where was the sample taken, what was the purpose of the monitoring, and how was the sample collected and analyzed. When data are submitted to the EPA, they go through a validation process to make sure all of those pieces of additional information are attached to the data (Young 2016). Taken together, this set of metadata provides robust context for understanding how to appropriately use the data from each sample.

After the WQX receives the data, it makes them available via web services through the Water Quality Portal. This allows more people to access the vast and diverse sets of data from the EPA's partners in a user-friendly interface, and provides "one stop shopping" for EPA, USGS, and the USDA's Agricultural Research Service's STEWARDS program data. People and organizations can then use the data from the Water Quality Portal to build value added services. The Water Quality Portal currently contains over 290 million water quality results, collected at over 2.3 million monitoring locations, and those numbers are growing. The WQX and Water Quality Portal have been well received by the EPA's partners, and the value added services and data analysis tools that are built around the Water Quality Portal provide incentives for partners to contribute their data (Young 2016).

***National Ground Water Monitoring Network***

Groundwater is an important national and local resource, but monitoring remains incomplete and the data poorly accessible. In 2006, the Heinz Center stated that the USGS network alone is "not adequate for national reporting (Cunningham 2016)." The SECURE Water Act of 2009 subsequently created a legislative mandate for national reporting on groundwater. This spurred the creation of the National Ground Water Monitoring Network (NGWMN), a collaborative system for integrating groundwater data from multiple sources.

Unlike the WQX, the NGWMN does not accept all data. Instead, it focuses on the select wells needed to assess the quantity and quality of U.S. groundwater reserves. The purpose of the NGWMN is to "develop and encourage implementation of a nationwide, long-term ground-water quantity and quality monitoring framework that would provide information necessary for the planning, management, and development of ground-water supplies to meet current and future water needs, and ecosystem requirements (Cunningham 2016)." NGWMN data can provide information on baselines, status, and trends of water levels and quantity. However, when combined with supplemental data and additional resources, it can help to answer additional questions, such as the impacts of land use changes on water supply and the effects of pumping (Cunningham 2016).

Similar to the WQX, the NGWMN also focuses on the fundamentals of metadata and standards. In order to submit data, the data provider needs to document its standards. Thus, the quality of the data is known, even if it is uneven. Again, similar to WQX, the NGWMN provides public access to its data through a web portal. The Portal allows the public to automatically and dynamically access data from national, state, and local partners in near-real time. The NGWMN currently collects data from 5,018 water-level wells and 1,392 water-quality wells, integrating data from 51 states and 14 agencies to cover 58 principal aquifers. Through the Open Geospatial Consortium standards, using the data sharing languages of WaterML2 and GWML2, the NGWMN also contributes to a transboundary data exchange with Canada for key locations (Cunningham 2016).

Several elements were critical for successfully developing and implementing the NGWMN: 1) leadership was needed at many levels; 2) the developers of NGWMN needed to build consensus on the approach and goals in order to create buy-in from partners; and 3) USGS took advantage of local expertise in designing the national system (Cunningham 2016). In addition, the NGWMN needed to tackle several thorny issues: 1) questions of data ownership; 2) concerns about data being used for regulatory decisions; and 3) security issues (Cunningham 2016). These lessons are likely to be applicable to many different data sharing scenarios.

### *Highlights and Insights*

Together, the experiences of the WQX and the NGWMN offer some important lessons. First, they both rely on the concept that data that is shared is more valuable than data that remains in a file cabinet. The more data are re-used, the more valuable they become. Sharing data maximizes the value of local, state, and federal monitoring resources, and can contribute to better policy and management decision-making (Cunningham 2016; Young 2016).  Second, both programs provide incentives to participate, including the creation of value added tools on the web-facing data portals.

Third, data standards and metadata are necessary components of successful data sharing. Metadata chronicles the reliability and quality of the data collected, allowing users to make well-informed decisions about how they use data of differing quality. Data standards allow for flexible incorporation of diverse monitoring programs – organizations can maintain their own systems and databases, but still contribute to national datasets. Shared standards allow for interoperability of databases and easier integration of different data sources.

Finally, national data networks and portals can help to develop a community of practice around data collection standards and data sharing. National programs benefit from well-documented and well-managed data at local levels, and national programs create opportunities for local data managers to learn from each other. They also provide the opportunity for reviews of data collection and management procedures in the field, and allow the national programs to learn from the successes and challenges of local data providers (Cunningham 2016, Young 2016).

