Nicholas Institute for
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Creating Data as a Service for U.S. Army Corps of Engineers Reservoirs

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CONTENTS

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Review
The work reported in this publication benefited from review from experts in the field.

SUMMARY

In the United States, our water data infrastructure does not allow us to consistently and quickly answer the most basic questions about our water system's quantity, quality, and use. The data to answer those questions are often collected but by multiple agencies across different scales and for different purposes, making them difficult to access, to integrate with other data, and to put to further use to support decision making. Even within single agencies, data are often not shared among regional offices, and even if they were, they would have to be standardized to be of use.

One huge repository of water data is the U.S. Army Corps of Engineers. Through a federated governance structure—whereby each region has its own political authority, management, and data—the Army Corps manages day-to-day operations. These operations, and their relevant data systems, are handled by 36 districts in the conterminous United States.

This report describes the challenges of and opportunities for integrating districts' historic reservoir data and management operations. It finds that historic reservoir data are open and accessible for 51% of districts. Those data account for 65% of reservoirs identified as owned and operated by the Army Corps. However, each district uses its own data formats, standards, and terms. Data infrastructure investments would be required to create additional insights for decision making—for example, to enable the Army Corps to understand how the nation's reservoirs are responding to stressors such as climate change. Such investments would also help the Army Corps increase the transparency of its reservoir operations.

A companion tool to visualize data related to this report is available at https://nicholasinstitute.duke.edu/reservoir-data/. The data are available for download in CSV format but are provisional, extend only to September 30, 2015, and have not been vetted by the Army Corps.

INTRODUCTION

In the United States, water data have been collected by multiple federal, state, and local agencies for decades, yet we are still unable to answer fundamental questions about our water systems in a timely way: How much water is there? What is its quality? How is it used (withdrawn, consumed, or returned)? Because the data have been collected by different agencies, for different purposes, at different scales, and are scattered across multiple platforms with different standards, they are rarely used to support real-time decision making or to develop an in-depth understanding of entire watersheds.

The U.S. Army Corps of Engineers (Army Corps), like many federal agencies, has a tiered, federated governance structure whereby 36 districts located within 7 divisions in the conterminous United States have their own political authority, management, and often data systems. The tiered structure has enabled the Army Corps to develop expertise to accommodate regional differences in climate and geography in project planning and implementation, but it has also meant that each district has developed its own data system with different formats, standards, and accessibility.[1] To become widely usable, the data must be standardized and made accessible.

This report describes the process and challenges of integrating individual districts' data on Army Corps-owned and -operated reservoirs, which may not always be meeting the goals for which they are authorized and designed because of post-construction changes in environmental conditions (e.g., climate change and sediment yield) and societal conditions (e.g., water and energy demand and minimum flows).

The effort resulted in three findings.

First, there are large gaps in the online availability of historic reservoir data. Only 51% of districts currently provide historic reservoir data online. Those data account for 65% of reservoirs identified as owned and operated by the Army Corps. To guide decision making to efficiently address the impacts of changing conditions on reservoir operations, the Army Corps should update its list of baseline data (elevation, storage volume, inflow, outflow, evaporation, precipitation, and so on) that must be collected and reported, and it should specify the format of that data.[2]

Second, making the Army Corps' reservoir data interoperable (accessible and usable beyond the purpose for which they were originally collected) will require significant effort given that data formats, standards, and terminology vary from district to district.

Third, the benefits of doing so are worth that effort. By creating a single Corps-wide data system with standardized data and terminology, the Army Corps could do the following:

- Lessen confusion about how to interpret its data.
- Reduce the costs of gathering data for internal studies and allow development of analytical tools applicable to all district reservoirs, potentially providing new insights and strategies to address water resource challenges.

[1] Fragmented data systems are not a problem unique to the federal government. State and local agencies (e.g., counties or municipalities) also have their own data systems.
[2] The Management of Water Control Data Systems was last updated in 1994 (USACE 1994a), prior to the data revolution.

- Increase trust in the Army Corps' reservoir management by making that management more transparent.
- Make its data usable by other agencies at all levels of government and by other organizations and individuals.

On the basis of the data integration effort detailed in this report, Patterson and Doyle (2018) have demonstrated the value of integrated data by developing consistent metrics to assess reservoir performance in terms of meeting management goals. Understanding the drivers of systematic operational departures requires making additional data—including climate, population, water use, land cover, and sediment—interoperable.

THE SLOW DATA REVOLUTION FOR WATER

Making Data Open Offers Benefits and Presents Challenges

The amount of data of all kinds has grown exponentially in the past decade and is expected to double at least every two years (Ffoulkes 2017). Water resources data are experiencing a similar expansion with the development of new satellites and low-cost sensors and through the efforts of citizen scientists (Grossman et al. 2015). Much of those data are collected to meet a particular mission or regulatory requirement, and rarely are they shared or integrated. Consequently, the usefulness of the data beyond their original collection purpose is limited (Patterson et al. 2017).

Before data can be shared they must be open, meaning freely available, accessible, and machine readable. Open data are not only more efficiently shared among agencies but are also less costly to obtain. The result is improved public engagement, economies of scale for analytics, and increased business and economic development opportunity (Schrier 2014). For example, the private sector has used public road infrastructure data coupled with global positioning systems to produce transportation apps and climate satellite data to create weather apps that greatly benefit the public sector (Patterson et al. 2017).

Making data open does present technical and institutional challenges, some of which are well-illustrated in the public health sector (van Panhuis et al. 2014). Overcoming these challenges is an important step to sustainably managing water resources. Currently, fundamental questions about the quantity, quality, and use of water within river basins cannot be answered in a timely way (Patterson et al. 2017). As suggested above, the data to answer these questions often exist, but they may not be open or easily integrated between platforms, creating significant use constraints. Sharing and integrating water data will make agencies better situated to address prevalent water problems ranging from extreme flooding, scarcity, and contamination as well as better equipped to restore aquatic systems.

The Value of Open Water Data Has Not Been Quantified and Communicated

Data are necessary for federal agencies and inter-agency leadership to make informed decisions, assess the impacts of changing conditions (e.g., climate, population), and maximize the future value of existing water infrastructure projects (IWR 2016). However, federal and state agencies have struggled to make real-time use of the rapidly growing volume and variety of data. Much publicly held water resources data (such as quantity, quality, and use) are only beginning to be shared and standardized (Grossman et al. 2015).

In 2016 and 2017, the Aspen Institute convened a series of stakeholder meetings to address the institutional barriers to sharing and integrating water data with the goal of more sustainably managing our water resources (Patterson et al. 2017). One of the main findings was that the value of open, shared water data has not been widely quantified or communicated. Therefore, public agencies cannot anticipate the potential return on investments to improve their data infrastructure—investments often viewed as a low priority given other pressing needs. Moreover, that return typically accrues to data users, whereas its costs typically are borne by data producers. Addressing this mismatch is necessary to meaningfully open up the large amounts of public data held by local entities (Patterson et al. 2017).

A second finding was that before data can be shared and integrated, they must be open—that is, machine readable, discoverable, and complete with metadata. There was agreement within the Dialogue that the initial priority should be to focus on data already collected and managed by public agencies for public purposes. Federal data are public data, and making federal data open was the subject of the 2013 executive order "Making Open and Machine Readable the New Default for Government Information."[3] This order required federal agencies to support downstream dissemination activities for all new information created and collected.[4] Once these data are shared and integrated, data from non-governmental sources (e.g., citizen science, crowd sourcing) can be incorporated with them to create a more holistic, real-time understanding of the quantity, quality, and use of water within a watershed.

THE OPEN WATER DATA INITIATIVE

In line with the executive order, the federal government has made efforts to open water data. In 2014, the Open Water Data Initiative (OWDI) was launched through the Advisory Committee on Water Information in a joint partnership with the Federal Geographic Data Committee. The goal of OWDI is to improve access to data and to enable the open exchange of water information to address the increasing pressure of climate change, particularly increased extremes in flood and drought. In 2016, amid a five-year drought in the western United States, the White House issued the Long-Term Drought Resilience Plan, which prioritized cross-agency data collection and integration to strengthen decision making and support adaptive responses to drought and drought risk. Several decision support tools have been created that provide access to data while informing the public about the impact of drought on water resources (https://cida.usgs.gov/ca_drought/ and https://www.doi.gov/water/owdi.cr.drought/en/). In 2014, OWDI launched the National Flood Interoperability Experiment to demonstrate capacity to integrate precipitation forecasts with hydrologic modeling to improve flood forecasts. From this project was born the National Water Model, hosted by the National Oceanic and Atmospheric Administration (NOAA), which simulates observed and forecasted streamflow across the entire continental United States (http://water.noaa.gov/).

Much of the data used in the National Water Model comes from agencies that have already developed their own data portals. The United States Geological Survey (USGS) provides open access to data from

[3] At least three executive orders from 2013 require the Army Corps to open and integrate its reservoir data. First, there is the aforementioned executive order to make open and machine-readable data the new default for government information. The second executive order, Federal Leadership in Environmental, Energy, and Economic Performance, required federal agencies to evaluate the risk and vulnerabilities of all projects and mission areas to climate change in both the short and long term (Llewellyn and Vaddey 2013). The third executive order, Preparing the United States for the Impacts of Climate Change, required agencies to engage in partnering and information sharing, to support risk-informed decision making and associated tools, and to incorporate adaptive learning into management strategies.

[4] Federal water management agencies have been developing mechanisms for making their data more open. For example, Project Open Data Dashboard (https://labs.data.gov/dashboard/offices) tracks the progress of federal agencies in opening their data. Thus far, it has inventoried 22 federal agencies holding 61,288 datasets, of which 90.4% are classified as public datasets with file downloads. Many of these datasets are located on the U.S. government's open data portal (www.data.gov), which currently has more than 192,322 datasets within the database. A keyword search for "water" returned 58,476 datasets, of which 93% are from the federal government (April 20, 2016).

its water gages through the National Water Information System (http://waterdata.usgs.gov/nwis), which incorporates data from thousands of water gages from the late 1800s to the present. NOAA provides weather and climate data, both raw data as well as modeled and forecasted data (http://www.ncdc.noaa.gov/data-access).

Other agencies have come together to create data portals containing data from a variety of sources. For example, the National Water Quality Monitoring Council provides water quality data collected by more than 400 state, federal, tribal, and local agencies through a single portal (http://waterqualitydata.us/portal/). Agencies submit their data to the Water Quality Portal (WQP) using the Water Quality Exchange (WQX) schema, which is a common data model that facilitates data integration and quality assurance. The portal makes the participating agencies data available to the public without transferring ownership of the data to another organization (Blodgett et al. 2016). Another example is the National Ground-Water Monitoring Network (NGWMN) (http://cida.usgs.gov/ngwmn/index.jsp). NGWMN retrieves data from its data sources and aggregates the different formats on the fly before transmitting them to the data portal. This model is relatively user friendly for data providers, who do not have to adopt a particular software or schema to be part of the network (Blodgett et al. 2016).

Importance of Developing Approaches and Protocols for Standardizing and Integrating Water Data

The aforementioned federal programs have been active in integrating data *across* agencies. In many cases, however, data have yet to be integrated *within* federal agencies because these agencies have a federalist organizational structure: political authority, management, and often data are handled separately by each U.S. region. For example, the Environmental Protection Agency has 10 regional offices, the Bureau of Reclamation has 5 regions and 7 regional offices in the western United States, the National Resources Conservation Service (NRCS) has 11 national centers spread over 4 regions with offices in each state, and the United States Army Corps of Engineers has 9 divisions and 43 districts managing day-to-day operations. This federalist structure has often led to very different approaches to organizing data of similar types within an agency. Because this is a challenge across multiple agencies, including state agencies (e.g., counties or municipalities within a state), it is important to develop approaches and protocols for standardizing and integrating water data. Water transcends political boundaries, requiring effective governance of water-related issues (quantity, quality, and use) at the scale of the watershed or river basin of interest (Newig and Fritsch 2009; Gerlak 2006; Hooghe and Marks 2003). Data needs to be shared and integrated at a similar scale to holistically manage the water system.

Challenges and Opportunities of Open, Integrated Data: Case Study of the Corp of Engineers

The National Resource Council (NRC 2004) recommended that federal water agencies monitor operations to adjust to new information, environmental changes, and changing regulations. The Army Corps is the predominant steward of waterways and reservoir systems across the United States, providing navigation, flood risk reduction, hydropower, recreation, and water supply (Pinson et al. 2016). Until recently, the Army Corps had no centralized database containing historic records of reservoir levels, flows, or operations. Thus, it had not been able to develop a systematic, nation-wide analysis of the impacts of changing conditions on reservoir operations. The Army Corps is now integrating these data and providing the most recent data (within the last five days) through the Access to Water Resources Data – Corps Water Management System (CWMS) Data Dissemination tool (https://water.usace.army.mil). The Army Corps has coalesced these data through inquiries to each district (IWR 2016). In cooperation with the Army Corps, we developed a national reservoir database of historic reservoir data and the Army Corps' management goals using primarily data that were open and available as of 2015. We were not able to automate our approach, because district websites have changed from the start of this project in 2013 (preventing us to scrape data) and in some instances the district had to provide the data directly (because they were not available online).

This report describes the challenges and opportunities of integrating currently open but disparate data from a single public water resource management agency. Specifically, we collected and integrated daily reservoir data from the 36 Army Corps districts located within the conterminous United States. The effort of integrating data within a single public agency highlights the types of decisions that need to be made to standardize data and the challenges associated with data integration as well as the potential opportunities of such efforts. For example, this dataset can be used to assess the performance of Army Corps reservoirs relative to operational targets—that is, management goals for reservoir levels over time (Patterson and Doyle 2018) and identification of those reservoirs whose operations are particularly sensitive to changing climate, environmental, or societal conditions. The results of such a synthesis are dependent on the underlying data, which were not originally collected for that purpose; thus, it is important to have good metadata to understand relevant decisions, limitations, and caveats.

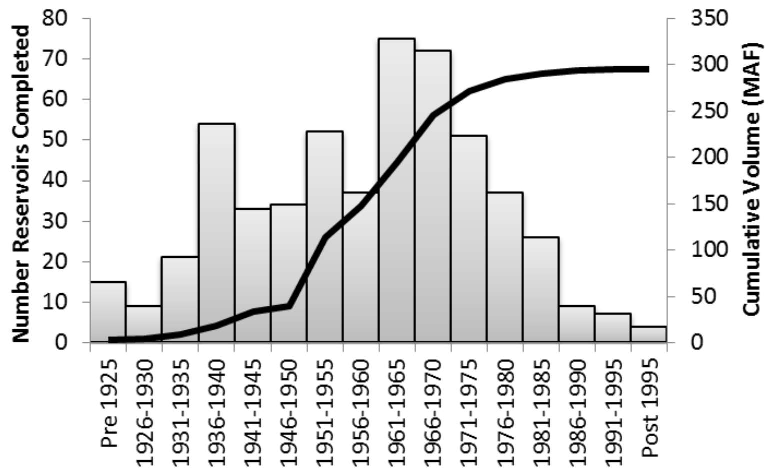
THE ARMY CORPS' FEDERALIST STRUCTURE FOR RESERVOIR OPERATIONS AND DATA MANAGEMENT

The Army Corps has operated as a tiered, federalist system since its inception in the 19th century (GAO 2010). The top tier is the Army Corps headquarters, which is primarily responsible for the development of policies and plans that set the direction of the entire organization. In the conterminous United States, 7 regional divisions are responsible for coordinating projects among 36 districts, which are responsible for planning and implementing projects approved by the division and headquarters (GAO 2010) (Figure 1). Individual projects, including reservoirs, are operated and managed at the district level. The tiered structure has enabled the Army Corps to develop expertise to accommodate regional differences in climate and geography in its project planning and implementation. However, this tiered structure has also allowed development of an autonomous culture in each district (GAO 2010). That culture is beneficial to address region-specific issues, but it also has led each district to develop its own data system with the result that data formats, standards, and accessibility differ from region to region.

Figure 1. Army Corps divisions and districts within the conterminous United States

Tremendous technological shifts occurred during the time period in which most Army Corps reservoirs were constructed (Figure 2). For instance, the first computer was created in 1946, at which point 132 reservoirs were completed. The first personal computer was invented in 1975 (442 reservoirs). The internet did not come online commercially until the 1990s, after 98% of currently operating reservoirs were already constructed. Thus, an open, integrated national water system for the Army Corps and other federal agencies are, by necessity, an afterthought.

Figure 2. Number of Army Corps-constructed reservoirs (bars) and their cumulative storage volume (line)



Each district's data system has evolved considerably with technological advancements; most districts transitioned to electronic formats by the early 1990s (IWR 2016). For example, prior to 1979, data for the Tulsa District were provided as graphs; between 1979 and 1994, the data were provided in pdf tables; and after 1994, the data were digital and provided online. This accumulation of data formats and technology, occurring commensurately with reservoir construction and operation, is one of the central challenges to data integration. And it is important to recognize that the Army Corps is not unique; other data systems have developed concurrently with changes in science, technology, and policy (e.g., water quality measurement techniques to meet EPA standards and policies).

Transforming disparate data and integrating them into a database with an online platform requires resources, financial and human. Although many federal agencies recognize the value of data, obtaining the necessary resources has been challenging. The Army Corps has been unable to obtain adequate funding for new projects, let alone maintenance and operation of existing infrastructure (GAO 2010). [5] Typically, data management and new data integration programs receive lower priority than traditional projects, thus reducing available funding. Overall, the Army Corps experienced a 21% decrease in allocations for staff between 1980 and 2009 (GAO 2010), limiting human resources to take on additional work.

[5] Civil work funds for the Army Corps are appropriated for specific projects, and when funding is not obtained, the projects go on standby (GAO 2015). The most recent Water Resources Development Act (WRDA 2014) established new procedures in sections 6001 and 6003 to manage the backlog of uncompleted work and removed those projects with an authorization data prior to November 8, 2007, that have received no federal funding. Several water control manual updates and reallocation studies have not taken place due to funding constraints (GAO 2015).

OPEN DATA MODELS

The OWDI identified four conceptual models that the Army Corps could adopt as it moves toward a shared and integrated reservoir database: data catalog, data as a service, data enrichment, and a community of practice (Blodgett et al. 2016). The conceptual models are described below and then applied to the Army Corps in subsequent sections.

Water Data Catalog

The data catalog approach is akin to the data.gov clearinghouse approach of listing and providing links to data: it focuses on making data discoverable. Searching for "Army Corps of Engineers" resulted in 994 datasets (1,372 datasets for "Corps" and 700 for "USACE"); the majority of these datasets are static data such as boundaries for divisions and districts and individual project sedimentation studies (April 2017). A search for "water" turned up one dataset linked to the Army Corps (Major Dams of the United States).

