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Hearing on the Status of Drought Conditions Throughout the Western United States

Before the
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Subcommittee on
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*Introduction*

Thank you for the opportunity to testify today regarding drought conditions across the United States, and the products, information, and services that the National Oceanic and Atmospheric Administration (NOAA) provides to mitigate drought's impacts. The role of NOAA in protecting people's livelihoods and ecosystems in times of drought is a vital one. My testimony today will detail the current drought conditions and forecasted outlook, and will offer insights into the national capabilities NOAA is delivering to drought-affected communities.

Throughout our nation's history, droughts have taken a significant toll on communities in ways unique from other extreme weather events. Drought is the absence of precipitation, rather than the presence of an event, such as a hurricane. Its onset has no precise appearance to it, nor does its termination. It is often described as a "creeping phenomenon" because it operates on many different timescales at which it slowly impacts many sectors of the economy - from large-scale agriculture and hydropower, to small recreation and tourism businesses. However, the force of these events should not be understated simply because their presence is not always visible or quickly felt. According to NOAA's National Centers for Environmental Information (NCEI), droughts cost the United States an average of $6.3 billion annually, and they can also exacerbate the conditions that lead to wildland fires with multi-billion-dollar losses - wildfire impacts totaled $16.5 billion in 2020 alone.

According to the U.S. Drought Monitor,[1] nearly 40% of the United States is currently experiencing at least moderate drought. Across much of the Southwest, California, and parts of

[1] The U.S. Drought Monitor produces weekly maps depicting the severity and extent of drought in the United States. Since its inception in 1999, it has been produced jointly by NOAA, the National Drought

the Pacific Northwest and Missouri River Basin, the footprint of drought is significantly worse with severe to exceptional drought throughout those regions. According to NCEI, from April 2020 to March 2021, Arizona, New Mexico, Nevada, and Utah had their driest April to March period in 126 years, with California and Colorado having their third and fourth driest April to March period, respectively. As such, snowpack is well below average across the Southwest, Utah, California, and portions of Nevada and Colorado. Snow drought and early, accelerated snowmelt have raised serious concerns about available water this summer. In particular, snow drought conditions returned in winter 2020–2021 to the Sierra Nevada Mountains where snowpack peaked at 60% of normal and then experienced a rapid and early decline, currently the fifth earliest melt on record. Poor soil moisture conditions have also plagued much of the region since early 2020.

As drought persists, negative impacts on numerous sectors amplify. Recent NOAA-supported research on drought impacts in the West demonstrates that each additional month under extreme drought conditions decreases corn and wheat production by more than 3%; reduces total wages paid to employees in agriculture and in agricultural supply by 0.5%; and reduces total employment in the agricultural supply sector by 1.2%. Additional impacts are experienced when drought reduces water supplies. For regions that depend on irrigation for agriculture production, including Arizona where 96% of crop acreage is irrigated, reservoir storage and irrigation management provide a buffer against short-term drought, but longer-term drought affects reservoirs, causing significant crop losses.

The current U.S. Seasonal Drought Outlook produced by NOAA's Climate Prediction Center predicts continuation of the current drought across the southwest United States and development of drought across the northwest United States over the next several months. Amelioration of drought in the southwest United States will depend on the strength and timing of the Southwest Monsoon. The Southwest Monsoon is a pattern of enhanced rainfall during the Northern Hemisphere Summer (June-September), which impacts New Mexico, Arizona, Colorado, and Utah.

Continued warmer- and drier-than-normal conditions across the West into this summer have many implications for significant fire activity. According to the National Interagency Fire Center Predictive Services, the Southwest is forecast to have above-normal significant fire potential through June before the Southwest Monsoon arrives. The region will get a reprieve if we get a near normal Monsoon season. Other regions of the West are expected to have above-normal significant fire potential, including parts of the Great Basin and Rockies and Central Oregon into southeast Washington beginning in June, with portions of the Coast Ranges, Sierra, and Cascades in California increasing to above normal in June and July and continuing through August. Vegetation drying earlier than normal, such as at high elevations where below normal snowpack is rapidly melting, will prime some areas for earlier-than-normal fire seasons, depending on weather (i.e., fire weather) conditions.

