FLASH DROUGHT

CURRENT UNDERSTANDING & FUTURE PRIORITIES

NOAA

NIDIS

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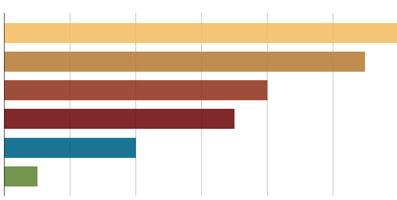
◄ ON THE COVER Drought-damaged cornfield on a farm in southern Wisconsin. Credit: Earl D. Walker



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A storm approaches over an arid landscape and windmill in Kansas. Credit: Scott Book

EXECUTIVE SUMMARY

Droughts are often thought of as slow-moving natural hazards. However, some serious droughts occur with such rapid onset that it seems as if they appear in a "flash," rendering them and their consequences hard to predict and prepare for. These flash droughts can have substantial agricultural and economic consequences, including billions of dollars in losses.

Various notable flash droughts over the past several years (e.g., the Central U.S. in 2012, Northern Plains in 2017, and Southeast U.S. in 2016 and 2019) have sparked intense interest in flash drought by both the research community as well as drought managers/practitioners (hereafter "practitioners") and the public.

There are differing understandings of what flash drought is and how it differs from other types of drought. Equally important, there is widespread recognition that existing monitoring and forecasting products and tools do not provide adequate early warning for flash drought. To address these issues, National Oceanic and Atmospheric Administration (NOAA) National Integrated Drought Information System (NIDIS) held a virtual workshop in December 2020 that convened researchers, practitioners, and other interested stakeholders to explore characteristics and definitions of flash drought, and to coordinate and co-develop a research agenda to address its associated management challenges. This report describes the workshop's key takeaways and provides a list of priority actions

The Flash Drought Virtual Workshop was structured to address four main objectives:

- Strive for agreement on the basic set of characteristics to which definitions of flash drought should adhere and explore "most useful" flash drought definitions by sector, region, and application.
- Discuss, understand, and document how existing monitoring and prediction tools and research can be shaped to meet user needs around flash drought, both in the near term and in the future.
- Develop a list of outstanding research needs in monitoring, prediction, and planning/response to improve early warning of flash drought.
- Agree upon next steps for this emerging domain and how NIDIS and other partners can support research and coordination related to flash drought.

to help both NIDIS and the broader research community advance flash drought research activities and tool development.

In total, around 120 people attended the workshop, representing academia, government (foreign, federal, state, local), nonprofit organizations, and other interested stakeholders. A series of five sessions over three days included a combination of presentations, plenary discussions, and small breakout groups designed to encourage broad dialogue. The workshop provided one of the first opportunities for a structured discussion on the concept and implications of flash drought between researchers and the practitioners who have to manage and respond to flash droughts.

There was widespread agreement that there needs to be a more *definitive characterization* of flash drought—one that is developed with practitioner engagement. There was strong consensus that the key feature of flash drought is rapid onset/rapid intensification of drought conditions, although more remains to be settled about how those two concepts differ and how exactly to standardize terms like "rapid." Another strong consensus view was that regionality, seasonality, and impacts are essential attributes for characterizing flash drought, implying a need for an integrated set of indicators, given the complexity of the phenomenon and its cascading impacts.

Important items to advance applied research on flash drought include: (1) identifying the key indicators specific to flash drought to use for drought monitoring, and including these also in prediction products; (2) researching the cascading and compounding impacts of flash drought; and (3) finding ways to effectively communicate the research results to those planning/responding to drought conditions. Activities that were identified as of high importance but likely difficult were to increase *in situ* and remotely-sensed monitoring (in order to improve the tools/data that are currently available) and also to predict flash drought at lead times of weeks to months.

Finally, attendees also stressed the importance of improved collaboration between researchers involved with monitoring flash drought and those involved with prediction, and between researchers and the practitioners managing flash drought response and planning.

Based upon the discussions at the workshop, as well as a more general analysis of workshop materials and subsequent discussion, a series of priority objectives and actions have been identified to guide the research agenda for flash drought:

- **Forge consensus on a general framework for characterizing flash drought,** by sponsoring a collaborative process that includes both research and practitioner communities.

- **Characterize the various ways in which flash drought manifests by region and season,** including identifying key indicators specific to flash drought, and their thresholds and appropriate triggers for action.
- **Better understand practitioner perceptions of flash drought and their needs for improved flash drought preparedness and response,** via a series of focus groups organized by NIDIS Drought Early Warning (DEWS) regions.

▲ **Agricultural field on which, due to a drought, the green leaves of sugar beets have wilted. Credit: rsooll**

- **Increase real-time data (e.g., soil moisture, evapotranspiration, streamflow, and other key variables)** to improve monitoring and prediction tools and to make high-quality datasets available for general research.
- **Establish a baseline of flash drought impacts and monitoring resources,** including such components as a catalogue of existing flash drought-relevant observational data and tools, and a database of flash drought impacts.
- **Better understand the limits of flash drought predictability,** by supporting research to identify new sources of predictability for flash drought by region.
- **Improve forecast models to better support flash drought prediction,** including higher resolution, longer hindcasts, consistent initialization protocols, and advanced land surface models that incorporate flash drought-related land surface processes (e.g., dynamic vegetation).
- **Develop practical decision-support tools** to help decision makers identify when they are in a flash drought, or could experience flash drought development, and what potential response options might be available.
- **Improve the ability to communicate about flash drought—what it is and how it manifests in the environment,** by supporting research into people's perception/understanding of flash drought and how best to communicate flash drought implications to a general audience.
- **Build stronger connections and coordination between flash drought researchers and practitioners,** by providing ongoing opportunities for sharing, including a regular forum (e.g., an annual flash drought conference).

This is an ambitious set of activities to improve flash drought monitoring, prediction, and planning/response. Working with partners at all levels, NIDIS will use this as the basis for an ongoing agenda for flash drought. This set of objectives, along with other findings in this report, may be useful to other agencies, organizations, researchers, and policy makers as we collectively work to improve both national and regional capacity for flash drought early warning and response.

The Alice Creek Fire started by lightning strike on July 22, 2017, near Lincoln, Montana. Because of extremely low humidity, above-average temperatures, and windy conditions, fire fighters struggled to contain the blaze. It eventually burned a total of 29,252 acres and four buildings. Credit: U.S. Forest Service

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INTRODUCTION

Droughts are often thought of as slow-moving natural hazards. Occasionally, serious droughts occur with such rapid onset that it seems as if they appeared in a "flash," rendering them and their consequences hard to predict. Often occurring in the central and eastern U.S. during the warm season, flash droughts can have substantial agricultural and economic consequences.

The 2012 flash drought across the Central U.S. affected approximately 80% of U.S. agricultural land,[1] resulting in $34.5 billion in economic losses.[2] More recently, the 2017 Northern Plains flash drought was associated with fires that burned 4.8 million acres and U.S. agricultural losses in excess of $2.6 billion dollars.[3] In both of these events, neither the drought's swift onset nor its severity was forecast in a timely manner. Episodes like these have been observed around the country in the last several years and have sparked intense interest in flash drought in both the research community and the practitioner/end user[4] (hereafter "practitioner") community. While a clear conceptualization of flash drought is important to both groups, there are differing understandings and therefore some confusion on what flash drought is and how it differs from other types of droughts. Equally important, there is widespread recognition that existing monitoring and forecasting products and tools[5] do not provide adequate early warning for flash drought.

To address these issues, National Oceanic and Atmospheric Administration (NOAA) National Integrated Drought Information System (NIDIS) held a virtual workshop in December 2020 that convened researchers, practitioners, and other interested stakeholders to explore characteristics and definitions of flash drought, and to coordinate and co-develop a research agenda to address its associated management challenges. This report describes the workshop's key takeaways and provides a list of priority actions to help both NIDIS and the broader research community to advance flash drought research activities and tool development.

1.1 ABOUT NIDIS

NIDIS was authorized by Congress in 2006 (P.L. 109-430) with a mandate for interagency coordination and integrated drought research that builds upon existing federal, tribal, state, and local partnerships to create a national drought early warning system (DEWS). The program was reauthorized in 2014 (P.L. 113-86) and again in 2019 (P.L. 115-423). NIDIS is working toward this goal by developing a network of regional DEWS. These regional DEWS utilize existing networks of federal, state, local, academic, private sector, and other partners to make climate and drought science readily available,

1 *https://www.ers.usda.gov/webdocs/publications/45066/37191_err-148-summary.pdf?v=3645.3*
2 *https://www.ncdc.noaa.gov/billions/events/US/2012*
3 *https://www.drought.gov/documents/flash-drought-lessons-learned-2017-drought-across-us-northern-plains-and-canadian*
4 "End user," "user," and "practitioner" are terms used in this report to represent individuals who are responsible for alerting others to, preparing for, and/or managing drought on the ground, i.e., those who use flash drought monitoring, prediction, and planning/response resources. This would include both those serving in an advisory capacity (e.g., state climatologists) and those directly impacted by drought (e.g., producers, water managers, the public). "Decision makers" is used to indicate those practitioners who must make specific decisions relative to drought management or response.
5 The terms "products" and "tools" are intended to include databases, maps, applications, websites, and other such resources designed to assist in the monitoring, prediction, or planning/response to drought. Throughout the document these terms are used interchangeably, although the predominant term used is "tools."

easily understandable, and usable; and to improve regional capacity to respond to and cope with drought.

1.2 ABOUT FLASH DROUGHT

In its simplest form, flash drought is the rapid onset or intensification of drought conditions, unlike conventional droughts which evolve more slowly. Flash droughts are driven by prolonged periods of reduced precipitation, abnormally high temperatures, winds, and/or incoming radiation that leads to abnormally high evapotranspiration (ET) rates. Flash droughts seem to occur more often than generally perceived and can cause major agricultural and other losses, which may be exacerbated in the absence of timely prediction and detection.

For example, the 2012 flash drought over the central U.S. was the most spatially extensive drought to affect the country since the Dust Bowl of the 1930s. Moderate to extreme drought conditions affected more than half the country for most of the year, and had a significant impact on the entire Central Plains' summer growing season. This drought brought the greatest summertime rainfall deficit to the Central Plains in 117 years, surpassing 1934, 1936, and 1988.[6] Drought conditions affected approximately 80% of U.S. agricultural land,[7] resulting in $34.5 billion in economic losses.[8] The unique aspect of the 2012 drought is how quickly it developed. Otkin et al. (2016, p 1,073)[9] wrote, "...according to the U.S. Drought Monitor (USDM), many locations across the central United States during the 2011 and 2012 flash droughts experienced up to a three-category increase in drought severity in only one month, meaning that areas that were drought free at the beginning of the month were characterized by severe to extreme drought conditions by the end of the month." Hoerling et al. (2013)[10] reported that NOAA operational forecasts in May failed to predict below-average precipitation that

What is Flash Drought?

Flash drought is a subset of other drought types that is defined by the rapid onset or intensification of drought conditions culiminating in impacts to one or more sectors (agricultural, hydrological, etc.).

Types of Drought

Meteorological drought refers to a deficit compared to average precipitation over a period of time for a given location.

Agricultural drought occurs when plant water requirements are unmet during the growing season, especially during certain periods critical for yield development.

Hydrological drought develops if deficits in net surface water supply become large enough to reduce river, reservoir, or groundwater levels.

Socioeconomic drought considers the impact of drought conditions on the supply and demand of economic goods and services.

Ecological drought has been proposed by Crausbay et al. 2017, referring to an episodic deficit in water availability that leads to ecosystem declines and affects ecosystem services.

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6 Hoerling, M., J. Eischeid, A. Kumar, R. Leung, A. Mariotti, K. Mo, S. Schubert, and R. Seager, 2014: Causes and Predictability of the 2012 Great Plains Drought. Bull. Am. Meteorol. Soc., 95, 269–282, *https://doi.org/10.1175/BAMS-D-13-00055.1*.

7 *https://www.ers.usda.gov/webdocs/publications/45066/37191_err-148-summary.pdf?v=3645.3*

8 Supra 2: *https://www.ncdc.noaa.gov/billions/events/US/2012*

9 Otkin, J. A., M. C. Anderson, C. Hain, M. Svoboda, D. Johnson, R. Mueller, T. Tadesse, B. Wardlow, and J. Brown, 2016: Assessing the evolution of soil moisture and vegetation conditions during the 2012 United States flash drought. Agric. For. Meteorol., 218–219, 230–242, *https://doi.org/10.1016/j.agrformet.2015.12.065*.

10 Hoerling, M., S. Schubert, and K. C. Mo, 2013: An Interpretation of the Origins of the 2012 Central Great Plains Drought Assessment Report. 50 pp. Available online at *https://psl.noaa.gov/csi/factsheets/pdf/noaa-gp-drought-assessment-report.pdf*

led to drought conditions in the central U.S. from June to August. During this time, the term "flash drought" began to resonate with both the media and the scientific community in the United States.[11]

The term "flash drought" can be found in the scientific literature as early as 2002, but research on the topic significantly increased following the 2012 Central U.S. drought. The American Meteorological Society's Glossary of Meteorology defines "flash drought"[12] as "an unusually rapid onset drought event characterized by a multiweek period of accelerated intensification that culminates in impacts to one or more sectors (agricultural, hydrological, etc.)." Despite this definition and a proposal in Otkin et al. (2018, p.918)[13] to define flash drought by "its rate of intensification rather than its duration," until 2020 there had been no clear indication that the research community was coalescing around a definition of flash drought. Within the literature, two principles are generally applied: (1) rapid onset or intensification of drought, and/or (2) short, intense drought events.[14] The rapid development and heterogeneous nature of flash drought research, as well as the potential disconnect between research and practitioner community perceptions of flash drought, motivated NIDIS's interest in helping to clarify the concept of flash drought and coordinating the development of an agenda to improve flash drought early warning capabilities.

