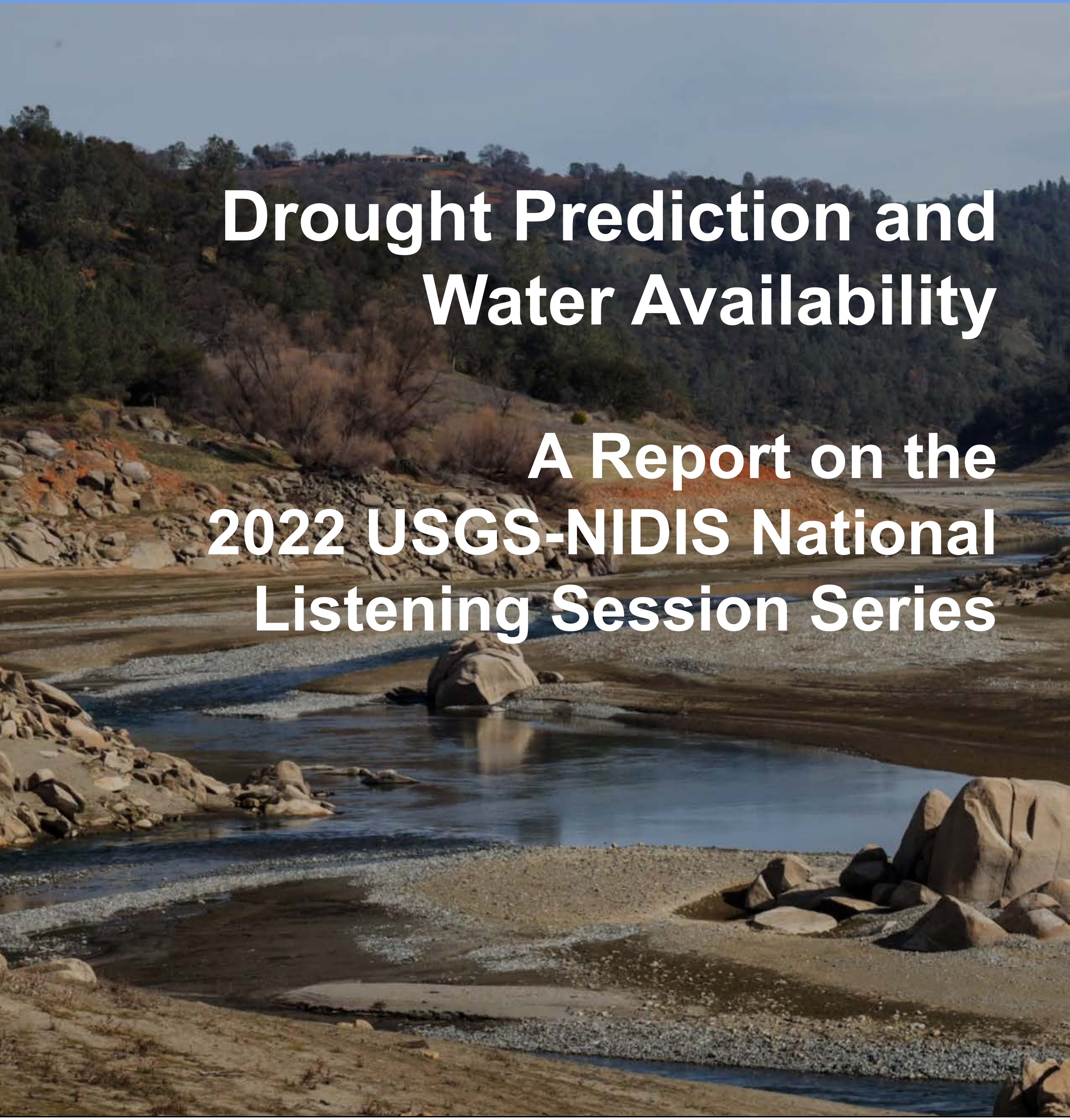

Drought Prediction and Water Availability

A Report on the 2022 USGS-NIDIS National Listening Session Series

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Findings from the USGS-NIDIS Drought Prediction and Water Availability Listening Sessions reflect the dialogue and discussion of participants, and do not represent official Administration policy or position, or an official policy or position of the individual organizations/agencies represented at the sessions; the findings do represent the general views of the National Integrated Drought Information System and the U.S. Geological Survey.

Table of Contents

Executive Summary

The U.S. Geological Survey (USGS) and the National Oceanic and Atmospheric Administration's (NOAA) National Integrated Drought Information System (NIDIS) conducted a series of four Listening Sessions in 2022 – each with a different application or topical focus – to seek input on priorities and needs related to predicting water availability changes under drought conditions at national and regional scales. This input was gathered to help inform the USGS Drought Program, regional and national drought efforts at NIDIS, and other national drought efforts. The series started with a February 2022 kick-off that introduced the series of Listening Sessions being held from March through September 2022. This kickoff also provided an overview of the USGS Drought Program's work to characterize hydrological (e.g., streamflow and groundwater) drought, drought variability, drivers, and trends over the past century. Participants in these Listening Sessions included diverse stakeholder representation and perspectives.

