Institute for Water Resources

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Status and Challenges for USACE Reservoirs

A Product of the National Portfolio Assessment for Water Supply Reallocations

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US Army Corps of Engineers®

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The Institute for Water Resources (IWR) is a U.S. Army Corps of Engineers (USACE) Field Operating Activity located within the Washington DC National Capital Region (NCR), in Alexandria, Virginia and with satellite centers in New Orleans, LA; Davis, CA; Denver, CO; and Pittsburg, PA. IWR was created in 1969 to analyze and anticipate changing water resources management conditions, and to develop planning methods and analytical tools to address economic, social, institutional, and environmental needs in water resources planning and policy. Since its inception, IWR has been a leader in the development of strategies and tools for planning and executing the USACE water resources planning and water management programs.

IWR strives to improve the performance of the USACE water resources program by examining water resources problems and offering practical solutions through a wide variety of technology transfer mechanisms. In addition to hosting and leading USACE participation in national forums, these include the production of white papers, reports, workshops, training courses, guidance and manuals of practice; the development of new planning, socio-economic, and risk-based decision-support methodologies, improved hydrologic engineering methods and software tools; and the management of national waterborne commerce statistics and other Civil Works information systems. IWR serves as the USACE expertise center for integrated water resources planning and management; hydrologic engineering; collaborative planning and environmental conflict resolution; and waterborne commerce data and marine transportation systems.

The Institute's Hydrologic Engineering Center (HEC), located in Davis, CA specializes in the development, documentation, training, and application of hydrologic engineering and hydrologic models. IWR's Navigation and Civil Works Decision Support Center (NDC) and its Waterborne Commerce Statistical Center (WCSC) in New Orleans, LA, is the Corps data collection organization for waterborne commerce, vessel characteristics, port facilities, dredging information, and information on navigation locks. IWR's Risk Management enter is a center of expertise whose mission is to manage and assess risks for dams and levee systems across USACE, to support dam and levee safety activities throughout USACE, and to develop policies, methods, tools, and systems to enhance those activities.

Other enterprise centers at the Institute's NCR office include the International Center for Integrated Water Resources Management (ICIWaRM), under the auspices of UNESCO, which is a distributed, intergovernmental center established in partnership with various Universities and non-Government organizations; and the Conflict Resolution and Public Participation Center of Expertise, which includes a focus on both the processes associated with conflict resolution and the integration of public participation techniques with decision support and technical modeling. The Institute plays a prominent role within a number of the USACE technical Communities of Practice (CoP), including the Economics CoP. The Corps Chief Economist is resident at the Institute, along with a critical mass of economists, sociologists and geographers specializing in water and natural resources investment decision support analysis and multi-criteria tradeoff techniques.

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This report is based on a wide range of data gathering, analysis, product development and reporting completed by U.S. Army Corps of Engineers subject matter experts since the National Portfolio effort began in 2008. Their work could not have been completed without the efforts of Corps staff throughout the country in responding to the initial survey and data collection efforts. Many thanks and sincere appreciation are due to all of those in the field who must fit surveys such as these into their already full schedules. The subject matter experts who managed specific efforts described in the report sections included (in alphabetical order): Mr. Bryan Baker, USACE Engineer Research & Development Center Cold Regions Research and Engineering Laboratory; Ms. Deborah Cooper, USACE Engineer Research & Development Center Coastal and Hydraulics Laboratory; Dr. John Hickey, USACE Institute for Water Resources Hydrologic Engineering Center; Ms. Meg Jonas, Headquarters USACE; Mr. Dave Shepp, Headquarters USACE (retired); and Dr. David Williams, USACE Tulsa District. The leadership and expertise provided by these individuals over the past several years is much appreciated. Their efforts have significantly contributed to a better understanding of the status and challenges facing the Corps as the largest reservoir management agency in the United States.

The National Portfolio effort began in the Corps Water Supply Business Line. As it evolved to include more aspects of multi-purpose reservoir operations, the Water Supply Business Line remained responsible for management of the overall effort. Special thanks are due to Ms. Jeannette Baker, the current Water Supply Business Line Manager at the USACE Institute for Water Resources, and Mr. Ted Hillyer (retired), former Water Supply Business Line Manager, for providing direction and oversight throughout the effort. Mr. Hillyer led this effort from its beginning nearly ten years ago, prepared the draft of this report, and continues to support the effort as a contractor. His endurance is an inspiration to the team, and his wealth of knowledge and wisdom remain an invaluable resource.

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Executive Summary

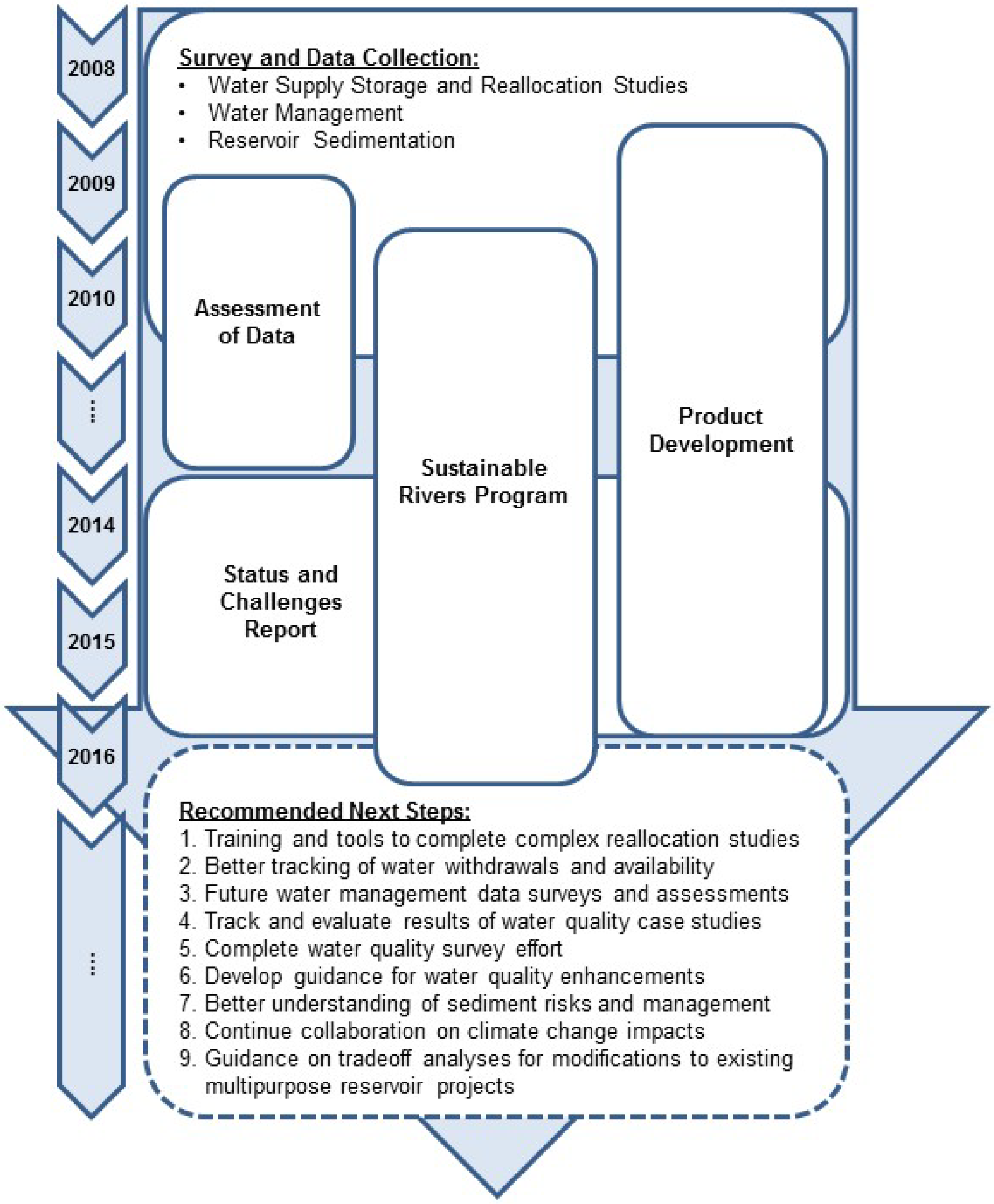
The era of the federal government funding and constructing large, multipurpose dam and reservoir projects in the United States was relatively brief but resulted in long-lasting changes to society and the environment. Many regions in the country have come to depend on U.S. Army Corps of Engineers (USACE, Corps) reservoir projects to manage the risks of flooding, ensure reliable supplies of water for public health and economic production, generate clean and affordable electricity, provide safe and enriching opportunities for water-based recreation to the public, and maintain adequate levels of streamflow to support navigation and commerce on the inland waterways, aquatic and wildlife habitat, and water quality. Most of the Corps dam and reservoir projects have passed the end of their original 50-year planning lives and are entering a life-cycle phase of long-term maintenance and modification. This report examines the current status and some of the challenges facing the Corps in achieving its strategic goal of continuing to manage its portfolio of reservoir projects to consistently and sustainably deliver the vital services they provide to the Nation.

This report focuses on a portfolio of 356 reservoir projects[1] owned and operated by the Corps. For purposes of this report, a "reservoir" project is defined as having storage space allocated for either, and typically both flood risk management and conservation purposes, and does not typically include the many lock and dam projects that serve the inland waterways system. The National Portfolio effort began in the early 2000s with a Fiscal Year (FY) 2005 budget proposal to review how the Corps portfolio of reservoir projects could best continue to support and enhance contemporary economic and ecosystem values, identify changes in operational policies requiring more in-depth studies, and support state and local planning efforts, such as state water plans.

The National Portfolio effort was first funded by Congress in FY 2008 and began with a comprehensive survey of water management, water supply and reservoir sedimentation issues that continued through FY 2010. An initial assessment of sedimentation data was completed in FY 2008 and in FY 2010 the Corps presented an assessment of water supply storage reallocation study needs to the Assistant Secretary of the Army for Civil Works. In subsequent years, the focus of the portfolio responded to Administration and Congressional direction and funding, and included additional assessments of the survey data, product development and case studies, and partnerships with related efforts such as the Nature Conservancy's Sustainable Rivers Program. **Figure ES-1**, on the following page, illustrates the general timeline and components of the overall National Portfolio effort. In FY 2014, the Corps began preparing this report to assess the status and challenges to the reservoir project portfolio.

[1] See **Section 3-3** for discussion of this count of reservoir projects.

Figure ES-1. National Portfolio Effort Timeline



There have been two overarching objectives throughout the National Portfolio effort: eliminate duplication through outreach and collaboration across the organization, and support the Civil Works Strategic Plan. The body of the report details the successes that have been achieved in eliminating duplication of efforts. This report addresses two objectives of the current (2014 – 2018) Corps Civil Works Strategic Plan, under Goal 5, "Manage the life-cycle of water resources infrastructure systems in order to consistently deliver sustainable services:"

- Objective 5.4. Provide water supply storage in partnership with State and local interests. The original focus of the National Portfolio effort was on the Corps water supply program.
- Objective 5.2. Capitalize, recapitalize, operate and maintain water resources infrastructure to provide maximum value to the Nation. Many of the challenges identified in this report relate to this objective.

Furthermore, throughout this report the reader will find applications of the strategies and collaborative approaches adopted in the Civil Works Strategic Plan. Multi-purpose reservoir projects embody integrated water resources management (IWRM), and the holistic thinking of IWRM, as well as systems approaches, are necessary in solving the challenges facing these projects. The long-term federal/non-federal partnership reflected in water supply storage agreements is also an example of the innovative financing approaches being pursued in other water resources mission areas, as water supply users at Corps reservoirs have always been responsible for repaying the allocated costs of water supply storage. Case studies of adaptive management are presented where Corps districts, sometimes in partnership with the Nature Conservancy, are exploring operational changes that can benefit the ecosystems linked to reservoirs and better position the projects to maximize operational benefits in an uncertain future. Underlying all of the studies and examples in this report is the risk-informed decision making and communication that must support the necessary tradeoffs involved when operating these projects for multiple purposes.

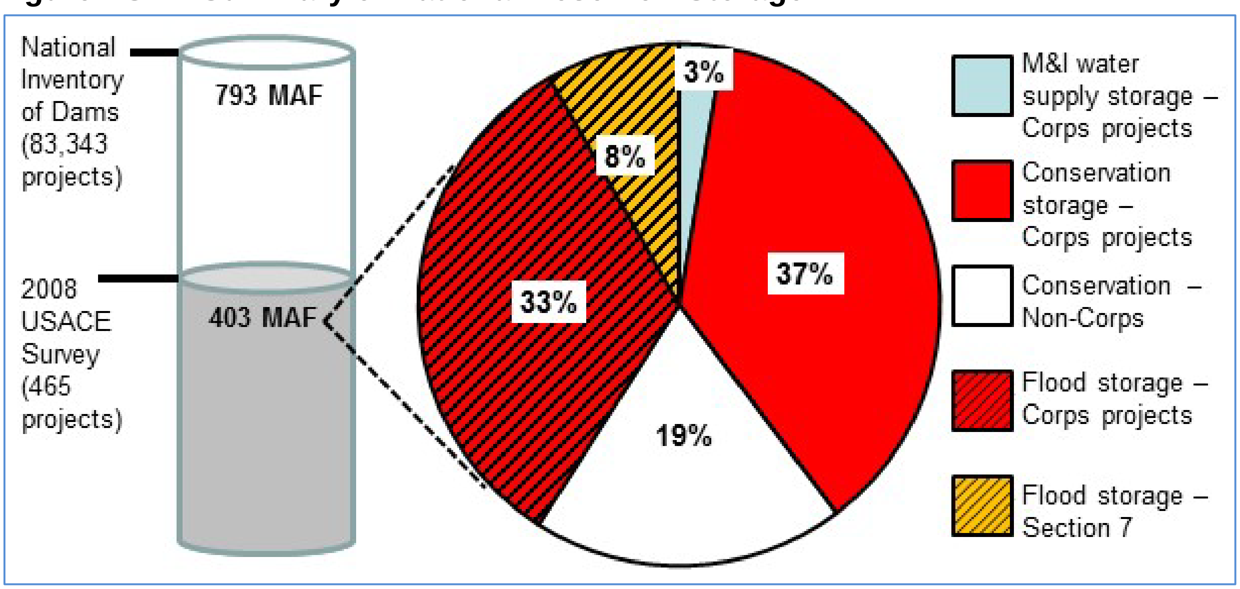
The overall topic of status and challenges to aging dam and reservoir projects in the country is very broad, including the condition of the physical infrastructure as well as the changing conditions and requirements that impact project missions, and the funding and resources to sustain, adapt and continue those missions into the future. This report focuses on five topics that have been primary areas of review for the National Portfolio effort: reallocations of reservoir storage to serve increasing water supply needs, water management data and trends, project changes to sustain and enhance environmental conditions for water quality and aquatic ecosystems, reservoir sedimentation and uncertainty in future conditions. The reader should keep in mind that, while discussed separately in this report, these focus areas remain inherently linked with very important programs and ongoing efforts not discussed in detail here, such as dam safety and asset management.