Data discoverability is a primary tenant of open data (Patterson et al. 2017), and that discoverability is dependent on standardizing keywords and tags associated with different datasets and agencies. The data catalog approach would likely be the most cost-efficient because several districts already provide their data online. The Army Corps could simply make a list of districts websites at which users can locate historic reservoir data. Additionally, some districts would need to first make this data open and available. This list would need to be updated when links change. The downside to this approach is that districts provide data in different formats and downloads (all data in one download, monthly downloads, and so on). Acquiring and formatting reservoir data across many districts require significant effort. The benefits of having the data accessible through a data catalog would be limited because the user would need to collect, standardize, and format the data from multiple sources prior to using the data. A common lament at the 2016–2017 Aspen Institute stakeholder meetings on sharing and integrating data was that analysts within companies spend the majority of their time gathering, formatting, cleaning, and estimating missing data; only a small fraction of time is spent on converting that data into information and insights.

Water Data as a Service

Data as a service means providing data in a way that they are usable to analysts and developers, just as the above-described water quality and groundwater portals do. Data for all reservoirs would be provided in a single location, would be consistently formatted, and would be ready for use.

The Army Corps will almost certainly need a service approach to understand how reservoirs are responding to changing conditions. Since the start of this project (2013), the Army Corps has released two ongoing efforts at creating data as a service. RiverGages (http://rivergages.mvr.usace.army.mil) provides the water levels of rivers and lakes across the United States; however, the data available at sites ranges from the full record, to a few years, to no data, and each data component needs to be downloaded separately (i.e., lake levels would be one download, inflow, another). The CWMS Data Dissemination tool (http://water.usace.army.mil/) provides information on reservoir characteristics and recent (last five days) water levels, storage, and flow (as of April 2017). The public version of this tool serves mostly as a means of communication and short-term decision-making.

Water Data Enrichment

Enriching data means linking the data to hydrologic networks, models, and other relevant data sources through a geospatial framework. Reservoirs are complex systems that are influenced by climate, land use change, water demand, policies, and decisions made upstream and downstream of a reservoir. Building a comprehensive picture of a reservoir requires pulling data together from multiple sources. An example of enriching data would be the National Water Model (http://water.noaa.gov/) linking together precipitation forecasts (NOAA), stream gage data (USGS), and stream networks (National Hydrology Dataset) to predict water volumes in streams across the United States. Another example would be the USGS development of SPARROW, which models in-stream water quality measurements with watershed characteristics to predict the origin and fate of contaminants in river basins (https://water.usgs.gov/nawqa/sparrow/). The EPA has also moved toward enriching water data; for example, the Climate Resilience Evaluation and Awareness Tool (CREAT) pulls a variety of climate information together to provide decision support to utilities through construction of scenarios of potential climate conditions (temperature, precipitation, extreme events, and sea-level rise) (https://www.epa.gov/crwu/build-resilience-your-utility). The EPA has also developed EnviroAtlas (https://www.epa.gov/enviroatlas), an interactive resource that allows users to discover, analyze, and download a variety of data and tools. The Army Corps provides two public tools, a sea-level change calculator and climate-impacted hydrology, as part of its effort to proactively address climate change (http://www.corpsclimate.us/ptcih.cfm).

Building a Water Data Community

Building a water data community means creating an environment in which data users and analysts can operate within one platform, sharing knowledge, papers, code, tool development, and so on. The USGS has built a community of users for its data through its Office of Water Information using the R programming language and GitHub (Blodgett et al. 2016). The focus of this effort is to develop a community contributing to, and developing, data analysis software for water resources (https://owi.usgs.gov/R/). The effort reflects the insight of Larsen that the performance metric that counts is not number of visitors to your website but number of applications supported by your data (von Kaenel 2015).

Another example of the data community approach is the Army Corps Federal Support Toolbox that provides a variety of data, models, educational and collaboration opportunities, and water resource management policies and documents through a single portal (http://watertoolbox.us). The toolbox is structured to make access to information easy and to limit contributions of information to only those by trusted users (Blodgett et al. 2106). This approach was taken to ensure the quality of the content and it erects a barrier common to many community-curated catalogs (Blodgett et al. 2016). Searching the toolbox for “reservoir” provided 0 results, searching for “dam” provided 47 results, and searching for “lake” provided 29 results (September 2016), with little overlap between “dam” and “lake” outputs. Many use these terms interchangeably, highlighting the significance of standardizing terms, metadata, and tags on archived data and search engines.

BUILDING A NATIONAL DATABASE OF ARMY CORPS RESERVOIRS

Our goal was to create a prototype data as a service, that is, to standardize the Army Corps districts’ disparate formats for historic daily reservoir data, along with their operational targets, and to place the uniformly formatted data in a centralized data repository. These targets represent the management goals for reservoirs in terms of lake elevation. Synthesizing both historic reservoir levels and operational targets within a single database facilitates immediate use of the data to assess how well reservoirs are meeting their operational targets.

To determine the number of reservoirs and the reservoirs' key characteristics (such as storage volume) and authorized purposes, we used five national databases:

- National Inventory of Dams (http://nid.usace.army.mil/)
- Cornell's Project List and Authorization Database (https://www.law.cornell.edu/cfr/text/33/222.5)
- Army Corps report on the Authorized and Operating Purposes of Corps of Engineers Reservoirs (1994),
- Corps Water Management System (CWMS) Data Dissemination tool (http://water.usace.army.mil)
- Appendix C of the Institute for Water Resources (IWR) Report (2016).

How Many Reservoirs Does the Army Corps Own and Operate?

The Army Corps has no publicly available list that only contains the reservoirs it owns and operates. Thus, we turned to the National Inventory of Dams (NID), a congressionally authorized database released by the Army Corps to document all dams within the United States and containing information on dam location, size, purpose, and type (USACE 2013). The NID lists 87,359 dams ranging from small private dams to large federally owned reservoirs (June 2013). This dataset was used to identify reservoirs owned and operated by the Army Corps. The NID is the most comprehensive database of reservoirs in the nation, but the data are inconsistent (IWR 2016). For example, the Army Corps had 55 aliases that had to be identified and standardized (e.g. CESAW, CESPK, CORP OF ENGINEERS, CORPS OF ENGINEERS), making identification of Army Corps-owned and -operated reservoirs a time-consuming venture.

Once Army Corps reservoirs were identified, additional work was required to determine the actual number of reservoirs. Although each reservoir has a unique identifier (NIDID), some have multiple entries. One of five entries for NC00173 was B. Everett Jordan Reservoir; the other four entries were for dikes around the reservoir. After removing duplicate entries, we identified 593 reservoirs as belonging to the Army Corps. Additional reservoirs were later eliminated because they were duplicates of the same reservoir but with unique NIDID numbers (for example, reservoirs crossing state boundaries might have two NIDIDs, one for each state) or because they had been removed (e.g., Pearl River lock and dams 4, 5, and 6). Finally, we eliminated reservoirs that are owned but not operated by the Army Corps or vice versa, identifying 537 reservoirs in the conterminous United States that are both owned and operated by the Army Corps. We did not include in that number the Alaskan reservoir or the three lock and dam structures at the base of the Great Lakes.

The "messiness" of the data has resulted in different estimates of the number of reservoirs owned and operated by the Army Corps. For example, a recent GAO (2016) document reported that the Corp owns and operates more than 700 dams, whereas an IWR (2015) report stated that the Army Corps operated 380 reservoir projects (we assume IWR did not count locks and dams). A Cornell University database provided information for 506 reservoirs. One document in the 1990s listed "over 500" reservoirs (Wurbs 1990), and a USACE (1994) report noted 541 reservoirs. The recent IWR (2016) study incorporated 465 reservoirs; 356 were identified as flood control or multi-purpose reservoirs owned and operated by the Army Corps, and the remaining 108 reservoirs (referred to as Section 7 reservoirs) were identified as owned by another entity but managed for flood control by the Army Corps. The lack of standardization and explicit definitions regarding what constitutes an Army Corps reservoir has made something as simple as identifying the number of Army Corps reservoirs a costly challenge in terms of time and effort, and uncertainty about the final number remains.

How Many Reservoirs Are Located within Each Division and District?

The Great Lakes & Ohio River Division contains the most reservoirs, 132 (24.6%), followed by the Mississippi Valley and Southwestern divisions at 95 (17.6%) and 90 (16.8%), respectively. The divisions with the fewest reservoirs are the South Atlantic and South Pacific divisions at 40 and 43, respectively (Table 1). The number of reservoirs within a district ranged from 0 to 44 (Table 2). Five districts (Huntington, Louisville, Pittsburg, New England-Concord, and Tulsa) contain more than 30 reservoirs each, comprising 34% of Army Corps reservoirs. One quarter of the Army Corps' reservoir volume is located in the Omaha District, the majority of which is held in the six dams along the Missouri River. Eleven districts contain five or fewer reservoirs.

Table 1: Number and volume of reservoirs by division

Division	N	Percent N	Gross volume (MAF)	Percent volume
Great Lakes & Ohio River	132	24.6	38.7	13.1
Mississippi Valley	95	17.8	32.0	10.9
North Atlantic	57	10.6	3.6	1.2
Northwestern	80	14.9	111.3	37.8
South Atlantic	40	7.5	27.4	9.3
South Pacific	43	8.0	11.4	3.9
Southwestern	90	16.8	70.3	23.9
Total	**537**		**294.7**	

Table 2: Number and volume of reservoirs by district

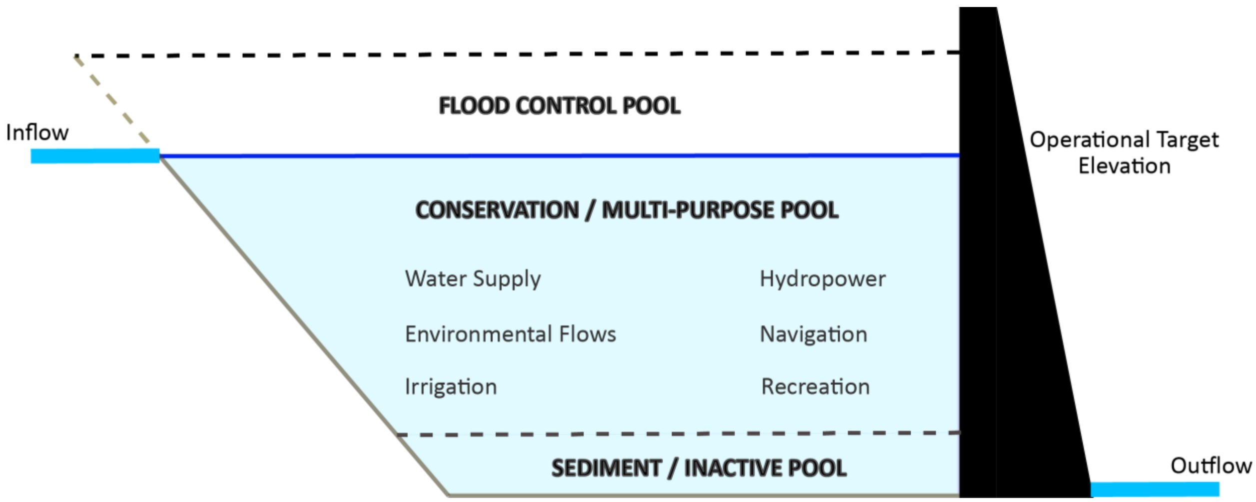
Division	District	N	Percent	Gross volume (MAF)	Percent volume
Great Lakes & Ohio River	Buffalo	1	0.19	0.30	0.10
	Chicago	0	0.00	0.00	0.00
	Detroit	9	1.68	1.10	0.37
	Huntington	44	8.19	6.18	2.11
	Louisville	30	5.59	11.45	3.90
	Nashville	10	1.86	14.44	4.92
	Pittsburg	38	7.08	5.34	1.82
Mississippi Valley	Memphis	0	0.00	0.00	0.00
	New Orleans	0	0.00	0.00	0.00
	Rock Island	27	5.03	6.99	2.38
	St. Louis	11	2.05	4.54	1.55
	St. Paul	29	5.40	9.77	3.33
	Vicksburg	28	5.21	10.68	3.64
North Atlantic	Baltimore	16	2.98	1.59	0.54
	Concord	34	6.33	1.26	0.43
	New York	1	0.19	0.00	0.00
	Norfolk	1	0.19	0.42	0.14
	Philadelphia	5	0.93	0.30	0.10

Division	District	N	Percent	Gross volume (MAF)	Percent volume
Northwestern	Kansas	18	3.35	15.61	5.32
	Omaha	29	5.40	74.10	25.26
	Portland	19	3.54	5.98	2.04
	Seattle	6	1.12	8.62	2.94
	Walla Walla	8	1.49	7.02	2.39
South Atlantic	Charleston	1	0.19	0.00	0.00
	Jacksonville	1	0.19	4.60	1.57
	Mobile	27	5.03	9.21	3.14
	Savannah	3	0.56	6.91	2.36
	Wilmington	8	1.49	5.14	1.75
South Pacific	Albuquerque	9	1.68	4.05	1.38
	Los Angeles	16	2.98	4.11	1.40
	Sacramento	16	2.98	2.73	0.93
	San Francisco	2	0.37	0.50	0.17
Southwestern	Ft. Worth	25	4.66	19.50	6.65
	Galveston	2	0.37	0.41	0.14
	Little Rock	25	4.66	24.87	8.48
	Tulsa	38	7.08	25.56	8.71

What Are Reservoirs' Authorized Purposes?

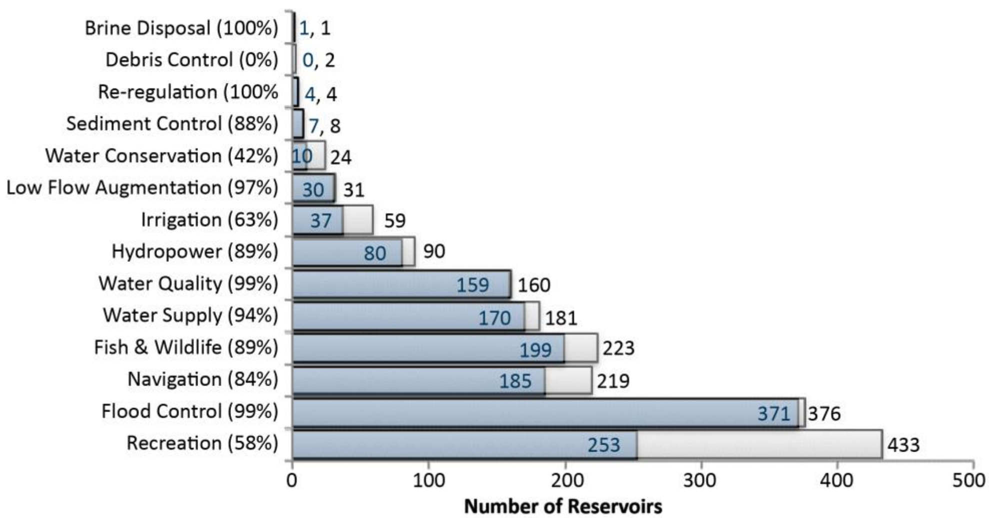
An important element of understanding how reservoirs are managed is understanding the reservoirs' purpose. We linked reservoir data to Congressional authorization whereby Congress authorizes the allocation of storage volumes to different purposes for each reservoir. The three primary purposes are navigation, flood control, and ecosystem restoration (Raff et al. 2013). Single-purpose navigation reservoirs tend to be lock and dams and are operated as run-of-the river reservoirs, meaning little or no water storage is provided. Single-purpose flood control reservoirs tend to be dry dams, meaning the reservoirs are kept empty and only filled with flood waters. No reservoirs are created for solely environmental purposes; however, reservoirs operated under environmental authorizations typically have a minimum flow that must be released from the reservoir to provide enough water for downstream aquatic habitats. Most reservoirs are authorized for multiple purposes, including a primary purpose with additional secondary purposes. Secondary purposes include hydropower and recreation, both of which are additional benefits of reservoirs built for navigation and flood control (USACE 2011). Water supply was added as an authorized purpose with passage of the Water Supply Act of 1958. Other secondary purposes authorized within the conservation pool include water quality, irrigation, and fish and wildlife (Figure 3). Secondary operations may be affected by changing environmental or societal conditions, but they may not necessarily trigger new operations if primary purposes are still being fulfilled (Raff et al. 2013).

Figure 3. Schematic of reservoir pools



Authorized purposes were compiled from USACE (1994), along with authorizing laws and operational purposes. Operating purposes refer to the purposes for which actual water control management decisions are being made (USACE 1994). As a general rule, reservoirs are operated for their authorized purposes; however, there are exceptions (outlined below). For this project, the data were updated—on the basis of the Brougher and Carter (2012), Hillyer (2004), and IWR (2015) —to include water supply as an authorized and operating purpose for those reservoirs reallocated after 1994. Nearly all reservoirs were authorized to provide the secondary purpose of recreational benefits (93%), followed by the primary purpose of flood control (85%). Navigation was an authorized purpose at 52% of reservoirs, and water supply or irrigation purposes were authorized at 51% of reservoirs (Figure 4).

Figure 4. Number of reservoirs by authorized purpose and by operating purpose



Note: Gray = authorized purposes; blue = operating purpose (blue). Percent is percent of reservoirs operating as authorized by purpose.

Army Corps reservoirs were authorized by 86 laws, and a single reservoir might have a purpose authorized by multiple laws. In total, 2,098 purposes were authorized at 537 reservoirs. Versions of the Flood Control Act and River and Harbor Act were used to authorize 1,508 purposes. PL 85-500 includes aspects of the Water Supply Act, Flood Control Act, and River and Harbor Act. It was used to authorize 157 purposes (74 related to water supply). As such, PL 85-500 was used as the authorizing law for all reservoirs reallocated since 1994. Nine reservoirs (e.g., Benbrook Dam and Whitney Reservoir) were authorized for water supply through specific laws. The Fish and Wildlife Coordination Act was used to authorize purposes at 103 reservoirs for fish and wildlife; 9 additional authorizations were under the Endangered Species Act. The Clean Water Act authorized water quality protection at 84 reservoirs and low flow augmentation at two reservoirs.

Are Reservoirs Operating for the Same Purposes for Which They Were Authorized?

USACE (1994) indicated that authorized purposes and operating purposes are not always the same, that is, some reservoirs might not be operated for a purpose that was originally authorized. For example, although 498 reservoirs were authorized for recreational purposes, only 58% incorporate recreation into their operating procedures (Figure 4). Five reservoirs authorized for flood control are not operated for flood control; their flood control authorization was removed prior to construction, while their other authorizations were left intact. Thirty-four reservoirs authorized for navigation are not operated for navigation because the associated river is no longer used for commercial purposes, no storage was allocated for navigation, or other lock and dams were built. Ten reservoirs authorized for hydropower power were later found not to be economically viable or power demand never materialized. Alternatively, the reservoirs may be associated with non-federal power, but the reservoir is not operated for hydropower. Irrigation and water supply have been authorized for some reservoirs, but those purposes never materialized. Additionally, reservoirs have some authorized purposes, such as low flow augmentation, navigation, water quality, and water supply, for the unfilled portion of the sediment pool. As sediment storage is depleted, those authorized purposes become increasingly limited.