The first of the four Listening Sessions focused on **streamflow** (March 3, 2022) and included a short introduction to the USGS national streamflow drought research, the properties of a national drought prediction system, as well as presentations by other agencies on different drought prediction and forecasting efforts. The second session focused on **groundwater** (May 5, 2022), and included presentations on groundwater drought, sustainable groundwater management, and improving our understanding of soil moisture, groundwater, and surface water drought. The third session focused on **water use** (July 14, 2022), and included a discussion of the different drought types, as well as an introduction to several key projects, including the USGS Upper Colorado River Basin Study, the Ogallala Data Directory project, and a multi-agency drought prediction partnership in Oklahoma. The fourth and final Listening Session focused on **water availability prediction for ecosystems** (September 8, 2022) and included presentations on the development of a national capacity for eco-hydrological and drought science, building climate resilience, and actionable ecodrought resources.

Each of the four Listening Sessions included break-out discussions related to participants' current use of hydrologic data as well as research priorities for product and information development or improvement at the national and/or regional scale to support drought decision making. Questions asked included:

1. How do you use hydrologic information to anticipate changes related to drought conditions?
2. Based on your organization, what are challenges, special considerations, or common uncertainties for predicting changes related to drought, or in other words, what about drought makes your job hard?
3. What products or indices do you currently use to predict hydrologic changes in your region?
4. What improvements to hydrologic information and prediction would help you the most?

Top information and prediction improvements needed, identified from breakout session discussions in each Listening Session, are as follows:

- For **streamflow**:
  - A watershed forecasting approach that communicates forecasts based on key contributing factors for each area,
  - Providing a range of prediction values, at multiple time scales from annual to weekly, with uncertainty estimates included, and
  - Data enhancement: integrating different datasets and increasing monitoring of underserved areas.
- For **groundwater**:
  - Improving our understanding between soil moisture, groundwater, and surface water drought, including assessment of how groundwater data correlates with other indices,
  - Higher spatial resolution and monitoring frequency of groundwater data, and
  - A guided one-stop-shop for data at different scales.
- For **water use**:
  - Harnessing existing data and making it more consistently reported, systematic, accessible and actionable for a wide audience,
  - Better education/collaboration to ensure the data are fit for purpose, and

    - Coordination among water managers across basins and data products.
- For **water availability prediction for ecosystems**:
    - Further assess end user needs to help identify priorities in prediction improvement,
    - Tools for past, current, and future water availability, including uncertainty information, and
    - Public-facing streamflow predictions that account for anthropogenic activity.

At the closing session for the series (October 20, 2022), the USGS and NIDIS provided a report on the analysis of the feedback received over the four topical sessions (as delineated above) and also shared key overarching takeaways for the USGS and NIDIS, as well as other national drought programs. These **additional key takeaways from the Listening Sessions** include:

- There is **high interest in better water availability information**, across user groups and across topical areas (streamflow, groundwater, water use, and ecosystems).
- The user community is **very diverse and has diverse needs**, meaning that there is not necessarily a one-size-fits-all for product development (in terms of latency, geographic scope, etc.).
- The **end user perspective must be front and center** as products and services are developed, reflected in a co-development process.
- Regardless of what has already been done in the way of "user-friendly" products, **more must be done to make data and information easier to access and use.**
- There is a strong demand for **predictions, models, and forecasts of all types.**
- Information about the **uncertainty around forecasts and models** is important and necessary.
- There is strong demand for **innovations all along the data pipeline,** from more data collection to more help interpreting and putting data to use, and not just the development of new tools or end products.
- There is strong **interest in observational data, such as more streamflow monitoring in natural hazard prone areas (places subject to floods, hurricanes, etc.) and monitoring information/tools**, in addition to more and better prediction services.
- There is a need to **better understand the overall natural system**, in addition to practical and directly applicable information.
- Participants found value in **hearing & learning from others' experiences,** in addition to sharing their own perspectives.
- **Challenges exist in using existing drought prediction information** and include the following: data fidelity issues; communicating uncertainty; understanding human interactions with the water supply; legal and organizational barriers; and climate change and variability.
- **Opportunities identified to improve utilization of hydrological prediction and information** include the following: increasing spatial and temporal resolution of all primary data production collection, from stream gages to soil moisture data; expanding the integrated data access through a curated "one-stop" shop for all types of water-themed

data, models, and forecast tools; improving analysis and assessment of groundwater/surface-water interactions and of base flow; improved understanding of real water use and consumption rates that can complicate water resource planning.

The USGS and NIDIS have already begun using the feedback from these Listening Sessions in their current and future programmatic efforts related to drought prediction and early warning.

It should be noted that this Listening Session series does not represent a final assessment of user needs. Instead, both USGS and NOAA/NIDIS are committed to an adaptive management process, which includes continued efforts to solicit and engage with the user community and other federal agencies to make programmatic adjustments and further improvements in drought prediction over time.

In addition to making the important but largely incremental changes to programmatic activity derived from these Listening Sessions, there is also recognition of the importance of identifying ways to take bolder, “paradigm-shifting” steps to advance data- and science-driven drought planning, management, and response capabilities, for example by integrating drought science with decision science.

Introduction and Relevance

In 2022 the U.S. Geological Survey (USGS) and NOAA's National Integrated Drought Information System (NIDIS) hosted a series of Listening Sessions to seek input on priorities and needs related to predicting water availability changes under drought conditions at national and regional scales. These Listening Sessions provided an opportunity for community members to provide perspective and potential guidance for drought program planning, drought program orientations, and drought early warning activities within both USGS and NOAA/NIDIS. The primary goal of that engagement was to understand as much as possible what useful model output should look like, what scales (spatial and temporal) are important and what hydrologic variables are needed in those decisions and what format is ideal for communicating that information.

