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PNNL-29737

# Improving Discovery, Sharing, and Use of Water Data

## Initial Findings and Suggested Future Work

April 2021

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Kelford C. Mitchel
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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Stanford Woods Institute for the Environment

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Pacific Northwest National Laboratory
Richland, Washington 99354

[1] Pacific Northwest National Laboratory
[2] Stanford Woods Institute for the Environment, Stanford, CA

# Abstract

Collaborative management of water resources requires a broad suite of “water data” that extends beyond basic information about water quantity and quality to other related topics such as water infrastructure, aquatic ecosystem health, socioeconomic factors, and power generation. Water data are disparate in nature because they are collected and provided by many entities, and in some cases, remain challenging to access and use. The U.S. Department of Energy’s Water Power Technologies Office initiated a project to characterize relevant categories of water data; describe the current state of accessing, using, and visualizing water data; and outline investigative pathways for future efforts aimed at improving the discovery, sharing, and use of water data. Input on these topics was solicited from a small but diverse cross section of members of the water resources community. Fourteen broad categories of water data were identified: dams; ecology; flood control; hydroclimatology; hydrography; hydrology; hydropower; management landscape; migratory barriers; recreation and aesthetic importance; socioeconomic; water quality; water availability and use; and weather. Stakeholder perspectives indicate the accessibility and usability of water data are affected by a complex set of technical and social factors. However, stakeholders generally agreed that better access to water data can provide a range of benefits to water management, and they stressed the need to generate broad support from water data users and producers. Two investigative pathways are outlined that, taken together, provide a logical progression toward the goals of the project. The first pathway emphasizes further investigation to better define target audiences and data needs, identify opportunities for collaboration between related efforts, and conduct value demonstration activities to generate further support for improving discovery and access of water data. The second pathway focuses on creating a comprehensive vision for potential solutions that improve the discovery of water data. Several potential activities that align with the first pathway are suggested for the next phase of the project.

# Summary

Decision-makers engaged in the management of water resources require a broad suite of data and information about water-related topics, collectively referred to here as “water data.” Water data tend to be disaggregated because they are collected and provided by many entities. As a result, they are challenging to find, access, and use. In response to growing recognition of this problem, the U.S. Department of Energy’s (DOE’s) Water Power Technologies Office (WPTO), initiated a project in October 2019 to investigate potential pathways to improving the discovery, sharing, and use of water data. This report summarizes initial findings from the first phase of this work which sought to characterize relevant categories of water data; describe the current state of accessing, using, and visualizing water data; and outline potential pathways and collaborations for future work.

Input about these topics was solicited through structured phone interviews with a small but diverse cross section of members of the water resources community from federal and state natural resource agencies, academia, nongovernmental organizations (NGOs), the hydropower industry, and consultants. Interviews covered four broad topic areas: the types of data that are important to stakeholder respective decision-making processes; the challenges experienced accessing and using these data; the importance and means of visualizing data; and the perceived need for improving access to and coordination of water data.

A total of 14 broad categories of water data were identified: dams; ecology; flood control; hydroclimatology; hydrography; hydrology; hydropower; management landscape; migratory barriers; recreation and aesthetic importance; socioeconomic; water quality; water availability and use; weather. Stakeholder opinions about data categories were generally tied to their respective roles and organization’s mission. All agreed that hydrology, hydrography, and water quality data are generally accessible and fundamental to understanding water-related issues, whereas other categories tend to be less accessible and their importance is more user-specific. Many identified a growing need for enriched water data, i.e., data that have undergone some value-added process to contain or represent additional layers of information beyond the primary purpose of the original data.

Key challenges related to the accessibility of water data were characterized from the perspectives of data users, data producers, and data user-producers. The user-producer group describes a subset of users who also produce enriched, proprietary, or unofficial copies of water data, such as research and academic institutions, certain NGOs, and hydropower owners/operators.

A data user’s ability to access data is influenced by the availability and efficacy of information technology (IT), as well as social aspects like their existing knowledge of data resources and their professional network. A data producer’s ability to make data accessible is affected by the presence of internal or external mandates, personnel and funding, and the sensitivity of the data. Data user-producers face the combined challenges of data use and production and are an important group because they can become recognized sources of enriched data or information.

Stakeholder viewpoints about the accessibility of water data revealed five key findings.

- First, access to potentially sensitive or proprietary water data (e.g., hydropower operations, cultural resources, agricultural water use, data submitted through the Federal Energy Regulatory Commission licensing process) was commonly cited as important and represents

a major challenge in this project because such data are fundamentally difficult to make accessible.

- Second, some stakeholders felt the accessibility of water data is better in river basins, states, or regions that have a greater abundance of data resources, although it is unclear whether this perception is due to a greater abundance of water data resources or better systems for accessing data.
- Third, views about data accessibility sometimes overlapped with concerns about data gaps, which are more related to desires for better spatial and temporal granularity of water data (i.e., improvements in where and when data are collected) to support site-specific decision-making.
- Fourth, views about data accessibility varied by organization type and level of interaction with water data, indicating certain user groups will benefit more from efforts to improve the accessibility of water data.
- Finally, many stressed the importance of building relationships among stakeholders to facilitate sharing and increase trust regarding water data, noting that is difficult to get agreement on data needs and responsibilities. This finding highlights the importance and challenge this project identified concerning the need to generate buy-in from the diverse community of water data users and producers before initiating technical work on solutions to advance the discovery, sharing, and use of water data.

During the interviews, concerns about the usability of water data, i.e., transforming data to information, were discussed less than data accessibility. Common issues mentioned regarding usability included quality (e.g., completeness, precision, accuracy), interoperability (e.g., non-standard, or proprietary formats), spatial and temporal resolution, supporting documentation or metadata, and user knowledge. The fact that many water data are multi-sourced contributes to these issues and represents a major challenge in improving usability. Expert users expressed less concern about making data usable and were more knowledgeable about possible uses of data, suggesting that addressing knowledge gaps may play an important role in improving the overall usability of water data.

Approaches and tools for gaining information by visualizing water data were briefly discussed during interviews. User methods for visualizing data were driven largely by their familiarity with those methods and their respective use case for the data. Many users expressed a preference for obtaining raw data and creating their own visualizations rather than using third-party products. For viewing geospatial water data, non-technical users can use Google Earth for simple visualization. Many users acknowledged the growing need for Geographic Information System (GIS) professionals and the increasing availability and importance of geospatial water data in their organizations.

A select number of related efforts to improve the accessibility and use of water data are summarized in this report to provide additional context for the current state of water data in the United States. The authors note this summary is incomplete and will continue to be broadened in the second phase of work. The summary includes related efforts by the U.S. Geological Survey, U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, the Consortium of Universities for the Advancement of Hydrologic Science, Inc., Nicholas Institute for Environmental Policy Solutions at Duke University, and several notable state-level efforts in California, Wisconsin, and New England states.

Two investigative pathways that emerged from this preliminary effort are intended to help plan activities for future phases of the project. The pathways are intended to be successive, that is, the first pathway is intended to inform the second. The first pathway emphasizes conducting further investigation to better define the target audience and their data needs, build a more in-depth understanding of and connections to related efforts, and demonstrate the value of this work to build support for future initiatives. The second pathway focuses on developing a comprehensive vision for potential solutions that improve the discovery of the full breadth of water data that exist for U.S. river basins. Suggested activities for future phases of the project are based on the first investigative pathway. Activities based on the second investigative pathway are not proposed at this time, but presumably would occur after the following suggested activities:

- Continue outreach activities with water data users and producers, placing more emphasis on the latter, to broaden the perspectives presented here and better characterize the target audience and target data categories.
- Continue outreach activities with entities conducting related efforts to improve access to and use of water data to better align our initiative and identify opportunities for collaboration.
- Develop a series of compelling online “data stories” based on a variety of use cases for water data that demonstrate the value of open access to diverse categories of water data and highlight some of the underlying challenges with the current state of discovering, accessing, and using water data.
- Conduct workshop(s) with national and regional stakeholders to gather feedback on data stories and to assess the value of continuing efforts to improve discovery and access to water data.

Data stories are a powerful tool for creating immersive stories by combining text, interactive maps, and other multimedia content. For future work, we suggest developing a collection of stories based on a variety of use cases for water data in three regions of interest identified by WPTO: California, Wisconsin, and New England. The purpose of these data stories is threefold: to (1) highlight the process of gaining information from disparate water data, both quantitatively and geographically; (2) serve as example end-uses of a hypothetical platform that enables discovery of disparate water data; and (3) provide a common approach for project partners to tell unique stories that can be collectively tied together in a clear manner.

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- Kevin Gardner and Weiwei Mo (University of New Hampshire)
- Sam Roy and David Hart (University of Maine).

# Acronyms and Abbreviations

| | |
|---|---|
| ACWI | Advisory Committee on Water Information |
| AW2 | USACE's Access to Water Resources Data – Corps Water Management System |
| BLM | U.S. Bureau of Land Management |
| CDWR | California Department of Water Resources |
| CNRA | California Natural Resources Agency |
| CUAHSI | Consortium of Universities for the Advancement of Hydrologic Science, Inc. |
| DFW | Department of Fish and Wildlife |
| DOE | U.S. Department of Energy |
| DOT | Department of Transportation |
| DRIP | Dam Removal Information Portal |
| EPA | U.S. Environmental Protection Agency |
| EPSCoR | Established Program to Stimulate Competitive Research |
| ESA | Endangered Species Act |
| FAO | Food and Agricultural Organization |
| FEMA | Federal Emergency Management Agency |
| FERC | Federal Energy Regulatory Commission |
| FGDC | Federal Geospatial Data Committee |
| GIS | Geographic Information System |
| HIS | Hydrologic Information System |
| IoW | Internet of Water |
| IT | information technology |
| MRLC | Multi-Resolution Land Characteristics |
| NABD | National Anthropogenic Barrier Dataset |
| NASA | National Aeronautics and Space Administration |
| NCAR | National Center for Atmospheric Research |
| NCEI | National Centers for Environmental Information |
| NEST | New England SusTainability Consortium |
| NGO | nongovernmental organization |
| NGWOS | Next Generation Water Observing System |
| NHD | National Hydrography Dataset |
| NHDPlus | National Hydrography Dataset Plus |
| NID | National Inventory of Dams |
| NIEPS | Nicholas Institute for Environmental Policy Solutions |
| NMFS | National Marine Fisheries Service |
| NOAA | National Oceanographic and Atmospheric Administration |

| | |
|---|---|
| NPS | National Park Service |
| NSF | National Science Foundation |
| NWIS | National Water Information System |
| NWM | National Water Model |
| NWS | National Weather Service |
| ODFW | Oregon Department of Fish and Wildlife |
| ORNL | Oak Ridge National Laboratory |
| OSU | Oregon State University |
| OWDI | Open Water Data Initiative |
| PNNL | Pacific Northwest National Laboratory |
| QA | quality assurance |
| QC | quality control |
| RISE | Reclamation Information Sharing Environment |
| RWIS | Reclamation Water Information System |
| SARP | Southeast Aquatic Resources Partnership |
| SCT | Stream Classification Tool |
| SSWD | Subcommittee on Spatial Water Data |
| SWDV | Surface Water Data Viewer |
| SYW | Surf Your Watershed |
| TNC | The Nature Conservancy |
| TWDB | Texas Water Development Board |
| UNA | User Needs Analysis |
| USACE | U.S. Army Corps of Engineers |
| USBR | U.S. Bureau of Reclamation |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey |
| USSCS | U.S. Stream Classification System |
| WDNR | Wisconsin Department of Natural Resources |
| WPTO | Water Power Technologies Office |
| WSDOT | Washington State Department of Transportation |

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## Tables

# 1.0 Introduction

In recent years, there has been increasing awareness of the benefits of collaborative river basin planning efforts. We briefly mention several model examples in the United States, including the Penobscot River Restoration Project in Maine (Opperman et al. 2011), the Clark Fork Project in northern Idaho and northwest Montana (Saulsbury et al. 2010), and Lower Yuba River Accord in California (Water Education Foundation 2009). While the focus and range of issues in each of these efforts were unique, the model examples share several key commonalities:

- First, all three efforts involved a broad coalition of stakeholders and extensive negotiation to agree upon feasible solutions.
- Second, potential solutions were developed by considering river basins as integrated systems.
- Third, goals were designed to achieve mutually beneficial objectives, with the common understanding that compromise was necessary.
- In all cases, these activities spanned multiple years and required considerable time, resources, and ongoing willingness to participate.
- Finally, comprehensive data and information about key issues in each basin (referred to herein as “water data”) were necessary at all stages to inform decision-making. Although less frequently cited, the importance of this last factor to improving the management of water resources is broadly acknowledged and deserves further attention.

Rivers can be viewed as complex systems composed of integrated natural and human systems. Thus, basin-wide approaches to managing water resources need to draw from a wide variety of water data (Pegram et al. 2013). The categories of water data needed extend beyond basic information about water quantity and quality to a wide range of issues such as human uses, ecology, energy generation, climate, and recreational interests. These data are collected and maintained by many entities including federal and state agencies, research, and nongovernmental organizations (NGOs), and private entities. Consequently, sources of water data are diverse and highly fragmented, and data sets are often incomplete, inconsistent, or not interoperable. These issues underlie many of the challenges associated with discovering, accessing, sharing, and using water data, and they pose potential barriers to effective water management.