Water Supply Storage and Reallocation (Section 2)

Storage space for water supply is typically included in Corps reservoir projects under the authority of the 1958 Water Supply Act (WSA). This law creates a unique partnership where the Corps continues to own, maintain and operate the project for multiple purposes, while non-federal entities have the right to access and use storage space in the reservoir to enhance the reliability of variable streamflow for their municipal and industrial (M&I) water supply needs, on the condition that the non-federal users must reimburse the full costs of constructing, operating and maintaining the portion of the project allocated to water supply. The 1958 WSA authority does not include needs for commercial irrigation, although many Corps projects in the Western United States also serve this purpose. As the construction of major federal reservoir projects came to an end in the 1980s, the focus of the Corps water supply program shifted to reallocation of storage space in existing projects from another purpose, or purposes, to specifically serve water supply needs. Decisions to reallocate reservoir storage space to water supply have become increasingly difficult over time, as they are intertwined with all of the other challenges facing our aging dam and reservoir projects and increasingly competing demands for limited supplies of water.

The most current data shows that the Corps currently maintains M&I water supply agreements for about 9.8 million acre-feet of storage space at 136 reservoir projects across the country. The great majority (over 90 percent) of this storage was included at the request of non-federal users at the time the projects were being planned, designed and constructed. The remaining 10 percent represents storage that has since been reallocated from the originally authorized project purposes for developing water supply needs. Almost 90 percent, by storage volume, of these reallocations have occured since 1980. **Figure ES-2** shows the total 9.8 million acre-feet of currently authorized M&I storage space in perspective with the 403 million acre-feet of total reservoir storage volume in 465 projects surveyed by the Corps in 2008, according to the National Inventory of Dams (NID) at the time[2]. The 465 projects included all reservoirs in the country with federally-authorized storage for flood risk management, including both those operated directly by the Corps and indirectly under Section 7 of the 1944 Flood Control Act.

Figure ES-2. Summary of National Reservoir Storage



[2] See Section 3-3 for a detailed discussion of this figure and data.

The 403 million acre-feet of storage in these 465 projects represents about half of all reservoir storage in the country. While many of the reservoirs in the NID not surveyed by the Corps may contain storage for water supply needs, and in fact some exist solely for water supply purposes, the 465 projects in the Corps survey represent a significant portion of large reservoirs in the country, and, with little or no new reservoir storage space under construction, reallocation of existing storage space in these reservoirs will continue to be an attractive alternative for the non-federal entities responsible for serving the growing water supply needs of the Nation.

The 2010 information paper prepared for the Assistant Secretary of the Army for Civil Works on water supply storage reallocation studies recommended a priority list of 52 projects for study, and presented alternatives for shifting the funding of reallocation studies to the prospective non-federal users in accordance with guidance from the Office of Management and Budget. One recommendation for alternative funding, to allow non-federal sponsors to voluntarily contribute funds for studies, was subsequently enacted through legislation with the passage of the FY 2012 Energy and Water Development Appropriations Act in 2011. Since 2012, fifteen reallocation studies have received funding through the normal budget process to some stage of completion. After the expansion of the contributed funds authority, 33 U.S.C. §701h, voluntarily contributed funds have been accepted to begin two additional studies, bringing the total number of funded studies to seventeen. Including one additional study that was completed in 2010, 26 of the 52 priority projects identified in 2010 have been studied to some degree, and there have also been study efforts at an additional ten projects.

Water Management Data and Trends (Section 3)

As discussed above, the National Portfolio survey covered 465 projects that together account for about half of the total constructed reservoir storage space in the United States. The survey collected data and responses in an effort to understand how water is managed at these projects in terms of reservoir storage and release decisions. Data collection, assessment and interpretation was managed by the Corps' Institute for Water Resources Hydrologic Engineering Center and resulted in over 37 million daily values representing about 80 percent of the operational history of the surveyed projects. The data interpretation described in detail in this report included the allocation of storage and motivating factors for release decisions and operational changes at reservoir projects. Allocation of storage is described above in **Figure ES-2**. It should be noted that the division between conservation and flood risk management (shown as cross-hatched in the figure) storage at many projects is seasonal, and the total of either category may be greater or less by about seven percent depending on the season.

Historically, operational changes at projects have been most frequently motivated by flood risk management considerations (41 percent). The other two areas considered in detail in this report are also the next two most frequent motivating purposes for operational changes, with water supply at 15 percent and environmental flows (both chemical and biological needs) at 14 percent. Operating changes for environmental flows were rare prior to 1990, but have increased significantly since then. The motivating purpose for release decisions is harder to describe from the data collected, but, with assumptions as described in **Section 3**, since 1989 most releases appear to have been motivated by hydropower generation. This characterization is heavily influenced by the volume of releases from the mainstem reservoir projects on the Columbia and Missouri Rivers, as well as data for Hoover Dam on the Colorado River. The nine dams on these rivers covered in the survey account for nearly half of the total project outflows recorded since 1989. It should be noted that the releases made through the hydropower turbines may be coordinated with other downstream needs, but, the available data was insufficient to quantify other uses of hydropower releases.

Environmental Conditions (Section 4)

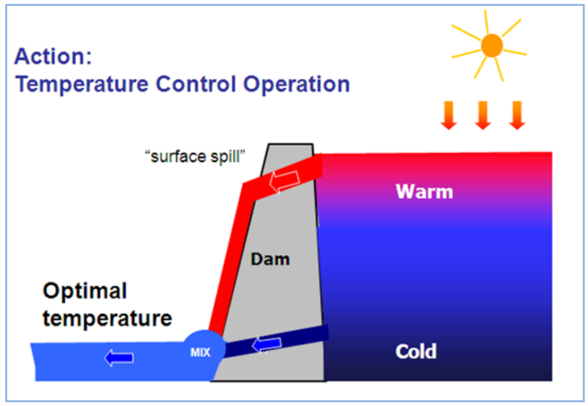
While some environmental releases are made in order to affect physical, chemical and biological conditions in the reservoir pool itself, most of the releases at the surveyed projects typically address downstream, minimum flow requirements (61 percent of environmental releases), or temperature management (17 percent) goals. Of the downstream minimum flow requirements, two-thirds were reported as constant flow targets, while the remaining one-third varied either seasonally or conditionally.

This report describes two complementary efforts that have been administered through the National Portfolio to better understand challenges and opportunities to make changes in reservoir operations that may benefit physical, chemical and biological conditions. This section of the report documents efforts involving nearly 70 Corps dam and reservoir projects to work with other agencies, stakeholders and communities to improve environmental conditions related to Corps projects. The Corps Committee on Water Quality is charged with providing leadership, policy and technical guidance on issues involving water quality and ecological sustainability. Since the assessment of the 2008 survey data, the Committee has produced a compilation of case studies of benefits realized from relatively modest structural and operational changes at projects, and an information paper on water quality and ecological challenges to multi-purpose reservoir project missions. Challenges identified by the Committee include: variability in weather and departures from observed long-term patterns, increasing frequency and severity of harmful algal blooms in Corps reservoirs, growing pressure on existing water resources due to rapidly increasing demands in some areas, and interest in non-federal retrofit hydropower facilities at Corps dams.

While the Committee on Water Quality case studies show how relatively minor changes, often within existing operational guidelines, can enhance environmental conditions, such as the example shown in **Figure ES-3**, on the following page, some situations may require more complex, programmed efforts, as exemplified by the

Sustainable Rivers Program (SRP) partnership between the Corps and The Nature Conservancy. Since FY 2010, funding through the National Portfolio has supported both national and project site efforts in the SRP focus areas of implementation, science, technology and outreach. Work at SRP sites currently involves 36 reservoirs in eight river basins. The overall objective of the SRP is to restore and protect the environmental health of dammed river systems, while continuing to serve human needs such as flood risk management, water supply and hydropower generation. An additional six sites have expressed interest in the program, potentially involving 22 more reservoir projects as well as navigation lock and dam projects.

Figure ES-3. Example Case Study at Detroit Dam, OR



Reservoir Sedimentation (Section 5)

The National Portfolio survey effort also looked at sedimentation in Corps projects. Of the 363 projects in this data set (which included some projects outside of this report's definition of "reservoir"), fourteen projects were reported as having greater than 25 percent of the original conservation storage filled by sediment. Respondents were also asked to describe the impact of sedimentation on project purposes as either moderate (limiting operation for the purpose 10% or more of the time), significant (limiting operation 25% or more of the time) or severe (limiting operation nearly all of the time). For the surveyed reservoirs, 221 moderate impacts were reported, indicating that project operations become impacted when sediment accumulations are less than 25% of the original project storage. Only seven instances of signifcant or severe impacts were reported.

The survey found that the average age of sediment surveys at Corps reservoirs at that time was about 15 years. Current Corps guidance suggests that sediment surveys should be performed at intervals of 5 to 15 years, although requirements are specific to each project. Most districts reported that surveys had been performed using the traditional rangeline method of sampling sections across the reservoir and estimating the total volume from the sample. Only a few reported a total bed survey, although these are expected to become more common as technological advances make them more cost effective.

About 40 percent of surveyed projects reported utilizing some sediment management practices, the most common of which were reported as "minimal site-specific sediment removal," and "other." About 15 percent of projects reported periodic or regular use of measures to dredge, sluice or flush sediment from the reservoir. Respondents were also asked to describe obstacles to performing sediment management. The most common responses indicated lack of funding and regulatory compliance issues as the major obstacles to sediment management, with insufficient knowledge of technical methods and estimated benefits, and potential conflicts with project partners also reported as significant obstacles.

The survey did not gather information on sedimentation rates. Sedimentation is a fact of life for reservoir projects, and, if not managed, will only continue to grow in significance of impacts. After the asssessment of data, related efforts to monitor and understand sedimentation at reservoir projects were partially funded through the National Portfolio effort. The first was a cooperative effort with the United States Geological Survey to build the national Reservoir Sedimentation (RESSED) database. To support RESSDED and compile additional information needed for agency understanding of sediment issues, the Corps has proceeded to develop an internal Reservoir Sedimentation Information (RSI) system. The RSI system provides comprehensive storage and display capabilities for sedimentation conditions at Corps projects. The system will allow USACE to evaluate trends, life expectancy and reservoir vulnerabilities to climate change. **Figure ES-4** demonstrates the reporting and analysis capabilities of RSI.

Figure ES-4. Example RSI Data Summary Display

Provisional

TOTAL VOLUME LOSS REPORT CARD

Division	District	State	Name	Last Survey Year	% Loss From Initial Survey
Southwestern	Tulsa	KS	Big Hill Lake	2010	10.3%
			Council Grove Lake	2008	-29.8%
			El Dorado Lake	2011	3.5%
			Elk City Lake	2010	9.9%
			Fall River Lake	2010	7.7%
			John Redmond Lake	2007	11.9%
			Marion Lake	1994	4.4%
			Toronto Lake	2011	11.3%
		OK	Arcadia Lake	2010	0.6%
			Birch Lake	2010	4.1%
			Broken Bow Lake	2011	1.3%
			Canton Lake	2010	12.4%
			Copan Lake	2002	4.0%
			Denison Dam	2010	15.6%
			Eufaula Lake	2010	11.4%
			Fort Gibson Lake	1950	-0.2%
			Fort Supply Lake	2010	6.6%
			Heyburn Lake	2015	8.0%
			Hugo Lake	2015	1.7%
			Hulah Lake	2014	10.6%
			Kaw Lake	2015	7.4%
			Keystone Lake	2008	15.6%
			Oologah Lake	2014	10.4%
			Pine Creek Lake	2011	1.6%
			Robert S.Kerr Lock And Dam	1976	0.9%
			Tenkiller Lake	2015	-0.6%
			Wister Lake	2011	11.2%

DIVISION
All

DISTRICT
All

STATE
All

LEGEND
Gain or No Loss
0.1% to 10% Loss
10.1% to 25% Loss
25.1% or More Loss

Large negative % loss numbers are resulting from differences with data collection techniques. Traditional methods use range lines that can be 10's of miles apart. Now, hydrographic surveys provide great data density thereby filling in real data where the range method would interpolate. Future efforts will address this issue.

Uncertainty in Future Conditions (Section 6)

Just as the overall topic of status and challenges to aging dam and reservoir projects is very broad, there is a wide range of methods, assumptions and uncertainties in planning for future operations. This report includes information on activities of the Corps' Responses to Climate Change program that have either been undertaken in partnership with, or are directly related to the National Portfolio effort in order to better understand uncertainties in future conditions as they relate to the National Portfolio objectives. Two activities that are discussed in detail in the report are a pilot study that was conducted by the Tulsa District to examine the use of down-scaled climate model predictions in projecting potential future conditions and the resulting impacts on the Marion Lake project in Kansas, and a nationwide review of drought contingency plans at Corps reservoir projects.

Current policy requires the Corps to mainstream climate change preparedness and resilience in all activities to help enhance the resilience of our water resources infrastructure. The basic purpose of dam and reservoir projects – regulation of varying streamflow and storage of water – provides flexibility in meeting multiple objectives and improves community and environmental resilience in the face of changing and unforeseen conditions. As demands on these projects increase, however, the tradeoffs involved in changing operations to meet new challenges will become more difficult to assess and recommended changes may be more controversial to implement.

Conclusions and Next Steps (Section 7)

In summary, the National Portfolio work begun in 2008 has contributed greatly to a better understanding of the current status of the Corps portfolio of reservoir projects. There are many challenges to maintaining the current levels of service that these projects provide. Many of these challenges, such as aging infrastructure and adequacy of funding, are being addressed through other programs and initiatives, such as dam safety, asset management and innovative financing. The challenges highlighted in this report relate more to the adaptability of these critical projects to meet changing conditions and needs. As the assessment of data phase of the work was completed and the current effort began, an overall goal was identified to develop a framework for making future funding decisions to best address these challenges. The recommendations for next steps summarized below are intended to make progress towards that goal.