Hydrologic drought is defined as the condition where low water supply becomes evident in the water system. This type of drought is usually identified following a period of low precipitation that is sufficiently long or severe that surface or subsurface water supply (i.e., streamflow, reservoir and lake levels, groundwater) experiences impactful shortfalls. Hydrologic drought impacts typically lag other drought indicators as it can take some time for precipitation deficiencies to manifest in deep soil moisture, streamflow, groundwater and reservoir levels. Communities impacted by hydrologic drought may also be slow to recover as there is also a time lag in precipitation percolating into surface and groundwater storage. These drought impacts can be isolated spatially to the watershed, river basin or aquifer.

The impacts of a prolonged hydrologic drought can ripple through the economy from local to global scales. Industries typically impacted by prolonged hydrologic drought include irrigation and irrigated agriculture, recreation, navigation, and hydropower. In addition, hydrologic drought can negatively impact wildlife habitats and flood control infrastructure. The ecological and economic impacts can be mitigated, to some degree, by forward planning, drought modeling and drought early warning systems.

Hydrologic drought models are one tool that can help build drought resilience in watersheds, communities, and economies. But there are certain challenges in building, implementing and communicating the outputs of drought models. One way to overcome some of these challenges is through an open dialogue between those providing drought information, including hydrologic model output, and those who would use that information in their day-to-day decision-making processes.

In total, four Listening Sessions, along with one introductory webinar and one concluding webinar, were held over the course of the year. The structure and details of each of these sessions are listed in the following section. In total, these sessions included 234 participants, all from North America and the Pacific Islands. While demographic information of the participants were not taken, of the 652 total registrants across the six sessions, 215 represented the U.S. Federal

Government, 127 represented State or Provincial governments, 32 represented academic institutions, 23 were from Canada, 5 Tribal nations were represented, and one attendee joined from Costa Rica. The remaining 164 registrants had .com or .net email addresses which ranged from county and municipal governments to private corporations and others that could not be identified.

Within each session, the participants were asked to **identify, in a general sense, how they use hydrologic prediction products**: 25.3% said they "regularly use hydrologic prediction products," 18.7% said they "develop hydrologic models and other prediction products," 18.3% said they "generate information to create hydrologic prediction products," 16.8% said they "sometimes use hydrologic prediction products," 9.7% said they "don't currently use hydrologic prediction products," 7.7% said they "rarely use hydrologic prediction products," and 3.4% said they use hydrologic prediction products in a way that was not listed in the options. This indicates that participants represented all components of the hydrologic data production and use process.

This report captures the structure and key takeaways from these Listening Sessions with the intention that this information will be useful and inform future projects and products within the USGS and NOAA and may also be utilized by other federal agencies and organizations that are working to build resilience to drought.

Listening Session Series Events

The USGS-NIDIS Listening Session Series included an opening kickoff webinar, four topical sessions (Streamflow, Groundwater, Water Use, and Water Availability for Ecosystems), and a final summary session that provided an overview of results and key takeaways.

Series Kickoff, 9 February 2022

This webinar introduced the user Listening Session series and provided a short overview of the USGS Drought Program and efforts to characterize hydrological (e.g., streamflow and groundwater) drought variability, drivers, and trends over the past century.

Speakers included Brian Clark, USGS Drought Science Program Manager, who provided some context for USGS' role in drought monitoring and prediction, and John Hammond, USGS Regional Drought Project Manager, who described current USGS hydrologic drought prediction projects. A recap of the session is available here, including a full session recording and the webinar Q&A.

Topical Sessions Structure

As mentioned, there were four topical sessions that formed the core of the Listening Session Series, each focusing on a different aspect of hydrologic drought: Streamflow, Groundwater, Water Use, and Water Availability for Ecosystems. Each of these sessions followed the same format, which included short introductory presentations on relevant program activities at the federal, state, local, or research/university level for that topic, then a guided breakout session to allow for small group sharing of perspectives and user needs. The session concluded with a report from each breakout group on the "one improvement to information and prediction" for that topic area that would "help users the most," and then a plenary polling exercise which allowed all participants to vote on their top improvement from the list. The results provide a sense of overarching priorities from each session.

Drought Prediction: A Focus on Streamflow, 3 March 2022

This session focused on user needs relative to streamflow information. For the initial presentation section, speakers included:

- Stacey Archfield, USGS National Drought Project Manager, who detailed the USGS national streamflow drought research portfolio, and the properties of a national drought prediction system,
- Andy Wood, National Center for Atmospheric Research Climate and Global Dynamics, who presented on "Streamflow Forecasting for Drought in the U.S.: Strong Capabilities and Compelling Opportunities for Advancement," and
- Heather Patno, Bureau of Reclamation, Hydropower and Reservoir Operations, who presented on "Colorado River Basin Ensemble-Based Operational Forecasting Methodologies to Determine Risk and Uncertainty During Drought."

After the breakout sessions, the top improvements in information and prediction of streamflow that were identified in the plenary polling included:

- A watershed forecasting approach that communicates forecasts based on key contributing factors for each area,
- Providing a range of prediction values, at multiple time scales from annual to weekly, with uncertainty estimates included, and
- Data enhancement: integrating different datasets and increasing monitoring of underserved areas.

A recap of the session, including a full recording, is available here.

Drought Prediction: A Focus on Groundwater, 5 May 2022

This session focused on user needs relative to groundwater information. For the initial presentation section, speakers included:

- Todd Caldwell, Groundwater Hydrologist, USGS Nevada Water Science Center, who provided an overview of groundwater drought onset, recovery, and propagation,
- Ed Swaim, Executive Director Bayou Meto Water Management District, Arkansas, who described the Arkansas Water Data and the Bayou Meter Water Project Implementation focused on groundwater recharge, and
- Tyler Hatch, Supervising Engineer in the Sustainable Groundwater Management Office at the California Department of Water Resources, who spoke about Groundwater and Drought in California.