Efforts are under way to address these challenges (see Section 6.0). For example, California’s *Open and Transparent Water Data Act* (AB 1755), enacted in 2016, charges state agencies with integrating currently fragmented water and environmental data systems. However, the bill does not prescribe how this can or should be done. The U.S. Geological Survey (USGS) has begun to roll out parts of their Next Generation Water Observing System (NGWOS). The focus of this effort, however, is limited to data and information about water quantity and quality. Another example is the *Internet of Water* project, established in 2018 by the Nicholas Institute for Environmental Policy Solutions (NIEPS), which seeks to “…build a network of communities and institutions to facilitate the opening, sharing, and integration of water data and information (NIEPS 2020).” The project has inventoried the types, purposes, and openness of water data being collected by public agencies and conducted studies of the value of water data to help lay the groundwork for other initiatives.

Inspired by these and other efforts, Pacific Northwest National Laboratory (PNNL) and Stanford University’s Woods Institute for the Environment initiated a collaborative effort in October 2019, on behalf of the U.S. Department of Energy's (DOE's) Water Power Technologies Office (WPTO), to investigate potential pathways to improving the discovery, sharing, and use of water data. This report describes initial findings from the first phase of this effort, which sought to characterize relevant categories of water data; describe the current state of accessing, using, and visualizing water data; and outline potential pathways and collaborations for future work. The first two objectives were informed by interviews with water data users and producers representing a cross section of public and private organizations at national, regional, and local levels.

The following sections of this report provide an explanation of "water data" (Section 2.0), followed by a summary of our interview process with water data users and producers (Section 3.0); discussion of key categories of water data (Section 4.0); summary of initial findings about the accessibility, usability, and visualization of water data (Section 5.0); and summary of related efforts to improve access and use of water data (Section 6.0). We conclude by outlining potential pathways for future work (Section 7.0) and suggested work activities for future phases of this project (Section 8.0).

# 2.0 Water Data

The term “water data” is inherently ambiguous and can be used to describe a broad range of data categories that are relevant to water-management issues. In addition, fundamental differences between authoritative and nonauthoritative variants of water data have important implications for improving the accessibility and use of water data. This section briefly describes the meaning of the term “water data” as intended by the authors (Section 2.1) and key characteristics of “authoritative” and “nonauthoritative” water data (Section 2.2).

## 2.1 What are Water Data?

The term “data” is commonly used in multiple contexts depending on the domain. This was evident in our conversations with stakeholders who had different impressions about and interests in “water data.” We adopt the following description of this term from Cantor et al. (2018) to clarify our use in this report and highlight how the multi-faceted nature of this term represents a major challenge to improving the accessibility and use of water data.

Cantor et al. (2018) use “water data” to refer to “...the broad suite of data and information that inform decision-making and research on water-related topics, including data to characterize systems and monitor systems.” They further suggest the term “data” refers to “...measurements of basic properties of the world” and the term “information” refers to “...data that has been processed or synthesized to answer questions.” We find this definition appropriate because it refers to the diverse nature of water data, in both raw and processed forms, and is consistent with the impressions of the stakeholders who we interviewed.

The complexity of water data—both in its diversity and form—makes it inherently challenging to address issues pertaining to data accessibility and use. Some of these issues are described in Section 5.0 to provide further context. Possible technical solutions to improving access and use of water data are not addressed in this report, although they are of interest for future work.

## 2.2 Authoritative and Nonauthoritative Water Data

Water data are produced by a wide range of sources ranging from government agencies, national laboratories, academia, industry, and NGOs. These data can be grouped into two general classes— “authoritative” and “nonauthoritative” data—which help to explain the underlying motives for collecting data, making data publicly available or not, establishing quality standards, and assuring long-term access to data. Ultimately, these characteristics affect whether data can be trusted, and they have important implications for designing systems to improve discovery, access to, and use of water data.

In interviews with stakeholders, we found that interpretations of authoritative data vary but that there is a consistent theme of quality and trust. More technical descriptions of authoritative data can be found in the data management domain, although there are no universally accepted definitions. Here, we offer the following general definitions adapted from Federal Geospatial Data Committee guidance (FGDC-SCD 2008):

- *Authoritative Data* – officially recognized data that can be certified and are provided by an authoritative source (e.g., stream gage data published on the USGS National Water Information System).

- *Authoritative Source* – an entity that is authorized by a legal authority to develop or manage data for a specific business purpose. The data this entity creates are authoritative data (e.g., USGS is an authoritative source of stream gage data).
- *Trusted Source* and *Trusted Data* – a service provider or agency that publishes data from authoritative sources (e.g., National Hydrography Dataset Plus [NHDPlus] published by Horizon Systems Corporation for the U.S. Environmental Protection Agency [EPA]). These publications are often compilations and subsets of the data from more than one authoritative source. The data are “trusted” because there is an official process for compiling the data from authoritative sources and their limitations, currency, and attributes are known and documented.
- Authoritative data are generally assumed to be the most current and accurate version of a data set. They are sometimes referred to as the “primary” data source because they often come directly from the original source/creator. Trusted sources are recognized by the authoritative source as an “official” publisher of trusted data, i.e., data that are published by someone other than the authoritative source. Trusted sources are typically established to integrate data from multiple jurisdictions and to compile them in a standard format.

We can make some generalizations about “authoritative” and “nonauthoritative” data based on the above definitions. For example, authoritative data:

- are born from a legal responsibility provided by a legislative body
- can be collected, maintained, and disseminated by an entity that has legal authority (authoritative source), or an entity that is officially appointed/contracted by the former (trusted source)
- are synonymous with “official data”
- have been vetted according to official rules and policy established by the source
- have a known accuracy and lineage
- are regarded as the most current “official” version of that data
- are appropriately documented in metadata.

By comparison, nonauthoritative data:

- are not directly tied to any legal mandates
- can come from any source or collection of sources
- can apply to “unofficial” copies of authoritative data
- have not been vetted according to official rules or policies established by an authoritative source, and therefore do not qualify as trusted data
- may have unknown accuracy and lineage
- may not have well-documented or standardized metadata.

These key differences between authoritative and nonauthoritative are important to consider in the context of the current effort of evaluating ways to improve the discovery, sharing, and use of water data. First, authoritative data can generally be found more easily because they are intended to be made publicly available, whether through an authoritative or trusted source. Conversely, nonauthoritative may be less accessible if there is no underlying obligation or desire to make them available. Future efforts to improve access to water data should consider existing modes of accessibility for both data classes when considering whether to integrate them into new platforms.

Another consideration for future efforts is whether there should be a focus primarily on authoritative, nonauthoritative, or both classes based on the underlying goals and objectives of the efforts. For example, if a goal is to provide open access to water data, future efforts will need to evaluate whether the desired data currently conform to open access standards or require further manipulation and quality verification to meet open access standards. Nonauthoritative data are less likely to conform to open access standards and may require further manipulation or may not be able to be openly distributed. Similarly, data use agreements will need to be considered when evaluating which data to include in future efforts.

While authoritative data are generally regarded as the most current version, this may not always be the case. Authoritative data can grow stale because the process for validating and certifying data is often rigorous and takes considerable time, resulting in longer refresh cycles. Consequently, the value of authoritative data may degrade over time relative to the rate of updates. In some cases, nonauthoritative (or “unofficial”) versions of authoritative data may represent the most current and accurate version but lack official certification to become trusted data.

Nonauthoritative water data can provide value to improving stakeholder dialog and basin-wide planning processes, assuming they were collected, validated, and documented using best practices. However, it is generally not feasible to provide oversight of this aspect, which creates a risk of distributing poor quality data and reducing trust. An alternative is to establish minimum documentation and quality assurance requirements that data providers must present with their data.

# 3.0 Water Resource Community Interviews

We solicited input from a diverse sample of members of the water resources community (referred to herein as “stakeholders”) on four broad topics: (1) the types of data that are important in each stakeholder’s respective decision-making processes; (2) the challenges experienced accessing and using these data; (3) the importance and means of visualizing data; and (4) the perceived need for improving access to and coordination of river-related data.

We interviewed members representing a wide array of organizations and interests at national, regional, and local levels, including members from federal and state natural resource agencies, academia, NGOs, hydropower industry, and consultants. We also attempted to identify members who might be characterized as “data users” and “data producers.” We relied on our knowledge of relevant literature and our experience from both previous (e.g., WPTO’s Basin-Scale Opportunity Assessment Project) and ongoing (e.g., Stanford University’s Demonstrating Value of Improved Data Access to Support Basin-Wide River Planning Efforts Project) projects to identify specific interview candidates from each organization. We focused, to some degree, on identifying members in California, Wisconsin, and New England states because of the project team’s familiarity with related projects and opportunities in those areas.

Approximately 50 members were initially identified for potential interviews, from which we selected 22 as higher priority because of the interviewee’s knowledge of the subject matter and existing relationships with the project team given the time and personnel constraints of the project (Table 1). We acknowledge this represents a small fraction of the water resource community, which is why we prioritized getting a diverse group to interview. Also, most members we interviewed considered themselves data users. However, this was done intentionally because we decided to postpone interviewing most of the key data producers we have identified. Additional discussions are suggested for the next phase of the project, placing more emphasis on identifying potential partners for future work.

We conducted semi-structured telephone interviews between November 2019 and January 2020. All interviews followed a generic interview template, which was further customized for each interview based on each interviewee’s mission and responsibilities. At least two members of the project team participated in every interview, during which one team member served as the lead interviewer and the other focused on taking notes and asking supplemental questions.

Table 1. Summary of organizations and corresponding individuals interviewed or contacted for an interview between November 2019 and January 2020.

| Organization | Interviewees |
|---|---|
| American Whitewater | Dave Steindorf |
| California Data Exchange Center | Jeremy Hill, David Parker |
| California Department of Fish and Wildlife | Beth Lawson |
| Cube Hydro | Jose Zayas |
| Kearns & West | Anna West, Brianna Mosely |
| Low Impact Hydropower Institute | Shannon Ames, Maryalice Fischer |
| Metropolitan Water District of Southern California | Allison Collins, Corey Phillis, Roger Patterson, Brandon Goshi |
| National Hydropower Association | Jeff Leahey, Malcom Woolf |
| National Oceanic and Atmospheric Administration | Melanie Harris, Bjorn Lake |
| The Nature Conservancy | Tara Moberg, Brian Stranko |
| U.S. Geological Survey | Sally Eberts, Emily Read |
| Wisconsin Department of Natural Resources | Cheryl Laatsch, Ben Callan |
| Yuba County Water Agency | Willie Whittlesey, John James, Brent Hastey, Curt Aikens, Naser Bateni |
| World Wildlife Fund | Jeff Opperman |
| **Organizations Contacted but Not Yet Interviewed** | |
| American Rivers | Brian Graber |
| California Department of Water Resources | Curtis Anderson, Bill Ehorn, Lauren Bisnett |
| Federal Energy Regulatory Commission | Nick Jayjack |
| Natel Energy | Gia Schneider |
| University of New Hampshire and University of Maine | Kevin Gardner, Sam Roy, Weiwei Mo, David Hart |
| U.S. Army Corps of Engineers | Daniel Rabon |
| U.S. Bureau of Reclamation | Kurt Wille |
| U.S. Fish and Wildlife Service | Frankie Green |

# 4.0 Water Data Categories

The range of issues involved in water-management decisions in a river basin extends beyond water quantity and quality to a wide range of issues such as human uses, ecology, energy generation, climate, and recreational activities. The interdependence of these issues emphasizes the need for decision-makers to consider a basin as an integrated system and to have the ability to integrate data among these different issues. Improving access to and interoperability of these diverse categories of water data remains a central challenge to achieving this goal. Identifying pathways to doing so begins with identifying relevant categories of data and analyzing issues related to their use.

This section describes important categories of water data that can be factored into integrated management processes for river basins. We begin with a tabular overview of the categories (Section 4.1), followed by relevant feedback we received during our interviews with members of the water resources community (Section 4.1), and conclude with brief descriptions and example sources of each category of water data.

## 4.1 Summary of Categories

A total of 14 general categories of water data were identified through literature and Internet research, expert opinion, and further vetting during interviews with stakeholders (Table 2). While some of these categories are closely related (e.g., Dams and Migratory Barriers), we felt there are certain aspects that warrant their distinction. We attempt to clarify these distinctions in the category descriptions in Table 2 and Section 4.3.

We acknowledge our categories are subjective, so for additional reference we compare them to another comprehensive set of water data categories provided by Cantor et al. (2018). Our intent is to be comprehensive, not suggest one set of categories is better than the other. We refer readers to Cantor et al. (2018) for detailed descriptions of their categories. All data categories listed by Cantor et al. (2018) are represented in Table 2.

In general, the two sets of categories are very similar and complementary. One distinction is that Cantor et al. (2018) differentiate “Mapping & Modeling” as a separate category, whereas we note the possible existence of mapping (or spatial) data for each category. We also note that some categories we list are not explicitly described by Cantor et al. (2018) or vice versa; however, they can be logically associated with other categories as we have done here.