The subjects and activities discussed in this report – reallocation of project storage to serve increasing water supply needs, operational and structural changes to protect and enhance the environment, impacts of reservoir sedimentation and resilience to changing conditions – all typically involve some tradeoffs in the context of multi-purpose reservoirs. For example, increasing resilience to potential drought conditions may require the acceptance of greater risks of impacts from flooding, or substantial investments may be required to increase project benefits in one mission area while maintaining the same level of service in others. Future work should continue to understand and improve the methods and processes for forecasting future conditions and making good decisions in the face of tradeoffs and uncertainties.

An invaluable contribution of the National Portfolio effort to date has been the initial collection and assessment of a large amount of previously uncollated data regarding Corps reservoir projects. Data is a necessity to inform the types of decisions that need to be made to maximize the value of these projects into the future. Future work should also continue the collection of data started in this effort and develop trends and analyses. Specific recommendations developed for future work are summarized here and discussed in more detail in **Section 7**. Each recommendation is also related to the report section and focus area which it primarily addresses.

Recommendations for Next Steps

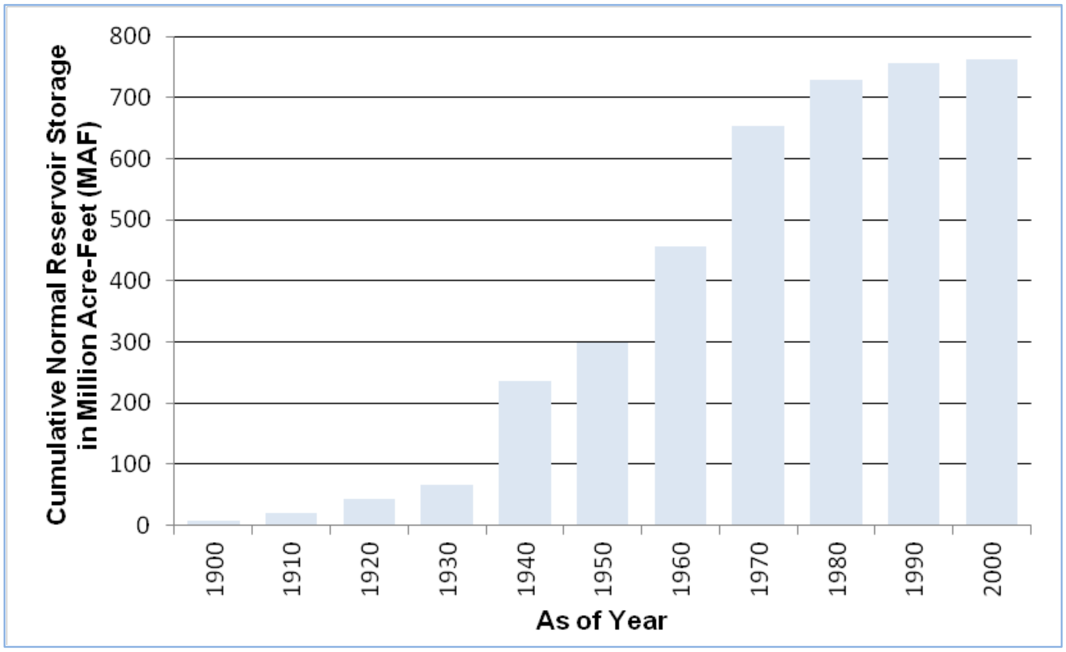
- Develop training and tools to assist study teams in completing increasingly complex water supply storage reallocation studies (**Section 2**).
- Develop processes to track water withdrawals and forecast water availability in order to better inform project planning and sustainable operations (**Section 2**).
- Develop a recommended scope and frequency for future water management data collection and assessments (**Section 3**).
- Track results of case studies on project modifications to enhance water quality and ecosystems (**Section 4**).
- Develop policy and technical guidance for project modifications to enhance water quality and ecosystems (**Section 4**).
- Complete the water quality survey initiated by the Corps Committee on Water Quality and use the results to refine and prioritize the challenges and needs assessment presented in **Section 4**.
- Continue to identify and prioritize project risks associated with sedimentation, and understand and explore methods for overcoming obstacles to sediment management (**Section 5**).
- Continue to collaborate with other programs to assess the potential impacts of climate change on multi-purpose reservoir projects (**Section 6**).
- Develop methods, tools and guidance for the complex tradeoff analyses and decision-making involved in evaluating modifications to existing multi-purpose reservoir projects (**Section 7**).

1. Background and Overview

1.1. Background

Over half of the existing reservoir storage space in the United States was constructed in the 1950s, 60s, and 70s. **Figure 1-1** shows the approximate timeline of reservoir construction in the U.S. through the 20th century. Much of this storage space is contained in large, multi-purpose federal reservoir projects. Authorization, funding and construction of these projects began to slow in the 1970s. Only a handful of federally-funded dams have been built since the late 1980s and enactment of the revised cost sharing provisions in the 1986 Water Resources Development Act.

Figure 1-1. Cumulative Reservoir Storage Volume Constructed by Decade



Source: USGS Small-scale Dataset - Major Dams of the United States, 2006

1.1.1. Origin of the National Portfolio Program

The 1958 Water Supply Act began a unique partnership, where state and local interests could partner with the federal government to include storage space for municipal and industrial (M&I) water supply needs in reservoir projects initially planned primarily for flood risk management and navigation purposes. As the development of new storage space has stagnated, one possible solution to meet increasing requirements for water supply is to reallocate existing storage from the original authorized purposes to M&I water supply, when the existing reservoir and the unmet demand for M&I water are in proximity. When state or local interests request a reallocation of storage for M&I water supply, the Corps must conduct a reallocation study to establish the appropriate approval authority, assess structural and operational considerations related to public safety, and identify benefits, costs and implementation requirements.

Reallocation of storage from one purpose to another typically impacts operations and expected benefits of the project. Operations of Corps reservoir projects are prescribed in water control manuals and plans for each project and system of reservoir projects. Water control plans seek to meet the legislative requirements and criteria developed throughout the process of planning, authorizing, designing and constructing a federal multipurpose reservoir project. Water control plans are coordinated with other federal, state and local agencies as required, and the Corps considers adjustments to established plans, when possible, to adapt to changing local conditions.

As funding for the Federal share of reallocation studies became harder to obtain because of tighter budgets and higher priority projects, in fiscal year (FY) 2005, the Corps proposed a program to review operating plans at major Corps reservoir projects. The overall objectives of the program were to assure that the reservoirs were continuing to support and enhance economic and ecosystem values, identify changes in operational policies requiring more in-depth studies, and support state and local planning efforts, such as state water plans.

1.1.2. Development of Program Scope

For FY 2007 the program focus was refined towards a more specific objective to identify the best candidates and opportunities for operational changes and/or reallocation of reservoir storage at existing Corps reservoir projects. Although not funded in FY 2007, the Office of Management and Budget approved the proposal in FY 2008 with the caveat that, "…the methodology will also include identification and assessment of alternate funding arrangements that rely on program beneficiaries to provide the funding for any follow-up studies." Funding for the FY 2008 budget proposal was subsequently appropriated.

In further developing the program scope, the Corps reviewed existing information and found it to be inadequate for the proposed study purposes, and determined that a survey would be necessary for data collection. It was known that the Corps had about 375[3] major multi-purpose dam and reservoir projects that provided significant flood risk management, navigation, hydropower, water supply, environmental and recreation benefits in regions throughout the continental U.S. It was further recognized that some of these dams were many years old and might no longer have operational plans that reflected the best overall economic and environmental benefits to the nation. During

[3] Counts of Corps projects often vary due to the diversity of dam and reservoir projects.

this review it was found that the Corps was also considering two other USACE-wide surveys oriented towards multi-purpose reservoir projects: one on sedimentation and one on water management.

Many of the questions being considered in the formulation of the National Portfolio study applied to all three survey aspects and in most cases the same personnel from the Corps divisions and districts would be involved in all three surveys. As a result, in order to save time and money, the three surveys were combined into one. The Corps Institute for Water Resources (IWR) and IWR's Hydrologic Engineering Center (HEC) joined forces with Headquarters USACE (HQUSACE) to develop one survey request. This combined request, titled "Survey for the Water Supply Reallocation Portfolio Assessment and the Water Management and Sediment Management aspects of Corps Projects," was sent to the relevant Corps organizations in division and district offices, and an existing reservoir sedimentation project team in June 2008.

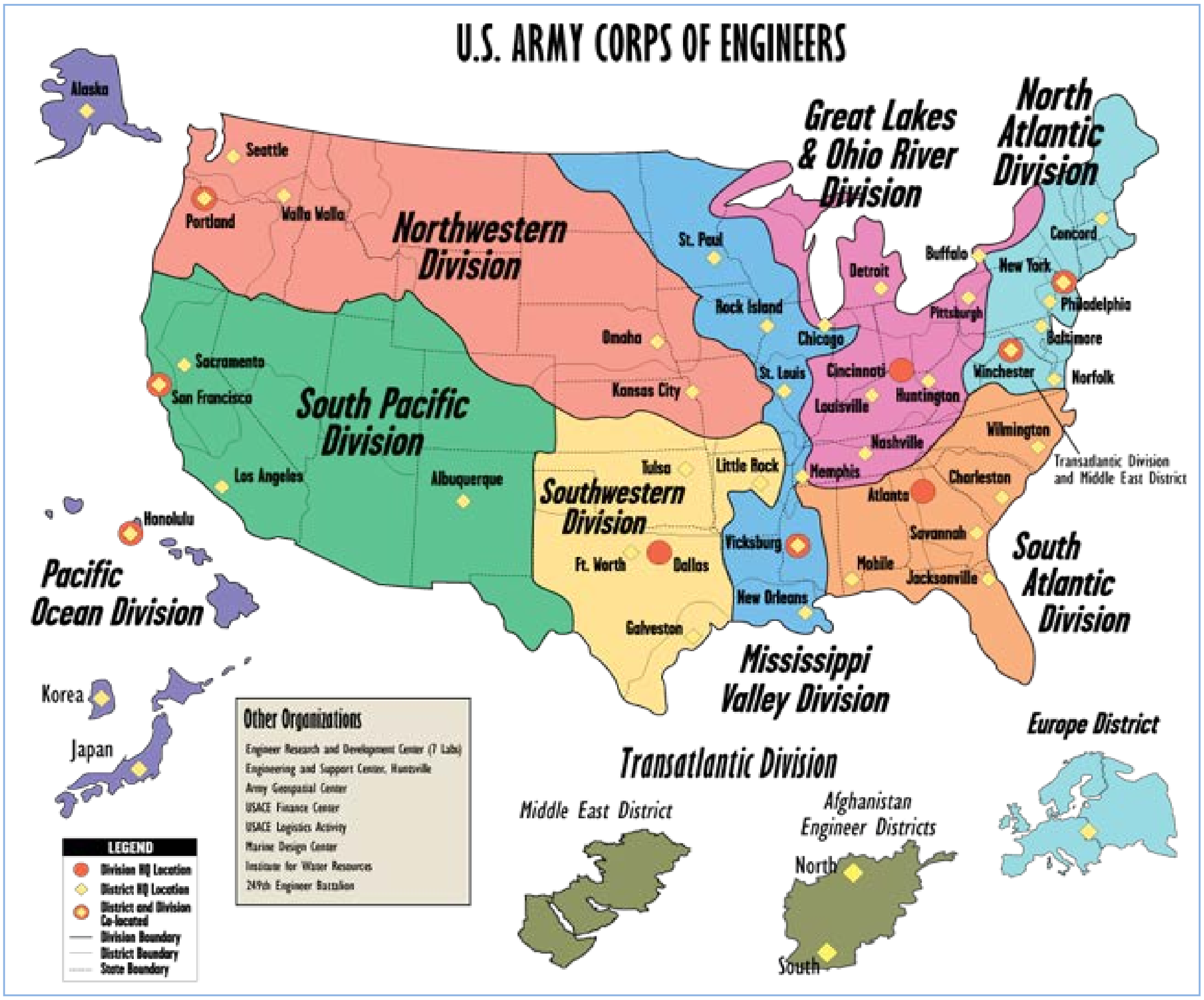
1.1.3. USACE Organization and Reservoir Management

Organizationally, USACE in composed of a headquarters, divisions, districts, and an assortment of laboratories and centers of expertise. Divisions, also referred to as Major Subordinate Commands (MSC), and districts have specific geographical areas of responsibility. The United States is split into 8 divisions, all of which have water management responsibilities, and 38 districts, 32 of which manage reservoirs with federally authorized flood storage space. **Figure 1-2**, on the following page provides a map of Corps offices. Division and district offices are identified with a unique three-letter abbreviation. **Appendix A** provides a list of the abbreviations for specific Corps offices used throughout the tables and appendices in this report.

The Great Lakes and Ohio River Division (LRD) oversees six district offices that operate flood risk management reservoirs. Mississippi Valley Division (MVD), North Atlantic Division (NAD), South Atlantic Division (SAD), South Pacific Division (SPD), and Southwestern Division (SWD) each oversee the operations of four districts. Pacific Ocean Division (POD) oversees one, the Alaska District.

The Northwestern Division (NWD) is organized differently than the other divisions. Its water management staff is split into two primary groups: Columbia River Water Management in Portland, Oregon, and Missouri River Reservoir Control in Omaha, Nebraska. These are the only division offices that directly manage reservoirs. Other divisions provide oversight of reservoirs managed at the district level as well as coordination of system operations. The Northwestern Division office in Portland (NWD-CR) also oversees the reservoir operations of the Portland, Seattle, and Walla Walla districts. The division office in Omaha (NWD-MR) oversees the Kansas City and Omaha districts.