After the breakout sessions, the top improvements in information and prediction of groundwater that were identified in the plenary polling included:

- Improving our understanding between soil moisture, groundwater, and surface water drought, including assessment of how groundwater data correlates with other indices,
- Higher spatial resolution and monitoring frequency of groundwater data, and
- A guided one-stop-shop for data at different scales.

A recap of the session, including a full recording, is available here.

Drought Prediction: Water Use Information, 14 July 2022

This session focused on user needs relative to water use information. For the initial presentation section, speakers included:

- Diana Restrepo-Osorio, a Geographer with the USGS Kansas Water Science Center, who presented on how drought is assessed from a social science perspective,
- Cait Rottler, New Mexico Climate Adaptation Specialist with the South Central Climate Adaptation Science Center, who described the Ogallala Data Directory Project, a directory of natural resources and agriculture datasets in the Ogallala Aquifer area, and

- Collins Balcombe, Supervisor of Water Resources Planning and Project Development with the Bureau of Reclamation Oklahoma-Texas Area Office, who described the partnership between the Oklahoma Water Resources Board, Lugert-Altus Irrigation District, and Mountain Park Master Conservancy District to provide drought prediction.

After the breakout sessions, the top improvements in information and prediction of water use that were identified in the plenary polling included:

- Harnessing existing data and making it more consistently reported, systematic, accessible, and actionable for a wide audience,
- Better education/collaboration to ensure the data are fit for purpose, and
- Coordination among water managers across basins and data products.

A recap of the session, including a full recording, is available here.

Drought Prediction: Water Availability Prediction for Ecosystems, 8 September 2022

This session focused on user needs relative to water availability prediction for ecosystems. For the initial presentation section, speakers included:

- Jake Weltzin, Senior Science Advisor for the USGS Ecosystems Mission Area, who described current USGS programs related to predicting water availability for ecosystems,
- David Jenkins, Assistant Director, Resources and Planning for the Bureau of Land Management, who provided an overview of Bureau of Land Management efforts to plan for ecosystem change and the role of water availability in building climate resilience, and
- Shelley Crausbay, Senior Scientist, Conservation Science Partners, who presented on a process she and colleagues developed to help make eco-drought science more actionable.

After the breakout sessions, the top improvements in water availability prediction for ecosystems that were identified in the plenary polling included:

- Further assess end user needs to help identify priorities in prediction improvement
- Tools for past, current, and future water availability, including uncertainty information
- Public-facing streamflow predictions that account for anthropogenic activity

A recap of the session, including a full recording, is available here.

National Listening Session Series Next Steps: Drought Prediction and Water Availability, 20 October 2022

The final session of the series was an opportunity for the USGS and NIDIS partners to provide an overview and synthesis on the feedback received over the four topical sessions and to delineate key takeaways to be integrated into programmatic work.

Findings presented at the report-out are described in the next section. A recap of the session, including a full recording, is available here.

Cross-cutting Analysis of Participant Feedback

Methods

All four topical sessions included a guided breakout session that asked four questions, structured the same across each session with the questions adjusted for the particular topical session. The questions focused on current use and what was missing (Questions 1-3), as well as what improvements would be most helpful (Question 4):

1. How do you use hydrologic information in your work to anticipate changes related to drought conditions?
2. What are your organization's challenges, special considerations, or common uncertainties related to drought?
3. What hydrologic products or indices do you currently use, and what are your opinions on those products? and
4. What improvements to hydrologic information and prediction would help you the most?

Participant feedback on these questions was documented in session notes as well as through the use of polling. After completing the four topical sessions, a small team from the USGS and NIDIS classified and sorted the feedback from all sessions using a digital whiteboard. After sorting all comments received by session, breakout group, and question, the group focused on organizing the comments into distinct themes to be reported back to the participants and used to formulate key take-aways and future areas of focus for the USGS and NIDIS.

Findings Regarding Current Use of Hydrologic Drought Information: Q1-Q3

As mentioned, participants were asked to provide input on three questions about their current use of hydrologic drought information.

Question 1: For the first question, participants were asked, “How do you use hydrologic information to anticipate changes related to drought conditions?” Overall, across the four Listening Sessions, there were 467 comments and answers to these questions. Most of the information from this question pointed to data or tools that people use and generally fell into four categories: Monitoring Drought, Predicting Drought, Water Permitting, and Decision Making. To provide insight into what decisions people are using the data for, the following are some responses that specifically stated “I use X to do Y” where X is hydrologic information, data or a tool and Y represents a decision made or a specific activity.

Monitoring:

- I use time-lapse camera to see water in springs and streams
- To communicate status across region
- I use weekly data to input into U.S. Drought Monitor
- I use 5-year studies to understand what is pumped
- I rely on well levels to monitor droughts
- I use subsidence data as proxy to groundwater changes
- I use streamflow data at gaged basins to extrapolate in ungauged basins
- I use mine remediation info to monitor runoff issues

Predicting:

- I use USGS data to produce seasonal temperature model
- I use previous year's water use to predict current demand
- I use flow, precipitation, groundwater to understand the future
- I use indices to predict multi-year droughts

Permitting:

- To allocate to senior users
- I use surface runoff data for reporting, compliance
- To manage water rights
- To incorporate drought into water rights processes
- I use water use data to inform permit thresholds

Decision Making:

- I use storage and available water info to declare emergencies from drought protocols
- To determine rangeland allotments

Question 2: The second question asked, "Based on your organization, what are challenges, special considerations, or common uncertainties for predicting changes related to drought, or in other words, what about drought makes your job hard?" This question received 443 comments that generally fell within five categories: Data Issues, Uncertainty, Human Interactions with the Water Supply, Legal and Organizational Process, and Climate Change & Variability.