On the other end of the spectrum are the reservoirs operating for purposes that have not been authorized by Congress. For example, reservoirs in the Nashville District operate for water supply purposes even though they are not authorized for water supply. Some reservoirs, such as West Point Dam (Mobile District), assume increased responsibility for minimum downstream flow for water supply during droughts. The Nashville District attempts to ensure water levels do not drop below intake pipes during drought. Since 1994, 40% of the Nashville District reservoirs have reallocated space for water storage through Congress. It is unclear how many of the remaining reservoirs are back-logged for water supply reallocation and how many of these reservoirs are deemed minor reallocations (43 U.S.C. §390b; ER 1105-2-100 (Table E-31)). There are 181 reservoirs that are both authorized and operating for water supply. There are 24 reservoirs authorized for water supply but not operating for water supply purposes, and there are 11 reservoirs (12 including Buford Dam) reported to be operating for water supply without authorization as of 1994 (Table 3). Interestingly, Buford Dam is listed as authorized for water supply—a contentious listing given the litigation surrounding Buford's supply of water to Atlanta (Payne 2014).

Table 3: Reservoirs that operate, but are not authorized, for water supply

NIDID	Reservoir	District
WI00814	Menasha Genlaws	Detroit
FL00435	Jim Woodruff	Mobile
GA00820	West Point	Mobile
MS03605	Jamie L. Whitten Lock and Dam	Mobile
KY03001	Barkley	Nashville
KY03010	Wolf Creek Dam / Cumberland Lake	Nashville
KY03061	Martins Fork	Nashville
TN02101	Cheatham Lock and Dam	Nashville
TN03702	Old Hickory Lock and Dam	Nashville
TN15901	Cordell Hull Lock and Dam	Nashville
OK10318	Fort Supply Lake	Tulsa
GA00824	Buford Dam / Lake Lanier	Mobile

Reservoirs Operating for Both Flood Control and Water Supply

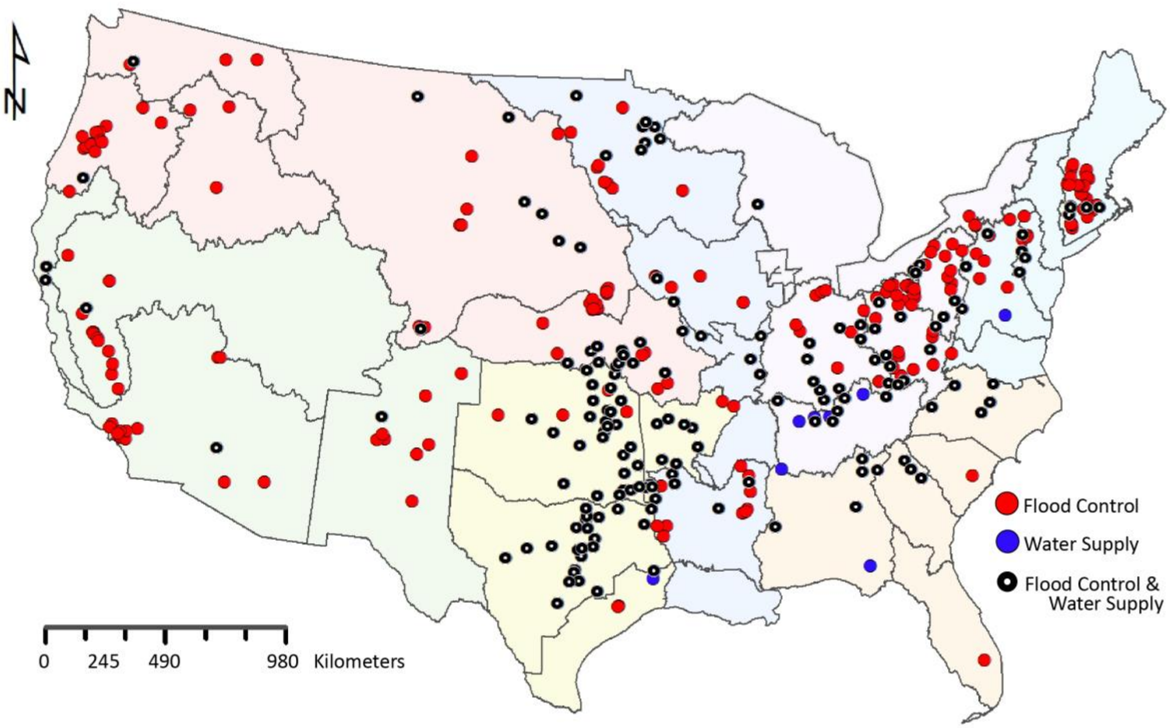
Utilities reliant on reservoirs operated, but not authorized, for water supply are perhaps more vulnerable to climatic extremes because water supply is not mandated or prioritized as it becomes limited during drought conditions. This vulnerability to drought was highlighted in 2007–2008 by Buford Dam (Lake Lanier). The reservoir was not authorized to provide water supply, but it had become the dominant water source for the city of Atlanta. The Army Corps had been allocating “temporary” storage for water supply to Atlanta since the 1970s under five-year interim contracts, and it recommended Congress reallocate 207,000 acre feet (AF) to water supply in 1989. The process of reallocation has since been caught up in litigation processes for a variety of reasons (Payne 2014). On March 30, 2017, the reallocation of 254,170 AF of to water supply was signed by the Assistant Secretary of the Army (USACE 2017).

Reservoirs that are authorized for both flood control and water supply are likely to face growing challenges in meeting both missions as a warming climate brings more extreme floods and droughts (Trenberth 2011; Huntington 2006). The goal of flood control is to maximize the amount of storage space without water, whereas the goal of water supply is to maximize the amount of water in a storage space. There are 162 reservoirs operating for both flood control and water supply (Figure 5; Table 4). The majority of these reservoirs are located in the Southwestern Division, an area prone to both extreme floods and droughts. For example, both Texas and Oklahoma were predominantly in drought from 2011 to 2015; that drought was broken by the wettest month on record for both states in May 2015 with 15 to 20 inches of rainfall. Several reservoirs that had been in prolonged drought conditions (i.e., water levels were well below management goals) exceeded their flood control pool during this month. How can reservoir operations (and improved forecasts) adjust to meet increasingly extreme precipitation regimes (wetter wet and drier dry) while serving populations growing increasingly reliant on water provided by these reservoirs?

Table 4. Number of reservoirs operated for flood control, water supply, or both purposes

Division	Flood control	Water supply	Both
Great Lakes & Ohio River	78	36	32
Mississippi Valley	44	17	17
North Atlantic	54	12	11
Northwestern	69	21	21
South Atlantic	15	15	13
South Pacific	41	5	5
Southwestern	70	64	63

Figure 5. Reservoirs operated for flood control, water supply, or both purposes



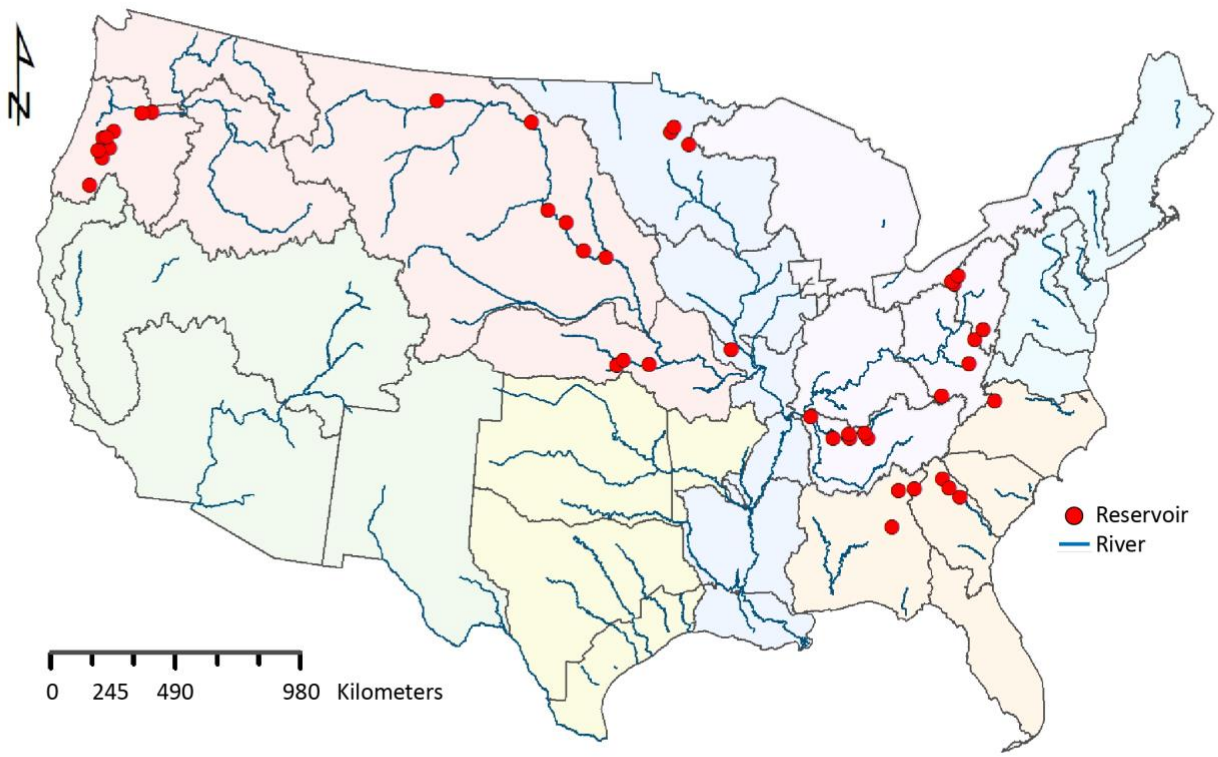
Reservoirs Operating for Multiple Purposes May Have Decreased Flexibility

Almost 70% of Army Corps reservoirs are operated for multiple purposes (Table 5). Single-purpose reservoirs comprised 30.6% of all reservoirs, the majority serving as lock and dams for navigation (105 reservoirs) or dry dams for flood control (53 reservoirs). The remaining 6 were reported to be operated for brine disposal (1), hydropower (3), recreation (1), and water supply (1). There were 330 reservoirs (61.5%) reported to be operating to meet 2 to 5 purposes. Only 42 reservoirs (7.8%) were operated for more than 6 purposes. These reservoirs include the 6 mainstem dams on the Missouri River, lock and dams located on large rivers, and an assortment of other reservoirs (Figure 6). As changing conditions increase stress on water systems, it may become difficult to meet all operating purposes.

Table 5. Number of reservoirs by number of operating purposes

Number of purposes	Number of reservoirs	Percent
1	164	30.6%
2	99	18.5%
3	103	19.2%
4	70	13.1%
5	58	10.8%
6	28	5.2%
7	13	2.4%
8	1	0.2%

Figure 6. Location of reservoirs operating for six or more purposes



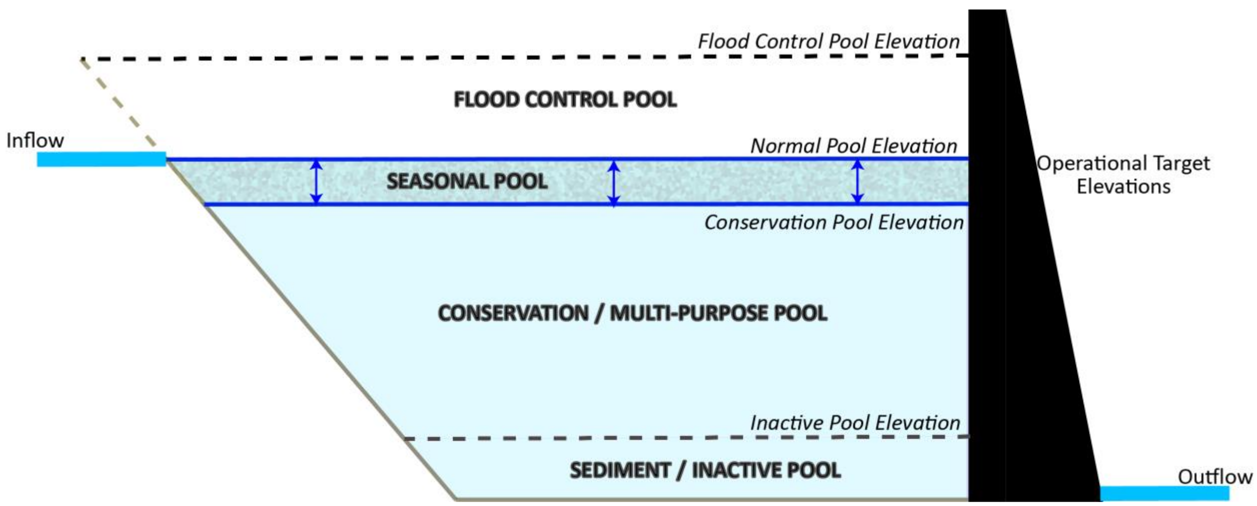
INCORPORATING FEDERATED DISTRICT DATABASES

Next, we incorporated historic daily reservoir data from districts, including elevation, volume, inflow, outflow, evaporation, and precipitation. Available data varies by district, as does terminology, units, and accessibility. The lack of standardized terminology and data formatting made it challenging to integrate district data to create a coherent database. IWR (2016) noted that "management of different reservoir systems are typically divided organizationally such that the methods and technologies, even the terminology, used by water managers differ regionally to the extent that it is difficult to characterize water management at a national level."

How Many Districts Have Made Their Historic Reservoir Data Open and Accessible?

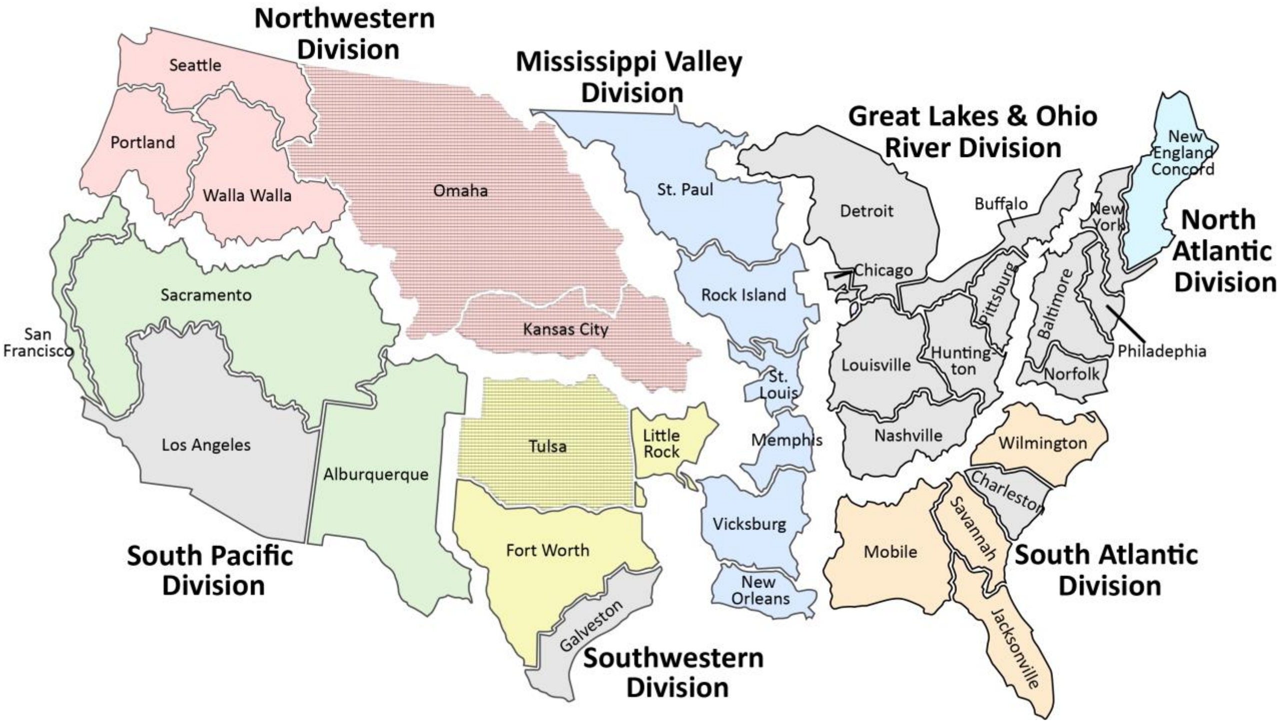
Data on authorized pool volumes (flood control, conservation, and inactive storage) were obtained from districts and validated using the CWMS Data Dissemination portal. There were challenges with standardization of these data, too. For example, the New England District provides all elevation data relative to the base of the reservoir (as of November 2016), whereas other districts provide the elevation relative to a vertical datum (most often NGVD29) or select no datum. In some instances, the term "normal" pool was used instead of "conservation" pool, and it was unclear whether the terms reflect different pools. In general, "conservation" refers to the minimum conservation pool elevation (e.g., drawdowns of the operational target during the wet season so more space is available to store floods), whereas "normal" refers to the maximum conservation pool elevation (e.g., raising the operational target during the dry season to hold more water in the reservoir for use) (Figure 7). Sometimes the top of the conservation or normal pool was simply designated as the "bottom of the flood control pool." These inconsistencies created challenges for automating a method of downloading metadata for pool levels and volumes, requiring concerted efforts to ensure data quality and accurate representation and presentation of those data.

Figure 7. Reservoir pool elevations based on CWMS data dissemination terms (italics)



The majority of daily reservoir data were obtained from district websites (Table 6). We were able to obtain data from online sources for 17 districts and through information requests for 3 districts (Kansas City, Omaha, and Tulsa) (Figure 8). We attempted, but were unable, to get data from other districts. The Great Lakes and Ohio River Division had only a few years of historic daily data available online (RiverGages data went back to 2007).

Figure 8. Districts from which data were obtained



Note: Data were obtained from the 20 districts not represented in gray. Grey means no data. Data from the three textured districts were obtained directly from those districts (the data were not available online). The Memphis and New Orleans districts have no reservoirs.