1.3 WORKSHOP OBJECTIVES AND STRUCTURE

The motivations for the workshop were to bring together researchers and practitioners to collaboratively explore and expand understandings of flash drought and to co-develop a path forward for research activities and product development. To that end, the workshop was structured to address four main objectives:

- Strive for agreement on the basic set of characteristics to which definitions of flash drought should adhere and explore "most useful" flash drought definitions by sector, region, and application.
- Discuss, understand, and document how existing monitoring and prediction tools and research can be shaped to meet user needs around flash drought, both in the near term and in the future.
- Develop a list of outstanding research needs in monitoring, prediction, and planning/response to improve early warning of flash drought.
- Agree upon next steps for this emerging domain and how NIDIS and other partners can support research and coordination related to flash drought.

The workshop was initially planned as an in-person event to be held in Boulder, Colorado in June 2020 but transitioned to a virtual workshop in December 2020 due to the COVID-19 pandemic. As a virtual workshop, this event attracted not only an audience across the United States, but an international audience as well, with attendees from Australia, China, the Philippines, the Caribbean, and Europe. In total, around 120 people attended the workshop, representing academia, government (foreign, federal, state, local), nonprofit policy groups, and other interested stakeholders (see Figure 1.1).

The workshop was organized by NIDIS with the assistance of a planning team including Andy Hoell (NOAA Physical Sciences Laboratory (PSL)), Jason Otkin (University of Wisconsin-Madison/Space Science and Engineering Center), Mark Svoboda

Workshop Topics

What are the basic characteristics of flash drought?

How are existing tools meeting user needs?

What are key research needs in monitoring, prediction, and planning/response?

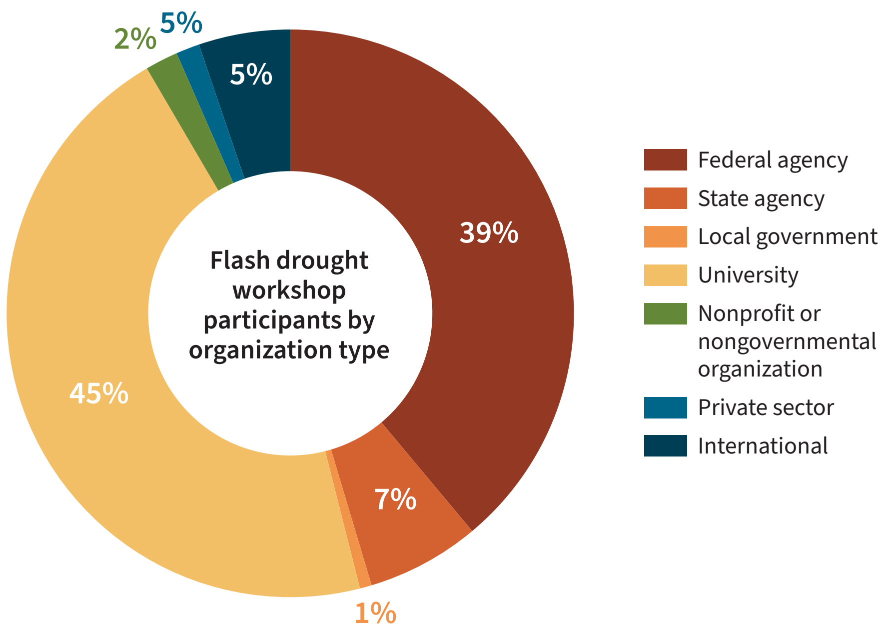
How can NIDIS and other partners better support research and coordination?

11 Otkin, J. A., M. Svoboda, E. D. Hunt, T. W. Ford, M. C. Anderson, C. Hain, and J. B. Basara, 2018: Flash Droughts: A Review and Assessment of the Challenges Imposed by Rapid-Onset Droughts in the United States. Bull. Am. Meteorol. Soc., 99, 911–919, *https://doi.org/10.1175/BAMS-D-17-0149.1*

12 *https://glossary.ametsoc.org/wiki/Flash_drought*

13 Supra 11: Otkin et al., 2018.

14 Lisonbee, J., M. Woloszyn, M. Skumanich, 2021: Making sense of flash drought: definitions, indicators, and where we go from here. Journal of Applied and Service Climatology, Volume 2021, Issue 001, *http://doi.org/10.46275/JOASC.2021.02.001*



◄ **Figure 1.1: Flash drought workshop participants by organizational type.**

(University of Nebraska-Lincoln/National Drought Mitigation Center), Mike Hobbins (University of Colorado-CIRES and NOAA PSL), Veva Deheza (NIDIS Executive Director), and Roger Pulwarty (NOAA PSL). The planning team provided NIDIS with guidance on topics to cover, based on the current state of science, and feedback on the objectives and structure of the workshop.

Through a series of five sessions over three days, each of the workshop objectives were addressed in turn. The sessions included a combination of presentations, plenary discussions, and small breakout groups designed to encourage broad dialogue. NIDIS staff recorded the workshop, took extensive meeting notes, and saved the "chat box" dialogue, breakout presentations, and other meeting materials to support subsequent analyses. All of these materials were used as the basis for this report.

1.4 ORGANIZATION OF THIS REPORT

Chapter 2 provides a more detailed review of the workshop agenda along with highlights from each session. A full discussion of key takeaways, organized by workshop objectives, is presented in Chapter 3. Finally, Chapter 4 provides a series of priority action items to advance flash drought early warning; these were based on discussions at the workshop, a prioritization exercise on the last day, and a subsequent analysis of workshop materials.

Agricultural field on which, due to a drought, the green leaves of sugar beets have wilted. Credit: rsooll

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WORKSHOP AGENDA AND HIGHLIGHTS

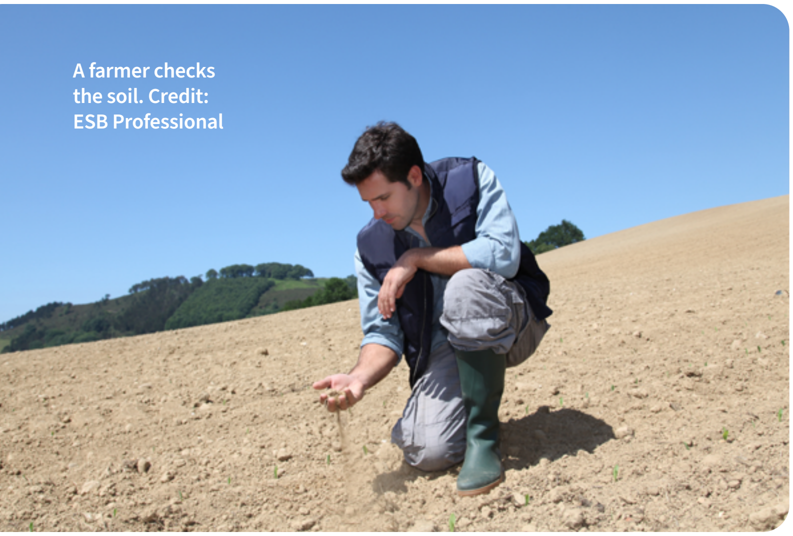
2.1 WORKSHOP AGENDA

The workshop agenda was organized to address each of the four objectives in sequence. Each day focused on one or two objectives, which provided time to explore each topic and build a shared understanding of key issues. The full agenda is provided in Appendix B.

Day 1: Setting the context and exploring the concept of flash drought

The first day consisted of two sessions related to Objective 1: Strive for agreement on the basic set of characteristics to which definitions of flash drought should adhere; explore "most useful" flash drought definitions by sector, region, and application.

- ***Session 1: Scene Setting—Going Beyond Research:*** This session provided a shared context on the overall issue of flash drought. It included a presentation on how the term "flash drought" was first used, as well as three presentations by practitioners on their own experiences managing flash droughts.
- ***Session 2: Exploring Flash Drought Characteristics:*** This session included initial presentations on how the term 'flash drought" is understood by both researchers and practitioners, and then transitioned to a breakout session allowing open discussion about how participants thought "flash drought" should be characterized.



Day 2: Existing tools vs. user needs
The second day (***Session 3: Shaping Tools/Research to Meet User Needs***) was focused on Objective 2: Discuss, understand, and document how existing monitoring and prediction tools and research can be shaped to meet user needs both in the near-term and in the future. A value proposition canvas[15] technique was used to explore what "users' needs" (i.e., practitioners' needs) are relative to flash drought management and response, which of these needs are not being met by existing tools (e.g., datasets, maps, applications, etc.) and services, and, inversely, which existing tools and services intended for flash drought are not in fact serving their needs.

Day 3: Outstanding research needs and next steps
The third day included two sessions focused on the final two objectives, respectively: Objective 3: Develop a list of outstanding research needs in monitoring, prediction, and planning/response to improve early warning, and Objective 4: Agree upon next steps for this emerging domain and how NIDIS and other partners can support research and coordination related to flash drought.

- ***Session 4: Identify Research Needs in Monitoring, Prediction, and Planning/Response:*** The session began with presentations from experts in each topic area (monitoring, prediction, and planning/response) and then transitioned to a breakout session to discuss potential research activities and tool-development projects in small groups.
- ***Session 5: The Path Forward:*** The final session pulled together lists of potential projects in each topic area from the previous sessions and ranked them according to importance (impact, value, etc.) and ease. This session included an in-workshop prioritization polling exercise and a discussion on a virtual white board to arrive at a short-list of priorities for possible next steps.

2.2 HIGHLIGHTS FROM EACH SESSION

2.2.1 Session 1: Scene Setting—Going Beyond Research:

The workshop began with a series of presentations from individuals who have experience communicating and/or managing past flash drought events. These presentations served to underscore the difficulties posed by flash drought to sectors of the economy and environment, and the importance of developing better early warning indicators and systems.

Mark Svoboda, Director of the National Drought Mitigation Center (NDMC) and Associate Professor at the University of Nebraska-Lincoln, initiated the session with a presentation on what led to the creation of the term "flash drought": a severe drought that formed within 8–12 weeks in the late-summer of 2000 in the Southern Plains. The term was intended as a communication tool that would resonate with people and reinforce the point that droughts sometimes develop quickly.

Pam Knox, Agricultural Climatologist at the University of Georgia Cooperative Extension, described the 2016 and 2019 flash droughts in Georgia. As Pam stated, Georgia is not a stranger to drought, but these two "exploding" flash droughts were particularly impactful. Both droughts developed rapidly, although 2016 was characterized more by lack of rainfall rather than high temperatures, while 2019 was characterized more by high temperatures rather than low precipitation (although low precipitation was still a major contributor). Both caused widespread impacts, including crop

15 Osterwalder, A., Y. Pigneur, G. Bernarda, A. Smith (2014) Value Proposition Design: How to Create Products and Services Customers Want, John Wiley and Sons; ISBN: 978-1-118-96805-5; also see *www.strategyzer.com*.

yield reductions, forage completely lost, wildfires (2016), streamflow reductions, etc.

Pat Guinan, Missouri State Climatologist at the University of Missouri, recounted that the 2012 flash drought in Missouri amazed him by how quickly things went downhill, from no drought to becoming an historic event. A key issue was the timing: the flash drought started early in the growing season just when vegetation was most vulnerable due to shallow roots. The impacts extended far beyond agriculture. Pat pointed to the importance of communication in this situation, including the need to get the phrase "flash drought" out to the public.

Michael Downey, Water Planning Section Supervisor for the Montana Department of Natural Resources and Conservation described the surprise nature of the 2017 Northern Plains Drought. Antecedent conditions in the fall of 2016 included high precipitation, below-normal temperatures, ample soil moisture, and a generally deep snowpack. Going into the spring, the main concern was actually the potential for flooding. However, despite the precipitation through winter, the "spigot shut off" in May, which was accompanied by high temperature anomalies. By late May, there were early signs of moderate drought (D1) in northeastern Montana, but within four weeks this morphed into extreme drought (D3). By the end of July, 80% of the state was in some level of drought. Interestingly, though May–July precipitation was the lowest since 1895, the water year (October 2016–September 2017) ended with near-normal precipitation. As a response to the drought, Montana modified its drought-monitoring process by diversifying the groups involved in monitoring activities, increasing drought consultations to a weekly basis (from monthly), developing a regional drought-indicators dashboard, and formalizing the Montana Drought Impact Reporter.

Survey results showed that over half of end users found the term "flash drought" either "somewhat" or "very" confusing.