Data Issues: Most comments regarding challenges with hydrologic data were that many data sources provide insufficient temporal or spatial resolution. Often data are sparse or of poor quality. Sometimes data are provided but in wrong/Inconsistent data formats that must first be wrangled or processed before they are useful. Some people mentioned the difficulty accessing the right data while others described the difficulty taking hydrologic observations in hard-to-get-to places or with limited resources.

Uncertainty: All observations and models come with some level of inherent uncertainty. Although this is a known and unavoidable aspect of most hydrologists' jobs, it is often noted that this is one aspect that makes predicting drought difficult to do and difficult to communicate.

Human Interactions with the Water Supply: Very closely related to observation and model uncertainty is the uncertainty that arises from unaccounted for human interactions on water supply, e.g., groundwater pumping impacts on surface water, water reuse, unmetered/unreported withdrawals, etc.

Legal and Organizational Process: Though not specifically about drought prediction, many of the respondents to this question pointed to water permitting, policy, water rights legislation, and general bureaucracy as a challenge within their organization for providing drought information and predictions.

Climate Change and Variability: Many of the challenges expressed were regarding climate change, underlying trends in the statistics of the climate, and large variability, the large and sometimes rapid swings from/to persistent wet or dry conditions.

Question 3: The third question was, "What products or indices do you currently use to predict hydrologic changes in your region?" For this question, participants were asked to mention some specific products they use and also to provide some comments about them. The products mentioned most often include:

- Forecasts, models, outlooks, and predictions
- Groundwater data
- Streamgage data
- Evapotranspiration (ET) data, OpenET
- The U.S. Drought Monitor
- Soil Moisture information

A few comments about individual products include: “The USGS Groundwater Recharge model needs accurate daily rainfall, ET, land cover and soil type," “ET/Open ET is useful for irrigation," “Stream gauge data are useful where available," “NASA/GRACE data can be challenging to understand," “USGS Reports are outdated by [the time of] publication," as well as critiques of long data latency and coarse spatial resolution.

Findings Regarding Improvements to Drought-related Information: Q4

The final question related to the most useful improvements for streamflow information and prediction, groundwater prediction, water use information and prediction, or water availability information and prediction for ecosystems. Overall, across the four Listening Sessions, there were 435 comments and answers to this final question. Four categories were used to classify all feedback from the final question: (1) primary data production and collection; (2) data access; (3) analysis and assessment; (4) forecasts and the need for improved forecast tools and models. Additionally, some of the feedback from participants on the first three questions were also included in the analysis; namely any comments that mentioned desired improvements to drought prediction products or information.

The four categories can be represented as successive layers in a pyramid that guides users towards informed decision making at the top (see Figure 1). This approach can apply to both higher-level policy makers and on-the-ground water resource managers as they use available data and information to make informed decisions related to drought. Starting at the bottom, **primary data production** includes all monitoring and on-the-ground data. Feedback during the breakout groups often mentioned the need for increasing the spatial and temporal resolution of all primary data collection, from streamgages to soil moisture data. The next category in the pyramid classification, **data access**, addresses the data tools and delivery pathways. The need for improved data tools and new delivery pathways was frequently mentioned in each of the breakout group sessions. Additionally, users requested easily accessible information catalogs and the need for interactive portals. The third category, **analysis and assessment** (listed as analysis, part of third tier), covers comments about and suggestions for any kind of analysis that can improve or better interpret data collected, analyze data trends, improve and aid decision making, and assess future risks. The fourth category, **forecasts** (part of the third tier), dealt with the need for improvements in tools, models, forecasts, and predictions, and also the uncertainty around forecasts and models.