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Mitigation Center at the University of Nebraska-Lincoln, and the U.S. Department of Agriculture (USDA). https://www.cpc.ncep.noaa.gov/products/Drought/

According to the last National Climate Assessment (2018), high temperatures are projected to worsen the intensity, duration, and frequency of drought over the coming decades in the western United States and in similar climates around the world. NOAA science plays a vital role in informing the Nation about drought and changes in the climate system. Ongoing research and investment is advancing our capabilities in drought monitoring and prediction, and delivering innovative new ways to understand and better communicate timely and relevant drought information to mitigate its negative impacts on livelihoods and ecosystems.

*NOAA's Drought Portfolio*

NOAA's drought products and services stand firmly rooted upon our agency's world-class Earth System and climate science, reaching Americans from farms to fisheries to the floor of the Chicago Mercantile Exchange. NOAA subseasonal to seasonal forecasts, which support forecasting of drought conditions, are climate forecasts and are supported by both the Weather Research and Forecasting Innovation Act of 2017[2] and the National Integrated Drought Information System Reauthorization of 2018.[3] They rely on observations and monitoring over land, but also on our ability to observe the ocean and detect large scale climate patterns like El Nino and La Nina. As I often say, if you like your seasonal forecast, thank an oceanographer.

Our leadership on drought issues as an agency is also demonstrated by our National Integrated Drought Information System (NIDIS), originally authorized by Congress with bipartisan support in 2006[4] and reauthorized in 2014 and 2019.[5] NIDIS has an interagency and intergovernmental mandate to coordinate and integrate drought research, building upon existing federal, tribal, state, and local networks in support of creating a national drought early warning system. NIDIS fosters an applied research environment that focuses on drought risk assessment, forecasting, and proactive management. Through its eight Regional Drought Early Warning Systems (DEWS) nationwide, NIDIS and its partners provide the leadership and partnerships to ensure successful implementation of integrated national drought monitoring and forecasting into decision making.

Given the serious nature of current western drought conditions, NIDIS is proactively supporting state leaders to prepare for drought, wildfire, and water supply deficits by communicating those conditions, forecasts, impacts, and escalating risks in the region with consistent, coordinated information delivery. Across the Southwest in particular, including California, NIDIS is partnering with U.S. Department of Agriculture's (USDA) Climate Hubs, NOAA's Regional Climate Centers, the California Nevada Climate Applications Program - a NOAA Regional Integrated Sciences and Assessments (RISA) team, and others. Through these partnerships, NIDIS provides regular drought and snow drought updates to thousands of stakeholders; hosts monthly or bimonthly webinars for the public and the media on conditions, outlooks, and helpful decision-making tools; and convenes regular interagency meetings to ensure coordinated response efforts.

[2] Pub. L. No. 115-25.
[3] Pub. L. No. 115-423.
[4] National Integrated Drought Information System Act of 2006, Pub. L. No. 109-430.
[5] National Integrated Drought Information System Reauthorization Act of 2014, Pub. L. No. 113-86; National Integrated Drought Information System Reauthorization Act of 2018, Pub. L. No. 115-4234.

NOAA, together with states in the Southwest, Federal agencies, tribes, and other partners, will convene a Southwest Drought Virtual Forum this summer focused on collaborative solutions to address the crisis and improve long-term resilience. The Southwest Forum follows on and will localize national-level resilience actions identified at the 2019 National Drought Forum, which was planned and coordinated by NIDIS, along with the federal National Drought Resilience Partnership (NDRP).

In January 2021, NOAA launched a completely redesigned U.S. Drought Portal (www.drought.gov) to better connect communities across the United States with resources to strengthen their resilience to drought. The Drought Portal is the only Federal website of its kind, providing a one-stop shop for data, decision-support products, and information on drought from across the Federal government, tribal nations, state and regional organizations, academia, and the private sector. On Drought.gov, Americans can view current drought conditions and forecasts at a high resolution—from the city and county level to state, watershed, and global scales—and explore interactive, easily shareable maps and statistics on precipitation conditions, snow drought, soil moisture, wildfires, and more. The Drought Portal also aggregates and presents drought impact data for economic sectors such as agriculture, energy, water utilities, and recreation and tourism.