Table 6. Data sources

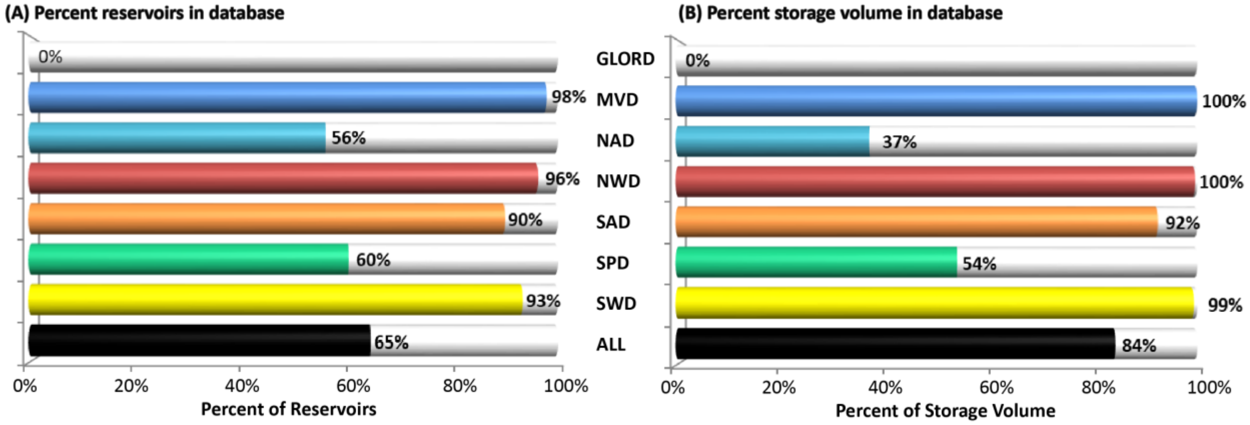
Divisions	District	Data Source	Notes
Mississippi Valley	Rock Island	RiverGages	Data are usually limited data to elevation and precipitation. Website is clunky and slow. Data sometimes do not match data provided by the district.
	St. Paul	St. Paul District	Data required significant cleaning of datum and gage elevation changes. Site has been discontinued and now uses RiverGages.
	St. Louis	St. Louis District	Daily data was provided by month through 2014 as pdfs.
	Vicksburg	RiverGages	Data are usually limited to elevation and precipitation. Website is clunky and slow. Data sometimes do not match district data.
North Atlantic	New England	NAE Reservoir Control Center	Data obtained back to 1997. Website gives warning that it is unsafe to proceed. Precipitation data are challenging to format. Storage seems to be only for flood control, meaning conservation storage must be estimated.
Northwestern	Kansas City	Kansas City District	Data could not be found online and were requested. Data were provided quickly and staff was incredibly helpful. Some data were updated through WY 2015 using USGS.
	Omaha	Omaha District	Data could not be found online and were requested. Data were provided quickly and staff was incredibly helpful. Some data were updated through WY 2015 using USGS.

Divisions	District	Data Source	Notes
Northwestern	Portland Seattle Walla Walla	Northwest Division	Plethora of data provided but not user friendly. A single variable has several links depending on data collection method and resolution. Data were stitched together from multiple methods. Elevation and storage volume were difficult to match because of different measurement methods and timing.
South Atlantic	Jacksonville	South FL Water Management District	Data could not be found on the Army Corps website but were found at the South Florida Water Management District website. Significant amounts of data were missing.
	Mobile	Mobile District	Data were downloaded individually for each variable and year, a time-consuming process. Storage volume was estimated from pdfs of area capacity curves. No storage volume data are available for lock and dams.
	Savannah	Savannah District	Data, including the operational target, were downloaded by parameter over time. Simple and quick to obtain data.
	Wilmington	Wilmington District	Data were obtained in text format for each month in 10-year chunks with notes at the bottom of each month. The data required formatting to make usable. Operational targets were provided. Data have not been updated since May 2014.
Southwestern	Galveston	Galveston District	Data could not be found online and though requested, they were not obtained.
	Fort Worth	Fort Worth District	Hydrologic data were downloaded over the period of interest. Simple and quick method to obtain data.
	Little Rock	Little Rock District	Data were downloaded for each month back to 1989. Data were well formatted but took time to download and stitch together.
	Tulsa	Tulsa District	Data could not be found online prior to 1994 and were requested. Data were provided in pdf files through an external hard drive and were then digitized. Digitized data and hard drive were returned to the district.
South Pacific	Albuquerque	Albuquerque District	Data were downloaded for each month back to 1991. Data were well formatted but took time to download and stitch together.
	Los Angeles	Los Angeles District	Data could not be found online (beyond the most recent 180 days) and were requested, but they were never obtained.
	Sacramento San Francisco	Sacramento District	Data were downloaded for each month back to 1990. All reservoirs were missing data from 1993-1994. Data were well formatted but took time to download and stitch together.
Remaining Districts (Figure 8)		No Data	Data could not be found online and we were asked not to request data from districts. Some data can be found on RiverGages but only back to 2007.

What Data Are Provided by Different Districts?

Daily reservoir data were obtained for 349 reservoirs, representing 65% of Army Corps reservoirs (Figure 9). Overall, 84% of the storage volume owned and operated by the Army Corps is represented in this database.

Figure 9. Percent of reservoirs and their respective storage volumes with historic daily data by division



Note: GLORD = Great Lakes & Ohio River Division; MVD = Mississippi Valley Division; NAD = North Atlantic Division; NWD = Northwestern Division; SAD = South Atlantic Division; SPD = South Pacific Division; SWD = Southwestern Division; ALL = All Divisions.

Most districts provided data pertaining to elevation, storage volume, inflow, and outflow (Table 7). Districts in the Southwestern and South Pacific divisions also tracked evaporation, precipitation, and unaccounted losses. The units of measurements varied among districts. For example, some of the older reservoirs in the Mississippi Valley Division had a change in gage elevation that needed to be adjusted to produce a consistent time series. Other districts provided multiple readings (e.g., 8 a.m. and 12 p.m.) within a day or provided the opportunity to download instantaneous data. We chose those elevations that matched the time at which storage volume was reported. Reservoir volumes were all standardized to acre feet (AF) (the Northwest Division reported volumes in KAF—thousands of AF). All inflow and outflow discharges were converted to cubic feet per second (CFS) (the Northwest Division reported flow in KCFS—thousands of CFS, and the Southwest Division reported flow in day-second-feet). Water supply use was converted from CFS to AF (for the Wilmington District) to match units reported by western divisions.

Some districts have digitized data going back to the start of reservoir operation (e.g., Wilmington District); other districts have digital data available only since the beginning of 1997 (New England District), 1994 (Tulsa District), 1991 (South Pacific Division), and 1989 (Little Rock District). The Tulsa District provided pdfs going back to the start of reservoir operation; we digitized those pdfs back to October 1979. Prior to 1979, data were displayed in graphs rather than text. Detailed information on data and cleaning procedures for each district are provided in Appendix B.

Table 7. Data provided by each district

Division	District	OT	Elevation	Storage volume	Inflow	Outflow	Water supply	Evap.	Precip.
Mississippi Valley	Rock Island		X	O	O	O			O
	St. Paul		O	O	O	O			O
	St. Louis		X	O	O	O			
	Vicksburg		O						
North Atlantic	New England		X	O	O	O			O
Northwestern	Kansas City		X	X	X	X			X
	Omaha		X	O	X	X			
	Portland		X	O	O	O			O
	Seattle		X	O	O	O			O
	Walla Walla		X	O	O	O			O
South Atlantic	Jacksonville		X						
	Mobile		X	O	O	O			O
	Savannah	X	X	X	X	X			X
	Wilmington	X	X	X	X	X	X		
South Pacific	Albuquerque		X	X	X	X		X	X
	Sacramento	X	X	X	X			X	X
	San Francisco	X	X	X	X	X	X	X	X
Southwestern	Fort Worth		X	X	X	X		X	X
	Little Rock		X	X	X	X	X	X	X
	Tulsa		X	X	X	X		X	X

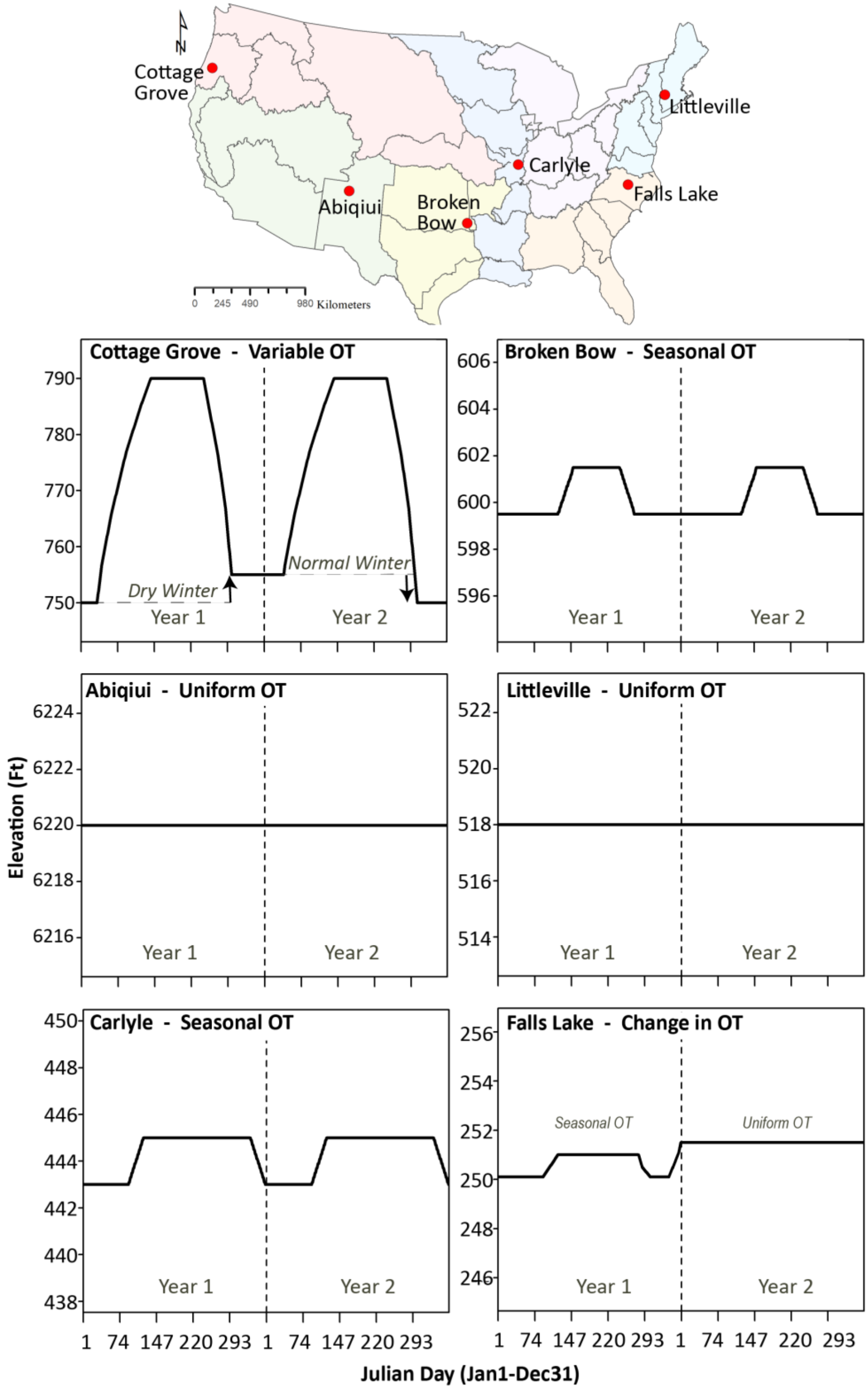
Note: O indicates missing, inconsistent, and estimated data.

Operational Targets Vary in Terms and Rarely Change

We use "operational target" (OT) to refer to a reservoir's operating rules, terminology for which varies from district to district. For example, the Wilmington District refers to these rules as "guide curves," the St. Paul District refers to them as "conservation pool targets," and the Portland District refers to them as "rule curves" (Table 8). Operating targets refer only to the goal of maintaining a certain lake elevation throughout the year and not to efforts to meet downstream flow requirements.

Operating targets were typically obtained from the district website and were applicable for the current year (Table 8 and Figure 10). Most reservoirs operate from a relatively static water control manual and do not change their operational targets each year. However, some reservoirs in the Northwest and South Pacific divisions do have annual operation targets based on winter snowfall. Traditionally, the Army Corps makes operating decisions on the basis of water on the ground (i.e., snowmelt), rather than forecasts of precipitation (Raff et al. 2013).

Figure 10. Operational targets for six reservoirs



Note: The elevations (y-axis) vary by reservoir. Elevations are in feet above sea level, based on how the Army Corps conveys information about operational targets.

In the majority of districts, the operational target was available only for the current year. Therefore, older targets may not be captured in the database in those instances in which the OT has changed over time. The exceptions are reservoirs in the Savannah, Wilmington, Sacramento, and San Francisco districts, which supplied the daily operational target over time. In the Northwest Division, the operational target for the current year and for the years 1990–1992 were available. Prior to 1994, the Tulsa District often listed the OT for each month.

Table 8. Description of different operational targets

Operational target	Description	Example
Uniform	Single elevation maintained year round	Falls Lake, Wilmington District
Seasonal	OT elevation changes by time of year	Buford Lake, Mobile District
Variable	OT elevation changes depending on snow melt or flow predictions	Albeni Falls Dam, Seattle District
Target bands	Lower and upper OT elevations are provided	Pokegama Lake, St. Paul District
System	OT elevations are determined in tandem with other reservoirs to manage a system	Mainstem dams operated for Gavin Point, Omaha District
Run-of-the-river	Dry flood control dams, lock and dams, etc.	Lock and Dam 2, St. Paul District

Many reservoirs had sedimentation surveys during the period of record, which means the relationship between elevation and storage volume (referred to as area capacity curves) changes over time. The transition to new area capacity curves in the provided data was not always seamless, and some reservoirs required the storage volume at the operational target to be adjusted to match the area capacity curve at each time period. Other reservoirs did not provide the storage volume; we estimated the volume from area capacity curves (e.g., for the Mobile District) or reports (e.g., for the Seattle District). We applied the single area capacity curve to the entire period of record to estimate storage volumes (Table 9).

Table 9. Operational targets for reservoirs by district

Division	District	N	Run of river	Uni-form	Seasonal / Variable	System	Operational target
Mississippi Valley	Rock Island	**27**	23	2	2	0	OT came from 2 documents. Assumed constant over time. Some numbers vary between the reports; best judgment used.
	St. Paul	**29**	14	3	12	0	OT were sometimes linked to other reservoir operations. Obtained from water control manuals or pdfs on district website. High uncertainty.
	St. Louis	**11**	5	1	5	0	OT obtained from documents and district website. One was estimated. Uncertainty ranges from low to high.
	Vicksburg	**28**	19	1	8	0	OT obtained from documents from Army Corps and state. Uncertainty ranges from medium to high.

Division	District	N	Run of river	Uni-form	Seasonal / Variable	System	Operational target
North Atlantic	New England	**34**	18	7	9	0	OT available for current year only. Assumed constant over time. Most reservoirs had no, or small, permanent pools.
Northwestern	Kansas City	**18**	0	0	18	0	OT available for current year only. Communication with district indicated operations can vary within 5% of flood control pool volume and with state conditions.
	Omaha	**29**	0	22	1	6	OT were provided by the district. There is higher uncertainty and estimation on the 6 mainstem reservoirs based on most recent annual operating plan.
	Portland	**19**	5	0	14	0	OT were based on 1990–1992 targets. If more recent OT were found, the two were compared with the most recent version being used and applied through time.
	Seattle	**6**	1	1	4	0	OT varies based on snow pack, and ranges were estimated on basis of prior rule curves found through web searches.
	Walla Walla	**8**	0	1	7	0	OT estimated from a Northwest Council document and an academic paper.
South Atlantic	Jacksonville	**1**	0	0	1	0	OT obtained from the South Florida Water Management District.
	Mobile	**27**	20	0	7	0	OT obtained for the current year through the website or water control manuals. Some OT were obtained from other sources with greater uncertainty.
	Savannah	**3**	0	1	2	0	OT obtained from the website for current year. Assumed constant over time.
	Wilmington	**8**	3	3	2	0	Daily OT provided throughout the period of record.

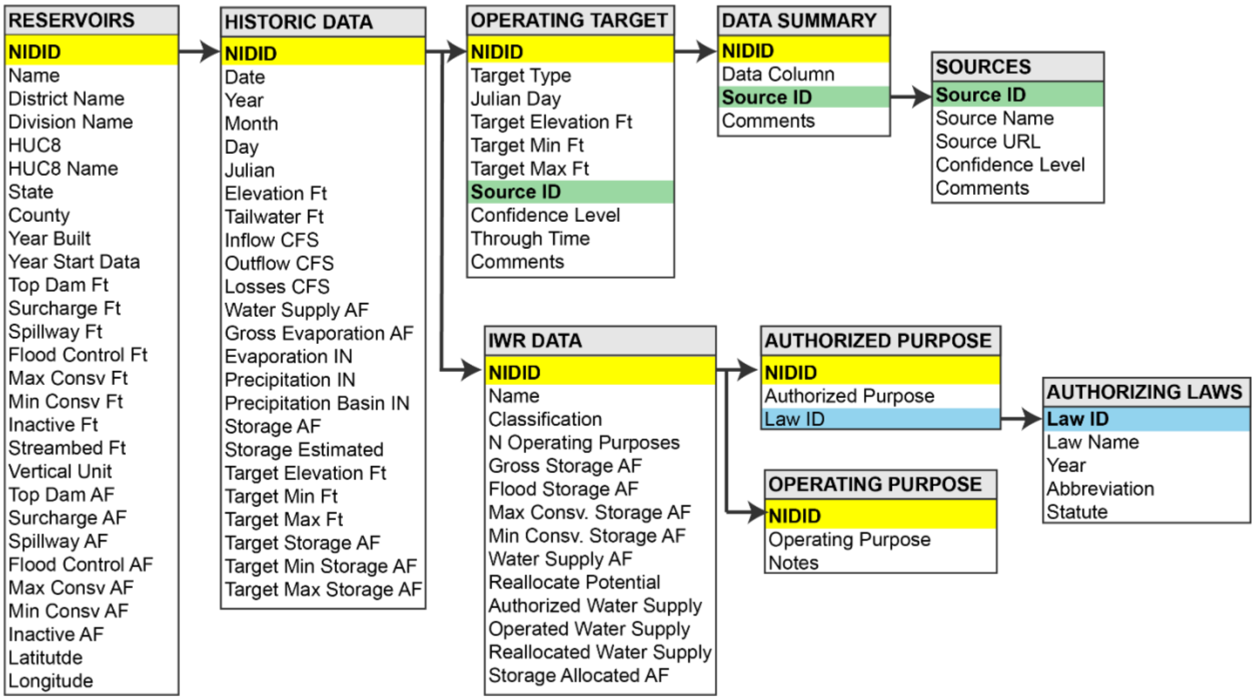
Division	District	N	Run of river	Uni-form	Seasonal / Variable	System	Operational target
Southwestern	Fort Worth	**25**	0	24	1	0	OT obtained from the district website, TX website, and USACE documents.
	Little Rock	**25**	2	4	19	0	OT obtained for the current year from the district. Lock and dam OT were based on flow and not elevations; median elevations by day of year were used to estimate OT. Inflow/outflow data are needed to accurately estimate OT.
	Tulsa	**38**	7	22	9	0	Uniform OT obtained from website. Seasonal OT derived from pdf documents. Some dams changed from seasonal to uniform OT.
South Pacific	Albuquerque	**9**	0	2	7	0	OT obtained as the top of the conservation pool from the CWMS portal. Assumed same OT over time.
	Sacramento	**16**	5	2	8	0	OT provided with the daily data throughout the period of record.
	San Francisco	**2**	0	1	1	0	OT obtained through Army Corps reports.
	TOTAL	**363**	**122**	**97**	**137**	**6**	

Note: Missing operational targets were assigned as run of river.

