SECOND NATIONAL

DROUGHT FORUM

JULY 30–31, 2019 | WASHINGTON, DC

NATIONAL INTEGRATED DROUGHT INFORMATION SYSTEM

Co-hosted by the National Integrated Drought Information System (NIDIS) and the National Drought Resilience Partnership (NDRP)

#DROUGHTFORUM

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Document drafted and prepared by the National Integrated Drought Information System (www.drought.gov), with support from Thrivner (www.thrivner.com). Special thanks to Veva Deheza, Elizabeth Ossowski, Adam Lang, Elizabeth Weight, and Fiona Martin for editing and writing.

On the cover: An artist contrasts drought with a green landscape. Credit: by-studio

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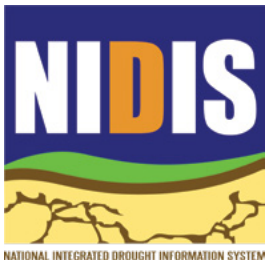

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Vine sprout in dry ground. Credit: Chepko Danil Vitalevich

INTRODUCTION

On July 30–31, 2019, the second National Drought Forum was held at the U.S. Institute of Peace in Washington, D.C. The Forum was planned and coordinated by the National Integrated Drought Information System (NIDIS), a part of the National Oceanic and Atmospheric Administration (NOAA), along with the National Drought Resilience Partnership (NDRP).

The first National Drought Forum was held by NIDIS in December 2012, in large part to take stock of the 2012 drought across much of the Great Plains. Forum participants assessed the status of national drought readiness, discussed the extent of the 2012 drought impacts and response, and helped provide new information and guidance for coordination to improve the nation's preparedness to drought. Since 2012, several major drought events have impacted regions around the United States, including the multi-year California drought, the Northern Plains drought of 2017, a historic drought across New England and New York in 2016, and ongoing drought conditions throughout the Intermountain West region.

In the wake of the 2012 National Drought Forum and subsequent droughts, a number of programs and partnerships have launched or occurred to help predict and monitor drought, and to better understand and mitigate drought impacts, including:

- National Drought Resilience Partnership (2013)

- NIDIS Reauthorization (2014)
- Western Governors Association Drought Forum (2014)
- NOAA's National Water Center (2014)
- USDA Climate Hubs launched (2014)
- U.S. Drought Monitor in Farm Bill Reauthorization (2014)
- Bureau of Reclamation's Drought Response Program (2014)
- State of California Sustainable Groundwater Management Act (2014)
- State of Nevada Drought Forum (2015)
- Drought Risk Management Research Center (2015)
- NASA Western Water Application Office (2016)
- Four new NIDIS Drought Early Warning Systems: Midwest, Pacific Northwest, Nevada, and Northeast (2016, 2017)
- USGS Integrated Drought Science Plan (2017)
- Colorado River Drought Contingency Plan (2019)
- NIDIS Reauthorization (2019)
- American Water Works Association's M60 Drought Preparedness and Response Manual (2019)
- $700M in WIFIA drought resilience loans (2019)

These initiatives have resulted in earlier drought warning, better response and coordination across the Federal government and state governments, improved preparedness, and long-term drought resilience. Yet, challenges remain to address the persistent gaps and meet the needs of communities that continue to feel the impact of drought events. For example, significant advances in our observing, process understanding, and modeling capabilities are needed to improve drought prediction and information services.

The second National Drought Forum convened high-level drought experts and decision-makers from drought-impacted regions and economic sectors of the country, along with the private sector, research institutions, nonprofit organizations, global institutions, and officials across all levels of government to review progress made, and to discuss and determine new priority actions around emerging drought early warning and long-term resilience issues. A National Drought Forum Planning Committee was formed to assist in the Forum's steering and planning. In advance of the Forum, the Committee helped to shape the Forum's goals and objectives, agenda, identified speakers and participants, and helped prepare for the event.

The Forum's accomplishments included:

- Taking stock of lessons learned and progress towards U.S. drought readiness since the first Forum in 2012;
- Strengthening the state–federal relationship to realize greater collaboration and promote, where appropriate, cooperative partnerships with U.S. businesses to address drought across time scales and across levels of government and sectors;
- Featuring the Federal Water Officials and their 2019 priority actions for the National Drought Resilience Partnership
- Discussing new information and opportunities for coordination that help move the nation from a reactive to a proactive approach to drought risk management; and
- Producing a list of action items that could improve U.S. drought readiness and resilience.

Action Items were subsequently organized in several key areas:

- Advancing Applied Research and Process Understanding
- Strengthening Drought Monitoring and Observations
- Developing Decision Support Tools
- Quantifying Drought Impacts
- Prioritizing Integrated Water Resource Management
- Mitigating Drought through Ecosystem Restoration
- Financing Pre-Disaster Drought Mitigation
- Communicating and Coordinating Drought Information

The Priority Actions resulting from the National Drought Forum reflect the dialogue and discussion from Forum attendees, and do not represent official Administration policy or position, or an official policy or position of the individual organizations/agencies represented at the Forum. Attendees, along with the broad community of concerned drought stakeholders at large, all have a role to play in advancing these actions, including identifying potential means to fund such actions.

NOAA'S NATIONAL INTEGRATED DROUGHT INFORMATION SYSTEM

NIDIS logo

In the late 1990's, as severe droughts continued to occur without ample warning and without a central source of timely and accurate information, the National Drought Policy Act became law and established the National Drought Policy Commission. Their report, *Preparing for Drought in the 21st Century*, concluded that the U.S. would benefit from the development of a national policy with preparedness as its core. Furthermore, the report called for expanded partnerships among federal as well as nonfederal governments and private interests to develop tools and strategies for formulating and carrying out appropriate drought preparedness strategies. The commission concluded that, at the time, federal programs lacked a coordinated approach to the delivery of drought-related services. They called for more efficient, effective, and timely practices to be put in place.

These recommendations were the key behind Congress passing the National Integrated Drought Information System (NIDIS) Act. The NIDIS Act was authorized by Congress in 2006 (Public Law 109-430) and reauthorized in 2014 and 2019 with an interagency mandate to develop and provide a national drought early warning information system, by coordinating and integrating drought research, and building upon existing federal, tribal, state, and local partnerships. NIDIS is led by the National Oceanic and Atmospheric Administration (NOAA). NIDIS's mission is to improve the nation's capacity to proactively manage drought-related risks, by providing those affected with the best available information and resources to assess the potential for drought and to better prepare for, mitigate, and respond to the effects of drought.

THE NATIONAL DROUGHT RESILIENCE PARTNERSHIP

The National Drought Resilience Partnership (NDRP) was established in March 2016 through a Presidential Memorandum as an interagency task force to enhance coordination of Federal drought resilience policies, to work collaboratively to support state, tribal, local, and private-sector approaches to managing drought risks and impacts, and to reduce the impact of drought events on livelihoods and the economy. In addition to meeting the expressed goal of building toward a drought resilient Nation, activities of the NDRP also support related overarching Administration goals, including those expressed in the October 2018 *Presidential Memorandum on Promoting the Reliable Supply and Delivery of Water in the West*, where the importance of improving forecasts of water availability and the use of technology to increase that water availability are outlined.

This report does not reflect the views or policy positions of any federal agency. NDRP agencies, with the exception of NIDIS, NOAA, and the U.S. Department of Commerce, do not join in the release of this document and no statements contained herein should be attributed to any of those agencies.

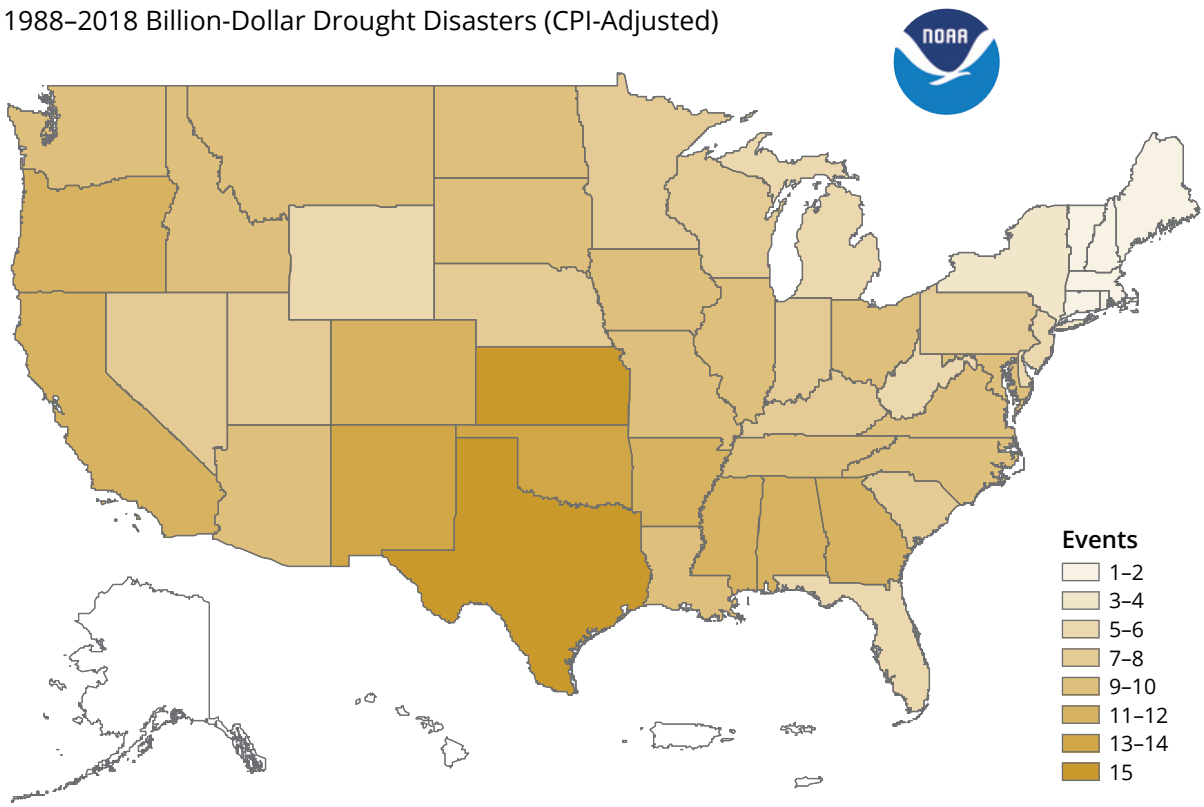
Washington DC at sunset. Credit: Dan Thornberg

Second National Drought Forum session on National Security and Drought, hosted by Sherri Goodman with the Wilson Center. Credit: NOAA NIDIS

FORUM GOALS & CONTEXT

The second National Drought Forum was opened by Forum Planning Committee Co-Chairs Bill Northey, USDA Undersecretary for Farm Production and Conservation; Tony Willardson, Executive Director, Western States Water Council; and Chuck Chaitovitz, Vice President, Environmental Affairs and Sustainability, U.S. Chamber of Commerce. They laid out the goals and objectives of the Forum, and reminded the participants of the opportunities presented by the Forum dialogue. While the 2012 Forum was held during a year of record drought, 2019 began as a year of record wetness rather than drought, making it an opportune time to convene and prepare to manage the next severe drought. The chairs acknowledged several priority areas that emerged out of pre-Forum planning discussions as timely, pressing topics for the country to address:

- We still do not have an effective way to measure the full economic impact of a drought event.
- New technologies and solutions developed by the private sector have expanded our capacity to build drought resilience, and we need to shape public–private partnerships around leveraging the capacity of these new resources.
- We need to improve our skill in drought forecasting to provide earlier warnings of drought.



From 1988–2018, there were 24 drought events with losses exceeding $1 billion (CPI-Adjusted) each across the United States. Adapted from: Billion-Dollar Weather and Climate Disasters (https://go.usa.gov/xVrHs).

- We need to improve drought observations and process understanding, as well as identify sources of predictability, and address systematic errors in global models in order to realize significant improvements in drought prediction.
- We need to manage our water supplies more effectively and identify new sources of local water to ensure sustained water availability, while also ensuring that our Nation's infrastructure and laws are more resilient and keep pace with this challenge.
- We need 21st-century decision-making tools for water solutions.
- We need to address the (national, water, and food) security implications of drought and extreme weather events.

THE ECONOMICS of drought events—from understanding the full scope of a drought's economic impact to learning about innovations within the private sector to build drought resilience—was a key area of interest for Forum stakeholders. While droughts may lack the immediate and dramatic visuals associated with events such as hurricanes and tornadoes, these recurrent extreme weather events often carry a huge price tag. Over the past three decades, droughts have been responsible for the second-largest number of billion-dollar weather disasters. With annual impacts nearing $9 billion in agriculture losses alone, droughts are a serious hazard with substantial socioeconomic risks for communities across the United States.

LINKING NATIONAL SECURITY AND DROUGHT

The United States depends on vital, up-to-the-minute drought information for preparedness, response, and recovery, not only to mitigate economic, social, ecological, and human health impacts, but also to ensure national security and the protection of our nation's critical infrastructure. Water scarcity, access to clean water, and extreme weather events like droughts and floods can disrupt the conditions upon which people live, threatening stability abroad and causing consequences for national security. A panel of national security and defense experts listed below opened the two-day Forum to frame our national drought issues within the context of global water scarcity challenges:

- Sherri Goodman, Senior Fellow with the Wilson Center, member of the U.S. Water Partnership National Executive Committee
- VADM Lee Gunn (U.S. Navy, Retired), Vice Chairman of CNA's Military Advisory Board
- Gerry Galloway, Jr. (U.S. Army, Retired), Research Professor, Glenn L. Martin Institute Professor of Engineering, University of Maryland

Half of the world's population will face water shortages by 2035.[1] Around the globe, vulnerable communities can grow increasingly unstable in periods of drought made worse by poor water management and storage practices. Climate change is a threat multiplier for global instability, exacerbating existing stressors such as poverty, poor governance, and social tension that can prime an area for violence, migration, and terrorism. Many experts agree that the five successive years of drought faced in Syria from 2006 to 2011 caused agricultural workers and their families to move from the countryside into already crowded cities, placing increased stress on resources and services, and playing a large role in the start of the ongoing Syrian civil war. Countries important to U.S. strategic interests are experiencing drought and heightened tensions over scarce resources. Our military is paying close attention to climate and particularly water scarcity issues, because of the need to be ready to provide humanitarian relief as well as military services.

In the United States, domestic drought can affect the readiness of our military, from water availability and water quality challenges, to drought-related wildfires and excessive heat issues that impact military exercises. Military installations domestically and internationally are at risk from multiple vulnerabilities due to extreme weather events such as floods and droughts, and military bases around the country must now identify the key issues it faces in order to plan and prepare for such eventualities.

However, the national security apparatus is about more than military might. Economics is an important pillar of national security, and disturbances in key sectors such as energy and food production due to low water supplies, whether around the corner or around the globe, can have ripple effects throughout economies, affecting social cohesion, and potentially leading to civil strife.

> **"We don't have a world water crisis, we have a world water management crisis."**
>
> **BRIGADIER GENERAL GERALD GALLOWAY (USA, RET.)**

Undertaking the following actions can address drought and national security concerns, and support the military as it continues to plan for a more secure future:

- Improve our predictive capabilities for security risks related to disruptive water events in order to improve planning;
- Include groundwater availability in planning around drought and water scarcity in the United States; and
- Study resilient communities in order to learn from their methods of planning and preparing, and invest in resilience measures in vulnerable communities and on military bases facing drought.

[1] United States. National Intelligence Council. Global Trends Paradox Of Progress. 2017. *https://www.dni.gov/files/documents/nic/GT-Full-Report.pdf*

Aerial view of a combine harvester working in a wheatfield. Credit: LALS Stock

An American variety of long-grain rice. Credit: USDA Agricultural Research Service.