Table 2. Summary and Basic descriptions of Water Data Categories (in Alphabetical Order)

| Category | Description | Cantor et al. Categories |
|---|---|---|
| Dams | Spatial and metadata information about dams, including dam uses, ownership, licensing, age, operations, risk/safety status, etc. | Infrastructure & Utilities |
| Ecology | Spatial and/or quantitative data about the presence of sensitive aquatic and terrestrial species, habitats, land cover, land use, conservation activities, etc. | Ecology, Land Use |
| Flood Control | Spatial and quantitative data about historical flood plains, flood control infrastructure, flood risk, etc. | Water Storage |

| Category | Description | Cantor et al. Categories |
|---|---|---|
| Hydroclimatology | Spatial and/or quantitative data depicting current or future regional climate (temperature and precipitation) and climate-informed hydrology | Weather & Climate |
| Hydrography | Spatial and quantitative data about the physical characteristics of basins, sub-basins, watersheds, streams, stream order, canals, pipelines, etc. | Mapping & Modeling |
| Hydrology | Spatial and/or quantitative data about the quantity and timing of water in a basin, including stream gage data, modeled streamflow, reservoir storage, hydrologic alteration, aquifers, groundwater recharge, etc. | Water supply, Geology & Soils |
| Hydropower | Spatial, quantitative, and metadata information about hydroelectric dams, generation, ownership, licensing, and associated infrastructure | Infrastructure & Utilities |
| Management Landscape | Spatial and metadata information about land ownership, protection status, zoning, etc. | Land Use, Mapping & Modeling |
| Migratory Barriers | Spatial and metadata information about anthropogenic barriers to fish migration and aquatic habitat use | Ecology |
| Recreation & Aesthetic Importance | Spatial and metadata information about areas reserved for recreation or aesthetic purposes | Land Use |
| Socioeconomic | Spatial and/or quantitative data related to the socioeconomic value of water resources, cultural resources, land, water uses, hydropower, fisheries, and other factors | Socioeconomic |
| Water Quality | Spatial and/or quantitative data about surface-water and groundwater quality (e.g., dissolved oxygen, nitrates, contaminants of concern) | Water Quality |
| Water Availability & Use | Spatial and quantitative data about surface-water and groundwater use/availability for public supply, domestic, irrigation, thermoelectric power, industrial, mining, livestock, and aquaculture, as well as water rights | Agriculture, Water Demand & Use |
| Weather | Spatial and/or quantitative weather observation data | Weather & Climate |

## 4.2 Community Feedback

Stakeholders interviewed for this effort indicated that the list of data categories (Table 2) was representative of the range of categories they use or are aware of others using in river basin management. Some stressed the importance of including groundwater data in our list, indicating that the need for such data is increasing and integral to gaining a comprehensive understanding of surface-water hydrology in many areas. We acknowledge groundwater under the “Hydrology” category, although reasonable arguments could be made for considering it as a separate category.

When asked what categories are most important to them, stakeholders’ opinions varied considerably and were generally influenced by their respective roles. However, most stakeholders indicated that hydrology (e.g., observed and modeled streamflow), hydrography (e.g., spatial representations of surface waters and groundwater, and hydrologic boundaries such as basins, sub-basins, watersheds, etc.), and water quality data (e.g., temperature, dissolved oxygen [DO], nitrates, contaminants of concern [CoCs]) were important or necessary to their work. They noted these categories are fundamental to understanding most water-related issues, whereas other categories such as ecology, dams, hydropower, recreation/aesthetics, and socioeconomics are applicable in specific cases. However, the importance of these categories in their respective use cases is often critical.

Several stakeholders indicated there is a growing interest in hydroclimatology data among multiple sectors (e.g., energy, environment, agriculture) within the water management and research domain. The interest appears to be driven by growing recognition of potential impacts of climate change on water use and environmental flows. Stakeholders who expressed interest in hydroclimatology data also generally expressed a need for better spatially and temporally down-scaled variants of these data to support improved site-scale and reach-scale decision-making. Some stakeholders are actively engaged in projects to improve the interpretation and use of hydroclimatology data (e.g., Yuba Water Agency working with several universities).

A common thread among stakeholders we interviewed was a desire for enriched water data, i.e., data that have undergone some value-added process to contain or represent additional layers of objective information beyond the primary purpose of the original data. One example is the National Anthropogenic Barriers Dataset, which was developed to assess stream connectivity and barriers to fish migration by co-locating dam locations from the National Inventory of Dams data set with stream locations in the National Hydrography Dataset. Improving access to enriched data is challenging because these data are generally produced to meet a specific need and may not be intended for broad use.

## 4.3 Category Descriptions and Example Data Sources

More detailed descriptions and example data sources for each data category are provided in the following sections. The sections are organized in alphabetical order. For quick reference, a table is provided in Appendix A that summarizes all the example data sources (with embedded hyperlinks) mentioned in this section.

### 4.3.1 Dams

Dam data include spatial and metadata information about dams including their location, uses, ownership, licensing, age, operations, energy potential, and safety status. All dams in the United States that are either over 25 feet in height, contain over 50 acre-feet in reservoir storage, or are classified as a significant hazard are recorded in the National Inventory of Dams (NID), which is maintained by the U.S. Army Corps of Engineers (USACE 2018b). Another source of data and information about U.S. dams is HydroSource, hosted by Oak Ridge National Laboratory (ORNL), which contains information about existing hydroelectric dams and new hydropower potential at non-powered dams and in undeveloped stream reaches (e.g., calculated head, monthly estimated flow, monthly energy potential) (ORNL 2019). The challenge with data on dams is related to the availability of operations data, which may be sensitive and only available after obtaining a formal agreement between the dam operator and requestor.

### 4.3.2 Ecology

Ecology data include spatial and/or quantitative data about the presence of sensitive aquatic and terrestrial species, habitats, land cover, and land use. In addition to containing information about dams and hydropower, HydroSource also contains certain environmental data aggregated by watershed, including habitats of *Endangered Species Act* (ESA)-listed species, fish species of concern, fish traits, protected lands, water quality concerns, water use estimates, recreation and aesthetics, and land disturbance and development (ORNL 2019). Another source of ecology data is NatureServe, which hosts both raw data and derived indicators of ecological health for the United States, including biodiversity indicators, landscape condition, fish distribution, and endangered species (NatureServe 2019).

The U.S. Fish and Wildlife Service (USFWS) is the authoritative source of geospatial data about ESA species designated Critical Habitat (USFWS 2019). An exception is ESA species under the jurisdiction of the National Marine Fisheries Service (NMFS), which is available through the National Oceanographic and Atmospheric Administration (NOAA) Fisheries Critical Habitat portal (NOAA 2019c). In addition, 46 of the 50 United States have their own endangered and threatened species portals, which have been compiled in one location by the EPA (EPA 2020a).

Land cover and land use data are also important ecology data types to consider in basin-wide planning. The Multi-Resolution Land Characteristics Consortium (MRLC), a group of federal agencies who coordinate and generate consistent and relevant land cover information at the national scale, provides updated landcover information every two to three years (MRLC 2016).

Some of the challenges with ecology data are related to their completeness and currency. For example, baseline information about species distribution and populations is often lacking, incomplete, or out of date.

### 4.3.3 Flood Control

Flood control data include spatial and quantitative data about historical floodplains, flood control infrastructure, and flood risk. The Federal Emergency Management Agency (FEMA) produces floodplain maps for the entire nation but they vary in scale and accuracy (FEMA 2019). The FEMA database also includes levees, bridges, and other flood structures. Dams that provide flood control are identified in the NID. Flood control data beyond FEMA floodplain maps are not easily discoverable. Information about flood control infrastructure not related to dams may not be available.

### 4.3.4 Hydroclimatology

Hydroclimatology seeks to better understand how current and future climate affects spatial and temporal variations in the hydrologic cycle. Hydroclimatic data refer to spatial and/or quantitative data depicting current and future regional temperature and precipitation data, in addition to climate-informed hydrology. These data are derived from a family of integrated models of climate, land surface, and hydrologic processes. Universities and government agencies are the primary producers of hydroclimatology data. Hydroclimatological information is increasingly being used to give water policymakers a broader perspective when developing sustainable management criteria for water resources. NOAA’s National Centers for Environmental Information (NCEI) house many hydroclimatological data sets along with weather data (NOAA 2019a). In addition, NASA’s Distributed Active Archive Centers for Hydroclimatology archives many types of relevant measurements and data (NASA 2019). Spatial climatology data are available from the North American Land Data Assimilation System (NCAR 2019) as well as the PRISM group at Oregon State University (OSU 2020).

While there is growing interest in applying hydroclimatology data in basin-wide planning processes, there are significant challenges to doing so because of the coarse spatial and temporal resolution of models, range of possible future climate scenarios, and lack of understanding outside the modeling community.

### 4.3.5 Hydrography

Hydrography data for river management refers to spatial and quantitative data about the physical characteristics of basins, sub-basins, watersheds, stream networks, and infrastructure. Authoritative data sets in this category include the medium- and high-resolution versions of the National Hydrography Dataset (NHD; USGS 2020a) and the National Watershed Boundary Dataset (USGS 2017). An enriched version of NHD, called NHDPlus, contains additional information about stream networks, modeled streamflow, and drainage basin area (Horizon Systems Corporation 2012). The National Watershed Boundary Dataset contains spatial information about hydrographic characteristics defining the areal extent of surface-water drainage to an outflow. These watersheds are represented in a nested, hierarchical structure, i.e., smaller watersheds nested inside larger watersheds. These data are well-known, readily discoverable, and easily accessible online. Challenges with these data are primarily related to their usability, which requires strong Geographic Information System (GIS) expertise and understanding of the underlying data model to extend use beyond basic cartography purposes.

### 4.3.6 Hydrology

Hydrology data include modeled or observed spatial and temporal information about the quantity and timing of surface-water and groundwater states. Example data types include stream gage, streamflow, reservoir storage, hydrologic alteration, and aquifer data. Hydrology data is a foundational category of water data that is necessary for understanding many water-related issues.

Numerous hydrologic data sets are available from federal and state authoritative sources, most notably the USGS National Water Information System (NWIS) which aggregates data from many sources, including data such as gage/stage height, and stream discharge for streams and rivers, as well as water elevation in lakes and reservoirs. NWIS also contains groundwater information and water quality data for both surface water and groundwater (USGS 2014). The USGS is also piloting its NGWOS (USGS 2019d) in the Delaware and Colorado River Basins; the pilot seeks to integrate fixed and mobile monitoring assets in the water, ground, and air to provide high temporal and spatial resolution data on streamflow, evapotranspiration, snowpack, soil moisture, water quality, groundwater/ surface-water connections, stream velocity distribution, sediment transport, and water use (Eberts 2019).

Other notable sources of hydrology data include the NOAA National Weather Service's river forecasting data (NOAA 2019b) and the U.S. Department of Agriculture Natural Resources Conservation Service's snow telemetry (SNOTEL) and snow course data (USDA 2020). NOAA also stewards the National Water Model (NWM; NOAA 2020), which is a modeling framework for simulating observed and forecasted streamflow over the entire continental United States. The NWM complements National Weather Service (NWS) river forecasts by providing hydrologic guidance to simulate streamflow at millions of other locations that do not have traditional river forecasts.

There is enormous interest and investment in hydrological observation and modeling in the United States and these data are well-known, readily discoverable, and easily accessible online. Common challenges with hydrology data include spatial or temporal gaps due to ungauged reaches or gage retirement, and quantifying uncertainties associated with snow-water estimations and surface-groundwater interactions.

### 4.3.7 Hydropower

Hydropower data are the spatial, quantitative, and metadata information related to hydroelectric dams, generation, ownership, licensing, and associated infrastructure. Some of this information, e.g., location and capacity of a hydropower facility, is available in NID. Grid-scale hydropower statistics are publicly available through individual Independent System Operators or through the Energy Information Administration. The HydroSource platform hosted by ORNL contains hydroelectricity generation and water-management data for the hydroelectric dams in the United States (ORNL 2019), including the National Hydropower Plant Dataset, which contains locations and key characteristics of U.S. hydropower plants under development, in operation, or retired. Generation data from individual facilities is generally not publicly available because they typically are considered business-sensitive information. In some cases, private generation data may be shared in a limited capacity.

### 4.3.8 Management Landscape

The management landscape refers to the status of natural resource management in a river basin, watershed, county, state, conservation district, or other unit of area. Example data types in this category include spatial and metadata information about land ownership, protection status, zoning, and land use history. Much of the information and data for a watershed's management landscape are publicly available, although not always freely. The Bureau of Land Management provides surface management agency (ownership) spatial data that show the federal and state ownership responsibility by entity and location (BLM 2019). Private land is included but individual landowners are not identified. Information about protection status is available in the USGS Protected Areas Database, the official national inventory of U.S. terrestrial and marine protected areas (USGS 2019e). Zoning data, if they exist, are managed by the zoning entity (city, county, or state). State-specific data about existing and past management of a watershed is available through the EPA Healthy Watersheds Assessments, which scores watershed health and vulnerability (EPA 2020e). Though there may be current indicators of past land use, land use history is generally not well mapped. Other than federal ownership and protection status, data about the management landscape are not easily discoverable. Local information about zoning or use history is typically housed within different organizations making discoverability a challenge. The veracity of these data also is unknown in many cases.

### 4.3.9 Migratory Barriers

A common topic in river management is removing barriers to fish migration, whether by physically removing the barrier or by improving passage over the barrier. Dams are not the only barriers to fish migration—culverts, water diversions, tide gates, and many other manmade features can also impede the migration of fish. Migratory barriers data are spatial and metadata information about anthropogenic barriers to fish migration and aquatic habitat use. National-scale migratory barriers data are available in the National Anthropogenic Barriers Dataset (Ostroff et al. 2013). However, the data set only includes information about dams from the NID and does not include information about all types of barriers.

Many state natural resource agencies and some regional entities have assembled migratory barrier data sets, some of which include information about non-dam barriers. The USFWS Region 4 in the southeastern United States has funded a partnership to develop a comprehensive database of barriers in the region (SARP 2020). The Nature Conservancy has assembled migratory barrier data for the northeastern United States, available through their Northeast Conservation Planning Atlas (TNC 2019), which includes dams and road stream crossings for which barriers are classified by their severity to fish migration. Many western states have detailed data sets about barriers. For example, California's CalFish (CalFish 2019), Oregon's Natural Resources Information Management Program (ODFW 2019), and Washington's Fish Passage and Diversion Inventory (WSDOT 2020) have robust data about migratory barriers.