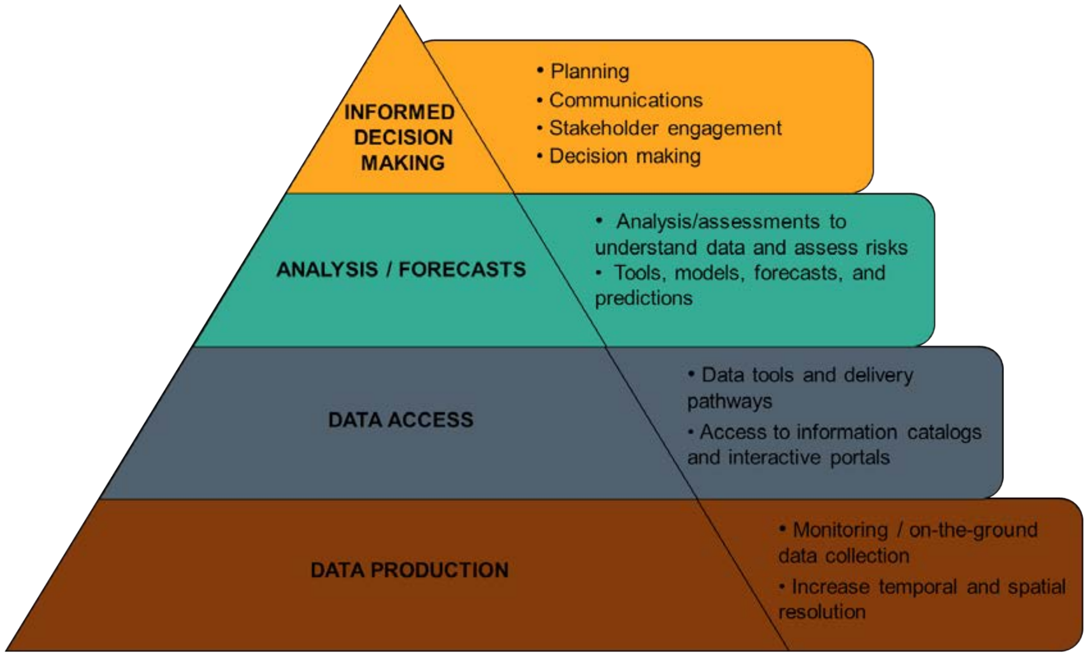

Figure 1. Informed Decision Making Framework used in this analysis, adapted with permission from the decision framework developed by the Texas Water Development Board in designing the Texas Water Data Hub.

Primary Data Production

For primary data production, common feedback across the breakout groups included the need for improved spatial or temporal resolution. This feedback ranged from the specific interest in more streamgages in a particular region, to the need for higher data collection frequency for all data types. One participant mentioned the need for "more long-term historic time series data with broader scale and higher resolution." Another comment mentioned the need for "wall-to-wall soil moisture." Also, a few comments related to more access in rural areas and a lack of data access for smaller towns and boroughs. Related to temporal resolution, the timing of data collection, such as the seasonal component of data collection, can be important when dealing with heavy water usage and during periods of drought. For example, it was mentioned that coastal tourist areas and areas in the Sun Belt can experience heavy swings in water demand with tourist seasons. For regions that experience freezing temperatures, there can be a lack of winter data given that it can be difficult to acquire.

The other large category for data production related to the types of data collected, with the most common requests related to soil moisture, streamgages, groundwater, water use, evapotranspiration, water quality, and meteorological data. For soil moisture, requests included multiple depths at the same location. Related to streamgages, a higher density of gages to capture the "spatial resolution for smaller streams," and also co-locating sensors of different types at the same location as streamgages. Related to water use, more metered water use data was deemed useful, and for other types of records, the need for full lengths of record. Other comments related to the continuity of records, and the importance of long, continuous records to evaluate trends. It should be noted that the request for more data was not necessarily noted with the comment as far as the underlying need for the data, such as whether the request for more data of a certain type was for a specific area, or a general assumption that more data of a certain type is needed.

Data Access

For data access, a common theme across the breakout groups was the interest in more integrated access through a "one-stop" shop for all types of water-themed data, models, and forecast tools. Even though individual agencies have their own portals, participants wanted more integration across the agencies rather than the need to visit multiple webpages or portals. Additionally, a few people mentioned more application programming interface (API) capabilities to help make accessing data more streamlined to pull data into existing data management projects. A few other comments mentioned the lack of integrated portals required having "multiple sources and webpages all open at the same time to figure anything out." A few commenters mentioned poor organization on the USGS website and that it was often not clear on the types of data available. In a theme similar to data access, there was a need expressed for a central hub to showcase hydrological models, as well as more information on forecast products with the associated uncertainty.

Another theme in the data access category corresponded to communication, coordination, and training. One Listening Session participant requested "communicating info to non-scientists or impacts and risks to decision makers." Multiple agencies communicate during extreme events, such as droughts, therefore dashboards could integrate those communications across agencies. For drought, participants expressed a desire for more interagency communication and collaboration, and agreement on best products for end users. Within the water management community, more coordination that incorporates multiple basins as well. The other two sets of comments around data access related to better accessibility and training. Users need easy-to-use websites for accessing long-term records, and agencies should attempt to design websites towards looking at the end user first. For training, more training around available drought management tools would be desirable in addition to better public dissemination about available tools.

Analysis

The third category, analysis, had a wide range of different comments across major themes. Groundwater / surface-water interactions and the topic of base flow came up on multiple occasions, not only in the Groundwater-focused session, but also frequently in the Ecosystems session and Water Use session. Part of the connection for these comments related back to the prolonged droughts, particularly in the western United States, where the relevance of the connection to groundwater is important in the face of falling groundwater levels. Another theme around water use covered comments on the lack of understanding on measured or reported water use and consumption rates that can complicate water resource planning during droughts. Connected to the water use topic was the issue of water availability; participants noted that there can also be conflicting water needs to maintain minimum flows to maintain healthy ecosystems while still providing water for all the societal demands and functions. It was mentioned “drought restrictions for ecosystem services have socioeconomic consequences," and that there is a need for “more ecosystem science tied to flow to determine needs." In general, there needs to be “better social and economic impact analysis for drought."

On the water planning side, participants commented that a better understanding is needed on drought effects for affecting planning. Some comments noted a need to “identify practical triggers for municipal water suppliers” and more knowledge on how to “manage emergency levels properly." Those responsible for making decisions, such as water resource managers and State water resource agencies, “need to identify products stakeholders need," as well as engage in “better education and collaboration to ensure the right data is being used to answer questions” around water planning. Some noted that the “Drought Monitor is not necessarily the best way to devise drought plans," and while finding the monitor useful, some decisions have to be made locally at small scales, so they need more guidance for their area.