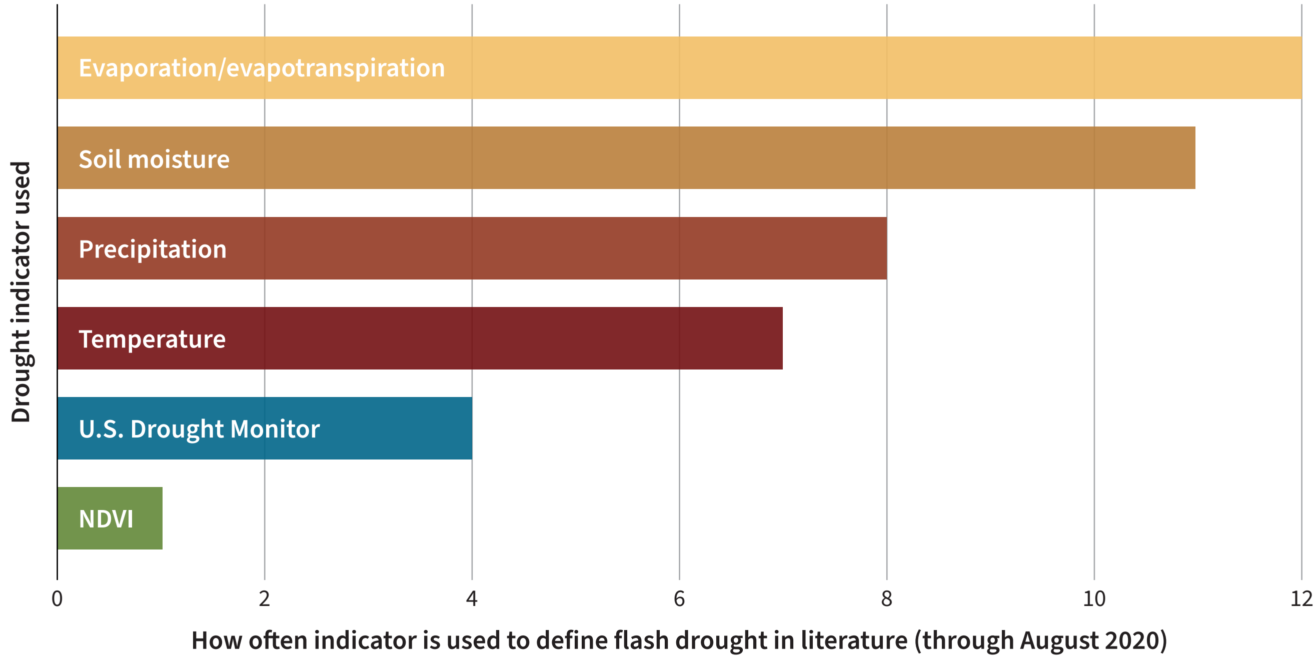
2.2.2 Session 2: Exploring Flash Drought Characteristics

This segment began with two complementary presentations on different groups' perceptions of flash drought. First, Tonya Haigh of NDMC presented results of a survey exploring how the term "flash drought" is currently perceived by both researchers and end users/practitioners. Results showed that over half of end users found the term either "somewhat" or "very" confusing. While most end users understood that the speed of onset or intensification was a characteristic of flash drought, other characteristics that end users emphasized did not necessarily align with those emphasized by flash drought researchers. As one example, end users focused more on impacts and less on drivers (such as low precipitation) than did researchers. Also, end users were more likely to assume "flash drought" was defined as a short-term (that is, short-lasting) phenomenon. Finally, some end users did not perceive a significant difference between flash drought and other drought events, indicating some difference of opinion on the usefulness of the term. All of this points to a potential disconnect between how flash drought is understood within the research community and how it is understood by those who use drought information for policy and decision making.

On the research side, Joel Lisonbee of NIDIS presented a review of the current use of the term "flash drought" in the literature. The earliest reference to the term was in 2002.[16,17] The number of publications increased significantly in response to the 2012 Central U.S. drought, and is continuing to rise each year. As of July 2020, there have been over 50 publications wholly devoted to the topic and at least 142 others that mention the term "flash drought" in relation to other topics. Within these publications, unique defining criteria have been applied to flash drought at least 20 times. Currently, the literature has not coalesced around a specific definition for flash drought; however, as detailed by Lisonbee et

16 Svoboda, M., D. LeComte, M. Hayes, R. Heim, K. Gleason, J. Angel, B. Rippey, R. Tinker, M. Palecki, D. Stooksbury, D. Miskus, and S. Stephens, 2002: The Drought Monitor. Bull. Amer. Meteor. Soc., 83, 1181–1190, *https://doi.org/10.1175/1520-0477-83.8.1181*.

17 Peters, A. J., E. Walter-Shea, A. Vina, M. Hayes, and M. D. Svoboda, 2002: Drought monitoring with NDVI-based Standardized Vegetation Index. Photogramm. Eng. Remote Sens., 68, 71–75.



▲ **Figure 2.1: Indicators used to define flash drought in the peer-reviewed literature. ("Evaporation/ Evapotranspiration" refers to both actual and potential values; "US Drought Monitor" is a weekly graphical depiction of U.S. drought conditions prepared by NDMC, USDA, and NOAA; "NDVI" stands for Normalized Difference Vegetation Index, a satellite measure of vegetation greenness.) Adapted from Lisonbee et al. 2021.**

al. (2021),[18] researchers generally focus on either: 1) the rapid onset or intensification of drought conditions; or 2) short-duration, intense drought events. Lisonbee et al. (2021) also detailed the key indicators of flash drought identified in the literature and how often they were referenced, as shown in Figure 2.1.

Following the two presentations, a breakout session allowed for small-group exploration of flash drought effects, characteristics, and indicators. Each group was configured to include a mix of researchers, individuals in organizations that provide information to support practitioners (described as "boundary organizations" in this report), and end users/practitioners. The groups were then tasked to answer the following questions:

- What are the effects of flash drought? How is it distinct from conventional, or slowly developing, drought?
- What does each group believe are the key characteristics of flash drought?
- What indicators does each group believe are most important for characterizing flash drought?

Through the breakout sessions as well as subsequent plenary discussions on Day 1 and Day 3, workshop attendees came together on a series of key takeaways related to the concept of flash drought and how to characterize and define it, as detailed in Chapter 3. However, notwithstanding progress in clarifying the concept of flash drought, it was agreed that work remains to ensure that the term "flash drought" is clearly described and communicated.

2.2.3 Session 3: Shaping Tools/ Research to Meet User Needs

The second day of the workshop focused on practitioners' needs and exploring which existing or potential tools and research activities could meet those needs now and in the future. In addition to this session, the topic of practitioners' needs came up frequently throughout the three-day workshop.

18 Supra 14: Lisonbee et al., 2021.

The technique used to explore user needs was the Value Proposition Canvas (VPC).[19] The VPC is a structured process to identify which products (including research projects) best align with the user's needs and which user's needs are currently unmet. Users' needs (in this case, flash drought practitioners' needs for early warning and response) are organized into jobs (the activities, tasks, or actions they perform before and during a flash drought), pains (what makes those jobs difficult) and gains (what makes those jobs easier). Relevant existing tools (datasets, maps, applications, etc.) or research activities are then evaluated for the degree to which they are gain-creators and pain-relievers, i.e., tools/research that create value or are impactful. For this exercise, we also included an additional third step to record ideas for future tools or research topics.

It is still not well understood how predictable flash drought is, and whether there are clear climate signals, or if flash droughts are due to the chaotic fluctuations of the atmosphere.

Attendees were divided into eight sector groups and asked to take on the role of a practitioner in that sector if they were not one, and to identify assumed user needs and the current tools intended to meet those needs. The sector groups were as follows: energy and industry, water resources, forestry and ecology, fire management, disaster preparedness and response, recreation and tourism, livestock production, and farming and cropping. The discussions and resulting VPCs by sector were shared in the plenary session, and then were used to help focus subsequent discussions about priority research topics and tool development on the following day.

2.2.4 Session 4: Identify Research Needs in Monitoring, Prediction, and Planning/Response

The third day of the workshop began with keynote presenters providing an initial overview of the challenges, opportunities, gaps and needs for three aspects of drought early warning: monitoring, prediction, and planning/response.

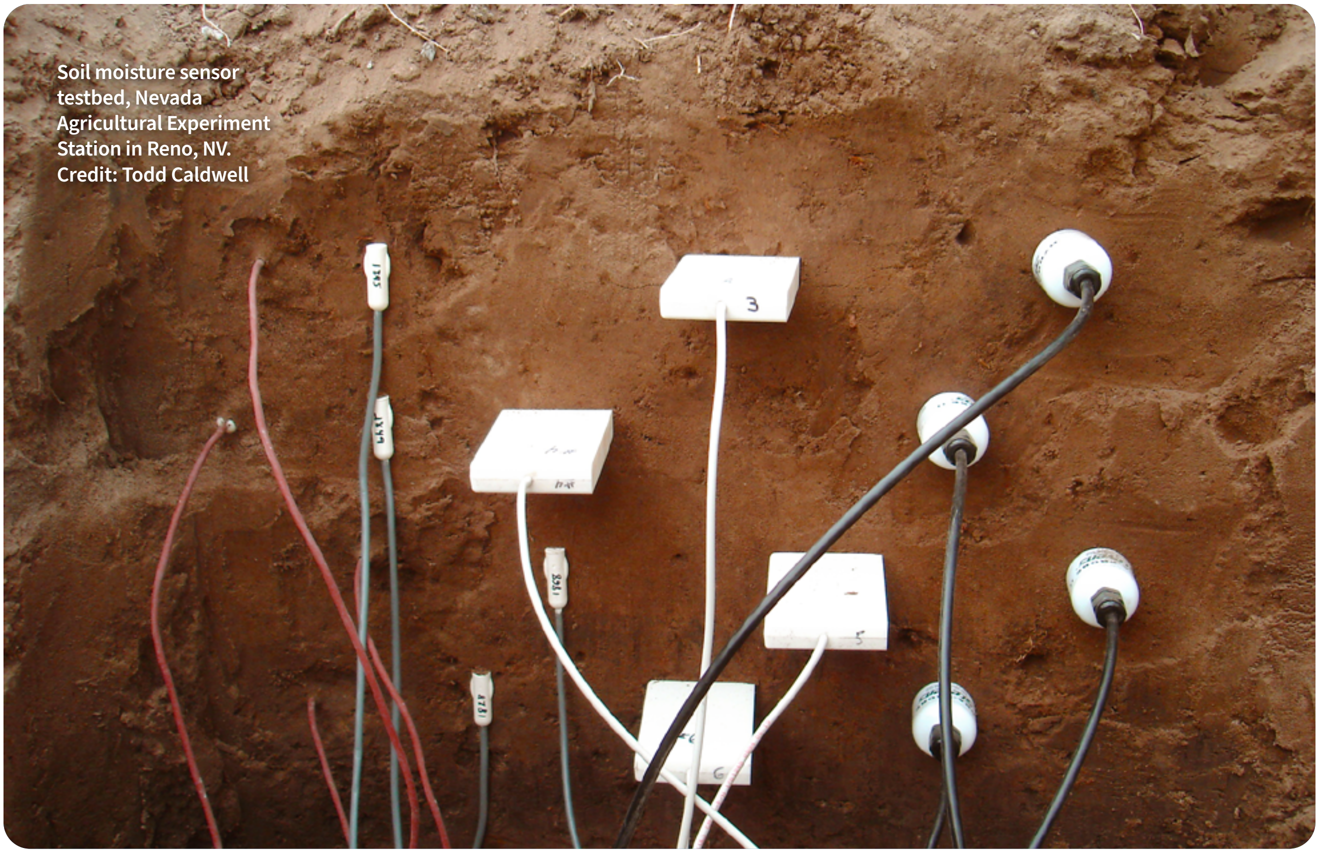
First, Jason Otkin, a flash drought researcher from the University of Wisconsin-Madison, and Mark Svoboda, the Director of the NDMC, presented on the challenges and opportunities, as well as gaps and needs, related to flash drought monitoring. Their presentation accentuated the importance of using a suite of indicators and tools to properly monitor the evolution of flash drought from its inception to the end of the rapid intensification period and beyond. In addition, they emphasized the importance for the flash drought research community to agree on a general framework for flash drought since this strongly impacts how we monitor and forecast this phenomenon.

Next, Andrew Hoell from NOAA Physical Sciences Laboratory and Hailan Wang from the NOAA Climate Prediction Center presented on the challenges, opportunities, gaps, and needs related to flash drought prediction. It is still not well understood how predictable flash drought is, and whether there are clear climate signals, or if flash droughts are due to the chaotic fluctuations of the atmosphere. This presentation highlighted the inadequacy of current operational forecasts and other forecast tools in providing skillful and detailed forecasts for flash drought development. They noted the need for exploratory research to identify new sources of predictability for flash drought, and for evaluation as to how well these new sources of predictability are represented in current and future forecast models.

Finally, the challenges, opportunities, gaps, and needs for flash drought planning and response were presented by Tim Hall, who serves as the Hydrology Resources Coordinator for the Iowa Department of Natural Resources (DNR). Mr. Hall described how the 2012 drought in the central United States helped state partners expand their understanding of the various roles and responsibilities each one plays during a drought. The 2012 drought also helped increase coordination among Iowa's state agencies and led to the development of the Iowa Water Summary Update,[20] which continues to be produced by multiple state agencies and provides an easy-to-understand overview of

19 Supra 15: Osterwalder et al., 2014.

20 *https://www.iowadnr.gov/Environmental-Protection/Water-Quality/Water-Summary-Update*



Soil moisture sensor testbed, Nevada Agricultural Experiment Station in Reno, NV. Credit: Todd Caldwell

state water conditions. The role of the Iowa DNR during drought is to assess the technical data and communicate the data and their potential implications to a fairly broad audience. Given this role, the Iowa DNR would find additional communication tools extremely useful, especially tools such as a metric/index that would effectively communicate the rapid intensification aspect of flash drought, and those that have proven successful.