Data as a Service: Constructing a Centralized Relational Database

The NID reservoir ID was used as the unique identifier to link the majority of the tables together (Figure 11). Grossman et al. (2015) noted that data must be available, standardized, and integrated before it can be transformed into information and knowledge for decision making. Once formatted and standardized and contained in one location, data can be analyzed to gain insights. We put the data into a single database, building the relationships shown in Figure 11. Relational databases enable the data to be accessed and reassembled in different ways through queries without table reorganization (Codd 1979). See Appendix A for table descriptions and relationships.

Figure 11. Schematic of the oracle database



Note: NIDID refers to the reservoir ID.

DISCUSSION

Finding 1: Only 51% of Districts Have Open Reservoir Data

IWR (2016) was the first effort to collect data from across districts. The study found that data formats varied as well as data quality. The study's collection efforts were internal; the districts provided the data and clarification as needed.

Through the process of attempting to compile the data through online platforms, as mandated by the open data initiatives of the federal government, we found large variation in data availability and accessibility among districts. Two districts (5.2% of reservoirs) had all of their data online, and the data were easily downloadable and usable. Sixteen districts (41.3% of reservoirs) had no historical data available for download online. The remaining 15 districts (53.4%) had data available online, but collecting and formatting them into a usable time series took considerable time and effort. Many of these districts provided their data by months, which had to be downloaded individually and integrated. Providing the data by month likely stems from section 13.d in ER 1110-2-240. It states that "a monthly record of reservoirs/lakes operated by the Corps of Engineers …will be promptly prepared and maintained by district/division commanders in a form readily available for transmittal…Record data may be prepared in either graphical form… or tabular form" (USACE 1982). Newer versions of ER 110-2-240 specify that data be provided on a real-time basis (USACE 2016), which in practice often means that the data are provided on district websites for the current day or week (e.g., CWMS tool).

RiverGages and the CWMS Data Dissemination portal are ongoing efforts by the Army Corps to gather formatted data into a single location. At this time neither tool is user friendly, nor functions to provide data as a service. RiverGages has no data for many locations; other data starts after 2012, meeting the requirement that new information be made open and available online. However, short time series are not helpful to identify long-term trends (e.g., climate or land use change). The data are also not consistently formatted. The portal uses multiple methods to display missing data and shifting gage heights over time. The CWMS Data Dissemination portal compiles relatively static reservoir characteristics together with five days of data at 15-minute intervals. As noted above, lack of standardization of terms and formats makes the data difficult to download and use without significant post-processing efforts. Data for several reservoirs were missing as of September 2016.

Finding 2: Data Interoperability Is Required to Reduce Uncertainty and Gain Efficiencies

To fully benefit from the data that it is collecting and storing, the Army Corps must make the data *available* and *accessible* (Patterson et al. 2017a). Once accomplished, data interoperability will facilitate analyses and guide decision making. It will also increase efficiency, which is necessary given limited funds available to address the impacts of changing conditions on reservoir operations.

Data availability means the information are collected and standardized across districts. To make data available, the Army Corps headquarters could establish a list of baseline data (elevation, storage volume, inflow, outflow, evaporation, precipitation, and so on) that must be collected in a standard format. Unambiguous metadata are needed for each variable. For example, it should be clear to what precipitation refers. Is precipitation measured at one gage, at the reservoir, or basin-wide? Is the precipitation reported for the same day as reservoir elevation measurements or for the 24 hours prior to that measurement? This type of metadata can help to ensure the data are being correctly applied in analyses. In addition, the Army Corps could ask districts to provide daily operational targets for their reservoirs, as is the case currently for just four districts (Sacramento, San Francisco, Savannah, and Wilmington). This information will enable analyses of whether reservoirs are consistently meeting operational targets or whether systematic departures are occurring. In the absence of operational targets for some reservoirs, we used state documents, fish and wildlife documents, or academic publications, the accuracy of which is impossible to know. By providing operational targets for all reservoirs, the Army Corps will avoid the costs of Freedom of Information Act (FOIA) requests or time spent clearing up confusions resulting from use the wrong data.

Data accessibility means data users and analysts can access the data in a usable format. The data are not accessible or usable when large blocks of time are required to download and format data for reservoirs in a single district, let alone across districts. Providing the data in a usable format as a service would help the Army Corps and other partners assess climate, land use, water demand, and other impacts at a district, division, or national scale.

Finding 3: The Army Corps Has the Opportunity to Tell a Story with Its Data

Eventually the Army Corps' data will be available, either because the government continues to move toward making data open, or because technological improvements (satellites, drones, and sensors) enable the collection of non-governmental data that independently tracks reservoir elevations and flows. Currently, the Army Corps has an opportunity to frame the story it wants to tell with the data so as to ensure accuracy in how those data are interpreted.

As outsiders (i.e., non-Army Corps personnel), we came to several incorrect conclusions when we began downloading and interpreting Army Corps data. For example, our impression was that operating targets are legally binding and that failure to meet those targets on a consistent basis at any given reservoir indicates a problem that opens up the possibility of litigation. Through conversations with the Army Corps, we realized that the operational targets are guidelines and that they are highly flexible. On the other hand, as we learned, many reservoirs are operated to multiple targets in addition to the operational target, such as minimum flow requirements or, during flood conditions, discharge limits.

When we started the project, we also did not realize that provided storage volumes can change drastically following a sedimentation study. Area capacity curves relate reservoir elevation to storage volume. Currently, changes in the area capacity curve (relationship between elevation and storage volume) are not identified in the downloadable data. Attributing a volume to the operational targets (no districts provided the target volume) would be problematic if the data user doesn't know to adjust for changes in area capacity curves. The lack of communication or metadata can result in errors in the analysis by outsiders who don't have access to the data or understand that the relationship between elevation and storage can change over time (Table 10). Finding where these changes occurred in the data is a tedious process, particularly when the area capacity curves aren't consistent and when multiple data collection methods make it difficult to knowing which data to pair (Northwest Division DataQuery).

Table 10. Unmarked changes in the area capacity curve (red line) can create errors in the analysis

Elevation (Ft)	Storage (AF)	Operational target (Ft)	Operational target (Ft)	Percent of target	
100	2000	100	2000	100%	Correct
100.5	2050	100	2000	103%	Correct
100.4	2040	100	2000	102%	Correct
100.1	2010	100	2000	101%	Correct
100	900	100	2000	45%	Incorrect
100.5	950	100	2000	48%	Incorrect
100.4	940	100	2000	47%	Incorrect
100.1	910	100	2000	46%	Incorrect

Finding 4: The Benefits of Open and Interoperable Data Need to Be Articulated and Advocated

The costs of integrating disparate data systems across the Army Corps are relatively small compared to capital expenditures—but the benefits will be immense. Having available and accessible data as a service will drastically reduce the costs of gathering data from different systems for internal studies (IWR 2016), will allow individuals and agencies to develop tools to use the Army Corps data to provide new insights and strategies to address water resource challenges, and will decrease litigation costs and FOIA requests as water supply issues and interest in them grow. Moreover, trust between the Army Corps and local and state governments may increase as the Army Corps' reservoir management becomes more transparent.

DATA AVAILABILITY

The Army Corps plans to check the data and release a version of the database through their system (in process). Portions of the data, particularly those used in Patterson and Doyle (2018), may be downloaded from the data visualization website (https://nicholasinstitute.duke.edu/reservoir-data).

APPENDIX A: TABLE DESCRIPTIONS

The following outlines the types of data contained in each table in Figure 11.

Reservoirs: Generally static information about the reservoir such as name, location, watershed, year of construction, pool elevations, and current storage volumes.

IWR data: Information from IWR (2016) on gross operating table and water supply storage plus the number of operating purposes and reservoir classification (single-purpose, multi-purpose, dry dam, lock and dam, and so on).

Operating purpose: Operating purposes for each reservoir.

Authorizing purpose: Authorizing purposes and law for each reservoir.

Authorizing laws: Name, year, and statute of the authorizing law.

Historic data: Daily information obtained from the districts—data dependent on available district and reservoir purpose (i.e., not all reservoirs supply water or hydropower).

Operational target: Each reservoir's most recent operating target, whether uniform, seasonal, or so on. The OT elevation and minimum and maximum range are reported for each Julian day of the year from 1 (Jan 1) to 365 or 366 (Dec 31).

Data summary: List of available data (corresponds to column names in the historic data table), data sources, and comments.

DT sources: Information pertaining to data sources such as website address and confidence levels in data accuracy.

APPENDIX B: DESCRIPTION OF DISTRICT DATA

This appendix contains information regarding data collected from each district and any steps required to format, standardize, or estimate values.

MISSISSIPPI VALLEY DIVISION

Rock Island District

Data Source: Data were obtained from RiverGages, which appears to reflect an effort to compile stream gauge and reservoir data together in a single interface. The earliest available data varies by reservoir and contains information regarding lake elevation, tailwater elevation, inflow, outflow, and precipitation. All data components had to be individually downloaded. Area capacity tables were provided from some reservoirs, allowing computation of storage volumes. Area capacity from one table was applied through time.

Formatting: The data required little formatting, but different versions of missing data had to be located. Values included M, -9399, -999, '--', depending on the gage.

Operating targets: Operating targets for the Illinois Waterway were obtained from an Interim Report for the Upper Mississippi River. The Coralville reservoir operating target was obtained from a climate change study; Saylorville, from the 2014 Master Plan; and Red Rock, from a document describing changes in the conservation pool in 1979, 1982, 1988, and 1992. No operational targets were found for the remaining reservoirs, including the Mississippi River lock and dams.

Summary: There is high confidence in the elevation and storage data, but in a few cases data values were missing, which were extrapolated assuming a linear regression (i.e., if a day with missing data was immediately preceded and followed by days with data, the average value of the data for those days was assumed). Operating targets are dynamic, and it would be best to use the actual operating targets for each year. Storage volumes were estimated through time using the same area capacity curves.

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Big Creek Barrier Dam	IA00018	1974 - 2015	4,200	Single Purpose	1
Big Creek Terminal Dam	IA00015	1995 - 2015	27,500	Single Purpose	1
Brandon Road Lock & Dam	IL00001	1936 - 2015	4,500	Lock and Dam	1
Coralville Dam	IA00012	1960 - 2015	1,054,800	Multi-purpose	3
Dresden Island Lock & Dam	IL00002	1933 - 2015	12,000	Lock and Dam	1
Farmdale	IL00005	MISSING	15,500	Dry Dam	1
Fondulac	IL00006	MISSING	3,780	Dry Dam	1
La Grange Lock & Dam	IL01015	1939 - 2015	55,000	Lock and Dam	1
Lockport Lock * Dam	IL00007	1933 - 2015	25,000	Lock and Dam	1
Marseilles Dam	IL00003	1938 - 2015	14,000	Lock and Dam	1
Mississippi River Lock & Dam 11	IA00003	1945 - 2015	170,000	Lock and Dam	1
Mississippi River Lock & Dam 12	IA00004	1940 - 2015	92,000	Lock and Dam	1
Mississippi River Lock & Dam 13	IA00005	1945 - 2015	192,000	Lock and Dam	1
Mississippi River Lock & Dam 14	IA00006	1947 - 2015	82,000	Lock and Dam	1
Mississippi River Lock & Dam 15	IA00007	1937 - 2015	88,500	Lock and Dam	1
Mississippi River Lock & Dam 16	IA00008	1960 - 2015	99,400	Lock and Dam	1
Mississippi River Lock & Dam 17	IA00009	1970 - 2015	99,600	Lock and Dam	1
Mississippi River Lock & Dam 18	IA00010	1970 - 2015	113,600	Lock and Dam	1
Mississippi River Lock & Dam 19	IL01238	1960 - 2015	292,000	Lock and Dam	1
Mississippi River Lock & Dam 20	MO10303	1960 - 2015	134,300	Lock and Dam	1
Mississippi River Lock & Dam 21	MO10304	1960 - 2015	135,000	Lock and Dam	1
Mississippi River Lock & Dam 22	MO10305	1960 - 2015	137,500	Lock and Dam	1
Peoria Lock & Dam	IL01014	1940 - 2015	225,000	Lock and Dam	1
Red Rock Dam	IA00013	1968 - 2015	2,366,300	Multi-purpose	3
Saylorville Dam	IA00017	1978 - 2015	1,525,000	Multi-purpose	4
Starved Rock Lock & Dam	IL00004	1940 - 2015	16,000	Lock and Dam	1
Thomas J. Obrien Controlling Works	IL01013	1988 - 2015	9,700	Lock and Dam	1

St. Louis District

Data source: Data were obtained from the St. Louis District historic data archive from the time of reservoir construction to 2014. The archive has not been updated beyond 2014, and the data could not be found on RiverGages. Data included lake elevation, tailwater elevation, inflow, and outflow. Storage volumes for some of the reservoirs were obtained from area capacity curves. These curves were found in several documents such as Analysis of the Operation of Lake Shelbyville and Carlyle Lake to Maximize Agricultural and Recreation Benefits (1975), Rend Lake Report of Sedimentation 2009 Resurvey, and Report of Sedimentation 1997 Resurvey Mark Twain Lake.

Formatting: The data were provided in yearly pdfs. Each variable had a separate pdf. The pdfs were machine readable, however, it took considerable time to export the data into excel and to reformat them as a usable time series rather than a day by month matrix (Figure B1).

Figure B1. PDF of one year of data (left) transformed into a more usable format (right)

Day	January	February	March	April	May	June	July	August	September	October	November	December
1			588.54	589.57	590.25	593.46	598.65	604.75	599.42	599.20	598.96	598.51
2			589.02	589.54	590.25	593.51	598.62	604.61	599.46	599.22	598.90	598.50
3			589.15	589.60	590.28	593.95	598.61	604.48	599.44	599.20	598.84	598.50
4			589.24	589.65	590.24	594.70	598.60	604.31	599.42	599.19	598.84	598.46
5			589.27	589.72	590.26	595.21	599.20	604.10	599.40	599.15	598.76	598.46
6			589.38	589.82	590.43	595.50	599.85	603.86	599.40	599.13	598.77	598.48
7			589.50	589.76	590.43	595.64	600.42	603.60	599.38	599.10	598.71	598.61
8			589.55	589.79	590.55	595.76	600.73	603.36	599.37	599.04	598.69	598.59
9			589.58	589.84	590.58	595.84	600.87	603.12	599.35	599.07	598.69	598.60
10			589.60	589.87	590.64	595.87	601.15	602.85	599.34	599.04	598.66	598.87
11		578.49	589.65	589.89	590.69	595.90	602.91	602.60	599.33	598.99	598.66	599.18
12		578.76	589.70	589.94	590.85	596.35	603.95	602.29	599.35	599.00	598.65	599.50
13		578.90	589.60	590.02	590.81	596.82	604.25	601.98	599.29	598.98	598.65	599.73
14		578.96	589.60	590.03	590.85	597.00	604.88	601.69	599.27	598.98	598.63	600.08
15		579.05	589.65	590.04	591.03	597.13	605.45	601.45	599.25	598.98	598.65	601.26
16		579.10	589.90	590.08	591.25	597.30	605.78	601.16	599.23	598.99	598.64	602.72
17		579.22	590.10	590.14	591.45	597.37	606.05	600.85	599.20	598.98	598.63	603.57
18		579.52	590.15	590.18	591.58	597.40	606.28	600.55	599.18	598.96	598.61	604.03
19		580.08	590.25	590.19	591.65	597.47	606.40	600.31	599.13	598.96	598.62	604.57
20		580.47	590.38	590.19	591.68	597.85	606.41	600.20	599.17	598.96	598.60	605.00
21		580.97	590.39	590.20	591.75	598.21	606.34	600.14	599.15	598.96	598.62	605.29
22		582.24	590.42	590.24	591.82	598.35	606.20	600.06	599.14	599.00	598.58	605.39
23		584.00	590.37	590.23	591.84	598.42	606.08	599.98	599.10	599.02	598.56	605.48
24		585.20	590.29	590.26	592.13	598.50	606.02	599.88	599.10	599.01	598.55	605.55
25		586.08	590.25	590.22	592.39	598.53	605.86	599.79	599.08	599.00	598.52	605.58
26		586.85	590.16	590.24	592.63	598.57	605.70	599.68	599.19	598.96	598.50	605.60
27		587.48	590.03	590.25	592.98	598.60	605.50	599.57	599.19	598.95	598.53	605.60
28		588.09	589.95	590.24	593.13	598.61	605.35	599.50	599.19	598.96	598.52	605.45
29		----	589.82	590.25	593.24	598.60	605.24	599.46	599.19	598.95	598.55	605.31
30		----	589.73	590.27	593.33	598.61	605.11	599.45	599.22	598.99	598.54	605.20
31		----	589.63	----	593.40	----	604.90	599.41	----	598.98	----	

Reservoir	Year	Month	Day	Elev_Ft
Shelbyville	1971	2	11	578.49
Shelbyville	1971	2	12	578.76
Shelbyville	1971	2	13	578.90
Shelbyville	1971	2	14	578.96
Shelbyville	1971	2	15	579.05
Shelbyville	1971	2	16	579.10
Shelbyville	1971	2	17	579.22
Shelbyville	1971	2	18	579.52
Shelbyville	1971	2	19	580.08
Shelbyville	1971	2	20	580.47
Shelbyville	1971	2	21	580.97
Shelbyville	1971	2	22	582.24
Shelbyville	1971	2	23	584.00
Shelbyville	1971	2	24	585.20
Shelbyville	1971	2	25	586.08
Shelbyville	1971	2	26	586.85
Shelbyville	1971	2	27	587.48
Shelbyville	1971	2	28	588.09
Shelbyville	1971	3	1	588.54
Shelbyville	1971	3	2	589.02
Shelbyville	1971	3	3	589.15
Shelbyville	1971	3	4	589.24
Shelbyville	1971	3	5	589.27
Shelbyville	1971	3	6	589.38
Shelbyville	1971	3	7	589.50
Shelbyville	1971	3	8	589.55
Shelbyville	1971	3	9	589.58
Shelbyville	1971	3	10	589.60
Shelbyville	1971	3	11	589.65
Shelbyville	1971	3	12	589.70
Shelbyville	1971	3	13	589.60
Shelbyville	1971	3	14	589.60
Shelbyville	1971	3	15	589.65
Shelbyville	1971	3	16	589.90

Operating targets: Operating targets for Shelbyville and Carlyle Lake were taken from the aforementioned 1975 report. The Clarence Cannon Dam (Mark Twain Lake) operating target was taken from the 1997 survey, and the reregulation dam operational target was taken from the Mark Twain Lake Master Plan. The operating target for Rend Lake could not be located and was based on historic lake elevations and pertinent data on allocated pool elevations. Wappapello operating targets were taken from a Water Control Plan Revision document (2014). No operational targets were found for the lock and dams.

