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Protecting Life, Property, and the Economy Through Transformative Water Prediction Services

Introduction

Good morning Chairman Shelby, Ranking Member Shaheen, and Members of the Committee, I am honored to be here today to discuss a critical matter of global and national security: water risks. My testimony will describe how we at the National Weather Service (NWS), and across all of the National Oceanic and Atmospheric Administration (NOAA), are working with our partners, including federal, state, local, and tribal officials, the academic community, and the private sector, to improve water prediction and to better inform critical decisions to address those water risks.

Water presents three risks to communities across the United States. Stated simply the risks are summed up as follows: too much water, too little water, and poor-quality water.

This threat of water risks arises from several factors, including the water-related threats driven by weather events and seasonal variability that impact water availability and quality across the Nation. As I often say, “You can’t talk weather without thinking water.” These water risks vary regionally and include an increased frequency and intensity of heavy downpours leading to flooding, increased frequency and intensity of coastal storm surge, impacts on water quality resulting from changes in temperature patterns and nutrients and pollutants in runoff, as well as longer, more punishing periods of drought, often broken by extensive flooding, as just happened this past winter in the Western United States. I will address each of these risks to provide an integrated picture of these growing challenges, and how NOAA is using advances in the science and technology of water prediction to better understand and address those threats.

In particular, I will emphasize the progress we have made with the establishment of the National Water Center in Tuscaloosa, Alabama. This facility is intended to be a catalyst for enhanced collaboration with federal, academic, and private sector partners, which can accelerate our capacity to bring cutting edge science to NWS operations and improve NOAA's water prediction capabilities. These new capabilities rely not just on a single model or tool, but on exploiting and advancing the full range of water science, research, and services NOAA and our federal and non-federal partners have to offer. The Chairman's leadership and this Committee's strong support in this area has been appreciated.

A central activity of the NWC is the development and implementation of NOAA's new community-based National Water Model released in August 2016[1]. This new, continental-scale water resources model is based on the best available science, and leverages investments in NOAA's full suite of atmospheric weather models to produce water forecasts—including streamflow[1], water level, runoff, flood inundation, snowpack, soil moisture, and evapotranspiration—for 2.7 million rivers and stream reaches nationwide. The National Water Model emerged from a community modeling framework developed by the National Center for Atmospheric Research (NCAR). Augmenting NOAA's river forecasts at 4,000 stream gauges maintained by the U.S. Geological Survey (USGS), the National Water Model represents a 700-fold increase in the spatial density of the nation's water forecast information. With this new level of detailed forecast information, NOAA is working with federal partners to effectively communicate when, where, and how deep floodwaters will be during a storm event.

A second hydrologic forecasting capability is being implemented with support provided by the scientific community and individual states. The Hydrologic Ensemble Forecasting Service (HEFS) is an operational system that provides forecasts for risk-based water resources decision-making. This information seamlessly spans hours to days to seasons, and out through the full water-year. By leveraging this new information, water resource managers can make more informed decisions to optimize both the use of our increasingly limited water resources and response to emergency events. For example, the New York City Department of Environmental Protection (NYCDEP) worked with NOAA to accelerate the implementation of HEFS forecasts to aid the optimization of water management decision-making. Using this new water forecast information in conjunction with other tools, NYCDEP can determine how best to manage its reservoirs.

[1] Streamflow refers to the volume of water flowing in a channel over time, measured in the United States in cubic feet per second (cfs).

Moreover, I will show how our key federal partners such as the USGS, the U.S. Army Corps of Engineers (USACE) and the U.S. Bureau of Reclamation (USBoR), work with us hand in glove, on a daily basis, to provide the water observations and data necessary for NOAA to generate comprehensive water predictions. I will also highlight how these relationships, internally with NOAA's research division, and others with the National Science Foundation (NSF), National Center for Atmospheric Research (NCAR), and the broader academic community through the Consortium of Universities for the Advancement of Hydrologic Sciences, Inc. (CUAHSI), play a critical role in the effort to improve our water prediction capabilities. In addition, NOAA's federal partners in the water information enterprise also include the Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA), and the National Aeronautics and Space Administration (NASA).