Figure 1-2. Divisions and Districts of the U.S. Army Corps of Engineers

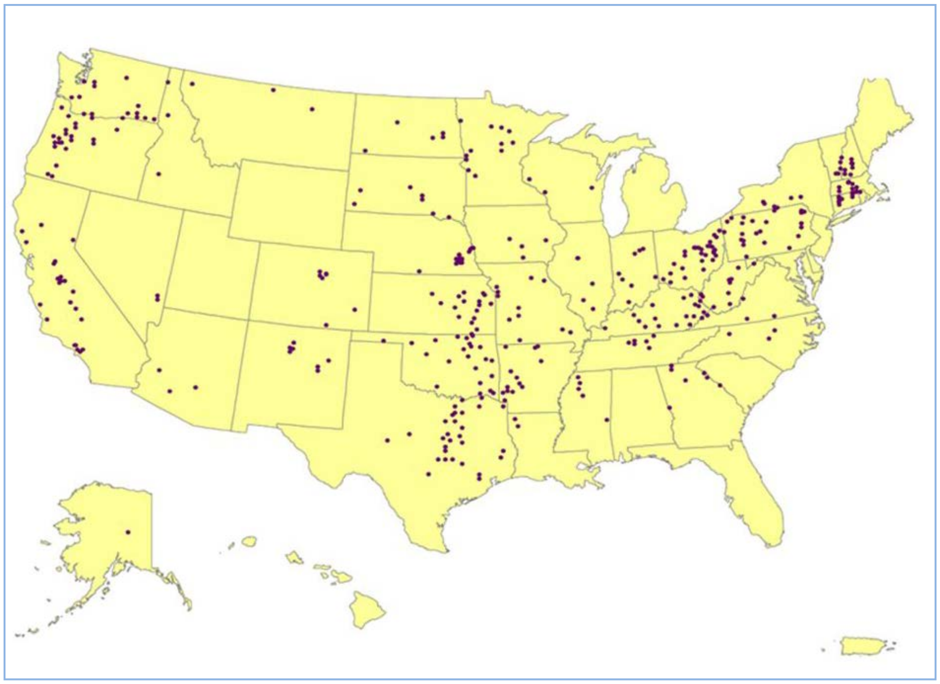


Source: www.usace.army.mil/Locations.aspx

1.2. Survey Phase

Overall, the combined survey scope included 375 reservoir projects owned and operated by the Corps, and an additional 109 projects primarily owned and operated by other agencies, but which include reservoir storage for flood risk management or navigation that is operated by the Corps in accordance with Section 7 of the 1944 Flood Control Act. **Figure 1-3**, on the following page, shows the location of the surveyed Corps reservoir projects.

Figure 1-3. Reservoir Projects Operated and Maintained by USACE



The initial list of projects to be queried was proposed by the water supply portion of the survey. This list was obtained from the Corps Hydrologic Engineering Center (HEC) report PR-19, "Authorized and Operating Purposes of Corps of Engineers Reservoirs," dated November 1994. Districts were instructed to include all projects in which storage space could possibly be made available for water supply users, resulting in a list of 375 projects. The survey included projects without a normal conservation pool, with instructions to note that they were "dry" dams. Similarly, the instructions were to include projects that do not regulate streamflow, or "run-of-river" projects, with appropriate notation, however, no survey information was filled in for these projects. Only Corps reservoir projects were queried for water supply storage reallocation as there is no authority to investigate reallocations at non-Corps reservoirs.

The water management portion of the survey set out to query all reservoirs in the United States with federally authorized flood storage, including non-Corps reservoirs. This added 108 more projects; however, 18 of the projects included in the original water supply list did not have flood storage and were subtracted, resulting in a list of 465 reservoirs. The sediment management survey was based on the Corps projects included in the water supply survey, with a few differences, for a total of 378 projects. No information on sediment management was returned for 25 of the projects, resulting in a total of 353 positive responses. A summary of the topics collected for each survey is shown in **Table 1-1**, on the following page. A detailed list of definitions and explanations of survey fields was provided to the respondents. This list, while not inclusive of all data collected in the survey, is provided as **Appendix B**.

Table 1-1. 2008 USACE Reservoir Survey Topics

Water Supply (n=375) [1]	Water Management (n=465)	Sediment Management (n=378)
Reservoir name	Reservoir name	Reservoir name
Managing office	Managing office	Managing office
Year of completion	Year of completion	Basin hydrology description
Drainage area (total)	Drainage areas (local and total)	Sediment contributing land use
Storage allocations	Storage allocations	Percentage storage depletion
Authorized purposes	Authorized purposes	Impacts to authorized purposes
Operating purposes	Ownership	Sediment management practices
Location (lat-long)	Minimum flow requirements	Obstacles to sediment management
Watershed	Maximum power release	Historical sediment surveys
River	Max release at min top of con	
Congressional district	Objective flow locations	
Dam safety classification	Objective flow levels	
Project yield	Max non-damaging flows	
Reallocation possibilities	Exceedances of objective levels	
	Fish passage presence	
	Fish passage effectiveness	
	Water temp management	
	Infrastructure condition	
	Dam safety restrictions	
	Start/end electronic database	
	Start/end data in any format	
	Water control manuals	
	Operational changes	
	Motivation for changes	
	Testing of alternative operations	
	Motivation for testing	
	Time series data (daily): Inflows, outflows, storage, and top of conservation storage	
Notes: [1] n = number of projects surveyed		

1.2.1. Water Supply Storage and Reallocation Survey

The survey for water supply storage and reallocation collected general project information on identification, location (latitude and longitude, state, watershed, river and congressional district), and year of project completion, as well as more specific topics on dam safety action class, authorized and operating purposes and assigned storage space of each, pool storage areas and project yield. The respondents were also asked to provide any additional remarks concerning reallocation possibilities including estimated demands for water supply and when those demands might be required. **Section 2** of this report summarizes the water supply storage reallocation survey effort, as well as the resulting products and related efforts.

1.2.2. Water Management Survey

The purpose of this survey was to assess status and trends for reservoir management, with the following specific focus areas:

- Reservoir storage allocations;
- Release decisions;
- Other management practices (fish passage, thermal management, flood operations, infrastructure, testing of alternatives); and
- Evolution of reservoir management policy.

The survey requested information on all projects where the Corps manages storage for flood risk management. This included 356 of the 375 Corps projects included in the original water supply survey list, as well as 109 Section 7 projects, or 465 projects in total. There are 181 other Corps dams that were not included in the survey as they do not operate for flood risk management. The initial survey effort was not funded through the National Portfolio effort, but portfolio funding was used to analyze and summarize the data. **Section 3** of this report discusses the water management survey effort in more detail, as well as subsequent related products and efforts.

1.2.3. Reservoir Sedimentation Survey

The purposes of the reservoir sedimentation survey were to assess the current impacts of sedimentation on Corps reservoirs as well as identify sediment management practices being utilized, and better understand obstacles to sediment management. The survey returned data on the percentage of storage in Corps reservoirs adversely affected by sedimentation, as well as qualitative assessments of the severity of impacts on the various project purposes of: flood risk management, navigation, hydropower, water supply, water quality, recreation, and fisheries. **Section 5** of this report discusses the sedimentation survey in more detail, as well as subsequent products and efforts funded through the National Portfolio.

1.3. Assessment of Data and Product Development

The FY 2010 budget saw two major changes to the National Portfolio funding effort. It moved into the assessment of data phase, and an increment was added to the funding to support the Sustainable Rivers Program (SRP), described in more detail below. This two-pronged funding effort continued for the next few years. During the assessment of data phase, the National Portfolio collaborated with other related efforts, and several products were produced in this time that provide benefits in several of the Corps' Civil Works mission areas. A summary of these products follows, with more detailed discussion in the subsequent sections of the report.

1.3.1. Assessments of Survey Data

The responses and data received through the water supply, water management and reservoir sedimentation surveys were assessed primarily by the subject matter experts identified in the acknowledgments at the beginning of this report and in the report sections on each subject area. The first product prepared was a draft information paper, completed in FY 2009, reviewing the reservoir sedimentation survey results. The findings are summarized in **Section 5** of this report. In FY 2010, a "National Portfolio Assessment for Reallocations Information Paper" was produced. As discussed in **Section 1.1.2**, above, this report satisfied the original guidance for the study from OMB by identifying the best opportunities to reallocate storage for water supply needs, as well as alternative funding options for those studies. This paper and efforts related to the assessment of water supply survey data are highlighted in more detail in the following section. The water management survey produced the largest set of responses and data, and the assessment is provided in **Section 3** of this report.

2010 National Portfolio Assessment for Reallocations Information Paper

The data gathered from the 2008 water supply survey was used to develop an information paper provided to the office of the ASA(CW) in 2010 that recommended 52 priority projects for future water supply storage reallocation studies, and identified and discussed potential alternative funding arrangements for the studies as requested by OMB. The survey also complemented the development of the water supply module of the Corps Operations and Maintenance Business Information Link (OMBIL) database. The OMBIL water supply module records data on the over 340 existing M&I water supply storage agreements at Corps reservoir projects across the country. **Section 2** of this report provides a summary of this paper and an update on the related information.

While completion of this report could have signaled the end of the National Portfolio effort, the Corps recognized that it would be desirable to continue this effort in order to assess all the data that had been collected in the three-part survey discussed above and put it to use for better management of our reservoir projects. This plan was approved by the ASA(CW) and OMB through the budget development process.

1.3.2. Product Development and Related Efforts

As discussed, the original National Portfolio survey effort expanded beyond the water supply mission to eliminate duplication with the related water management and sedimentation survey activities. Similarly, as the assessment of survey data progressed, it was recognized that follow-on work in these areas could also be completed more efficiently through the ongoing National Portfolio effort. The following sections briefly describe the products and related work that will be discussed in more detail in the main sections of the report. These sections are presented in the order they follow in the main report.

Water Quality

Since 2011, related work of the Corps' Committee on Water Quality has been funded under the umbrella of the National Portfolio effort. The primary charge of the Committee is to provide technical assistance, develop policy guidance and exert leadership in all issues involving water quality and ecological sustainability for the Corps. During this time the committee produced three major projects and initiated effort on one additional item in support of the National Portfolio assessment. These are:

- An information paper documenting considerations and needs for technical guidance on improving water quality and ecological sustainability at Corps multi-purpose reservoirs;
- A compilation of case studies documenting actual on-the-ground examples of relatively modest changes in the structural elements and operations of our multi-purpose reservoirs for the purpose of enhancing water quality and ecological sustainability;
- An information paper on water quality and ecological threats to Corps multi-purpose reservoirs; and
- An online survey to gather information regarding the status of water quality and ecological management concerns related to Corps multi-purpose reservoirs.

The survey effort is ongoing. Additional information on the related water quality efforts can be found in **Section 4**.

Sustainable Rivers Program (SRP)

The SRP is a collaborative effort between the Corps and The Nature Conservancy, to investigate changes in dam operations to restore and protect the ecological health of rivers while maintaining and enhancing project benefits to human needs such as flood risk management, hydropower and water supply. The program is being carried out under a Memorandum of Understanding between the Corps and the Conservancy. SRP includes both national and project site activities in three major categories: science, implementation and outreach. Work at SRP sites currently involves 36 reservoirs in eight river basins. SRP is discussed in more detail in **Section 4** of this report, and more information is available on The Nature Conservancy website at http://www.nature.org/ourinitiatives/habitats/riverslakes/sustainable-rivers-project.xml.

Reservoir Sedimentation Database (RESSED)

The National Portfolio effort supported collaborative work with the United States Geological Survey to develop the Reservoir Sedimentation Database under the guidance of the Subcommittee on Sedimentation of the federal government's Water Information Coordination Program. RESSED was a first effort to evaluate reservoir sedimentation and storage depletion on a national scale. More information on RESSED is provided in **Section 5** of the report and available at http://water.usgs.gov/osw/ressed/.

In addition to RESSED, USACE developed an internal database and tool, the Reservoir Sediment Information system that collects the information necessary for RESSED, as well as additional information and analyses for internal agency use.

Reservoir Sediment Information (RSI)

Soon after the 2008 sediment survey was completed, The American Recovery and Reinvestment Act of 2009 enabled the Corps to update reservoir sediment surveys at many projects. The National Portfolio effort, in partnership with the Corps' Responses to Climate Change program, supported the Reservoir Sediment Information (RSI) initiative to explore how the Corps could better accomplish goals of sedimentation monitoring in a sustainable manner under current and future budget constraints. The new RSI web-based portal provides a central database of Corps' reservoir sedimentation information and the ability to communicate with other enterprise data systems, such as the National Inventory of Dams and the Corps Water Management System. **Section 5** of this report provides more information on RSI.

Climate Change Pilot Studies

Current policy requires the Corps to mainstream climate change preparedness in all activities to help enhance the resilience of our built and natural water resources infrastructure, and to reduce potential vulnerabilities to the effects of climate change and variability. In accordance with this policy, two pilot studies conducted under the Corps Responses to Climate Change Program were used to examine the potential impacts of climate change on the water supply mission at multi-purpose reservoirs. The main product of the funding from the National Portfolio effort was a pilot study of the Marion Lake reservoir in Kansas. A study at Oologah Lake in Oklahoma also estimated the change in reservoir yield under future climate scenarios. Additional information on the climate change program of the Corps of Engineers and these pilot studies can be found in **Section 6** of this report. A detailed report on the Marion Lake study is included as **Appendix F**.

1.4. Status and Challenges for USACE Reservoirs Report and Future Work

As the National Portfolio evolved from the original assessment of water supply storage reallocations into a more comprehensive examination of Corps reservoir projects, the overall goal of the effort became one of developing a framework for future basin or project-specific funding decisions to ensure existing Corps reservoirs contribute to enhanced economic and ecosystem values as conditions evolve. In the context of water supply storage at Corps reservoirs, for example, it was envisioned that existing data could be expanded to include river basin and regional assessments of water supply availability and sustainability over the next 10, 20 and 50 year periods. In support of the overall framework, this report was proposed to synthesize and assess the efforts completed to date, and prepare recommendations for additional work. These recommendations are included in **Section 7** of the report.

1.5. Summary of Funding

Funding for the National Portfolio effort has been on a year-to-year basis and has driven the scope of the program as well as the products produced. A summary of the funding is provided in **Table 1-2**.

Table 1-2. National Portfolio Funding History

Program Development and Survey Phase	
FY 08	$280K funded with the direction to look at "alternative funding" methods for water supply reallocation studies.
FY 09	$270K funded to continue FY 08 activities.
Assessment of Data Phase	
FY 10	$570K funded: $286K for the assessment of data stage and $285K for the Sustainable Rivers Program (SRP).
FY 11	$571K funded to continue the FY 10 activities, including $285K for SRP.
FY 12	$560K funded to continue the FY 11 activities, including $280K for SRP.
FY 13	$555K funded: $278K to develop "National Portfolio Assessment of Data for Reallocations: Status and Challenges" report and $278K to continue SRP activities.
Status and Challenges Report and Future Work	
FY 14	$571K funded to finalize the National Portfolio Assessment report, including $285K to continue SRP activities.
FY 15	$1,060K funded for National Portfolio activities, including $500K for initial assessments of reallocation studies and $282K to continue SRP activities.
Note: Incremental amounts may not sum to annual total due to rounding.	