Forecasts

Forecasts and models can be useful mechanisms to make informed decisions. As the last tier of under-informed decision-making, forecasts (models) are built on effective data production and easy access to data. Participants agreed there is a strong demand for predictions, models, and forecasts of all types, recognizing many already exist. For example, climate ensemble datasets often combine several models, so participants mentioned the need for forecasts for streamflow, particularly during periods of low flow. Also, several people would like to have the U.S. Drought Monitor pushed further ahead than the current Drought Monitor. It was also mentioned that it would be useful, if possible, to have projections for areas with highly regulated flows.

For the frequency of forecasts and models, comments included that “seasonal streamflow outlook would be helpful, particularly for low-flow forecasts” and also further out, if possible, for the current National Weather Service ensemble. With all forecasts and models comes uncertainty, and many participants mentioned more studies focused on “forecast certainty and having acceptable confidence levels for translating to actionable decisions." There needs to be more caveats with using models, and better “communication of forecast and model uncertainty to decision makers” that might be relying on them.

Key Takeaways and Next Steps

The Listening Sessions, and particularly the breakout groups within each session, provided a wealth of information on user needs related to information and prediction of hydrologic drought. While there were a few findings that were specific to certain hydrologic topics (streamflow versus groundwater), most of the current gaps and needs in information crossed over topic areas. Many of the findings were intuitive given the state of the science, but there were also some findings that were surprising.

Some of the findings that were expected include:

- There is **high interest in better water availability information**, across user groups and across topical areas (streamflow, groundwater, water use and ecosystems).
- The user community is **very diverse and has diverse needs**, so there is not necessarily a one-size-fits-all for product development (in terms of latency, geographic scope, etc.).
- Participants in the sessions reinforced the importance of putting the **end user perspective front and center** in planning for and developing products and services.
- Regardless of what has already been done in the way of "user-friendly" products, there is always **more to do to make data and information easier to access and use.**

But there were also several findings that provided a correction to initial assumptions:

- It was expected that participants would emphasize specific new tools or end products that they wanted. Instead, many participants actually wanted to see **innovations all along the data pipeline,** including: more data, easier access to data, more/different tools, more navigation of existing tools and information, and more help interpreting and putting data to use. This full-system perspective is important.
- It was expected that participants would emphasize getting more and better prediction services; i.e., that the focus would be on predicting future conditions. Instead, participants were also **very interested in observational data and monitoring information/tools**; that is, in having a sense of what are current conditions, as well, in some cases, past conditions to use as comparison.
- It was expected that participants would be focused on getting very practical and directly applicable information. However, participants also wanted to **better understand the overall natural system** (e.g., the water cycle) - information beyond what would immediately serve a decision need. This again points to the importance of a full-system approach.
- It was expected that participants came to share their thoughts and be heard. However, most came to **learn & to hear from others as well**.

The USGS and NIDIS have already begun using these overarching findings, as well as the specific analysis of breakout questions feedback, as each agency plans and executes program activity.

Some examples of how the USGS is using the information gained from the sessions include:

- Based, in part, on feedback during these Listening Sessions, the USGS Drought Program began a rescoping activity in early fiscal year 2023 that included starting a new project. This new project leverages drought characterization and prediction efforts within the USGS Water Resources Mission Area to assess the effects of social-economic drivers, ecological needs, and water planning and water use on drought risk.

- For the Data-Driven Drought Prediction project (USGS Water Mission Area, Drought Program), there are five key areas where the USGS has received feedback from these Listening Sessions that will be used to enhance ongoing streamflow drought and groundwater drought prediction efforts.
  - First, focusing on improving within and between agency coordination on the development and enhancement of drought prediction products. By incorporating user feedback more frequently along the science production pipeline, the USGS is hoping to develop complementary capabilities and tools to address different elements of drought prediction.
  - Second, there is now a focus on developing predictive tools to address data needs for historical, real-time, and forecast periods while providing predictions for gaged and ungaged locations at a fine spatial scale but broad areal extent. Historical estimates of drought properties may be useful for connecting to historical ecological and human water availability estimates to better examine historical drought impacts.
  - Third, in developing forecasting capacity, the USGS is applying methods for both short-term and seasonal forecasting needs, with predictions made for both streamflow and groundwater components.
  - The fourth element where feedback is being incorporated involves predictive uncertainty. The USGS has adapted its predictive tools to provide the range of uncertainty associated with each prediction, and optimized their models through experimentation to reduce prediction uncertainty as much as possible.
  - Feedback on critical model inputs and processes has been folded into the approaches being developed. For example, there is now a focus on including more information on human flow alterations (dams, diversions, irrigation) as well as groundwater-surface water interactions to better inform USGS data-driven models.
- The USGS will also be using this feedback in ongoing coordination with NOAA partners in hydrologic research and products, including the NOAA National Water Center and regional NOAA River Forecast Centers.
- Finally, new regional USGS projects are building cross-disciplinary connections to further weave together scientific knowledge and stakeholder perspectives related to drought conditions and effects. For example, the Actionable and Strategic Integrated Science and Technology (ASIST) project supports collaboration and co-development between stakeholders, scientists, and technology specialists within the Colorado River Basin. The complexity of drought effects on human and natural systems in the basin requires the USGS to use interdisciplinary science to provide the data and tools needed to

address multiple cross-cutting stakeholder scientific priorities. For more information and updates please visit https://www.usgs.gov/mission-areas/water-resources/science/drought-prediction-science.