Finally, I will discuss how the aim of all of our work is to build a Weather- and Water-Ready Nation through the provision of impact-based decision-support services. Research efforts executed within and sponsored by NOAA's Oceanic and Atmospheric Research (OAR) ensure the observing methodologies and modeling approaches are well founded and continue to advance the state of the art. NOAA's Satellite and Information Service (NESDIS) delivers continuous and comprehensive observations from NOAA, NASA, and international partner agency satellites, to provide comprehensive environmental information to support the models and forecasts. To ensure we deliver decision support services effectively, with the maximum reach and value possible, we collaborate with our customers, partners in federal, state, regional, local, and tribal governments and agencies. In addition, NOAA's success depends critically on continuing to foster and expand relationships with partners in academic, non-governmental, and private sector organizations, as well as international partners. These members of the broader water enterprise will contribute to and benefit from advances in water prediction. In time, these efforts can stimulate growth of the private-sector component of the water enterprise and foster effective decisions from critical decision makers at all levels.

NOAA's full range of capabilities—from weather and water modeling to precipitation forecasting, to drought early warning—are central to addressing these aforementioned risks. Our goal is to foster ongoing strategic partnerships and provide the water intelligence to help communities and decision makers prepare for and mitigate water risks, as well as more effectively manage and protect their water resources.

Water Risks

Flooding

I will begin with the threat from inland flooding and coastal inundation—too much water. In 2016 alone, the U.S. experienced four inland flood events costing over one billion dollars per event. Billion-dollar inland flood events of this magnitude have not occurred twice in the same year in the United States since 1980. Those four events included: 1) the Sabine and Red River flooding on the border between Texas and Louisiana in March; 2) the Houston, Texas, floods in April; 3) the West Virginia floods in June; and 4) the flooding in Southern Louisiana on August. The last example in Louisiana was the most damaging U.S. flood event since Superstorm Sandy impacted the Northeast in 2012. These four inland flood events together took 49 lives and cost $16 billion to the U.S. economy[2]. Moreover, these numbers exclude the costly impacts of Hurricane Matthew from Florida to North Caroline in October 2016, which claimed an additional 49 lives and cost an additional $10 billion. Much of those costs were due to historic levels of river flooding in eastern North Carolina that damaged 100,000 homes, businesses, and other structures. In this example, as with all land-falling tropical cyclones, coastal storm-surge and inland flooding combined to exacerbate inundation in coastal communities, a point that I will return to when discussing NOAA's planned capabilities for integrated water prediction at the coast.

While most of these examples come from the Southern United States, every part of the country experiences costly flooding, and every state is at risk, as illustrated by recent examples from California, to Iowa, to West Virginia, to the Carolina Coast. We only have to go back a few years to see the flooding and devastation that occurred in New England in 2011 from the remnants of Hurricane Irene. This past summer in my own back yard in Ellicott City, Maryland, the town experienced a destructive flash/river flood. Today, we are concerned about the ongoing flooding from snowmelt in the West as well as the potential for flooding in North Dakota.

Drought and Water Availability

Only five years ago in 2012, we had an extensive drought that covered over 80 percent of the contiguous United States. This was the most extensive drought to affect the United States since the Dust Bowl of the1930s. In 2012, moderate to extreme drought conditions affected more than half the country for a majority of that year. Costly drought impacts and their associated effects on water availability occurred across the central agriculture states resulting in widespread harvest failure for corn, sorghum and soybean crops, among others. The associated summer heat wave also caused 123 direct deaths, but an estimate of the excess mortality due to heat stress is still unknown. Additionally, these conditions resulted in an estimated $31.5 billion in economic loss[3]. As a result, Federal Agencies, including NOAA convened a National Drought Forum, bringing together state, regional, industry, and federal partners to identify a set of priority actions for working with these partners to help reduce the impacts of future events. From 2012 through 2016, significant portions of the country, especially nearly the entire state of California, continued to experience “exceptional drought” conditions, causing extensive economic and health impacts, including challenges to the viability of agricultural production, impacts on drinking water supplies, increased energy costs, and harm to ecosystems. Fortunately, the 2016-2017 winter rain and snowfall have mitigated drought conditions in much of the West. Unfortunately, new areas of extreme drought developed in states across the Northeast and Southeast. As of March 14, 2017, nearly 90 million Americans are affected by drought conditions[4].