Summary: There is high confidence in daily collected data. Storage volumes were estimated from area capacity curve tables with different dates. One reservoir reflects the volumes present in 1975, whereas another reflects volumes available in 2009. Operating targets were obtained from documents dating from a similar range, 1975 to 2014, and do not capture changes that may have occurred over time.

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Carlyle Lake Dam	IL00113	1965 - 2014	982,900	Multi-purpose	5
Clarence Cannon Dam / Mark Twain Lake	MO82201	1984 - 2014	1,428,000	Multi-purpose	7
Clarence Cannon Re-Regulation Dam	MO12086	1982 - 2014	8,500	Reregulation	1
Kaskaskia Lock & Dam	IL00115	1973 - 2014	25,246	Lock and Dam	1
Lake Shelbyville Dam	IL00118	1971 - 2014	684,000	Multi-purpose	5
Mississippi River Lock & Dam 24	MO10300	1939 - 2014	125,363	Lock and Dam	1
Mississippi River Lock & Dam 25	MO10301	1939 - 2014	176,000	Lock and Dam	1
Mississippi River Lock & Dam 27	MO10302	1951 - 2014	50	Lock and Dam	1
Melvin Price Lock & Dam	IL50077	1990 - 2014	238,000	Lock and Dam	1
Rend Lake Dam	IL00117	1971 - 2014	294,000	Multi-purpose	5
Wappapello Lake Dam	MO30204	1941 - 2014	582,200	Multi-purpose	2

St. Paul District

Data source: Data were obtained from the St. Paul District water control center, http://www.mvp-wc.usace.army.mil/, through 2013. This web portal has since been discontinued; data are now provided on RiverGages. Data for some reservoirs goes back to the time of reservoir construction; data for others, such as Eau Galle reservoir, is available only from September 2015 onwards in RiverGages. Data include lake elevation, tailwater elevation, and computer-estimated inflow and outflow. Area capacity tables allow computation of storage volumes.

Formatting: The district required concerted formatting efforts because some sections of the raw data appear on a single row, whereas other sections appear on multiple rows (Figure B2). Elevation data were missing for many of the reservoirs; if a day without data was immediately preceded and followed by days with data, the average value of the data for those days was assumed.

Figure B2. Formatting changes

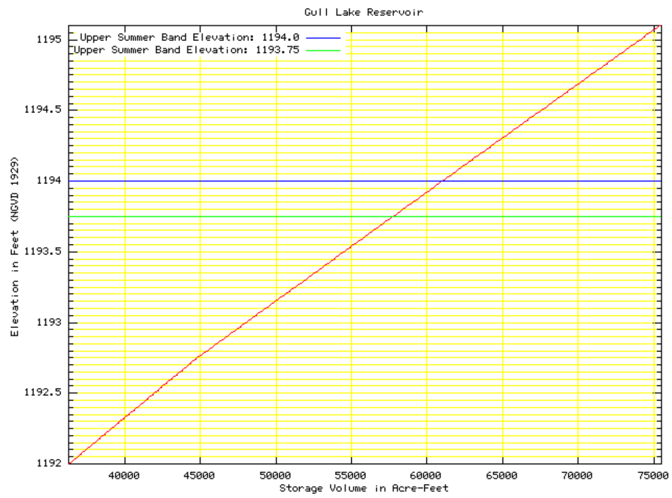
Date	Elevation (Ft)	Tailwater (Ft)	Inflow (CFS)	Outflow (CFS)
17-Mar-41	1192.75	1190.9	-13	118
18-Mar-41	1192.74	1189.73	13	32
19-Mar-41	1192.74	1189.63	32	33
20-Mar-41	1192.74	-	33	33
20-Mar-41	-	1189.57	-	-
21-Mar-41	1192.74	-	34	-
21-Mar-41	-	1189.56	-	34

Need to merge to single date

There were also challenges with combining the St. Paul District data with RiverGages data. Values for the same data do not match up. It was unclear if some data processing had occurred, or if the data were for different gages or were taken at different times during the day. Precipitation data were very different, and it was unclear whether precipitation was being measured at the same resolution (at the reservoir versus across the basin). When there were large discrepancies between the district data and the RiverGages data, we did not include the RiverGages precipitation data.

Operating targets: Many of the reservoirs in the St. Paul District have operating targets dependent on the flows of other reservoirs and snow pack. Several reservoirs operated their summer season within elevation bands that served as minimum and maximum operating targets (Figure B3). Many of these reservoirs had a normal drawdown during winter months as well as a maximum drawdown level. We applied a "normal" year's operational target to the reservoir period of record and used the maximum drawdown as the minimum target.

Figure B3. Example of banded operational targets



Operating targets were obtained from the water control website as well as from water control manuals for groups of projects. For example, Gull Lake, Big Sandy, and Pine River Dam operations are linked; La Qui Parle and Marsh Lake are operated together. No storage data or operating target information are available for lock and dams.

Summary: There is high confidence in the elevation and storage data with the exception of many isolated missing data values that were estimated through linear regressions. The operating targets are often dynamic, and it would be best to use the actual operating targets for each year.

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Baldhill	ND00309	1951-2015	101,300	Multi-purpose	2
Eau Galle	WI00780	1969-2013	43,580	Multi-purpose	2
Gull Lake	MN00596	1912-2015	71,000	Multi-purpose	5
Highway 75 Dam	MN00581	1983-2015	91,000	Multi-purpose	3
Homme Dam	ND00310	1948-2015	2,847	Multi-purpose	2
Lac Qui Parle Dam	MN00580	1940-2015	162,300	Multi-purpose	2
Leech Lake Dam	MN00585	1900-2015	1,043,000	Multi-purpose	6
Mississippi River Lock & Dam 1	MN00593	1904-2015	9,300	Lock and Dam	1
Mississippi River Lock & Dam 2	MN00594	1930-2015	787,000	Lock and Dam	2
Mississippi River Lock & Dam 3	MN00595	1934-2015	290,000	Lock and Dam	1
Mississippi River Lock & Dam 4	WI00727	1934-2015	878,000	Lock and Dam	1
Mississippi River Lock & Dam 5	MN00589	1934-2015	106,600	Lock and Dam	1
Mississippi River Lock & Dam 5A	MN00588	1934-2015	260,000	Lock and Dam	1
Mississippi River Lock & Dam 6	WI00802	1900-2015	180,000	Lock and Dam	1
Mississippi River Lock & Dam 7	MN00587	1930-2015	105,000	Lock and Dam	1
Mississippi River Lock & Dam 8	WI00803	1930-2015	260,000	Lock and Dam	1

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Mississippi River Lock & Dam 9	WI00733	1934-2015	470,000	Lock and Dam	1
Mississippi River Lock & Dam 10	IA04014	1932-2015	212,000	Lock and Dam	1
Red Lake Dam	MN00573	1965-2015	2,690,000	Multi-purpose	2
Marsh Lake Dam	MN00579	1940-2015	124,000	Multi-purpose	2
Orwell Dam	MN00574	1952-2015	17,750	Multi-purpose	3
Pine River Dam / Cross Lake	MN00582	1898-2015	188,000	Multi-purpose	5
Pokegama Lake Dam	MN00584	1900-2015	158,000	Multi-purpose	5
Reservation Highway Dam / Lake Traverse	MN00576	1942-2015	165,000	Multi-purpose	2
Sandy Lake Dam (Big Sandy)	MN00583	1920-2015	118,000	Multi-purpose	6
St. Anthony Falls Lower Lock & Dam	MN00591	1950-2015	420	Lock and Dam	1
St. Anthony Falls Upper Lock & Dam	MN00590	1950-2015	4,900	Lock and Dam	1
White Rock Dam	MN00577	1942-2015	85,000	Multi-purpose	2
Winnibigoshish Dam	MN00586	1900-2015	1,151,000	Multi-purpose	6

Vicksburg District

Data Source: Data were obtained from RiverGages. The earliest available data varies from reservoir to reservoir and extends to 2015. Data are limited to lake elevation and sometimes tailwater elevation. No storage volume data were located.

Formatting: The data from RiverGages requires little formatting, but different versions of the missing data had to be located. Values included M, -9399, -999, '--'.

Operating targets: Operating targets for Degray and Narrows dams were found in an Arkansas State Water Plan (1987). Caddo's operating target was found in its 1982 Water Control Plan. Blakely Mountain (Lake Ouachita) operating targets were found at a Southwestern Power Administration website for 2015; however, that link is no longer active. The remaining rule curves were found in the plots of current year hydrographs (2016) available at the Vicksburg District.

Two pumping stations are used to manage water levels at Lake Chicot: Connerly Bayou and Ditch Bayou Station. Ditch Bayou station is the primary regulator, but Connerly Bayou fluctuates seasonally with those operations. Operating targets were based on the Lake Chicot Management Plan. This plan was complicated because every five years the lake is drawn down (1999, 2004, 2009 and 2014); however, the target drawdown elevation articulated in the document has not been reached according to the data. Lake management changed in 1959 and 1985.

Bayou Bodacou and Caddo Dam are operated as run-of-the-river. No operational targets were found for the flood control structures or the lock and dams.

Summary: Little data are available for the Vicksburg district. Operating targets were taken from a single year, and some of the operating targets were difficult to understand and data were difficult to confirm. Ideally, the Vicksburg District would provide the operating targets for the other reservoirs on its website to increase confidence in the accuracy of its data.

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Arkabutla Dam	MS01496	1942-2015	493,800	Multi-purpose	4
Bayou Bodcau Dam	LA00179	1950-2015	967,900	Single Purpose	1
Blakely Mountain Dam	AR00150	1961-2015	2,770,174	Multi-purpose	4
Caddo Dam	LA00181	1932-2015	755,000	Run of River	1
Columbia Lock & Dam	LA00177	1973-2015	156,800	Lock and Dam	2
Degray Dam	AR00151	1972-2015	881,900	Multi-purpose	5
Ditch Bayou Station – Lake Chicot	AR00989	1938-2015	34,000	Multi-purpose	3
Enid Dam	MS01495	1953-2015	602,400	Multi-purpose	5
Felsenthal Lock & Dam	AR01514	1984-2015	76,700	Lock and Dam	2
FWR Structure Site No. 30	MS03475	2012-2015	3,993	Multi-purpose	3

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
FWR Structure Site No. 38	MS03599	2012-2015	5,753	Single Purpose	1
FWR Structure Site No. 47	MS03356	2012-2015	3,476	Single Purpose	1
FWR Structure Site No. 52	MS03411	2012-2015	13,686	Single Purpose	1
Grenada Dam	MS01494	1954-2015	1,251,700	Multi-purpose	4
H.K. Thatcher Lock & Dam	AR01515	1984-2015	108,000	Lock and Dam	1
Jonesville Lock & Dam	LA00175	1973-2015	149,300	Lock and Dam	1
Lake Calion Dam	AR00591	MISSING	16,400	Lock and Dam	1
Narrows Dam	AR00154	1962-2015	407,910	Multi-purpose	3
Pearl River Lock & Dam 1	LA00089	2007-2015	7,960	Lock and Dam	1
Pearl River Lock & Dam 2 / Bogue Chitto Sill	LA00088	2007-2015	1,300	Lock and Dam	1
Pearl River Lock & Dam 3 / Pools Bluff Sill	LA00086	2007-2015	6,500	Lock and Dam	1
Red River Lock & Dam 1 / Lindy Claiborne Boggs	LA00584	1987-2015	100,000	Lock and Dam	1
Red River Lock & Dam 2 / John Overton	LA00581	1987-2015	67,500	Lock and Dam	1
Red River Lock & Dam 3 / W.W.	LA00582	1992-2015	108,500	Lock and Dam	1
Red River Lock & Dam 4 / Russell B. Long	LA00583	1995-2015	70,500	Lock and Dam	1
Red River Lock & Dam 5 / Joe D. Waggoner Jr.	LA00580	1995-2015	59,900	Lock and Dam	1
Sardis Dam	MS01493	1940-2015	1,461,900	Multi-purpose	4
Wallace Lake Dam	LA00180	1949-2015	96,100	Multi-purpose	2

NORTH ATLANTIC DIVISION

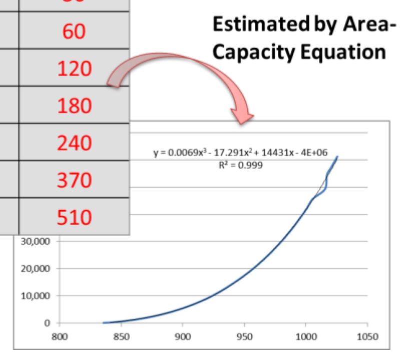
New England Concord District

Data source: Data for reservoirs in the New England District were obtained from Reservoir Regulation Section (the website link has changed several times – link as of May 25, 2017). Many reservoirs in this district were primarily built for flood control; some lakes become dry between flood events. The website allows data to be downloaded for up to 999 days at a time and contains data from as far back as 1997. Data include lake elevation, tailwater elevation, inflow, outflow, cumulative precipitation (to different start dates), air temperature, and percent of storage filled. The percent storage is relative to flood control storage only and does not account for normal storage volumes if a conservation pool is present. The website also provides area capacity curves; however, volume is reported only for flood pools, and conservation pool volumes had to be found in reports or estimated on the basis of acres. No data were found for Dewey Mills or Woonsocket Falls. Hall Meadow Dam, Mad River Dam, and Sucker Brook Dam appear to be owned by the state of Connecticut and not the Army Corps; however, information for the dams is provided on the Reservoir Regulation website.

Formatting: The conservation pool storage volumes needed to be estimated. This task involved fitting a polynomial equation to the area-capacity curve for flooding and taking into consideration the acres of water present (Figure 4B). In some instances, the normal pool volume is reported, and it served as an anchor point.

Figure 4B. Estimating conservation storage volume

Elevation (ft)	Area (acres)	Capacity (ac-ft)	Full (Percent)	Estimate (ac-ft)
805	0	0	0.0	0
810	4	0	0.0	30
815	8	0	0.0	60
820	12	0	0.0	120
825	16	0	0.0	180
830	20	0	0.0	240
835	27	130	0.0	370
840	34	270	0.5	510



Precipitation also required formatting. From 2008 onward, precipitation started at 0 inches on October 1 and accumulated through September 30. We converted the cumulative precipitation to daily precipitation values. Prior to 2008, the precipitation record appeared to restart at 0 randomly throughout the year, with values increasing and decreasing. It was unclear how to account for the underlying error.

Operating targets: Operating targets in this district are either uniform or seasonal and are provided on the Reservoir Regulation website. Operating targets provided elevations for winter and summer pools. The transition time between winter and summer was estimated using the data.

Summary: Data for this district are available for all reservoirs with area capacity curves, and operational targets are provided. The largest challenges were that data were available only from 1997 to the present, and storage volumes had to be estimated.

UPPER CONNECTICUT RIVER BASIN	NIDID	Data collected	Gross storage (AF)	Classification	Operating purposes
Ball Mountain Dam	VT00001	1997-2015	54,690	Run of River	2
North Hartland Dam	VT00002	1997-2015	71,100	Run of River	3
North Springfield Dam	VT00003	1997-2015	50,500	Run of River	2
Otter Brook Dam	NH00006	1997-2015	18,320	Run of River	2
Surry Mountain Dam	NH00007	1997-2015	33,011	Run of River	2
Townshend Dam	VT00004	1997-2015	33,700	Run of River	2
Union Village Dam	VT00005	1997-2015	38,000	Single Purpose	1
LOWER CONNECTICUT RIVER BASIN					
Barre Falls Dam	MA00962	1997-2015	24,000	Single Purpose	1
Birch Hill Dam	MA00963	1997-2015	49,900	Dry Dam	1
Colebrook River Dam	CT00506	1997-2015	97,700	Multi-purpose	3
Conant Brook Dam	MA00965	1997-2015	3,740	Dry Dam	1
Knightville Dam	MA00969	1997-2015	49,000	Single Purpose	1
Littleville Dam	MA00968	1997-2015	32,400	Multi-purpose	2
Tully Dam	MA00970	1997-2015	22,025	Run of River	2
MERRIMACK RIVER BASIN					
Blackwater Dam	NH00001	1997-2015	46,000	Dry Dam	1
Edward MacDowell Dam	NH00005	1997-2015	12,950	Run of River	2
Everett Dam	NH00002	1997-2015	92,500	Run of River	2
Franklin Falls Dam	NH00003	1997-2015	150,600	Single Purpose	1
Hopkinton Dam	NH00004	1997-2015	70,800	Run of River	2
THAMES RIVER BASIN					
Buffumville Dam	MA00964	1997-2015	11,480	Run of River	2
East Brimfield Dam	MA00966	1997-2015	32,220	Multi-purpose	3
Hodges Village Dam	MA00967	1997-2015	13,250	Dry Dam	1
Mansfield Hollow Dam	CT00503	1997-2015	49,650	Run of River	2
West Thompson Dam	CT00502	1997-2015	26,800	Run of River	2
Westville Dam	MA00972	1997-2015	11,100	Run of River	2
NAUGATUCK RIVER BASIN					
Black Rock Dam	CT00508	1997-2015	8,755	Run of River	2
East Branch Dam	PA00104	1997-2015	84,300	Multi-purpose	5
Hancock Brook Dam	CT00507	1997-2015	4,030	Run of River	2
UPPER CONNECTICUT RIVER BASIN					
Hop Brook Dam	CT00504	1997-2015	6,970	Run of River	2
Northfield Brook Dam	CT00505	1997-2015	2,430	Run of River	2
Thomaston Dam	CT00501	1997-2015	42,000	Dry Dam	1
BLACKSTONE RIVER BASIN					
West Hill Dam	MA00971	1997-2015	12,440	Dry Dam	1
Woonsocket Falls Dam	RI03902	1997-2015	300	Single Purpose	3
Dewey Mills	VT00155	MISSING	1,000	MISSING	1

NORTHWESTERN DIVISION

Kansas City District

Data source: The Kansas City District provided historic reservoir elevations, area-capacity curves following sedimentation surveys, and water manual controls.

Formatting: The data provided were already formatted.