Although data sharing is not easy, and can run into challenges with funding, personnel resources, privacy, and data ownership, both the WQX and the NGWMN offers blueprints for success in meeting the needs of users for national scale collection and sharing of water data.

## 4. Findings and recommendations

Water poses challenges and opportunities throughout the country and the world. These challenges and opportunities are often acutely evident in coastal areas, which are both incredible national resources and sites of significant vulnerability. Stressors like population growth and land use change combine with high impact weather events to threaten coastal communities. Many communities that already suffer the effects of high impact weather will face new and magnified risks over the coming decades due to ongoing changes in climate. Effective coastal risk management depends on minimizing vulnerabilities while preparing for and responding to unavoidable hazards.

Communities face multiple complex challenges and opportunities relating to water, including how to cope with a water regime that is subject to large natural variations; reduce existing vulnerabilities; project future changes in an increasingly human-influenced water regime; and invest most effectively in long-term projects involving transportation, health care, and manufacturing.

*Coastal risk management hinges upon the ability of communities to avoid and manage hazards, maintain and enhance community health, and sustain a diversified economy that is robust in the face of multiple stressors.*

Improved environmental intelligence to understand all the ways that water moves through the coastal environment and impacts individuals and communities would help to address these serious challenges and opportunities. Developing an integrated view of water, from mountains to coasts, across timescales, across spatial scales, and across societal challenges, and transitioning the resulting environmental intelligence into services that most effectively protect life and property, is essential to increasing the nation's weather preparedness, decreasing coastal vulnerability, and adapting to climate change.

***Finding: A common set of challenges***

Communities across the country deal with a common suite of water-related issues that challenge their coastal risk management. Most, if not all, of the communities examined during the course of this study struggle with natural hazards (flooding and erosion); water quality (saltwater intrusion, harmful algal blooms and dead zones, salinity, bacteria, and ocean acidification); changing water levels and local sea level rise; changes in water quantity and supplies; and maintaining navigation and transportation infrastructure.

There is also a common set of change agents influencing coastal communities. Climate change is driving changes in quantity and timing of precipitation, seasonal temperatures, and ice cover. Local sea level rise, influenced both by global climate change and local factors like subsidence, exacerbates existing challenges and creates new ones. Land use changes, including urbanization, changing agricultural methods, increases in impermeable surfaces, and human-made changes to hydrology and hydraulics (dams, dredging, channelization, etc.) can have substantial impacts on water and coastal conditions. And, finally, population growth not only drives land use changes, but also increases the number of people impacted by coastal impacts.

### *Finding: Shared challenges in addressing coastal risk management*

Just as many communities share a common set of issues, many also share a common set of challenges in addressing and dealing with coastal vulnerability. For example, communities and programs are constantly dealing with turnover in staff and elected officials. This can lead to loss of institutional knowledge and expertise, as well as changing policy and program priorities.

Another common frustration is the need for consistent, harmonized monitoring and observations. This encompasses a suite of inter-related elements, including maintaining existing USGS stream gages, sharing and accessing data from different sources, and collecting accurate and useful metadata. Scientists and decision-makers also struggle with modeling the coastal zone – the interaction of freshwater and saltwater is difficult on many dimensions. Moreover, NHDPlus, the geospatial database underpinning many of the new water modeling capabilities, becomes less accurate on coastal stream reaches.

Many communities struggle with balancing the water needs of upstream and downstream users, and addressing conflicts among users who are separated by local, state, and federal jurisdictions. They also struggle to find manageable solutions to repetitive losses, exacerbated by a shortage of steady funding for mitigation and preparedness work. Finally, local boundary organizations, water specialists, and emergency managers all identified the need for, and difficulty of, providing information and tools that stakeholders can understand. Successful stakeholder engagement and then translating knowledge gained through engagement into useful tools is consistently challenging.

### *Working towards successful coastal risk management*

In this study we identify seven key approaches for advancing coastal risk management. These seven approaches are:

1) Provide Actionable Information
2) Prepare and Empower Information Users
3) Create Decision Support Products and Services that Harness Scientific Advances for Societal Benefit
4) Build Strong Partnerships Among Stakeholders, Practitioners, and Information Providers
5) Develop the Next Generation Workforce
6) Align Roles and Responsibilities
7) Recognize Linkages and Potential Leverage

**Provide Actionable Information (observations, science, and forecasts)**

Coastal risk management can be enhanced through improvements in observational capabilities, science (including research, data assimilation, and models), and computational power.