Local Variability from Flood to Drought - Managing Water Resources

Over time for a given community, flood and drought are potentially interrelated events, as they represent a pendulum between extremes in regional hydrometeorology—that is the relationship of the weather and the natural water system of a given region—often over a period of only a few years or less. While the severity of these water extremes varies regionally, we have seen these swings in every part of the country. This situation was particularly well illustrated in California in 2016 as the 5-year drought persisted. In late 2016 and 2017, drought in many areas ended with near record mountain snowfalls and lower-elevation rainfall and associated historic flooding. Nevertheless, the long-term impacts of the drought in California continue to be felt, as more than 100+ million trees, which perished in the drought, have become a public safety hazard due to falling limbs and compromised root systems. In addition, extensive wildfire driven by the drought expanded the risk of erosion and debris flows during flood events. A second example of the inter-relationship between flood and drought comes from the Mississippi Basin where threats to river navigation impacted barge traffic between 2011 and 2012. Challenges ranged from opening spillways to manage river flooding in 2011, to using explosives to remove rock pinnacles in 2012 to allow for safe navigation during the extreme low flows created by rapidly developing drought conditions. These extreme swings from flood to drought, and the rapid variation from one extreme to another, underscore the value of and need for improved water intelligence to enable water resources managers, and other decision makers, to make informed decisions that mitigate impacts and optimize the use of our increasingly stressed water supply.

Water Quality

Finally, the combination of flood, droughts, and high temperatures have a cumulative damaging effect on water quality, and poorer water quality impacts human and ecosystem health, the third threat in this trio of growing water risks. Floods can move contaminants, droughts concentrate them, and warmer water temperatures accelerate biochemical processes, which lead to the generation of harmful algal blooms and hypoxia conditions. Natural events, however, such as heavy downpours, high-temperatures, high-runoff, low stream flow, and coastal inundation can combine with human activities to pose serious threats to water quality. When water temperatures warm, these threats can take the form of harmful algal blooms, hypoxia, and pathogens that can have a significant impact on the effective management of riverine, estuarine, and marine ecological systems, which support a wide variety of human uses and community needs including recreational and drinking water purposes.

NOAA, through NOS, continues its efforts in partnership with states and other federal agencies to predict the runoff of chemicals from fertilizers and to forecast the evolution of harmful algal blooms and hypoxia to better warn citizens and agencies. These types of predictive services help local communities, managers and state-based decision-makers make timely, effective decisions that impact public health and safety.

The Need for an Integrated Response

Across the country, communities are struggling with inter-related and increasing threats from water extremes from flood to drought, and their associated threat to water quality. In the context of day-to-day decision making about water resource management, transportation and navigation, and ecosystem management, these variable conditions require a more advanced and integrated approach to more effectively support both event-driven, high impact events and routine high-value decision making.

NOAA's Response: Progress to Date

NOAA is bringing its long tradition of science and technology to bear on the problem of water risks and water resource management, and has taken critical new steps to transform its capabilities to provide integrated water prediction services to meet the needs of our user community, including water resource managers and emergency managers.

Water at NOAA

Water is a common thread that runs through NOAA's mission areas serving stakeholders through a variety of field offices, laboratories and national service outlets. It is important to note that NOAA offices are both producers and consumers of water information services.

NOAA's portfolio includes several well-known programs that feature forecast and modeling products and services. These include the river forecasts provided by NWS River Forecast Centers, the Digital Coast service provided by the National Ocean Service (NOS), the water temperature modeling produced and used by the National Marine Fisheries Service, the large-scale precipitation data collected and managed by NESDIS, and the water-related research activities of OAR's grant-making programs, labs and cooperative institutes. In addition, NOAA is home to the National Integrated Drought Information System (NIDIS), an interagency program based at NOAA that implements the NIDIS Act (Public Law 109-430) to, among other things, provide drought early warning information and coordinate federal research in support of drought information.

Within NOAA, and in fact among all federal agencies, the NWS is unique in that weather and water forecasting are explicitly articulated in its mission statement. Yet water prediction is quite different from weather prediction in three important respects. The first is that weather prediction takes place on a scale of minutes and hours, to days and weeks, whereas water prediction begins at minutes and hours, and extends to much longer time scales, out to weeks to months and even years. The second difference is that humans alter the natural water systems to harness the nation's water resources for transportation, energy, agriculture, recreation, ecosystem management, and water supply missions. In order to accurately model surface water, NOAA's water prediction systems must account for these human-driven processes as they have a profound impact on the water forecast. The third is that responsibility for these operations spans multiple federal, tribal, regional, state and local entities. While weather and water prediction is the responsibility of NOAA, water prediction requires a symbiotic partnership with multiple federal and state water agencies. For example, the USDA has been generating statistical water supply forecast for the western United States since the 1930s.