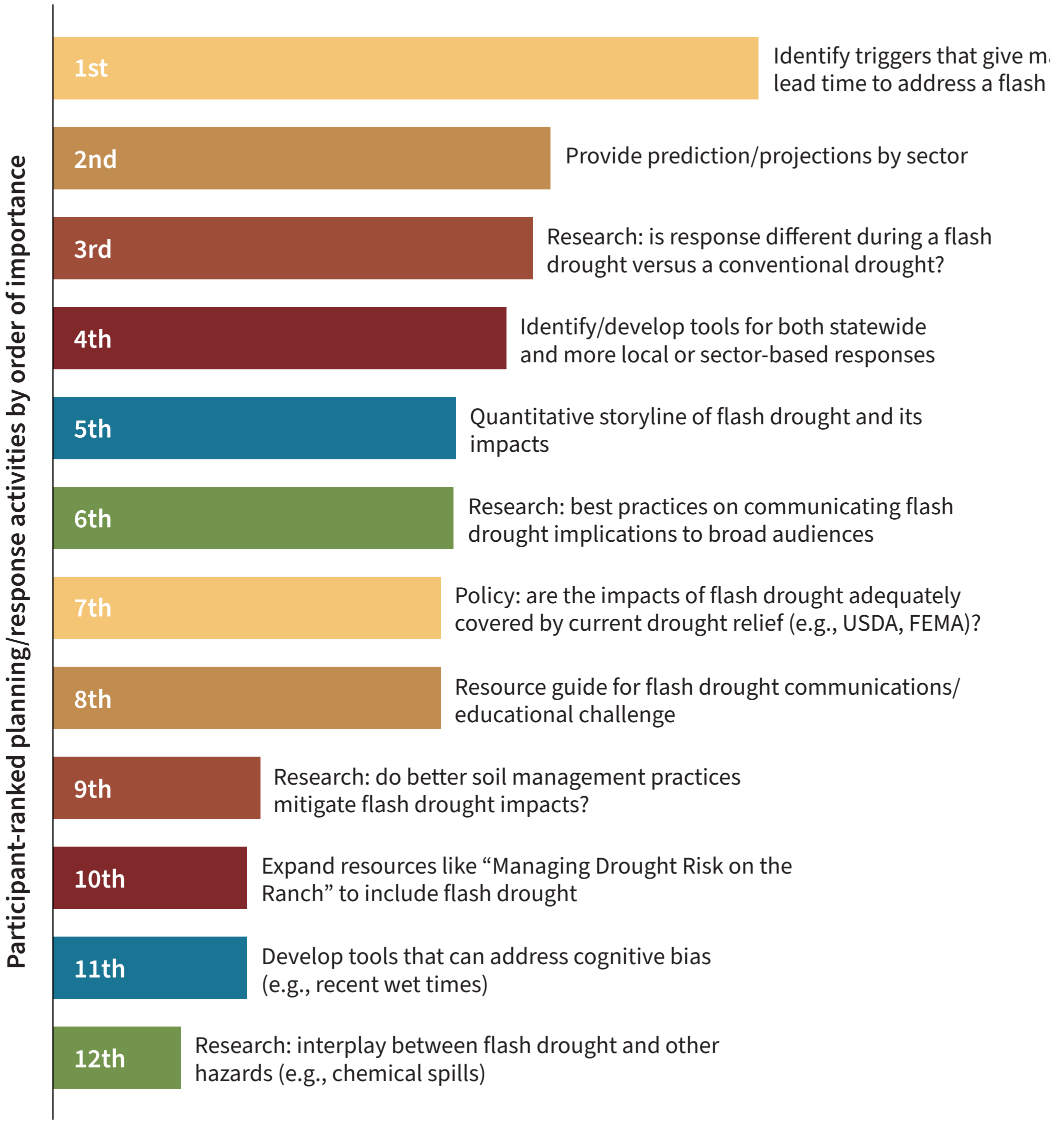
Following the three scene-setting presentations, the workshop started its final round of breakout groups to further discuss the gaps and needs for monitoring, prediction, and planning and response. One of the goals of these breakout groups was to develop a list of outstanding research and tool needs for each of the topics. In addition, the breakout groups were designed to identify opportunities to leverage existing resources or activities to help meet these needs. Each group was tasked to answer the following questions for their specific topic (i.e., monitoring, prediction, or planning/response):

- What are the gaps and needs in research in this topic area?
- Given the user needs you've heard during the workshop, what existing and new tools do you think would create the most value?
- What current activities could be leveraged to help meet either the research or tool needs?

Ideas generated during the breakouts were used as the basis for the discussion on next steps in the final session. These ideas and other key takeaways are detailed in Chapter 3.

2.2.5 Session 5: The Path Forward

The fourth and final objective of the workshop was to agree upon next steps for this emerging domain and how NIDIS and other partners can support research and coordination related to flash drought. The last session of the workshop focused on this objective by capturing ideas for future work (research, activities, etc.) and prioritizing them according to their relative importance to the researcher and practitioner and to the relative ease in accomplishing these projects.

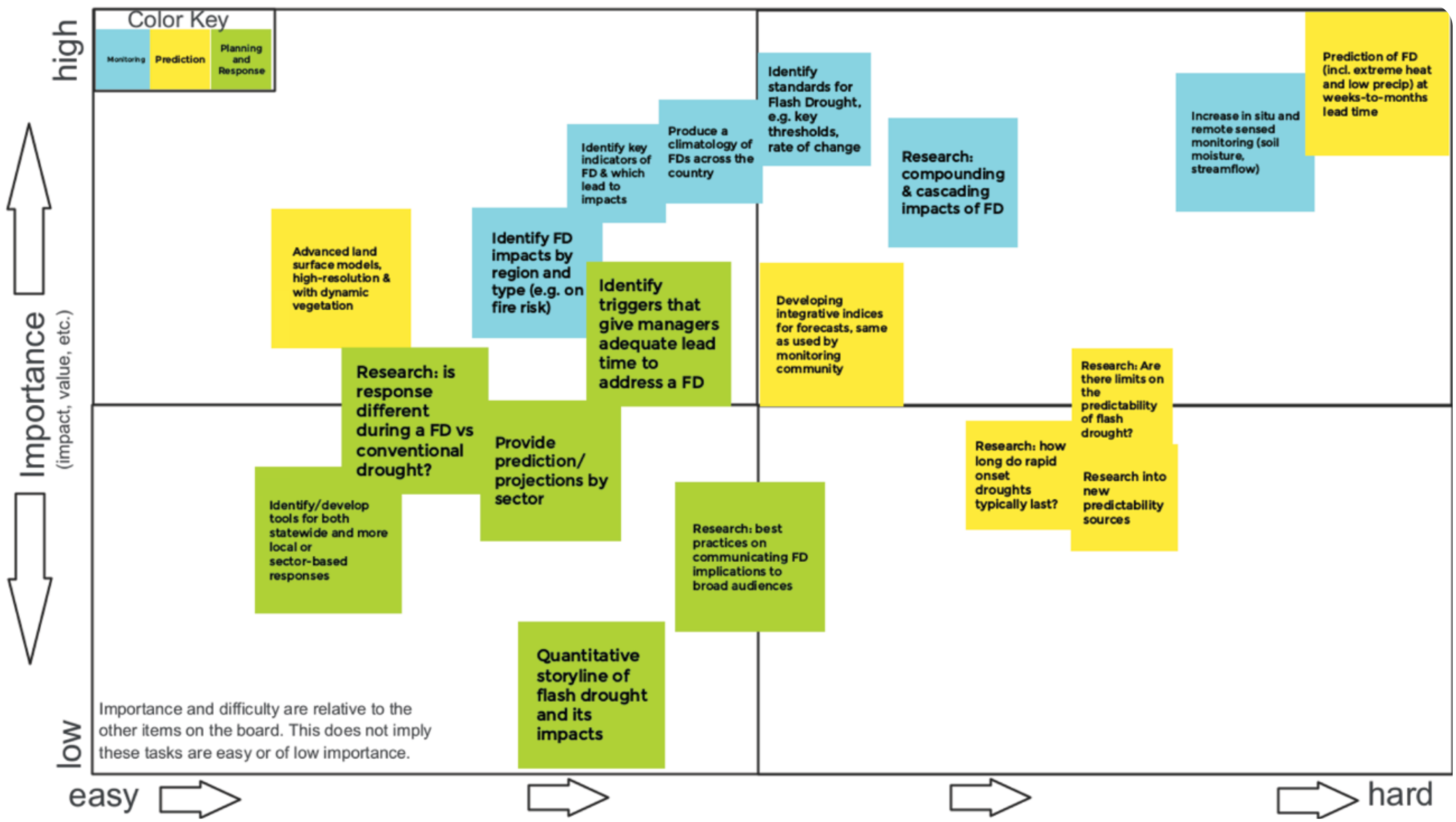


◄ **Figure 2.2: The results of one of the Mentimeter polls used to identify the activities the participants felt were important in the planning/response topic area. This figure is included to illustrate the result of the Mentimeter process.**

Ideas for potential projects for each topic area (monitoring, prediction, and planning/response) were gleaned from the presentations and breakout groups throughout the workshop, particularly from Session 4 described above. The 12 most salient ideas for each topic area were then prioritized by workshop attendees using a real-time Mentimeter poll.[21] Each workshop participant was asked to rank the project ideas in order of importance in relation to their work or responsibilities (see Figure 2.2 for an example of the ranked ideas). The entire list of research and application/tool project ideas identified during this session is shown in Appendix A.

The final activity was a virtual "whiteboard" exercise using the sharable, on-line tool JamBoard.[22] The top six project ideas for each topic area (selected from the top Mentimeter poll results) were sorted according to their relative difficulty, importance, and sequencing dependencies (i.e., which activities need to come first). The workshop participants were invited to share their thoughts about which activities would be easier to accomplish , which were more important, and finally which needed to come first based on its dependencies. The final sorting of activities is shown in Figure 2.3, and details on specific outcomes are provided in Chapters 3 and 4.

21 *https://www.mentimeter.com/*
22 *https://workspace.google.com/products/jamboard/*



▲ Figure 2.3: **The results of a "whiteboard" exercise to rank project ideas by difficulty and importance. Note that the importance and difficulty are assessed relative to the other items on the board, and do not imply that items in the bottom left quadrant are inherently unimportant or easy. Results from this exercise are captured in Section 3.4: Research and Applications Needs for Flash Drought Monitoring, Prediction, and Planning/Response.**

Young corn plants show signs of drought stress. Credit: Kent Weakley

3

KEY TAKEAWAYS

The Flash Drought Workshop provided one of the first opportunities for a structured discussion about the concept and implications of flash drought, both among flash drought researchers and between the research community and practitioners who manage and respond to flash droughts. This chapter provides the key takeaways from the discussion and forms the basis for the priority actions enumerated in Chapter 4.

3.1 CHARACTERIZING FLASH DROUGHT

There was broad agreement among workshop participants that a *clear conceptualization of flash drought is important and necessary,* both to help guide research efforts and to support the development of early warning indicators and management actions to assist decision makers. Identifying the basic principles or characteristics of flash drought requires continued collaboration between the research community and practitioners. This will ensure that research is best oriented towards addressing real-world impacts and needs.

On the characteristics of flash drought, there was general consensus that the key feature of flash drought is the *rapid onset* or *rapid intensification* of drought conditions, regardless of whether the resultant conditions are short-lived (e.g., a few weeks) or persistent. Practitioners described flash droughts as a sudden and unexpected appearance of drought impacts that seem to "come out of nowhere" and catch communities off guard, in sharp contrast to more conventional droughts, which are typically understood as slowly evolving events. As one participant stated, "All of a sudden lawns and crops seem to change almost overnight, the vegetative environment is shocked." A similar comment came from a survey participant: "The drought event completely reversed previously wet conditions in an unusually short amount of time, so fast that it became difficult to accept that wet conditions were completely erased and not persisting as is often the case."

From a research perspective, this reflects a high rate of change in conditions relative to climatologically normal rates of change for a particular location: "Whatever climate you're in, you're accustomed to conditions changing at some rate. When they start changing faster than that, that's the 'flash' part." And for practitioners, the key implication is that any such rapid change in conditions and impacts requires an equally rapid management response, which in many cases they are not prepared for due to inadequate drought monitoring and forecasting.

Suburban lawn during drought. Credit: Suzanne Tucker

The key feature of flash drought is rapid onset or intensification: "All of a sudden lawns and crops seem to change almost overnight, the vegetative environment is shocked."

The fundamental physical dynamic of flash drought was described as the *rapid depletion of available water in the landscape;* that is, some combination of factors (e.g., high temperature, below-normal precipitation, high winds, etc.) that causes atmospheric evaporative demand to deplete landscape reservoirs of water such as soil moisture and fuel moisture (i.e., moisture in trees, downed wood, or grasses), leading to vegetative stress, fire risks, and other impacts.

There was recognition of the need for some standardization on the terms "rapid" and "intensity." How "rapid" a change would qualify as a flash drought? Most attendees considered that the general timeframe would be a change occurring on the order of weeks. In addition, how "intense" a change would qualify (e.g., how many category changes of the U.S. Drought Monitor or other metrics used for thresholds would imply a flash drought?). It was noted that the concept of flash drought should not include events characterized by minor fluctuations in conditions without discernible impacts; participants were sensitive to not wanting to be "the boy that cried wolf."

