April 4, 2017

National Water Hazards & Vulnerabilities: Improved Forecasting for Response & Mitigation

Subcommittee on Commerce, Justice, Science and Related Agencies, Committee on Appropriations, United States Senate, One Hundred Fifteenth Congress, First Session

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Chairman Richard Shelby Opening Statement
Committee on Appropriations Subcommittee on Commerce, Justice, Science, and Related Agencies

Hearing titled "National Water Hazards & Vulnerabilities: Improved Forecasting for Response & Mitigation"

April 4, 2017

(*As prepared for delivery*)

Good afternoon and welcome to the first Commerce, Justice, Science Subcommittee hearing of 2017.

I want to begin by recognizing the Subcommittee's new Ranking Member, Senator Shaheen of New Hampshire, who I believe will be a good partner in accomplishing the Subcommittee's work moving forward.

I also want to thank our panel of witnesses for agreeing to be here today to testify about the important issue of water-related hazards.

Severe flooding, extended droughts, and dangerous storm surges, among others, threaten communities across our nation.

In 2015 and 2016, property damage caused by flooding alone resulted in 105 deaths and an estimated $20.6 billion in losses.

Over the same time-period, losses due to drought amounted to $8.1 billion.

Improving our ability to predict and forecast these events will help save lives and protect property by allowing emergency managers to better prepare and respond to extreme weather incidents.

Collecting water-related data and distributing it in a useable form is an invaluable task—one that takes a collective effort by the federal government, states, and the private sector.

Cutting-edge research is needed to advance our current prediction and modeling capabilities.

One example of a recent advancement spurred by university research is the unveiling of the National Water Model, which is a predictive tool that simulates water flow across the continental United States.

The National Water Model is the product of collaboration between federal agencies and universities to solve a complex problem: tracking water flow across the country to aid local communities and emergency managers in responding to water-related threats.

Our nation's water forecasting capability is headquartered at the National Water Center, located in Tuscaloosa, Alabama. This unique Center serves the entire nation by bringing together federal agency officials, university researchers, and other interested parties to research, track, and forecast water-related events across the country.

This hearing will examine the current activities being conducted by the federal government, states, universities, and the private sector in the area of water hazard forecasting and mitigation.

I hope the panel will not only inform this Subcommittee about the good work being done, but also speak to the areas in need of improvement, the gaps that need to be filled, and any unnecessary overlap between public and private sector activities that could be streamlined.

Before recognizing the Ranking Member for her remarks, I would like to briefly introduce the panel.

Dr. Louis Uccellini is director of the National Weather Service at the Department of Commerce, and can speak about specific activities of the federal government in water prediction.

Dr. Antonio Busalacchi is President of the University Corporation for Atmospheric Research, a consortium of universities focused on better understanding naturally occurring water-related events.

Mary Glackin, Senior Vice President of the Weather Company for Private-Public Partnerships, will speak to the important work being done by the private sector in partnership with government agencies.

Finally, Bryan Koon is the director of the Florida Division of Emergency Management, but comes with an extensive background in national emergency management experience—including serving during the Clinton and Bush administrations in the President's Emergency Operations Center. Bryan also has experience in the private sector serving as director of Emergency Management for Wal-Mart Stores, Inc., and is former President of the National Emergency Managers Association.

Welcome to all of you.

Now I would like to recognize the Ranking Member, Senator Shaheen, for her opening remarks.

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Dr. Louis Uccellini, Assistant Administrator for Weather Services and Director of the National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce

Testimony to the Appropriations Committee Subcommittee on Commerce, Justice, Science, and Related Agencies United States Senate

April 4, 2017

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:

The National Water Model - 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.

National Water Hazards & Vulnerabilities: Improved Forecasting for Response & Mitigation

Statement of

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President, University Corporation for Atmospheric Research (UCAR),

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before the

United States Senate

Committee on Appropriations

Subcommittee on Commerce, Justice, Science and Related Agencies

April 4, 2017

Good Morning Chairman Shelby and Ranking Member Shaheen, and members of the subcommittee. I am Dr. Tony Busalacchi, President of the University Corporation for Atmospheric Research, and recently elected member of the National Academy of Engineering. UCAR is a nonprofit consortium of 110 member universities granting degrees in atmospheric and related earth sciences. UCAR's primary activity is managing, on behalf of the National Science Foundation, the National Center for Atmospheric Research (NCAR). In addition, UCAR manages a suite of programs (UCAR Community Programs) that provide service and support to the academic community.

NCAR is a Federally Funded Research and Development Center with over 600 scientists and engineers conducting weather, water, climate, air quality, and space weather research. Staff also manage supercomputers, research aircraft, and Earth observing systems available as a resource to the nation's research community. Our UCAR member universities and staff scientists conduct research for use by government agencies and the private sector. We aim to further the understanding of atmospheric and related phenomena and help create more accurate environmental forecasts that protect lives and property, spur economic growth, support the national defense, and enhance our quality of life.

Prior to becoming the UCAR President, on August 1, 2016, I served as Director of the Earth System Science Interdisciplinary Center and Professor of Atmospheric and Oceanic Science at the University of Maryland. Before my time at the University of Maryland I was a civil servant for 18 years at the NASA Goddard Space Flight Center (GSFC), the last 10 years of which I was a chief of the Laboratory for Hydrospheric Processes and member of the Senior Executive Service.

Let me begin first by thanking you Mr. Chairman for your strong support of science in particular with respect to your vision on the topic of this hearing, as well as all the members on this committee. During my 34 years working in Maryland and now at UCAR I have observed the tremendous support this committee has provided for the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), the National Institute for Standards and Technology (NIST), and the National Aeronautical and Space Administration (NASA), as well as for the university research communities that collaborate with these agencies.

There can be no doubt that science and the resulting societal benefit from these agencies and universities has enhanced our quality of life while contributing to both economic and national security. Much of the work we do at UCAR and NCAR would not be possible without robust funding for the Geosciences directorate at NSF and many of the successes you hear today are the result of past funding that enabled the science. Moreover, the topic of today's hearing on water is one that fits exactly in the nexus of scientific and social understanding that supports economic development and national security so thank you for inviting me to testify on this very timely subject.

Following the suggestion in the committee's letter inviting me to testify, I will organize my testimony around the following questions that I believe are critical in examining the "water nexus":

1. What constitutes the current state of the nation's water enterprise?

2. What is the desired future state of the nation's water enterprise?

3. What are the gaps that need to be addressed to get to the desired future state?

4. What processes and policies are needed to identify roles and responsibilities? What, if any, are the next steps for Congress?