Through these efforts, NOAA is able to connect decision makers, the media, and the private sector with easy-to-understand resources for drought monitoring, forecasting, and planning, all in one place. For example, on Drought.gov's Historical Data and Conditions page, users can explore past conditions for their state or county across three historical drought datasets, using an interactive map and time series graph. These three datasets (showing drought conditions as far back as 2,000 years ago) have never been displayed side by side before, with graphics and statistics that are easy to include in media briefings, state drought plans, impact assessments, and reports. The Drought Portal also includes a new interactive, up-to-date map of all drought information statements issued by Weather Forecast Offices, describing local drought conditions, outlooks, and impacts. This centralized access to timely, reliable, and actionable drought information from a wide network of partners is especially important as drought conditions continue to worsen across the West.

NOAA operates many of the observing systems that inform drought, particularly space-based platforms that allow for spatially complete observation and estimation of soil moisture, vegetation condition, and fire danger. Ground-based observations from NOAA's National Mesonet Program, Automated Surface Observing System, Cooperative Observer Network, and others critically assist to "ground truth" and calibrate the satellite data. NOAA's NCEI maintains the official historical climate record that is used to compute and define drought over the past 100+ years, and this information is shared across our climate services partnerships. Weather and drought observations are collated across the country into its operational daily data sets. These include many high-altitude and western observations from networks run by USDA, stream gauges run by the U.S. Geological Survey (USGS), and other federal agencies that help characterize drought conditions in the unique western environment.

Additional products developed by NOAA to help stakeholders and the public monitor and prepare for drought conditions include the previously mentioned U.S. Drought Monitor, monthly and seasonal U.S. Drought Outlooks, and Drought Information Statements. Monthly and Seasonal Drought Outlooks[6] from NOAA's National Weather Service provide one- and three-month predictions of the evolution of drought conditions, including the onset of drought and amelioration of existing drought conditions. The U.S. Drought Monitor (USDM) is a joint effort of the National Drought Mitigation Center, USDA, and NOAA, and it is used by USDA to distribute drought relief to agricultural producers through programs such as the Livestock Forage Program. The USDM is a prime example of a cross-NOAA operational climate service partnership in action.

NOAA also has several examples of incorporating citizen science to help inform our science and drought monitoring. In January, the agency finalized the NOAA Citizen Science Strategy.[7] This Strategy outlines a path for the agency to engage the public in support of key mission areas. Citizen science as well as crowdsourcing, and challenge competitions, all provide opportunities for the agency to engage the American public, address societal needs and accelerate science, technology, and innovation. The National Weather Service's Cooperative Observer Program (COOP), created in 1890 and codified by Section 8 of the National Integrated Drought Information System Reauthorization Act of 2018, is the Nation's weather and climate observing network of, by and for the people. Nearly 9,000 volunteers take observations on farms, in urban and suburban areas, National Parks, seashores, and mountaintops. The data are truly representative of where people live, work and play. The COOP's purpose is to provide observational meteorological data required to define the climate of the United States and to help measure long-term climate changes, critical to drought depiction, monitoring, and forecasting. Similarly, NOAA's Community, Collaborative Rain, Hail and Snow Network (CoCORaHS) collects reports of precipitation, soil moisture, and soil condition measurements from over 20,000 volunteers which helps inform NOAA drought monitoring efforts, particularly in areas of otherwise-sparse instrumentation. Finally, the U.S. Drought Monitor includes a Drought Impact Reporter function that allows the interested public to submit drought impact and condition reports.

NOAA provides drought-related, impact-based decision support services to our regional and local partners. These services include partner briefings in times of drought, the issuance of Drought Information Statements, outlooks, local drought impacts, and co-developed workshops to help regional staff better utilize available drought monitoring and forecast tools, coordinate with partners and neighboring offices, and provide effective messaging and graphics to stakeholders. NOAA also provides drought-related capacity development, including tools for assessing climatological risks, and training for staff and partners on product and services. Professional development courses include distance learning modules and hands-on training practices.

[6] https://www.cpc.ncep.noaa.gov/products/Drought/

[7] https://sciencecouncil.noaa.gov/Portals/0/Citizen%20Science%20Strategy%20_final.pdf?ver=2021-01-15-103436-693

To address the growing demand for water resources forecasts and services in watersheds nationwide, NOAA has implemented and continues to evolve a new National Water Model.[8] This continental scale, state-of-the-science water prediction model provides service equity by creating low to high flow forecast guidance for nearly three and a half million miles of rivers and streams nationwide. It provides high resolution hydrologic guidance that significantly expands geographic coverage and provides water budget information.