For any particular weather or climate event, sources of water may include precipitation, tides, waves, sea level rise, storm surge, and rivers. Factors that influence water's behavior include geomorphology, hydrological connectivity, land use patterns and grey or green infrastructure (e.g., marshes, wetlands, levies, seawalls, and other physical barriers). Forecasts of water quantity and quality are most useful when they account for all sources of water and all factors that influence water's behavior.

Providing accurate information along the coasts is particularly difficult, both because of observational gaps and lack of interoperability among different modeling approaches (e.g., river forecast, wave, ice, estuarine hydrodynamic, and storm surge models). In addition, it is important to understand the linkages among weather, water, and climate, and to confront the specific challenges that arise over different weather and climate timescales (i.e., minutes to two weeks; two weeks to two months; and two months and beyond).

The natural and social sciences also provide critical information relating to coastal risk assessment and management. For example, the natural sciences help reveal potential human health related impacts and responses of biological systems—including the potential to enhance or disrupt biological resources and the goods and services that they provide to coastal communities.

The social sciences help reveal the socioeconomic implications of weather events, which can disrupt social institutions and disturb biological resources upon which coastal communities often depend in complex ways. Critically, improved integration of physical, natural, and social sciences is necessary for understanding linkages among the physical climate system, biological systems, and socioeconomic wellbeing.

Observations, science, and services are often critical infrastructure for critical infrastructure: They provide the environmental intelligence for the success of long-term investments that are sensitive to weather, water, and climate events. Coastal risk management can be enhanced through improvements in observational capabilities, science (research, data assimilation, and models), and computational power.

Moreover, observations of water and science-based services building on those observations have grown organically, in response to local needs and state-level policies. This approach offers advantages of low-cost and highly relevant services for local needs. It suffers, however, from underfunding and from difficulties sustaining that funding over time. By contrast, federally-based approaches, which tend to be more enduring, too often suffer from lack of specificity and relevancy to local and regional requirements.

Development of a hybrid approach combining the advantages of both would be useful but has thus far eluded policymakers. Government agencies at both federal and state levels struggle to engage the private sector, which is an important stakeholder. Dialog bringing the parties together would be beneficial. At the federal level, the Department of Commerce might provide needed convening power, especially given the connections to the private sector implied in the name. However, experience has also shown that sometimes such dialogs are best facilitated by organizations perceived as neutral. A group of scientific and professional societies might come together to provide a neutral forum to discuss policy options.

Together, these represent a major opportunity for improvement. Advances in observations, science (data assimilation and modeling), and computing capabilities will lead to improved understanding and management of water resources over all weather and climate timescales.

**Prepare and Empower Information Users**

Stakeholders, emergency managers and other practitioners, policy makers, the media, and the public need to be equipped to use information effectively. This can greatly enhance the value of information.

Formal education at all levels (pre-K through college and graduate training) and informal education are central to the development of people's capacity to take up and use information effectively.

Effective communication and stakeholder engagement are also critical in building an informed public that recognizes coastal vulnerabilities, effectively weighs options for risk management, and knows how to respond appropriately when confronting hazards. Public awareness is also a central component of effective governance in a democratic society, as policy decisions and funding priorities ultimately reflect the choices of the people.

*We cannot rely on a handful of experts to address societal challenges. Raising public awareness of water and coastal issues will help to build a nation of responsible actors.*

Influxes of people and turnover among coastal populations ensure that efforts to prepare and empower information users must be ongoing. Similarly, long periods of time between the recurrence of high impact events require strategies for overcoming complacency and for ensuring that people know how to respond to threats and opportunities in a timely and constructive manner.

Understanding peoples' perception of water is important. Researchers and policy makers need to understand what community members know about the state of water in their region. If perceptions are significantly different from reality, it can compromise water management efforts. For example, Oregon Sea Grant researchers found that many people in Portland think municipal water users consume a far greater share of water than they actually do, but undervalue the amount of water used by the agriculture and energy sectors. As a corollary, it is also important to understand how water is valued in each community.

Critically, insights from the social sciences can improve our understanding of how to engage effectively with stakeholders, emergency managers and other practitioners, information users, policy makers, the media, and the public. Most notably, though not exclusively, through enhanced risk communication. For example, education and outreach efforts are often most effective when they meet a well recognized need. This is why public receptiveness to proactive risk management is often highest during or shortly after high-profile events..

Sustained efforts are required. As a result, AMS intends to continue to assess the role that our society can play in raising awareness of water issues. Our scientists, broadcast meteorologists, local chapters and Education program all have a role in building understanding of weather, water, and climate-related challenges.