I will highlight the areas where the water nexus can best provide value to the taxpayer and where impacts can best be made. I will also discuss how this is an area where we have seen one of the most significant research to operations (R2O) transfers in our nation's history and it demonstrates how the research and operations communities collaboratively addressed a hard problem that has tremendous benefit to all American taxpayers.

1. **What constitutes the current state of the nation's water enterprise?**

Today's water enterprise is a triumvirate that consists of academia, the public sector and the private sector. The government's traditional role within this triumvirate is the protection of life and property; the building and management of both small and large infrastructure; and the enhancement of national security through the issuance of forecasts for severe weather to include floods, droughts and anything water related. The private sector's traditional role is to create customized and tailored hydrologic products and services to a broad customer base of private individuals and businesses in a multitude of sectors. The academic and research community, including federal laboratories and centers, works to improve our common understanding of the Earth System and improve operational products. The three work together, often in a public-private partnership, to advance synergistically our knowledge and operational capabilities.

We must also acknowledge that the growth of private sector products and services in the water enterprise has benefitted from public investment both in providing foundational observational data and observing networks, and in creating open community models which have enabled companies to quickly make new products that have hydrologic applications – not just in the United States, but around the world. This approach has provided an incalculable return on investment of public tax dollars and goes largely unnoticed even as we all recognize that the protection of life and property is paramount.

Now is an extremely exciting time in the world of water. The investments over several decades have led to advances in science and technology such that the US is poised to make a leap forward in our understanding of weather, climate and water through modeling, monitoring, and forecasting. These advances include the development of new and more complex models of the land surface and, more broadly, the Earth System; vastly improved weather predictions that help us estimate weather and water risk; expanding resources for supercomputing and communications; and new statistical techniques to enhance the skill of streamflow forecasts. NCAR is collaborating with federal agencies such as NOAA, NASA, DOI and DOD to integrate these advances into tools and services that will deliver far more information to water sector entities than has been possible before.

A key example of this collaboration in the water enterprise is the new National Water Model (NWM), which was recently operationalized by the National Weather Service at the National Water Center in Tuscaloosa, Alabama. The implementation of this forecast tool could not be more timely given the serious flood catastrophes in 2016 as we saw in Baton Rouge, La, Ellicott City, MD, and Kanawha County, WV. The NWM generates hydrologic (streamflow) forecast outputs in real time for an unprecedentedly comprehensive collection of the nation's rivers and streams – 2.7 million total locations for prediction. This detailed information from the NWM provides a significant complement to the existing operational streamflow forecasting service, which previously relied solely on simpler models and techniques to forecast for thousands of critical locations. These forecasts are vital for the operation of the nation's water infrastructure, supporting hydropower, agriculture, navigation, recreation and other purposes, and informing emergency management during floods and droughts with vital watch, warning and outlook products. The initial deployment of the NWM is a major new direction for the water enterprise, and one that has enormous future potential to augment the value of the traditional forecasting services, with broad economic and social benefits. Achieving this full potential will depend on the success of continued investments and progress toward resolving long-standing scientific and observational challenges in water prediction.

The National Water Model's history begins with the initial investment in basic research by the National Science Foundation to develop a regional weather research forecast (WRF) tool at NCAR. WRF was developed in an open-platform, open-access community manner that ensured that anyone who wants to utilize it to test forecasting hypotheses, to tune it to specific phenomena, or privatize could easily do so without charge or clearance. WRF's developers also ensured that it was highly adaptable and portable, so researchers could use it as the foundation for forecasting systems that could predict a wide variety of environmental phenomena. Indeed, since WRF's creation, researchers from academia, government and industry have created WRF-Chem, Hurricane WRF, WRF-Crop, WRF-Fire, and many others.

One such WRF spin-off is WRF-Hydro, which has connected hydrological forecasting with weather forecasting. WRF-Hydro is an excellent example of the triumvirate across academia, the public sector and the private sector as the initial investment by the NSF was leveraged with contributions by mission oriented agencies such as NOAA, NASA, and the USGS together with a partnership with the private sector in the form of Barron Weather Services. This model enabled the utilization of a vast array of environmental observations – from stream gauges to satellites – to provide an initial capability to forecast the flow of a region's rivers and streams, the moisture of its soil, and the quantity and type of precipitation. Initial testing of this model in Colorado during the anomalous flooding events of 2013 demonstrated several of the model's strengths over conventional flood forecasting methods. Working with Barron Weather Services of Huntsville, AL, NCAR scientists then applied the model for further testing and operationalization in Romania. Later, the nation of Israel collaborated with NCAR to implement their own version of WRF-Hydro for operational hydrologic prediction. The success of the model's implementation in these two countries led NOAA to pursue utilizing elements of WRF-Hydro as the basis for the National Water Model, following several rounds of improvements, testing, and integration with existing weather forecasting systems.

The development and implementation of this model from research to operations could not have happened without sustained collaborative engagements between academia, industry, and government. The implementation has already proved useful in the provision of flood forecasting associated with several anomalous events – including a Hurricane landfall in North Carolina last year and the more recent flood events in California this winter. I should also add that NCAR delivered the model two years ahead of schedule and on budget.

The model's implementation has identified several new and exciting research questions for the academic community to pursue, including the improvement of quantitative precipitation forecasts to enhance our capacity to predict rapidly changing flood inundation conditions. Knowing how much, when, and where precipitation will fall is a vexing question and a critical one to answer in order to improve flood forecasting and water resource management more generally.

The model's implementation has also created several new and exciting opportunities for industry, with the prospect of broadcast hydrology on the horizon. Imagine turning on the nightly news and getting not just a weather forecast, but also street level visualization of river and stream forecasts. Such services could be highly valuable not just to private citizens and small businesses, but also emergency managers. Such services could also be provided abroad, providing benefits to citizens of other nations who struggle to manage their water issues.

Such predictive models are only as good as the observations that go into them. In the past three years, NASA and NOAA have launched three satellites that have been vital in improving water forecasting and services. In 2014, NASA and the Japanese Aerospace Exploration Agency (JAXA) launched the Global Precipitation Measurement (GPM) satellite, which provides next-generation observations of rain and snow worldwide every three hours. The GPM mission contributes to advancing our understanding of Earth's water and energy cycles and improves the forecasting of extreme events that cause natural disasters. GPM applications include extended capabilities in monitoring and predicting hurricanes; enhanced prediction skills for weather and climate; improved forecasting capabilities for floods, droughts, and landslides; better agricultural crop forecasting; and the monitoring of freshwater resources.