Reconnaissance of atmospheric rivers is proving to be an extremely helpful forecast tool that water managers have begun to incorporate into decision making. This reconnaissance of atmospheric rivers occurs offshore by NOAA and other aircraft prior to landfall and the data can be assimilated into numerical weather prediction models to improve hydrologic and drought forecasts. This information can be essential as too few or too many atmospheric rivers in the winter can determine the difference between localized floods and droughts. While reservoir systems in the area are designed to deal with these extremes, issues remain. The U.S. Army Corps of Engineers and other water managers have partnered with meteorologists and hydrologists to establish that with accurate enough predictions of atmospheric rivers up to a few days out, it is possible to mitigate some of the challenges of managing through either drought or flood. This is Forecast-Informed Reservoir Operations (FIRO), and it is a partnership between the U.S. Army Corps, NOAA, the U.S. Bureau of Reclamation, the U.S. Geological Survey, the Sonoma County Water Agency, Scripps Institution for Oceanography Center for Western Weather and Water Extremes, the California Department of Water Resources, Orange County Water District, and the Yuba Water Agency. Much of the data from remote locations is transmitted via Geostationary Operational Environmental Satellite Data Collection System to central monitoring offices where alerts and warnings are generated.

FIRO is a reservoir-operations strategy that better informs decisions to retain or release water by integrating additional flexibility in operation policies and rules with enhanced monitoring and improved weather and water forecasts. Simply put, FIRO allows reservoir managers to use forecasts to determine whether to release additional water before a heavy rainfall event, or to retain water while managing flood risk. The FIRO Final Viability Assessment for Lake Mendocino in California has shown that FIRO is viable for the atmospheric river-fed basin and provides immediate and significant water-supply and environmental benefits. The assessment recommends officially updating the U.S. Army Corps Water Control Manual to reflect the FIRO strategy. Additional FIRO assessments are now underway at Prado Dam in Southern California and for the Yuba and Feather River systems in the northern Sierra.

NOAA is working with state partners across the West to share lessons learned from FIRO's success and explore future applications of FIRO in other areas. To inform FIRO pilot studies, NOAA completed work to implement the Hydrologic Ensemble Forecast Service (HEFS) that provides probabilistic streamflow and reservoir inflow forecasts for forecast ranges from hours to more than a year. Precipitation and temperature forecasts from NOAA's global atmospheric models are critical inputs to the probabilistic streamflow forecasts generated by HEFS.

[8] https://water.noaa.gov/about/nwm

Continued enhancement of these global models will improve HEFS streamflow and reservoir inflow forecasts to better inform decisions made by reservoir operators, particularly in watersheds with competing demands. These forecasts are particularly critical to California reservoir operators to help them manage outflow to meet user needs.

Forecast skill for predicting drought onset has been relatively flat for the past fifteen years. This is strongly tied to similar slow progress in improving the prediction skill for precipitation on seasonal timescales. This lack of improvement in seasonal precipitation prediction skill underscores the need for addressing this grand challenge in a systematic way in order to provide enhanced climate services for stakeholders from the water resources, agriculture, and other sectors.

NIDIS is investing in efforts to improve our agency's suite of drought outlook forecasts and products, creating new probabilistic drought outlooks for drought across time scales from weeks (e.g. flash drought) to months, answering a long-requested, decision-making need. These investments will also include multi-year social science research to improve the understandability and useability of NOAA's Climate Prediction Center drought and hazards outlook products.

Drought can also impact wildland fire planning, fire behavior, fire effects, and subsequently wildland fire management overall. While local weather—temperature, wind, and humidity—drives day-to-day fire activity, the timing, intensity, and frequency of drought events can have wildly divergent impacts on fuel flammability and fire behavior. Wildland fire management agencies are also challenged with drought-related impacts from increased uncertainty in decisions and long-term planning, to changes in suppression and prescribed fire resource availability, to the need for more agency coordination. NOAA's NIDIS Drought and Wildland Fire Nexus (NDAWN) defines the needs and challenges of fire managers to effectively use drought information and aims to establish a robust drought and wildland fire decision-support information network.