## Create Services and Decision Support Products that Harness Scientific Advances for Societal Benefit

Information is necessary but not sufficient for effective coastal risk assessment and management. In order for users and stakeholders to take advantage of the information generated by the weather, water, and climate community, that information must be in forms that are easy to access and that meet users' needs. Products and services that are tailored to user needs make it easier for municipalities to integrate risk management into their decision-making.

*Quantifying the value of water and risk management*

In order to encourage investment in water infrastructure and coastal risk management, it is important to quantify the value of water and risk management efforts. Quantification does not necessarily encompass the full scope of the value of water (e.g., cultural continuity and community identity), but it meets the basic need to frame information in ways that are relevant to the work of municipalities and communities. When communities make investment decisions, they have to be able to assess costs and benefits and to quantify a return on investment.

It is important to note that quantification and monetization are not synonymous. Assigning a dollar value to water or ecosystems can be problematic, but monetization is merely a subset of quantification. There are other ways to rigorously evaluate the environmental impacts and risk reduction of investment and policy decisions. For example, The Nature Conservancy developed metrics for quantifying the ecosystem services provided by different green and grey infrastructure proposals in Howard Beach, Queens, NY. It is not a monetary value, like the cost of damages avoided, but allows for standard comparisons across different design options (TNC 2015).

*Data sharing, inter-operability, and use*

Standardizing data and facilitating data sharing is an important opportunity for promoting coastal risk management. Challenges in facilitating data sharing include the need for accurate and well-defined metadata, common data standards, interoperable databases, and directories to help people find relevant datasets. In addition, technology innovation is leading to a new age of "big data," and there may be value in reaching out to new partners who can help create better services to deal with the expanding volume and velocity of data streams.

*For users and stakeholders to take advantage of the information generated by the weather, water, and climate community, it must be in forms that are easy to use and meet end users' needs.*

Open data is already a priority of the federal government: President Obama issued Executive Order 13642 in 2013, which made open and machine-readable data the standard for the federal government. The Advisory Committee on Water Information has been working for years to coordinate water resources information within the federal agencies, with subcommittees on spatial water data, methods and data comparability, and the National Water Quality Monitoring Council, among others. Federal agencies have also participated in the international public-private effort to develop WaterML2, a hydrology data exchange standard. In addition, the EPA and USGS in particular have developed several important data sharing platforms, including the National Ground Water Monitoring Network and the Water Quality Portal. However, this work is still incomplete, and opportunities remain to take advantage of big data and data analytics.

Big data and data analytics offer increasing potential to contribute to risk management services and decision support products. To be effective, there is need for a common and straightforward data collection systems, formatting, and user-friendly access. Data (and model) interoperability among information providers and users can enhance uptake and use.

*Facilitating learning*

The federal government can play an important role in facilitating learning across the different regions and states. It is difficult for individual staff and organizations to stay up to date on best practices and lessons learned in other locations. It is also difficult, if not impossible, to run controlled lab studies on coastal vulnerability and risk management, but we have fifty states in which to try out different approaches, providing opportunities for learning and innovation. The federal government can strategically promote learning and transferability of best practices by cataloguing and curating case studies and examples, and helping with the early detection of successes and failures.

*The federal government can strategically promote learning and transferability of best practices by cataloguing and curating case studies and examples, and helping with the early detection of successes and failures.*

Efforts to reduce repetitive losses may be particularly promising. One option to reduce repetitive losses is to conduct National Transportation Safety Board (NTSB)-style analyses following high-impact events. Such efforts could identify factors contributing to losses and potential responses to avoid recurrence. Scenario-based exercises might extend this capability to help identify avoidable risks ahead of time and recommend response options, perhaps somewhat similar to stress tests for banks. Such efforts could inform voluntary buyouts programs and regulatory responses.

*Tailored local solutions*

Not every solution is right for every community. Moreover, ”bottom-up” processes can be valuable for creating awareness of the issues and possible solutions in local communities. Local deliberation on issues, objectives, and methods can create both better stakeholder buy in and more appropriate solutions. For example, the District of Columbia is working to make the city “spongier” by increasing stormwater retention and infiltration with rain gardens and bioswales. But those same strategies for stormwater management would be disastrous on the clay bluffs on Michigan, where increased groundwater infiltration would quickly destabilize the cliffs. Services that can be tailored to local conditions, or that support community-led processes, may be more widely adopted and implemented.