In 2015, NASA launched the Soil Moisture Active Passive (SMAP) satellite, which provides measurements of the land surface soil moisture and freeze-thaw state with near global coverage. SMAP measurements coupled with hydrologic models can determine soil moisture conditions in the root zone, which enables forecasters to better understand water and energy fluxes at the land surface and improve flood prediction and drought monitoring.

Most recently, in 2016, NOAA and NASA launched the Geostationary Operational Environmental Satellite – R Series (GOES-R, now GOES-16 since launch and operationalization). GOES-16 provides weather pattern images every 30 seconds, providing more accurate and timely information on severe storms from space than ever before. Additionally, GOES-16's Geostationary Lightning Mapper instrument can detect the presence of lightning, providing forecasters with the ability to focus on developing extreme weather and before storms produce precipitation.

In addition to overhead observations, real-time stream gauges from the United States Geological Survey (USGS) and other agencies are also critical to the modeling effort. The USGS, in partnership with many state, local, and tribal entities, provides a backbone of both surface and underground water information, all of which can directly feed into national forecasting systems and improve model performance.

Scientific understanding of the water cycle and its interconnectedness with the Earth system underpins activities across many federal agencies. The U.S. Army Corps of Engineers, the Bureau of Reclamation, and the Department of Energy now use the latest in atmosphere-hydrology modeling to understand risks to water security. A critical emerging capability is continental-domain hydrologic modeling, where the latest hydrologic models can now produce realistic estimates of weather and climate risk over large geographical domains. These advances enable water agencies to develop coherent strategies to modernize and maintain their infrastructure investments.

Water security is clearly of global importance. We have recently seen how droughts are the catalyst for migration and regional instability, motivating the need for new understanding of water security in different corners of the globe. The recent community efforts in Earth System modeling capabilities have resulted in incredible advances in global hydrologic modeling. In one recent example, NCAR's Community Earth System Model was used to simulate the limited water availability in Iran. There is currently a strong collaboration between NCAR and the university community (led by the Consortium for the Advancement of Hydrologic Science Inc.) to substantially advance global hydrologic modeling capabilities. The effort focuses on integrating scientific understanding and modeling capacity developed by different groups working around the world in order to improve simulations of hydrology worldwide.

Although the water enterprise has a long history of integrating advances in science, technology and engineering for the betterment and protection of society, it is currently undergoing a major transformation through leveraging these new datasets, models, and computational resources. This transformation is exciting and will, with continued investment, lead to major gains in capability that benefit the United States on many fronts. I truly believe these are gains that the public will be able to readily grasp. At present, we have a new modeling approach that shows enormous potential in forecasting events that affect life and property.

Looking over the horizon, there are capabilities we will want to obtain in a future state that will better enhance economic and national security. Needless to say, given the scarcity of water, it is incumbent for us to move towards this future state as rapidly as possible.

2. **What is the desired future state of the nation's water enterprise?**

Better understanding of water requires an appreciation by society of its intrinsic value and its inter-connected nature to other events. Thus, an Earth system approach that encompasses more than just water should shape our thinking. I believe that sub-seasonal (2 weeks) to seasonal (3 months) forecasts are the sweet-spot the scientific community should aim to improve to build a generation of operational water products that empower our society to better manage water resources. Such forecasts, however, are only possible by considering the entire earth system as whole as Sub-seasonal to Seasonal (S2S) forecasts are driven by global factors such as the pattern of sea surface temperature in the Pacific and Atlantic. These sea surface patterns, in turn, drive tropical thunderstorms that can drive weather patterns over the U.S. causing floods and drought. While the research community has established this connection, the creation of a reliable S2S forecasting system based on this knowledge of ocean-atmosphere coupling is in its infancy and requires a significant research investment.

In times of drought, particularly in the Western US, water resource managers rely heavily on the ability to predict conditions at seasonal time scales – that is, looking three months ahead, or even further – as they need to know the likely snowmelt runoff volume that can be expected to refill reservoirs in the spring. These managers need to anticipate their long-term ability to provide water for agriculture, hydropower, the environment, and the needs of the populations of major cities. Seasonal streamflow forecasts are likely the most economically valuable water prediction in the western US, which the allocation and management of billions of dollars' worth of water depend. Recently, sub-seasonal forecasting for shorter periods, such as looking out 3 and 4 weeks ahead, or beyond this to the following month, has emerged as a major focus of scientific and operational research. Reservoir release decisions can be made based on sub-seasonal information that lead to water savings and better economic decision making about water supplies for a range of customers each year. NCAR is working with NOAA, USACE and the Bureau of Reclamation to find the best ways to harness sub-seasonal weather predictability and develop new information products for the water sector, including ensemble atmospheric and streamflow predictions at the watershed scale, looking ahead for weeks to seasons.

Ensemble methods are a computationally intensive strategy for getting a handle on uncertainties in simulating weather, climate and water. Because all of our models and datasets are not perfect, scientists and forecaster work to quantify forecast errors by running them many times rather than just once, each time with slight variations that represent possible errors in our data and models. This gives a forecaster a basis for telling a decision-maker the confidence of the forecast – including the risk that it may be wrong, or that it may exceed a critical threshold, such as a levee elevation. Along with improving model resolutions, ensemble methods are a major strategy through which weather, climate, and water modeling agencies around the world are seeking to upgrade the value of the information that can be provided to decision makers. NCAR has developed real-time ensemble forecasting capabilities for a number of USACE and Reclamation reservoirs, some of which are now helping to guide the development of decision approaches for better management of water resources in the face of weather and climate variability that leads to extremes such as floods and droughts.

The state of hydrologic forecasting and the enterprise that supports it should progress in a similar fashion as the weather enterprise – particularly in the development of the private sector. Currently, private weather companies provide tailored, visualized, and broadcast weather forecasts for private individuals and businesses. This capability is built on the foundation of strong government and academic observations and modeling. New developments like the National Water Model and the success of National Integrated Drought Information System (NIDIS) help to show that we are now on the verge of rapid development of forecasting abilities for water and related issues. When these modeling and monitoring systems are as robust as weather observations and models, then we can expect a similar rapid development of the hydrologic services industry. Several industry sectors would seek such services – energy, agriculture, fishing, shipping, recreation, tourism, etc. Additionally, private citizens living near rivers and streams would pull up applications and websites to get real-time hydrologic information and forecasts at their specific locations of interest. As the hydrologic industry strengthens, more well-paying private sector job opportunities will manifest, companies will manage their operations more effectively and efficiently (meaning more profits for shareholders, more opportunities for export, and better prices for customers), and private citizens will mitigate risks to themselves and their property.