FORUM SUMMARY

National Drought Forum participants came from different parts of the country and represented diverse levels of government and sectors of the economy, but all were united by their commitment to addressing drought and mitigating its impacts on communities, now and into the future. Their vision for how the nation, states, counties, and organizations can become more resilient to drought was captured through pre-event assignments, event panels and discussions, facilitated breakouts, plenaries, and comment cards and boards. A summary of that input is provided below.

DROUGHT CONDITIONS: PAST, PRESENT, AND FORECASTED

The following experts discussed progress since the first National Drought Forum in 2012; looked back at the 2012 Great Plains Drought and the 2011–2017 California Drought; considered the role of intergovernmental coordination in drought response; and reviewed current drought conditions:

- Peter Grevatt, Chief Executive Officer, The Water Research Foundation
- The Honorable Mike Bawden, Mayor, Riverdale, Iowa, and Mississippi River Cities and Towns Initiative
- The Honorable Daron McDaniel, Supervisor, District 3, County of Merced, California, and First Vice Chair, Rural County Representatives of California
- Brad Rippey, Meteorologist, U.S. Department of Agriculture and co-author, U.S. Drought Monitor
- David Dewitt, Director, Climate Prediction Center, National Oceanic and Atmospheric Administration

In 2012, nearly two thirds of the country experienced some degree of drought. From 2013–2019, many regions and states also experienced significant drought events including the Northern Plains, the Southwest, the Northeast, California, Hawaii, and Alaska.

While the skill for predicting the end or continuation of drought is high (approximately 78 percent), the skill for predicting the onset of drought is limited.[2] This forecasting challenge is largely due to scientific limitations in accurately predicting precipitation beyond the two-week timeframe. To do so, the experts at the Forum noted that a significant investment in applied research focused on identifying the key biases in global models that are stalling improvements in precipitation prediction at subseasonal to seasonal (S2S) timescales is needed. To address these biases, there is the need to focus future observations and research activities on process level understanding to improve physical parameterizations in global models.

These droughts come with direct and indirect costs that impact lives, livelihoods, and ecosystems. For instance, in San Joaquin, California, which ranks seventh in the world for total agriculture production, farmers were forced to fallow land, which resulted in agricultural losses of $3.3 billion.[3] Similarly, the 2012 drought along the Mississippi River shut down barge traffic on at least three occasions, costing $300 million each day that river closed, according to the Port of New Orleans. These are examples of the direct impacts of drought; the indirect impacts are much more difficult to quantify. For instance, human health during the California drought was impacted by increasing infections of Valley Fever and West Nile Virus.[4] Additionally, many areas in California turned to groundwater as an alternative

[2] Hao, Z., Singh, V. P., and Xia, Y. (2018). Seasonal drought prediction: Advances,challenges, and future prospects.Reviews of Geophysics,56, 108–141. *https://doi.org/10.1002/2016RG000549*

[3] Zelenzy, Lynnette and Xuanning Fu. "Impact of the Drought in the San Joaquin Valley of California," July 2015. *http://www.fresnostate.edu/academics/drought/documents/Fresno%20State_Drought%20Study_Minus%20Executive%20Summary_FINAL.pdf*

[4] Paull, Sara H, Daniel E. Horton, Moetasim Ashfaq, Deeksha Rastogi, Laura D. Kramer, Noah S. Diffenbaugh and A. Marm Kilpatrick. "Drought and immunity determine the intensity of West Nile virus epidemics and climate change impacts." Proceedings. Biological sciences 284, no. 1848 (2017). *doi.org/10.1098/rspb.2016.2078*

water source during the drought with some aquifers being overdrafted, resulting in ground subsidence of as much as three feet in some areas, which caused significant impacts to infrastructure.

The Forum experts also requested that the cascading effects that severe climate events such as droughts and floods have on the economy and ecology be identified and measured through the entire value chain. To that end, NIDIS is partnering with the Mississippi River Cities and Towns Initiative (MRCTI), NOAA's Office of the Chief Economist, and the U.S. Department of Agriculture's (USDA) Office of the Chief Economist, to produce the first study to quantify drought's impacts to the trade footprint of the Mississippi River Corridor.

To help make other communities more resilient to drought, the Forum experts noted that local and federal agencies must use the response and recovery time following a drought to prepare for the next drought, which requires:

- Including the thousands of civil servants and individuals affected by extreme climate events in drought, fire, and flood planning efforts;
- Including forest management in these plans to reduce the risk of wildfire and to act as a snowpack water reservoir;
- Creating an integrated portfolio of programs and services that facilitate prevention, resilience, and mitigation as well as recovery;
- Incorporating an "all-water approach," managing surface water and groundwater as a whole system, into drought management decisions;
- Reversing aquifer depletion;
- Developing partnership opportunities between local, regional, state, tribal, and federal agencies that will be a force multiplier for collaboration when and where needed;
- Developing a better way for current federal agencies and programs to leverage and align their investments in recovery efforts from severe climate events to make them more resilient;
- Clarifying and streamlining how states, counties, communities, and the private sector can partner with FEMA and other federal agencies like USDA and Environmental Protection Agency (EPA).

DROUGHT DECISIONS AROUND THE NEW (AB)NORMAL: WATER SCARCITY, DROUGHT, AND ARIDITY

When examining drought, it is important to also understand aridity and the difference between the two. Aridity is defined, in meteorology and climatology, as "the degree to which a climate lacks effective, life-promoting moisture" (*Glossary of Meteorology, American Meteorological Society*). Aridity is permanent, while drought is temporary.

The implications of water management decision-making under increasingly arid conditions involve: (1) the role of existing water infrastructure in arid environments and investment-based opportunities of infrastructure for drier conditions; (2) opportunities consistent with the *Presidential Memorandum on Promoting the Reliable Supply and Delivery of Water in the West*; (3) the use of natural water storage as an effective response to a more arid future; (4) the U.S. Farm Bill and opportunities for Western irrigated agriculture; and (5) associated research priorities, which were addressed by:

- Roger Pulwarty, Senior Scientist, National Oceanic and Atmospheric Administration
- Upmanu Lall, Alan and Carol Silberstein Professor of Engineering; Chair, Department of Earth and Environmental Engineering; and Director, Columbia Water Center
- David Raff, Science Advisor, Bureau of Reclamation
- Laura Ziemer, Senior Council and Water Policy Advisor, Trout Unlimited
- Astor Boozer, Regional Conservationist, Natural Resources Conservation Service, West U.S. Department of Agriculture

Increasingly arid conditions in the American Southwest produce threats that have implications for the storage of both surface water and groundwater. However, the experts at the Forum noted that there is very little understanding of the total "stock" of water available to communities even though it is a key piece that drives many of the economic engines of the country (e.g., energy, agriculture, transportation). Water is neither treated nor managed like

other assets (e.g., facilities, crops, ships). In order to proactively determine how groundwater assets and surface water supply systems should be managed under arid conditions, communities, in collaboration with public (e.g., Bureau of Reclamation) and private (e.g., private dam operators) partners, should first answer:

- What is your stock of water?
- How is it used by the critical economic sectors in your area?
- Are there ways to decrease use in addition to seeking ways to increase supply?
- What is the strategy when/if the water supplies are depleted?

The goal of such a management plan is to achieve healthy ground–surface water interactions that can provide a more resilient landscape that help to blunt the impacts of drought, flood, and wildfire events. To support this goal, planning and investments for infrastructure construction and management must be on the same scale for groundwater as they are for surface water. This is part of the reason that natural water storage—and more broadly, ecosystem restoration—is increasingly considered a complementary solution to effectively manage water resources, and one that can have multiple collateral benefits. An expert highlighted that natural water storage can act to slow the movement of surface water, allowing it to replenish water storage and to be absorbed back into features such as floodplains, aquifers, and riparian wetlands. Strategies for ecosystem restoration that have increased water storage include constructing beaver dam analogues, impoundment structures, and water channel realignments, although additional research is needed to quantify and compare the recovery benefits of this type of storage.

Along with infrastructure improvements, strategies for mitigating the impacts of drought require improving management of resources. As the largest wholesaler of water and the second largest supplier of hydroelectric power,[5] the Bureau of Reclamation reports that it is focused on managing the risk of water delivery in increasingly arid conditions. The key is to collaboratively plan with other water and power delivery entities and to allow the federal government to take on some of the risk that local entities do not have the resources to address on their own. For instance, the Colorado River Compact was originally agreed to in 1922, a time when the signatories could not foresee the reservoir system being at half capacity[6] after nineteen years of drought. In coordination with the Bureau of Reclamation, the seven Colorado River Basin states recently signed a consensus-based Drought Contingency Plan for the Upper and Lower Colorado River basins. The agreement is designed to reduce risks and protect the single most important water resource in the Western U.S. through voluntary reductions and other measures.[7]

As users of water from the Colorado River Basin, farmers, ranchers and forest landowners in the West are also partnering with USDA's Natural Resources Conservation Service (NRCS) to address their resource concerns, such as water quality and quantity. The NRCS sees an opportunity to connect water suppliers (e.g., Bureau of Reclamation) with heavy water users (e.g., farmers) to help increase the success of various projects and programs. For instance, through the WaterSMART Initiative, NRCS can provide technical and financial assistance to eligible producers to install water use efficiency conservation practices on irrigated lands.[8]

The panelists noted several opportunities and considerations for action to incorporate aridity into research and planning, including:

- Additional research to quantify the benefits of natural water storage, in terms of aquifer storage and recharge benefits towards the restoration of natural ecosystem services
- Opportunities for greater drought risk management through the development of insurance instruments that consider groundwater and surface water in a unified context

[5] U.S. Bureau of Reclamation, "About Us: Fact Sheet," Updated January 31, 2019. *https://www.usbr.gov/main/about/fact.html*

[6] United States Bureau of Reclamation. "Colorado River Basin Drought Contingency Plans." Last Updated June 5, 2019. *https://www.usbr.gov/dcp/*

[7] U.S. Bureau of Reclamation, "Interior and states sign historic drought agreements to protect Colorado River," Released May 20, 2019. *https://www.usbr.gov/newsroom/newsrelease/detail.cfm?RecordID=66103*

[8] United States Department of Agriculture. "Environmental Quality Incentives Program." Accessed October 6, 2019. *https://go.usa.gov/xV6dG*

- Additional support for multi-stakeholder dialogue around long-term water and drought planning, addressing short-term economic dislocation in order to achieve greater consensus around long-term solutions

KEYNOTE ADDRESS

Joaquin Esquivel, California Water Resources Control Board Chair

The recent drought fundamentally changed the State of California's water management. In 2015, then-Governor Jerry Brown ordered statewide mandatory water restrictions, directing cities and communities to reduce usage by 25%. In addition, many rural communities suffered from unclean drinking water due to groundwater pumping. As a result, the public began to understand the vulnerabilities they face in a changing climate.

California is taking advantage of the current, favorable water conditions to improve water management plans and prepare for future droughts. In April 2019, California Governor Newsom signed Executive N-10-19, directing his administration to develop a comprehensive strategy to build a climate-resilient water system, including an inventory and assessment of current water supplies and the health of waterways, future demands, and challenges. Moreover, California is investing $130 million over the next ten years for operations and maintenance for water management in the Sacramento–San Joaquin River Delta region. Since it is inevitable that future droughts will occur, questions remain, such as:

- How do you develop meaningful connections between government and citizens that leads to effective collaboration?
- How do you take small, successful projects and apply them at the watershed scale?
- How do you develop metrics to assess progress?
- How do you develop systems that gather and synthesize data for better decision making?
- How do you set drought resilience targets?
- What do our water systems need to look like in future scenarios at a 30–50-year time horizon?
- What are the economic consequences of water policy choices?
- How can communities impacted by water policy choices be supported?

ECONOMICS OF DROUGHT: UNDERSTANDING THE COST OF DROUGHT

Representatives from diverse economic sectors discussed the ways in which drought is impacting bottom lines and ecosystems throughout the country and how our nation can better measure those economic impacts:

- Tracy Rouleau, President, TBD Economics
- Colby Pellegrino, Director of Water Resources, Southern Nevada Water Authority
- Tom Iseman, Director, Freshwater Conservation Program, The Nature Conservancy
- Nathan Allen, Executive Director, WaterStart
- Jan Stoddard, Bureau Chief for Sales and Constituent Services, Montana Office of Tourism and Business Development

Like a game of dominoes, drought creates a ripple effect of impacts that cascade through the economy. The direct impacts are akin to the first row of dominoes and are the ones that gain the greatest attention—the dry corn stalks in a field, the cattle suffering from dehydration, the lake bed that is well below its normal limit. The next row of dominoes, such as food manufacturers, grain suppliers, and those involved in the tourism industry, begin to fall; however, those secondary and tertiary impacts are not fully understood or captured in most economic impact analyses. Additionally, the ecological and societal impacts of drought have yet to be widely identified and quantified because they are far-reaching and poorly-documented. Several examples clarify these points.

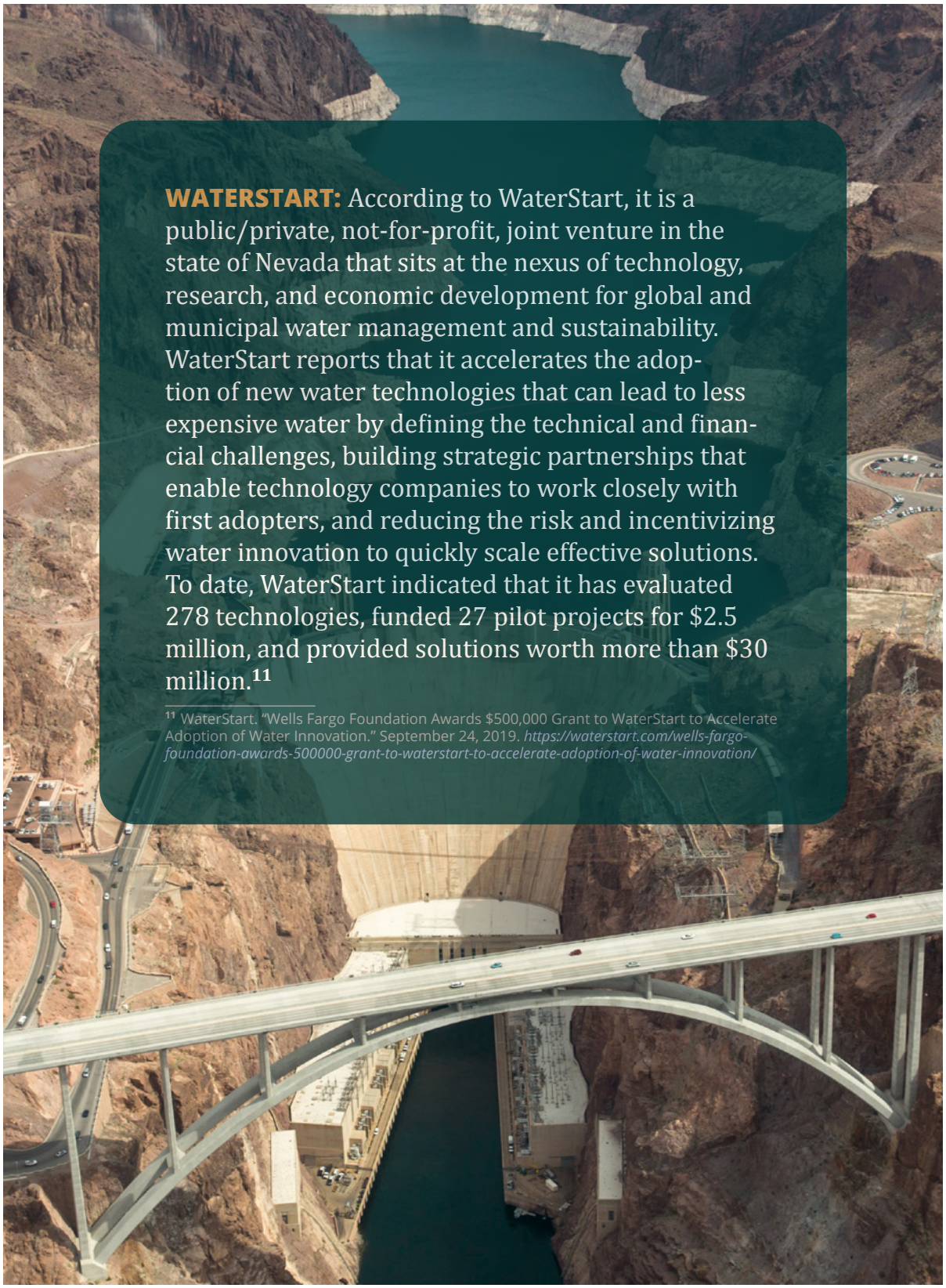
SOUTHERN NEVADA WATER AUTHORITY: In Nevada, 90% of the municipal water provided by the Southern Nevada Water Authority (SNWA) to the greater Las Vegas community comes from Lake Mead, a reservoir fed by the Colorado River.[9] The Colorado River Basin has suffered from drought conditions for the past nineteen years. As a result, water levels in Lake Mead have fallen more than 100 feet and are expected to continue to decline, impacting SNWA water treatment plants and infrastructure and threatening sensitive species.