Operating targets: The operational targets were termed "seasonal lake fluctuation plans" or "water level management plans." At many of the reservoirs, these targets represent annual agreements with the state resource agencies to improve the pool values for fish, wildlife, and recreation, and therefore they have changed over time. The district gave an example of the flexibility, stating that "A wet spring may not allow us to fill the pool to five feet higher than normal if we need to preserve flood pool capacity. On the other hand, one year we drained 10 feet from Tuttle Creek Lake to provide navigation flow support on the Missouri River, rather than taking equivalent amounts of water from a total of six lakes, at the request of the state." In general, the seasonal pool fluctuation plans result in operational targets of ±5% of flood pool capacity. Water control manuals for many of these reservoirs were located.

Summary: Data quality is high; few data are missing. The operating targets for many reservoirs were located. Confidence in the data is high.

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Blue Springs Dam	MO12099	1988-2015	26,557	Multi-purpose	3
Clinton Dam	KS00026	1984-2015	394,117	Multi-purpose	5
Harlan County Dam	NE01066	1960-2015	814,111	Multi-purpose	4
Harry S. Truman Dam	MO20725	1983-2015	5,187,032	Multi-purpose	5
Hillsdale Dam	KS82201	1986-2015	159,840	Multi-purpose	5
Kanopolis Dam	KS00005	1952-2015	418,752	Multi-purpose	5
Long Branch Dam	MO11176	1982-2015	64,516	Multi-purpose	5
Longview Dam	MO82202	1987-2015	46,944	Multi-purpose	4
Melvern Dam	KS00007	1976-2015	360,258	Multi-purpose	5
Milford Dam	KS00008	1968-2015	1,145,485	Multi-purpose	6
Perry Dam	KS00009	1971-2015	722,079	Multi-purpose	6
Pomme De Terre Dam	MO30201	1964-2015	644,177	Multi-purpose	4
Pomona Dam	KS00010	1966-2015	240,331	Multi-purpose	5
Rathbun Dam	IA00016	1971-2015	570,553	Multi-purpose	5
Smithville Dam	MO12084	1983-2015	243,443	Multi-purpose	5
Stockton Dam	MO30200	1972-2015	1,650,953	Multi-purpose	5
Tuttle Creek Dam	KS00012	1964-2015	2,150,872	Multi-purpose	6
Wilson Dam	KS00013	1974-2015	772,732	Multi-purpose	4

Omaha District

Mainstem Dams

Data Source: The Omaha District provided reservoir elevations, inflows, and outflows through time. Storage volumes for the six mainstem dams were obtained from the 2006 Master Water Control Manual, which contains tables of area-capacity curves. We obtained data from 1967 to 2014 (the time at which we contacted the district). Some of the data were updated using USGS.

Formatting: Data provided were already formatted. The area capacity curves were converted from KAF to ACF and each 0.1 increment of elevation was infilled with a linear equation (Figure B5).

Figure B5. Sample calculation of the storage volumes

Elevation (FT)	Volume (ACFT)	Calculation	
100	**2300**	= 2300	
100.1	2340	= + (2500-2300)/5	40
100.2	2380	...	
100.3	2420	...	
100.4	2460	...	
100.5	**2500**	= 2500	

Operating targets: Information regarding reservoir pool allocations for the mainstem reservoirs were obtained from the Summary of Engineering Data table in the Annual Operating Plan for 2013–2014. The mainstem reservoirs operate as an overall system and do not have a set annual operating target for individual reservoirs. Therefore, a variety of technical manuals, operating plans, and project statistics were used to derive the most common operating target for each independent reservoir given the time of year, and that rule was applied throughout the period of record. **Any operating target analysis with regard to the mainstem dams should be considered with care until a record of targeted elevations through time is obtained (if possible).**

Summary: No historic water data could be found online. The Omaha District responded rapidly and thoroughly to our request for data. Operating targets for the mainstem reservoirs are complicated and require further research.

MAINSTEM	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Big Bend Dam	SD01092	1967-2014	1,917,600	Multi-purpose	7
Fort Peck Dam	MT00025	1967-2015	18,463,000	Multi-purpose	7
Fort Randall Dam	SD01093	1967-2015	5,418,000	Multi-purpose	7
Garrison Dam	ND00145	1967-2014	23,821,000	Multi-purpose	8
Gavins Point Dam	NE05050	1967-2015	470,000	Multi-purpose	7
Oahe Dam	SD01095	1967-2014	23,137,000	Multi-purpose	7

Tributary Dams

Data source: The Omaha District provided daily elevation, inflows, and outflows from data of construction to 2014 as well as the most recent area capacity curves. We applied that relationship to obtain storage volumes through time. Elevation data were updatable using RiverGages (2014–2015), and storage volumes were estimated using the area capacity curves provided by the district. Only two reservoirs were missing: Red Dale Gulch and Spring Gulch. Our understanding is that these are dry dams that are not actively managed.

Formatting: The data provided were already formatted.

Operating target: The Omaha District provided operating targets for Chatfield and Bowman-Haley reservoirs. We were informed that the rest of the tributary dams are operated to the top of the multi-purpose (MP) elevations, which were obtained from the daily bulletin.

Summary: The quality of data (elevation, storage volume, inflows, and outflows) is high, and no data are missing for the majority of the dams. The operating targets were provided by the district.

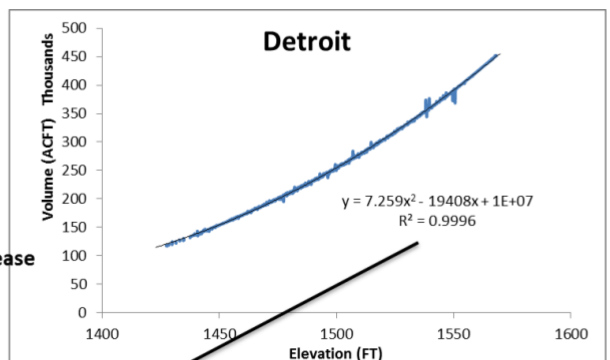
TRIBUTARY	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Bear Creek	CO00004	1977-2015	30,586	Multi-purpose	3
Bowman Haley	ND00147	1967-2015	91,482	Multi-purpose	3
Chatfield Dam	CO01281	1975-2015	234,207	Multi-purpose	4
Cherry Creek Dam	CO01280	1957-2015	133,134	Multi-purpose	3
Cold Brook Dam	SD01097	1953-2015	7,200	Multi-purpose	3
Cottonwood Springs Dam	SD01096	1972-2015	8,385	Multi-purpose	3
Papillion Creek 11 – Glenn Cunningham	NE01518	1975-2015	16,907	Multi-purpose	4
Papillion Creek 16 – Standing Bear	NE01065	1973-2015	4,782	Multi-purpose	4
Papillion Creek 18 – Zorinsky	NE02185	1991-2015	10,512	Multi-purpose	4
Papillion Creek 20 – Wehrspan	NE01882	1985-2015	8,611	Multi-purpose	4
Pipestem Dam	ND00146	1974-2015	142,107	Multi-purpose	3
Salt Creek 2 – Olive Creek Dam	NE01062	1965-2015	4,957	Multi-purpose	3
Salt Creek 4 – Bluestem Dam	NE01064	1963-2015	9,660	Multi-purpose	3
Salt Creek 8 – Wagon Train Dam	NE01056	1963-2015	8,375	Multi-purpose	3
Salt Creek 9 – Stagecoach Dam	NE01059	1964-2015	5,864	Multi-purpose	3
Salt Creek 10 – Yankee Hill Dam	NE01058	1967-2015	7,468	Multi-purpose	3
Salt Creek 12 – Conestoga Dam	NE01055	1965-2015	9,415	Multi-purpose	3
Salt Creek 13 – Twin Lakes Dam	NE01060	1967-2015	7,182	Multi-purpose	3
Salt Creek 14 – Pawnee Dam	NE01057	1966-2015	27,597	Multi-purpose	3
Salt Creek 17 – Holmes Lake	NE01061	1963-2015	6,628	Multi-purpose	3
Salt Creek 18 – Branched Oak Dam	NE01063	1969-2015	96,759	Multi-purpose	3
Red Dale Gulch	SD01098	MISSING	155	Dry Dam	1
Spring Gulch	CO01279	MISSING	1,752	Dry Dam	1

Portland District

Data source: Data were obtained from the Northwestern Division dataquery system. Available data varied from reservoir to reservoir but often include lake (forebay) elevation, tailwater elevation, inflow, outflow, precipitation, and storage volume. Multiple methods were used to collect data covering different time periods. When possible, we selected the daily record that was manually collected because it typically covered the longest period of time. Where gaps in data occurred, we attempted to supplement with data collected through other methods snapped to a daily time step.

Formatting: Data were compiled by matching records to the same date. There were some errors in elevation data (e.g., two digits swapped, 1900.3 ft was 9100.3 ft). Obvious outliers were corrected, and when it was not possible to determine how the error occurred, a value of "NA" was assigned. Storage volumes were problematic for many of the reservoirs; multiple volumes were reported for a single elevation, perhaps due to differences in timing of data collection and methods. It appears unlikely to be due to a shift in the area capacity curve after a sedimentation study because the fluctuation was not consistent by date. Where available, the data were supplemented with area capacity curves found online. If no area capacity curves were available, the average storage volumes were used to create the curves (Figure B6).

Figure B6. Example equation of estimating storage volume based on data



Volumes should increase with elevation

Elevation	Average Storage	Calculation	Difference	Estimated Storage
1432.9	127,988	7.259x²-19,408x+1E7	-115	128,070
1433	126,248		-1962	128,210
1433.1	127,863		-486	128,349
1433.2	126,582		-1907	128,489
...				

Adjust this variable to best match surrounding values

Operating targets: Operating targets for 1990 through 1992 were obtained from the dataquery system and were checked with more recently published targets where possible. The majority of the operating targets matched, but where there were differences, the most recent guide curve was applied through time. This solution is likely too simple for reservoirs whose rules adapt to snowpack and other reservoirs within the system.

Summary: There were some issues with the quality of the data that needed to be resolved. Confidence in storage volumes obtained through Army Corps-published area capacity curves is high. There is uncertainty about storage volumes estimated from the data. Operating targets were obtained for 1990–1992 and were updated if more recent curves were found.

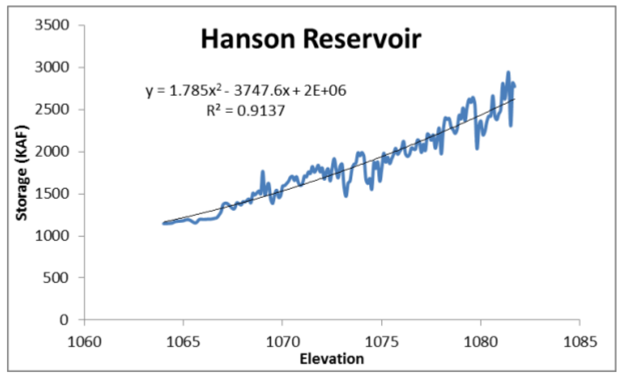
Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Applegate	OR00624	1990-2015	83,300	Multi-purpose	3
Big Cliff	OR00003	1960-2015	5,930	Multi-purpose	2
Blue River	OR00013	1990-2015	89,520	Multi-purpose	5
Bonneville Lock & Dam	OR00001	1960-2015	277,000	Run of River	5
Cottage Grove	OR00005	1982-2015	32,900	Multi-purpose	5
Cougar	OR00015	1971-2015	200,000	Multi-purpose	6
Dalles Lock & Dam	OR00002	1961-2015	277,000	Run of River	6
Detroit	OR00004	1961-2015	472,600	Multi-purpose	6
Dexter	OR00006	1961-2015	34,924	Multi-purpose	3
Dorena	OR00008	1982-2015	77,500	Multi-purpose	5
Fall Creek	OR00007	1982-2015	12,500	Multi-purpose	5
Fern Ridge	OR00016	1975-2015	111,400	Multi-purpose	5
Foster	OR00012	1969-2015	60,800	Multi-purpose	7
Green Peter	OR00010	1969-2015	428,000	Multi-purpose	6
Hills Creek	OR00014	1963-2015	356,000	Multi-purpose	6
John Day Lock & Dam	OR00011	1969-2015	2,523,900	Multi-purpose	7
Lookout Point	OR00009	1971-2015	455,800	Multi-purpose	6
William L. Jess Dam / Lost Creek Lake	OR00612	1977-2015	465,000	Multi-purpose	7
Willow Creek	OR00746	1990-2015	14,091	Multi-purpose	4

Seattle District

Data Source: Data were obtained from the Northwestern Division dataquery system. The data vary from reservoir to reservoir but often include lake (forebay) elevation, tailwater elevation, inflow, outflow, precipitation, and storage volume. Multiple data collection methods are used, and different time periods are covered. When possible we selected the daily record that was manually collected because it typically covered the longest period of time. Where gaps in data occurred, we attempted to supplement with other data collected through other methods snapped to a daily time step.

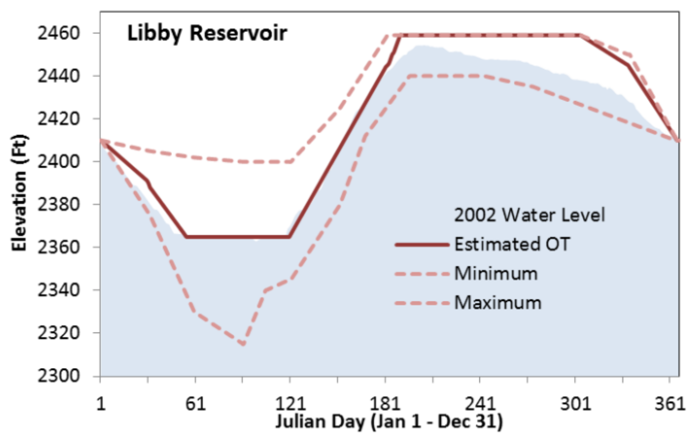
Formatting: Data were compiled by matching records to the same date. Storage volumes were problematic for many of the reservoirs; multiple volumes were reported for a single elevation (Figure B7), perhaps because of differences in timing of data collection and methods. Where available, data was supplemented with area-capacity curves found online. If no area capacity curves were available, the average storage volumes were used to create them. Those curves were applied to the data through time. No storage volume data were found for Mud Mountain reservoir.

Figure B7. Multiple volumes reported per elevation



Operating targets: Operating targets because they are based on winter snow pack and ice conditions. Operating targets for 1997 were obtained from the district. Targets were provided as an operating band for flood control. Some reservoirs provided minimal information, and inferences had to be made to estimate timing of pool increases and decreases (Figure B8). Given the district's variable operating targets, reporting of daily operating targets would be ideal. Any analysis should be considered with care.

Figure B8. Range of variable operating targets for Libby Reservoir



Summary: Data quality is hard to ascertain given the variety of data sources. There are some issues with missing data and storage volumes for those reservoirs without available area-capacity curves. Rule curves in this district are dynamic and not accurately captured at this time. No data was found for Hiram M. Chittenden Lock and Dam.

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Albeni Falls	ID00319	1960-2015	1,561,000	Multi-purpose	4
Chief Joseph Dam	WA00299	1960-2015	516,000	Run of River	1
Hiram M. Chittenden Lock & Dam	WA00301	MISSING	458,000	Lock and Dam	2
Howard A. Hanson Dam	WA00298	1981-2015	105,650	Multi-purpose	3
Libby	MT00652	1975-2015	5,869,392	Multi-purpose	3
Mud Mountain Dam	WA00300	1990-2015	106,275	Dry Dam	1

Walla Walla District

Data source: Data were obtained from the Northwestern Division dataquery system. The data varies from reservoir to reservoir but often include lake (forebay) elevation, tailwater elevation, inflow, outflow, precipitation, and storage volume. Multiple data collection methods are used and cover different time periods. When possible, we selected the daily record that was manually collected because it typically covered the longest period of time. Where gaps in data occurred, we attempted to supplement with other data types snapped to a daily time step.

Formatting: Data were compiled by matching records to the same date. Large sections of data are missing for Lucky Peak and Mill Creek. The average storage volume by elevation was used to estimate volumes for Lucky Peak and Mill Creek. Lucky Peak had large fluctuations in storage volumes per elevation. Storage volumes for Dworshak, Ice Harbor, Little Goose, Lower Granite, Lower Monumental, and McNary were obtained from area capacity curves published by the Army Corps.

Operating targets: The district's reservoir projects are dynamically operated; however, given limited data, we applied a typical year to the period of record. The operating target for Dworshak Dam was estimated from Giovando and Dozier (2011). Operating targets for Ice harbor, Little Goose, Lower Granite, and Lower Monumental reservoirs were estimated from a Northwest Council document. The McNary rule curve is based on flow, and the aforementioned group of dams is operated to meet McNary's target flows. The top of the conservation pool was used as the operating target for McNary. Both Lucky Peak and Mill Creek operating targets were estimated on the basis of the average elevations for each day in the year. Mill Creek elevations are reported far below the dams' operating range, and it is unclear where the discrepancy occurs.

Summary: Confidence in the historic data for all reservoirs in this district except Lucky Peak and Mill Creek is high. Uncertainty about the operating curves for this district is high.

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Dworshak Dam	ID00287	1973-2015	3,468,000	Multi-purpose	5
Ice Harbor Lock & Dam	WA00347	1961-2015	406,500	Run of River	5
Little Goose Lock & Dam	WA00331	1970-2015	565,200	Run of River	5
Lower Granite Lock & Dam	WA00349	1975-2015	485,000	Run of River	5
Lower Monumental Lock & Dam	WA00270	1969-2015	432,000	Run of River	5
Lucky Peak Lake	ID00288	1974-2015	307,043	Multi-purpose	5
McNary Lock & Dam	OR00616	1960-2015	1,350,000	Run of River	5
Mill Creek Storage Dam	WA00348	1993-2015	9,437	Multi-purpose	2

SOUTH ATLANTIC DIVISION

Jacksonville District

Data source: Data could not be found on the Army Corps website but were obtained from the South Florida Water Management District (SFWMD). Only pool elevations were provided, and 7.8% of those data were missing between 1990 and 2015.

Formatting: The data required little formatting.

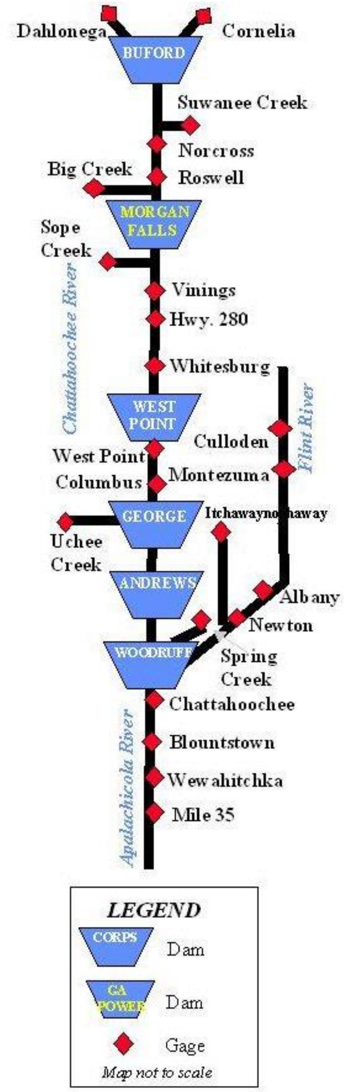
Operating targets: The operating target was located in the 2008 Water Control Plan available on the Army Corps website. Figure 7-2 was used to obtain the operational bands (high and low operating targets) for the lake.