Efforts such as the National Water Model provide a compelling example of the future development of academic research into the coupled nature of hydrology and other earth systems. The NWM also provides useful insights into Operations-to-Research pipeline activities – given that researchers have long been intrigued by the scientific questions raised when a research model becomes operational. When an operational prediction model confronts observations on a 24/7 basis, the research community is presented with a wealth of information as why a forecast is successful and when it is not. Research fields are emerging from these early advances in a variety of areas such as improving streamflow forecasts relevant to managed water systems, coupled freshwater-atmosphere modeling, and coupled freshwater-ocean modeling. Interdisciplinary science between hydrology and soil science, land use, geography, and other fields could are also emerging as opportunities for new research and, eventually, applications.

3. What are the gaps that need to be addressed to get to the desired future state?

A host of improved water cycle observing capabilities are needed to accelerate our predictive capacity for hydrology. These measurement platforms include expanded space-borne and ground radar estimates of precipitation, expanded high altitude Unmanned Aerial Vehicle operations for very high resolution measurement of snowpack, glaciers and flood inundation in near real-time or as events, expanded groundwater observing and monitoring networks and significantly expanded streamflow measurement networks. Each of these measurements provide critical hydrologic characterization information that quantifies where water exists on and within the land. Utilizing our modern communications capabilities in combination with scientific innovation we can ingest these critical observations into a new generation of water forecasting tools thereby improving model forecast accuracy and timeliness.

The underlying hydrologic modeling systems themselves are already undergoing rapid transformation, moving from fairly simple place based models, to highly detailed descriptions of water moving on and through the Earth's landscape, including its interactions with human infrastructure. However, we are only just beginning to quantify and realize the potential we have for transforming this information into actionable forecasts. Significant work remains in linking together the different components of the Earth System in these models, in particular, the ways in which we quantify the impact humans have on hydrologic processes. Improved descriptions of groundwater systems, snowpack, precipitation forecasting, flood inundation and vegetation water use all remain as critical focus areas. The methods in which we ingest or 'assimilate' observational data into these models remains a key challenge for many forecast systems and, finally, our models must always have the capacity to evolve as changing landscape conditions and changing water management practices continue to drive real change in local and regional hydrologic cycles.

This new generation of computer models, like the National Water Model, are both data intensive and computationally intensive. They are designed to model the continuum of water from the highest peaks to the ocean shores and do so with ever increasing spatial fidelity. Like an early, grainy digital photograph which now has become crystal sharp and lifelike, these models continue to improve their spatial resolution which creates an enormous need for high performance computing. Also, like early digital cameras, the computers of today will simply not be adequate or acceptable in a few years' time to meet the challenge of predicting "water everywhere, all the time." These new computing systems will push the 'Petaflop' horizon and will also create new challenges and opportunities in data transmission to get critical information from centralized computing centers out to the public and to the private sector where its value can be realized. Already, data from platforms like the national radar network and, soon, the National Water Model will be ubiquitously available from cloud internet services. This creates enormous opportunities for private sector capital investment and revenue potential in addition to the basic goal of saving lives and property. In short, there is now and will continue to be a "flood" of hydrologic information and the public-private-academic water enterprise stands at the crossroads of meeting societies water needs and opportunities.

To create better Quantitative Precipitation Forecasts, more work needs to be done to better understand the interplay between soil moisture and water vapor, a better monitoring of the water vapor in the atmosphere in features such as atmospheric rivers, and better modelling at higher resolution scales that resolves convection in a more accurate manner. Research funding to pursue the scientific understanding will make us more aware of the earth's interconnected systems, instrumentation funding for remotely sensed and in situ observations will better monitor the earth's water, and investments in computing, data assimilation, and science will yield better models.

Understanding the atmosphere-ocean connection and modelling it well will enhance various water forecasting tools. An opportunity to leverage the advances made possible by the National Water Model is better coastal forecasting so that approaches to predicting inland flooding can be merged with coastal flooding. 50% of America's population lives near the coast of an ocean or the Great Lakes. The blending of tidal, storm surge, and coastal inundation forecasts is in its nascent stage – and work has barely begun to couple these traditionally coastal forecasting tools with the National Water Model. The nation's estuaries are a source of great economic strength, and their utility is best realized when we can predict and understand ebb and flow anomalies. Further investments in updating these traditional ocean models to combine with the National Water Model would significantly improve the protection of life and property at the coasts, and provide for the security of US Naval, Coast Guard, and Merchant Marine installations. Atmospheric Rivers (AR's) – narrow bands of water vapor carried from the south pacific to the west coast – also significantly impact water conditions, particularly in California. Over the past year, these intense rain events have reversed the California drought, but have also caused localized flooding. Investments in better AR modelling will enable water resource managers to anticipate intense precipitation and manage reservoirs accordingly. Finally, weather events that initiate over the oceans – hurricanes, deep low pressure systems, and severe storms – are hard to predict partly because of the relative lack of in situ data sources. Sustained ocean observations at various depths and coordinates will enhance our ability to initialize models and assimilate good data into these models so that we can better predict weather events. All of these forecasting tools – coastal forecasts, AR forecasts, and other weather forecasts – are significantly improved through improved and sustained ocean observations.

4. **What processes and policies are needed to identify roles and responsibilities? What, if any, are the next steps for Congress?**

Clearly, the water enterprise relies on all three partners of the weather enterprise, that being, the public sector, the private sector and academia. What can Congress do to leverage the best hydrologic forecast at the least cost? What is the role of the public sector relative to the private sector? The real issue is what do we want this enterprise to look like 20 years from now at the national and international level?

U.S. leadership in water forecasting technology is essential. Other nations are already aggressively utilizing their foreign aid programs to market and deploy their water observation and prediction technology. Once in place those systems can create strong partnerships for decades in terms of technology and IT exchange. By not actively pursuing these applications with flagship U.S. technologies the U.S. will miss out on a host of water related development business opportunities. Water is both essential and a potential problem everywhere in the world and the nations with strong relationships on water and water infrastructure development are nations that have a common cause for strategic policy development. How nations use and share their water resources are inextricably tied to their fundamental views on fairness, freedom and opportunity.