*Scaling up*

There is also a need for scalable solutions. It can be resource-intensive and time-consuming to try and touch communities individually to address coastal vulnerabilities. However, trying to address coastal vulnerability on larger scales can risk losing the meaning, relevance, and suitability of the work. Coastal risk management relies in large part on building relationships across all the different professional communities and stakeholder groups involved, and there are sometimes limits to how meaningful those relationships can be at large spatial scales.

One example of a tool that could be scaled to different geospatial levels is the idea of “report cards.” The Galveston Bay Foundation uses a report card to score the Bay on different metrics of environmental health. Developing indicators that are widely applicable and relevant at different scales could allow for the development of a set of nested report cards at local, state, regional, and national levels. This would allow for a more consistent understanding of coastal health across different geospatial levels and jurisdictions. Another example of a similar idea is the ecosystem classification frameworks developed by NatureServe, including the Coastal and Marine Ecological Classification Standard and the U.S. National Vegetation Classification. These allow for standardized classifications of very diverse ecosystems.

**Build Strong Partnerships Among Information Providers, Users, and Stakeholders**

Common opportunities and challenges exist in determining public, private, and academic roles across the weather, water, and climate enterprise. Understanding differing perspectives, values, and priorities is critical to successful engagement efforts and collaboration. Efforts to manage water resources have the best chance of success when all stakeholders understand and respect differing views, and work to identify shared values that can be advanced together.

*People have powerful, personal, and unique relationships with water resources.*

There is a need for strong, sustained networks of connected partners working together across federal agencies and among local, regional, and federal organizations and stakeholders. These relationships must be built and maintained over time. That often requires investments of resources to support collaborative structures and relationships. Institutionalizing key relationships, including focusing on effective mechanisms for bringing groups together, can make them more robust in the face of personnel turnover within agencies and among experts and service providers.

People, and even communities, often have powerful, personal, and unique relationships with water resources. They fish in the river. They learned to swim in the lake. They lost everything when the creek rose. They rely on water for their livelihood and for their community. These personal experiences and relationships with water can strongly influence peoples' perspectives, values, and priorities. Understanding differing perspectives, values, and priorities is critical to successful engagement efforts and collaboration. Efforts to manage water resources have the best chance of success when all stakeholders respect differing views, work to identify shared values that can be advanced together, and find ways to shape solutions to those values.

*Institutionalizing relationships*

It is also valuable to institutionalize relationships. The most successful and long-lasting regional collaborations use institutional structures to maintain collaboration even in the face of staff turnover. For example, the Galveston Bay Council, the Tillamook Estuary Partnership, and the USACE Silver Jackets National Program's state teams, have all allowed regions to coordinate the work of multiple, diverse partners with interests in the coasts. Moreover, collaboration takes time and money; someone needs to be responsible for actually supporting and advancing the work of collaboration. In comparison, the work of the Advisory Committee on Water Information on harmonizing water data sharing standards has been slow because the participants are working on marginal time.

### Develop the Next Generation Workforce

Future generations will be most likely to thrive if the scientists and practitioners who contribute to coastal risk management are trained in the skills and techniques that matter most. Skills of high value are likely to include expertise in probabilistic modeling, stakeholder engagement, risk communication, integrated risk assessment, data analytics, and the integration of the physical, natural, among others.

*Scientific societies often bring together diverse, and sometimes conflicting, groups.*

A highly skilled and capable next generation workforce combined with the public's well-developed capacity to use that information would be a powerful combination for helping to ensure that coastal communities recognize vulnerabilities and respond effectively to hazards.

### Align Roles and Responsibilities

Conflicts arise among users who are separated across local, state, and federal jurisdictions. This creates a need for aligning responsibilities and jurisdictions, and setting the appropriate spatial scales for management. Regional and national coordination is needed for issues that exceed local jurisdictions

In addition, coastal risk management will be most effective when it acknowledges and addresses the realities facing communities and local governments. This includes aligning incentives for sustainable development practices and accounting for the multiple, sometimes conflicting, priorities in water management.

Suboptimal allocations of resources can occur when decision-making responsibilities are narrowly focused, and efforts to deal with a problem at one scale can create new problems at other locations or scales. For example, water in dams may have greater value than its use-value for energy but decisions are often made based on energy needs alone.

Efforts to deal with one problem at one scale can create new problems at other locations or scales. For example, efforts to address inland flooding in Louisiana led to decreased inputs of soil to the delta which led to the encroachment of the Gulf of Mexico inland. That increased coastal flooding. Though challenging, care is needed to implement solutions that work across spatial and temporal scales and that attempt to account for the needs of all users.