As an illustration of routine and real-time collaboration among agencies, NOAA issues river and water supply forecasts leveraging stream gauge observations from the USGS and reservoir operation information from USACE. In turn, the USACE uses NOAA forecasts to make reservoir release decisions in accordance with their operational manuals, which are then integrated into the NOAA forecast models. NOAA also collaborates closely with state water agencies and decision makers across the country, such as in New York, Colorado, Oklahoma, and California all of whom use NOAA forecasts in their prediction efforts.

Given the close operational relationship among agencies at the federal level, the USGS, the USACE, NOAA, and Federal Emergency Management Agency (FEMA) have joined together in a consortium for Integrated Water Resources, Science, and Services, or (IWRSS). IWRSS was formalized in May 2011 by the signing of a Memorandum of Understanding by the Administrators for NOAA and the USGS, and the Assistant Secretary of the Army for Civil Works, who, together with the Deputy Administrator of FEMA renewed the MOU in March 2016. In additional, NOAA is an active participant in the Western States Federal Agency Support Team (WestFAST), an interagency team created to support the Western States Water Council and the Western Governors Association on water resources. NOAA is currently providing the federal liaison to that team to ensure we address the complex challenges and needs of water resources stakeholders in the Western US. NOAA also is a co-chair, with USDA, of the National Drought Resilience Partnership, which engages with a wide array of stakeholders and coordinates federal agency activities related to drought resilience.

The National Water Center acts as a catalyst for these interagency activities, especially as they relate to the improvement of NOAA's water prediction capability and decision support services. The National Water Center is focused on developing national water prediction capabilities and facilitating collaboration among the entire water enterprise, including public, private and academic sectors. Moreover, it was purposefully built with an operational forecasting center, which is envisioned to be staffed with personnel from multiple federal agencies. The goal is to establish an integrated and common operating picture for water resources.

The Demand for Improved Water Prediction and the Impetus for Change

Stakeholders from across the spectrum have called for improvements in water prediction services over the past several years.

Given the complexity of water risks, the equally complex landscape of inter-related water jurisdictions, and the demand for trusted, reliable data and information NOAA is challenged to provide the highest degree of excellence in official predictions of water resources.

In 2012, a report from the National Academy of Sciences reinforced this challenge, noting a significant gap between the state of hydrologic science today and current hydrologic prediction operations of the NWS. The services in use today are reliable, accurate, and dependable, but still rely heavily on scientific techniques from the 1970's. The report noted that substantive advances in hydrologic and water resources science accomplished by the research community during the past three decades have generally not been incorporated into the NWS river forecast operations[5].

In addition, a report published by the National Academy of Public Administration in 2013 found that NWS needs to significantly shift its approach from generating weather products and service outputs to fully embrace societal outcomes, what we now call impact-based decision-support services. The report also found that without considerable engagement of stakeholders and a framework for change, it would be difficult for the agency to fully achieve this vision[6].

From 2012 through 2014, NOAA carried out engagement sessions with water resources stakeholders across the United States, which reinforced the demand for improved water prediction. These sessions revealed the need for consistent, high space and time resolution, integrated water analyses, predictions and data to address critical unmet information and service gaps related to floods, drought, water quality, water availability, and weather. Simply put, stakeholders articulated a clear need for “street-level” water information to address gaps necessary to inform critical water resources decisions communities make on a daily basis.

Finally, from May to July 2016, NOAA held a series of meetings with water resources stakeholders across the United States that we called, “The National Conversation on Integrated Water Information for the 21st Century.” Participants in these meetings highlighted and further validated the need for and importance of consistent, integrated water predictions, data, and analyses. They also emphasized the importance of NOAA's work to convert predictions, data, and analyses into actionable “street-level,” water intelligence by developing effective visualization and decision support tools that link hydrologic, infrastructural, economic, demographic, environmental, and political data and are informed by social science. Perhaps most importantly, participants emphasized the need for regular communication, consultation, and engagement with decision makers. These regional conversations also highlighted the growing need to improve the accuracy of seasonal prediction of rainfall and related drought conditions, particularly for state-level water resource managers. This year, NOAA launched a new set of stakeholder engagements to continue this important dialogue in basins around the country.