The workshop participants identified *seasonality*, *regionality*, and *impacts* as three fundamental and inter-related attributes of flash drought characterization. In particular, season and region both are driving factors in the types of impacts, or whether there are impacts at all. Effects vary by season based on the phenological state or sensitivity of plants; the seasonal timing of an event will imply different impacts on agriculture and the environment. Effects also vary by region, given the different climates found across different parts of the country. In eastern and central regions, flash drought is typically a warm-season phenomenon that expresses first as vegetative stress (particularly in areas without irrigation); while in the arid west, changes in evaporative stress might be less important because normal evaporative demand is always quite high, and flash drought might express through increased fire risk in forests and grasslands.

As for impacts, there was general agreement that a climatological phenomenon without physical impacts (e.g., wilting plants, fire danger) would not be considered flash drought for the purposes of supporting real-world applications. As one participant stated, "In Montana we might have the 'indicators' of a flash drought in winter (e.g., a rapid warm-up), but does it really count as that since there are no impacts?" As for types of impacts, as mentioned previously, vegetative stress is often the first expression; while water storage (e.g., in reservoirs) is usually a lagging indicator. It is important to look not just at water quantity but also water quality, as rapid changes in water quality might be linked to flash droughts, triggering adverse health effects, negative implications for energy production, industry, and wildlife. It was also noted that ecological effects should be considered alongside human-based impacts. For example, it is possible to have ecological impacts from small streams drying up, even as reservoirs and drinking water supplies are unaffected. It is important to take a broad approach when considering impacts, including incorporating perspectives from across different sectors.

As to the question of whether a short duration should be considered a key characteristic of flash drought,[23] participants compared the terminology of flash drought to other "flash" events, such as flash flood or flash fire. These "flash" events are unexpected, sudden, and generally understood to be of short duration. However, it was pointed out that while a flash flood or flash fire might end quickly, the impacts from each can linger, as can the impacts of flash droughts. There was a general consensus that defining flash drought by duration was not necessarily useful for several reasons. First, from the perspective of early warning, criteria for monitoring and forecasting need to be independent of duration, since the objective would be to support action before significant impacts have been felt. Researchers could look back on a flash drought's duration retrospectively for historical studies, but it could not be used as a defining characteristic to trigger communication in real time. Furthermore, as one practitioner stated, "Once you are in drought, you are in drought—the duration might be two months or a year—but the need to take action won't change." From this vantage point, a rapid change of state is a far more important characteristic than duration.[24] However, participants agreed that there might need to be some minimum duration to be considered a flash drought, to avoid the use of the term for variable weather patterns without impacts significant enough to merit action.

▲ **Vegetative stress is often the first indication of flash drought, whereas reservoir levels are a lagging indicator. Flathead River above Kerr Dam, Montana. Credit: Girl Grace.**

Participants identified some additional topics that require more research and deliberation. First, there was discussion about the difference between rapid onset and rapid intensification and whether the term "flash drought" should be used for both, i.e., both for a rapidly developing event that initiates from non-drought conditions, and for one that occurs within the context of a longer-term, slower-evolving drought. While overall there was a sense that both can have the same "unexpected" impacts—and therefore can be considered flash drought—some potential differences were noted. For example, in a rapid-onset flash drought, a reversal to more normal climatic conditions through receiving ample precipitation could potentially eliminate impacts before they become critical. Whereas in the context of a long-term drought, a return of precipitation for a period of time may not be enough to offset impacts. In addition, from a response perspective, going rapidly from no drought to drought may be more of a surprise, and make it harder to initiate actions; whereas if an area is already in drought, some response measures are likely already in place, making additional responses easier to implement.

23 Lisonbee et al. (2021)[12] categorized flash drought definitions by "short duration" or "rapid onset/intensification" but found that most of the flash drought research publications generally considered to be in the "short duration" category were not specifically about duration, but instead focused on the presence of high-threshold heat waves, which by their nature are short-lived events.

24 It should be noted that this discussion does not necessarily imply that the duration of a flash drought isn't important, but simply that duration may not be a useful defining characteristic of flash drought.

There was discussion about the distinction between flash drought and more conventional, slowly developing drought. Participants asked: Is it important to consider them as different phenomena, or are they simply different points along a continuum of intensification rates? Flash drought can blend/evolve into conventional drought, but how and when to define that transition might be difficult. Finally, a related question: How can the impacts of flash drought be distinguished from those of conventional drought, particularly in the case of rapid drought intensification occurring during an ongoing drought?

In summary, throughout the discussions, it was clear that, even as the workshop served as a much-needed first step in clarifying the concept of flash drought, there is more work to be done before the term "flash drought" can be clearly described and communicated by the research and practitioner communities. Attendees noted that two different terms might possibly be needed: one for the rapid onset of drought from drought-free conditions; and another term for rapid intensification that occurs during a pre-existing drought. One suggestion was: "flash drought" for rapid onset, and "embedded flash drought" in cases of intensification. Another suggestion was to use the term "flash phase" for a flash drought event within an ongoing drought.

Any definition should acknowledge the difference between defining flash drought climatologically versus defining it for public decision making. Again, given the important real-world consequences, the latter should be an equal priority. Attendees emphasized the value of a coordinated effort to bring researchers and practitioners together on a general framework for characterizing flash drought, allowing for adjustments over time (and region) as more is learned about the phenomenon and its impacts.

Attendees emphasized the value of a coordinated effort to bring researchers and practitioners together on a general framework for characterizing flash drought, allowing for adjustments over time (and region) as more is learned about the phenomenon and its impacts.

3.2 INDICATORS OF FLASH DROUGHT

Workshop attendees were provided a flash drought literature review ahead of the workshop and given an opportunity to provide some preliminary input on the question of what might be appropriate indicators of flash drought. There was agreement that an integrated set of indicators would be needed, given the cascading and overlapping impacts that can be triggered, and the variability in the phenomenon across seasons and regions. Indicators should be focused on leading impacts (e.g., vegetative stress, soil moisture, and fuel moisture levels), weighted for different regions and seasons, and more short-term oriented, as opposed to traditional, generally longer-term indicators. Ideally, the set of indicators would be able to identify potential intensification of drought conditions, with some guidance for determining if this is relevant to a particular region and/or season. Specific indicators to consider and evaluate, all of which should be standardized to the local climatology, include:

- **Soil moisture,** along with information about soil types to help with interpretation.
- **Evapotranspiration (ET):** this indicator can have a complex relationship with flash drought. Elevated ET can be a contributing cause of flash drought, but ET will eventually decline (sometimes rapidly) in a drought, as moisture becomes limited and there is no more water in the landscape to evaporate. Meanwhile, in hot and water-limited climates (e.g., the desert Southwest), ET will decrease rapidly due to inherent climate conditions whether the region is in drought or not, and regardless of the rate of drought onset.
- **Evaporative Stress Index (ESI) and variants,** to capture vegetative stress. These metrics are easier to use than ET because they are normalized by a reference or potential ET that accounts for the actual atmospheric evaporative demand.

- **Evaporative demand and atmospheric aridity:** metrics such as vapor pressure deficit, potential evapotranspiration (PET) and the Evaporative Demand Drought Index (EDDI) provide a measurement of atmospheric "thirst" especially as a flash drought is developing.

Indicators should be focused on leading impacts (e.g., vegetative stress, soil moisture, and fuel moisture levels), weighted for different regions and seasons, and more short-term oriented...

- **Wind, temperature, precipitation, and solar radiation anomalies,** which are contributing factors towards increased evapotranspiration.
- **Indicators based on specific impacts,** such as the condition of cropland/pasture/rangeland. However, it was recognized that impacts, by themselves, are not the best candidates to serve as leading indicators of flash drought, given the need to provide early warning of flash drought before impacts become evident.

3.3 PRACTITIONER ENGAGEMENT

3.3.1 Key Takeaways from the VPC Exercise on User Needs

For some sectors, the needs of practitioners for flash drought were the same as those for conventional drought. For example, the group discussing the needs of the forestry and ecology sector noted increased fire danger and disruption to prescribed burns from both types of droughts. The livestock sector group noted the difficulty in selling stock and the loss of animal genetics in both flash and conventional droughts. However, some groups noted the additional challenges that come from rapid onset or intensification of drought conditions. For example, the forestry and ecology group noted not having enough time to apply for government support, and the water resources group mentioned the stress that comes from not having enough time to make operational decisions. The farming and cropping group mentioned that it is unclear how some crops will respond to rapid changes in temperatures and water availability, and that some stages in the cropping cycle are more sensitive than others.

Some non-agriculture related groups expressed frustration that most drought declarations are based on water resource availability for agriculture, and they expressed a need for more information about the non-agricultural impacts of flash droughts. Another common theme was that dry conditions alone do not always cause an issue for practitioners. Rather, it is the associated phenomena such as heatwaves, poor water quality, and increased fire danger that cause the most problems.

When it comes to currently available flash drought tools, there were a few comments questioning whether certain tools are adequate or sufficient. These comments include:

- There might be too many indicators for ranchers (31 tools were listed in the VPC); a gain for the livestock industry would be to know which tools work best and when.

  The USDM was mentioned seven times, twice as an "existing tool" and five times as "not meeting needs." These latter comments were either that the USDM did not seem to adequately reflect local conditions or that it lagged local conditions, making it difficult to use in a flash drought situation.
- Fire managers, who are making daily decisions, suggested that even a five-day lag makes tools such as EDDI and QuickDri "useless [for fire management]" under potential flash drought conditions. This point highlights an unmet need for this sector for data and tools that are updated daily.
- Workshop participants did not know whether or how users' needs are being met by private sector tools.

Ideas for future research or tools included many suggestions that were subsequently raised in the later sessions on future research priorities. A few common themes include:

- Improved soil moisture monitoring (mentioned in some form seven times)

- Improved skill for sub-seasonal forecasts
- A call for more practitioner involvement in the development of future tools and research

It was suggested that when it comes to flash drought, current forecasts are not meeting needs. Some of the comments regarding frustrations with current forecasting tools expressed a practitioner need for:

- Longer range (beyond two weeks) flash drought forecasts
- Low-flow river forecasts similar to river flood forecasts
- A forecast product that links expected hot/dry conditions to fire danger ratings
- Subseasonal forecasts of climate indices that are tied to drought conditions

Notwithstanding the clear insights that were gained by the VPC exercise and other discussions related to practitioners' needs for flash drought preparedness and response, it was apparent that there is still much to learn. It became evident through the course of the workshop that, while the discussions provided a good starting point, *more engagement is needed with practitioners who are "on-the-ground"* responding to and/or planning for flash drought. Such practitioner engagement can help to ensure that definitions/principles for flash drought attend to the actual functional needs of the user community. As one commenter at the workshop emphasized in regard to getting end-user input to the formulation of flash drought terminology, "researchers can adjust terms a lot easier than changing the entire public." Collaboration between the research community and practitioners is also important to ensure researchers understand management decisions, planning and response activities, and the costliest impacts of flash drought.

3.4 RESEARCH AND APPLICATIONS NEEDS FOR FLASH DROUGHT MONITORING, PREDICTION, AND PLANNING/RESPONSE

The workshop focused on three key topic areas of flash drought research and applications (tools/services): monitoring, prediction, and planning/response. These topic areas were explored in presentations by research experts, through breakout session discussions, and via plenary prioritization exercises (described in Chapter 2). Several key takeaways to guide future priorities were identified for each topic; these are described below.

The suite of indicators used to assess flash drought must include variables that reflect land–atmosphere interactions, like soil moisture and evapotranspiration, in addition to the meteorological drivers of flash drought.

3.4.1 Monitoring

It is vital for the research community to agree on a general framework for characterizing flash drought because this strongly impacts how we monitor, forecast, respond to, and plan for this phenomenon. This framework should include the distinguishing features of flash drought, such as the characteristic of rapid onset/intensification.

A suite of indicators and tools is needed in order to properly monitor the evolution of flash drought from its inception to the end of the rapid intensification period and beyond. The suite of indicators used to assess flash drought must include variables that reflect land–atmosphere interactions, like soil moisture and evapotranspiration, in addition to the meteorological drivers of flash drought. Therefore, indicators that are best suited for flash drought monitoring will use anomalies in precipitation, evaporative demand, soil moisture, evapotranspiration, and vegetation health.

It is important to look at the changes in these flash drought indicators, since it is the rapidity of changes that are a key characteristic of flash drought that distinguishes it from conventional drought. Similarly, there is a need to identify minimum rates of change for the rapid intensification during flash drought, including key thresholds for flash drought indicators. Future research is needed on developing an integrated set of key indicators that are specific to flash drought.

Flash drought characteristics and impacts will vary by season and region. Therefore, there is a need to better understand where and when each indicator is most important for flash drought monitoring, and to communicate this information to practitioners who are responding to or planning for flash drought. Other key features of flash drought indicators and monitoring tools include using those that respond quickly to changing conditions, those with high-resolution datasets, those with a long period of record in order to compare to normal, and those that minimize data latency for operational applications.

Research is needed to better understand the compounding and cascading impacts of flash drought, and how they vary by region, season, and sector.

Gathering and documenting the impacts of flash drought is essential in order to fully understand the phenomenon, to find ways to mitigate or adapt to the potential impacts, and to reduce the societal and environmental risks of flash drought overall. Research is needed to better understand the compounding and cascading impacts of flash drought, including better understanding where the impacts of flash drought first manifest in various economic sectors. In order to do this, flash drought impacts need to be identified by region, season, and sector.

Finally, flash drought monitoring relies upon various types of data including *in situ* observations, remotely sensed data, and modeled data. In order to both monitor conditions and validate satellite and modeled data, "on the ground" information is critical; therefore, more *in situ* observations are needed, including soil moisture, precipitation, snowpack, radiation, and evapotranspiration. However, it will be a challenge to install a sufficient number of *in situ* measurements across the country. Augmentation of *in situ* networks with improved satellite and modeled data will be needed as well.