The Bureau of Reclamation projects that Lake Mead faces a 35% risk of falling nearly another 100 feet to below 1,000 feet in 2026.[10] If this happens, SNWA will lose access to the two current intake structures; the Hoover Dam will generate less hydropower; and other communities that rely on the Colorado River (e.g., Arizona, California, and Mexico) will also face limited ability to meet water demands. In response to the severe drought conditions, SNWA spent over $1.4 billion revising infrastructure and operating plans, including updating existing, and constructing new, intake pipes and low-level pumping stations to better access quality water below the thermocline to avoid higher treatment costs. In addition to upgrading its infrastructure, SNWA is educating consumers to reduce use through initiatives such as converting their traditional lawns and gardens to water-efficient landscaping.

[9] Southern Nevada Water Authority. "Lake Mead." Accessed September 26, 2019. *https://www.snwa.com/water-quality/watershed/lake-mead.html*

[10] Colorado River District, "Meeting Demands in Drought: Southern Nevada's Example," Accessed September 25, 2019. *https://www.coloradoriverdistrict.org/wp-content/uploads/2018/09/2018-09-14-seminar-pellegrino-snwa-web.pdf*

Lake Mead at sunrise. Credit: fellswaymedia



WATERSTART: According to WaterStart, it is a public/private, not-for-profit, joint venture in the state of Nevada that sits at the nexus of technology, research, and economic development for global and municipal water management and sustainability. WaterStart reports that it accelerates the adoption of new water technologies that can lead to less expensive water by defining the technical and financial challenges, building strategic partnerships that enable technology companies to work closely with first adopters, and reducing the risk and incentivizing water innovation to quickly scale effective solutions. To date, WaterStart indicated that it has evaluated 278 technologies, funded 27 pilot projects for $2.5 million, and provided solutions worth more than $30 million.[11]

[11] WaterStart. "Wells Fargo Foundation Awards $500,000 Grant to WaterStart to Accelerate Adoption of Water Innovation." September 24, 2019. *https://waterstart.com/wells-fargo-foundation-awards-500000-grant-to-waterstart-to-accelerate-adoption-of-water-innovation/*

Aerial view of Hoover Dam and the Colorado River Bridge in Nevada and Arizona. Credit: veeterzy

STATE OF MONTANA: In the summer of 2017, Montana spent $390 million to respond to a devastating wildfire season. Additionally, the state estimates that 800,000 fewer tourists visited due to the fires with an associated loss of $240.5 million in visitor spending, or 12.4% loss for the quarter and a 6.8% loss in expected annual spending.[12] This created a ripple effect of impacts that are not fully understood or captured in the economic loss estimates, including lost wages, reduced consumer spending, lost business revenue, reduced quality of life, and health impacts from smoke inhalation. For the state of Montana, this led to the following lessons learned:

- Develop a proactive approach to communications that ensures interagency meetings are held on a regular basis and that all of the relevant agencies are represented, even those sometimes overlooked like tourism and recreation;
- Educate visitors and the public through advertising campaigns such as "Don't Fuel the Fire," which helps people understand that sharing overly dramatic images of fire and smoke on social media can have negative consequences on businesses and communities that rely on travel and tourism; and
- Provide visitors with consistent and reliable messaging on the areas open and activity options for them to enjoy.

[12] University of Montana, "The Montana Expression 2017: 2017's Costly FireSeason," December, 2017. *https://scholarworks.umt.edu/cgi/viewcontent.cgi?article=1364&context=itrr_pubs.*

Forest fires over Montana. Credit: William T. Smith

THE NATURE CONSERVANCY: The full cost of drought to ecosystems is largely unknown due to limited impact data. What is known is that drought resilient strategies designed to help humans can also support ecosystems. The question thus becomes: How can water supply disruptions to human communities be reduced in a manner that will also yield benefits to ecosystems?

The answer begins to emerge when the value of water is quantified and traded within an exchange market like other assets. When the value of water is revealed through such a market, those with rights to water supplies are motivated to conserve and sell their surplus. If constructed and regulated properly, such transactions can stimulate water savings, increase water availability, improve productivity and allocation efficiency, and improve accountability for water use.[13]

Water markets have been used in many regions, including Australia and the western U.S., to stimulate water conservation and enable the transfer of saved water to other users who need more. Water markets can be especially effective when implemented in areas where water is mainly consumed for irrigation. In particular, if just a small percentage of the water used on farms is saved, it can free up a great volume of water that can be used for other purposes, including the protection and restoration of natural ecosystems.

[13] Richter, B. 2016. Water Share: Using water markets and impact investment to drive sustainability. The Nature Conservancy: Washington, D.C. *https://www.nature.org/content/dam/tnc/nature/en/documents/WaterShareReport.pdf*

Colorado Aquaduct in Southern California. Credit: Danita Delimont

Dr. Neil Jacobs, Assistant Secretary of Commerce for Environmental Observation and Prediction, speaks at the second National Drought Forum. Credit: NOAA NIDIS

KEYNOTE ADDRESS

Dr. Neil Jacobs, Assistant Secretary of Commerce for Environmental Observation and Prediction, and performing the duties of Undersecretary of Commerce for Oceans and Atmosphere, NOAA

Every day, NOAA's network of satellites and Earth-based observation system collect some 20 terabytes of environmental data.[14] However, only a fraction of the data collected from satellites is put into NOAA's weather and climate models. Since developing a national drought early warning information system requires improved forecast skill, an easy win toward that goal would be determining how to tap into the data already collected but unused. NOAA and the Executive Office of the President are examining how to use artificial intelligence to capture and use more of this data over shorter time spans.

NOAA has also recognized the need to increase efficiency and decrease complexity in the development of its modeling architecture and code base. As a result, NOAA is moving to a simplified production suite of forecasting models known as the Unified Forecast System (UFS) that will include input from the academic, scientific, and engineering communities. Legislatively, the NIDIS Reauthorization Act of 2018[15] authorizes NOAA to establish the Earth Prediction Innovation Center (EPIC), which will provide the framework for how this group can collaborate using cloud-based, high-performance computing and crowdsourcing. The UFS is currently focused on coupling ocean and atmospheric models. Once complete, the UFS will look to couple with biological and ecological models, perhaps including the National Mesonet Program and the National Soil Moisture Network.

DROUGHT RISK ANALYSIS AND INVESTMENTS

The following private sector and government representatives discussed creative financing solutions for drought early warning and resilience, opportunities to minimize drought costs to cities and businesses, and insights into how industry metrics are changing in the context of drought:

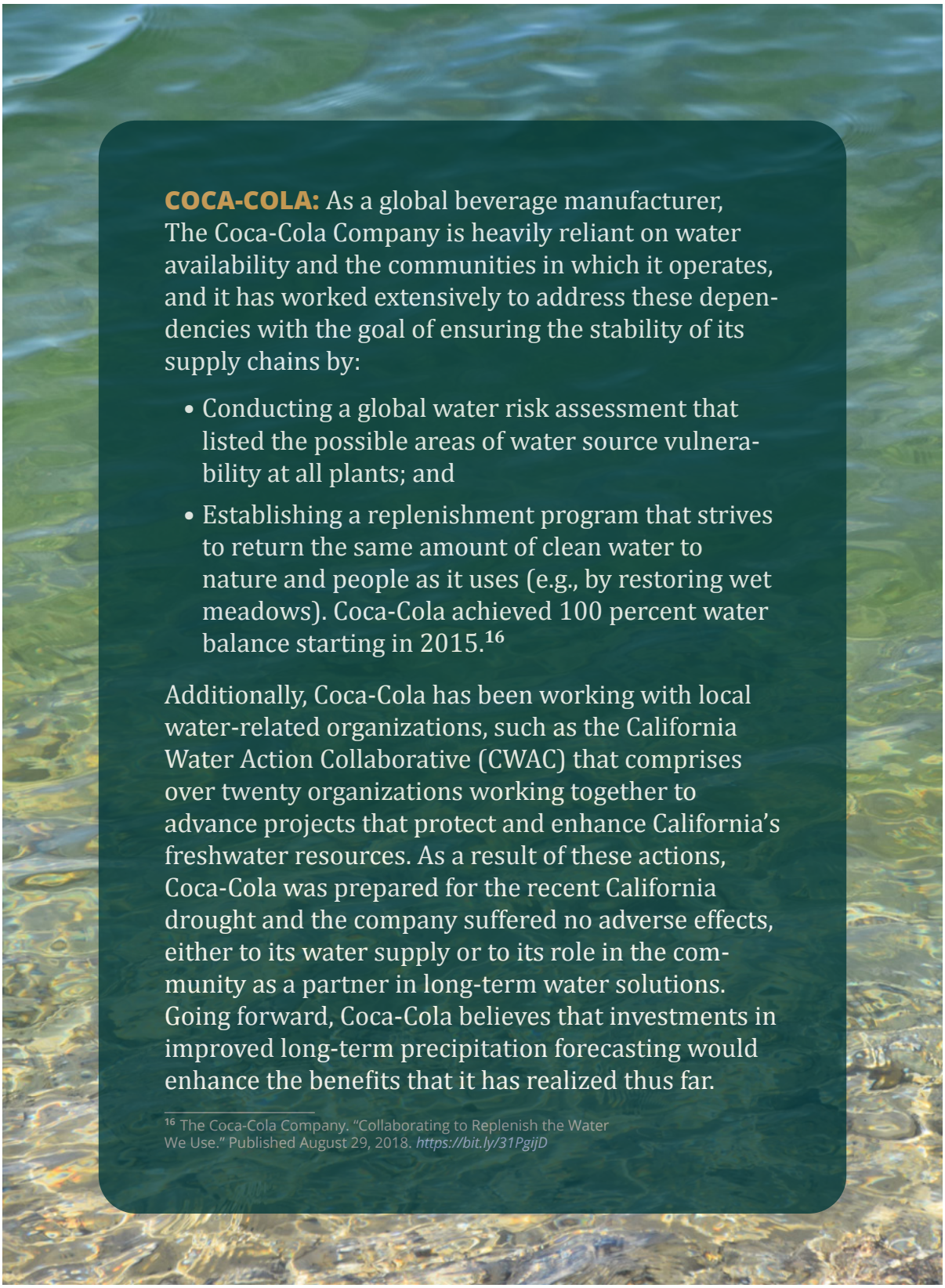
- Tracy Rouleau, President, TBD Economics
- Jon Radtke, Water Sustainability Program Manager, The Coca-Cola Company
- Warren Preston, Deputy Chief Economist, U.S. Department of Agriculture
- Jim Lochhead, CEO/Manager, Denver Water
- Greg Browder, Global Lead for Water Security, World Bank Group

As many private companies rely on an ample and reliable water supply to manufacture their goods or supply their services, they are increasingly asking to be included in drought management solutions. Corporations are partnering with local nongovernmental organizations (NGOs), companies, governments, and communities to help answer the following:

- How might new incentives be envisioned and existing financial incentives be leveraged to support drought resilience?
- How might drought risk drive innovation?

[14] NOAA National Environmental Satellite, Data, and Information Service, " Data Dive: Five NOAA Databases That Are Worth Exploring," Accessed September 25, 2019. *https://www.nesdis.noaa.gov/content/data-dive-five-noaa-databases-are-worth-exploring*

[15] United States. Congress. National Integrated Drought Information System Reauthorization Act of 2018. Public Law 115-423. Washington, D.C, 2018. *https://go.usa.gov/xVrB4*



COCA-COLA: As a global beverage manufacturer, The Coca-Cola Company is heavily reliant on water availability and the communities in which it operates, and it has worked extensively to address these dependencies with the goal of ensuring the stability of its supply chains by:

- Conducting a global water risk assessment that listed the possible areas of water source vulnerability at all plants; and
- Establishing a replenishment program that strives to return the same amount of clean water to nature and people as it uses (e.g., by restoring wet meadows). Coca-Cola achieved 100 percent water balance starting in 2015.[16]

Additionally, Coca-Cola has been working with local water-related organizations, such as the California Water Action Collaborative (CWAC) that comprises over twenty organizations working together to advance projects that protect and enhance California's freshwater resources. As a result of these actions, Coca-Cola was prepared for the recent California drought and the company suffered no adverse effects, either to its water supply or to its role in the community as a partner in long-term water solutions. Going forward, Coca-Cola believes that investments in improved long-term precipitation forecasting would enhance the benefits that it has realized thus far.

[16] The Coca-Cola Company. "Collaborating to Replenish the Water We Use." Published August 29, 2018. *https://bit.ly/31PgijD*

The blue waters of Lake Mead, the largest reservoir in the U.S. Credit: matteo_it

DENVER WATER: As the largest and oldest water utility in the state of Colorado, Denver Water continues to innovate as factors such as extreme events (e.g. drought), climate change, and increased water demand challenge the utility. Its service area covers more than 335 square miles, including the City and County of Denver and several suburban distributors (the total service area accounts for 25% of the state's population). A system of reservoirs networked by tunnels and canals provides water to more than a million people. Denver Water's water supply comes solely from surface water, with half of the supply subject to the Colorado River Compact. As a result, Denver Water has been heavily engaged in a long-term planning approach that combines an aggressive conservation plan and an innovative recycled water system with efforts to secure a new supply, such as turning old gravel pits into reservoirs.[17]

Denver Water's water management approach, while multifaceted, is a total watershed approach. It proactively manages the forest land that comprises much of its watershed, and considers this land part of its infrastructure. Investing in healthy forests is less expensive than dealing with the aftereffects of catastrophic wildfires (e.g., contamination of streams and reservoirs with sediment, nutrients, metals, and dissolved organic matter) and reduces costs for treating water. Denver Water is also investing in aquatic health in streams that feed its system and local economies. It is a partner with the communities that it serves, in watershed health and viability. With water supply being a major driver of economic growth in Colorado, Denver Water advocates for opportunities and solutions that meaningfully link sustainable water planning efforts with sustainable land use planning efforts.

Denver Water's financial and capital planning strategy has evolved from a traditional linear approach, with straight line population growth models, to one that looks at modularity. The utility's approach depends on long-term scenario planning to look at factors out of their control (e.g. growth and type of growth (dense/sprawl), climate change, dust on snow, extreme events, warmer water, drought). All of these factors contribute to water availability and quality. Denver Water's management strategies include expanded storage, and developing redundancy to reduce risk, increase efficiency, and increase re-use. Adopting these strategies gives Denver Water the operational readiness to respond to drought.