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2. Water Supply Storage Reallocation

This section describes the development of the National Portfolio effort with respect to water supply storage in Corps reservoirs. The 2008 water supply storage reallocation survey queried 375 reservoir projects including 19 projects classified as dry dams and 31 as run-of-river projects. These 50 projects are less likely to be priorities for reallocation as they do not currently impound a permanent conservation pool. The results of the survey were utilized in the development of the "National Portfolio Assessment for Reallocations Information Paper" in 2010. A summary of this paper follows.

The survey also complemented contemporary efforts to include water supply data in the Corps' Operations and Maintenance Business Information Link (OMBIL) system. Both the survey and OMBIL development efforts were managed by the Corps Water Supply Business Line, which is part of the Corps Institute for Water Resources (IWR). **Section 2.3** provides a current summary of the water supply program data subsequently captured in OMBIL. **Appendix C** identifies those projects where municipal and industrial (M&I) water supply storage is currently authorized and shows the total storage space and estimated yield for each project.

2.1. National Portfolio Assessment for Reallocations Information Paper

This report, the original purpose behind the National Portfolio funding effort, was developed by IWR and submitted to the Headquarters, USACE (HQUSACE), Planning and Policy Division in June 2010. This paper was subsequently forwarded by that office to the Assistant Secretary of the Army for Civil Works, ASA(CW), in August 2010. The paper was a two-part effort, consisting of a discussion of alternative methods for funding reallocation studies and a prioritized portfolio of projects for which funds for reallocation studies should be considered. A summary of the paper is provided in the following two paragraphs.

2.1.1. Alternative Funding Methods

Three alternatives were developed by IWR and coordinated with HQUSACE Planning and Policy Division and the Office of Chief Counsel:

1. Acceptance of non-federal funds to partially or fully fund the reallocation study;
2. Recovery of study costs through the cost-of-storage payments under water supply agreements; and
3. The establishment of a revolving fund for water supply reallocation studies.

The memorandum from Headquarters to the ASA(CW) presented the information paper as a good starting point for discussions as part of the fiscal year (FY) 2012 budget development process. The first of these three alternatives was implemented through Public Law 112-74, the Energy and Water Development Appropriations Act of FY 2012, enacted in 2011. Section 111 of Division B of this law expanded the contributed funds authority, 33 U.S.C. §701h, to accept voluntarily contributed funds for all project phases and purposes. HQUSACE subsequently issued implementation guidance on the application of this authority to reallocation studies. Under this authority contributed funds can now be accepted for reallocation studies budgeted in the Operations and Maintenance (O&M) account, and also for studies in the Investigations account, providing that some federal funds have first been appropriated for studies under Investigations. The alternative of recovering study costs through sponsor repayments of the cost of water supply storage was not supported. A proposal to establish a revolving fund was supported by the ASA(CW) in FY 2014, 2015 and 2016 budget negotiations, but it was not approved by the Office of Management and Budget (OMB).

2.1.2. Possible Projects for Water Supply Reallocation

The prioritized list of reallocations was developed by a team consisting of district and division planners and program managers, and led by IWR. This team looked at the 375 Corps multi-purpose reservoirs within the scope of the National Portfolio survey and, utilizing the survey data provided on likely reallocation opportunities, finalized a list of 107 projects with a near-term (defined as the next 5-10 years) potential for reallocation. A map showing the location of these 107 projects is shown in **Figure 2-1**, on the following page. These projects are also identified by name in **Appendix C**. As the figure shows, the potential for near-term reallocation needs was distributed throughout the country in the areas where the Corps operated multi-purpose reservoir projects.

The list of 107 projects was then subjected to a detailed examination to develop a final list of 52 priority projects for inclusion in the report. A map of the 52 priority projects is provided as **Figure 2-2,** on the following page. The list of 52 priority projects was further divided into three priorities of study: High (35 studies) Medium (16) and Low (2). These projects are also identified in **Appendix C**. The total number of studies included two studies that were recommended at one project, the Garrison Dam, Lake Sakakawea project in Omaha District. The determination of High, Medium and Low was based on a wide range of criteria including the project's Dam Safety Action Classification (DSAC) rating, if the study had recently been included in the district's annual budget request and if the project was currently being utilized for M&I water supply and/or hydroelectric power. It was stressed that the list of projects being recommended for reallocation was a dynamic list and would change over time as conditions and needs change.

Figure 2-1. 107 Possible Projects Identified for Reallocation

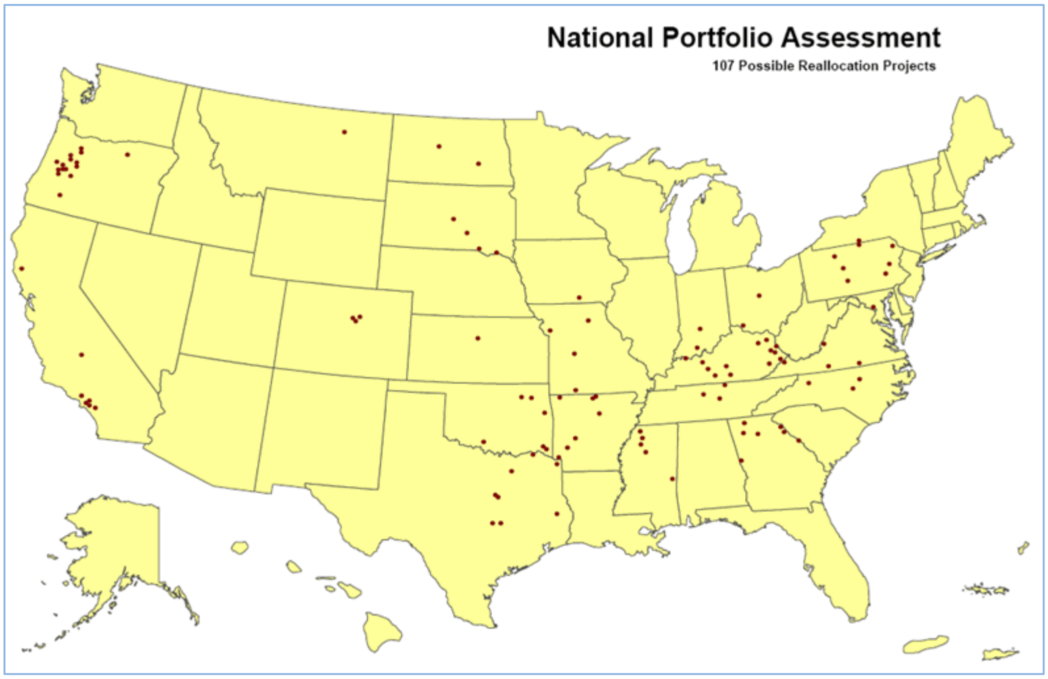
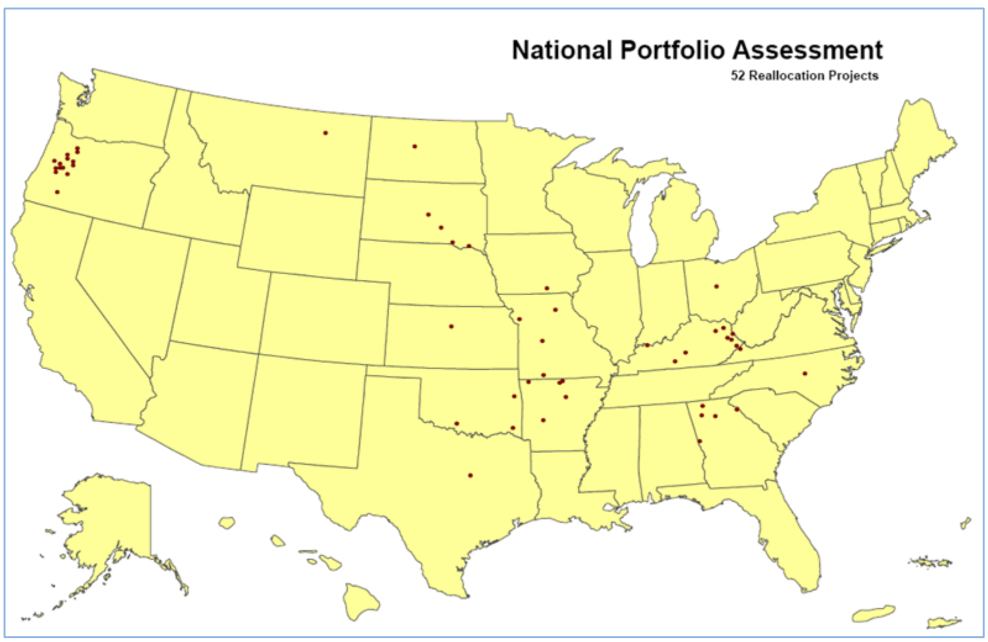


Figure 2-2. 52 Recommended Priority Projects for Reallocation



2.2. Updated List of Potential Reallocation Studies

In the years following the 2010 information paper, a revised list of recommended reallocation studies has been part of the annual budget proposal submitted to HQUSACE by the Corps Water Supply Business Line Manager. The budget proposal is developed based on recommendations from district and division offices and overall Administration budget guidance and constraints. Because of budget constraints and higher priority projects, it can be difficult to fund water supply storage reallocation studies. Since FY 2012, fifteen reallocation studies have received funding through the normal budget process. These studies and the funding mechanism are shown in **Table 2-1,** with a check mark indicating the studies that were funded to completion.

Table 2-1. Funded Reallocation Studies since FY 2012

Funding Account			
Investigations	**Funded to Completion**	**Operations and Maintenance**	**Funded to Completion**
Chatfield Lake, CO	✓	Missouri River Basin Mainstem Reservoirs, MT, ND, SD, NE	✓
Bear Creek Lake, CO		J. Percy Priest Dam and Reservoir, TN	
Willamette River Basin Review, OR		Wolf Creek Dam, Lake Cumberland, KY	
Sulphur River Basin, TX		R. D. Bailey Lake, WV	✓
		Hartwell Lake, GA & SC	
		Blakely Mt. Dam, AR	✓
		Greers Ferry Lake, AR	✓
		Stockton Lake, MO	
		Lavon Lake, TX	
		Granger Dam and Lake, TX	
		Beaver Lake, AR	✓

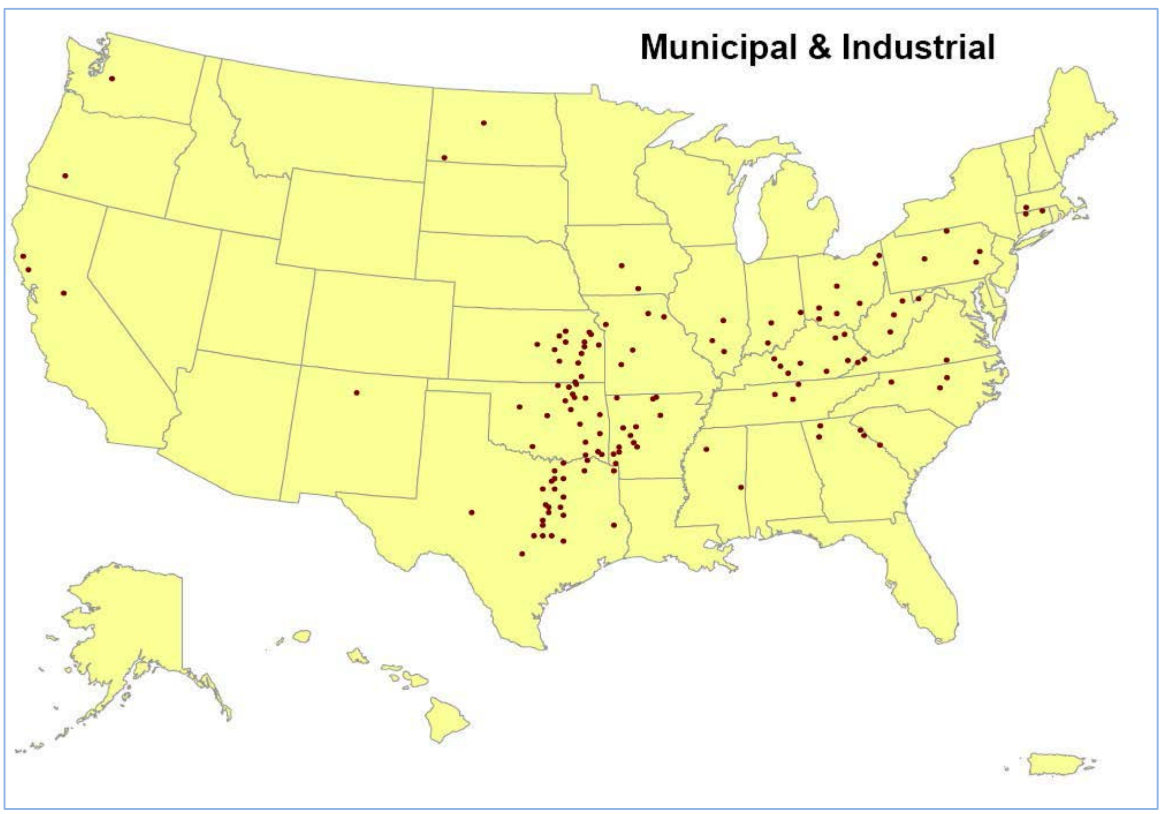
Funding a study to completion does not necessarily indicate that the study was approved or that final water supply agreements were executed. There are many reasons why a study may pause or terminate without final approval or signature of agreements. For example, the non-federal sponsor may withdraw from participation as they either delay their investigation of additional water supplies or pursue other alternatives. The studies in **Table 2-1**, as well as other studies that have been funded outside the normal budget process, either with contributed funds or reprogrammed operations and maintenance funding, are identified with the specific reservoir projects in **Appendix C**. Including one study that was completed in 2010, since the list of 52 priority projects was prepared, study efforts have been undertaken at 26 of those projects. Additional study work has been performed at 10 other projects in response to the evolving priorities identified through the budget process.

2.3. M&I Water Supply Database

The scope of the Corps of Engineers Municipal and Industrial (M&I) Water Supply program has been documented in recent years through a series of reports. The completion of the 2008 National Portfolio survey complemented the development of the Water Supply module for the OMBIL database. As the water supply data in OMBIL has matured, the database has increasingly become the basis for reporting. The most recent of these reports is IWR Report 2015-R-02, the 2014 Municipal, Industrial and Irrigation Water Supply Database Report (USACE IWR 2015).