Opportunities to Leverage

To increase *in situ* monitoring, existing federal and state monitoring networks should be leveraged wherever possible. This includes such networks as the USDA's Soil Climate Analysis Network (SCAN), NOAA's Cooperative Observer Network (COOP), the U.S. Climate Reference Network (USCRN), and over 40+ state mesonet programs. Another existing effort to leverage for flash drought monitoring is the National Coordinated Soil Moisture Monitoring Network (NCSMMN). The NCSMMN is a multi-agency, multi-institutional initiative by NIDIS/NOAA, USDA, and other partners to integrate soil moisture data from around the country and to capitalize on its transformative potential for a wide range of applications across sectors of the economy.

Identifying the most appropriate flash drought indicators to use by region and season remains an outstanding need. Currently, several research projects are trying to answer this question more broadly for all drought indicators. For instance, a team at NASA Goddard Space Flight Center is researching how to quantify the relative importance of several drought indicators in the U.S. Drought Monitor (USDM) as a function of region and season.[25] Results from this NASA project might be relevant to flash drought monitoring; a similar study could focus specifically on flash drought indicators. Another suggestion from a workshop attendee was to explore the idea of adding a "flash drought" designation on the USDM weekly map when applicable. However, as one attendee stated "We will need to use the USDM in some form. But the discrete nature of a weekly change in drought conditions by category sometimes cannot capture the exact situation during quickly shifting conditions. We would need something that is a little more continuous to overcome the discrete weekly nature of the USDM."

3.4.2 Prediction

Current prediction tools are inadequate to support consistently detailed and accurate operational flash drought development forecasts. Prediction tools are inadequate for the following reasons: (1) In general, flash drought predictability is limited, (2) forecast models have considerable biases, which limit their ability to accurately predict flash drought, (3) many forecast models cannot simulate key physical processes (e.g., lack of dynamic vegetation process for predicting vegetation stress), (4) some of the operational forecast systems do not make available key variables

25 *https://www.drought.gov/drought-research/quantifying-relative-importance-multiple-drought-indicators-us-drought-monitor*

relevant to flash drought or make them available in a timely manner, and (5) the resolution of forecast model outputs are too coarse.

To support improvements to flash drought prediction, the research community needs to better understand the physical processes underlying flash drought, and the interaction between these various processes, including precipitation, evaporative demand, temperature, wind, land–atmosphere feedbacks, and vegetation. Secondly, there are only a few known sources of predictability for flash drought events, which include Rossby waves propagation (i.e., alternating areas of high and low pressure) or fluctuations in the jet stream that guide precipitation-bearing storms. As one attendee stated, "Based on research done so far (as shown in current operational forecast systems), the predictability is currently limited to one to three weeks." Research is needed to identify new sources of predictability, and once identified, evaluation is also needed to see how well these new sources of predictability are represented in current and future forecast models. A critical part to improving the forecasting of flash drought is to improve the specific predictive models being used. As research improves physical understanding and predictability limits of flash drought, it is important to transfer this knowledge to improve dynamical models, including land–surface models.

Current prediction tools are inadequate to support consistently detailed and accurate operational flash drought development forecasts.

Furthermore, to facilitate the production of flash drought forecasts, it is recommended that operational forecast models use consistent initialization dates, produce at least weekly forecasts with adequate ensemble members, use a resolution of 0.5 degree or finer, and make forecasts for variables relevant to flash drought. The forecast systems should also use improved data assimilation for more accurate forecast initializations, include processes relevant to flash drought (e.g., dynamic vegetation), and longer hindcasts. Longer hindcasts, also known as retrospective forecasts, are needed to assess the accuracy of forecast models and whether their improvements lead to more accurate predictions. A challenge with predicting flash drought is that, due to the complexity and multivariate nature of this phenomenon, accurate prediction requires that models forecast multiple variables with skill simultaneously, not just one variable.

Opportunities to Leverage

Several opportunities exist to help advance the prediction of flash drought. NOAA's Climate Prediction Center (CPC), a leader and partner in drought prediction research, has recently been working to improve and make available a suite of prediction tools related to flash drought, including the Potential Flash Drought Development Tool,[26] and three others that do not directly predict flash drought but are related, which are the Objective Drought Tendency,[27] weekly 3-month Standardized Precipitation Index (SPI) forecasts,[28] and soil moisture forecasts.[29] CPC plans to develop operational flash drought outlooks in the coming years, for which they have recently recognized the need to incorporate an advanced land–surface model with a higher resolution and dynamic vegetation. In addition, an operational CPC tool is theWeek-2 U.S. Hazards Outlook, and they are currently exploring the idea of integrating a flash drought hazard designation to this map.

In August 2016, the National Water Model (NWM) was launched by NOAA. The NWM is a hydrologic modeling framework that includes many variables relevant to drought monitoring, including soil moisture at several depths and streamflow, and it does so on an unprecedentedly high-resolution grid of 250 meters. Recent research evaluated soil moisture and streamflow anomalies and explored developing experimental monitoring products from NWM outputs.[30] Moving

26 *https://www.cpc.ncep.noaa.gov/products/Drought/Flash_Drought/potential_development.php*
27 *https://www.cpc.ncep.noaa.gov/products/Drought/Flash_Drought/tendency_forecast.php*
28 *https://www.cpc.ncep.noaa.gov/products/Drought/Subseasonal/spi3_week1-4_forecast.php*
29 *https://www.cpc.ncep.noaa.gov/products/Drought/Subseasonal/smp_week1-4_forecast.php*
30 Hughes M, Jackson D, Cifelli R, Hobbins M, Webb RS, D. Unruh, F. Salas, Glaudemans MJ, Ogden F, Meng J, Wang H, and D DeWitt; Application of the National Water Model for Drought Monitoring, (poster) AMS Mountain Meteorology, July 2020

forward, utilizing the NWM output and coordinating with the National Water Center to improve flash drought prediction may be warranted.

3.4.3 Planning and Response

Flash drought events often serve as a catalyst for increased coordination for drought response; following the drought event, this motivates agencies/decision-makers to update their drought plans. The rapid onset of flash drought necessitates a rapid response at local and state levels, but more research is needed into how actions taken during a flash drought might differ from conventional drought. Assuming there are differences, is it the rapid rate of response required during flash drought that makes the actions different? For instance, are entities coordinating and communicating differently because of this rushed time schedule?

Hikers explore Harry's Ridge Trail near Mt. St. Helens, WA. Credit: Roman Khomlyak

Research is needed to better understand how flash drought development in different seasons affects decision making by sector, particularly those beyond agriculture (e.g., recreation/tourism, ecology, health).

Research is needed to better understand how flash drought development in different seasons affects decision making by sector, particularly those beyond agriculture (e.g., recreation/tourism, ecology, health). For drought planning, practitioners need adequate lead time to address the potential impacts of flash drought. Therefore, research is needed to identify the best indicators and triggers by time of year and sector to give them adequate time to respond.

More in-depth social science research is needed on people's perception of flash drought to support more effective communication. For instance, are people assuming flash droughts are less severe, less intense, and shorter because they come on quickly? How does this affect the actions they take? Or does a person's perception of flash drought depend on where they live? For instance, do those that live in a predominantly wet area and those who live in a dry area conceptualize flash drought differently?

In a broader sense, there are several drought relief and/or planning programs available at the national level through agencies like the USDA and FEMA.[31] These include programs like the USDA Farm Service Agency's Livestock Forage Program,[32] or FEMA's Building Resilient Infrastructure and Communities (BRIC) Program.[33] Research is needed to explore whether the impacts of flash drought are adequately covered by these existing programs, or if policy adjustments are necessary to improve drought relief and/or planning efforts for flash drought.

During drought response, regional, state, and local entities are often tasked with assessing the technical data (drought monitoring indices and forecasts) and communicating this information to technical and non-technical audiences. Methods and/or tools that have proven to be effective at communicating flash drought and the evolution of its impacts to end users, and research focused on identifying effective communication strategies, are needed to improve drought response. Communicating flash drought risks with probabilistic information could be effective with the drought planning and response audience because this type of information is often used in their decision making.

31 *https://www.drought.gov/drought-in-action/drought-relief-recovery-and-support*
32 *https://www.fsa.usda.gov/programs-and-services/disaster-assistance-program/*
33 *https://www.fema.gov/grants/mitigation/building-resilient-infrastructure-communities*

◀ **Drought conditions challenge spring soybean crops.Credit: M. Niebuhr**

Cross-Cutting Themes

- General framework for characterizing flash drought
- More *in situ* observations
- Improved collaboration among researchers themselves, and with practitioners

Opportunities to Leverage

There are several existing planning and response efforts that might be leveraged for flash drought. For example, the State Climate Office of North Carolina and NOAA's Carolinas Integrated Sciences and Assessments program recently completed a project focused on improving the usability and communication of drought-relevant information for North Carolina decision makers. This project focused on user engagement and developed tailored, sector-specific information for drought-relevant decisions in an actionable format to assist with drought response across the state.[34] The findings and takeaways from this project could provide a basis for establishing best practices in communicating flash drought, and its framework could be transferred to a similar project specific to flash drought.

Drought planning resources, like the NDMC's Managing Drought Risk on the Ranch[35] guide, could also be adapted to incorporate planning for both conventional and flash drought. Sector-based decisions calendars have been used for linking user needs for climate information, and these were also identified as a potential way to explore management decisions as they relate to flash drought. Decision calendars depict management decisions made in specific months and the climate factors that affect those decisions throughout the year.[36]

3.4.4 Cross-Cutting Themes

While there are several unique needs related to each independent topic, there are intersections between the research and application needs for flash drought monitoring, prediction, and planning/response.

First, to restate a major theme of the workshop, the agreement on a general framework for characterizing flash drought is crucial to advance all three topic areas. Until this is developed, there will be ambiguity as to what exactly is considered a flash drought in the monitoring, prediction, and planning/response communities. Second, more *in situ* observations (e.g., of soil moisture, vegetative stress, etc.) are needed not only to monitor and respond to conditions, but also to validate models and evaluate flash drought forecasts.

Another intersection among all three topics—and another theme heard throughout the workshop—is the importance of improved collaboration among researchers themselves, and with practitioners managing for flash drought. Improved coordination is needed between flash drought monitoring and prediction communities because the two often work with similar concepts but on different spatial and temporal scales. By better understanding the spatial and temporal limits and expectations of both communities, synergies can be identified to improve early warning capacity.

34 *https://climate.ncsu.edu/drought_comm*

35 *https://drought.unl.edu/ranchplan/Overview.aspx*

36 Takle, E. S., Anderson, C. J., Andresen, J., Angel, J., Elmore, R. W., Gramig, B. M., Guinan, P., Hilberg, S., Kluck, D., Massey, R., Niyogi, D., Schneider, J. M., Shulski, M. D., Todey, D., and Widhalm, M. (2014). Climate forecasts for corn producer decision making. Earth Interactions, 18(5), 1–8. *https://doi.org/10.1175/2013EI000541.1*

Similarly, there is a need for improved communication between researchers and practitioners (e.g., fire and natural resource managers, water utility providers, etc.) to better understand the decisions of these practitioners pertaining to flash drought. Intermediary or boundary organizations such as state climatologists, NIDIS, regional NOAA climate programs (e.g., Regional Climate Centers), and USDA Climate Hubs, who all often share information between researchers and practitioners, may be important as key translators of scientific indicators and realized impacts. Establishing opportunities for collaboration between researchers, boundary organizations, and practitioners can serve as a way to:

- Better understand and integrate practitioners' needs into flash drought monitoring and prediction;
- Translate technical monitoring and prediction information; and
- Co-develop appropriate flash drought indicators and triggers for response actions.

3.5 SUMMARY OF KEY TAKEAWAYS

The Flash Drought Virtual Workshop provided one of the first opportunities for a structured discussion on the concept and implications of flash drought between researchers and those who have to manage and respond to flash droughts. As a result, a rich body of information and takeaway messages was recorded that is worthy of further consideration. Below is a brief summary of the ideas that are particularly salient and that form the basis for the priority actions listed in the next chapter.

3.5.1 Characterizing Flash Drought

The workshop found widespread agreement that there needs to be a more definitive characterization of flash drought—one that is developed with practitioner engagement.

There was strong consensus that the key feature of flash drought is rapid onset/rapid intensification of drought conditions, although more remains to be settled about how those two concepts differ and how exactly to standardize terms like "rapid." Another strong consensus view was that regionality, seasonality, and impacts are essential attributes for characterizing flash drought, implying a need for an integrated set of different indicators, given the complexity of the phenomenon and its cascading impacts.

3.5.2 Practitioner Engagement

The Value Proposition Canvas session demonstrated the value of having researchers take the perspective of practitioners. It further revealed that impacts of flash drought can vary significantly by sector, as some sectors might see immediate problems while others might not.

Despite these and other insights into practitioner needs that were revealed during workshop discussions, attendees agreed there is still much more to learn from practitioners regarding the management decisions and timelines, planning and response needs, and serious impacts of flash drought.

3.5.3 Research and Applications

Important items to accomplish toward advancing applied research on flash drought include: (1) identifying the key indicators for drought monitoring that are specific to flash drought (and also implementing these in prediction); (2) researching the cascading and compounding impacts of flash drought; and (3) finding ways to effectively communicate the research results to boundary organizations and to those planning/responding to drought conditions. Activities that were identified as of high importance but likely difficult were to increase *in situ* and remotely sensed monitoring (in order to improve the tools/data that are currently available) and also to predict flash drought at lead times of weeks to months.