[17] Denver Water, "Water Supply Projects," Accessed September 25, 2019. *https://www.denverwater.org/your-water/water-supply-and-planning/long-range-planning/water-supply-projects*

Wildfires can potentially contaminate streams and reservoirs. High Park Fire in northern Colorado, June 2012.Credit: Ryan DeBerardinis

WORLD BANK GROUP: Drought threatens to trap generations of children in poverty.[18] Particularly in developing countries, droughts can result in intergenerational impacts due to the reduction in agriculture yield, income, consumption, and economic health. Moreover, long-term drought in childhood can impair physical and cognitive development. In short, drought can reduce wealth and trap individuals, families, and communities in an ongoing cycle of poverty.

The World Bank Group reports that it is a vital source of financial and technical assistance to developing countries around the world. It provides low-interest loans, zero–to–low-interest credits, and grants to developing countries. These financial instruments support a wide array of investments in such areas as health, infrastructure, agriculture, and environmental and natural resource management. The World Bank Group indicates that it works with countries suffering from drought to construct new water storage and to develop policies that control the demand for water.

[18] Damania, Richard, Sébastien Desbureaux, Marie Hyland, Asif Islam, Scott Moore, Aude-Sophie Rodella, Jason Russ, and Esha Zaveri. Uncharted Waters:The New Economics of Water Scarcity and Variability. Washington, DC: World Bank, 2017. doi:10.1596/978-1-4648-1179-1

Farm with silos. Credit: marchello74

USDA: The 2018 Farm Bill[19] calls on the U.S. Secretary of Agriculture to conduct a review of the data utilized by the U.S. Drought Monitor and to use those results to expand the collection of relevant data in states or geographic areas where coverage is currently lacking. Additionally, the Farm Bill requires the development of standards that allow, to the maximum extent practicable, for the integration of meteorological or climatological data into the United States Drought Monitor derived from: (1) in-situ soil moisture profile measuring devices; (2) citizen science, including data from the Cooperative Observer Program of the National Weather Service; and (3) other Federal agencies, State and local governments, and non-Federal entities.

[19] United States. Congress. Agriculture Improvement Act of 2018, P.L. 115-334. Washington, D.C., 2018. *https://go.usa.gov/xVrBB*

Close-up of millet, a cereal grain that does well warm climates and poor soils. Credit: Apichart Vathint

CONGRESSIONAL PERSPECTIVES

The following Congressional staffers discussed recently passed legislation, including the Farm Bill,[20] the NIDIS Reauthorization,[21] the Water Resources Development Act (WRDA),[22] and pending legislation that would address water infrastructure, soil moisture monitoring, and related issues.

- Nicole Carter, Specialist in Natural Resources Policy, Congressional Research Service.
- Rosalyn Brummette, Professional Staff, U.S. Senate Agriculture, Nutrition, and Forestry Committee
- Fern Gibbons, Deputy Policy Director, U.S. Senate Committee on Commerce, Science, and Transportation
- Camille Calimlim Touton, Professional Staff, U.S. House Committee on Transportation and Infrastructure

A common thread heard throughout this session was that input from diverse stakeholders is valued and requested as Congressional Committees take legislative action. Stakeholder feedback was useful in helping to craft recently passed drought-related legislation and will be needed again as new bills are considered. For example, the 2018 Farm Bill addressed the agricultural impacts of drought, in part, by:

- Calling for a review of the types of data currently utilized by the U.S. Drought Monitor, and to enhance the collection of data to improve its accuracy;
- Increasing funding for the Environmental Quality Incentives Program (EQIP) and the Conservation Reserve Enhancement Program (CREP), which support emerging conservation practices such as the use of cover crops that help to improve soil health, water quality, and wildlife habitats; and
- Improving the Regional Conservation Partnership Program (RCPP), including the ability to leverage public funding with private investment in order to stretch the pool of funding further, and increased funding for conservation programs that restore watersheds in order to protect sources of drinking water.

The 2017 Weather Act[23] called on NOAA to improve the skill of S2S forecasts in order for decision-makers to make informed decisions on those longer timescales. While seen as valuable and popular, the original authorization was set to sunset in two years. As a result, in 2019 Congress coupled the Weather Act with the NIDIS Reauthorization Act and asked NIDIS to begin considering S2S in its program. Congress also called on NIDIS to develop a strategy for a national coordinated soil moisture monitoring network.

The Water Resources Development Act (WRDA) is updated every two years. In 2018, WRDA included provisions on nature-based infrastructure, the potential for reusing dredge materials to replenish beaches or other infrastructure, and using data to enhance reservoir operations. In particular, it called on the U.S. Army Corps of Engineers (USACE) to report to Congress on the Forecast Informed Reservoir Operations (FIRO) pilot study being conducted in California's Russian River Basin. The goal of FIRO is to better prepare for droughts or floods by incorporating modern forecasting technology into decisions on when to retain and when to release water from reservoirs. The bill also authorized a new competitive drinking water resilience and sustainability grant program at $4 million for two years. WRDA 2020 may include options for expanding this project to other locations in the West.

DROUGHT COORDINATION: FEDERAL WATER OFFICIALS AND THE NATIONAL DROUGHT RESILIENCE PARTNERSHIP

Federal Water Officials and members of the National Drought Resilience Partnership (NDRP) offered

[20] United States Congress. Agriculture Improvement Act of 2018, P.L. 115-334. Washington, D.C., 2018. *https://go.usa.gov/xVrBB*

[21] United States Congress. National Integrated Drought Information System Reauthorization Act of 2018. Public Law 115-423. Washington, D.C, 2018. *https://go.usa.gov/xVrB4*

[22] United States Congress. America's Water Infrastructure Act of 2018, Public Law 115-270. Washington, D.C, 2018. *https://www.congress.gov/115/bills/s3021/BILLS-115s3021enr.pdf*

[23] United States Congress. Weather Research and Forecasting Innovation Act of 2017, P.L. 115-25, Washington, D.C., 2017. *https://go.usa.gov/xVrBK*

On August 24, 2017, local officials brief Secretary of Agriculture Sonny Perdue and Secretary of Interior Ryan Zinke, U.S. Senator Steve Daines, and U.S. Congressman Greg Gianforte, on the wildland fires in Montana on August 24, 2017. Credit: USDA, Lance Cheung

perspectives on coordination around drought planning, mitigation, and response, including issues and opportunities for integrated policies:

- Aubrey Bettencourt, Senior Advisor, Office of the Assistant Secretary for Water and Science, U.S. Department of the Interior
- Dave Ross, Assistant Administrator for the Office of Water, Environmental Protection Agency
- Bill Northey, Undersecretary of Farm Production and Conservation, U.S. Department of Agriculture
- Tim Petty, Assistant Secretary for Water and Science, U.S. Department of the Interior
- Daniel Simmons, Assistant Secretary, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy
- RDML Timothy Gallaudet (U.S. Navy, Retired), Assistant Secretary of Commerce for Oceans and Atmosphere, and Deputy Administrator, National Oceanic and Atmospheric Administration
- R.D. James, Assistant Secretary of the Army for Civil Works
- Brenda Burman, Commissioner, Bureau of Reclamation

Absent a department of water, the nation depends on more than 22 separate federal entities to coordinate and align on national-level water priorities. The NDRP, which was formally established in 2016 by Presidential Memorandum, is comprised of federal agencies that aim to leverage technical and financial federal resources, strengthen communication, and foster collaboration to productively support their efforts to build, protect, and sustain drought resilience capacity. *The Presidential Memorandum on Promoting the Reliable Supply and Delivery of Water in the West*[24] continues to foster collaboration within the Partnership.

The NDRP's 2019 Priority Actions Supporting Long-Term Drought Resilience[25] document provides background on the capabilities, ongoing activities, and opportunities of the NDRP. The document categorizes the NDRP's drought resilience efforts along the six drought resilience policy goals established in the NDRP Charter:

- **Goal 1: Data Collection and Integration.** Agencies shall share data and information related to drought, water use, and water availability, including data on snowpack, groundwater, stream flow, population health, and soil moisture with State, regional, tribal, and local officials to strengthen decision making to support more adaptive responses to drought and drought risk.
- **Goal 2: Communicating Drought Risk to Critical Infrastructure.** Agencies shall communicate with State, Territorial, regional, tribal, local, and critical infrastructure officials, targeted information about drought risks, including specific risks to critical infrastructure.
- **Goal 3: Drought Planning and Capacity Building.** Agencies shall assist State, Territorial, regional, tribal, and local officials in building local planning capacity for drought preparedness and resilience.

[24] United States Executive Office of the President. "Presidential Memorandum on Promoting the Reliable Supply and Delivery of Water in the West." Washington, D.C., 2018. *https://go.usa.gov/xVrBY*

[25] United States Department of Agriculture. "National Drought Resilience Partnership (NDRP) Priority Actions Supporting Long-Term Drought Resilience." Washington, D.C., 2019. *https://www.usda.gov/sites/default/files/documents/ndrp-priority-actions.pdf*

- **Goal 4: Coordination of Federal Drought Activity.** Agencies shall improve the coordination and integration of drought-related activities to enhance the collective benefits of Federal programs and investments.
- **Goal 5: Market-Based Approaches for Infrastructure and Efficiency.** Agencies shall support the advancement of innovative investment models and market-based approaches to increase resilience, flexibility, and efficiency of water use and water-supply systems.
- **Goal 6: Innovate Water Use, Efficiency and Technology.** Agencies shall support efforts to conserve and make efficient use of water by carrying out relevant research, innovation, and international engagements.

MONITORING AND FORECASTING OF DROUGHT

Over the past seven years, advances have been made in monitoring and forecasting of drought. However, many challenges remain, particularly in the areas of flash drought and how our nation connects drought observations, including decreases in soil moisture, with forecasting models. These experts identified priorities for strengthening existing capabilities in monitoring and forecasting, as well as applied research, to build our nation's drought early warning capacity:

- Doug Hilderbrand, Weather-Ready Nation Ambassador Lead, National Weather Service, National Oceanic and Atmospheric Administration
- Don Cline, Associate Director for Water Resources, U.S. Geological Survey
- Angela Bowman, Research Scientist, John Deere Intelligent Solutions Group
- Justin Huntington, Research Professor, Hydrology, Desert Research Institute
- Mark Svoboda, Director, National Drought Mitigation Center

While there is a robust flood warning system, there is not a comparable integrated prediction system for drought. The experts at the Forum identified priorities for a drought early warning system that could include:

- Mining historical data to develop maps of drought intensity risks to understand the statistical likelihood of drought (e.g., what is the likelihood of shifting into a wet or a dry period);
- Modernizing the nation's monitoring systems (e.g., satellite data, private sector observation data);
- Integrating access to data (i.e., gather all of the different data sets in one place so that they can be pulled into prediction systems);
- Integrating access to other relevant observing systems (e.g., USGS National Phenology Network because specific plants might be an indicator species of drought);
- Integrating national water modeling and prediction with drought indicators (i.e., hindcasts and forecasts, especially S2S and seasonal to decadal (S2D));
- Integrating multiple systems into decision support systems (e.g., integrating local-scale products into a national-scale system);
- Integrating best practices for warnings that produce an effective response;
- Establishing a reliable source of long-term funding for government-supported programs and tools.

Observations are the backbone of monitoring and forecasting tools. To support a drought early warning system, the experts at the Forum also identified observation priorities that could include:

- Resourcing and expanding the current observation network that provides longitudinal and latitudinal data;
- Developing the observations needed for precipitation forecasts at S2S timescales;
- Providing consistent data at granular levels to account for the differences in regions and localities;
- Leveraging collaborations between federal, state, and private partners to incorporate reliable data from all sectors; and
- Integrating artificial intelligence into modeling efforts to fully exploit those observations.

Additionally, experts at the Forum discussed examples of the tools currently in use, including the U.S. Drought Monitor (USDM)[26] for which the first map was released in 2000. Since that time, experts noted that it has become a valuable product for identifying and monitoring the location and intensity of current drought conditions. That, in turn, has assisted in drought planning.

John Deere provides farmers with information at the individual plant scale that can then be used to reduce water input while working to maximize crop yield. John Deere offers that its precision agriculture offers solutions in the face of the regional water scarcity challenges of its customers, and is fueled in part by open source Federal government data and research that companies can incorporate into operations and tools. The importance of using satellite derived data to provide insights on fields at parcel and individual plant scale was stressed, as was globally consistent data.

Additionally, Climate Engine was highlighted as a resource that is reported to leverage the power of the Google Earth Engine (GEE) platform, and as an example of public–private partnership in drought monitoring and forecasting. The resource represents a partnership between the Desert Research Institute, University of Idaho, and Google; and NIDIS has supported the tool's development since 2016. Climate Engine quickly processes and visualizes satellite earth observations and gridded weather data for environmental monitoring with the goal of improving early warning of drought, wildfire, and crop-failure risk. Through Google Earth Engine, data can be processed at various scales including parcel scales via a web browser without requiring archives of data to be downloaded. Through its use, scientists, researchers, and developers can detect land surface changes with granularity, map weather and climate trends, and quantify differences on the Earth's surface. For example, the Bureau of Land Management uses Climate Engine maps to compare vegetation greenness with precipitation levels, information vital for determining grazing permits.

In addition to the USDM, other related products discussed that could be developed include a U.S. snow drought monitor, a U.S. flash drought monitor, and/or a U.S. water monitor. This last idea in particular could be a complementary product to the USDM; one that provides information on both water supply (from too much to too little) and demand. It would potentially be able to integrate indicators such as the Standardized Precipitation–Evapotranspiration Index (SPEI), the Soil Climate Analysis Network (SCAN), and the Snow Telemetry (SNOTEL), NLDAS and National Water Models, as well as water levels associated with streamflow, reservoirs, and groundwater. This product would be able to tell the other part of the story that the U.S. Drought Monitor does not: the impacts of drought on water resources.

Almond trees in California. Credit: Melanie Hobson

[26] United States Drought Monitor. "United States Drought Monitor." Accessed September 25, 2019. *https://droughtmonitor.unl.edu/*

Fresh grapes on the vine. Credit: Chepko Danil Vitalevich

BREAKOUT SUMMARY

APPROACHES TOWARD DROUGHT PREPAREDNESS & RESILIENCE

In addition to defining new opportunities for drought research, practice, and policy throughout the event, Forum experts also participated in breakout sessions to identify forward-looking, solution-oriented, and practical actions that can be undertaken in the next five years to build greater drought early warning and resilience (synthesized approaches follow).

COORDINATION

Coordination, whether at the federal agency level, across the various levels of government, or between government agencies, NGOs, and private companies, requires a significant, sustained effort to confront gaps in access to information, organizational silos, territoriality, institutional barriers, lack of resources, and conflicting rules and regulations. Even when coordination makes sense, and even when partnerships are identified, challenges abound as organizations fulfill missions and responsibilities that may result in redundancies.

- **Apply successful drought-related coordination efforts.** Analyze and, where appropriate, follow the lead of entities engaged in successful coordination efforts. For example, the NIDIS federal partners' meetings bring together senior resource officials across federal agencies in order to regularly understand what each is doing around drought and to ensure collaboration while minimizing redundancy. Likewise, the state of Washington is working to achieve integrated water solutions in the Yakima River Basin in cooperation with the Bureau of Reclamation, the Yakama Nation, farmers, cities, counties, and environmental interests to implement projects associated with the Yakima River Basin Integrated Plan.[27]
- **Promote coordination through dedicated staffing resources.** Dedicate positions to facilitate interagency/intergovernmental coordination with the goal of establishing and sustaining relationships, overcoming institutional cultural barriers, exchanging knowledge, and producing collaborative initiatives. There must be leadership buy-in for this effort, both in terms of time allotted for employee participation and resources.
- **Leverage investments through collaboration.** Budgets reflect priorities; one goal of coordination should be to leverage budgets in ways that mitigate investment risks, reduce costs and uncertainties, scale effective local solutions, design long-term plans, and/or spur innovation in relation to developing a drought early warning system. Emergency management agencies at the state and federal level should be incorporated into this coordination, with drought understood to be a disaster on the same level as immediate impact events (e.g., floods, hurricanes, and tornadoes).