Challenges with acquiring and using barrier data are related to the discoverability, completeness, and consistency of collection methods. Finding data about barriers can be a difficult task and river data users may have to contact state management agencies directly to find out if such data exist. Combining migratory barriers data from multiple state agencies or entities can be challenging because the data may be collected and documented with differing levels of detail.

### 4.3.10 Recreation and Aesthetic Interests

Recreation data are spatial and metadata information about areas reserved for recreation or aesthetic purposes. Recreation and aesthetic interest data are available from NGOs, state agencies, and federal agencies. The USGS Protected Areas Database includes many land areas that are protected, in part, for recreation and aesthetic purposes (USGS 2019c). Other national recreation and aesthetic interest data sets include the Wild and Scenic Rivers data set (National Wild and Scenic Rivers 2019), American Whitewater National Whitewater Inventory (American Whitewater 2020), and National River Inventory (NPS 2020b). An example of a regional-scale recreation database is Coastal Plain Paddle Trails, which contains spatial data about hiking trails and access points for the inventoried trails in the coastal plain (North Carolina Department of Environmental Quality 2001). The common challenge with recreation and aesthetic data is their discoverability. In addition, data collection and mapping methods may not be consistent among data sets, and the veracity of data may also be unknown.

### 4.3.11 Socioeconomic

Socioeconomic water data are spatial and/or quantitative data related to the socioeconomic value of water resources, cultural resources, and land and water uses. Global data are maintained and published by the Food and Agricultural Organization (FAO) of the United Nations available on the AQUASTAT website (FAO 2019). The FAO collects, analyzes, and disseminates data and information about 180 variables and indicators (both current and historical since 1960) about water resources, water use, and agricultural water management. Specifically, the site provides data for the following socioeconomic water-related categories (among the 180 total variables and indicators): water withdrawal by sector (agriculture, municipal, industrial), irrigation techniques, and irrigated crop area and yield (FAO 2019). These global data may be useful for regional- and basin-scale assessment. Higher resolution data may be available from state and regional water development agencies. For example, the Texas Water Development Board offers county level data about water availability, use, and future impacts via a web-based dashboard (TWDB 2016).

Cultural resources data include both spatial and descriptive data about cultural resources that could be affected by water-management practices. The U.S. National Park Service (NPS) defines cultural resources as "physical evidence or place of past human activity: site, object, landscape, structure; or a site, structure, landscape, object or natural feature of significance to a group of people traditionally associated with it" (NPS 2020a). For water management, these resources typically include archaeological resources, historical structures, and cultural landscapes. One example of a national database of cultural resources that contains site-specific data is the National Register of Historic Places database maintained by the NPS (NPS 2019). Most State Historic Preservation Offices and Tribal Historic Preservation Offices also maintain databases of cultural resources at the state and local level; however, the quality and availability of data varies among states and tribes. The primary challenge with cultural resources data is their discoverability because of the need for federal, state, and tribal agencies to restrict access to data about the location of cultural resources, especially sensitive archaeological resources and cultural landscapes.

A common challenge with socioeconomic data is their discoverability because there are few authoritative sources of such data. Accessibility is also a common challenge, particularly for cultural resources data because of the above-stated need for federal, state, and tribal agencies to restrict access to location data about sensitive archaeological resources and cultural landscapes.

### 4.3.12 Water Quality

Water quality data includes spatial and/or quantitative data about physical and chemical properties (e.g., temperature, DO, nitrates, turbidity, pH, CoCs) that affect the quality of surface water and groundwater for aquatic organisms and human health. Water quality data are collected by federal, state, county, and local authorities, as well as by private entities that are required to do so to comply with water permitting processes. Volunteer and NGO entities may also collect water quality data. Consequently, water quality data can be collected using different collection protocols, equipment, calibration requirements, and temporal frequencies.

The Water Quality Portal is a cooperative service, led by USGS, EPA, and the National Water Quality Monitoring Council, that provides access to water quality data collected by more than 400 state, federal, tribal, and local agencies (National Water Quality Monitoring Council 2019). Water quality data are also available through USGS's NWIS (USGS 2014) data services.

The EPA has several tools that facilitate the rapid viewing and assessment of water quality issues in U.S. watersheds. The "How's My Waterway?" tool allows users to search anywhere in the United States to learn the condition of local streams, lakes, and other waters (EPA 2020a). The Watershed Index Online tool provides a means of viewing and downloading watershed characteristics such as measurements of ecological, stressor, and social characteristics (EPA 2020c). The EPA "Recovery Screening Potential" tool allows for assessment and prioritization of impaired waters (EPA 2020d).

Challenges associated with water quality data are often related to usability issues stemming from disparate sources, collection methods, and data management practices.

### 4.3.13 Water Availability and Use

Water availability and use data are spatial and quantitative data about the availability and use of surface water and groundwater for public supply, domestic, irrigation, thermoelectric power, industrial, mining, livestock, and aquaculture. Data and information about water rights are also included in this category. The USGS National Water Census is the primary mechanism for collecting and disseminating water availability and use data in the United States. The Census seeks to develop nationally consistent data sets that reflect the status and trends of major water budget components (i.e., streamflow, groundwater, water use, environmental flows, evapotranspiration) and water use. County and state water-use data have been reported every five years since 1950 and are available for download from the NWIS (USGS 2018). Water budget data for watersheds and counties are available through the National Water Census Data Portal (USGS 2020b). The greatest challenges with these data are related to the timeliness and scale of their collection. Some data sets may be state- or regional-scale data disaggregated to county level; others may not be collected in the year of the survey but interpolated from previous measurement years.

### 4.3.14 Weather

Weather data include spatial and temporal weather observation data. Authoritative sources of weather data include NOAA's NCEI and NWS. NCEI provides comprehensive data about atmospheric, coastal, oceanic, and geophysical measurements from land-based, satellite, and radar weather observations as well as data from numerical models used for weather prediction (NOAA 2019a). The NWS provides separate access to some of the same data sets offered by NCEI and may be more familiar to river data users. The discoverability and accessibility of weather data are generally considered good.

# 5.0 Accessibility, Usability, and Visualization of Water Data

This section summarizes general findings from stakeholder interviews and Internet research about the accessibility (Section 5.1), usability (Section 5.2), and visualization (Section 5.3) of water data. It is important to note that our findings regarding accessibility, usability, and visualization are qualitative in nature and are intended to help guide further investigation of these topics. In addition, most of the stakeholders we interviewed described themselves as data users; thus, their views are more heavily represented than those of data producers. We recommend that future efforts seek additional input from data producers regarding these topics.

## 5.1 Accessibility

Challenges facing the accessibility of water data should be considered from the perspectives of data users, data producers, and data user-producers (i.e., a subset of users who also produce derived, proprietary, or alternative copies of data that may be valuable to other users). We consider the perspectives of user-producers separately from the other two groups because there is growing recognition of the importance of this group, particularly as providers of nonauthoritative water data and because the challenges they face are common to those experienced by users and producers. In this section, we examine these perspectives more closely (Section 5.1.1) and then summarize stakeholder views about the accessibility of water data (Section 5.1.2).

### 5.1.1 General Perspectives

From a user's perspective, accessibility may be thought of as the ability to discover and obtain data. Key factors affecting this include the availability and efficacy of information technology (IT), as well as social aspects like users' existing knowledge of data resources and their professional network. It is commonly assumed in today's "Information Age" that water data should be readily accessible because of many advances in IT and its use in making certain categories of water data more accessible. However, many challenges remain with respect to various aspects of building IT systems for water data, including their construction, interoperability, usability, maintenance, and funding. Furthermore, these aspects are not always apparent to users. Social aspects such as experience level and professional networks also play a significant role in a user's ability to access data. Experienced users are less likely to face challenges when accessing data because of their depth of knowledge, and consequently they are less likely to express negative opinions about accessibility of water data. Related to this is the size and diversity of a user's professional network, which affects their ability to leverage others' knowledge of data resources. Both social aspects were evident in our interviews and highlight how knowledge can become siloed among certain user groups and affect perceptions about data accessibility. Improving the ability of users to share knowledge may play a role in improving data accessibility.

Accessibility may be thought of from a producer's perspective as the ability to publicize and disseminate data effectively. While many affect factors this ability, we emphasize the importance of internal or external mandates, personnel and funding, and the sensitivity of data as key factors. As discussed in Section 2.2, authoritative data tend to be more accessible than nonauthoritative data because of a legislative mandate to make authoritative data available. However, the degree to which authoritative data are accessible varies depending on the efficacy of data collection, quality assurance/quality control (QA/QC) requirements, dependence on legacy systems, volatility in funding cycles, and other factors. These factors also affect nonauthoritative data producers, although they face different challenges regarding incentives to make their data accessible. The availability of funds and technical personnel needed to make data accessible are common challenges among all data producers and were mentioned frequently during the interviews. Often, efforts to stand up web-based data portals span multiple years and require stable funding to maintain. The sensitivity of data was also frequently cited in the interviews as being a significant determinant of whether data are made accessible.

From a user-producer's perspective, factors affecting the accessibility of water data crosscut many of the same factors experienced by data users and data producers, e.g., availability of IT, knowledge of data resources, presence of internal/external mandates, personnel and funding, and sensitivity of data. Therefore, it may be more challenging to improve the accessibility of data from this group. Example members of this group might include research and academic institutions, certain NGOs, and hydropower owners/operators. In some cases, members of this group eventually become recognized sources of data and gradually grow into the role of being perennial data providers. Data produced by these members are often seen as valuable because they are typically enriched with new information, or the data involve proprietary information that would otherwise be unavailable.

### 5.1.2 Stakeholder Perspectives

When asking stakeholders about their views on the accessibility of the water data with which they work, there was consensus that some categories of data are more accessible than others. Most stakeholders indicated that access to hydrology and water quality data is generally good and has improved dramatically in the last decade. Conversely, stakeholders felt that access to other categories of water data such as hydroclimatology, water use, ecology, recreation and aesthetic interests, hydropower, and socioeconomic data is more limited.

Certain types of water data are often proprietary and not accessible to the public (e.g., hydropower operations, cultural resources, agricultural water use, raw data submitted through the Federal Energy Regulatory Commission [FERC] licensing process). Hydropower-related data (e.g., generation, Critical Energy Infrastructure Information, power marketing) was among the most cited categories of proprietary data about which stakeholders expressed having the most difficulty in accessing the data. Many stakeholders use FERC's eLibrary to find information related to the hydropower licensing process, but they note it can be difficult to mine information from eLibrary, and eLibrary is not intended to serve as a comprehensive resource for hydropower data. One stakeholder suggested that it might be difficult to find data for federal hydropower facilities because they are not subject to FERC licensing and a regular review process. In some cases, hydropower-related data types can be acquired from hydropower licensees, although typically under restricted use agreements that disallow redistribution. Some stakeholders indicated that they were able to gain access to proprietary data by establishing partnerships.

Some stakeholders indicated that access to modeled data is generally more challenging than access to observational data. Reasons for this are unclear, but there may be several possible explanations. One is that there are comparatively fewer sources of authoritative modeled data than observed data, and consequently few mandates to make modeled data available. Another possible reason is that modeled data are often generated to evaluate specific issues or research questions for a select group and are not intended to be shared for general use because they may be sensitive or misinterpreted. A third explanation is the need for a "human in the loop" to conduct modeling activities (i.e., design, parameterize, execute, QA/QC), which requires significant time and resources and can be difficult to automate. Finally, modeled data can have higher degrees of uncertainty and be based on complex methodologies that sometimes make it more difficult for the public to understand and trust. Some stakeholders expressed this concern about modeled data and indicated that better access to observational data is sometimes preferred because there are fewer trust issues.

Stakeholder viewpoints about data accessibility also indicated that it varies geographically across regions, states, river basins, and within river basins. For example, one stakeholder suggested that fisheries data were less accessible (and perhaps less abundant) in the Midwest compared to in the Pacific Northwest. It was supposed this may be related to differences in regulatory attention to fisheries issues in each region (e.g., endangered salmonids in the Pacific Northwest). Similarly, some stakeholders felt that data accessibility was tied to data richness, i.e., accessibility is generally better in areas that have a greater abundance of water data.

It is important to note that some stakeholder views about data accessibility overlap with views about data gaps, which we suggest are separate but related issues. Data accessibility pertains to the general ability to discover, obtain, share, and disseminate data, whereas data gaps refer to the existence of a data set (e.g., lack of population data for a rare fish species) or the spatial and temporal dimensions of a data set (e.g., stream gage data for specific stream reach or year). Data that are lacking, either completely or for a specific area or period, are by definition not accessible. However, collecting data to fill data gaps does not assure that they will be accessible. Nonetheless, data gaps influence people's perception of accessibility and future efforts to improve the accessibility of water data should clarify these key differences. A common viewpoint we heard from stakeholders regarding data gaps is a need for better granularity (spatial and temporal) of water data because decision-making often is site-specific.

We also found that stakeholder views about data accessibility varied by organization type and proficiency as data users or producers. In general, larger organizations experience fewer issues with data accessibility than smaller organizations, presumably because of having more technical staff and larger operating budgets. Stakeholders that described themselves as frequent water data users generally expressed fewer concerns about data accessibility than self-described infrequent users. These findings suggest that certain user groups will benefit more from efforts to improve the accessibility of water data than others.