Of the 375 Corps reservoir projects included in the 2008 water supply storage reallocation survey, about one-third (136) currently contain storage space for M&I water supply. These projects are located in 23 of the Corps 38 Civil Works districts, and in 25 states across the continental U.S. A map of these projects is shown in **Figure 2-3**. The 2014 M&I and Irrigation Water Supply Database Report provides detailed data for each project and agreement on: type of agreement (by authorization and whether originally constructed or reallocated); date of the agreement; storage yield; the assigned storage space and cost (whether presently being paid, payments deferred to the future, or not under contract) and the interest rate; and the remaining cost still owed on the storage space. The report also provides summary totals of storage space and costs by project, district and division.

Figure 2-3. USACE Projects with M&I Water Supply Storage



2.3.1. Summary of Data by Division

The national M&I water supply storage totals, summarized by Corps division offices are shown in **Table 2-2**. This table shows data for current valid agreements that are in force plus storage not currently under contract, where assurances were provided that some entity in the future would contract for the storage space, as allowed under the 1958 Water Supply Act prior to policy changes after enactment of the Water Resources Development Act (WRDA) of 1986. This summary includes both storage space originally authorized as well as reallocated storage, and the very few instances of surplus water agreements under Section 6 of the 1944 Flood Control Act and agreements for interim M&I use of irrigation storage under Section 931 of WRDA 1986.

Table 2-2. M&I Water Supply Storage Summary by MSC

MSC	No. of Projects	No. of Agreements / Future Storage Activations	Storage Space (acre-feet)				Principal Cost of Storage ($1,000) [1]		Balance to be Repaid (%)
			Under Contract Present	Under Contract Future	Not Under Contract	Total	Original Cost Owed	Balance to be Repaid	
NAD	7	7 / 0	167,435	0	0	167,435	141,267	58,457	41
SAD	10	25 / 0	209,623	0	0	209,623	35,148	11,947	34
LRD	28	46 / 0	602,653	0	8,460	611,113	79,860	36,764	46
MVD	8	14 / 0	230,597	202,220	13,293	446,110	46,421	21,891	47
NWD	17	35 / 4	498,646	413,630	101,877	1,014,153	124,533	70,469	57
SPD	4	4 / 0	565,000	0	0	565,000	127,706	97,952	77
SWD	62	211 / 76	5,706,942	770,860	310,699	6,788,501	948,873	340,361	36
TOTAL	**136**	**342 / 80**	**7,980,896**	**1,386,710**	**434,329**	**9,801,935**	**1,503,808**	**637,841**	**42**

Notes:
[1] All principal costs are reported directly from the agreements, and have not been updated to present values.

As shown, the 136 projects contain 9.8 million acre-feet of storage space allocated for M&I water supply with a corresponding total principal cost to be repaid of about $1.5 billion in nominal dollars at differing price levels depending on the date when each agreement was entered into. Nationwide, there are currently 342 separate repayment agreements through which local sponsors have repaid 58% of the original investment costs of the storage space. Actual costs repaid by the sponsors include the original investment cost plus interest on the principal when repayment is amortized, as well as any additional interest such as interest charged after the end of the 10-year interest free period on deferred future-use storage, and interest due on late payments. Sponsors must also typically reimburse the Government for a portion of the annual operations and maintenance expenditures at the project. There are no water supply storage projects in the Pacific Ocean Division.

2.3.2. Summary of Reallocations

As discussed, the original purpose driving the National Portfolio study was evaluating the needs for reallocations of storage in order to meet the water supply needs of local interests. The national summary of water supply storage reallocations to date are shown in **Table 2-3**. Overall, the total amount of reallocated storage is only about nine percent of all authorized M&I water supply storage space. While the Corps water supply reallocation activity dates back to the 1950s, it has become the primary component of the M&I water supply storage program since the dam building era came to an end in the 1980s. The progression by decade of the number of signed agreements, storage space and assigned costs as a result of reallocations, are shown in **Table 2-4**, on the following page.

Table 2-3. Reallocations by District

MSC	District	Number of Projects	Number of Agreements	Years Reallocated (Between)	Storage Space Reallocated (acre-feet)	Principal Cost of Storage ($) [1]
NAD	NAB	2	2	1986-1994	30,960	46,348,000
SAD	SAW	1	4	1984-2006	21,115	4,806,517
	SAS	3	13	1964-2001	31,279	6,762,336
	SAM	2	4	1963-1991	20,329	3,837,830
LRD	LRH	4	5	2000-2010	9,495	5,030,779
	LRL	4	6	1978-2006	4,111	549,599
	LRN	4	16	2003-2011	28,376	16,213,072
	LRP	1	1	2010	2,950	2,557,949
MVD	MVK	2	2	1996-1998	6,075	1,222,649
NWD	NWK	7	12	1986-2002	176,963	25,741,771
SWD	SWL	6	21	1970-2010	97,554	9,643,880
	SWF	2	2	1969-1984	65,526	15,462,000
	SWT	7	50	1953-2012	363,743	91,368,377
TOTAL	**13**	**45**	**138**	**1953-2012**	**858,476**	**229,544,759**

Notes:
[1] All costs of storage are reported directly from the agreements, and have not been updated to present values.

The single 1950s reallocation was the result of specific legislation. Public Law 82-273, approved 14 August 1953 provided for 21,300 acre-feet of storage to be reallocated at the Denison Dam, Lake Texoma, TX and OK project for water supply for the City of Denison, TX. In the 1990s there were 15 reallocations of 20 acre-feet or less. The main cause of this was a 1987 policy change that required all water withdrawal agreements previously citing 31 U.S.C. 483a (the Independent Offices Appropriations Act) as authority to be allowed to expire under the terms of the agreement, and replaced with reallocation agreements under the authority of the 1958 Water Supply Act. Activity in 2010 was highlighted by two agreements at Denison Dam, Lake Texoma, TX & OK in the Tulsa District: 100,000 acre-feet to the North Texas Municipal Water District and 50,000 acre-feet to the Greater Texoma Utility Authority. The reallocation at this project was possible because of legislation enacted in WRDA 1986 for the Corps to reallocate 300,000 acre-feet in the project from hydropower to M&I water supply storage.

Table 2-4. Reallocations by Decade

Decade	Number of Agreements Signed	Storage Space (acre-feet)	Principal Cost of Storage ($) [1]
1950's	1	21,300	292,861
1960's	11	80,698	5,783,108
1970's	8	11,300	945,428
1980's	15	187,038	77,539,731
1990's	56	254,825	42,936,906
2000's	35	112,282	28,871,667
2010's	12	191,033	73,175,058
TOTAL	**138**	**858,476**	**229,544,759**

Notes:
[1] Costs for the decades of the 50s, 60s and 70s are mostly based on as-built costs. Subsequent costs are typically based on construction costs escalated to then current price levels.

2.3.3. Costs of M&I Water Supply Storage

All revenues received from sponsors for M&I water supply are deposited into the U.S. Treasury as miscellaneous receipts. Revenues are comprised of the repayment of investments costs and the annual costs assigned to M&I for operation, maintenance, repair, replacement and rehabilitation, as well as the various categories of interest. These categories can include the interest: on principal when repaid over time, charged after the 10-year interest free period (when applicable) and on late payments. While water supply revenues have been returned to the U.S. Treasury as far back as at least 1944, the tracking of these revenues to water supply was only initiated in FY 2003. Costs of collection include the manpower required by the districts to determine the costs of repayment, bill the sponsor, collect the revenue and return the revenue to the U.S. Treasury. Data on revenues and collection costs were obtained from the Corps of Engineers Financial Management System. The last eight years of data (2007 to 2014) are provided in **Table 2-5**.

Table 2-5. Revenues and Costs of Collection for M&I Water Supply Storage

Fiscal Year	Sponsor Repayments ($)				Costs of Collection ($)
	Principal	Interest	O&M	Total	
2007	13,290,587	17,605,571	12,950,456	43,846,614	523,318
2008	15,343,450	16,756,846	10,633,173	42,733,469	524,072
2009	15,999,375	16,832,877	12,750,781	45,583,033	779,787
2010	49,235,151	33,034,364	16,996,372	99,265,887	1,257,143
2011	81,155,474	22,093,026	17,340,590	120,589,090	959,787
2012	30,959,961	16,130,127	18,618,283	65,708,371	1,005,298
2013	26,835,510	14,579,356	20,302,435	61,717,301	997,228
2014	18,547,719	14,541,829	13,083,406	46,172,953	1,334,933

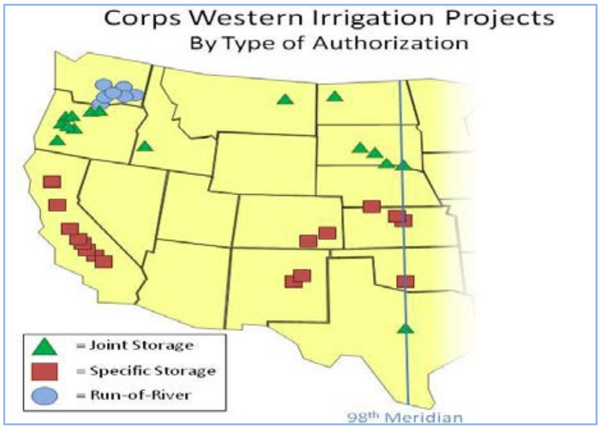
As would be expected, the yearly collections can vary considerably in those years when large payments are made for one reason or another. For example the increase in principal repayments in FY 2010 and 2011 resulted from three large lump sum payments for reallocation of storage at Lake Texoma, TX & OK, a legal settlement at the Sardis Lake, OK project and for repayment of originally authorized storage at Waurika Lake, OK.

2.4. Irrigation Water Supply Database

For irrigation purposes, the "West" is defined in Reclamation Law (Public Law 57-161) as those 17 contiguous states lying either partially or wholly west of the 98th meridian. There are a total of 46 multi-purpose Corps projects in the West with irrigation authorized as a purpose. At most of these projects, the irrigation function is administered by the Bureau of Reclamation. Of the 46 projects, 22 are authorized as joint storage, 17 are authorized as specific storage and 7 as run-of-river projects. Joint storage projects do not have a specific amount of storage allocated to irrigation, rather the storage in the conservation pool is used jointly to meet all of the authorized purposes according to the approved water control plan for the project. Specific storage projects have a specific amount of storage allocated to irrigation, and run-of-river projects, typically lock and dam projects, do not impound a conservation pool. This list of projects, by type of authority, is provided in **Table 2-6**, at the end of this section. A map of the 46 projects by type of authorization is shown on **Figure 2-4**.

The table and figure show that the type of authorization differs by the region of the country and river basin. The projects in the Missouri River, Middle Snake, Willamette and other small basins in Oregon are authorized for joint storage. The projects in the Lower Snake and the Columbia River Basins are run-of-river projects. Projects in the rest of the West are basically authorized with specific storage with the exception of the Belton project in Texas that is authorized for joint storage. Note that the Willamette Basin projects in southern Oregon are so close together at this scale that not all are identified by a distinct triangle.

Figure 2-4. Map of Irrigation Water Supply Projects



Data related to irrigation is harder to capture, as it is mostly administered by the Bureau of Reclamation. **Table 2-6** also indicates the 25 projects where irrigation agreements were reported. The Corps reports the amount of annual O&M expenditures at each project that are assigned to the irrigation project purpose to Reclamation, and Reclamation bills the irrigation users in accordance with their agreements with the Bureau. The Corps may collect data when releases are made from the dam specifically for downstream irrigation users, or may rely on data from Reclamation where water is withdrawn directly from the pool of the reservoir for authorized irrigation projects. Data on agreements and acres irrigated comes from Reclamation. The most recent snapshot of these data was collected in 2012 as follows:

- Number of irrigation agreements: 533.
- Average annual flow released for irrigation: 537,212 acre feet.
- Number of acres irrigated: 2,433,873
- Total annual O&M expenditures assigned to irrigation: $4,986,662.

Table 2-6. Irrigation Project Authorizations

District	Project	State	River Basin	Joint	Specific	Run-of-River	Irrigation Agreements
Omaha	Ft. Peck	MT	Missouri	X			
	Garrison	ND	Missouri	X			
	Oahe	ND/SD	Missouri	X			
	Big Bend	SD	Missouri	X			
	Ft. Randall	SD	Missouri	X			
	Gavins Point	SD/NE	Missouri	X			
Walla Walla	Lucky Peak	ID	Middle Snake	X			X
	Ice Harbor	WA	Lower Snake			X	
	Little Goose	WA	Lower Snake			X	
	Lower Granite	WA	Lower Snake			X	
	Lower Monumental	WA	Lower Snake			X	
	Mc Nary	WA/OR	Middle Columbia			X	
Portland	John Day	WA/OR	Lower Columbia			X	
	The Dalles	OR	Lower Columbia			X	
	Willow Creek	OR	Willow Creek	X			
	Lookout Point / Dexter	OR	Willamette	X			X
	Blue River	OR	Willamette	X			X
	Cottage	OR	Willamette	X			X
	Cougar	OR	Willamette	X			X
	Detroit / Big Cliff	OR	Willamette	X			X
	Dorena	OR	Willamette	X			X
	Fall Creek	OR	Willamette	X			X
	Fern Ridge	OR	Willamette	X			X
	Foster	OR	Willamette	X			X
	Green Peter	OR	Willamette	X			X
	Hills Creek	OR	Willamette	X			X
	Applegate	OR	Rogue	X			X
	Lost Creek	OR	Rogue	X			X
Kansas City	Harlan	NE	Republican		X		X
	Kanopolis	KS	Smoky Hill		X		
	Wilson	KS	Smoky Hill		X		
Sacramento	Black Butte	CA	Sacramento		X		X
	Eastman	CA	San Joaquin		X		X
	Hensley	CA	San Joaquin		X		X
	New Hogan	CA	San Joaquin		X		X
	Isabella	CA	Tulare-Buena Vista Lakes		X		X
	Kaweah	CA	Tulare-Buena Vista Lakes		X		X
	Pine Flat	CA	Tulare-Buena Vista Lakes		X		X
	Success	CA	Tulare-Buena Vista Lakes		X		X
Albuquerque	Abiqui	NM	Rio Grande		X		
	Conchas	NM	Upper Canadian		X		
	John Martin	CO	Upper Arkansas		X		
	Trinidad	CO	Upper Arkansas		X		X
	Santa Rosa	NM	Upper Arkansas		X		X
Ft. Worth	Belton	TX	Lower Brazos	X			
Tulsa	Waurika	OK	Red-Washita		X		
Total		**46**		**22**	**17**	**7**	**25**

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3. Water Management

All surface water reservoirs are comprised of a structure to regulate flow and impound water, and an area to hold the impounded water. Aside from these characteristics, however, reservoir projects are amazingly diverse. In the United States, the most comprehensive database of reservoir information is the National Inventory of Dams (NID), but the information in NID mainly relates to the dam structures. In 2008, the Corps water management survey was initiated to: 1) compile a database to examine the status of water management from local, regional, and national perspectives; 2) provide an engineering and scientific foundation for a national adaptive management program; and 3) assemble baseline data for investigating the evolution of operational policies. This survey included not only Corps dams, but also those Bureau of Reclamation and private dams with federally authorized space for flood risk management under Corps operational control. These projects are referred to as "Section 7" projects, in reference to Section 7 of the Flood Control Act of 1944, and a list is maintained in the Code of Federal Regulations, 33 CFR 208.11. This section discusses the information compiled from the 2008 Corps survey and relates it to information in the NID.