FLEXIBILITY

Across levels of government and sectors, a combination of funded programs and policies support communities by helping to manage water more efficiently, build resilience, protect resources, and mitigate damages. Many of these programs related to managing for extreme events were not designed to include drought. The scope of these programs and policies could be expanded to meaningfully address

[27] Department of Ecology, State of Washington. "Yakima River Basin Integrated Plan." Accessed October 6, 2019. *http://bit.ly/2MdMQ0w*

drought. This flexibility in approaches and actions is critical to strengthening drought adaptation and mitigation nationwide.

Identify federal/state programs that could integrate or expand scope to include drought. The following programs were identified as those which may have potential to be expanded/leveraged for drought preparedness and resiliency efforts:

- Better Utilizing Investments to Leverage Development (BUILD) Transportation Discretionary Grants (U.S. Department of Transportation);[28]
- Community Development Block Grant (U.S. Department of Housing and Urban Development);[29]
- Department of Defense (e.g., DoD operates more than 100 domestic wastewater facilities);[30]
- Emergency Watershed Protection Program (USDA);[31]
- Indian Health Service (U.S. Department of Health and Human Services);[32]
- Operational and maintenance spending for USACE;
- Building Resilient Infrastructure and Communities Program (FEMA);[33]
- Transportation Infrastructure Finance and Innovation Act (U.S. Department of Transportation);[34]
- Urban and Community Forestry Program (U.S. Forest Service);[35]
- Water Infrastructure Finance and Innovation Act (EPA);[36]
- Water Resources Program (USGS);[37] and
- Wetland Program Development Grants (EPA).[38]

Breakout group participants suggested that the nation would especially benefit from program flexibilities at FEMA. For instance, The Disaster Recovery Reform Act of 2018 (DRRA)[39] included updates to how the nation, primarily through FEMA, responds and recovers from disasters. While the National Institute of Building Sciences reports that the nation saves $6 for every $1 spent through federal mitigation grants,[40] FEMA's funding for such pre-disaster mitigation (PDM) grants previously relied on congressional appropriations that varied from year to year. The DRRA established a National Public Infrastructure Pre-Disaster fund that will focus on mitigation and resilience projects by setting aside up to 6% of estimated disaster

[28] United States Department of Transportation, "About BUILD Grants," Accessed September 25, 2019. *https://www.transportation.gov/BUILDgrants/about*

[29] Department of Housing and Urban Development, "Community Development Block Grant Program (CDBG)" Accessed September 25, 2019. *https://www.hud.gov/program_offices/comm_planning/communitydevelopment/programs*

[30] Strategic Environmental Research and Development Program: Environmental Security Technology Certification Program, "Treatment of Wastewater and Drinking Water," Accessed September 25, 2019. *https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Wastewater-and-Drinking-Water*

[31] United States Department of Agriculture Natural Resources Conservation Service, "Emergency Watershed Protection," Accessed September 25, 2019

[32] U.S. Department of Health and Human Services, "Indian Health Service," Accessed September 25, 2019. *https://www.ihs.gov/*

[33] Federal Emergency Management Agency, "Pre-Disaster Mitigation Grant Program," Accessed September 25, 2019. *https://www.fema.gov/pre-disaster-mitigation-grant-program*

[34] United States Department of Transportation, "Transportation Infrastructure Finance and Innovation Act (TIFIA)," Accessed September 25, 2019. *https://www.transportation.gov/buildamerica/programs-services/tifia*

[35] United States Department of Agriculture, "Urban and Community Forestry Program," Accessed September 25, 2019. *https://www.fs.fed.us/managing-land/urban-forests/ucf*

[36] United States Environmental Protection Agency, "Water Infrastructure Finance and Innovation Act (WIFIA)," Updated On September 20, 2019. *https://www.epa.gov/wifia*

[37] United States Geological Survey, "Water Resources," Accessed September 25, 2019. *https://www.usgs.gov/mission-areas/water-resources/programs*

[38] United States Environmental Protection Agency, "Wetland Program Development Grants and EPA Wetlands Grant Coordinators," Updated On July 25, 2019. *https://www.epa.gov/wetlands/wetland-program-development-grants-and-epa-wetlands-grant-coordinators*

[39] United States. Congress. FAA Reauthorization Act of 2018. Public Law 115-254. Washington, D.C, 2018. *https://go.usa.gov/xV6Gm*

[40] National Institute of Building Sciences, "Natural Hazard Mitigation Saves:2017 Interim Report" *https://www.fema.gov/media-library-data/1516812817859-9f866330bd6a1a93f54cdc61088f310a/MS2_2017InterimReport.pdf*

Billowing smoke from the Lodge Fire, California, August 2014. Credit: N. F. Photography

expenses. This change will allow FEMA to invest in projects that drive risk reduction and build capability for communities with a more reliable stream of funding tied to Presidential disaster declarations. Drought events and drought mitigation should be explicitly included in the project.

Clarify opportunities for the private sector to fund development that preserve profits and public good for infrastructure, early warning, mitigation, and resilience. Public and/or private investment can be incentivized by demonstrating and quantifying the economic benefits of early warning, mitigation, and resilience. In particular, as mitigation is increasingly quantified (e.g., as mentioned above, the National Institute of Building Sciences reports that society saves $6 for every $1 spent through mitigation grants funded through select federal agencies,[41]), the insurance and reinsurance sector can lower premiums and bond buying interest rates. Public and private sector organizations could be convinced to make these infrastructure investments if the economic benefits can be proven, both in terms of the immediate savings from lower insurance premiums and longer term savings from increased infrastructure resilience in the face of hazard events, and return on investment.

Examples of such opportunities include:

- The Forest Resilience Bond is a public–private partnership that enables private capital to finance much-needed forest restoration across the western U.S.;[42]
- The Conservation Reserve Program (CRP) is a USDA land conservation program that pays enrolled farmers to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality;[43]
- The Healthy Forest Restoration Act is a U.S. Forest Service Program that seeks to improve the process for hazardous fuel reduction and vegetation restoration projects;[44] and
- The U.S. Army Corps of Engineers launched "Engineering With Nature" in 2010.[45] The initiative aims to incorporate natural solutions to water management. To date, 56 projects have been undertaken that apply nature-based approaches for river management and flood control.

RESILIENCE

To improve readiness, responsiveness, and overall resilience to drought, capacity must be built within and across communities, governments, and economic sectors, and consideration should be given to those with elevated drought risk. Negative drought impacts and related cascading effects disproportionately affect vulnerable communities, sectors, ecosystems, small businesses, and geographic

[41] National Institute of Building Sciences, "Natural Hazard Mitigation Saves:2017 Interim Report" *https://www.fema.gov/media-library-data/1516812817859-9f866330bd6a1a93f54cdc61088f310a/MS2_2017InterimReport.pdf*

[42] Forest Resilience Bond, "Forest Resilience Bond," Accessed September 25, 2019. *https://www.forestresiliencebond.com/*

[43] United States Department of Agriculture, "Conservation Reserve Program," Accessed September 25, 2019. *https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/*

[44] United States Forest Service, "The Healthy Forests Initiative and Healthy Forests Restoration Act Interim Field Guide," Accessed September 26, 2019. *https://www.fs.fed.us/projects/hfi/field-guide/web/page03.php*

[45] Engineering with Nature, "Engineering with Nature," Accessed September 25, 2019. *https://ewn.el.erdc.dren.mil/index.html*

A hiking trail through burned trees in Custer National Forest, Montana. Credit: davidrh

regions in the country, elevating the risk for system failure.

Provide long-term drought planning, risk management, and response resources to empower vulnerable communities. Drought adaptation strategies are already being implemented in many drought-prone communities; however, some of these plans are drafted primarily based on the historical record. In addition, strategies and plans should be explored and developed that incorporate future risk projections under different climate change scenarios. Communities should understand their risk tolerance and build their plan accordingly (i.e., are they planning for the projected 100-year year drought under the worst case or best case scenario?). Where small scale and local entities don't have resources to assume that risk on their own, the Federal government has an important role to absorb some of that risk and develop local capacity.

Transfer knowledge. The learning curve for drought preparedness can be minimized by sharing knowledge from those who have built resilience with those who have not. For instance, a list of lessons learned and best practices regarding conservation and water loss control could be collected and disseminated to small and medium sized communities that may not have the resources to develop long-range planning and response systems. However, determining the best methods for transferring this knowledge are hampered due to the following issues:

- The number of contacts that have a role in water is staggering (e.g., the EPA estimates that there are 160,000 public drinking water systems in the U.S., and about one third of this total number [53,000] are "community water systems" that serve cities, towns, mobile home parks, or residential developments[46]);

[46] National Research Council. 2007. Chapter 2: EPA's Challenges in Water Security Research in "Improving the Nation's Water Security: Opportunities for Research." Washington, DC: The National Academies Press. *https://doi.org/10.17226/11872.*

- There is an asymmetry between watersheds (the level at which planning should occur) and political boundaries (the level at which planning usually occurs); and
- Given the costs of drought are under-reported and under-recognized, insufficient resources are allocated for drought planning and preparedness.

Implement drought early warning and resilience actions that have multiple benefits. Drought is just one piece of interrelated, complex events that include wildfire (hot temperatures and dry conditions increase the likelihood of wildfires) and flood (wildfires change landscapes and ground conditions, which can lead to increased risk of flooding during heavy rains because the burned ground is unable to absorb the falling rain). Thus, drought decision support services should include managing the risk of these interrelated hazards as well. Executing strategies across landscapes and watersheds is complicated by the diffuse ownership of assets (e.g., land owners and water right owners). Cooperative partnerships could be established between the various private and government owners, and the return on investment would need to be articulated to incentivize investment.

INNOVATION

What emerging technologies can help communities and businesses address the challenges of water scarcity and drought risk? The solutions must be informed by the drought scenarios being considered and desired outcomes, as well as what operational budgets can accommodate. Together, these inform the development of research and technologies that contribute to drought resilience.

Develop accessible technologies that allow for tracking water use. Focus on applied research and technology development to build affordable solutions for small and midsize water utilities to monitor water use for better drought scenario planning.

Leverage artificial intelligence and machine learning to incorporate multihazard data, diverse scenarios at local scales. Nanotechnology, biotechnology, information technology, artificial intelligence, machine learning, satellite and drone technology, and virtual reality may be applied in drought early warning, monitoring, and response. Artificial intelligence approaches can simultaneously incorporate the following:

- Behavioral modeling that accounts for the impacts of farmer, water manager, and policy decisions on the hydrologic system;
- Weekly, seasonal, annual, and decadal timescales;
- Multihazard data, including public health;
- Multiple scenarios and multiple models; and
- Map-based predictions and forecasts.

Drip irrigation in a garlic field. Credit: Cedorina

Image Caption

Healthy corn on cobs. Credit: Chepko Danil Vitalevich

PRIORITY ACTIONS

Through presentations and facilitated conversations, Forum participants took stock of the lessons learned and progress made towards U.S. drought readiness since the first National Drought Forum in 2012. In the final plenary session, they identified actionable opportunities to move the nation from a reactive to a proactive approach to drought risk management. The following list represents the synthesized priority action items that could improve U.S. drought early warning and resilience, in no particular order.

Note: Priority Actions resulting from the National Drought Forum do not represent official Administration policy or position, or an official policy or position of the individual organizations/agencies represented at the Forum. It is also important to note that means to fund any Priority Action was not explored during the National Drought Forum.

APPLIED RESEARCH

Priority Action #1 // Invest in applied research on precipitation, drought onset, drought termination, and multihazard risks including rapid shifts between drought and flood.

Several frequent questions are asked in a drought event, including: (1) When will our area be in a drought? (2) Are we in drought? (3) When will the drought end? (4) What are the linkages between drought and other natural hazards in our community? Success in answering these questions relies upon prioritizing, leveraging, and aligning investments across federal programs and opportunities to collaborate with the private sector:

- **Additional research in Subseasonal-to-Seasonal-to-Decadal (S2S2D) forecasts and predictions.** Advances in S2S2D forecasts and improvements in their skill could provide the accuracy in precipitation information that decision-makers demand, and will improve the quality and timing for early warnings about the start, duration, and end of droughts. Invest in applied research dedicated to: (1) drought forecasting with a particular focus on improving precipitation forecasting skill, especially for drought onset, flash drought, megadroughts, and rapid regime changes across multiple hazards, including between flood and drought on S2S2D timescales; (2) better understanding key underlying physical processes, including sources of predictability; and (3) identifying systemic biases in global models.
- **Additional research in flash drought forecast improvements.** To better understand sudden or "flash" droughts, invest in applied research to better understand heat waves and other drivers of flash drought. Research and improve modeling to better understand the interactions between precipitation, soil moisture, and evaporative demand, and model the whole water cycle.

DROUGHT MONITORING AND OBSERVATIONS

Priority Action #2 // Coordinate to enhance and expand drought observations and monitoring.

Coordinate to enhance and expand drought observations and monitoring, particularly for groundwater, groundwater interaction with surface water, snowpack, and soil moisture. Strengthening observations and monitoring supports improved understanding of the physical drought processes, the total water cycle, and adds detail into drought models. Employ artificial intelligence and machine learning to maximize the wealth of existing satellite data of

earth observations, only 8% of which currently utilized for prediction. Specifically:

- **Collect and leverage additional data.**
  - In coordination with U.S. Geological Survey (USGS)'s Next Generation Water Observing System (NGWOS) and Integrated Water Availability Assessments, invest in better groundwater, soil moisture, evaporation, and surface water monitoring, as well as better understanding of human influences on the water system.
  - Integrate drought monitoring tools with other, nontraditional observing systems that can inform our understanding of drought conditions, like the USGS National Phenology Network;
  - Expand existing efforts, including the efforts to build out a National Soil Moisture Network and collaborations with external activities (e.g., Internet of Water, OpenET, and Climate Engine).
  - Leverage and improve drought observations, including those at state and local levels, currently under-utilized or discarded because of challenges with accessibility, computer processing power, inconsistent measures, and inconsistent or missing metadata. Utilize nontraditional sources of verified observational data, such as citizen science data and remote sensed data.
- **Develop long-term data collection standards and protocols, and ensure interoperability across national observation networks.** To commit to long-term, consistent data collection, write and publish the collection standards, metadata standards, codebooks, and usage standards for the data. Ensure that consistent formats and metadata are used in national networks that collect, assimilate, and disseminate observation data, especially groundwater, surface water, and atmospheric data. Incorporate these standards into associated federal funding opportunities related to drought monitoring.

Cattle feeding. Credit: Papery

DECISION SUPPORT TOOLS

Priority Action #3 // Utilize improved analytics, indicators, predictions, and forecasts of drought to enhance and develop 21st century decision support tools.

Improved decision support tools for those impacted by drought, including water managers, reservoir managers, government leaders, and emergency managers, should assist in informing choices and decision trade-offs. There should exist robust efforts to coordinate across all relevant decision support tools, and to develop a process for sunsetting outdated resources. Specifically:

- **Develop integrated water management decision support tools.** Write and implement a plan for producing decision support tools that take into consideration the water cycle as a whole, tracking surface and groundwater supplies together, forecasting precipitation, and providing information about soil moisture and evaporative demand at multiple timescales. Tools should be driven by user-defined needs, through robust engagement that gathers routine feedback from stakeholders.
- **Develop and promote accompanying training resources for decision support tools.** Develop documentation, learning

aids, and training resources for researchers, state agencies, and water and land managers interested in applying decision support tools to the challenges they face.