It became evident during our discussions with stakeholders that many of their concerns regarding access to water data are non-technical in nature. Many stakeholders expressed the importance of building personal and professional relationships among stakeholders to establish trust and facilitate sharing and use of water data. Similarly, they indicated it would be necessary for future efforts aimed at improving access and use of water data to generate buy-in among the diverse community of water data users and producers before initiating technical work. Some stakeholders felt this is a significant challenge because it can be very difficult to get the community to agree on data needs and responsibilities. Key reasons they noted for this challenge include difficulty getting entities in a river basin to fund data collection and access activities, especially when they extend beyond project or jurisdictional boundaries or do not appear to directly benefit their mission. They acknowledge that while there are opportunities to learn from other efforts for which this has been done successfully, such success stories may be unique and not easily repeatable across basins.

## 5.2 Usability

We refer to the usability of water data as the ability to transform data into information that meets the needs of the user. This ability can be affected by a variety of issues including quality (e.g., completeness, precision, accuracy), interoperability (e.g., non-standard or proprietary formats), spatial and temporal resolution, supporting documentation or metadata, and user knowledge. Water data are often multi-sourced, which can contribute to many of these issues and represents a major challenge to improving the usability of water data.

Concerns about the usability of water data did not come up as frequently in the interviews as issues of accessibility. Some stakeholders indicated that issues with the quality and provenance of data were a limiting factor to using water data. Uncertainty about these issues sometimes led users to produce their own data or obtain data from elsewhere. The availability and quality of metadata (i.e., set of data that provides information about other data) were also mentioned by stakeholders as sometimes being problematic with water data. Stakeholders noted these issues collectively affect their trust in a data source, and ultimately their perception of its usability. Many stakeholders also commented about the importance of personal and professional relationships in shaping their trust in data. Several stakeholders expressed a desire for better spatial and temporal resolution of water data to improve data usability for local- or site-scale decision-making.

The role of a user's knowledge in determining the usability of data is often overlooked. So-called "expert" users may experience fewer challenges with making data usable because of their greater knowledge and depth of experience. In addition, certain users may be more knowledgeable about various uses of data. In both cases, improving the ability to transfer knowledge among users, particularly between expert and non-expert users, may help improve the usability of water data. Improving and expanding the use of meta-analysis of how data are being used (i.e., who, what, when, where, and why a given data set is being used) could be a preliminary step to improving knowledge transfer. However, collecting detailed use information is extremely difficult.

## 5.3 Visualization

We refer to the visualization of water data as the process of viewing data attributes (including geographic location), summaries, or information derived from data to improve the understanding of a phenomenon or some aspect about the data. We exclude tabular viewing of raw data from this definition. One example of visualizing water data is displaying streamflow data as a time-series graph or flow duration curve to improve understanding of the timing and magnitude of streamflow. Another example is visualizing the geographic locations of migratory barriers in relation to rivers and protected fish habitats to improve understanding of where fish passage improvements may be most valuable. There are many techniques and tools for visualizing data, which are typically customized with a specific end-use in mind.

During interviews with river data users we asked them about the importance and use of visualization in their work. We also were interested in learning about their use of GIS and geographic visualization techniques for visualizing water data. We did not focus on trying to identify specific visualization tools, but rather on hearing their general thoughts about visualization practices.

User methods for visualizing data were driven largely by their familiarity with those methods and their respective use case for the data. They also noted that while data visualization and analysis tools are helpful, they should always be able to obtain the raw data to perform their own analysis. In fact, some users preferred this option over using external analysis and visualization tools. For this reason, many users rely on spreadsheet software for data review, simple charting, or developing custom decision-support tools for internal use. They acknowledge this approach limits the use of more sophisticated visualization techniques, but suggested such techniques are generally not needed for their purposes. Few users mentioned using open-source visualization platforms for viewing summaries of time-series water data.

When asked about their use of GIS, Google Earth was the most mentioned platform for viewing the geographic distribution of data features in a basin. Many users indicated they use Google Earth instead of more sophisticated GIS platforms because of its ease of use and zero cost. However, they noted that its functionality is limited to simple viewing and that it is difficult to find spatial water data in compatible formats (i.e., KML or KMZ file types). A smaller number of users noted they occasionally use commercial GIS software for more complex analysis and viewing of geographic water data, but often defer such work to GIS professionals in their organization. Many users echoed the growing need to acquire personnel who have GIS experience because spatial water data are becoming increasingly available and offer additional layers of information that cannot be acquired otherwise.

# 6.0 Related Efforts

There have been many efforts in recent years related to improving the accessibility and use of certain categories of water data. While these efforts have had a net positive impact, to some degree they also contribute to the disaggregated nature of water data because they have not been coordinated. This section briefly describes a select number of these efforts, focusing on those that are national in scope, to provide additional context for the current state of water data in the United States and help inform thinking about potential pathways for future work. A summary of some notable state-level efforts in our areas of initial interest (California, Wisconsin, and New England states) is also provided. As such, this section is not a comprehensive review of related efforts and we recommend deeper exploration in future work.

### 6.1.1 USGS Next Generation Water Observing System

Building upon the USGS's nearly 140-year history of providing critical environmental and water measurements to decision-makers throughout the United States, the USGS's NGWOS aims to use new technologies to provide real-time data about water quantity and quality in an expanded set of locations (USGS 2019d). Methods such as webcams and ground/space-based sensors have provided new opportunities for collecting high-resolution temporal and spatial data in more affordable and rapid ways than previously possible. USGS will employ these methods to provide data about streamflow, evapotranspiration, snowpack, soil moisture, water quality, groundwater/surface-water connections, stream velocity distribution, sediment transport, and water use in a set of intensively monitored watersheds. Ultimately, it is envisioned that NGWOS will support advanced modeling tools to provide sophisticated flood and drought forecasts that can support emergency- and water-management decision-making nationwide.

The focus of this effort is provisional, real-time data to support advanced modeling efforts, such as NOAA's NWM (NOAA 2020). This aligns with USGS's expertise and builds upon their National Streamflow Network. However, NGWOS pivots from increasing the density and extent of *in situ* monitoring systems throughout all large watersheds and aquifers, to developing intensive monitoring networks in a select number of medium-sized watersheds (10,000–20,000 square miles) and underlying aquifers that are representative of larger regions across the United States. The USGS plans to use data from these select watersheds in combination with data from existing monitoring networks to inform advanced models, thereby reducing uncertainty and filling in gaps in current regional and national water assessments and predictions.

The USGS plans to include at least 10 representative watersheds in NGWOS, selected based on stakeholder input and incorporating a diverse set of environmental, hydrologic, and landscape conditions. At least one basin in each of the USGS's 18 water resource regions will compose the pool of watersheds that will be considered for selection.

The USGS began piloting the NGWOS in 2018 in the Delaware River Basin (USGS 2019a). Approximately half of the monitoring infrastructure was installed or modernized by late 2019. The USGS plans to implement monitoring in fiscal year 2020 (FY 2020) using sensors and remote sensing, and to continue to test additional technologies. In November 2019, the Upper Colorado River Basin was selected to be included in NGWOS based on a rigorous process of ranking western basins and gathering input from internal and external stakeholders. The USGS plans to begin implementing the first stages of NGWOS in the Colorado River Basin in FY 2020, including conducting network design and analysis (USGS 2019b). The USGS is also looking to engage with stakeholders on the selection of the third basin to be included in the NGWOS.

NGWOS is a complementary effort to USGS's longstanding Water Data for the Nation program. The program website (USGS 2019e) provides access to surface-water, groundwater, water quality, and water-use data collected at about 1.9 million sites in all 50 states, the District of Columbia, Puerto Rico, the Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands. In February 2019, the USGS began rolling out the Next Generation of USGS Water Data for the Nation that will incorporate real-time water data and modernize this resource using the latest web technology and techniques. USGS is seeking feedback on the new platform.

Another smaller-scale, USGS-sponsored effort worth mentioning is the Dam Removal Information Portal (DRIP), a USGS software release published in 2016 (Duda et al. 2016; USGS 2020c). DRIP is an online, map-based visualization tool that contains information about dam removal projects. Users can interact with the map to access data about the removed dam's location, size, and date built/removed. In addition, scientists and other stakeholder partners can access the most recent scientific studies associated with dam removal, if they are available. DRIP was developed in partnership with American Rivers, and its data are provisional.

### 6.1.2 USACE Access to Water Resources Data

The USACE's Access to Water Resources Data – Corps Water Management System (a.k.a., "AW2") Data Dissemination tool is used to support the USACE in managing many of its projects nationwide (USACE 2018a). AW2 uses visualizations and reports about storage information to provide continuous assessment, awareness, and effective decision-making support.

This effort focuses on storage and dam information for more than 700 USACE lock and dam projects throughout the United States. The data are provisional and intended for high-level assessments and display purposes only. Example information available for each project includes the project name, dam heights (e.g., top of dam, top of flood control pool, top of normal storage), and current conditions at the dam (e.g., storage used, flow in/out, change in elevation, precipitation). Users can view data using a map interface to visually identify the location of lock and dam projects nationwide, or they can browse a list view for a more informative description of each project.

The AW2 effort is currently funded through Section 2017 of the 2007 *Water Resources Development Act* and amended in the 2016 *Water Infrastructure Improvements for the Nation Act* (Public Law 114-322, S.612). Details about planned efforts or future funding status were not available on the project website.

### 6.1.3 USBR Reclamation Water Information System

The USBR's Reclamation Water Information System (RWIS) is "…a pilot version of a Reclamation-wide system for viewing, accessing, and downloading Reclamation's data via a centralized data portal" (USBR 2018). The focus of RWIS is provisional, time-series water data. The RWIS data include current and historical data about canal flow/stage, precipitation, streamflow, as well as reservoir elevation, inflow, release, and storage for U.S. Bureau of Reclamation (USBR) sites. However, not all sites, parameters, and data types are currently available through RWIS. Planned improvements to RWIS will expand the range of available data and improve website functionality. Currently, users can interact with a map interface to discover, view, and download data based on location. In addition, users can query for data based on site names and selected parameters (canal flow, streamflow, stage, precipitation, reservoir elevation, reservoir release, etc.).

Eventually, the Reclamation Information Sharing Environment (RISE) will evolve from RWIS to become a fully developed and long-term product for sharing USBR data and information. USBR is planning for RISE to include expanded offerings of water data, including data about hydropower, biological parameters, water quality, and infrastructure or assets. RISE will also incorporate spatial data, modeling and analytic results, and reports.

The USBR launched the RWIS pilot effort in April 2017 and will continue to make system improvements to the site to include more data, features, and functionality. The RWIS central database is being developed to include infrastructure, hydropower, and environmental data, and the addition of other data for other domains is planned. USBR also worked to form communities within these data domains to identify relevant data sets and create connections between regional data sources focused on infrastructure, hydropower, and environment. USBR staff worked with other federal agencies and partners to develop a series of tools, visualizations, and applications to showcase data in the portal.

The successor to RWIS, RISE, was anticipated in Fall 2019 but further details about this could not be found on the project website. The planning team is also working with USBR's IT capital planning team to formulate budgeting for FY 2021 and plan outreach activities associated with the RISE launch.

### 6.1.4 EPA Water Data Efforts

Over the last 20 years, the EPA has produced a variety of water data portals and tools. One of the more well-known examples is their Surf Your Watershed (SYW) data portal, which allowed users easy access to a vast collection of watershed information (EPA 2020e). SYW was recently decommissioned because of technology migration and potential security issues, and will be replaced in 2020 by "How's My Waterway? Version 2" (EPA 2020e). The predecessor "How's My Waterway? Version 1.0" (EPA 2020c) is aimed at providing non-expert users the ability to learn about the condition of their local water body using a 10- by 10-mile search box.

Another EPA water data tool is the Watershed Index Online (EPA 2020g), which is an online data portal for technical, scientific audiences to view watershed characteristics within user-selected geographic areas anywhere in the conterminous United States. The Watershed Index Online data sets are leveraged by the tools available on EPA's Recovery Potential Screening website (EPA 2020d), which provides comparative watershed indicators, assessment methods, and example projects, including a national set of state-specific watershed comparison tools. The EPA's Healthy Watersheds Protection (EPA 2020b) website contains comprehensive documentation of projects and analysis methods for protecting watersheds. The site also includes a preliminary assessment of watershed health in each of the 48 conterminous United States, using metrics such as health and vulnerability indices. Finally, EPA's WATERS GeoViewer (EPA 2020f) is a powerful mapping tool that gives users simple access to stream network data, including spatial data such as NHDPlus, as well as watershed level reports and capabilities for upstream/downstream linked data search and interactive watershed delineation.

### 6.1.5 DOE-WPTO HydroSource

ORNL launched HydroSource to offer comprehensive, detailed, reliable, and up-to-date geospatial data about hydropower resources, water, and environmental conditions in the United States (ORNL 2019). By providing a federal geospatial data standard for existing and potential hydropower resource evaluation in the United States, HydroSource is envisioned to provide information needed to promote acceleration of the U.S. hydropower market, deployment, technology-to-market activities, and environmental impact reduction. This information is intended to support initiatives of DOE's Water Power Technologies Office.

HydroSource includes a collection of explorers and tools that allow users to discover and apply HydroSource data. Some examples include the U.S. Stream Classification System (USSCS), Eastern Stream Classification Tool (SCT), National Hydropower Plant Dataset (Version 2), and HydroGIS. The USSCS seeks to organize the 2.6 million stream reaches in the United States into categories based on similar physical properties, resulting in a comprehensive layered typology of stream types (ORNL 2019). The SCT classifies nearly 1 million stream reaches in the Eastern United States based biophysical characteristics such as hydrologic, thermal, geomorphological, and ecological qualities (ORNL 2019). The National Hydropower Plant Dataset contains point-level data incorporating location and key characteristics of U.S. hydropower plants, including sites that are in the development pipeline, currently operating, withdrawn, or retired (ORNL 2019). The HydroGIS tool is a web map that summarizes HydroSource data relevant to new hydropower development, including data about existing hydropower assets, development potential at new stream reaches and non-powered dams, summarized environmental conservation layers, environmental mitigations for hydropower development, and hydrology and climate information (ORNL 2019).