On the near-term horizon, we see the need for investment in several observation, modeling, and computing activities to move the enterprise to the next step. We need more 'operational' satellite capabilities, but at an affordable cost. Several of the satellites I mentioned earlier are research grade, and do not meet data latency standards that are needed. Operational satellites should include constellations of low-earth orbiting platforms for improved precipitation measurement, improved land surface characterization through hyperspectral imagery, improved topographic profiling through laser altimetry and/or lidar based methods. Radar gaps in the western U.S. must be filled or supplemented by improved satellite, ground based, or airborne radar precipitation platforms. The water enterprise needs sustained support for advancing the use of data assimilation into all of our modeling systems, particularly hydrologic models, and in improving the spatial fidelity of those models. While various Earth System component modeling systems are beginning to be loosely connected, significant work remains in terms of making sure those coupled processes are completed with the accuracy and spatial resolution required for high value environmental prediction information. Finally, we have recently developed a set of potential compute requirements for the next four years for The National Water Model which will be nearly 10-fold from today's usage.

For better applications, the enterprise will need improved development of 'web mapping services' for the effective and efficient display and querying of geospatial data including weather and water forecasts. These new tools will form the backbone of environmental situational awareness, which synthesize not only weather and water forecast information but also information on human infrastructure, transportation, recreation, emergency response and economy. They will serve as the next generation of decision support tools which, like today's proximity sensors in cars, will provide decision makers and the public alike, information on hazards *before* they occur.

The Subcommittee should also seek to better connect research activities across the government with operational requirements at NOAA. Programs that support active and strategic research to operations pathways have been challenged in years past with fits and starts and ad hoc application. The success of the research to operations achievement in the development of the National Water Model should be replicated often, so as to bring the best science into water forecasting operations effectively and efficiently. Working across agencies can be difficult as well, as varying agency missions sometimes snag collective advancement towards specific goals. Offices with the funding and the wherewithal to ensure that research finds its way into operations will ensure that these successes are more common. I would also add that such activities should not be limited to government operations; indeed, many publicly funded research successes should more easily find their way into private sector solutions and applications. Finally, this pathway should be a two-way street. When scientists are tasked with research problems that are generated by an operational requirement, academics can directly participate in ensuring that society benefits.

Finally, I ask the committee to consider the institution of a decadal survey for the entire weather enterprise that would include water. The boundaries of operations have been driven by the science into new forecast areas, and the weather, water and climate enterprise needs to consider doing what we have done in the area of earth observations, and start planning over ten year periods. Prior to taking on my new position at UCAR, I served as the co-chair of the National Academies' Decadal Survey for Earth Science and Applications from Space and the roadmap it will provide will prove critical to NOAA, NASA and USGS. Given the implications of water and weather, I urge this committee to consider enacting into law a decadal survey for this community. The Board on Atmospheric Science and Climate at the National Academies is currently addressing the issue and there is wide spread recognition that with limited resources our community must present Congress and the Administration with priorities. A decadal process will allow us to prioritize what has to be done and do so in recognition of the current fiscal realities.

April 4, 2017

Testimony
of
Mary M. Glackin
Senior VP for Science and Forecast Operations
The Weather Company, an IBM Business

I appreciate the opportunity to share perspectives on weather forecasting in general and water forecasting in particular. Water is essential for human life and prosperity. Yet it often manifests itself in ways that put life and property in jeopardy. If there is too much or too little water, or whether it rains too much-too quickly, or even just unexpectedly, it presents challenges to individuals and businesses alike. U.S. businesses lose more than $500 billion each year because of water and weather-related issues. Thus short term warnings and forecasts as well as sub-seasonal, seasonal, and decadal forecasts are essential for planning and mitigation efforts.

The Weather Company and our subsidiary brands, The Weather Channel (weather.com) and Weather Underground (wunderground.com), provide millions of people and businesses around the world with the best weather forecasts, content and data, connecting with them through television, web, mobile, and tablet screens, as well as through our outside publishing partners including Apple, Samsung, Google and Facebook.

Our services provide critical decision support to a wide variety of business sectors. For example, our precipitation forecasts are essential for the agricultural sector for a range of decisions including watering and fertilizer application, as well as estimates of crop yields. In addition, our daily, sub-seasonal and seasonal forecasts are used by thousands of clients globally in the energy, insurance and aviation sectors clients in a wide variety of applications.

The Weather Company is a global enterprise headquartered in Atlanta, GA with operations centers in Andover, Massachusetts; Madison, Wisconsin; San Francisco, California; and other centers in the U.S. and around the world.

Recognizing the importance of weather and climate to the U.S. and global economy and the leading role we play in helping consumers and businesses make smarter decisions, IBM purchased The Weather Company a little over a year ago.

Our company like other U.S. companies are able to compete globally in the marketplace by leveraging the foundational capabilities including data, models and basic research provided by NOAA, NASA and other federal agencies. We improve the forecast and tailor products to customers' needs, utilizing other environmental, business, and social data and our deep understanding of business sectors to enable effective decision making.

The public, private and research sectors have worked together effectively in many areas. I would highlight the implementation of GOES R which is on-going. Through NOAA efforts, the private sector has been engaged every step of the way and able to provide input to improve utilization of this tremendous national resources.

I'll highlight two areas where the private, public and research sectors should be working work together to keep people safe from water threats and improve decision making.

Improved presentation of hazardous water warnings

The Weather Company is an essential partner in the NWS's public safety mission. We deliver on our web and mobile properties and through our partners, the National Weather Service's warnings to consumers, unaltered, with attribution and in a timely fashion. However, it troubles us to see the public often confused about this critical lifesaving information. Due to message composition and labeling, they are sometimes unable to comprehend the threat to their property and lives.

While, we applaud NWS' efforts to revamp its watch and warning paradigm we are concerned those efforts will still fall short of what is needed and may be too slow to evolve relative to the rapid pace of social change and communications technology.

Through The Weather Channel and our media partners, we are in the business of communicating information to the public and have garnered vast expertise in this critically important service. How the public consumes information has changed dramatically and we are leading those changes. The private sector has capabilities in this area that are unmatched in the other sectors. For that reason, the private sector must be more fully embraced by the government in the warning process to accomplish the needed transformation in how we collectively contribute to the public safety mission.

For example, for floods, flash floods and storm surges, we should be routinely delivering personalized information that clearly shows where the individual consumer is with respect to the expected or ongoing flooded areas -- right on their mobile device. We should be showing what surrounding areas are expected to be impacted under water and by how much. We should be depicting safe escape routes and other specific action recommendations. The current paradigm of generic worded messages and even the static images fall well short of serving the public effectively.