Poor alignment of incentives can also lead to suboptimal decisions. Thus, it is crucial to recognize and work with the realities facing local governments, to understand the local conditions that shape municipal behavior. For example, Georgia operates under home rule and Virginia under the Dylan Rule, both of which devolve significant power to municipalities. In Texas, most cities rely on property taxes for significant percentages of their revenue, thus providing a strong financial incentive to develop land rather than conserve it. And many communities already have put significant work into long-term planning. Incorporating adaptation and risk management efforts into existing municipal plans (ex: comprehensive plan, capital improvement plan, hazard mitigation plan, city ordinances), rather than in stand alone plans, can reduce the long-term implementation burden on cities.

Federal roles with respect to water resource management may include: setting of standards; identifying best practices; providing a repository of case studies and/or lessons learned; helping to ensure and enhance public goods; regulation; and the provision of resources to local and regional efforts. Federal efforts that apply to diverse local communities have greater chance of widespread adoption and success.

Providing incentives is a way for the federal government to motivate changes in local behavior and decision-making. Federal support can realign incentives to convince regions that progress on coastal risk management is both prudent and feasible. Regulations can also work to realign incentives, but it can sometimes be more productive to use carrots instead of sticks, especially when local governments may be willing to take action if they had the necessary resources, or when the federal government lacks statutory authority. Regulation may not be necessary if the federal government successfully sets standards and provides resources, expertise, and guidance. For example, the EPA encourages states to contribute their data to the Water Quality Exchange by providing value-added tools that contributors can use to better understand their own data, rather than by mandating participation in the program.

There are additional ways for the federal government to help realign incentives and use national programs to support regions. Possible models include the Coastal Zone Management Act, the Community Rating System (CRS), the USACE's nationwide living shorelines permit currently in development, federal highway funds, and offering credits on the deductible associated with Presidential Disaster Declarations. In particular, CRS came up several times in the regions that were the focus of this study, because the immediate financial savings from mitigation activities was often the entry point for communities to start dealing with long-term vulnerabilities.

*Public-private engagement*

Beyond the difficulties of overlapping federal, state, and local jurisdictions, there are challenges involved in aligning the roles of the public, private, and academic sectors.

Governments at all levels experience difficulty in attempting to draw in the expertise and perspective represented by academics and the private sector. For the private sector this is a particular problem. Businesses of all sizes and scales are threaded throughout water supply, hazard risk management, and environmental protection efforts, yet the federal regulatory framework makes it difficult for them to participate as strategic partners. It may be fruitful for a high-level body, perhaps the National Academy of Sciences or the National Academy of Public Administration, to convene a dialog addressing these challenges.

### Recognize Linkages and Potential Leverage

Connecting coastal vulnerability and risk management to other priorities, like infrastructure or jobs, can maximize the effective use of limited resources and help build interest in addressing coastal challenges. Coastal risk management projects that achieve multiple goals may be more appealing to local communities that must meet many high priority economic and social goals. For example, green infrastructure to mitigate coastal flooding may also provide fisheries habitat and recreational assets. Similarly, coastal projects can create local jobs or provide training in new skills.

Finally, challenges and opportunities to coastal risk management are often at least partly similar throughout the world. The United States can both learn from other countries and share our resources and information with other countries (e.g., identify common needs, case studies, and lessons learned).

This AMS Policy Program study is based primarily on two workshops that occurred in 2016 along with a literature review, off-line discussions with practitioners, and additional analysis. Opportunities for further advancement abound and a sustained effort to advance the national discussion on water is needed. The American Meteorological Society's Policy Program intends a series of follow-on activities to advance an integrated consideration of water and to build a community of practice that includes public, private, and academic sectors that works to provide the information and services needed for managing risks and realizing opportunities associated with weather, water, and climate challenges.

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# 6. Appendix

**Opportunities and Needs in Integrated Water Prediction, Risk Assessment, and Management for Coastal Resilience**

DRAFT WORKSHOP AGENDA

***Location: UC Washington Center, 1608 Rhode Island Ave., NW***
***Dates: September 27-28***

## Overview

Water is central to many of the issues that challenge coastal resilience. Maintaining and enhancing coastal resilience depends on communities having the information and tools they need to accurately predict, assess the impacts of, and make good management decisions about water issues. This requires accurate accounting for all sources of water and all factors that influence water's behavior.