Finally, attendees also stressed the importance of improved collaboration between researchers involved with monitoring flash drought and those involved with prediction, and between researchers and the practitioners managing flash drought response and planning.

Wah'Kon-Tah Prairie in Missouri. Credit: Tommy Brison

4

PRIORITY ACTIONS

This chapter provides a set of priority actions to advance flash drought early warning, based upon the discussions at the workshop, as well as a more general analysis of workshop materials and subsequent discussion documented in Chapter 3. The full list of research and application/tool project ideas identified at the workshop is provided in Appendix A.

These priority actions are structured in terms of overarching objectives, and the near-term actions to move each objective forward. In most cases, follow-on actions will be needed to fully accomplish each objective.

The objectives and actions have been organized under the following general categories:

- Clarifying the concept of flash drought
- Practitioner engagement
- Flash drought monitoring
- Flash drought prediction
- Planning and response for flash drought
- Network building and coordination

4.1 CLARIFYING THE CONCEPT OF FLASH DROUGHT

Clarifying the concept of flash drought is important in itself, but it is also a necessary precursor to make progress on a range of research and application/tool development opportunities. We propose both a process to forge consensus on a general framework for characterizing flash drought and an effort to move forward with the study of flash drought indicators and impacts by region and season.

Objective: Forge consensus on a general framework for characterizing flash drought.

- **Near-term action:** Implement a collaborative process to continue the process started at this workshop to coalesce both research and practitioner communities around the general characteristics of “flash drought.

- **Considerations:** Key steps in this process could include: sponsoring a researcher roundtable (with both monitoring and prediction researchers) to initiate the process and craft an initial framework for characterizing flash drought; establishing a committee composed of both researchers and practitioners to collaboratively revise the framework; and then conducting Town Halls at meetings of scientific organizations such as the American Geophysical Union (AGU) and the American Meteorological Society (AMS), as well as with practitioner peer-sharing organizations such as the American Association of State Climatologists (AASC) and similar forums to work towards a consensus framework.

Objective: Characterize the various ways in which flash drought manifests by region and season, including identifying key indicators specific to flash drought, and their thresholds and appropriate triggers for action.

- **Near-term action:** Support exploratory research to identify indicators and thresholds by region and season.

- **Considerations:** Pay attention to cascading and compounding drivers and indicators, as this was broadly acknowledged as a key feature of flash drought development. Also, note that the objective is not to identify a single set of indicators, but to allow for a range of indicators, given the different research and decision-making purposes to be addressed and the various ways flash drought manifests across different regions and seasons.

4.2 PRACTITIONER ENGAGEMENT

The workshop revealed there is much more to learn regarding the management decisions and timelines, planning and response needs, and serious impacts of flash drought from those directly affected.

▲ A heatwave causes the earth to dry and crack in a field of sprouting onions. Credit: EFDN

Objective: Better understand practitioner perceptions of flash drought, the impacts they experience, decision time frames, typical response actions, and their needs for improved flash drought preparedness and response.

- **Near-term action:** Organize a series of focus groups by DEWS region to build on the findings of the workshop and to more systematically document user needs relative to early warning and response.

- **Considerations:** Ensure that flash drought researchers are represented at the sessions, and that there is a mechanism to share outcomes across the research community to guide monitoring and prediction research. Consider also including a survey as part of the process to gather broader input. Here are some potential questions to consider in both focus groups and survey:

    - Are your responses to flash drought different from those taken during more conventional, slowly evolving drought? If so, how?

    - What is the decision timeframe? Are predictions aligned with decision timeframes?

    - With whom do practitioners need to coordinate during flash drought?

    - What missing information is preventing practitioners from effectively responding to

- flash drought? What is the necessary timing for receiving this information?
  - What sectors are impacted most by a flash drought and how are they impacted?

4.3 FLASH DROUGHT MONITORING

The workshop pointed both to the need for more data to support monitoring, including increased *in situ* data collection and increased use of existing (e.g., satellite and modeled) data. Another issue was the need for better documentation of existing flash drought monitoring information.

Objective: Increase real-time data (e.g., soil moisture, evapotranspiration, streamflow, and other key variables) to improve monitoring and prediction tools and to make high-quality datasets available for general research.

- **Near-term action:** Document geographic areas needing more *in situ* monitoring coverage, existing networks to be expanded, and opportunities for improvement, to help guide investments by federal agencies and other organizations.
- **Near-term action:** Assess existing *in situ* and satellite data for unrealized opportunities to include in developing products.

Objective: Establish a baseline of flash drought impacts and monitoring resources.

- **Near-term action:** Catalog existing flash drought-relevant observational data/tools and provide an initial assessment of their relevance to different regions/seasons/sectors, or determine if more research is needed to adequately characterize flash drought.
- **Near-term action:** Develop a database of flash drought impacts, informed by practitioner engagement and characterized by region/season/sector.
- **Near-term action:** Support research to produce a database of benchmark flash droughts that can be used to evaluate or explore flash drought definitions, indicators, thresholds, etc.
- **Near-term action:** Facilitate the organization of a Flash Drought Monitoring Working Group to provide a locus for organizing the aforementioned activities.

4.4 FLASH DROUGHT PREDICTION

Prediction of flash drought is hampered both by the resolution and sophistication of existing climate models, as well as by fundamental questions of predictability.

Objective: Better understand the limits of flash drought predictability.

- **Near-term action:** Support research to identify new sources of predictability for flash drought by region, and to explore the practical limits of whether there are limits to flash drought prediction.
- **Near-term action:** Establish a process with NOAA CPC, universities, and other institutions engaged in drought prediction to communicate findings from flash drought prediction research so they can be incorporated into new and existing early warning tools and products (i.e., to support research to operations).

Objective: Improve forecast models to better support flash drought prediction, including higher resolution, longer hindcasts, consistent initialization protocols and advanced land surface models that incorporate flash drought related land surface processes (e.g., dynamic vegetation).

- **Near-term action:** Assist NOAA, other federal agencies, and research partners in efforts to incorporate advanced land–surface models into the suite of operational flash drought prediction tools.
- **Near-term action:** Facilitate the organization of a Flash Drought Prediction Working Group to prioritize modelling improvement options, and develop a white paper for NOAA and other funding agencies on what is needed to improve prediction.

4.5 PLANNING/RESPONSE FOR FLASH DROUGHT

Workshop attendees stressed that effective planning and response activities in flash drought are dependent both upon adequate decision-support tools as well as on better communication.

Objective: Develop practical decision-support tools to help decision makers identify when they are in a flash drought, or could experience flash drought development, and what potential response options might be available.

- **Near-term action:** Work through DEWS regions to build awareness and use of the flash drought monitoring tools and resources developed in Section 4.3 above.
- **Near-term action:** Investigate and then document mitigation and response actions by sector for flash drought.
- **Near-term action:** Explore how state-of-the-art drought communication techniques, such as those represented by North Carolina's Project Nighthawk,[37] could be tailored to flash drought.

Objective: Improve the ability to communicate about flash drought—what it is and how it manifests in the environment.

- **Near-term action:** Support research into people's perception/understanding of flash drought and how best to communicate flash drought implications to a general audience.
- **Near-term action:** Develop a graphical communication tool (e.g., Story Map, quantitative storyline) to showcase flash drought evolution and impacts.

4.6 NETWORK BUILDING AND COORDINATION

Attendees expressed strong appreciation for the opportunity to communicate across disciplines at the workshop, and emphasized the importance of sustaining this type of activity.

Late summer watering hole along Hwy 20 near Camp Crook, Harding County, SD. Credit: Kevin Hyde, NOAA NIDIS

Objective: Build stronger connections and coordination between flash drought researchers and practitioners by providing opportunities for sharing, discussion, and problem-solving.

- **Near-term action:** Establish a regular forum (e.g., an annual flash drought conference) for researchers, practitioners, and other interested individuals to share new research, management approaches, communication approaches, and other topics related to advancing early warning and effective response to flash drought.

4.7 SUMMARY

The preceding list of target objectives and near-term action items represents an ambitious set of activities to improve flash drought monitoring, prediction, and planning/response. Working with our partners at all levels, NIDIS will use this as the basis for an ongoing agenda for flash drought. We also anticipate that the list, along with other findings in this report, may be useful to other agencies, organizations, researchers, and policy makers as we collectively work to improve both national and regional capacity for flash drought early warning and response.

37 https://climate.ncsu.edu/wp-content/uploads/2020/11/Nighthawk_FinalReport_short.pdf

APPENDIX A

COMPREHENSIVE LIST OF RESEARCH AND APPLICATION NEEDS, AND OPPORTUNITIES TO LEVERAGE

The following represent a compilation of the ideas provided throughout the workshop regarding research, tools, and/or other actions that are needed to improve our ability to monitor, predict, and plan/respond to flash drought. Those ideas that were rated highly during the Mentimeter poll are marked with an asterisk. (It should be noted however that given the significant number of ideas, not all of the ideas were polled).

A.1 MONITORING RESEARCH AND APPLICATION NEEDS

1. **Those related to flash drought indicators…**
    a. Research: Identify standards/framework for flash drought, e.g., key thresholds, key indicators, rate of change*

    b. Research: Identify when (season) and where (location) flash drought indicators/tools are most effective

    c. Research: Identify key indicators best suited for flash drought*

    d. Research: Determine when and where physical indicators are linked to flash drought impacts

    e. Research: Assess utility of vapor pressure deficit as a flash drought indicator

    f. Research: Develop more and better metrics of flash drought in the ecology sector

    g. Research: Explore earlier indicators for reduced water availability before impacts

    h. Research: How important information—like soil type—is best integrated into flash drought monitoring?

2. **Those related to flash drought impacts…**
    a. Research: Identify flash drought impacts by region, type, and sector*

    b. Research: Assess the compounding and cascading impacts of flash drought*

    c. Research: Where do flash drought impacts first manifest in each sector and region? (e.g., recreation and tourism)

    d. Research: Streamline approach for collecting flash drought impacts through various means (e.g., social media, boundary organizations, agencies responding)

    e. Research: Is there more fire risk during flash drought in the eastern U.S.?

    f. Research: Examine the fire danger link with soil moisture during flash drought

    g. Research: Is a flash drought following a very wet period less problematic or even beneficial?

    h. Research: How does wind factor into flash drought?

i. Research: How do management practices (e.g., tilling) impact soils and their ability to retain moisture?

j. Research: Snow melt and the ability of the soils to retain the water

k. Research: Interplay between flash drought and other hazards (e.g., chemical spills—cascading impacts)

l. Research: What is the impact of flash drought on the saltwater edge (coastal)? (e.g., power plants/ industry)

m. Research: Do flash droughts impact hydrology differently than conventional droughts because they come on quickly and sometimes can have a short duration (since hydrological drought is often considered an impact that comes later during drought)?

3. Those related to increased monitoring…

a. Data Need: Increase *in situ* (such as soil moisture, precipitation, ET, vegetation conditions) monitoring*

b. Data Need: Continue to augment *in situ* networks with satellite data*

c. Data Need: Denser snow measurement networks (e.g., SNOTEL), including sites at lower elevations

d. Data Need: Increase monitoring in forested areas/native lands

e. Data Need: Need for small-stream monitoring overall

4. Those related to tools…

a. Tool: Coordinated suite of indicators, including impact-based indices like soil moisture

b. Tool: Produce a climatology of flash drought events for the United States*

c. Research: Reduce latency of products for best real-time monitoring capabilities

d. Tool: Develop comprehensive "water monitor"

e. Tool: Remotely sensed monitoring of smaller water sources for livestock

f. Tool: Regional water quality monitoring (e.g., stock ponds)

g. Tool: Provide higher resolution (4-km, daily) evaporative demand, ET, and other data (modeled or satellite)

h. Tool: Communication/education resources for what flash drought is/is not (e.g., does rapid onset mean rapid return to normal?)

i. Research/Tool: Develop analog years for flash drought progression for comparison

j. Research: Engage with end users to understand their needs for monitoring tools

5. Opportunities to leverage…

a. Existing federal and state monitoring networks

b. Efforts of the National Coordinated Soil Moisture Monitoring Network (NCSMMN)

c. Potential opportunity to add a "flash drought" designation onto the U.S. Drought Monitor

d. Conduct a similar study for flash drought to the current NIDIS and NASA study that is looking at identifying the best drought indicators by location and season for the United States

e. Opportunity to engage with ICAMS, the Interagency Council for Advancing Meteorological Services, in which both NOAA and USDA are involved

f. Coastal Salinity Index for Southeastern United States (developed by USGS and NIDIS)

g. Grid DSSAT (Decision Support System for Agrotechnology Transfer)—high-resolution data; includes crop models, NEXRAD radar, and satellite data

h. Rapid Change Index maps (e.g., based on and 1-, 2-, 3-week change maps)

A.2 PREDICTION RESEARCH AND APPLICATION NEEDS

1. Overarching prediction research questions…

a. i. Research: What are the predictability limits of flash drought for different regions, seasons, and sectors? How can current tools push those limits?*

b. Research: Identify new sources of predictability for flash drought and assess how well they are represented in operational dynamical forecast systems*

c. Research: Prediction of extreme heat waves (sub-seasonal to seasonal timeframes)*

d. Research: To improve lead time, consider predicting other variables that are associated with flash drought but have more predictability than precipitation

e. Research: How does a warmer climate/climate change affect characteristics of flash drought?

f. Research: Improve understanding of the physical processes and interaction between those processes that contribute to flash drought (e.g., precipitation, evaporative demand, wind, land–atmosphere feedbacks, vegetation).

g. i. Research: how long do flash droughts typically last? Can this help us inform/communicate?*

h. Research/user need: From a user's perspective, what are the implications for having advanced prediction of flash drought?