Similarly, NIDIS is using the information gained from the Listening Sessions to help guide program direction. NIDIS and USGS have a long history of working together on everything from climate services to ecological drought to water monitoring and prediction. This includes active participation by USGS Science Centers and the USGS Regional Climate Adaptation Science Centers (CASC) in the NIDIS-led regional Drought Early Warning Systems (DEWS) and in the support and implementation of joint research activities.

Some examples of how the NIDIS is using the information gained from the sessions include:

- Shaping future regional DEWS activities, such as strategic planning and stakeholder engagement and the identification of new NIDIS-USGS collaborations around hydrologic and ecological drought;
- Informing future NIDIS grant competitions, such as NIDIS Coping with Drought, on topics that could include groundwater/surface water interactions during drought, and water use changes under drought in different regions;
- Guiding future projects and collaborations with USGS, which can include improved communication tools and improved data accessibility;
- Improving information delivery on the NIDIS-led U.S. Drought Portal (Drought.gov) to incorporate user needs related to drought prediction;
- Informing NOAA's broader efforts on hydrologic and drought prediction, including the National Weather Service's River Forecast Centers and the National Water Center, in support of NOAA's operational mandate to provide hydrological prediction to the nation, and
- Informing collaborations within NOAA and with other federal agencies on stakeholders hydrologic and drought information needs.

Conclusion

This series of Listening Sessions have provided the USGS and NOAA/NIDIS with a rich body of user feedback information that will help to guide programmatic activities on hydrologic drought information and prediction. The various concerns and suggestions that the participants shared provide clear direction for how USGS and NIDIS services and products can be more responsive to user needs.

It is important to acknowledge two qualifications to the findings. First, while there were over 600 individuals participating and sharing thoughts at the Listening Sessions, the user community for hydrological drought information and services is much larger than that. As a result, the outcomes here should be taken as part of an adaptive management process, wherein the agencies apply what was learned from this series, and then continue to solicit and engage with the user community, to make adjustments and further improvements over time.

In addition, many of the suggestions from these Listening Sessions represent relatively minor changes to existing programs, without challenging current underlying modes of operation. While there is always a benefit to doing the same program activities a little better, it is equally important to think more broadly about how to improve programs in new and more innovative ways. One point that was made very clear is that it is not enough for USGS and NOAA/NIDIS to simply build on existing data management and dissemination capabilities to provide "more and better data." There should also be a focus on ways to advance data- and science-driven drought planning, management, and response capabilities, for example by better integrating drought science with decision science. As incremental progress is made on some of the constructive feedback from these Listening Sessions, USGS and NIDS also intend to create more opportunities to explore and initiate such novel programmatic approaches. Also, many of these conclusions focused on viewing these comments in a science production perspective, but future listening sessions could possibly focus more on the responses from a user-centered perspective.

Appendix A: List of Presenters

The following individuals provided important subject matter presentations for the Listening Session series.

- Stacey Archfield, USGS National Drought Project Manager
- Collins Balcombe, Supervisor of Water Resources Planning and Project Development with the Bureau of Reclamation Oklahoma-Texas Area Office
- Todd Caldwell, Groundwater Hydrologist, USGS Nevada Water Science Center
- Shelley Crausbay, Senior Scientist, Conservation Science Partners
- Tyler Hatch, Supervising Engineer in the Sustainable Groundwater Management Office at the California Department of Water Resources
- David Jenkins, Assistant Director, Resources and Planning for the Bureau of Land Management
- Heather Patno, Bureau of Reclamation, Hydropower and Reservoir Operations
- Diana Restrepo-Osorio, a Geographer with the USGS Kansas Water Science Center
- Cait Rottler, New Mexico Climate Adaptation Specialist with the South Central Climate Adaptation Science Center
- Ed Swaim, Executive Director Bayou Meto Water Management District, Arkansas
- Jake Weltzin, Senior Science Advisor for the USGS Ecosystems Mission Area
- Andy Wood, National Center for Atmospheric Research Climate and Global Dynamics

Appendix B: List of USGS and NIDIS Staff Supporting this Series

The following USGS and NIDIS staff supported this series by moderating, providing technical support, facilitating breakouts, and/or taking notes during breakouts. Their support was key to the success of the Listening Session series.

Katrina Alger, USGS Stacey Archfield, USGS Kyle Blasch, USGS Todd Caldwell, USGS Darrin Carlise, USGS Shaleene Chavarria, USGS Brian Clark, USGS Terrance Conlon, USGS Dianna Crilley, USGS Katharine Dahm, USGS Jessica Driscoll, USGS Sandy Eberts, USGS Barbara Filip, USGS Joel Galloway, USGS John Hammond, USGS Scott Hamshaw, USGS Glenn Henz, USGS Nicole Herman-Mercer, USGS Diamond Holloman, USGS Leslie Hsu, USGS Adam Lang, NIDIS Shirley Leung, USGS Joel Lisonbee, NIDIS Christine Marsh, USGS	Stephanie Mathew, USGS Laura Medalie, USGS Matt Miller, USGS Olivia Miller, USGS Meredith Muth, NIDIS Elizabeth Ossowski, NIDIS Jamie Painter, USGS Britt Parker, NIDIS Jennifer Rapp, USGS Sylvia Reeves, NIDIS Diana Restrepo-Osorio, USGS Kelsey Satalino, NIDIS Amanda Sheffield, NIDIS Jennifer Shourds, USGS Caelan Simeone, USGS Marina Skumanich, NIDIS Erik Smith, USGS Marc Stewart, USGS Crystal Stiles, NIDIS Anne Tillery, USGS Alicia Torregrosa, USGS Josh Valder, USGS Molly Woloszyn, NIDIS