- **Develop a water risk monitor.** Develop a water risk monitor that accounts for scarcity, flooding, and water quality, so that users and decision-makers have a consistently-updated visual of the risks by geographical area. In particular, add layered maps of drought and risk of reduced water availability for drinking and agriculture that factor in reservoir capacity and levels and include triggers for decision-makers, such as water and reservoir managers.
- **Ensure Federal support for key drought monitoring tools, like the U.**S. Drought Monitor (USDM), and refine to strengthen decision-making across diverse sectors. The U.S. Drought Monitor, jointly produced by the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Department of Agriculture (USDA), and the National Drought Mitigation Center at the University of Nebraska, is utilized by the USDA for programs that help agricultural producers recover from drought and other natural disasters. The USDM is also used by countless local, state, federal, and tribal agencies; organizations, businesses, and industries; individuals; and policymakers and drought task forces in critical decision-making. However, its production is not supported with consistent, long-term Federal funding. Although the USDM is now a generalized map, it could be further refined to improve decision support for a diverse range of uses, from public health advisories to fire precaution levels. This action will be further informed by the USDA's review of the data utilized by the U.S. Drought Monitor and recommendations for enhancing the collection of relevant data.
- **Develop decision support tools for future scenario planning.** While data availability is improving our understanding of future drought scenarios, there is still a need for high resolution, locally relevant drought information at long-term time scales. Coupled with additional tools to support vulnerability analyses as well as cost benefit data on resilience strategies, these decision support systems can be an important component of long-range planning across state and local agencies.

QUANTIFY DROUGHT IMPACTS

Priority Action #4 // Quantify and monetize the impacts of drought.

Quantifying the full impact of a drought event, including direct as well as secondary and tertiary impacts, requires focused investments in applied research, data collection, and economic analysis. Though national and state-based systems exist to ingest and catalogue some reported drought impacts, more complete impact data is needed, together with development and application of innovative methodologies to analyze the data. These data and analyses can provide critical details on the costs and benefits of various investments, return-on-investments, and trade-off analyses that can inform and improve decision-making.

Quantify the impacts of drought by system. Identify existing and fund new research to quantify and monetize the downstream social and economic impacts of drought, including the qualitative, indirect, and cascading impacts for tourism, human health, wildfire, agriculture, ecosystems, as well as lost opportunity costs. Identify tipping points at which various impacts of drought intersect with one another, such as economic impacts and mental health impacts, as well as temporal and spatial scales that characterize a drought's unique impacts. Identify improved methodologies for impact assessment, and prioritize these assessments after major drought events.

Soil moisture is important for agricultural monitoring, weather prediction, and drought and flood forecasting. Credit: Valentina Morgun

INTEGRATED WATER RESOURCES MANAGEMENT

Priority Action #5 // Integrate water conservation and infrastructure initiatives to realize greater drought preparedness.

Extreme weather events and projected population growth will increasingly impact water availability and quality, requiring demand management that maximizes efficiencies in existing water infrastructure and incorporates water conservation. While conservation and infrastructure have historically been approached as separate areas of research and investment, with additional distinctions for green *versus* gray (i.e., natural landscapes and open systems versus built tunnels and storm drains), managing them holistically is now necessary.

- Relative to conservation, encourage potable reuse by replenishing groundwater basins and surface water reservoirs with recycled water, or introducing recycled water into a raw water supply immediately upstream of a water treatment plant.
- Relative to infrastructure, prioritize and invest in natural and built options for water storage that are landscape-scale distributed and flexible systems. Locate the water supply closer to water use. Invest in research to better understand how shifts towards decentralized, flexible water distribution systems and/or centralized systems in small and rural communities can help improve water access and availability.
- Continue advancements in employing reliable two-week forecasts to the management of reservoir operations that help proactively respond to early warning and monitoring of drought and flood.
- Identify strategies for financing drought-resilient infrastructure, both green and gray, and combine investments in adapting or building infrastructure with conservation measures such as reductions in use and increases in re-use and restoration measures such as (e.g., restoring impaired ecosystems to restore drought mitigation functionality).

ECOLOGICAL DROUGHT AND ECOSYSTEM RESTORATION

Priority Action #6 // Support research to evaluate ecosystem vulnerability to drought, and the role of ecosystem restoration in mitigating drought impacts.

When a drought impacts an ecosystem, there is often a ripple effect through communities that depend on those ecosystems for goods and services, but little is known about specifically how a drought influences those goods and services and how those values vary across timescales. In 2017, the SNAPP Ecological Drought Working Group, launched by the USGS's National Climate Adaptation Science Centers (CASCs), the Nature Conservancy, and the Wildlife Conservation Society, developed a framework for understanding the natural and human dimensions of ecological drought impacts, and promoting the application of solutions that provide mutual benefits to people and nature. By understanding the relevant drivers of ecological drought impacts in a given system, from human water consumption to land use, more targeted management strategies may be employed, including those mutually beneficial to humans and ecosystems.

- **Additional research to quantify drought exposure to an ecosystem due to direct human influences, natural climate variability, and climate change.** The effects of human water and land use on environmental water supplies are not often considered in ecological drought research, monitoring, or prediction. The relative importance of natural climate variability, climate change, and human influences on environmental water supplies vary across regions and ecosystems, and more research is needed to quantify and separate these aspects of drought exposure.
- **Additional research to characterize human and natural dimensions of drought exposure, sensitivity, and adaptive capacity in an ecosystem.** Integrate all aspects of ecological drought vulnerability simultaneously, to support the attribution of the causes of ecological impacts and their social implications.

Many communities have also explored and implemented innovative water management strategies to restore degraded, damaged, or destroyed

Low water level at spillway of dam reservoir at Standley Lake in Westminster Colorado. Credit: Merrimon Crawford

ecosystems and restore their function in flood and drought mitigation. Access to landscape scale information and additional research on how to successfully implement these strategies can benefit states looking for cost-effective alternatives to built solutions.

- **Additional research to understand the benefits of ecosystem restoration for drought mitigation purposes.** Strategies for ecosystem restoration that have increased water storage include constructing beaver dam analogues, impoundment structures, and water channel realignments. Additional research is needed to quantify and compare the recovery benefits of this type of storage.

DROUGHT PLANNING AND PREPAREDNESS

Priority Action #7 // Prioritize drought mitigation within programs designed to support planning and preparedness across other natural hazards.

Many federal and state programs related to managing for extreme events were not designed to include drought. The scope of these programs and policies could be expanded to meaningfully address drought early warning, response, and resilience. For example, the Federal Emergency Management Agency's (FEMA) Building Resilient Infrastructure and Communities (BRIC)[47] will be funded through the Disaster Relief Fund as a six percent set-aside from estimated disaster grant expenditures and, with FEMA's leadership, could be developed to include drought. This flexibility in approaches and actions is critical to strengthening drought adaptation and mitigation nationwide.

[47] Federal Emergency Management Agency. 2019. "Building Resilient Infrastructure and Communities (BRIC)."

- **Identify federal/state programs that could integrate or expand scope to include drought.** Several federal programs were identified at the National Drought Forum as those which may have potential to be expanded/leveraged upon for drought preparedness and resiliency efforts. Additional efforts should be made to understand the breadth of initiatives currently designed to support recovery from natural disasters that could incorporate drought. These efforts should solicit and incorporate the feedback of regional state, and local stakeholders across sectors.

Priority Action #8 // Further expand and strengthen opportunities for drought planning across multiple temporal and spatial scales.

- **Incorporate flash drought into planning.** Drought management plans should incorporate flash drought events when considering response and preparedness. As a part of this, develop information resources to support rapid response strategies that also look at the potential for flash drought as well as flash flood. Additional research is needed to evaluate which drought indices are most appropriate as triggers of rapid onset drought, including soil moisture data.
- **Incorporate ecological drought into planning.** Current drought planning efforts may consider ecological drought as it relates to minimum flows needed to sustain aquatic species population and habitat. However, this approach is limiting and doesn't account for the dynamic nature of river ecosystems. Variable flow regimes can help address this issue. Planning must also include indicators for monitoring drought's impacts to rangeland and forest systems (like soil moisture and health, and vegetation health).
- **Integrate land use planning and water resource planning.** Considering natural hazards and impacts to future land use is a federal requirement for hazard mitigation plans. Local planners have a unique role to play in the coordination and integration of drought information into existing planning mechanisms, and they often need support to access, interpret, and use drought and hazards-related data and information that are available at local scales.

PUBLIC–PRIVATE PARTNERSHIPS

Priority Action #9 // Grow Public–Private Partnerships to introduce private sector technology and innovation and provide more resilient infrastructure and better public services through improved operational efficiency.

- **Support the development of insurance and reinsurance instruments that build resilience to drought events.** Make sure that these instruments encourage pre-disaster mitigation steps as preventative measures against drought impacts, so that communities may realize immediate savings from lower insurance premiums and longer term savings from increased infrastructure resilience in the face of hazard events. These instruments should consider groundwater and surface water in a unified context.
- **Leverage advances in artificial intelligence (AI) and cloud computing to analyze drought data and formulate drought solutions.** Leverage artificial intelligence and machine learning to incorporate more data—such as meteorological information, reservoir and groundwater data, and agricultural production—and diverse scenarios at local scales into decision-making and planning. Microsoft, Google, IBM, and other technology companies are helping to narrow the data gaps and information lags in drought monitoring and prediction. Partnering with federal and state agencies, researchers, and technologists, AI tools have the potential to provide earlier warnings of drought and help mitigate drought impacts.

DROUGHT COMMUNICATION AND COORDINATION

Priority Action #10 // Communicate drought conditions, outlooks, and impacts through vehicles tailored to specific watersheds, populations and sectors.

Technology empowers us with emerging capabilities to send targeted, customizable information and messages to specific locations and populations. To

build drought resilience, drought services and information must be available to whomever needs it, as they need it, and the federal government has a role to play in delivering drought information directly to local communities. Ongoing coordination across federal agencies to strengthen drought communication is essential. Specifically:

- **Provided targeted drought communication.** Communicate drought plans publicly, and identify "what is drought" for each stakeholder community. Provide useful, understandable, and actionable graphics that are tailored to specific sectors or water users. Identify areas at the greatest risk for drought, and coordinate, especially between farmers and water managers, to produce drought-readiness campaigns that leverage social media.
- **Continue to improve coordination and communication across levels of government.** Incentivize local, regional, state, tribal, and federal agencies to share detailed information with each other and other water users about how they developed their drought messaging; what has worked; what has not worked. Incorporate co-production and cross-agency connections in the development of funding proposals and in the application of research.

APPENDIX AI

RESOURCES

Agriculture Improvement Act of 2018, P.L. 115–334, *https://go.usa.gov/xVrBB*

Colorado River Basin Drought Contingency Plans. *https://www.usbr.gov/dcp/*

National Integrated Drought Information System (NIDIS) program authorized by Congress in 2006 (Public Law 109-430; *https://go.usa.gov/xVrBg*)

National Integrated Drought Information System (NIDIS) program reauthorized by Congress in 2018 (Public Law 115-423; *https://go.usa.gov/xVrB4*)

Presidential Memorandum: Building National Capabilities for Long-Term Drought Resilience (*https://go.usa.gov/xVrB2*) [establishing the National Drought Resilience Partnership]

Presidential Memorandum on Promoting the Reliable Supply and Delivery of Water in the West (*https://go.usa.gov/xVrBY*)

Press Release: Federal Officials Announce Priority Actions Supporting Long-Term Drought Resilience (*https://go.usa.gov/xVrBT*)

The United States Drought Monitor (*https://droughtmonitor.unl.edu/*)

The United States Seasonal Drought Outlook (*https://go.usa.gov/xVrBD*)

Weather Research and Forecasting Innovation Act of 2017, P.L. 115–125 (*https://go.usa.gov/xVrBK*)

Water Resources Development Act of 2018, H.R. 8 (passed house as amended; (*https://go.usa.gov/xVrB9*)

APPENDIX A2

ACRONYMS

BRIC	Building Resilient Infrastructure and Communities [Grant Program]
BUILD	Better Utilizing Investments to Leverage Development
CNA	[nonprofit research and analysis organization, see also *www.cna.org*]
CRP	Conservation Reserve Program
CREP	Conservation Reserve Enhancement Program
DOD	Department of Defense
DPR	Direct Potable Reuse
DRRA	The Disaster Recovery Reform Act of 2018
EPA	Environmental Protection Agency
EPIC	Earth Prediction Innovation Center
E-QIP	Environmental Quality Incentives Program
FEMA	Federal Emergency Management Agency
FIRO	Forecast Informed Reservoir Operations
GEE	Google Earth Engine
LFP	Livestock Forage [Disaster] Program
MRCTI	Mississippi River Cities and Towns Initiative
NDRP	National Drought Resilience Partnership
NGO	Non Governmental Organization
NIDIS	National Integrated Drought Information System
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
PDM	Pre-Disaster Mitigation
RCPP	Regional Conservation Partnership Program
S2D	Seasonal to Decadal
S2S	Subseasonal to Seasonal
S2S2D	Subseasonal-to-Seasonal-to-Decadal
SCAN	Soil Climate Analysis Network
SNOWTEL	Snow Telemetry
SNWA	Southern Nevada Water Authority
SPEI	Standardized Precipitation–Evapotranspiration Index
UFS	Unified Forecast System
U.S.	United States
USACE	U.S. Army Corps of Engineers
USDA	United States Department of Agriculture
USDM	U.S. Drought Monitor
USGS	United States Geological Survey
USN	United States Navy
WRDA	Water Resources Development Act

APPENDIX B1

SPEAKER BIOGRAPHIES AND PARTICIPANT LIST

NATHAN ALLEN is the Executive Director of WaterStart. He has a long track record of successful program management. Past experience includes assistant scientist at Biosphere 2 and sustainability coordinator at Arizona State University.

HONORABLE MIKE BAWDEN was sworn in as mayor of Riverdale, Iowa in 2018. Since that time, he has become an active participant in the Mississippi River Cities and Towns Initiative, which is comprised of 80 mayors who represent cities on the main stem of the Mississippi River from Minnesota to Louisiana. A resident of the area for nearly twenty years, he is also a public relations and marketing consultant working with clients throughout the country.

AUBREY BETTENCOURT is Senior Advisor in the Office of the Assistant Secretary for Water and Science in the U.S. Department of the Interior. Ms. Bettencourt was appointed by the Trump Administration to serve as the state executive director of the California U.S. Department of Agriculture Farm Service Agency in November 2017. Prior to her appointment, she served as the executive director of the California Water Alliance, a leading educational voice and authority on water issues throughout the Golden State.

ASTOR BOOZER is the Regional Conservationist for the West Region for the U.S. Department of Agriculture. He oversees the conservation programs and activities of the 13 West region states. Through his leadership, Natural Resources Conservation Service has strengthened its partnership activities and relations within the region and worked to improve private and public lands conservation. He has worked to address animal, plant and soil health throughout the region and has worked to leverage partner dollars for additional boots on the ground to deliver conservation.

ANGELA BOWMAN, Ph.D., currently works as a Research Scientist at the John Deere and Company Intelligent Solutions Group in Urbandale, Iowa. Dr. Bowman conducts research in Hydrology and Remote Sensing applications to improve precision agriculture performance and efficiency. Her team incorporates satellite imagery, weather, and environmental data to improve every aspect of the crop production system.

GREG BROWDER, Ph.D., is the Global Lead for Water Security for the World Bank Group. He oversees the World Bank's knowledge program on Water Security and Water Resources Management and helps to ensure that global best practice is incorporated into World Bank projects and studies. In his 20 years at the World Bank, Greg has been involved in numerous large-scale water projects in East Asia, South Asia, and Latin America and has published studies related to water resources management and urban water supply and sanitation. He has a Ph.D. in Environmental Engineering from Stanford University.

ROSALYN BRUMMETTE serves as Professional Staff for the U.S. Senate Committee on Agriculture, Nutrition, and Forestry. She was raised on a third-generation family farm in Michigan and graduated from Michigan State with a major in Agribusiness Management and a minor in Environmental Economics and Policy.