Ongoing work through NDAWN has real-time benefits for both wildland firefighters and public health and safety in fire-prone areas across the West. For example, in California and Nevada, NDAWN partners are vetting and integrating common drought indices, such as the Evaporative Demand Drought Index (EDDI), into the Significant Wildland Fire Outlooks issued by the National Interagency Fire Center Predictive Services. EDDI is a powerful tool that, among other indicators, can offer early warning of fire-weather risk by providing near-real-time information on the emergence or persistence of anomalous evaporative demand in a region. NDAWN partners including NOAA and the National Wildfire Coordinating Group,[9] are also supporting a multiyear assessment of the Red Flag Warning forecast product with the aim of developing an improved product that meets NWS, the fire management community, and public warning needs.

Soil moisture is widely recognized as a critical but currently under-utilized land surface variable that can provide valuable insights for drought early warning, as well as applications such as agricultural monitoring, forest management, fire risk assessment, and more. Working in

[9] The National Wildfire Coordinating Group provides national leadership to enable interoperable wildland fire operations among federal, state, local, tribal, and territorial partners.

partnership with the USDA, USGS, National Aeronautics and Space Administration (NASA), U.S. Army Corps of Engineers, and others, NOAA is leading the strategic development of a National Coordinated Soil Moisture Monitoring Network (NCSMMN), a multi-institutional initiative to accelerate soil moisture data integration and research, and to capitalize on its transformative potential for decision making across a wide range of applications. Early successes of the NCSMMN include coordinated multi-state soil moisture network expansions in the Upper Missouri River Basin and in the southeastern U.S., both previously underrepresented areas, as well as the development of proof-of-concept gridded national soil moisture maps that blend in situ, satellite, and modeled data. As a key component of NOAA's investment in soil moisture information, a state-of-the art soil moisture sensor network has been established as part of the U.S. Climate Reference Network (USCRN). The USCRN provides high-quality national climate data, and its soil moisture component includes best-in-class triple sensor collocation, innovative approaches to data validation and quality control, and leading research on soil moisture data mapping, blending, and interpretation for drought early warning. NOAA NIDIS in partnership with the NCSMMN recently issued a National Coordinated Soil Moisture Monitoring Network strategy as required by the National Integrated Drought Information System Reauthorization Act of 2018.[10]

Indigenous experiences and perspectives of drought vary greatly across the United States, and to ensure the inclusion of these perspectives in our work, NOAA recently released a Tribal Drought Engagement Strategy for 2021-2025,[11] presenting guiding principles of tribal engagement, as well as key outcomes and activities to build tribal drought resilience across the country.

Finally, while addressing the current western drought crisis is a priority, the region's warming and drying trends indicate that future droughts may be more frequent, widespread and/or severe. It is vitally important that today's crisis response strengthens long-term drought resilience. This requires reducing inequitable impacts of drought and addressing critical drought risks and vulnerabilities through our nation's regional drought early warning systems. These systems provide long-term decision support services to state drought monitoring and planning entities in California, Nevada, Colorado, Arizona, and Utah to prepare for and respond to drought within the broader context of the region's water resources and across other natural hazards.

*The Role of Partnerships*

Partnerships are key to NOAA's successful development and delivery of drought information where it is needed most - in the hands of decision makers, business owners, land and water managers, and vulnerable communities. Partnership begins where the most critical decisions are being made on the management of water and other natural resources in times of drought. Much of the work I just noted is successful due to the variety and depth of the partnerships

[10] 15 U.S.C. § 313d(f).

[11] https://www.drought.gov/documents/nidis-tribal-drought-engagement-strategy-2021-2025#:~:text=The%20project%20aimed%20to%20strengthen,timely%20and%20relevant%20drought%20information

involved. For example, the all-hands-on-deck activities to respond to ongoing drought developments in the western U.S. are made possible through our partnerships across government, academia, and stakeholder groups.

Through DEWS, state, tribes, and local government agencies coordinate regularly with NOAA and other Federal agencies to determine current drought conditions, outlooks, and impacts; to strengthen our understanding of drought through scientific advancements and innovation; and to exchange information on drought-related challenges where NOAA can add value.