The National Water Center: A Catalyst for Advancing Operational Water Prediction

Recognizing these challenges, NOAA embarked on a new effort to augment its investments in river forecasting and dramatically improve water prediction through the establishment of the National Water Center (NWC) in Tuscaloosa, Alabama. With the support of Congress, design work began in 2010, and construction began in 2012, with a ribbon cutting ceremony declaring an initial operating capability of the NWC in May of 2015. The NWC is designed to facilitate partnerships and collaboration across organizations and sectors to deliver a new generation of water information and decision-support services that will:

- Strengthen the nation's water forecast capabilities by serving as an innovation incubator and research accelerator for water prediction;
- Improve national preparedness for water-related disasters;
- Provide predictive information to enable and advance integrated water resource management at the local, state, regional, and national levels;
- Serve as a hub for collaborative meetings between water managers, forecasters, stakeholders, and public officials;
- Inform event-driven, high impact, and routine, high-value water decisions at the local, state, regional, and national levels; and
- Provide water information that supports and promotes water stewardship.

Since 2015, the NWC has hosted over 60 interdisciplinary and scientific meetings, with more than 2,500 participants from a spectrum of government, academic and private sector entities. The NWC has become hub of activity and an incubator for national and international collaborations on the next generation of water resources science and services.

Designed to be a truly national center, the NWC supports water prediction nationwide. It already has begun fostering scientific excellence and innovation by promoting research and collaboration across federal water science and management agencies, academia, and the private sector and by accelerating the transition of research to operational applications and forecasting.

NOAA's Key Water Prediction Capabilities

NOAA has developed a suite of new capabilities and activities that address a full range of water information services from floods to drought to water quality challenges. These are highlighted below:

<u>The National Water Model</u> - The National Water Model referenced above, represents NOAA's first foray into high-performance computing for water prediction, thereby augmenting and supporting the generation of official forecasts at NWS River Forecast Centers (RFCs). In response to requests from a broad spectrum of water resources stakeholders, the National Water Model also produces spatially-continuous forecasts of soil moisture, evapotranspiration, runoff, snow water equivalent and other parameters. Considering just streamflow, the model suite produces over 32 billion discrete pieces of information each day. Moreover, the National Water Model leverages the National

Hydrography Dataset developed by the USGS and EPA as an authoritative geospatial representation of the nation's connected rivers and streams commonly used by other water information agencies and communities. This new capability expands NOAA's forecast density capability 700-fold, such that millions of people will be able to receive real-time relevant forecasts of water in their local rivers and streams based upon the spatial and temporal scales upon which communities make decisions; i.e. mapped right down to the street level.

Hydrologic Ensemble Forecast Service (HEFS) - The HEFS is an operational system that provides risk-based water information for local decision makers. This additional new transformational hydrologic forecasting capability is being implemented with support provided by the scientific community and individual states. HEFS leverages the skill in weather and seasonal forecasts to produce reliable and skillful ensemble forecasts of streamflow at lead times ranging from one hour to one year, which is particularly useful for long-range water resource planning. HEFS provides uncertainty ranges for water resources forecasts at all time scales and enables better risk-informed decisions to support water management. In 2015, the first version of HEFS was implemented at NOAA's thirteen RFCs. In 2016, all RFCs began running HEFS every day in real-time at selected headwater forecast locations.

Improving Seasonal Prediction of Precipitation - During the regional and national conversations, stakeholders articulated the clear need to improve seasonal predictions of precipitation related to drought and other water resource partner needs. To help meet this need, Geophysical Fluid Dynamics Laboratory (GFDL) research unit has made important advances for incorporating atmosphere, ocean, and land observations into their prediction systems. This, combined with recently developed modeling strategies, have led to improved understanding and prediction of weather elements (such as temperature and precipitation) on time scales from weeks to seasons and beyond. A recent advance from these efforts has been an improvement of the Forecast Low Ocean Resolution (FLOR) seasonal prediction model. GFDL has conducted experiments with the new version of FLOR that show significant improvements in seasonal precipitation forecast skill for the Western U.S. over a 25-year historical period, including during the 2015-2016 El Niño. The results represent a significant improvement over major national and international prediction models in more correctly simulating the western U.S. precipitation during the 2015-2016 El Niño. This emerging capability is being evaluated for operational implementation at NOAA's Climate Prediction Center, which issues seasonal precipitation and temperature forecasts.