Accelerate New Technologies to Operations

The second area is on the necessity to accelerate new technologies from research to operations. We applaud the joint effort of the National Centers for Atmospheric Research and NOAA that has advanced the community water modelling effort, known as WRF-Hydro now in operations at the NWS and providing critical stream and river forecasts. Beyond its utility to the general public, it also provides a valuable resource which we will utilize to serve business interests in sectors such as ground transportation. For example, rail companies need hyper local information about the potential of rail bed washouts to be proactively reroute trains, position repair crews and supplies.

A key area that should be addressed though is observations. In this case, I would point to the NASA's satellite Global Precipitation Mission, known as GPM. This mission has been extremely successful providing observations of global rainfall. However, because it is a NASA research mission the data isn't reported in a timely enough fashion to allow us to utilize the data for real time precipitation forecasting and alerting. Further, as a private company we are reluctant to invest in NASA missions because their long-term futures are uncertain.

The time and expense of satellite missions no longer allows us the luxury of having research missions and then follow on operational missions. This 1970s era paradigm of NASA flying research missions and then NOAA following years later with operational missions is no longer effective in meeting the nation's needs[1]. We should be selectively looking at research missions that have a potential high value return and take the steps to make them operational. The private sector could provide valuable input in selecting those missions. We believe GPM is clearly one.

Budget Choices

Finally, I'd like to comment on what I know will be difficult budget choices before the committee.

The ground- and space-based observations, modeling, and data archiving for weather, water, and climate provide foundational data sets for our value-added services. And, all major advances in weather and climate forecasting have been powered by federally sponsored research. These critical infrastructure programs underpin the nation's economic and national security and should be strengthened.

While it may be tempting to focus solely on water forecasting on times scales from minutes to months, the reality is local governments, businesses and many other public and private interests, seek to understand longer term weather and water trends as they make their critical infrastructure decisions. For sensitive businesses, an occasional drought may be acceptable but more frequent droughts would result in a different mitigation action. Availability of sufficient fresh water for both cities and agriculture is a critical national security issue, and having accurate long-term predictions of its supply is necessary for effective long-term planning and infrastructure.

[1] Because of necessity the Soumi NPP mission which was intended to be a research mission became an operational mission. This is the exception to the rule, not the norm though.

Federal dollars should focus on these foundational scientific capabilities which will enable the extremely capable private sector to better serve the nation.

Thank you.

Bryan Koon

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Director, Florida Division of Emergency Management

STATEMENT FOR THE RECORD

On behalf of the
National Emergency Management Association

Submitted to the Senate Appropriations Subcommittee on Commerce, Justice, and Science
United States Senate

"National Water Hazards & Vulnerabilities: Improved Forecasting for Response & Mitigation"

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Introduction

Thank you Chairman Shelby, Ranking Member Shaheen, and members of the Subcommittee for holding this hearing today. As you stated, I am the Director of the Florida Division of Emergency Management and I am testifying before you as the Past President of the National Emergency Management Association (NEMA), which represents the emergency management directors of the 50 states, territories, and District of Columbia. I am pleased to be here to address water hazards and the role of forecasting in response and mitigation efforts.

As we examine the threats from various water hazards, I want to be sure we recognize the great work being done across federal, state, and local governments, private sector, and community based organizations. I also believe we have tools at our disposal that remain underutilized and there are existing strategies we can leverage to promote the efficient use of taxpayer dollars before a disaster.

Threats from Floods and Other Water Hazards

The challenge of dealing with water hazards in the United States continues to evolve. Communities in my state prepare for and mitigate against changes in sea level that impact coastal cities that are critical to our economic health. Drought conditions in the Plains have wreaked havoc on agriculture and exacerbated wildfires over the last few years. Extreme variations in snowfall rates have caused California to shift from historic drought to overflowing reservoirs in less than a year. Historic flooding from a limited-warning, no-name event impacted millions of people and caused devastation in Louisiana outside of the 100-year flood plain. These hazards will continue to evolve and emergency managers, my peers across the country, understand that we play a critical role in communicating risk, mitigating against future disasters, and working with partners across government, advocacy organizations, and the private sector to build effective coalitions to ensure that we are prepared for these risks.

Flooding: Threats related to flooding were on full display last year, representative of the fact the flooding is this country’s most frequent and costliest disaster. According to MunichRE, 19 significant floods impacted the nation last year, the most in one single year since records began in 1980. There were 15 flood or climate-related disasters that exceeded $1 billion per event and in total, these events resulted in the loss of 138 lives and cost over $46 billion. In 2016, the expenses to the National Flood Insurance Program (NFIP) totaled $4 billion, exceeding the premium dollars it had collected to cover those claims. Significant events in Louisiana, Texas, West Virginia, and the numerous other states impacted by flooding and storm surge illustrate the need for attention to the enormous economic toll flooding takes on coastal and inland communities.

Although improved warning systems have reduced loss of life to floods during the past half-century, economic losses have continued to rise due to increased urbanization and coastal development.

The National Flood Insurance Program plays a significant role in highlighting credible data and encouraging the use of technology to improve mapping of flood risk zones across the country. The general purpose of the NFIP is both to offer primary flood insurance to properties with significant flood risk, and to reduce flood risk through the adoption of floodplain management standards. Generally, communities volunteer to participate in the NFIP in order to have access to flood insurance, and in return are required to adopt minimum standards. Better cooperation among FEMA, FIMA, NFIP, states, and locals to increase awareness of risks, urge adoption of standards that make structures insurable, and encourage risk reduction strategies that leverage critical data would help reduce the impact and cost of future floods.

It is absolutely critical that the NFIP be reauthorized by September 30th to ensure continuous coverage for existing policyholders and to provide stability for the housing market. While there are challenges related to affordability, underutilized or limiting policies, and the role of the private market, the program is essential to my state and many others across the country. The NFIP can be a force multiplier as we communicate risk and is one of the most local touchpoints the federal government has to move the needle on insured risk. The NFIP is not just an insurance program. It is a comprehensive flood risk management program. It helps communities make data-driven decisions and is essential for action that addresses risk and utilizes best-available data and science.

Two programs which could significantly reduce the cost of all disasters, not just flooding, but are underutilized are the Community Rating System of the NFIP, and the opportunity for states to earn 33% more post-disaster mitigation funding by having an enhanced mitigation plan approved by FEMA. Full participation in these programs by states would significantly improve their readiness by helping to put into practice well-researched and considered mitigation techniques. However, staffing and funding at the state and local level make participation in these programs difficult, and the reward is often too far removed from the risk to motivate those who choose to enact the program. These programs and others like them should be evaluated to determine how to improve the participation rates of eligible jurisdictions in order to maximize their impacts.