Moreover, many of the elements of water are inextricably linked. For example, groundwater plays a role in both pollution transport for water quality, and land subsidence that can contribute to flooding. Sea level rise contributes to both recurring flooding issues and saltwater intrusion into coastal aquifers. And coastal erosion impacts the habitats that can mitigate flooding impacts. Our goal is to tell an *integrated story of water* in each focal region.

Each session of this workshop will tell the story of a place, its successes, challenges, and opportunities. It is easy to break water issues into their component parts – to look at groundwater, water quality, or flooding – but less easy to then build it back into a coherent and integrated whole. By focusing on specific places, we hope to understand what actually goes into building coastal resilience and where federal, state, and local organizations can play a role. Ultimately, the stories from different regions and from communities of different sizes will reveal the commonalities needed to construct a national vision for coastal resilience.

## Structure of Workshops

Each workshop focuses on two regions. This workshop, Sept. 27-28, focuses on the East Coast and Great Lakes. The second workshop, Oct. 18-19, focuses on the Gulf Coast (Houston-Galveston and Mississippi River Delta) and West Coast (Tillamook Bay watershed and California's central coast). However, the questions asked of speakers will be the same at each workshop.

Each session will focus on building an understanding of water in the region; examining the water-related issues challenging coastal resilience; and highlighting lessons learned and success stories of effective stakeholder engagement, regional collaboration, research to operations transition, and data sharing.

There will also be talks addressing the specific thematic questions of data sharing, regional collaboration, stakeholder engagement, and research to operations. These will particularly focus on highlighting examples from across the water "silos" and case studies of initiatives that have been successful in the face of common challenges

**<u>Framing Questions</u>**

We developed a series of questions to help frame the workshop proceedings.

Understanding Water in the Region

- What are the top water-related challenges and opportunities facing the region?
- How well do we understand the magnitude and nature of risks we face in the coastal environment?
- In what cases is environmental intelligence sufficient and well-used, and where and why is it inadequate?

Cross-cutting Themes

- How well is water science and management integrated in the region?
- What lessons have you learned about making the following successful?
    - regional collaboration
    - data sharing and use
    - research to operations transition
    - stakeholder engagement
- What policies and regulatory structures are needed to support integrated water prediction, risk assessment, and management?

Day 1 – East Coast

**Introduction**

***Welcome***
***(8:00-8:05)***

Speaker:
- Paul Higgins, AMS Policy Program

***Overview of issues in coastal resilience***
***(8:05-9:00)***

Speaker:
- Paul Scholz, Office for Coastal Management

**Session 1: Savannah River region**

***Panel 1: Understanding water in the region***
***(9:00-10:15)***

Moderator:
- Jill Gambill, Georgia Sea Grant

Speakers:
- Paul Conrads, South Atlantic Water Science Center, USGS
- Bill Bailey, USACE Savannah District

**Break**
**(10:15-10:30)**

***Panel 2: Moderated discussion***
***(10:30-11:45)***

Moderator:
- Bill Hooke, AMS Policy Program

Speakers:
- Robert Merchant, Planning Department, Beaufort County
- Jennifer Kline, Georgia Department of Natural Resources

***Talk 1: Data Sharing***
***(11:45-12:15)***
- Water Quality Exchange / Water Quality Portal – Dwane Young, EPA

**Lunch**

**(12:15-1:15)**

**<u>Session 2: Chesapeake Bay</u>**

***Panel 3: Understanding water in the region***
***(1:15-2:30)***

Moderator:
- Zoe Johnson, Chesapeake Bay Office

Speakers:
- Christophe Tulou, EPA Office of the Administrator
- Emily Steinhilber, ODU
- Hamid Karimi, D.C. Natural Resources Administration

**Break**
**(2:30-3:00)**

***Panel 4: Moderated discussion***
***(3:00-4:15)***

Moderator:
- Doug Wilson, MARACOOS

Speakers:
- Ann Phillips, Navy Rear Admiral (Ret.), Old Dominion Research Foundation
- Rich Batiuk, Chesapeake Bay Program
- David Vallee, NWS