BEVIN BUCHHEISTER serves as a senior policy analyst for National Governors Association Center for Best Practices' Energy, Infrastructure, and Environment division. In this role, Ms. Buchheister leads the National Governors Association Water Policy Learning Network that provides information to governors' water policy advisors on best practices, policies, and programs being developed and implemented across the country.

NICOLE CARTER, Ph.D., is a Specialist in Natural Resources Policy at the Congressional Research Service (CRS). CRS is an agency within the U.S.

Library of Congress that supports Congress through nonpartisan research and analysis on legislative and oversight issues. Since 2003, she has provided research to Congress in the following areas: domestic and international water resource policy, flood and drought policy, river management, and water supply technologies. Much of her work at CRS relates to civil works authorization and appropriations for U.S. Army Corps of Engineers water resource activities. She studied civil engineering at The University of Texas at Austin (B.S.) and engineering at Stanford University (M.S., Ph.D.).

CHUCK CHAITOVITZ is vice president for environmental affairs and sustainability at the U.S. Chamber of Commerce. For more than 25 years, he has specialized in environment and energy issues, working with companies on strategies to improve their bottom line and competitive positioning. At the Chamber, Chaitovitz works with members to support company leadership on sustainability—building the business case and the enabling conditions through commonsense public policy and the actions of member companies.

DON CLINE, Ph.D., is the Associate Director for Water Resources at the U.S. Geological Survey (USGS), where he leads USGS research, monitoring, assessment, modeling, and prediction of the Nation's water resources. He previously spent 19 years with the National Oceanic and Atmospheric Administration's National Weather Service where he served as the Director of the National Water Center, the Chief of the Hydrology Laboratory, and the Director of the National Operational Hydrologic Remote Sensing Center.

PETER COLOHAN is the Executive Director of the Internet of Water, a project that seeks to facilitate the opening, sharing, and integration of water data and information. Previously, he served as a federal employee of the National Oceanic and Atmospheric Administration (NOAA) where he was a key advocate for the development of the National Water Model and the creation of the NOAA Water Initiative.

VEVA DEHEZA is the Executive Director of the National Integrated Drought Information System (NIDIS) at NOAA's Office of Oceanic and Atmospheric Research in Boulder, Colorado. She is responsible for the implementation of the NIDIS Public Law that authorized NIDIS in 2006 and reauthorized NIDIS in 2019. She supports agency congressional, legislative, and policy priorities to achieve the NIDIS mission, goals, and objectives. Veva is a NOAA/NIDIS co-lead on the National Drought Resilience Partnership (NDRP). She serves as the NIDIS liaison to the Western Governors' Association and the Western States Water Council. She oversees a staff that coordinates all nine NIDIS regional drought early warning systems around the country, ensuring that regional successes and lessons learned are connected and linked to each other to create an integrated National drought early warning system.

DAVID DEWITT, Ph.D., has been the Director of the Climate Prediction Center (CPC) of the National Weather Service (NWS) since 2014. Prior to coming to NOAA, he worked as a research scientist at the International Research Institute for Climate and Society (IRI) at Columbia University from 1999–2012. While at IRI, he led the Climate Program, which consisted of a team of scientists engaged in the development of seasonal climate forecasts and prototype decision support systems for the application of climate information in the fields of agriculture, health, and water resources. From 1994–1999, DeWitt worked at the Center for Ocean-Land-Atmosphere Studies developing coupled atmosphere-ocean models for seasonal forecasts and conducting research to better understand short-term climate variability.

DeWitt received his Bachelor of Arts (1989) degree in meteorology from Kean University, and his Masters (1992), and Ph.D. (1994) degrees in meteorology from the University of Maryland, College Park. He has published over 30 peer-reviewed journal articles, and is a leading expert on subseasonal to seasonal (S2S) forecasting and diagnostics, and coupled model development. He served as an executive editor of Climate Dynamics, and as a member of the World Climate Research Program Working Group on Seasonal to Interannual Prediction.

JOAQUIN ESQUIVEL was appointed to the California Water Resources Control Board by Governor Jerry Brown in March 2017 and designated by Governor Gavin Newsom as Chair in February 2019. Previously, he served as Assistant Secretary for federal water policy at the California Natural Resources Agency in the Governor's Washington, D.C. office, where he facilitated the development of

policy priorities between the agency, the Governor's Office, the California Congressional delegation, and federal stakeholder agencies. For more than eight years prior to that, he worked for U.S. Senator Barbara Boxer of California.

RDML TIMOTHY GALLAUDET, Ph.D. (U.S. Navy, Retired), is the Assistant Secretary of Commerce for Oceans and Atmosphere at the National Oceanic and Atmospheric Administration. He was previously a rear admiral in the U.S. Navy, where his most recent assignment was Oceanographer of the Navy and Commander of the Navy Meteorology and Oceanography Command. During his 32 years of military service, he took part in weather and ocean forecasting, hydrographic surveying, developing policy and plans to counter illegal, unregulated and unreported fishing, and assessing the national security impacts of climate change.

GERALD E. GALLOWAY, JR., Ph.D., is a Glenn L. Martin Institute Professor of Engineering, Department of Civil and Environmental Engineering, and an Affiliate Professor, School of Public Policy, University of Maryland, College Park, Maryland, where his focus is on water resources policy and management. He is also a Visiting Scholar at the U.S. Army Corps of Engineers Institute for Water Resources. He joined the faculty of the University of Maryland following a 38-year career in the U.S. Army, retiring as Brigadier General, and served eight additional years in the federal government, most of which was associated with water resources management.

FERN GIBBONS, Ph.D., is the Deputy Policy Director for Science, Oceans, Fisheries, and Weather on the U.S. Senate Committee on Commerce, Science, and Transportation. She previously worked for The Nature Conservancy, where she advocated for science-based environmental policy in the federal government. She also was a 2012 Sea Grant Legislative Fellow for the Commerce Committee.

SHERRI GOODMAN is a Senior Fellow at the Wilson Center's Environmental Change and Security Program and Polar Initiative. She is credited with educating a generation of U.S. military and government officials about the nexus between climate change and national security, using her famous coinage, "threat multiplier," to fundamentally reshape the national discourse on the topic. A former first Deputy Under Secretary of Defense (Environmental Security) and staff member on the Senate Armed Services Committee, she has founded, led, or advised nearly a dozen research organizations on environmental and energy matters, national security and public policy. Ms. Goodman serves on the Boards of the University Corporation for Atmospheric Research and the National Executive Committee of the U.S. Water Partnership. She has degrees from Amherst College, Harvard Law School, and Harvard Kennedy School. She received an honorary degree in Humane Letters from Amherst College in 2018.

PETER GREVATT, Ph.D., is the Chief Executive Officer of the Water Research Foundation. Dr. Grevatt has over 30 years of experience leading the implementation of public health and environmental protection programs including significant national leadership experience in the water sector. Most recently, Grevatt served as Director of EPA's Office of Ground Water [*sic*] and Drinking Water (OGWDW).

Prior to joining OGWDW in October 2012, Dr. Grevatt served as the Director of the Office of Children's Health Protection and as the Senior Advisor to EPA's Administrator for Children's Environmental Health. Dr. Grevatt has held leadership roles in EPA's national hazardous waste and water quality programs. Grevatt received his M.S. and Ph.D. degrees in Basic Medical Sciences from New York University Medical Center and earned his bachelor's degree in Biology from Earlham College.

VADM LEE GUNN (U.S. Navy, Retired), was named President of the Institute for Public Research at CNA Corporation (CNAC) on October 1st, 2003. Admiral Gunn came to CNAC after serving in the U.S. Navy for 35 years. For the last three years of his career, he served as the Inspector General of the Department of the Navy. Together with his Marine Deputy, he was responsible for the Department's overall inspection program and its assessments of readiness, training, and quality of service.

WAYNE HIGGINS, Ph.D., is the Director of the Climate Program Office (CPO) in NOAA's Office of Oceanic and Atmospheric Research. In this position, he serves as the focal point for climate programs within NOAA, supporting one of NOAA's primary mission goals: to understand climate variability and change to enhance society's ability

to plan and respond. Prior to his selection as CPO Director, Dr. Higgins was the acting Director of the National Weather Service, National Centers for Environmental Prediction (NCEP) in 2013 and the Director of NCEP's Climate Prediction Center from 2007–2013.

DOUG HILDERBRAND leads the National Weather Services' (NWS) Weather-Ready Nation Ambassador initiative, a NOAA-wide effort to recognize and strengthen NOAA partnerships to improve the nation's readiness, responsiveness, and resilience to extreme weather, water, and climate events. He has been with the NWS since 2002, first as a policy adviser on weather and satellites and then with the Communications Office.

JUSTIN HUNTINGTON, Ph.D., is a research professor of Hydrology at the Desert Research Institute and Western Regional Climate Center where he is focused on remote sensing, evapotranspiration, irrigation, drought, and hydrologic modeling. He co-leads the Climate Engine project, a public–private partnership between Google, the Desert Research Institute, University of Idaho, and NIDIS, for global on-demand cloud computing of place-based satellite and climate data via a Web Mapping and Application Programming Interface.

TOM ISEMAN is the director of the freshwater conservation program for The Nature Conservancy in Colorado. He works to protect rivers and wetlands and the plants and animals they support across Colorado and the American Southwest. He has served on statewide and regional water supply planning efforts, including Colorado's Statewide Water Supply Initiative and the Upper Colorado River Endangered Fish Recovery Program.

NEIL JACOBS, Ph.D., is the Assistant Secretary of Commerce for Environmental Observation and Prediction and is performing the duties of Under Secretary of Commerce for Oceans and Atmosphere at the National Oceanic and Atmospheric Administration (NOAA). He is responsible for the strategic direction and oversight of more than $5.5 billion in annual spending, including key investments in developing a community model framework to advance U.S. weather modeling and prediction; space innovation; streamlining unmanned systems research to provide critical data across NOAA's mission areas; and unlocking the partnership potential of nongovernmental and private organizations to study our Nation's oceans and promote a blue economy.

R.D. JAMES is the Assistant Secretary of the Army for Civil Works where he establishes policy direction and provides supervision of the Department of the Army functions relating to all aspects of the U. S. Army Corps of Engineers' Civil Works program. He previously was a self-employed farmer and manager of cotton gins and grain elevators for the A.C. Riley Company in New Madrid, Missouri and served on the Mississippi River Commission under Presidents Ronald Reagan, George H. W. Bush, George W. Bush, and Barack Obama.

UPMANU LALL, Ph.D., is the Director of the Columbia Water Center, the Alan and Carol Silberstein Professor of Engineering, and the Chair of the Department of Earth and Environmental Engineering at Columbia University. He has broad interests in hydrology, climate dynamics, water resource systems analysis, risk management, and sustainability. He is motivated by challenging questions at the intersection of these fields, especially where they have relevance to societal outcomes or to the advancement of science towards innovative application.

JIM LOCHHEAD is the CEO/Manager of Denver Water, a position he has held since 2010. He also currently serves on the boards of the Association of Metropolitan Water Agencies, the Water Research Foundation, the Water Utility Climate Alliance, the Water Foundation and the Denver Botanic Gardens. Prior to joining Denver Water, Mr. Lochhead was in private law practice, dealing with natural resource issues throughout the U.S. and internationally.

HONORABLE DARON MCDANIEL currently serves as Merced County, California Supervisor for District 3 and is the First Vice Chair for the Rural County Representatives of California (RCRC). The RCRC works with its membership to advocate on behalf of rural issues at the state and federal levels, including land use, wildfire protection policies, and water and natural resources. He has been a resident of Merced County for 33 years.

SHAUN MCGRATH was appointed Director of the Montana Department of Environmental Quality by Governor Steve Bullock in November

2018. McGrath most recently served as Regional Administrator of the U.S. Environmental Protection Agency for Region 8 in Denver. He was the Deputy Director for the Executive Office of the President's Office of Intergovernmental Affairs acting as a liaison between the Obama Administration and the Nation's governors. He spent 14 years as a Program Director working on behalf of the bipartisan Western Governors' Association.

FERNANDO MIRALLES-WILHELM, Ph.D., is Lead Scientist of Global Water at The Nature Conservancy. He is a hydrologist and water resources engineer and has been a Principal Investigator in over $250M research sponsored by National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, National Science Foundation, U.S. Department of Agriculture, U.S. Agency for International Development, the World Bank and other agencies. Additionally, he has worked as a consultant in water resources projects on five continents for over 25 years.

MEREDITH MUTH, Ph.D., recently joined the National Integrated Drought Information System (NIDIS) team as a Regional Drought Information Manager with a focus on supporting drought early warning systems in the southeast. Prior to NIDIS, Dr. Muth served for ten years as an International Program Manager in NOAA's Climate Program Office (CPO). Her responsibilities included leading several international partnerships and activities related to the development of climate information for decision-making with a strong emphasis on partnership development, coordination and policy. She received a Ph.D. from the University of Virginia in Environmental Sciences and a M.S. from Florida International University in Biological Sciences.

CLAUDIA NIERENBERG is the Division Director for the Climate and Societal Interactions division at the NOAA Climate Program Office. She entered federal service as a Presidential Management Intern with positions at the U.S. Treasury Department and the National Science Foundation. For the last twenty years, she has worked as a science manager in global change research.

BILL NORTHEY is the Under Secretary for Farm Production and Conservation at the U.S. Department of Agriculture. He is a fourth-generation corn and soybean farmer who previously served as Iowa's Secretary of Agriculture, as president of the National Corn Growers Association, and in other state and local roles for the Iowa Farm Bureau.

COLBY PELLEGRINO is the Director of Water Resources for the Southern Nevada Water Authority (SNWA), the agency responsible for the treatment, delivery, and management of Southern Nevada's water resources. Pellegrino joined the SNWA in 2003 and, in her current capacity, she is responsible for the management of the SNWA's water resource portfolio, which includes protecting Nevada's interests and rights to Colorado River water through interstate negotiations, developing regional water conservation programs, managing groundwater resources, and water resource planning.

TIM PETTY, Ph.D., is the Assistant Secretary for Water and Science at the U.S. Department of the Interior (DOI). Prior to his nomination, he served as Deputy Legislative Director and Legislative Assistant on issues of water, natural resources, environment, science, technology and telecommunications and space for U.S. Senator James E. Risch of Idaho, a member of the Senate Committee on Energy and Natural Resources. He also served as Acting Assistant Secretary and Deputy Assistant Secretary for Water and Science at DOI under President George W. Bush.

WARREN PRESTON, Ph.D., serves as Deputy Chief Economist at the U.S. Department of Agriculture (USDA), advising top policy officials on the economic implications of policies, programs, and legislative proposals affecting the U.S. food and fiber system and rural areas. Previously, he served in various leadership roles in the Agricultural Marketing Service and the former Grain Inspection, Packers, and Stockyards Administration at USDA and as an assistant professor of agricultural economics at Virginia Tech. He earned his bachelor's degree in dairy science from Ohio State University and his master's and doctoral degrees in agricultural economics from Purdue University.

ROGER PULWARTY, Ph.D., is a senior scientist and the co-chair of the National Integrated Drought Information System Executive Council. His publications focus on climate and risk management in the U.S., Latin America and the Caribbean. Throughout his career, he has helped develop and lead widely-recognized programs dealing with climate

science, adaptation, and services, including the Regional Integrated Sciences and Assessments, NIDIS and the Mainstreaming Adaptation to Climate Change project in the Caribbean.

JON RADTKE is the Water Sustainability Program Director and Chief Hydrogeologist for the Coca-Cola Company North America based in Atlanta, Georgia. In this role, he manages the company's water stewardship program, which assesses and mitigates water risks facing Coca-Cola operations. Primary areas of focus include water efficiency initiatives, source water protection strategies, community water partnerships and sustainable agriculture initiatives within the supply chain.