3.1. National Inventory of Dams (NID)

The NID currently contains information for more than 84,000 structures that impound surface water in the United States, Puerto Rico, and the U.S. Virgin Islands (USACE AGC 2011). Roughly 8,100 of these dams exceed 50 feet in height, impound a normal storage of 5,000 or more acre-feet (AF) of water, or have a maximum capacity of at least 25,000 AF. At 770 feet, Oroville Dam on the Feather River in California is the tallest listed. At more than 30 million acre-feet (MAF), Lake Mead, impounded by Hoover Dam on the Colorado River, can store the most water, excluding the Soo Compensating Works, a low head structure between Lakes Superior and Huron with a reported maximum storage of over 277 MAF. The Soo Compensating Works are excluded from the assessments in this section. Most dams in the NID are relatively small. The cumulative volume of the smallest 70,000 dams would only fill 40% of Lake Mead.

Operational purposes are coded succinctly in the NID. Oroville Dam's purposes, for instance, are simply noted as "CISHR", which indicate flood risk management, irrigation, water supply, hydroelectric and recreation, respectively. The purposes for Hoover Dam are recorded as "SHI", indicating water supply, hydroelectric and irrigation. All told, there are 103,317 purposes listed for the 80,735 dams that reported at least one of the 12 purposes tracked in the database. Just over 20% of the projects are multi-purpose, with as many as eight purposes listed for a single structure.

Recreation is a cited purpose for 43% of reporting dams, followed by flood risk management (20%); fire protection, stock or small fish pond (20%); irrigation (12%); water supply (12%); other (8.9%); fish and wildlife pond (6.0%); hydroelectric (3.3%); debris control (1.3%); tailings (1.2%); grade stabilization (0.8%); and navigation (0.5%).

Ownership is diffuse. A basic review (no screening for aliases) of NID data showed 48,502 owners for 79,633 dams, excluding the 4,501 dams where ownership was unknown or not reported. Certainly the number of owners is inflated by typographical inconsistencies and inclusion of aliases for individual owners. The Corps, for example, which by almost any measure (number of reservoirs, storage, and geographic distribution) is the largest water management organization in the United States, had 55 aliases. Most labeled the different Corps offices that manage reservoirs. While this might seem to make ownership slightly more uniform, it is actually symptomatic of another factor that complicates water management. For organizations that own and operate numerous reservoirs, 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.

This challenge becomes acute when working with operational databases. The NID is available online, but, apart from the coded list of operating purposes, offers little detail on how the dams are operated. Most operational data that describe reservoir management (e.g., inflows, outflows, storages, pool elevations, and other time series) are maintained in local databases, with little aggregated reporting. Some local data are available online, but the data are inconsistent and lacking standardization of units, data types, and quality assurance. These characteristics make it exceedingly difficult to quantitatively inform basic questions about collections of reservoirs, including: How is storage allocated among different operating purposes? How much water is managed? When water is released, what purpose or purposes does it serve? What environmental strategies are considered when release decisions are made? What policies guide operations? Are these subjects changing with time, and, if so, what drives that evolution?

3.2. 2008 USACE Survey

The 2008 Corps water management survey was a first attempt to answer these questions. It was formulated at the Corps' Hydrologic Engineering Center (HEC) in 2005, but unfunded until 2008. At that time, it was combined with the National Portfolio Assessment for Reallocations survey effort, and a third survey regarding sediment concerns at reservoirs developed by the Corps Subcommittee on Sedimentation, a group of technical experts that provides guidance regarding sedimentation considerations for Corps studies and operations. The point of contact for the Water Management portion of the survey was Dr. John Hickey of HEC who also took over the development of the survey response and authored the original draft of the contents of this section of the report.

3.2.1. Survey Distribution and Data Collection

The correspondence announcing the water management survey was distributed primarily to divisions, who in turn notified their associated districts that had a water management function. All told, 41 Corps offices (2 Northwest Division offices, 7 other divisions, and 32 districts) had responsibilities relevant for the survey. Of these offices, 33 maintain local databases (2 Northwest Division offices and 31 districts). Operational data for projects in San Francisco District are archived by Sacramento District, which with 45 reservoirs (not including the 3 in San Francisco District), has operational responsibilities for the most surveyed reservoirs of any office. Buffalo, Detroit, Norfolk, Jacksonville, and Alaska districts each reported only one flood risk management reservoir.

The initial challenge was to obtain survey responses from 41 offices and operational time series from the 33 offices that maintain data, and compile this mass of data into formats that would facilitate analyses of reservoir management activities. In support of this effort, a website was created that allowed water managers to input, review, and edit their responses and arranged informational data into a spreadsheet format. Also, a common reference entitled “definition of terms” was appended to the survey announcement and provided via the website to improve consistency in responses. This reference is included in this report as **Appendix B**. As early responses were received, it became clear that most effort would be spent working to assure that data submitted were of sufficient quality to facilitate the anticipated analyses.

3.2.2. Review of Informational Responses

Data for most informational queries were readily available and simply required screening for missing or suspect responses. A few queries, such as those related to objective flow exceedances (i.e., instances where operational and hydrologic conditions led to high flows that exceeded target flows at locations, often cities or towns, located below the dam), water control manuals, and testing of alternatives, were more involved. However, the process for compiling data remained the same: coordinate with responding offices, review submissions, and work with the responding offices until all data were deemed complete and of sufficient quality and detail to be used in subsequent analyses. This cycle was repeated as many as eight times per office. When all coordination and review were completed, the resulting informational database included 465 reservoir projects.

3.2.3. Review of Operational Data

Time series of reservoir inflow, outflow, minimum flow requirements, storage, and target storage were also collected on behalf of the survey. Only electronic data, preferable daily values, were requested. Data were submitted in formats ranging from text files to custom database applications. The quality of data varied widely. Some were nearly complete for all data types with excellent data quality. Others had poor data or a smaller fraction of historical operations. Time series of target storage, which is also known as top of conservation storage, and minimum flow requirements were largely unavailable and had to be reconstructed based on informational responses and operational knowledge and guidance.

Raw data were reviewed for errors and missing values. Wherever possible errors were corrected and data gaps filled using a daily mass balance approach based on storage, inflow, and outflow as shown in **Equation 3-1**.

$$Inflow_t = Outflow_t + (Storage_t - Storage_{t-1}) * 0.50417\left(\frac{cfs}{AF}\right) \quad \textbf{(Eqn. 3-1)}$$

Short data gaps of less than or equal to five days were filled with linear interpolation. Longer data gaps were filled with linear interpolation when hydrologic conditions were sufficiently consistent per the judgment of the data processor. Occasionally poor data that were not fixable through these screening methods were removed. Units were converted to cubic feet per second (cfs) for flow time series and acre-feet (AF) for storage time series as needed. Data from real-time operational databases, where values were relayed from gage equipment, used to inform release decisions and archived with no, or limited review, required the most processing. After screening, the resulting database contained 37.3 million daily values. When considered from the beginning of project operations, these data represent 81% of the operational history of surveyed reservoirs as shown in **Figure 3-1**, on the following page.

By the early 1990's, all local databases had transitioned to electronic formats. Nearly all missing data occurred between the beginning of reservoir operation and the beginning of available electronic data. Since then, and apart from the occasional and typically short gap, data have been consistently available. Only 0.5% of data were missing after data were initially reported for a project. Of the 465 reservoirs surveyed, 457 had time series data as displayed in **Table 3-1**, on the following page.

Figure 3-1. Operational Data Compiled for 2008 USACE Reservoir Survey

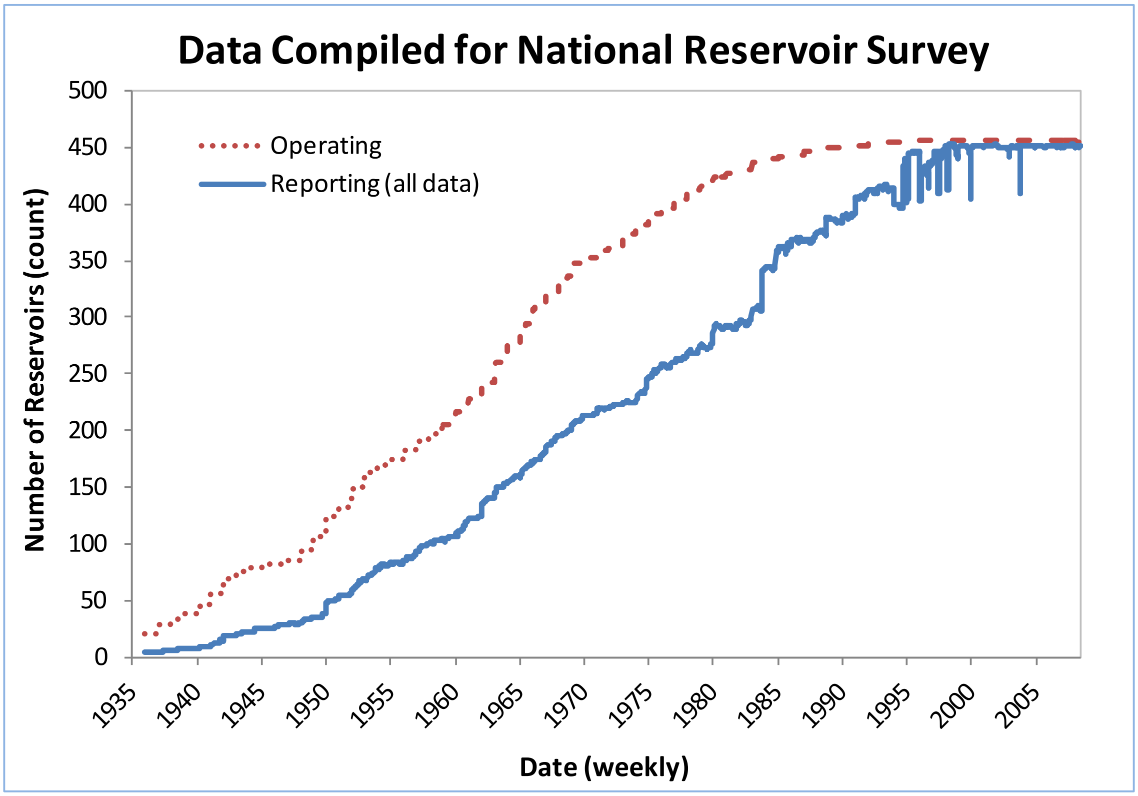


Table 3-1. Summary of Operational Database

Region	Reservoirs in Database	Mean Equivalent Years of Record	Percent Missing w/in Data Record	Percent Operational History
All	**457**	**40.1**	**0.5%**	**81.4%**
LRD	78	46.2	0.2%	89.7%
MVD	32	49.7	0.5%	88.6%
NAD	54	35.2	0.6%	73.1%
SAD	14	41.6	0.0%	99.5%
SPD	83	41.1	0.3%	84.1%
SWD	83	30.6	1.4%	65.8%
NWD-MR	67	42.3	0.0%	89.4%
NWD-CR	46	40.9	0.8%	76.7%
Note: Statistics are based on inflow, outflow, storage, and top of conservation time series				

3.3. Analysis of Data

Appendix C provides a listing by project of the classification and storage data described in this section.

3.3.1. Reservoir Classification and Characteristics

Even with the constant theme of federally authorized flood storage, surveyed reservoirs varied so widely in character that most analyses were more meaningful when performed for classifications and regional groupings of reservoirs. Three simple classifications were used: (1) Big River reservoir projects, (2) Dry Dam reservoirs, and (3) General reservoirs. Big River reservoirs are mainstem projects on the:

- Colorado River (Hoover Dam),
- Columbia River (Grand Coulee and John Day Lock and Dam/ Lake Umatilla), and the
- Missouri River (Fort Peck Dam and Lake, Garrison Dam/ Lake Sakakawea, Oahe Dam and Lake, Big Bend Dam/ Lake Sharpe, Fort Randall Dam/ Lake Francis Case, and Gavins Point Dam/ Lewis and Clark Lake).

These nine projects are distinct in that they have very large drainage areas and large amounts of storage relative to the other projects surveyed.

Dry Dam reservoirs are typically smaller and have fewer operating purposes than other surveyed reservoirs. Most were solely constructed for flood risk management and many release water passively, storing water only when inflows exceed the physical capacity of the unregulated outlets. Reservoirs were included in the dry dam category if their impoundments are dry (zero storage) under normal conditions, or survey responses specifically noted the project as such. Fifty-one projects, nearly 11% of all surveyed reservoirs, were identified as dry dams.

The remaining 405 projects were classified as general reservoirs. These reservoirs were split into regional groups based on Corps Division offices and then also separated into Corps and non-Corps ownership. The classifications and associated characteristics of reservoirs in the information database are provided in **Table 3-2**, on the following page.

Three reservoirs, Tioga-Hammond in Baltimore District, Two Rivers Dam in Albuquerque District, and Whittier Narrows Dam in Los Angeles District, are unusual in that each regulated two streams, had separate dams capable of releasing water to those streams, and had impoundments that merged into a single water body at high water levels. These reservoirs were represented by a single entry in the informational database and two entries in time series analyses. Two Rivers and Whittier Narrows are classified as dry dams and Tioga-Hammond as a general reservoir.