***Talk 2: Research to Operations***
***(4:15-4:45)***
- Ecological Forecasting Roadmap – Chris Brown, NESDIS

**Discussion and Synthesis of Opportunities and Needs**
**(4:45-5:30)**

Moderator:
- Bill Hooke, AMS Policy Program

Day 2 – Great Lakes

**Discussion of lessons learned**
***(8:00-8:30)***

Moderator:
- Paul Higgins, AMS Policy Program

## Session 3: Great Lakes

***Panel 6: Understanding water in the region – Lake Erie***
***(8:30-9:45)***

Speaker:
- Jeff Reutter, Ohio Sea Grant

***Talk 3: National Water Model***
***(9:45-10:15)***

Speaker:
- Peter Colohan, NWS

**Break**
**(10:15-10:30)**

***Panel 7: Understanding water in the region – Lake Michigan***
***(10:30-11:45)***

Moderator:
- Mary Munson, Coastal States Organization

Speakers:
- Howard Reeves, Michigan Water Science Center
- Steve Buan, North Central River Forecast Center

**Lunch**
**(11:45-1:15)**

***Panel 8: Moderated discussion***
***(1:15-2:30)***

Moderator:
- Josh Lott, Office for Coastal Management

Speakers:
- Michelle Selzer, Michigan Office of the Great Lakes
- Tony Friona, USACE

- Marvourneen Dolor, GLOS

**Break**
**(2:30-3:00)**

***Talk 4: Regional Collaboration***
***(3:00-3:30)***

Speaker:
- Ellen Mecray, Regional Climate Services Director

**Policy needs for integrated water prediction, risk assessment, and management – Final Discussion**
**(3:30-4:30)**

Moderator:
- Bill Hooke, AMS Policy Program

**Opportunities and Needs in Integrated Water Prediction, Risk Assessment, and Management for Coastal Resilience**

WORKSHOP AGENDA

***Location: AAAS Building, 2nd Floor, 1200 New York Ave. NW***
***Dates: October 18-19***

## Overview

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    - research to operations transition
    - stakeholder engagement
- What policies and regulatory structures are needed to support integrated water prediction, risk assessment, and management?

<u>Day One – Gulf Coast</u>

**Introductions**
***(9:00-10:00)***

***Welcome:*** Paul Higgins, AMS Policy Program
***(9:00-9:10)***

***Overview***: Ya'el Seid-Green, AMS Policy Program
***(9:10-9:30)***

***Lessons from the first workshop:*** Bill Hooke, AMS Policy Program
***(9:30-10:00)***

***Talk 1: National Water Model***
***(10:00-10:45)***

Speaker: Peter Colohan, National Weather Service

**Break**
**(10:45-11:00)**

<u>**Mississippi River Delta**</u>

***Speaker:*** Robert Twilley, Louisiana Sea Grant
***(11:00-12:00)***

**Lunch**
**(12:00-1:00)**

<u>**Houston-Galveston**</u>

***Speaker 1:*** Lisa Gonzalez, Houston Advanced Research Center
***(1:00-1:45)***

***Speaker 2:*** Paula Paciorek, Galveston Bay Foundation
***(1:45-2:30)***

**Break**
**(2:30-3:00)**

***Discussion Panel: Houston-Galveston***
***(3:00-3:30)***

Moderator: Bill Hooke, AMS Policy Program

**Discussion and Synthesis of Opportunities and Needs**
***(3:30-4:30)***

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Day Two – West Coast

**Discussion of lessons learned**
***(9:00-9:30)***

Moderator: Paul Higgins, AMS Policy Program

**Central California Coast**

***Speaker 1:*** Claudia Faunt, USGS
***(9:30-10:15)***

**Break**
**(10:15-10:45)**

***Speaker 2:*** Brian Garcia, Warning Coordination Meteorologist
***(10:45-11:30)***

***Discussion Panel: California***
***(11:30-12:00)***

Moderator: Carolyn Kousky, Resources for the Future

**Lunch**
**(12:00-1:00)**

***Talk 3: Data Sharing and Use: National Groundwater Monitoring Network***
***(1:00-1:30)***

Speaker: Bill Cunningham, USGS

**Tillamook Bay watershed, Oregon**

***Speaker 1:*** Lisa Phipps, Tillamook Estuaries Partnership
***(1:30-2:15)***

***Speaker 2:*** Nikki Hendricks, Oregon Department of Water Resources
***(2:15-3:00)***

**Break**
**(3:00-3:15)**

***Speaker 3:*** John Risley, USGS
***(3:15-4:00)***

***Talk 3: Envisioning alterative future scenarios of coupled natural/human system***
***(4:00-4:30)***

Speaker: Sam Chan, Oregon Sea Grant

**Policy needs for integrated water prediction, risk assessment, and management – Final Discussion**
***(4:30-5:00)***

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