Summary: Elevation data were obtained through the SFWMD, and the operating target was obtained from the 2008 Water Control Manual.

	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Herbert Hoover Dike / Lake Okeechobee	FL36001	1990-2015	4,596,000	Multi-purpose	5

Mobile District

Figure B9. Reservoirs in the ACF



Data source: Data were obtained from http://water.sam.usace.army.mil/ and were organized by major river basins. Figure B9 illustrates the dams connected in the Apalachicola-Chattahoochee-Flint Basin (ACF). Dams operating purely for navigation or recreation purposes provided daily pool elevations. Multipurpose reservoirs provided pool elevation, tailwater elevation, turbine flow, inflow, precipitation, and power generation data. Storage volumes were visually estimated from graphs of area capacity curves for Allatoona, Burford, Carter, Claiborne, R.F. Henry Jones, Millers Ferry, Walter F. George, West Point, and Jim Woodruff dams.

Formatting: Little formatting was required for lock and dam reservoir data with the exception of correcting some elevation data initially recorded as stage. The process of estimating storage volumes from area capacity curve pdf graphs was time consuming and likely to be error prone. Data points along the curve were selected and fitted with a polynomial trendline. The equation from the trendline was used to estimate storage volumes at elevations between selected data points.

Operating targets: The operating targets for reservoirs in the Apalachicola Chattahoochee and Flint (ACF) basin were obtained from a 2012 technical analysis. Operating targets for reservoirs in the Alabama Coosa Tallapoosa (ACT) River Bain were obtained from the appendices of a water control manual update. Zone 1 of the conservation target pool was implemented, and we assumed no drought conditions. The remaining operating targets were found through searches of technical manuals and reports.

Summary: Elevation data were available for all reservoirs in the Mobile District. No digital storage volumes were available. Storage volumes were estimated for reservoirs with data on area capacity curves and were applied back through time. There is a high degree of uncertainty regarding these volumes. Operational targets from the ACF and ACT basins were obtained through technical and water control manuals and were applied for the period of record. The remaining targets were derived from ad-hoc sources, and uncertainty regarding them is relatively high. Locks and dams were considered to be run-of-river.

APALACHICOLA-CHATTAHOOCHEE-FLINT BASIN	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Buford Dam / Lake Lanier	GA00824	1956-2015	3,850,000	Multi-purpose	7
George W. Andrews Lock & Dam	AL01433	1985-2015	18,180	Lock and Dam	2
Jim Woodruff Dam	FL00435	1957-2015	406,200	Multi-purpose	5
Walter F. George	AL01432	1963-2015	934,400	Multi-purpose	5
West Point	GA00820	1975-2015	774,800	Multi-purpose	7
ALABAMA-COOSA-TALLAPOOSA BASIN					
Allatoona Lake	GA03742	1950-2015	670,047	Multi-purpose	6
Carters Main Dam	GA00821	1975-2015	472,756	Multi-purpose	4
Claiborne Lock & Dam	AL01436	1982-2015	96,360	Lock and Dam	2
Millers Ferry Lock & Dam	AL01435	1970-2015	331,800	Lock and Dam	2
Robert F. Henry Lock & Dam	AL01434	1975-2015	234,200	Lock and Dam	2
BLACK WARRIOR-TOMBIGBEE BASIN					
A.I. Selden Lock & Dam	AL01429	1985-2015	49,100	Lock and Dam	2
Coffeeville Lock & Dam	AL01431	1985-2015	190,800	Lock and Dam	2
Demopolis Lock & Dam	AL01430	1985-2015	150,000	Lock and Dam	1
John Hollis Bankhead Lock & Dam	AL01427	1985-2015	296,000	Lock and Dam	2
Holt Lock & Dam	AL01426	1985-2015	117,990	Lock and Dam	2
William Bacon Oliver Replacement	AL01981	1985-2015	13,800	Multi-purpose	2
TENNESSEE-TOMBIGBEE BASIN					
Aberdeen Lock & Dam	MS03057	1985-2015	31,564	Lock and Dam	2
Amory Lock & Dam	MS03058	1985-2015	4,386	Lock and Dam	2
Fulton	MS03060	1988-2015	13,221	Multi-purpose	3
G.V. Montgomery	MS03604	1990-2015	7,700	Multi-purpose	3
Glover Wilkins Lock & Dam	MS03059	1985-2015	19,039	Lock and Dam	2
Howell Helfin Lock & Dam	AL01980	1985-2015	58,000	Multi-purpose	3
Jamie L. Whitten Lock & Dam	MS03605	1990-2015	180,000	Multi-purpose	4
John C. Stennis	MS03056	1985-2015	59,483	Multi-purpose	3
John Rankin Lock & Dam	MS82201	1990-2015	27,000	Lock and Dam	2
Tom Bevill Lock & Dam	AL01979	1985-2015	60,400	Lock and Dam	2
PASCOGOULA, ESCAMBIA BASINS					
Okatibbee Dam	MS01491	1974-2015	142,350	Multi-purpose	5

Savannah District

Data source: Data were obtained from http://water.sas.usace.army.mil/gmap/historicData.cfm. Data were available for all reservoirs from date of construction to the present. The data included elevation, storage volume, inflow, outflow, power generation, and precipitation. Some of the data were challenging to interpret without definitions of terms. For example, what is the different between local inflow, natural inflow, and net inflow? We selected net inflow for this database.

Formatting: The district supplied daily data; no additional formatting was required.

Operational target: The operational targets were provided on a daily basis through time, enabling changes in operation to be captured.

S**ummary:** Daily data through time were provided through a simple, easy-to-use query. Data were standardized and simple to combine. Certainty regarding data and operating targets is high.

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Hartwell Dam	GA01702	1962-2015	2,842,700	Multi-purpose	6
J. Strom Thurmon Dam	GA01705	1954-2015	2,900,000	Multi-purpose	6
Richard B. Russell Dam	GA01705	1948-2015	1,166,166	Multi-purpose	6

Wilmington District

Data source: Data were obtained from http://epec.saw.usace.army.mil. Data could were available for all multi-purpose reservoirs from construction through 2014, but not for lock and dams. Data has not been uploaded to the website since May 2014. Data include guide curve elevation, pool elevation, storage volume, water supply outflow, reservoir outflow, and reservoir inflow. The website also contains pertinent data regarding pool allocations.

Formatting: The district supplies data in 10-year increments, and the files had to be combined. No other major formatting was needed.

Operational target: Operational targets are provided on a daily basis and are either uniform or seasonally dependent. Because the operational target is provided through time, changes in operation are captured. For example, Falls Lake went from a seasonal operational target to a uniform target in 1999.

Summary: Data for this district were provided by month in 10-year increments. Data were standardized and simple to combine. Certainty regarding data and operating targets is high.

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
B. Everett Jordan Dam	NC00173	1974-2014	1,646,560	Multi-purpose	5
Falls Lake Dam	NC01713	1985-2014	1,020,980	Multi-purpose	5
John H. Kerr Dam	VA11701	1952-2014	3,364,500	Multi-purpose	5
Cape Fear Lock & Dam 1	NC00182	MISSING	20,000	Lock and Dam	1
Cape Fear Lock & Dam 2	NC00205	MISSING	3,000	Lock and Dam	1
Philpott Dam	VA08901	1951-2014	318,300	Multi-purpose	6
W. Kerr Scott Dam	NC00300	1962-2014	306,000	Multi-purpose	4
William O. Huske Lock & Dam	NC00206	MISSING	2,000	Lock and Dam	1

SOUTHWESTERN DIVISION

Fort Worth District

Data source: Data from Fort Worth District were obtained through a hydrologic data link. Data include elevation, storage, inflow, outflow, evaporation, and precipitation since construction. Some reservoirs' area capacity curves changed. Some reservoirs had sedimentation reports.

Formatting: Data were easy to format. The most time-consuming task was searching for changes in area capacity so that operating target volumes could be adjusted.

Operating targets: Operating targets were obtained from the district and various documents from the Texas Water Development Board. Most reservoirs have a uniform target.

Summary: There is high confidence in data, which are available through an easy-to-use tool.

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Aquilla Lake	TX08004	1983-2015	206,694	Multi-purpose	3
Bardwell Lake	TX00001	1965-2015	131,640	Multi-purpose	2
Belton Lake	TX00002	1972-2015	1,079,348	Multi-purpose	3
Benbrook Lake	TX00003	1952-2015	255,945	Multi-purpose	2
Canyon Lake	TX00004	1964-2015	733,602	Multi-purpose	4
Ferrells Bridge Dam / Lake O' Pines	TX00020	1957-2015	828,241	Multi-purpose	3
Granger Dam	TX08005	1981-2015	231,022	Multi-purpose	2
Grapevine Lake	TX00005	1952-2015	407,536	Multi-purpose	2
Hords Creek Lake	TX00006	1948-2015	24,734	Multi-purpose	2
Jim Chapman Lake	TX08012	1991-2015	428,570	Multi-purpose	2
Joe Pool Lake	TX08007	1986-2015	362,725	Multi-purpose	2
Lavon Lake	TX00007	1954-2015	649,367	Multi-purpose	2
Lewisville Lake	TX00008	1954-2015	886,732	Multi-purpose	2
Navarro Mills Lake	TX00009	1963-2015	206,185	Multi-purpose	2
North San Gabriel Dam	TX08006	1981-2015	130,737	Multi-purpose	2
O.C. Fisher Dam	TX00012	1952-2015	392,686	Multi-purpose	2
Proctor Lake	TX00010	1963-2015	370,407	Multi-purpose	2
Ray Roberts Dam	TX08008	1987-2015	1,261,460	Multi-purpose	3
Sam Rayburn Dam	TX00011	1965-2015	4,305,138	Multi-purpose	3
Somerville Lake	TX00013	1966-2015	495,455	Multi-purpose	2
Stillhouse Hollow Dam	TX00014	1966-2015	620,757	Multi-purpose	2
Town Bluff Dam	TX00015	1951-2015	218,200	Multi-purpose	2
Waco Lake	TX00016	1964-2015	735,754	Multi-purpose	2
Whitney Lake	TX00017	1952-2015	1,926,778	Multi-purpose	3
Wright Patman Dam	TX00021	1954-2015	2,607,112	Multi-purpose	3

Little Rock District

Data source: Data were downloaded from the Little Rock District at a monthly time step from 1989 to present. Data include two elevation records (7 a.m. and 12 p.m.), the volume for the 12 p.m. reading, power outflow, total outflow, average inflow, evaporation, precipitation within the reservoir, precipitation within the basin, water supply withdrawal, and unaccounted-for losses. Flow volumes are reported in days per second, which appears to be roughly equivalent to the more commonly used CFS metric. Data were missing for Lock and Dam 1 (Norrell).

Formatting: Data formatting largely consisted of stitching together the monthly elevation text files. The water supply withdrawn and unaccounted-for losses were supplied on a monthly basis. We distributed those values evenly to conform to a daily format (i.e., if 3,120 AF were withdrawn for water supply in January, each day would be recorded as having 3,120/31 = 100.6 AF withdrawn).

Operating targets: The district split into two categories: reservoirs and Arkansas rivers (lock and dams). Reservoir operating targets are provided by the district as elevation targets within a year. The Arkansas River operating targets are provided an elevation range defined by flow. Two lock and dams had seasonal pool limits and one had pool limits defined by tailwater elevations.

Summary: Data for this district are available for the majority of reservoirs and include reservoir elevation, storage volumes, and operating targets. The largest challenge was downloading the data at a monthly time step.

RESERVOIRS	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Beaver	AR00174	1989-2015	2,182,500	Multi-purpose	4
Blue Mountain	AR00157	1989-2015	653,480	Single Purpose	2
Bull Shoals	AR00160	1989-2015	6,013,000	Multi-purpose	4
Clearwater Dam	MO30203	1989-2015	911,150	Single Purpose	1
Dequeen	AR01201	1989-2015	370,600	Multi-purpose	4
Dierks	AR01202	1989-2015	221,600	Multi-purpose	4
Gillham	AR01200	1989-2015	238,310	Multi-purpose	4
Greers Ferry	AR00173	1989-2015	3,313,000	Multi-purpose	4
Millwood Dam	AR00536	1989-2015	2,618,750	Multi-purpose	4
Nimrod	AR00158	1989-2015	851,275	Multi-purpose	2
Norfork	AR00159	1989-2015	2,108,700	Multi-purpose	4
Table Rock Dam	MO30202	1989-2015	4,075,000	Multi-purpose	4

ARKANSAS RIVER	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Arkansas River Lock & Dam 1–Norrell	AR00161	MISSING	1,510	Lock and Dam	1
Arkansas River Lock & Dam 2–Wilber D. Mills	AR00169	1989-2015	133,200	Lock and Dam	2
Arkansas River Lock & Dam 3–Joe Hardin	AR00168	1989-2015	50,400	Lock and Dam	1
Arkansas River Lock & Dam 4–Emmet Sanders	AR00167	1989-2015	77,000	Lock and Dam	1
Arkansas River Lock & Dam 5-Col Charles Maynard	AR00166	1989-2015	68,500	Lock and Dam	2
Arkansas River Lock & Dam 6–David D. Terry	AR00172	1989-2015	59,600	Lock and Dam	1
Arkansas River Lock & Dam 7–Murray	AR00171	1989-2015	108,500	Lock and Dam	1
Arkansas River Lock & Dam 8-Toad Suck Ferry	AR00170	1989-2015	37,300	Lock and Dam	1
Arkansas River Lock & Dam 9-Arthur V. Ormond	AR00165	1989-2015	70,400	Lock and Dam	1
Arkansas River Lock & Dam 10-Dardanelle	AR00162	1989-2015	486,200	Lock and Dam	2
Arkansas River Lock & Dam 11-Montomery Point	AR01545	1989-2015	10,595	Lock and Dam	1
Arkansas River Lock & Dam 12-Ozark	AR00164	1989-2015	148,400	Lock and Dam	2
Arkansas River Lock & Dam 13-James W. Trimble	AR00163	1989-2015	59,100	Lock and Dam	1

Tulsa District

Data source: Post–1994 data were obtained from the Tulsa District website. Pre–1994 data were provided by the Tulsa District's through an external hard drive with pdfs. The data were digitized using an online OCR for more recent pdfs. Older pdfs were not readable and had to be manually entered. Data prior to October 1979 were presented as graphs.

Data include two elevation records (8 a.m. and 12 a.m.), the volume for the 12 a.m. reading, power outflow, total outflow, average inflow, evaporation, precipitation within the reservoir, and precipitation within the basin. Flow volumes are reported in days per second, which appears to be roughly equivalent to the more commonly used CFS metric. The pdfs contain notes on deviations for recreation, drowning deaths, and so on.

Data were missing for Chouteau lock and dam and Truscott Brine Lake. Truscott is a unique reservoir in that water is funneled into it and allowed to evaporate. Lock and dam information is not available online, so all records cease after 1994 (pdf data were digitized prior to that date).

Formatting: Data formatting consisted of stitching together the monthly elevation text files.

Operating targets: Operating targets were obtained from the Tulsa District. No operating targets are available for lock and dams.

Summary: Data are of high quality, and operating targets were provided by the district.

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Arcadia Lake	OK22178	1985-2015	92,020	Multi-purpose	2
Big Hill Lake	KS00049	1980-2015	42,564	Multi-purpose	2
Birch Lake	OK20508	1979-2015	59,030	Multi-purpose	3
Broken Bow Lake	OK10307	1979-2015	1,368,245	Multi-purpose	5
Canton Lake	OK10316	1979-2015	377,100	Multi-purpose	2
Chouteau Lock & Dam	OK10303	MISSING	23,340	Lock and Dam	1
Copan Lake	OK21489	1980-2015	221,491	Multi-purpose	4
Council Grove Lake LAKE	KS00001	1979-2015	238,695	Multi-purpose	3
Denison Dam / Lake Texoma	OK10317	1979-2015	5,061,062	Multi-purpose	4
El Dorado Lake	KS00027	1979-2015	301,104	Multi-purpose	4
Elk City Lake	KS00002	1979-2015	284,458	Multi-purpose	5
Eufaula Lake	OK10308	1979-2015	3,825,400	Multi-purpose	5
Fall River Lake	KS00003	1979-2015	254,876	Multi-purpose	2
Fort Gibson Lake	OK10314	1979-2015	1,284,400	Multi-purpose	4
Fort Supply Lake	OK10318	1979-2015	100,770	Multi-purpose	2
Great Salt Plains Lake	OK10319	1979-2015	241,695	Single Purpose	1
Heyburn Lake	OK10313	1979-2015	56,303	Multi-purpose	2

Name	NIDID	Data collected	Gross storage (ACFT)	Classification	Operating purposes
Hugo Lake	OK10300	1979-2015	960,323	Multi-purpose	4
Hulah Lake	OK10312	1979-2015	285,897	Multi-purpose	4
John Redmond Lake	KS00004	1979-2015	574,918	Multi-purpose	4
Kaw Lake	OK20509	1979-2015	1,327,155	Multi-purpose	5
Keystone Lake	OK10309	1979-2015	1,672,613	Multi-purpose	5
Marion Lake	KS00006	1979-2015	141,802	Multi-purpose	3
Newt Graham Lock & Dam	OK10302	1979-1994	23,500	Lock and Dam	1
Oologah Lake	OK10310	1979-2015	1,559,279	Multi-purpose	3
Optima Lake	OK20510	1979-1994	382,500	Run of River	1
Pat Mayse Lake	TX04359	1979-2015	182,942	Multi-purpose	2
Pine Creek Lake	OK10306	1979-2015	465,780	Multi-purpose	4
Robert S. Kerr Lock & Dam	OK10301	1979-1994	525,700	Lock and Dam	3
Sardis Lake	OK22199	1981-2015	468,057	Multi-purpose	2
Skiatook Lake	OK22200	1981-2015	543,626	Multi-purpose	3
Tenkiller Lake	OK10311	1979-2015	1,230,800	Multi-purpose	5
Toronto Lake	KS00011	1979-2015	200,839	Multi-purpose	3
Truscott Brine Lake	TX05996	MISSING	116,200	Single Purpose	1
W.D. Mayo Lock & Dam	OK10305	1979-1994	15,800	Lock and Dam	1
Waurika Lake	OK22203	1979-2015	451,107	Multi-purpose	4
Webbers Falls Lock & Dam	OK10304	1979-1994	170,100	Lock and Dam	2
Wister Lake	OK10315	1979-2015	427,485	Multi-purpose	5

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