### 6.1.6 Open Water Data Initiative

The Federal Geographic Data Committee (FGDC) and the Advisory Committee on Water Information (ACWI) launched the Open Water Data Initiative (OWDI) to integrate currently fragmented water information into a connected, national water data framework (ACWI 2019). OWDI seeks to leverage existing systems, infrastructure, and tools to streamline more effective innovation, modeling, data sharing, and solution development. In addition, OWDI includes efforts to promote the adoption of community data standards, protocols, and ontologies.

The OWDI is managed by the U.S. Department of the Interior, USGS, NOAA, and NOAA's NWS in partnership with other agencies and organizations, including the University of Texas, EPA, USACE. and USBR. While OWDI is supported and guided through the commitment of these agencies and partners, the ACWI and FGDC created the Subcommittee on Spatial Water Data (SSWD) as the effort's home base. The SSWD works to coordinate both federal and non-federal interests in spatial water data and includes more than 90 representatives of more than 30 organizations that span federal, state, and local governments, as well as industry leaders, nonprofit organizations, and academia.

The OWDI was launched in the summer of 2014 but was discontinued in late 2019. Efforts are under way to shift certain ODWI activities and interests to other initiatives.

### 6.1.7 Consortium of Universities for the Advancement of Hydrologic Science, Inc.

The Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) is a nonprofit research organization, founded in 2001, that represents more than 130 U.S. universities and international water science-related organizations. CUAHSI is funded by the National Science Foundation (NSF) and seeks to develop infrastructure and services for the advancement of water science in the United States (CUAHSI 2020).

CUAHSI builds, maintains, and hosts data tools and portals for improved data access, analysis, and collaboration. On their landing page visitors can browse data sets and tools developed by CUAHSI members. CUAHSI also houses two water data services: the Hydrologic Information System (HIS) and Hydroshare. Both tools give users access to data published by federal data providers, individual researchers, international governments, and citizen science groups.

The focus of HIS is on national and global time-series data about meteorology, groundwater, surface water, and water quality. Many of these data are viewable through the HydroClient web-map interface. Users can discover, download, and analyze environmental data from HydroClient, either on their local desktop or on the web-based HydroClient Workspace, using a personal Google account login. HIS is also a portal for data contributors to publish data either by requesting a database from CUAHSI or setting up their own server that is registered with the CUAHSI catalog.

The focus of Hydroshare is to provide an open-source, online collaboration environment for sharing data, models, and code. Users can collect and upload data and models and choose who has access to view them. Hydroshare automatically pulls available metadata from uploads and requires data providers to fill out a simple metadata form.

### 6.1.8 Internet of Water

The Internet of Water's (IoW's) mission is "… to build a dynamic and voluntary network of communities and institutions to facilitate the opening, sharing, and integration of water data and information" (NIEPS 2020). They intend to create this network by improving the connections between data producers, data hubs, and data users. In this way, IoW aims to provide a "backbone" structure like the Internet that provides support and governance structures to ongoing data sharing communities and connects these communities to one another.

IoW's focus is on creating an organizational structure to better connect existing data sources (currently those that are open access) and communities. This structure is centered around three key entities: data producers, data users, and data hubs. Data producers are entities that collect water data. In this role, data producers undertake both upfront capital costs and ongoing maintenance and operation costs. Data users are entities that create information and value from water data. Data users can assume costs in terms of resources spent discovering, accessing, and making data usable. Finally, data hubs are formalized, structure containers for managing and sharing data. Data hubs may import data published by data producers or they may be data producers themselves. These hubs bear costs to make data interoperable, including resources spent to build and manage data infrastructure.

The IoW project grew out of a 2017 dialog among a diverse stakeholder group led by NIEPS at Duke University, The Aspen Institute, and Redstone Strategy Group. The project officially began in 2018 and is managed by a small startup team currently housed at the Nicholas Institute. The project is supported by grants from philanthropic organizations. The IoW seeks to be a self-supported network funded by independent organizations by 2021.

### 6.1.9 The Nature Conservancy Natural Solutions Toolkit

As a global environmental nonprofit organization focused on water and land conservation, The Nature Conservancy (TNC) has been very active in developing data sets, visualizations, and tools for conservation outcomes. Its mission in these data support efforts is to make science-driven information accessible to public agencies, community members, and stakeholders alike. A particularly wide-ranging toolkit that TNC has developed in partnership with a diverse suite of global, regional, and local partners is the Natural Solutions Toolkit (TNC 2018). This spatial-based decision-support tool serves as a portal for a suite of web applications, many of which are tied to reports published by TNC. These applications include the Freshwater Network (TNC 2020c), Protecting Water Atlas (TNC 2020b), and the Natural Resource Navigator (TNC 2020a).

The Freshwater Network contains web-based tools that help users prioritize aquatic barriers for removal based on the greatest ecological benefit. The tools have mapping interfaces that allow users to explore, interact with, and customize data searches at various scales. The Freshwater Network also houses TNC's partnership with Research Triangle Institute International to model streamflow in Louisiana and Mississippi watersheds, as well as TNC's Water Quality Resource Inventory, which is focused on select watersheds in Louisiana. The Protecting Water Atlas is a global mapping tool that allows users to explore the benefits that watersheds can provide for improved water quality and quantity. It includes explorer apps focused on pollution reduction, water funds, and water scarcity to inform stakeholders where their investments would result in the greatest co-benefits. The Natural Resource Navigator allows users to explore data on natural resources throughout the state of New York, including explorers focused on current/future conditions of streams and freshwater flooding threats.

### 6.1.10 Open and Transparent Water Data Platform for California

In September 2016, the California legislature enacted *The Open and Transparent Water Data Act* (AB 1755), which charges state agencies with integrating currently fragmented water and environmental data systems to fulfill four primary goals: assuring that data are sufficient, accessible, useful, and used to support water resource management and address water resource-related questions (CDWR 2019a). Specifically, the California Department of Water Resources (CDWR), in cooperation with the California Water Quality Monitoring Council, State Water Resources Control Board, and California Department of Fish and Wildlife, must produce a strategic plan and protocol for data sharing, quality control, and documentation, and ultimately develop and operate a statewide water data platform. CDWR and its partner agencies are working to integrate the California Natural Resources Agency Open Data Platform (CNRA 2020) and the California Open Data Portal (GovOps 2020) to operate as a federated open data system.

As part of the implementation of AB 1755, a workshop series was held with engaged stakeholders and decision-makers to develop use cases to inform development of a decision-driven water data system (Cantor et al. 2018). A diverse set of 20 initial use cases was developed with examples such as planning a groundwater recharge project, managing water transfers, managing environmental flows to protect salmon habitat, contingency planning for water shortages, and investing capital in headwaters restoration (University of California Berkeley Law et al. 2017). Additional use cases continue to be developed.

In July 2019, several demonstrations were held for the two state-hosted open data portals. Ongoing efforts include a comprehensive data inventory of state water and ecological data sets, improvement of metadata documentation, and testing of the current data system to study how well the efforts address specific use cases (CDWR 2019b). The AB 1755 bill established the Water Data Administration Fund, which can receive voluntary contributions, but it did not include a funding appropriation. Therefore, consistent, long-term funding remains one of the effort's greatest challenges moving forward.

### 6.1.11 Wisconsin Department of Natural Resources

The Wisconsin Department of Natural Resources (WDNR) has developed several water data and information portals to improve access to and use of water data in the state, including the Gateway to Wisconsin's Basins and Watersheds, GIS Open Data Portal, and Surface Water Data Viewer.

The WDNR Gateway is intended to be a launching point to find out basic information about Wisconsin river basins and watersheds, including projects (e.g., dams, wildlife areas), monitoring stations, impaired waters, trout waters, and watershed and basin plans and maps (WDNR 2019). The WDNR GIS Open Data Portal is the state's primary location for downloading geospatial data developed or maintained by WDNR (WDNR 2017). The portal contains geospatial data for a broad range of categories, including water, fish and wildlife, managed lands, environmental protection, parks and recreation, forestry, transportation, indexes and Public Land Survey System, boundaries, and land cover/vegetation.

The WDNR Surface Water Data Viewer is a data delivery system that provides an interactive map tool for exploring a wide range of data sets related to water and sediment chemistry, physical, and biological data (WDNR 2020a). Some example layers include stream hydrography, watershed boundaries, monitoring sites for WDNR's Surface Water Integrated Monitoring System, statewide Fisheries Management Database Survey Sites, USGS gage stations, boat landings and access points, dam locations, FERC project area boundaries, floodplain data (including FEMA Flood Insurance Rate Map), EPA 303(d) Listed Impaired Waters, sediment inventory sites, mapped wetlands, ecoregions and vegetative cover, and political/administrative designations like Native American lands. Users can access data layers from a browser or select from different predefined map themes, develop maps for export, and obtain links to redirect to data sources. Additional features include drawing tools and the ability to upload the user's own georeferenced files. A complete inventory of data layers is also available through the Viewer (WDNR 2020b).

### 6.1.12 New England SusTainability Consortium

The New England SusTainability Consortium (NEST) is a regional research partnership—composed of researchers from Maine, New Hampshire, and Rhode Island—that aims to strengthen the scientific basis for decision-making concerning economic, environmental, and community development tradeoffs in New England (NEST 2018b). One of NEST's current initiatives is the Future of Dams Project, which aims to provide stakeholders with science to anchor decision-making about aging or failing dams (NEST 2018a).

NEST maintains a data repository and digital library called the Data Discovery Center (New Hampshire EPSCoR 2020), which provides free public access to the wide range of data sets generated by NEST research. The Data Discovery Center includes atmospheric, aquatic, and terrestrial sensor data, imagery, model results, and survey data. Data can be queried using a data set list or using an interactive map interface.

NEST has also developed The New England Dams Database (NEST 2019), an interactive map-based tool containing dam locations and their associated attributes for more than 7,000 dams in New England. The database aggregates data from the environmental state agencies in Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut, along with data from TNC's Northeast Aquatic Connectivity Tool, the NHDPlus, the USGS National Land Cover Database, and the American Rivers' Removed Dams Database. Each dam location captures an extensive list of data attributes, including variables like the original purpose of the dam, classification for dam hazard potential, distance from each barrier to the network mouth, maximum discharge, percent of developed open space land within the dam's watershed, and the state agency that has regulatory or approval authority over the dam. To supplement the data included in the database, The New England Dams Database Data Portal (NEST 2020) provides additional information to interpret dam attributes, including more detailed data descriptions, background information, and methodology.

The Future of Dams Project is currently supported in part by a $6 million, 4-year NSF Established Program to Stimulate Competitive Research (EPSCoR) grant. Details about future planned efforts or funding pathways were not available on the project website.

# 7.0 Investigative Pathways for Improving Discovery, Sharing, and Use of Water Data

During our interviews with stakeholders we solicited their feedback about potential pathways and challenges to improving the discovery, sharing, and use of water data. Stakeholders were presented with the concept of a hypothetical data platform designed to achieve improvements toward some, or all, of these aspects and asked to comment about the perceived need and value of such a resource. The purpose of this inquiry, and the entire interview process, was to help WPTO identify and make decisions about potential directions for future work.

From these discussions, two investigative pathways emerged that can be generally described as (1) further investigating the problem and value demonstration; and (2) envisioning solutions to improve data discovery. We believe these pathways, taken together in succession, provide a logical progression toward the project goal. The following sections provide a general description, rationale, and challenges for each of these pathways.

## 7.1 Pathway 1: Further Investigation and Value Demonstration

The first investigative pathway emphasizes conducting activities to better understand the range of issues surrounding discovery, sharing, and use of water data; better define target audiences and their needs; build more in-depth understanding of and connections to related efforts; and demonstrate the value of water data for the purpose of generating support among the water resources community and potential project partners. The goal of this pathway is to inform a decision to pursue activities under the second investigative pathway and refine those activities accordingly. The following sections provide the rationale for this pathway based on our interviews with stakeholders and briefly describe some of the key challenges to this pathway.

### 7.1.1 Rationale

While stakeholders generally thought the notion of a new platform for improving access to water data was valuable, many expressed uncertainties about its target audience and end-use(s), core capabilities, scope of data aggregation, custodianship, and funding sources. Some also expressed concerns about duplicating other efforts, particularly those with regional- or local-scale emphases that have high value to stakeholders in those areas. Some stakeholders did not view the disaggregated nature of water data as a major problem and noted that there are benefits to improving existing platforms that have more succinct missions, data sources, and end uses.

Stakeholders also expressed concern about generating support from the diverse community of water data users and producers. Some felt that a new platform would have to be better than existing tools to generate incentive, indicating it is important that we clearly identify and define the need before attempting to develop a new platform. Some also believed there would need to be a clear value proposition for users and producers to gain their participation. Several stakeholders acknowledged that improving access to data is a worthy effort but doing so was not paramount to building collaborative relationships because decision-making processes in river basins tend to be highly personal.

Opinions about the expressed need for aggregating disparate categories of water data varied among stakeholders and appeared to be related to their respective roles. Generally, those with well-defined and consistent data needs saw less value in aggregating disparate categories of water data than those whose data needs vary depending on the nature of their work.