Through an ongoing, iterative process to respond to needs on the ground, we work closely with Federal partners to coordinate resources and avoid duplication of efforts. NIDIS worked with the Department of the Interior's Climate Adaptation Science Centers to host a national webinar series to examine ecological drought, share actions that strengthen ecosystem resilience, and discuss research and management needs moving forward, which NIDIS is integrating into an FY21 grant opportunity. NOAA is working with FEMA and other interagency, cross governmental, and academic partners to build out an interactive Drought Planning Platform within the U.S. Drought Portal.

Academic partners such as the National Drought Mitigation Center at the University of Nebraska Lincoln — a key partner in the production and delivery of the U.S. and North American Drought Monitors — are critical to our success as reliable long-term partners for understanding and acting on drought. University partnerships through our various Cooperative Institutes, RISAs, state Sea Grant programs, and NOAA Cooperative Science Centers enhance our capacity to conduct research, connect with communities, and build the next generation of scientists who will advance the field.

Partnerships with national-level organizations representing sectors deeply impacted by drought events are also vitally important. The U.S. Chamber of Commerce supported NOAA in hosting a National Drought Forum in 2019, which linked drought to national security issues, examined water scarcity and increasing aridity in the West, explored the cost of drought, and highlighted private sector advancements in water conservation, precision agriculture, and public-private partnerships. The Western States Water Council, along with the Western Governors Association, is also an essential partner in ensuring the needs of western decision-makers are accounted for in strengthening NOAA's drought tools and resources. In addition, the American Water Works Association provides NOAA with a valuable network upon which to disseminate and collaborate on drought-related information and resources that are meaningful to water utilities impacted by drought events. The American Association of State Climatologists is an active participant and partner in improving NOAA's climate services, broadly and with respect to drought.

*Climate Services*

NOAA touches every U.S. community and business with information to help them understand how weather, water, and climate conditions are changing, and how they can prepare. For over

50 years, NOAA has built the climate science and services structure that provides actionable information American communities and businesses need to address the climate crisis. NOAA is immensely prepared to accelerate the nation's progress in building back *better* in the face of a changing climate--better adaptation, better resilience.

NOAA produces trusted, usable climate information that evolves based on stakeholder needs, helping the public, and other decision makers understand how the Earth's climate is changing, how that change is affecting their lives, and what they can do to protect human lives, property, and natural systems. We make available stakeholder-driven research and offer extensive education, outreach, and technical assistance to a broad suite of local, state, and regional partners that specialize in community-based engagement. In an increasingly global society, climate impacts and response strategies around the world affect the well-being of communities within U.S. borders, as well as private and public sector international investments in: commerce (e.g., supply chain continuity, trade); international development and humanitarian assistance (e.g., sustainable development goals, migration, disaster relief); public health and safety (e.g., food security, infectious diseases); and national security (e.g., conflict and stability, migration). NOAA will reinvigorate its long-term commitment to international scientific collaboration and leadership through strategic investments in adaptation research and capacity building that reflect the global nature of climate's impact across commerce, health, security and development and its role in resilience. An international community working together to prepare for and adapt to climate change in support of climate resilient pathways using sound, interdisciplinary climate science, is a safer and more productive one for the U.S. and for the rest of the world.

NOAA also serves and contributes to our nation's and the world's leading scientific organizations, including the U.S. Global Change Research Program and its National Climate Assessment, the World Meteorological Organization (WMO), the World Climate Research Programme, the United Nations Intergovernmental Panel on Climate Change, the U.S. military, tribal, state, and regional governments, NGOs, the U.S. scientific community, and private sector companies across a broad swath of our nation's economy.

Given the importance of drought worldwide and in line with NOAA mission and mandates, NOAA has long been engaged in international collaborative efforts that foster proactive drought risk reduction through leading roles within the United Nations (UN) WMO's Integrated Drought Management Programme and Expert Team on Drought; the UN Office for Disaster Risk Reduction; the UN Convention to Combat Desertification; the Global Water Partnership; and the Commission for Environmental Cooperation (CEC), which addresses shared priorities identified by the governments of the U.S., Canada, and Mexico.