2. Model needs and specifications…

a. Research: Improved drought outlook skill

b. Research: Improved protocols for dynamical model forecasts—e.g., consistent initialization dates, more ensemble members, etc.

c. Research: Improvements to dynamical models (including land–surface models) based on improved physical understanding of predictability limits

d. Tool: Advanced land–surface models (high resolution with realistic representations of flash drought related processes such as dynamic vegetation)*

e. Tool: Higher-resolution soil type layer in models

f. Research: Improved statistical post-processing of dynamical model forecasts

g. Research: More supercomputing power to accommodate longer hindcasts, more ensembles, and higher spatial resolution

h. Research: Improved data assimilation for more accurate initial conditions for flash drought forecasting

i. Research: Development of statistical prediction models for flash drought, by for example leveraging machine learning approaches

3. Tool and information needs…

a. Information: Forecasts using flash drought indicators that are used by the monitoring community like soil moisture, evaporative demand, etc.*

b. Tool: Operational forecasts that are issued frequently (preferably weekly or even more frequently), are probabilistic, and are aligned with impacts.

c. Research: Improve the ability to forecast the duration of the flash drought event

d. Tool: Forecasts for flash drought at over two weeks lead time

e. Tool: Connect flash drought forecasts with potential impacts by sector and region

f. Tool: Low-flow river forecasts (similar to flood forecasts, but for low flow)

g. Tool: Remotely sensed forecasting of smaller water sources for livestock

h. Tool: Satellite-based observations; microwave-based Evaporative Stress Index (ESI)

4. Opportunities to leverage…

a. Development of dynamical forecast models and systems (e.g., the Unified Forecast System—UFS) and subseasonal dynamical forecasts they produce (e.g., GEFS version 12)

b. NOAA CPC tools, including:

   i. Flash Drought Monitoring Tool[38]

   ii. Potential Flash Drought Development Tool[39]

   iii. Objective Drought Tendency [40]

   iv. Weekly SPI3 forecasts[41]

   v. Weekly soil moisture forecasts[42]

   vi. Week-2 U.S. Hazards Outlook: CPC is exploring potentially adding flash drought hazard to this map

c. National Water Model (NWM): hydrological forecasts

d. NOAA ESRL's deterministic 14-day Quantitative Precipitation Forecast (QPF) using (Global Forecast System) GFS reanalysis

38 *https://www.cpc.ncep.noaa.gov/products/Drought/Flash_Drought/fd_monitoring.php*
39 *https://www.cpc.ncep.noaa.gov/products/Drought/Flash_Drought/potential_development.php*
40 *https://www.cpc.ncep.noaa.gov/products/Drought/Flash_Drought/tendency_forecast.php*
41 *https://www.cpc.ncep.noaa.gov/products/Drought/Subseasonal/spi3_week1-4_forecast.php*
42 *https://www.cpc.ncep.noaa.gov/products/Drought/Subseasonal/smp_week1-4_forecast.php*

A.3 PLANNING AND RESPONSE RESEARCH AND APPLICATION NEEDS

1. **Those related to planning and response actions…**
   a. Research: are local response/management actions different during a flash drought vs a more conventional drought?*
      i. If so, is it the speed of action required during a flash drought that makes the actions different? (Are you coordinating differently, communicating differently, using different sources, etc. because of this rushed time schedule?)*
   b. Research: Is recovery different from a flash drought vs. a conventional drought?
   c. Research: What ways does flash drought development at different times of year (e.g., season) affect decision making? What time of year does it not have effects?
      i. Research to answer these questions for different sectors, particularly specialty crops and those beyond agriculture (e.g., rec/tourism, ecology, manufacturing).
   d. Research: At what point is flash drought "real" for people? What makes them take action like declarations, etc.?
   e. Research: Are people assuming flash droughts are less severe, less intense, and shorter because they come on quickly? And how does this impact actions and declarations?
   f. Research: Does a person's perception of flash drought vary depending upon where they live? (For instance, in an otherwise wet area—do they have cognitive bias towards more recent events?)
   g. Research: Identify triggers that give managers adequate lead time to address flash drought*
   h. Research: How to identify effective state-wide triggers for drought
   i. Research: Do better soil management practices mitigate flash drought impacts?
   j. Research: Management and accountability of private wells in the eastern U.S. in particular.

2. **Those related to communication…**
   a. Research: Identify best practices on communicating flash drought and its implications to end users*
   b. Research: Social science research to understand the nuances of flash drought characteristics, and how to best communicate this to decision makers
   c. Research: Is there an effective communication structure or resources/fund structure to put in place that allows end users to respond more quickly?

3. **Those related to policy…**
   a. Research: Are the impacts of flash drought adequately covered by current drought relief programs (e.g., USDA, FEMA)?
   b. Policy: Expand mechanisms for policy makers to provide drought relief (e.g., FEMA)
   c. Research: Connect science on flash drought to changes in policy
   d. Policy: Update National Drought Policy Act

4. **Tool and information needs…**
    a. Tool: Provide prediction information for flash drought by sector (preferably information about impacts with relative time information)*
    b. Tool: Quantitative storyline of flash drought and its impacts by sector, showing the rapid onset and evolution thereafter (showing that impacts will likely not disappear as quickly as they appeared)*
    c. Tool: Probabilistic information that indicates the likelihood…
        i. of the event happening;
        ii. that this is a flash drought vs. a conventional drought; and
        iii. that this is going to be a short-duration event or a fast entry into a longer-term drought.
    d. Tool: A dashboard or tool where a user can toggle between different flash drought scenarios at different times of the year and geographies, and explore potential impact data to help planners determine thresholds for action in drought plans.
    e. Tool: Utilize tools that can address cognitive bias, particularly for areas that have been wetter than normal in recent years.
    f. Tool: Design tools for non-technical partners
    g. Tool: Identify critical times for flash drought information and provide tools specific to that sector
    h. Tool: Provide information about small stream response to flash drought events
    i. Tool: Resource guide for educating and communicating about flash drought

5. **Opportunities to leverage…**
    a. North Carolina's research "Project Nighthawk" on communicating drought in general; are there lessons to take for flash drought?
    b. Expanding NDMC's "Managing Drought Risk on the Ranch" to include flash drought
    c. Identify and potentially use existing tools to help overcome cognitive bias
    d. Decision calendar research by NDMC: could build upon this framework and relate to flash drought
    e. Use boundary organizations like state climatologists, NIDIS, NWS, state agencies, etc. to translate monitoring and forecasts results to the public; will depend on ensuring communication channels between forecasters and the boundary organizations
    f. Use historical seasonality of precipitation to help end users (e.g., ranchers) understand the probability of recovering from the drought based on climatology
    g. Use active social media accounts of local emergency management to connect
    h. National Drought Resilience Partnership (NDRP) to assist with policy efforts
    i. NDMC's QuickDri and the Rapid Change Index of the Evaporative Stress Index

* Asterisks indicate ideas that were rated highly during the Mentimeter poll.

APPENDIX B

WORKSHOP AGENDA

TUESDAY, DECEMBER 1, 2020

Block 1: Scene Setting—Going Beyond Research		
Time (ET)	**What**	**Who**
11:00 AM	Workshop Welcome and Purpose	Moderator: Marina Skumanich, NIDIS Welcome: Veva Deheza, NIDIS
11:10 AM	Setting the Context: Flash Drought Stories and Experiences	Presenters: • Mark Svoboda, National Drought Mitigation Center (NDMC)/Univ. of Nebraska-Lincoln • Pam Knox, University of Georgia • Pat Guinan, University of Missouri • Michael Downey, Montana Department of Natural Resources and Conservation
12:00 PM	5-Minute Break	
12:05 PM	How is Flash Drought Defined in Practice? Report on End-User Survey Results	Tonya Haigh, NDMC
12:20 PM	Q & A / Discussion	Facilitator: Marina Skumanich, NIDIS
12:30 PM	Lunch Break (45 minutes)	

Block 2: Exploring Flash Drought Characteristics		
Time (ET)	**What**	**Who**
1:15 PM	Flash Drought Literature Review Recap	Joel Lisonbee, NIDIS
1:30 PM	Breakout B1 Discussions: • What are the effects of flash drought? How is it distinct from "normal" drought? • What are key characteristics of flash drought? • What indicators are most important?	• "B1" Breakout Groups
2:15 PM	15-Minute Break	
2:30 PM	Breakout B1 Report-Out and Group Discussion	Moderator: Marina Skumanich, NIDIS
3:30 PM	Adjourn Day 1	

WEDNESDAY, DECEMBER 2, 2020

Block 3: Shaping Tools/Research to Meet User Needs		
Time (ET)	**What**	**Who**
11:00 AM	Introduction to Day 2: Shaping Tools/ Research to Meet User Needs	Joel Lisonbee, NIDIS
11:10 AM	Breakout B2 Discussions • What are user needs related to flash drought? • How can existing tools and research be shaped to meet those needs?	"B2" Breakout Groups (by sector): 1. Energy/industry 2. Water resources 3. Forestry/ecosystem 4. Fire management 5. Response/relief 6. Recreation/tourism 7. Ag-Livestock 8. Ag-Crops
11:55 AM	15-Minute Break	
12:10 PM	Breakout B2 Report-Out and Discussion	Moderator: Joel Lisonbee, NIDIS
1:15 PM	Adjourn Day 2	

THURSDAY, DECEMBER 3, 2020

Block 4: Identify Research Needs in Monitoring, Prediction, and Planning/Response		
Time (ET)	**What**	**Who**
11:00 AM	Introduction to Challenges, Opportunities, Gaps and Needs Session	Molly Woloszyn, NIDIS
11:05 AM	Flash Drought Monitoring: Challenges, Opportunities, Gaps and Needs	Presenters: • Jason Otkin, University of Wisconsin • Mark Svoboda, NDMC
11:20 AM	Flash Drought Prediction: Challenges, Opportunities, Gaps and Needs	Presenters: • Andy Hoell, NOAA Physical Sciences Laboratory • Hailan Wang, NOAA Climate Prediction Center
11:35 AM	Flash Drought Planning and Response: Challenges, Opportunities, Gaps and Needs	Presenter: Tim Hall, Iowa Department of Natural Resources
11:55 PM	5-Minute Break	
12:00 PM	Breakout B3 Discussions: Challenges, Opportunities, Gaps and Needs	"B3" Breakout Groups
12:45 PM	Lunch Break (45 minutes)	

Block 5: The Path Forward		
Time (ET)	**What**	**Who**
1:30 PM	Breakout B3 Report-Out and Group Discussion	Molly Woloszyn, NIDIS
2:25 PM	10-Minute Break	
2:35 PM	Group Discussion: Revisit Flash Drought Characteristics from Day 1	Facilitator: Joel Lisonbee, NIDIS
3:05 PM	Introduction to Next Steps: A clear path forward for this emerging domain, and how NIDIS and other partners can support the research and coordination	Veva Deheza, NIDIS
3:10 PM	Group Discussion: Prioritization • Which actions/activities are the highest priority? • Which are “low hanging fruit”?	Facilitator: Molly Woloszyn, NIDIS
3:40 PM	Workshop Wrap-Up	Veva Deheza, NIDIS
3:45 PM	Adjourn Workshop	

APPENDIX C

WORKSHOP ATTENDEES

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APPENDIX D

ACRONYMS

AASC	American Association of State Climatologists
AGU	American Geophysical Union
AMS	American Meteorological Society
BRIC	Building Resilient Infrastructure and Communities
CPC	Climate Prediction Center
CIRES	Cooperative Institute for Research in Environmental Science
COOP	Cooperative Observer Network
CRN	Climate Reference Network
D0–D4	Drought categories from the U.S. Drought Monitor Report
DEWS	Drought Early Warning System
DNR	Department of Natural Resources
DSSAT	Decision Support System for Agrotechnology Transfer
EDDI	Evaporative Demand Drought Index
ESI	Evaporative Stress Index
ESRL	Earth System Research Laboratories
ET	Evapotranspiration
FEMA	Federal Emergency Management Agency
GEFS	Global Ensemble Forecast System
GFS	Global Forecast System
ICAMS	Interagency Council for Advancing Meteorological Services
NASA	National Aeronautics and Space Administration
NCSMMN	National Coordinated Soil Moisture Monitoring Network
NDMC	National Drought Mitigation Center
NDRP	National Drought Resilience Partnership
NDVI	Normalized Difference Vegetation Index
NEXRAD	Next-Generation Weather Radar
NIDIS	National Integrated Drought Information System
NOAA	National Oceanic and Atmospheric Administration
NWM	National Water Model
NWS	National Weather Service
PET	Potential Evapotranspiration
PSL	Physical Sciences Laboratory
QPF	Quantitative Precipitation Forecast
QuickDri	Quick Drought Response Index
SCAN	Soil Climate Analysis Network
SNOTEL	Snow Telemetry
SPI	Standardized Precipitation Index
SWE	Snow Water Equivalent
UFS	Unified Forecast System
USDA	U.S. Department of Agriculture
USDM	U.S. Drought Monitor
USGS	U.S. Geological Survey
VPC	Value Proposition Canvas

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