### 7.1.2 Challenges

Our preliminary findings indicate that access and use of water data are affected by a complex range of technical and social and factors. While further investigation will help to understand these factors better, it may be challenging to identify which are most important for WPTO and its partners to address to achieve meaningful advances in improving access to water data. Improving access to water data is likely to require many solutions as opposed to one.

Demonstrating the value of improved access to water data without providing real examples of where or how access was improved is fundamentally challenging. In addition, improved access to data can be valued in multiple ways, e.g., time and cost savings, information gained, mutual benefits achieved. Future efforts to demonstrate the value of improved access to water data will need to consider these factors and be clear about the type of value they intend to demonstrate.

## 7.2 Pathway 2: Envision Solutions to Improve Data Discovery

The second investigative pathway involves developing a comprehensive vision for potential solutions to improve the discovery of water data. The focus on data discovery in this pathway, and not also sharing and use, is because it is seen as a precursor to addressing these other issues. The process of developing a comprehensive vision could include conducting extensive User Needs Analysis (UNA); identifying technological, sociological, and economic barriers; identifying potential research, development, and partnering pathways to resolving barriers; identifying critical investments and resources; and developing overarching timelines and benchmark achievements.

It is assumed this pathway is informed and justified by outcomes of the first pathway, including there being significant support among key water data users and producers. This pathway also assumes a major barrier to improving the accessibility and use of water data is the ability to discover the full breadth of data that exist for a river basin. The “breadth” of data applies to both the spatial and temporal dimensions of data sets, as well as the variety of disparate data across multiple categories. This pathway attempts to fill a unique niche by bringing together disparate categories of water data (see Table 2) to better support multi-objective, multi-stakeholder planning processes.

One possible trajectory of this pathway is developing a technical vision for an Information Management platform that is a central location for accessing a comprehensive set of water data in a river basin and directing users to official sources of those data. This approach acknowledges the value that independent and distributed platforms bring to improving access to water data and works to improve the discoverability of these resources among a more diverse community of stakeholders. This value is expected to grow as the number of independent platforms continues to grow.

A stretch goal for a new platform developed under this pathway is to develop the capability for users to publicize enriched data, i.e., data that have undergone some value-added process to contain or represent additional layers of objective information beyond the primary purpose of the original data. The intent of this capability is to promote sharing and transparency of water data that may have more direct applicability to decision-making.

### 7.2.1 Rationale

Many stakeholders indicated there could be value in creating a central resource for disparate types of water data, but they were cautious about duplicating other efforts. Some noted that existing water data platforms, particularly those with regional- or local-scale emphases, might be more valuable to and trusted by stakeholders in those areas because they are more likely to be designed with their input and needs in mind. However, some stakeholders who work primarily at national or regional scales noted that these resources can be difficult to find or work with for those who are not regularly engaged in basin-specific activities. Thus, some stakeholders suggested it may be appropriate to create a conduit that helps people connect with official sources of water data rather than duplicate dissemination of data. Some indicated that this conduit should focus on improving access to categories of water data that people have more difficulty finding (e.g., recreation, cultural resources, energy, socioeconomic).

This pathway considers the distributed nature of water data to be a positive aspect for several reasons. One reason is that it continues to foster independent efforts to provide open access to water data. These efforts help to serve as models for other aspiring efforts and enable initiatives at more local levels. Another reason is that it that keeps custodianship of data in the hands of the data producers. Pathway 2 also acknowledges that many users prefer to get data from sources with whom they are familiar and that these sources should not be replaced. Finally, Pathway 2 avoids some of the challenges associated with centralizing and redistributing data from disparate sources such as housing and maintenance burdens, creating secondary services and endpoints, reducing latency times, and mitigating discontinuities caused by versioning or interoperability issues.

### 7.2.2 Challenges

Pathway 2 has multiple challenges. First, generating buy-in from the broader community of water data users and producers may be challenging because the perceived need for this activity varies among members. From our conversations with stakeholders it was evident that the target audience of this pathway may be a narrower subset of the broader community. Demonstrating the value of this pathway with compelling use cases may help generate buy-in, although choosing among the many such possible use cases represents an added challenge. Better identifying the target audience for this pathway may help inform selection of appropriate use cases.

A second challenge is enabling improvement of discovery and sharing of proprietary data in a way that mitigates privacy concerns and is useful for multi-objective decision-making. A related issue is improving discovery of water data that are publicly available but not easily accessible.

A third challenge is assuring that resulting tools have relevancy at multiple scales. Some stakeholders expressed concern that a national-scale effort may inadequately incorporate or represent local-scale data, which is often critical in many decision-making processes in river basins.

Identifying an appropriate platform custodian is another significant challenge to developing a new resource for water data. Stakeholder views on this matter varied considerably; suggestions ranged from public agencies and national labs to collaborations with private organizations and universities. Some indicated that a consortium of these entities should work together as a governing body for such a platform. Similarly, some suggested the custodian(s) not be associated with a specific interest group.

Appropriate funding to design, develop, and maintain a new resource for water data is another important challenge to consider. This topic often came up in stakeholder interviews when discussing factors that may influence custodianship.

# 8.0 Conclusions and Suggested Future Work

This report is intended to give WPTO and other interested parties a better understanding of issues surrounding the accessibility, usability, and visualization of water data and help guide efforts to improve the discovery, sharing, and use of these data. Two investigative pathways are identified that are intended to provide a logical progression toward the project goals (see Section 7.0). Here, we suggest broad activities for future work that are based on the first investigative pathway. These activities are intended to inform the decision to pursue additional activities under the second pathway. Activities based on the second investigative pathway are not proposed at this time.

The first pathway involves conducting activities to better understand the range of issues surrounding discovery, sharing, and use of water data; better defining the target audience and their needs; building more in-depth understanding of and connections between related efforts; and demonstrating the value of water data to generate support. Efforts to determine which categories of water data and groups of water data users would benefit the most from improving the discoverability of water data are considered precursory to conducting a more detailed UNA. Conducting UNAs is a common practice for designing Information Management platforms, which is not proposed under this pathway.

Based on the direction of the first pathway, the following broad activities are intended to be undertaken:

- Continue outreach activities with water data users and producers, placing more emphasis on the latter, to broaden the perspectives presented here and better characterize the target audience and target data categories.
- Continue outreach activities with members of related efforts to better align our initiative and identify opportunities for collaboration.
- Develop a series of compelling online “data stories” based on a variety of use cases for water data that demonstrate the value of open access to diverse categories of water data and highlight some of the underlying challenges with the current state of discovering, accessing, and using water data.
- Conduct workshop(s) with national and regional stakeholders to gather feedback on the data stories and to assess the value of continuing efforts to improve discovery and access to water data.

Data stories can convey powerful messages by combining text, interactive maps, and other multimedia content. They are attractive for the purposes of this effort for several reasons. First, they represent a compelling way to highlight the process of acquiring information from disparate water data, either quantitatively or geographically, without having to build new software. In this sense, they can serve as illustrative examples of end-uses of a hypothetical platform designed to bring together disparate water data to help inform water-management issues in river basins. Second, data stories provide a great deal of design flexibility to users and they are easily shareable online. Finally, data stories provide a common approach for project partners to tell unique stories, which helps to tie them together to increase the overall impact of the project.

We propose using data stories to highlight a variety of use cases for water data in three regions of interest: California, Wisconsin, and New England. These regions were identified during the early planning phases of this project based on ongoing work by project partners and emerging issues that are of interest. The general plot structure for data stories will contain a description of the use case, description of data and information needs, discussion of relevant data resources and their accessibility, and visual depictions of key data sets and example information derivatives that are possible with fusion of disparate data. If successful, these data stories can hopefully help communicate the needs, complexities and opportunities related to water data access to diverse audiences, using real-world examples, and help to build a body of knowledge on which future actions to improve access to water data can be based.

# 9.0 References

AB 1755. *The Open and Transparent Water Data Act*. California Assembly Bill No. 1755, Chapter 506. 23 September 2016. Accessed 30 January 2020. Available at: https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1755.

ACWI (Advisory Committee on Water Information). 2019. “Open Water Data Initiative Overview.” Website. Accessed 30 January 2020. Available at: https://acwi.gov/spatial/owdi/.

American Whitewater. 2020. “National Whitewater Inventory.” Website. Accessed February 18, 2020. Available at: https://www.americanwhitewater.org/content/River/view/

BLM (U.S. Bureau of Land Management). 2019. “BLM Navigator - GIS Data.” Website. Access 27 January 2020. Available at: https://www.blm.gov/services/geospatial/GISData

CalFish. 2019. “California Fish Passage Assessment Database.” Website. Accesses 30 January 2020. Available at: https://www.calfish.org/ProgramsData/HabitatandBarriers/CaliforniaFishPassageAssessmentDatabase.aspx

Cantor A, Kiparsky M, Kennedy R, Hubbard S, Bales R, Pecharroman LC, Guivetchi K, McCready C, and Darling G. 2018. *Data for Water Decision Making: Informing the Implementation of California’s Open and Transparent Water Data Act through Research and Engagement*. AB 1755 Stakeholder Working Group Synthesis Report. Center for Law, Energy & the Environment, UC Berkeley School of Law, Berkeley, CA. 56 pp. Available at: https://doi.org/10.15779/J28H01.

CDWR (California Department of Water Resources). 2019a. “AB 1755: Open and Transparent Water Data Platform for California.” Website. Accessed 29 January 2020. Available at: https://water.ca.gov/ab1755.

_____. 2019b. “Open and Transparent Water Data Act – Implementation Journal.” Website. Accessed 29 January 2020. Available at: https://dwr.maps.arcgis.com/apps/MapJournal/index.html?appid=50323246e8d148a0a504038a0d40fb7f.

CNRA (California Natural Resources Agency). 2020. “California Natural Resources Agency Open Data.” Website. Accessed 29 January 2020. Available at: https://data.cnra.ca.gov/.

CUAHSI (Consortium of Universities for the Advancement of Hydrologic Science, Inc.). 2020. “What is CUAHSI?” Website. Accessed 27 January 2020. Available at: https://www.cuahsi.org/about/what-is-cuahsi/.

Duda JJ, Wieferich DJ, Bristol RS, Bellmore JR, Hutchison VB, Vittum KM, Craig, L, and Warrick JA. 2016. *Dam Removal Information Portal (DRIP)—A map-based resource linking scientific studies and associated geospatial information about dam removals*. U.S. Geological Survey Open-File Report 2016-1132, 14 p. Available at: http://dx.doi.org/10.3133/ofr20161132.

Eberts SM, Wagner CR, and Woodside MD. 2019, Water priorities for the Nation – The U.S. Geological Survey Next Generation Water Observing System: U.S. Geological Survey Fact Sheet 2019–3046, 2 p., https://doi.org/10.3133/fs20193046.

EPA (U.S. Environmental Protection Agency). 2020a. “EPA EcoBox Tools by Receptors – Endangered, Threatened, or Other Species of Concern.” Website. Accessed 21 February 2020. Available at: https://www.epa.gov/ecobox/epa-ecobox-tools-receptors-endangered-threatened-or-other-species-concern.

_____. 2020b. “Healthy Watersheds Protection.” Website. Accessed 18 February 2020. Available at: https://www.epa.gov/hwp.

_____. 2020c. “How’s My Waterway? Version 1.0.” Website. Accessed 18 February 2020. Available at: https://watersgeo.epa.gov/mywaterway/.

_____. 2020d. “Recovery Potential Screening.” Website. Accessed 18 February 2020. Available at: https://www.epa.gov/rps.

_____. 2020e. “Surf Your Watershed.” Website. Access 18 February 2020. Available at: https://www.epa.gov/waterdata/surf-your-watershed.

_____. 2020f. “WATERS GeoViewer.” Website. Access 18 February 2020. Available at: https://www.epa.gov/waterdata/waters-geoviewer.

_____. 2020g. “Watershed Index Online.” Website. Access 18 February 2020. Available at: https://www.epa.gov/wsio.

FAO (Food and Agricultural Organization of the United Nations). 2019. “AQUASTAT.” Website. Accessed 13 February 2020. Available at http://www.fao.org/aquastat/en/.

FEMA (Federal Emergency Management Agency). 2019. “FEMA Flood Map Service Center.” Website. Accessed 30 January 2020. Available at: https://msc.fema.gov/.

FGDC-SCD (Federal Geospatial Data Committee Subcommittee for Cadastral Data). 2008. “Authority and Authoritative Sources: Clarification of Terms and Concepts for Cadastral Data, Version 1.1.” Available at: http://nationalcad.org/download/Authority-and-Authoritative-Sources-Final.pdf. Accessed October 29, 2019.

GovOps (Government Operations Agency). 2020. “California Open Data Portal.” Website. Accessed 29 January 2020. Available at: https://data.ca.gov/.

Horizon Systems Corporation. 2012. “National Hydrography Dataset Plus version 2.” Website. Accessed 30 January 2020. Available at: http://www.horizon-systems.com/nhdplus/

MRLC (Multi-Resolution Land Characteristics Consortium). 2016. “National Land Cover Database.” Website. Accessed 30 January 2020. Available at: https://www.mrlc.gov/

NASA (National Aeronautics and Space Administration). 2019. “ORNL DAAC Hydroclimatology Collection.” Website accessed 28 Jan 2020. Available at: https://daac.ornl.gov/cgi-bin/dataset_lister.pl?p=10

National Water Quality Monitoring Council. 2019. “Water Quality Portal.” Website. Accessed 29 January 2020. Available at: https://www.waterqualitydata.us/

National Wild and Scenic River System. 2019. “National Wild and Scenic River System.” Website. Accessed 18 February 2020. Available at: https://www.rivers.gov/mapping-gis.php

NatureServe. 2019. “Conservation Tools & Services, Data & Maps.” Website. Accessed 18 February 2020. Available at: https://www.natureserve.org/conservation-tools/data-maps

NCAR (National Center for Atmospheric Research). 2019. "The Climate Data Guide: NLDAS: North American Land Data Assimilation System.” Website. Accessed 19 February 2020. Available at: https://climatedataguide.ucar.edu/climate-data/nldas-north-american-land-data-assimilation-system

NEST (New England SusTainability Consortium). 2020. “New England Dams Database.” Website. Accessed 29 January 2020. Available at: http://ddc-dams.sr.unh.edu/about/project_description/.