Through these engagements, NIDIS's holistic, integrated drought early warning systems approach has proven to be successful and is being replicated and scaled globally. For example, NIDIS serves on the Steering Committee for the CEC's 2019-2021 initiative on improving the effectiveness of early warning systems for drought across the U.S, Mexico and Canada. The project produced guidelines on drought indicators and indices for North America and

recommendations for local communities to improve their access to and use of tools for drought and multi-hazard planning. Similarly, as a member of the WMO Expert Team on Drought, NIDIS is contributing to a report on drought early warning systems around the world, as well as updating the global WMO Handbook of Drought Indicators and Indices.

The North American Drought Monitor (NADM) is a cooperative effort between drought experts in Canada, Mexico and the United States to monitor drought across the continent on an ongoing basis. The program was initiated in 2002 and is part of a larger effort to improve the monitoring of climate extremes on the continent. As with the U.S. Drought Monitor, the NADM synthesizes multiple indices, outlooks and local impacts, into an assessment that best represents current drought conditions. The final map is a consensus of federal, state and academic scientists and is updated every month.

*Future Outlook*

As more climate, weather, and remote sensing products become available, approaches to allow decision makers to quickly access, analyze, and visualize these environmental data at relevant scales is lacking. Specifically, there is a need to quickly process and visualize data to improve monitoring and early warning of drought, groundwater dependent ecosystems, fire danger, and crop failure risk. In response to this need, NOAA's NIDIS program supports the Desert Research Institute and University of Idaho in partnership with Google and other federal agencies, to develop ClimateEngine.org — an innovative web application that enables users to quickly process and visualize satellite earth observations and gridded weather data for environmental monitoring. NIDIS's support of Climate Engine has provided opportunities to leverage the tool's capabilities, such as in collaboration with NASA's Western Water Applications Office work supporting the Navajo Nation Resource Managers. Additionally, the Department of Interior's Bureau of Land Management, which administers nearly 48 million acres of public land in Nevada, uses Climate Engine in grazing allotment decision making.

In the coming years, NOAA's drought information, tools, and products will include new drought indicators to provide early warning of flash drought events, which develop rapidly and can cause significant agricultural impacts. We are also working to enhance the consistency and effectiveness of local drought messaging, through regional collaboration and by working in coordination with partners and stakeholders. These trainings will include updated professional development courses that will utilize modern training techniques and virtual tools such as webinars. In addition, NOAA programs are developing techniques and concepts to advance the operationalization of climate extreme event attribution, particularly for drought events and thermal (hot/cold) events. The fruits of this work will help clarify how climate change may or may not impact the severity or duration of drought events while the impacts of those events, and related lessons, are still fresh in the public's mind.

Advances in modeling will continue to improve our ability to predict extremes such as drought. NOAA's Seamless System for Prediction and EArth System Research (SPEAR) model was developed as a next generation modeling system for seasonal to multidecadal prediction and

projection. In February 2021, SPEAR real-time seasonal predictions became part of the North American Multi-Model Ensemble, an effort to combine multiple global systems to generate seasonal predictions and support operational seasonal outlooks (e.g., temperature, precipitation, Atlantic hurricane outlook, winter outlook). In addition to real-time experimental predictions, the new SPEAR system will be used as the foundation for ongoing research toward improving climate predictions and projections on timescales from one season to multiple decades ahead, with a focus on climate extremes. These extremes include hurricanes, drought, heat waves, atmospheric rivers, and hydrologic extremes.

Early model performance indicates that SPEAR has extended the timescale at which important phenomena can be predicted. New experimental work with this model has shown predictive skill for atmospheric rivers as much as 10 months in advance, a major breakthrough for extended prediction of the western U.S. water resources. Current performance results suggest that SPEAR is a significant advance in our ability to make predictions on seasonal to multidecadal time scales. The SPEAR system is also used to make decadal climate predictions that are transmitted to the UK Meteorological Office as part of a WMO international collaborative activity. In addition, cloud computing and related technologies (e.g., artificial intelligence, machine learning, “big data” operations) will facilitate a next generation of climate services.

Droughts are among the most damaging of all natural hazards, with annual economic losses for the U.S. often in the billions of dollars. The future outlook on drought conditions is not promising; we expect to see longer and more intense fire seasons and greater aridification in the West. However, NOAA is prepared to work with our federal, tribal, state, and local partners to provide the best science, products, and climate services possible to meet those future challenges.