Storm Surge: Communicating the risks of storm surge is essential for coastal communities across the country. A majority of hurricane-related evacuation is based on storm surge forecasting and has undoubtedly saved lives. As the Country's coastal population and density continues to grow, the need to improve forecasting and messaging capability remains paramount.

Communicating vulnerability to the everyday American is a challenge. "Nearly three out of five [respondents to a survey on perceived vulnerability] have never heard or read an estimate of the potential storm surge risk in their area. A significant portion of the U.S. coastal population is not fully aware of their storm surge vulnerability. (Lazo and Morrow 2013)."

While we evacuate for storm surge, some are unaware that hurricane and tropical storms can also bring damaging freshwater flooding from heavy rainfall, which is something we do not necessarily evacuate people for during a hurricane event unless they are near a river. Freshwater flooding from hurricanes is a secondary hazard, but can be just as deadly and damaging as the coastal storm surge. Even if the storm is not a hurricane, tropical storms can be a major disaster (examples: Tropical Storm Fay 2008 and Tropical Storm Allison in 2001) due to the heavy rain threat.

This was also apparent in Hurricane Matthew in North Carolina. While high winds were not expected, heavy rain was anticipated and resulted in $1.5 billion in damage to over 100,000 homes. However, since people's attention was on the hurricane and where it was heading, communicating the high flood risk was a challenge and 28 people died as a result. Rainfall-induced flood deaths occur in more tropical cyclones than any other hazard.

In 2014, the National Hurricane Center introduced a new Potential Storm Surge Flooding Map to improve the public's awareness of the potential impacts for an approaching tropical cyclone. However, due to computer processing limits, this map cannot be released until a Hurricane Watch is issued. Additionally, once it begins to be issued for a storm, updates remain out of sync with other storm related products.

Data and the Utilization of Technology to Communicate Risk
As in almost every other profession or discipline, emergency management practitioners rely on data and advances in technology to address the emerging threats to our communities.

Forecasting: When it comes to forecasting, we have made major strides over the years but continued improvements are necessary. Forecasting hurricane intensity is a major contributor to accurately predicting storm surge and the improvement in hurricane forecasting accuracy means fewer unnecessary evacuations, which saves lives and allows us to focus assets where they are most needed.

There has been modest improvement in this area over the past 20 years and only recently has shown some improvement due to the efforts made by the Hurricane Forecast Improvement Project (HFIP). However, the HFIP budget was cut by more than half in 2015. Improvements to forecasts depend on how fast research can be made useful to forecasters who analyze this information and push data and information essential to public communication and informed decision making by emergency responders. This budget (Joint Hurricane Testbed) has also been cut in half.

There is no doubt that weather modeling had reduced forecast errors and expanded forecast capabilities, but we need to continue this work. The potential for massive loss of life due to storm surge persists and provides a call to action for the nation's hurricane research and operations program to develop and implement new storm surge mitigation strategies.

Acquiring and retaining IT staff and the infrastructure needed to develop new products or make forecast more user friendly to emergency managers and the public is essential to continue making advances in information gathering and dissemination. Weather modeling needs to be on par with European agencies. This will help with lead times for emergency managers and the public 4-5 days versus the 48 hours they are given now (or even less in some cases).

Mapping: It is important to have quality maps coming from a detailed study with a desire to consistently provide better data, more detail, and enhanced information. FEMA risk maps must be updated more frequently so critical stakeholders can make decisions about land use, shelter locations, and evacuation routes and to smooth out insurance premium rate increases.

Access to the best data would allow communities to determine the highest risk areas and help them to mitigate the best way possible. It is important to note, especially as the President's skinny budget proposes changes to funding FEMA's RiskMAP, that while mapping is done in part to support the NFIP, maps are used for many other purposes. FEMA (with engagement of NOAA and USGS and stakeholders) should look at how such maps are being used and identify opportunities to enhance mapping to meet multiple needs.

In addition to improving currently existing federal efforts, FEMA and others should recognize outstanding efforts done by state and local entities and encourage their adoption nationwide. Following Hurricane Floyd in 1999, North Carolina established and has funded a statewide Floodplain Mapping Program. This program, recognized by FEMA as a Cooperating Technical Partner, has to date:

- Acquired two rounds of statewide LiDAR derived topographic data;
- Studied over 31,000 stream and coastal miles with Base Flood Elevations established or updated for all studied streams;
- Facilitated the adoption of the maps by all 100 counties in North Carolina and the Eastern Band of the Cherokee Indian Nation;
- Transitioned completely away from costly cartographic mapping to an efficient, dynamic database derived display for all data and maps;
- Assessed flood damage impacts for all structures in North Carolina for five flood events;
- Established ability to calculate and provide flood insurance premium rates for all structures in North Carolina;
- Established a real-time flood warning system that calculates real-time data to structures; and,
- Established Flood Risk Information System (FRIS) that houses and dynamically displays all flood data, models, maps and risk associated with flood. This system also houses and displays data for Virginia, Alabama and Florida which is highly efficient and a cost savings for each state.

Modeling: Modeling and communicating the total water hazard is a challenge and an opportunity. Modeling the impact of storm surge on rivers, combined with the streamflow and water runoff from rain is extremely difficult and often requires additional high-resolution data to accurately predict an area susceptible to inundation.

Inundation modeling along rivers is very sparse nationwide, and the availability of water-related forecast products are far more advanced over the eastern half of the country versus the West Coast. This results in a degradation of service for western residents and needs to be addressed with a level of standardization that comes from personnel and other developmental resources.

The Role of Mitigation in Reducing Threats and Hazards

When discussing any natural disaster, it is hard to argue against taking action before the catastrophe occurs, rather than waiting until costly damage has affected homes, businesses, and critical infrastructure. Over the years, Congress has authorized and appropriated significant financial and technical assistance to state and local government to pre-empt damages and distress resulting from a natural disaster such as flood, hurricane, tornado, or blizzard.

Mitigation activities can take many forms and the use of mitigation programs often differ by region. What does not differ, however, is the return on investment of these programs. There have been numerous studies over the years that show mitigation saving four dollars for every one dollar spent. These averages are conservative and many projects achieve much higher return on investment. FEMA's mitigation programs have been effective in reducing the property damage, personal and commercial hardship, as well as long-lasting monetary burdens after a disaster.