_____. 2019. “New England Dams.” Website. Accessed 29 January 2020. Available at: https://ddc-nedams.sr.unh.edu/.

_____. 2018a. “The Future of Dams.” Website. Accessed 29 January 2020. Available at: https://www.newenglandsustainabilityconsortium.org/dams.

_____. 2018b. “The New England Sustainability Consortium.” Website. Accessed 29 January 2020. Available at: https://www.newenglandsustainabilityconsortium.org/.

New Hampshire EPSCoR Program. 2020. “Data Discovery Center.” Website. Accessed 29 January 2020. Available at: https://ddc.unh.edu/.

NIEPS (Nicholas Institute for Environmental Policy Solutions). 2020. “Internet of Water.” Website. Accessed 27 January 2020. Available at: https://internetofwater.org/.

NOAA (National Oceanic and Atmospheric Administration). 2020. “The National Water Model.” Website. Accessed 30 January 2020. Available at: https://water.noaa.gov/about/nwm

_____. 2019a. “National Centers for Environmental Information.” Website. Accessed 30 January 2020. Available at: https://www.ncei.noaa.gov/

_____. 2019b. “National Weather Service Advanced Hydrological Prediction Service.” Website. Accessed 30 January 2020. Available at: https://water.weather.gov/ahps/rfc/rfc.php

_____. 2019c. “NOAA Fisheries Critical Habitat.” Website. Accessed 30 January 2020. Available at: https://ecos.fws.gov/ecp/report/table/critical-habitat.html

North Carolina Department of Environmental Quality. 2001. “Paddle Trails – Coastal Plain”. Website. Accessed 30 January 2020. Available at: https://www.nconemap.gov/datasets/coastal-plain-paddle-trails-points.

NPS (National Park Service). 2020a. “Acadia National Park, Maine: Cultural Resources.” Website. Accessed 17 February 2020. Available at: https://www.nps.gov/acad/learn/management/rm_culturalresources.htm

_____. 2020b. “Nationwide Rivers Inventory.” Website. Accessed 18 February 2020. Available at: https://www.nps.gov/subjects/rivers/nationwide-rivers-inventory.htm

_____. 2019. “National Register of Historic Places.” Website. Accessed 21 February 2020. Available at: https://www.nps.gov/subjects/nationalregister/index.htm.

ODFW (Oregon Department of Fish and Wildlife). 2019. “Natural Resources Information Management Program Fish Barrier Data.” Website. Accessed 30 January. Available at: https://nrimp.dfw.state.or.us/nrimp/default.aspx?pn=fishbarrierdata

Opperman JJ, Royte J, Banks J, Day LR, and Apse C. 2011. The Penobscot River, Maine, USA: a basin-scale approach to balancing power generation and ecosystem restoration. *Ecology and Society* 16(3).

ORNL (Oak Ridge National Laboratory). 2019. “HydroSource.” Website. Accessed 27 January 2020. Available at: https://hydrosource.ornl.gov/.

Ostroff A, Wieferich D, Cooper A, Infante D, and USGS Aquatic GAP Program. 2013. “2012 National Anthropogenic Barrier Dataset (NABD).” U.S. Geological Survey – Aquatic GAP Program, Denver, CO. Accessed 30 January. Available at: https://www.sciencebase.gov/catalog/item/56a7f9dce4b0b28f1184dabd.

OSU (Oregon State University). 2020. “PRISM Climate Data.” Website. Accessed 19 February 2020. Available at: http://www.prism.oregonstate.edu/

Pegram G, Li Y, Quesne TL, Speed R, Li J, and Shen F. 2013. River basin planning: Principles, procedures and approaches for strategic basin planning. Paris, UNESCO. https://www.gwp.org/globalassets/global/toolbox/references/river-basin-planning.pdf

Public Law 114-322, S.612. *Water Infrastructure Improvements for the Nation Act or the WIIN Act*. 114th United States Congress (2015-2016). Accessed 25 February 2020. Available at: https://www.congress.gov/bill/114th-congress/senate-bill/612.

SARP (Southeast Aquatic Resources Partnership). 2020. “Southeast Aquatic Resources Partnership.” Website. Accessed 30 January 2020. Available at: https://southeastaquatics.net/

Saulsbury JW, Geerlofs SH, Cada GF, and Bevelhimer MS. 2010. *Basin-Scale Opportunity Assessment Initiative: Background Literature Review.* Oak Ridge National Laboratory Technical Report ORNL/TM-2010/291. 56 p. Available at: https://www.osti.gov/biblio/1001301.

TNC (The Nature Conservancy). 2020a. “Natural Resource Navigator.” Website Accessed 18 February 2020. Available at: http://www.naturalresourcenavigator.org/

_____. 2020b. “Protecting Water Atlas.” Website. Accessed 18 February 2020. Available at: https://maps.protectingwater.org/#.

_____. 2020c. “The Freshwater Network.” Website. Accessed 18 February 2020c. Available at: https://freshwaternetwork.org/.

_____. 2019. “Northeast Conservation Planning Atlas.” Website. Accessed 30 January 2020. Available at: https://nalcc.databasin.org/.

_____. 2018. "Natural Solutions Toolkit." Website. Accessed 18 February 2020. Available at: https://coastalresilience.org/natural-solutions/toolkit/.

TWDB (Texas Water Development Board). 2016. "Socioeconomic Impact Analysis." Website. Accessed 14 February 2020. Available at: http://www.twdb.texas.gov/waterplanning/data/analysis/index.asp

University of California Berkeley Law, UC Water, and California Council on Science and Technology. 2017. "Data for Water Decision Making: Compilation of Stakeholder-Developed Use Cases." Website. Accessed 29 January 2020. Available at: https://www.law.berkeley.edu/wp-content/uploads/2018/01/DFWD-Use-Cases.pdf.

USACE (U.S. Army Corps of Engineers). 2019. "USACE Recreation Areas." Website. Accessed 27 January 2020. Available at: https://catalog.data.gov/dataset/usace-recreation-areas.

_____. 2018a. "Access to Water Resources Data." Website. Accessed 27 January 2020. Available at: http://water.usace.army.mil.

_____. 2018b. "National Inventory of Dams." Website. Accessed 27 January 2020. Available at: https://nid.sec.usace.army.mil/.

USBR (U.S. Bureau of Reclamation). 2018. "Reclamation Water Information System." Website. Access 27 January 2020. Available at: https://water.usbr.gov/.

USDA (U.S. Department of Agriculture). 2020. "Natural Resource Conservation Service Snow Telemetry (SNOTEL) and Snow Course Data and Products." Website. Accessed 30 January 2020. Available at: https://www.wcc.nrcs.usda.gov/snow/

USFWS (U.S. Fish and Wildlife Service). 2019. "ECOS Environmental Conservation Online System." Website. Accessed 30 January 2020. Available at: https://ecos.fws.gov/ecp/report/table/critical-habitat.html

USGS (U.S. Geological Survey). 2020a. "National Hydrography Dataset." Website. Access 30 January 2020. Available at: https://www.usgs.gov/core-science-systems/ngp/national-hydrography/national-hydrography-dataset.

_____. 2020b. "National Water Census Data Portal." Website. Accessed 19 February 2020. Available at: https://cida.usgs.gov/nwc/.

_____. 2020c. "USGS Dam Removal Information Portal (DRIP)." Website. Accessed 21 February 2020. Available at: https://www.sciencebase.gov/drip/.

_____. 2019a. "Next Generation Water Observing System: Delaware River Basin." Website. Accessed 27 January 2020. Available at: https://www.usgs.gov/mission-areas/water-resources/science/next-generation-water-observing-system-delaware-river-basin?qt-science_center_objects=0#qt-science_center_objects.

_____. 2019b. "Next Generation Water Observing System: Headwaters of the Colorado and Gunnison River Basin." Website. Accessed 27 January 2020. Available at: https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/atoms/files/UCOL-BriefingSheet%20final.pdf.

_____. 2019c. “Protected Areas Database.” Website. Accessed 27 January 2020. Available at: https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap/science/protected-areas

_____. 2019d. “USGS Next Generation Water Observing System (NGWOS).” Website. Accessed 27 January 2020. Available at: https://www.usgs.gov/mission-areas/water-resources/science/usgs-next-generation-water-observing-system-ngwos?qt-science_center_objects=0#qt-science_center_objects.

_____. 2019e. “USGS Water Data for the Nation.” Website. Accessed 27 January 2020. Available at: https://waterdata.usgs.gov/nwis.

_____. 2018. “USGS Water Use Data for the Nation.” Website. Access 15 February 2020. Available at: https://waterdata.usgs.gov/nwis/wu.

_____. 2017. “National Watershed Boundary Dataset.” Website. Accessed 14 January 2020. Available at https://www.usgs.gov/core-science-systems/ngp/ngtoc/watershed-boundary-dataset

_____. 2014. “National Water Information System.” Website. Accessed 27 January 2020. Available at: https://waterdata.usgs.gov

Water Education Foundation. 2009. “The Lower Yuba River Accord: From Controversy to Consensus.” Water Education Foundation, Sacramento, CA. 23 p. Available at: https://www.yubawater.org/DocumentCenter/View/84/Lower-Yuba-River-Accord-PDF?bidId=.

*Water Infrastructure Improvements for the Nation Act of 2016*. Public Law No: 114-322…?

*Water Resources Development Act of XXXX*, as amended. Public Law…?

WDNR (Wisconsin Department of Natural Resources). 2020a. “Surface Water Data Viewer.” Website. Accessed 29 January 2020. Available at: https://dnr.wi.gov/topic/surfacewater/swdv/.

_____. 2020b. “Surface Water Data Viewer (SWDV): Data List and Descriptions.” Website. Accessed 29 January 2020. Available at: https://dnr.wi.gov/topic/SurfaceWater/swdv/datalist.html.

_____. 2019. “Gateway to Wisconsin’s basins and watersheds.” Website. Accessed 30 January 2020. Available at: https://dnr.wi.gov/topic/Watersheds/basins/.

_____. 2017. “WiDNR Open Data.” Website. Accessed 30 January 2020. Available at: https://data-wi-dnr.opendata.arcgis.com/.

_____. 2015. “Dams Overview.” Website. Accessed 18 February 2020. Available at: https://dnr.wi.gov/topic/Dams/DamsOverview.html.

WSDOT (Washington State Department of Transportation). 2020. “Fish Passage Inventory.” Website. Accessed 31 January 2020. Available at: http://geo.wa.gov/datasets/084325b33b0d49a7846cc46a19f38fdc_4

# Appendix A

## Example Data Sources

| Category | Data Sources |
| --- | --- |
| Dams | National Inventory of Dams<br>ORNL Hydrosource |
| Ecology | EPA EcoBox<br>MRLC National Land Cover Database<br>NatureServe<br>NMFS Critical Habitat<br>ORNL Hydrosource<br>USFWS Critical Habitat |
| Flood Control | FEMA Flood Zone Maps<br>National Inventory of Dams |
| Hydroclimatology | NASA Hydroclimatology Archive<br>NCAR North American Land Data Assimilation<br>NCEI Hydroclimatology Datasets<br>PRISM |
| Hydrography | National Hydrography Dataset<br>USGS Water Data for the Nation<br>USGS Watershed Boundaries |
| Surface Water & Groundwater Hydrology | National Hydrography Dataset<br>NOAA National Water Model<br>NOAA National River Forecast Center<br>SNOTEL<br>USGS Next Generation Water Observation System<br>USGS Water Data for the Nation |
| Hydropower | National Inventory of Dams<br>ORNL Hydrosource |
| Management Landscape | EPA Healthy Watersheds<br>USBLM Land Ownership Viewer<br>USGS Protected Areas Database |
| Migratory Barriers | Calfish<br>National Anthroprogenic Barriers Dataset<br>Oregon Department of Fish & Wildlife Fish Barriers Dataset<br>South Aquatic Resources Partnership<br>TNC Northeast Conservation Planning Atlas<br>Washington Department of Transportation Fish Passage Inventory |
| Recreation/ | American Whitewater National Whitewater Inventory |

| Category | Data Sources |
|---|---|
| Aesthetic Importance | NC OneMap<br>NPS Nationwide River Inventory<br>USGS Protected Areas Database<br>Wild and Scenic Rivers |
| Socioeconomic | NPS National Register of Historic Places Database<br>Texas Socioeconomic Impact Analysis<br>Food and Agriculture Organization of the United Nations AQUASTAT |
| Water Availability and Use | USGS National Water Census |
| Water Quality | CA Groundwater Data<br>EPA How's My Waterway<br>EPA Recovery Potential Screening<br>EPA WATERS Viewer<br>EPA Watershed Index Outline<br>USGS National Ground-Water Monitoring Network<br>USGS Water Data for the Nation<br>Water Quality Portal |
| Weather | National Centers for Environmental Information<br>National Weather Service |

**Pacific Northwest National Laboratory**

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354
1-888-375-PNNL (7665)

***www.pnnl.gov***