DAVID RAFF, Ph.D., was named as Reclamation's Science Advisor in February 2014. In this position, he serves as Reclamation's Scientific Integrity Officer—ensuring that the agency follows the Department of the Interior's Scientific and Scholarly Integrity Policy while overseeing Reclamation's Research and Development Office. He returned to Reclamation after working as the Senior Hydrologic and Hydraulic Engineer with the Institute for Water Resources in the U.S. Army Corps of Engineers. Raff is involved with the academic community, publishes articles in peer-reviewed journals, presents at numerous conferences on hydrologic and climate change activities, works with multiple federal interagency committees, and serves within the engineering community as a member of the American Society of Civil Engineers and American Geophysical Union within the Hydrology Section.

BRAD RIPPEY is an agricultural meteorologist with the U.S. Department of Agriculture's Office of the Chief Economist, and the managing editor of the Weekly Weather and Crop Bulletin. He is also one of eleven rotating authors of the weekly U.S. Drought Monitor and a contributor to the monthly North American Drought Monitor.

DAVE ROSS is the Assistant Administrator for the Office of Water at the U.S. Environmental Protection Agency. Prior to joining EPA in January 2018, he worked as the Director of the Environmental Protection Unit at the Wisconsin Department of Justice, where he worked closely with the Wisconsin Department of Natural Resources on environmental and natural resources issues. He also worked in the Wyoming Attorney General's Office representing the Water Quality Division of the Wyoming Department of Environmental Quality.

TRACY ROULEAU is the President and Owner of TBD Economics, LLC, an environmental economics consultancy providing expertise in coastal and ocean economic policy and analysis. She is a Senior Fellow at the Center for the Blue Economy and an Editorial Board Member for the Journal for Ocean and Coastal Economics. Previously, she was Deputy Chief Economist for the National Oceanic and Atmospheric Administration.

DANIEL SIMMONS is the Assistant Secretary for Energy Efficiency and Renewable Energy at the U.S. Department of Energy. He previously served as the Institute for Energy Research's Vice President for Policy, overseeing its energy and climate policy work at the state and federal level, as the director of the Natural Resources Task Force of the American Legislative Exchange Council, as a research fellow at the Mercatus Center, and as Professional Staff on the Committee on Natural Resources, U.S. House of Representatives.

DORI STIEFEL, Ph.D., has served businesses, universities, not-for-profits, and federal agencies for decades with solutions to pressing issues in environment and energy. Dr. Stiefel also has conducted extensive peer-reviewed research on resilience, sustainability, human existential risk reduction, unintended consequences, and futures.

JAN STODDARD is a Bureau Chief with the Montana Office of Tourism and Business Development Division at Montana's Department of Commerce in Helena. Her team, Industry Services and Outreach, is responsible for programs and products that assist tourism organizations and communities in developing sustainable tourism infrastructure and strategies. This includes tourism and development grants, conferences, the Made in Montana program, and other outreach and educational programs.

MARK SVOBODA, Ph.D., is a climatologist and the Director of the National Drought Mitigation Center (NDMC). He has been with the NDMC since it was established in 1995, and has been one of the U.S. Drought Monitor authors since it was established in 1999. Dr. Svoboda serves on the National Integrated Drought Information System (NIDIS)

Implementation Team and co-chairs the NIDIS Portal Development Team.

CAMILLE CALIMLIM TOUTON serves as Professional Staff to Chairman Peter DeFazio on the U.S. House Committee on Transportation and Infrastructure. She has also served as Deputy Assistant Secretary for Water and Science at the U.S. Department of the Interior; as Senior Policy Advisor to the U.S. House Natural Resources Committee, Subcommittee on Water and Power; and as an aide to Senate Majority Leader Harry Reid on public lands and water issues.

TONY WILLARDSON was named as Executive Director of the Western States Water Council (WSWC) in July 2009, having first joined the WSWC staff in 1979. The Council, representing 18 states, was created by western governors in June 1965, and members are appointed by their governors. The Council has authored numerous articles and reports covering a wide range of water resource issues, including drought, water project financing and cost sharing, groundwater management and recharge, water conservation, drought, water use fees, remote sensing of water use and inter-regional water transfers. The WSWC also hosts a web-based water data exchange providing access to state water rights, water use, and planning data.

LAURA ZIEMER serves as Trout Unlimited's (TU) Senior Counsel and Water Policy Advisor. She has worked on collaborative, water-saving projects with agricultural producers, watershed groups, and federal and state agencies for almost two decades and she has helped grow TU's water work to nine western states to restore and maintain stream-flows for healthy trout rivers. She has worked to create more state and federal funding for collaborative conservation work through such vehicles as the Farm Bill, SECURE Water Act, and Army Corps funding.

KATHERINE ZITSCH serves as Manager of the Natural Resources Division at the Atlanta Regional Commission (ARC). In this role, she is responsible for overseeing the work of the Metropolitan North Georgia Water Planning District, the 15-county water planning agency for Metropolitan Atlanta. Katherine also coordinates ARC's work on water litigation issues, oversees ARC's Green Communities program, and oversees implementation of the Metropolitan River Protection Act. Prior to working for the Atlanta Regional Commission, Katherine was a Vice President with CDM Smith, an environmental engineering consulting firm.

APPENDIX B2

PARTICIPANT LIST

(alphabetical by last name)

Jacob Adler	U.S. Environmental Protection Agency
Nathan Allen	WaterStart
Lee Angelelli	IBM
Diego Arias	World Bank Group
Jennifer Arrigo	U.S. Global Change Research Program
Leah Baker	U.S. Department of the Interior
John Balay	Susquehanna River Basin Commission
Holly Bamford	National Fish and Wildlife Foundation
Daniel Bannier	Rural Community Assistance Corporation
Braelan Barnett	Center for Water Security and Cooperation
Mike Bawden	Mayor, Riverdale, IA
Nancy Beller-Simms	National Oceanic and Atmospheric Administration
Natalie Bennett	U.S. Global Change Research Program
Carolyn Berndt	National League of Cities
Aubrey Bettencourt	U.S. Department of the Interior
Katherine Bevington	National Oceanic and Atmospheric Administration
Annalise Blum	Johns Hopkins University
Astor Boozer	U.S. Department of Agriculture
Angela Bowman	John Deere
Jolie Breeden	Natural Hazards Center
Sarah Brennan	National Aeronautics and Space Administration
Patrick Breysse	Centers for Disease Control and Prevention
Greg Browder	World Bank Group
Rosalyn Brummette	U.S. Senate Agriculture Nutritionand Forestry Committee
Mark Brusberg	U.S. Department of Agriculture
Bevin Buchheister	National Governors Association
Eileen Burke	World Bank Group
Brenda Burman	Bureau of Reclamation
Faith Burns	U.S. Department of Agriculture
Michael Buse	Lewis-Burke Associates, LLC
Shelby Callaway	U.S. Department of Agriculture
Isabella Caltabiano	Wilson Center
Alexandra Campbell-Ferrari	Center for Water Security and Cooperation
Adam Carpenter	American Water Works Association
Nicole Carter	Congressional Research Service
Melissa Castera	World Bank Group
Chuck Chaitovitz	U.S. Chamber of Commerce
Elizabeth Clark	National Oceanic and Atmospheric Administration
Don Cline	U.S. Geological Survey
Peter Colohan	Internet of Water, Duke University
Chelsea Combest-Friedman	National Oceanic and Atmospheric Administration
Michael Connor	WilmerHale
Elizabeth Conzo-Kershner	John Deere
Daniel Cotter	U.S. Department of Homeland Security
Brittany Croll	National Oceanic and Atmospheric Administration
April Croxton	National Oceanic and Atmospheric Administration
Bill Cunningham	U.S. Geological Survey
Julie Cunningham	Oklahoma Water Resources Board
Barbara De Rosa-Joynt	U.S. Department of State

Jonathan DeHart	Office of the Deputy Assistant Secretary of Defense
Veva Deheza	National Oceanic and Atmospheric Administration
David DeWitt	National Oceanic and Atmospheric Administration
Lucy Dickhoff	The Water Research Foundation
Emily Durham	Lewis-Burke Associates, LLC
Theresa Eisenman	Bureau of Reclamation
Joaquin Esquivel	State of California, Water Resources Control Board
Lisa Fantinato	U.S. Department of Agriculture
Carol Flaute	Nebraska Department of Natural Resources
Peter Folger	Congressional Research Service
Richard Fordyce	U.S. Department of Agriculture
Elizabeth Foster	Urban Land Institute
Josh Foster	American Society of Adaptation Professionals (ASAP)
David French	ENS Resources
Brian Fuchs	National Drought Mitigation Center
Neal Fujii	State of Hawaii, Department of Land and Natural Resources
Aliza Furneaux	U.S. Environmental Protection Agency
Mariah Furtek	Wilson Center
Tim Gallaudet	National Oceanic and Atmospheric Administration
Gerry Galloway	University of Maryland
Fern Gibbons	U.S. Senate Committee on Commerce, Science, and Transportation
Mark Glaudemans	National Oceanic and Atmospheric Administration
Sherri Goodman	Wilson Center
Roger Gorke	U.S. Environmental Protection Agency
Stephanie Granger	National Aeronautics and Space Administration
Monica Grasso	National Oceanic and Atmospheric Administration
Peter Grevatt	Water Research Foundation
Lee Gunn	Lee Gunn Group
Jimmy Hague	The Nature Conservancy
Eric Hanson	U.S. Department of Commerce
Nagaraja Harshadeep	World Bank Group
Kelly Hereid	Chubb
Chris Hess	U.S. Department of Agriculture
Wayne Higgins	National Oceanic and Atmospheric Administration
Doug Hilderbrand	National Oceanic and Atmospheric Administration
Debbie Hill	U.S. Department of Agriculture
Julie Hill-Gabriel	National Audubon Society
Melissa Hopkins	The Center for Water Security and Cooperation
Fiona Horsfall	National Oceanic and Atmospheric Administration
David Hunter	Electric Power Research Institute
Justin Huntington	Desert Research Institute
Maggie Hurwitz	National Oceanic and Atmospheric Administration
Austin Igleheart	National Association of Counties
Tom Iseman	The Nature Conservancy
Neil Jacobs	National Oceanic and Atmospheric Administration
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Kevin Jayne	U.S. Department of Energy
Robert Johansson	U.S. Department of Agriculture
Andrea Juarez-Lucas	World Bank Group
Christopher Kearney	The Ferguson Group
Patrick Kelly	Office of the Deputy Assistant Secretary of Defense
Melissa Klein	U.S. Environmental Protection Agency
David LaFrance	American Water Works Association
Upmanu Lall	Columbia University
Adam Lang	National Oceanic and Atmospheric Administration
Nicole LaRosa	Federal Emergency Management Agency
Jason Larrabee	Van Ness Feldman LLP
Chris Lauer	National Oceanic and Atmospheric Administration
Stu Levenbach	National Oceanic and Atmospheric Administration
Geraldine Link	National Ski Area Association
Jim Lochhead	Denver Water

Sue Lowry	Interstate Council on Water Policy
Ian Lyle	National Water Resources Association
Carol Lynn MacCurdy	U.S. Department of State
Natalie Mamerow	American Society of Civil Engineers
Lea Markley	Institute for Global Environmental Strategies
Aubrey Massmann	U.S. Global Change Research Program
Fiona Martin	Visualizing Science, LLC
Mark Masters	ACF Stakeholders
Mark Matlock	Pennsylvania Department of Environmental Protection
David Matthews	U.S. Department of Agriculture
Lauren Mayer	U.S. Environmental Protection Agency
Darion Mayhorn	Bureau of Reclamation
Jon McClean	Evoqua Water Technologies
Daron McDaniel	Supervisor, Merced County
Shaun McGrath	Montana Department of Environmental Quality
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Melissa Mejias	U.S. Environmental Protection Agency
Zachery Michael	U.S. Department of Energy
Kimberly Miller	Office of Management and Budget
Fernando Miralles-Wilhelm	The Nature Conservancy
Dave Mitamura	National Water Supply Alliance
Joe Montoni	Office of Management and Budget
Meredith Muth	National Oceanic and Atmospheric Administration
Bala Narapusetty	National Oceanic and Atmospheric Administration
Michael Nardolilli	Interstate Commission on the Potomac River Basin
Claudia Nierenberg	National Oceanic and Atmospheric Administration
Bill Northey	U.S. Department of Agriculture
Kevin Norton	U.S. Department of Agriculture
Marilee Orr	U.S. Department of Homeland Security
Jennifer Orr-Greene	Pennsylvania Department of Environmental Protection
Elizabeth Ossowski	National Oceanic and Atmospheric Administration
Donna Page	National Oceanic and Atmospheric Administration
David Palumbo	Bureau of Reclamation
Brittany Parker	National Oceanic and Atmospheric Administration
Tim Parker	Parker Groundwater
Colby Pellegrino	Southern Nevada Water Authority
Tim Petty	U.S. Department of the Interior
Sandra Pinel	U.S. Department of Homeland Security
Benjamin Pratt	Susquehanna River Basin Commission
Warren Preston	U.S. Department of Agriculture
Christine Prouty	American Society of Civil Engineers
Roger Pulwarty	National Oceanic and Atmospheric Administration
Amanda Quintana	U.S. Global Change Research Program
Abigail Rader	U.S. Environmental Protection Agency
Jon Radtke	The Coca-Cola Company
David Raff	Bureau of Reclamation
David Reynolds	Association of California Water Agencies
Brad Rippey	U.S. Department of Agriculture
Natalie Rochmann	Reinsurance Association of America
David Ross	U.S. Environmental Protection Agency
Tracy Rouleau	TBD Economics
Edgar Ruiz	Council of State Governments, West
Claudia Saavedra	Cargill
Vasit Sagan	St. Louis University
Keaton Sandeman	The Nature Conservancy
Jennifer Sara	World Bank Group
Lynn Schloesser	American Council of Engineering Companies
Cherie Schultz	Interstate Commission on the Potomac River Basin
Jim Schwab	Urban Planner
Adria Schwarber	American Institute of Physics
Laura Schweitzer	Council of Western State Foresters

Ward Scott	Western Governors' Association
Andrew Shaffer	U.S. Department of Agriculture
Geoffrey Sheaffer	U.S. Department of Agriculture
Amanda Sheffield	National Oceanic and Atmospheric Administration
Reid Sherman	U.S. Global Change Research Program
Nick Shufro	Federal Emergency Management Agency
Matthew Siegel	U.S. Department of Commerce
Daniel Simmons	U.S. Department of Energy
Morgan Snyder	Walton Family Foundation
Mackenzie Solomon	National Oceanic and Atmospheric Administration
Samantha Staskiewicz	American Institute of Physics
Melanie Steele	Council on Environmental Quality
Jan Stoddard	Montana Office of Tourism and Business Development
Jack Stuart	Stimson Center
Mark Svoboda	National Drought Mitigation Center
Jessica Tanner	Association of California Water Agencies
Brandt Thorington	Mississippi River Cities and Towns Initiative
Richard Tinker	National Oceanic and Atmospheric Administration
Camille Calimlim Touton	House Committee on Transportation and Infrastructure
Diane VanDe Hei	Association of Metropolitan Water Agencies
Rachel von Gnechten	International Water Management Institute
Kevin Wagner	Universities Council on Water Resources
Kirsten Wallace	Upper Mississippi River Basin Association
Mary-Ann Warmerdam	Rural County Representatives of California
Robert Webb	National Oceanic and Atmospheric Administration
Elizabeth Weight	National Oceanic and Atmospheric Administration
Colin Wellenkamp	Mississippi River Cities and Towns Initiative
Cynthia West	U.S. Forest Service
Don Wilhite	University of Nebraska
Anthony Willardson	Western States Water Council
Alexa Williams	House Committee on Transportation and Infrastructure
Luke Wilson	The Center for Water Security and Cooperation
Molly Woloszyn	National Oceanic and Atmospheric Administration
Makena Wong	National Audubon Society
Sally Yozell	Stimson Center
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