Unfortunately, funding decisions at the federal level do not match with goals of proactively addressing risk. From 2004-2013, FEMA spent $71.2 billion in Public Assistance and Individual Assistance to help communities recover from disasters, in addition to tens of billions of dollars spent by the Departments of Housing and Urban Development and Labor, the Federal Highway Administration, the Federal Transit Authority, the Small Business Administration, and the Army Corps of Engineers. In that same time period, only $5.2 billion was spent on Hazard Mitigation Grants (post-disaster) and another $800 million on Pre-Disaster Mitigation (PDM) to reduce the impact of future events. There can be no doubt that mitigation spending pales in comparison to money spent to clean up once the damage is done.

Mitigation activities should not be accomplished solely with federal funding. The goal is to reduce vulnerabilities and increase resilience for the future using all available resources and these efforts can be more sustainable when coupled with investments from state, local, and tribal government as well as private sector and individual stakeholders. Collaborative mitigation strategies encourage relationship building and facilitate innovative funding mechanisms that can support the type of long-term, community-driven investments that risk reduction efforts require. The efforts by the inter-agency Mitigation Framework Leadership Group (MiTFLG) to identify a disaster resilience investment strategy and the congressionally established National Institute of Building Sciences to develop holistic approaches to hazard mitigation incentivization are important initiatives in this realm.

Hazard mitigation is a demonstrably cost-effective effort with a documented return on investment. Providing incentives and empowering communities, business owners, and government officials at all levels to mitigate is a compelling narrative that shifts the focus from federal to community priorities that reflect evolving risk on the ground.

In order to encourage investment and promote the goals of mitigation activities on the state and local level, specific recommendations should be considered.

- *Better Coordination Between Federal Agencies with Roles in Mitigation*
  No single agency or level of government, sector of business, or individual community can achieve successful mitigation on its own. While a few professional disciplines identify hazard mitigation as a core mission area, the activities of these disciplines alone are not nearly enough to achieve effective investments and policies that protect against the hazards that lead to future disasters. One potential opportunity for a reinvention and reinvigoration of mitigation in built infrastructure could be in the President's much discussed infrastructure plan. If this plan is pursued, I strongly urge the Administration and Congress to incorporate principals of mitigation and resilience to ensure these investments can withstand extreme weather and support prepared communities as they weather disasters.

- *Connect Mitigation to Other Programs*
  Mitigation objectives for specific projects can differ among individuals, but if the same project supports multiple desired outcomes, success and achievement are increased. Opportunities where a mitigation action actually produces more important non-disaster related benefits should also be sought.

- *Rethink Federal Grant Structure*
  The current mitigation structure is centered on the federal government and is traditionally reactive, not proactive. Is this the way we want it to be? The federal government does not have to be convinced that mitigation is effective because it reduces the obligations of the federal government but has, over time, shown an unwillingness to invest anywhere close to as much in pre-disaster mitigation as it does in response and recovery costs after a disaster. States understand this, and try very hard to promote mitigation but lack the dollars to incentivize meaningful mitigation adoption on a scale that moves the needle on large-scale risk reduction. The funding that comes from the federal government must *supplement* not *supplant* the work already being done at the state and local level but federal funding is a critical incentive and catalyst for action on a mutually beneficial risk reduction strategy.

Working with the National Weather Service
As you know, the National Weather Service (NWS)—an agency within NOAA—plays a crucial role in providing weather forecasts and warning for the United States. As defined in its strategic plan, NWS is working towards a "Weather-Ready Nation." This vision has led to a number of initiatives such as developing specific practical pilot projects like mobile Emergency Response Specialists being embedded in Emergency Operations Center and in the field with first responders before, during, and after natural disasters. These initiatives have helped protect lives by informing people with better information so that they can make more knowledgeable decisions. This outlook ties in with that of the emergency management community.

The NWS works hand-in-hand with the emergency management community. In fact, a few years ago, the NWS released a study on their operations and structure. As part of the review, the National Academy of Public Administration and a study team conducted interviews with a range of internal and external stakeholders, including NEMA members and congressional staff. The commitment to work with the emergency management community helps ensure that disaster alert messages are disseminated and that the Nation is in an appropriate readiness posture. The importance of the National Weather Service's field offices cannot be understated. Offices like the National Hurricane Center (NHC), the Storm Prediction Center (SPC), and many others provide critical data to the states, who then use the information to inform their decisions and public messaging to help protect and save lives.

The NWS has seen great success in its forecasting and warning efforts for some hazards, such as hurricanes. There has been a significant reduction in weather-related deaths as a result of improved warnings. Not only have advancements in notification and warning systems saved lives, but they have also reduced the negative weather-related economic impact to communities.

In Florida, we deal with the six NWS offices that serve the state, and we also house the National Hurricane Center on the grounds of Florida International University. Our emergency managers at the state and local level are on a first-name basis with those local forecasters, and engage with them on a daily basis. During a tropical cyclone event in the state, we host twice-daily conference calls between the state, all of the counties, the NHC, and the impacted forecast offices to ensure that governmental officials responsible for decision-making are able to hear the latest information directly from those who are producing it. It is one of our most fundamental and important relationships, and it provides the foundation necessary for us to protect the lives and property of our citizens.

Engaging the Private Sector

The private sector obviously plays an important role in providing weather forecasts and alerts. A number of private weather companies exist, and in many cases they provide excellent services. These companies utilize National Weather Service information to meet the specific and diverse needs of their clientele. This could include helping farmers manage their crops, ensuring that retailers get the right merchandise mix to their stores on time, assessing the impact of an event so that electrical providers get power restoration crews on the scene as quickly as possible, or providing graphics and detailed local forecasts to radio and television stations and newspapers so the American public is aware of emerging conditions. This is a completely appropriate and symbiotic relationship between government and the private sector that meets the needs of everyone involved.

Academia also plays an important part in this process, training the meteorologist, climatologists, and other scientists necessary to do all of this work. They are also the developers of and home to many of the models that serve as the engine to this work. Continued attention must be paid to this resource to ensure that it continues to provide the work force necessary to accomplish our ambitious agenda.

Conclusion

Water-related threats and hazards will continue to be significant drivers for action at the state and local level. Emergency managers, community leaders, private sector stakeholders, and individuals must be equipped with data and empowered by incentives to achieve goals of preparedness and resilience. As technology evolves and successful coalitions emerge, governments must remain flexible and agile. The federal government can be a catalyst for action at all levels and their investments are critical for sustained and significant investments in the future. We must prioritize informed action with the support of high quality, quantifiable data before disaster occurs if we are to break the cycle of increasing disaster spending following an event.

I thank you for the opportunity to testify today and welcome any questions you may have.