Runoff Risk Tool - The Runoff Risk tool provides real-time guidance related to the influence of soil conditions, rainfall rates, and snowmelt on runoff. This provides farmers with information about when to apply fertilizer and manure to their fields, and when not to, in order to minimize loss of nutrients to rivers and lakes. This technique relies on experimental runoff risk analyses from NOAA combined with on-farm research data and partner relationships at the state and local levels. Wisconsin and other states are beginning to offer this science-based approach to nutrient-application timing in order to minimize the subsequent runoff into streams, rivers and lakes and other water bodies that ultimately contribute to Harmful Algal Blooms (HAB).

Digital Coast - The NOAA-sponsored Digital Coast website is focused on helping communities address coastal issues and meeting the needs of the coastal management community. The website provides not only coastal data, but also the tools, training, and information needed to make these data truly useful. For example, The Red Cross is using the Digital Coast's Coastal County Flood Exposure Snapshot to communicate vulnerability information to its network members. This tool captures the numbers of elderly and impoverished residents living in the floodplain as well as the number of critical facilities located there, which is valuable information for pre-event and recovery planning.

National Water Level Observation Network (NWLON) and Operational Water Level Forecasting - NOAA provides a network of 210 long-term, continuously operating water level stations throughout the United States and its territories and is the "go to" for real-time coastal water level and meteorological observations. This network provides a key coastal component to NOAA's forecast model framework and is critical for developing and validating NOAA tsunami and storm surge warnings. NWLON is also a framework for other local to federal partner gauging networks, providing water level observations for integrated-water decision support applications, such as Coastal Inundation Dashboard and High Tide Bulletin. NOAA enhances these observations and applications with a national network of Operational Nowcast and Forecast Hydrodynamic Model Systems (called, OFS) that generate predictions about the present and future states of coastal water levels. The hydrodynamic models are driven by real-time data and meteorological, oceanographic, and/or river flow rate forecasts and are located in ports, harbors, estuaries, Great Lakes and coastal waters of the United States. The Operational Forecast System will be a critical connection between riverine and coastal environments as these models are integrated into the National Water Model effort.

The National Integrated Drought Information System (NIDIS) Regional Drought Early Warning Systems - NIDIS is building a nationwide network of drought early warning systems (DEWS) to improve drought monitoring, forecasting, planning, and preparedness capabilities. The development and implementation of regional DEWS allows for responsiveness to particular geographic and hydrologic circumstances, as well as value-added information needs specific to stakeholders in the respective areas. Eight regional DEWS have been established, and to complete a national drought early warning system, NIDIS will continue to develop regional DEWS in watersheds and regions across the country, such as the Mid-Atlantic and New England areas.

Lake Shasta Prediction Tools - In California's water system, endangered salmon and other protected species require cold water to survive, especially during drought conditions. Monitoring and understanding water temperature, particularly the cold-water pool in Lake Shasta, is crucial to balancing the competing demands of California water users and protected resources. In 2016, NOAA implemented new environmental monitoring and modeling systems as part of a suite of experimental decision-support tools that water managers will use to evaluate water management trade-offs. During this water year, a new distributed temperature sensor provided real-time water temperature profiles in Lake Shasta, and these observations are fed into reservoir, stream temperature, and salmon survival forecast models. Regular interactions with California's State Water Board, the California Department of Water Resources, the California and U.S. Departments of Fish and Wildlife, the USBoR and others in the Central Valley's Technical Management Team ensured that these efforts were guided by the needs of water managers.

Forecasting Harmful Algal Blooms (HAB) - NOAA produces operational HAB forecasts in the Gulf of Mexico and Lake Erie. Based on monitoring programs and models of water flow and circulation, these forecasts alert coastal managers to highly toxic harmful algal blooms before they cause serious illness and even death, and pose serious threat to fish, shellfish, and other wildlife. Early warning provides health officials, environmental managers, and drinking water treatment facility operators' information to guide beach and shellfish bed closures and adjustments to water treatment. HAB and other ecological forecasts are illustrative of NOAA's developing capability in integrating water predictions, weather predictions, and water quality predictions. For example, an early-season HAB forecast for Lake Erie estimates the bloom severity based on measurements of phosphorus loading from the Maumee River combined with historical records to create the weekly estimates for the remainder of the loading season. In the Gulf of Maine, NOAA provides weekly graphical river hydrologic and weather outlooks that feed HAB forecasts from March through June, including real-time updates on precipitation variations, snow melt, and the likelihood of significant precipitation, river runoff, and northeast wind potential for the seven-day period. NOAA is partnering with the EPA, NASA, and USGS to expand our HAB prediction abilities in other large inland waters to allow better national-level HAB management.

Going Forward: The NOAA Water Initiative

With the establishment of the new National Water Center, NOAA has now embarked on a comprehensive effort, the NOAA Water Initiative, an unparalleled level of internal collaboration across NOAA, effectively merging research, satellite observations, data analytics, and unmatched user and customer connections to enhance the agency's capability to develop and deliver better water information services. This NOAA Water Initiative, published in December 2016, envisions a Nation in which everyone from individual citizens to businesses and public officials has timely, actionable information about their vital water resources at their fingertips, and can factor this information wisely into their decisions about water risks, use, management, planning, and security. The common goal of the NOAA Water Initiative is to transform water information service delivery to better meet and support evolving societal needs. To achieve this goal, the agency will pursue five interdependent strategic objectives: (1) build strategic partnerships for water information services; (2) strengthen water decision support tools and networks; (3) support water modeling, forecasting, and precipitation prediction; (4) continue water information research and development (R&D); and (5) sustain water-related observations. In particular, the future pillars of our water prediction efforts will include:

- Transforming NOAA's inland and coastal hydrologic prediction services through ongoing improvements to existing services, including the continued development of the National Water Model, coastal mapping, and continued implementation and utilization of the HEFS;
- Transforming NOAA's quantitative precipitation forecasting capabilities at time scales necessary to support water supply and water resource management—from daily to weekly to seasonal, and to decadal, at continental-to-global scales — through research into key underlying physical processes, including sources of predictability, levels of forecast uncertainty, and the development of forecast tools on sub-seasonal to seasonal and longer timescales;
- Recognizing water as habitat by integrating physical and ecological modeling of water quantity and water quality (e.g., temperature, salinity, ocean color, etc.) to inform effective management of riverine, estuarine, and marine ecological functions and processes in support of a wide variety of human uses and community needs; and
- Working with the larger water research community to continue NOAA's water modeling efforts in support of the longer range goal of integrated Earth system modeling in the context of a unified modeling approach, where best practices in process understanding, model development, data assimilation, post-processing, and product dissemination will be leveraged across disciplinary boundaries. This

activity will be carried out in keeping with the updated interagency Charter for the Partnership on the National Earth System Prediction Capability.

To achieve these goals and related efforts and address our nation's growing water resources challenges, NOAA will tap into the Nation's best talents from the public, private, and academic sectors. The NOAA Water Initiative calls for a growing partnership across multiple sectors to create and deliver water information to meet the needs of the 21st century. NOAA will support this idea by working toward the objectives and outcomes of the initiative and leveraging the resources of the National Water Center to provide next-generation, science-based water information and decision support services. We look forward to collaborating with a full array of partners, decision makers, and users to achieve this vision for the benefit of our communities, our economy, and our planet.

Conclusion

Water is essential to our way of life. Integrated water risks stemming from increasing demand, limited supply, floods, droughts, and water quality require more comprehensive, integrated, state-of-the-science solutions. The new National Water Center, established at NOAA, serves as a necessary catalyst for ongoing advancements in water prediction to serve society's needs. With this new center in place, NOAA is fostering strategic partnerships to help communities and decision makers prepare for and mitigate water risks, as well as more effectively manage and protect our nation's water resources.

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[1] http://water.noaa.gov/about/nwm

[2] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2017). https://www.ncdc.noaa.gov/billions/

[3] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2017). https://www.ncdc.noaa.gov/billions/

[4] U.S. National Integrated Drought Information System, U.S. Drought Portal, www.drought.gov/drought/

[5] *Weather Services for the Nation: Becoming Second to None*, Report of the Committee on the Assessment of the National Weather Service's Modernization Program, National Academy of Sciences, 2012.

[6] *Forecast for the Future: Assuring the Capacity of the National Weather Service,* National Academy of Public Administration, 2013.