To summarize, 465 reservoirs were surveyed which, from information received, represents every reservoir in the United States with federally authorized flood storage. The informational database describes all 465, comprised of 9 big river, 51 dry dam, and

405 general reservoirs. The time series database describes 457 (the 465 total, minus 11 that did not have data, plus 3 records for split-pool reservoirs), comprised of 9 big river, 44 dry dams (subtracting 9 with no data and adding 2 split-pool reservoirs), and 404 general reservoirs (subtracting 2 with no data and adding 1 split-pool reservoir).

Table 3-2. Reservoir Classification and Characteristics

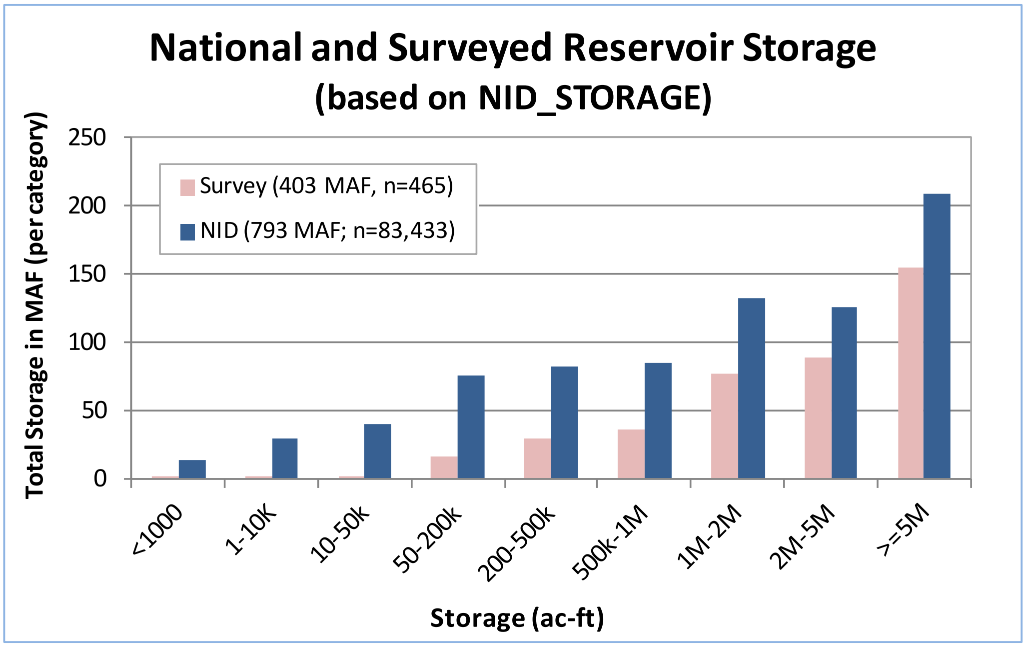
Category Region	Number of Reservoirs			Mean Average [1]		
	All	Corps Owned	Non-Corps Owned	Total D.A. (sq. mi.)	Total Storage (AF)	Max Normal Storage (AF)
Big River	**9**	**7**	**2**	**193,613**	**12,457,258**	**11,336,373**
SPD	1	0	1	167,740	27,377,000	25,877,000
NWD-MR	6	6	0	212,447	12,184,500	11,406,833
NWD-CR	2	1	1	150,050	5,815,661	3,854,678
Dry Dam	**51**	**44**	**7**	**314**	**78,966**	**4**
LRD	6	6	0	613	181,539	0
MVD	2	2	0	16	9,640	0
NAD	9	9	0	73	25,309	0
POD	1	1	0	1,496	200,000	0
SPD	26	23	3	363 [2]	75,391 [2]	8 [2]
SWD	2	2	0	133	204,900	0
NWD-MR	4	0	4	19	2,787	3
NWD-CR	1	1	0	400	106,275	0
General	**405**	**305**	**100**	**2,381**	**598,654**	**338,240**
LRD	73	73	0	857	372,374	185,522
MVD	32	32	0	1,894	746,196	290,400
NAD	44	42	2	188	74,613	22,939
SAD	14	13	1	2,027	1,394,426	829,356
SPD	56	18	38	2,105	614,403	485,030
SWD	82	68	14	4,962	931,082	430,839
NWD-MR	61	39	22	2,371	504,646	446,858
NWD-CR	43	20	23	3,141	629,059	274,002
All	**465**	**356**	**109**	**5,964**	**776,031**	**514,010**

Notes:
[1] Mean average of individual reservoir data is provided to illustrate general differences among classifications and regions.
[2] Excludes Painted Rock, which is a dry dam in Los Angeles District with a drainage area of 50,800 sq. mi., total storage capacity of 2.3 MAF, and max normal storage of zero AF.

3.3.2. Percentage of National Reservoirs Surveyed

Based on comparison with the NID data, the surveyed reservoirs comprise a small fraction (less than 1%) of the number of surface water reservoirs in the United States, but include increasing percentages of larger reservoirs: 29% of the nation's reservoirs with greater than 50 thousand acre-feet (TAF) of storage, 43% of those greater than 200 TAF, 52% of those greater than 500 TAF, and 61% of those greater than 1MAF. These sampled reservoir percentages by volume of storage are shown in **Figure 3-2,** on the following page.

Figure 3-2. Percentage of National Reservoirs Surveyed

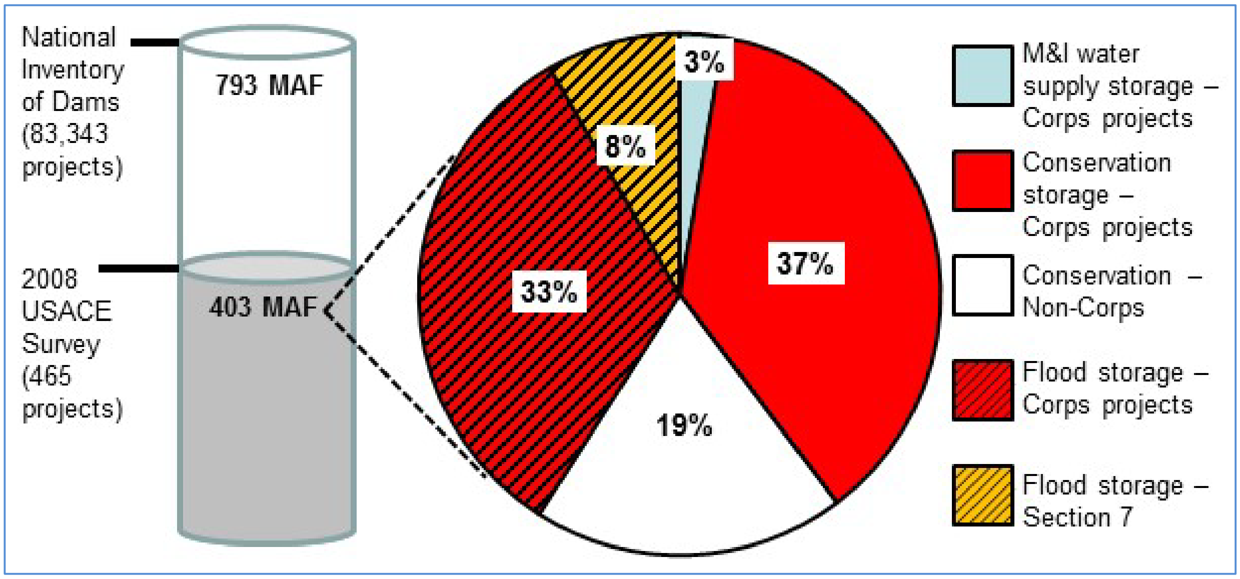


Before comparing storage volumes, the NID database needed to be screened for duplicate reservoirs because multiple entries in the NID may describe a single reservoir project. For example, Folsom Dam and Lake, a reservoir with flood storage near Sacramento CA has 11 NID entries related to different structures at the project (Folsom Dam, Folsom - Mormon Island Auxiliary Dam, Folsom Dikes 1-8, and Folsom Left Wing) each showing a storage of 1.12 MAF, which is the total capacity of the reservoir. In order to prevent this type of duplication, the following screenings were performed.

For projects greater than or equal to 10 TAF, entries with adjacent and duplicate storages were reviewed and deleted if storage was redundant. This removed 484 entries and 328 MAF of storage. Secondly, projects with duplicate database identifiers (NIDID values) were deleted if storage was redundant – this removed 283 entries and 11 MAF of storage. This screening applied to data in 25 of the 50 states, the other states had unique NIDID values for each entry. Thirdly, for projects greater than or equal to 200 TAF, entries were reviewed manually and deleted if storage was redundant – this removed 20 entries and 40 MAF of storage. Finally, redundant and suspect storage amounts found when comparing the NID and survey databases were removed from the NID data. This removed 4 entries and 288 MAF of storage, including the Soo Compensating Works project and its recorded 277 MAF of storage.

After screening, the resulting combined storage of all of facilities in NID, based on the "NID_STORAGE" field values in the NID database, totaled to 793 MAF for 83,343 projects. Also using the screened values in the "NID_STORAGE" field, the 465 surveyed reservoirs have a combined storage of 403 MAF. As shown in **Figure 3-3**, on the following page, surveyed reservoirs therefore have about half of the nation's surface water reservoir storage capacity. If the same comparison is done using normal reservoir storage (based on "NORMAL STORAGE" in the NID database), the surveyed reservoirs comprise 46% of the nation's surface water reservoir storage capacity.

Figure 3-3. Summary of Surveyed Reservoir Storage



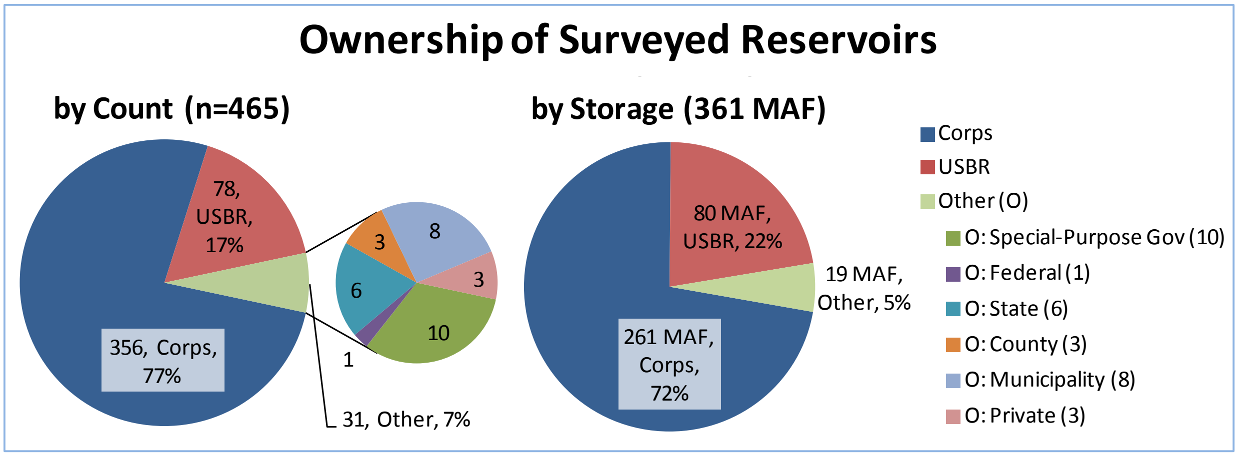
The 2008 survey reported less total storage for the 465 reservoirs, 361 MAF, than was reported in the NID. The pie chart in the figure shows the percentages of the total surveyed storage allocated, on average, to flood risk management (41%) and conservation (59%) purposes, based on the survey total. The survey reported both minimum and maximum normal conservation pools for those projects that change seasonally. The breakout in the figure is an average of the minimum and maximum normal conservation storage which vary by +/- 7%. The 3% of conservation storage identified as water supply storage corresponds to the 9.8 MAF of allocated storage in Corps reservoirs as discussed in **Section 2**.

3.3.3. Ownership of Surveyed Reservoirs

The Corps is the primary federal agency responsible for managing flood risks through operation of large dam and reservoir projects. It is also the principal owner and operator of reservoirs with federally authorized flood storage. There are also reservoirs owned and operated by entities other than the Corps that have federally authorized flood storage space. These reservoirs are often referred to as "Section 7" projects in reference to that section of the Flood Control Act of 1944 which authorized the Corps to prescribe regulations for use of storage at all reservoirs constructed wholly or in part with Federal funds provided for flood storage (Public Law 534, December 22, 1944, 78th Congress, 2nd Session). This blanket authority excludes the Tennessee Valley Authority, except in case of danger from floods on the Lower Ohio and Mississippi

Rivers. Of the 465 surveyed reservoirs, 356 were owned and operated by the Corps and 109 were Section 7 projects, of which 78 were owned in full or in part by the U.S. Bureau of Reclamation. The remaining 31 projects were owned by a variety of other federal, state, regional and local agencies and interests. **Figure 3-4** shows ownership of reservoirs with federally authorized flood storage by count and total (gross pool) storage.

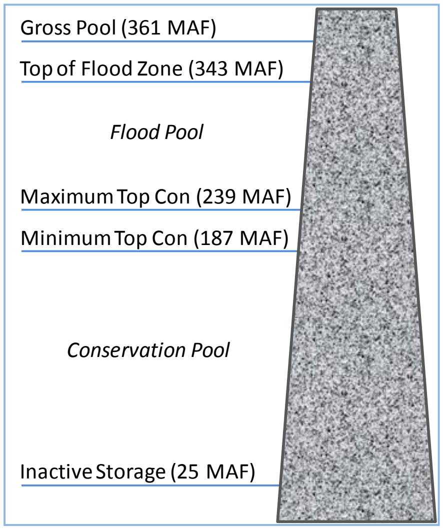
Figure 3-4. Ownership of Surveyed Reservoirs



3.3.4. Reservoir Storage Allocation

Designation of flood storage is one mechanism that creates zones in reservoirs. Flood storage is held as vacant as possible to attenuate potentially damaging high flows. Conservation storage is reserved for a variety of purposes including water withdrawals and releases for environmental, municipal and industrial and irrigation water supplies, hydropower, and recreation uses. Inactive storage is water that is physically too low to be released through reservoir outlets and/or reserved for sedimentation. The boundary between conservation and flood zones is typically called the "top of conservation" and can fluctuate seasonally, as a function of the prevailing hydrologic conditions and as a function of storage in other system reservoirs. Rules that guide reservoir outflows differ between zones (USACE 1982). These zones and the combined storage allocations from the 465 reservoirs are shown in **Figure 3-5**, on the following page.

Figure 3-5. Combined Storage Allocation of Surveyed Reservoirs



3.3.5. Reservoir Operational Purposes

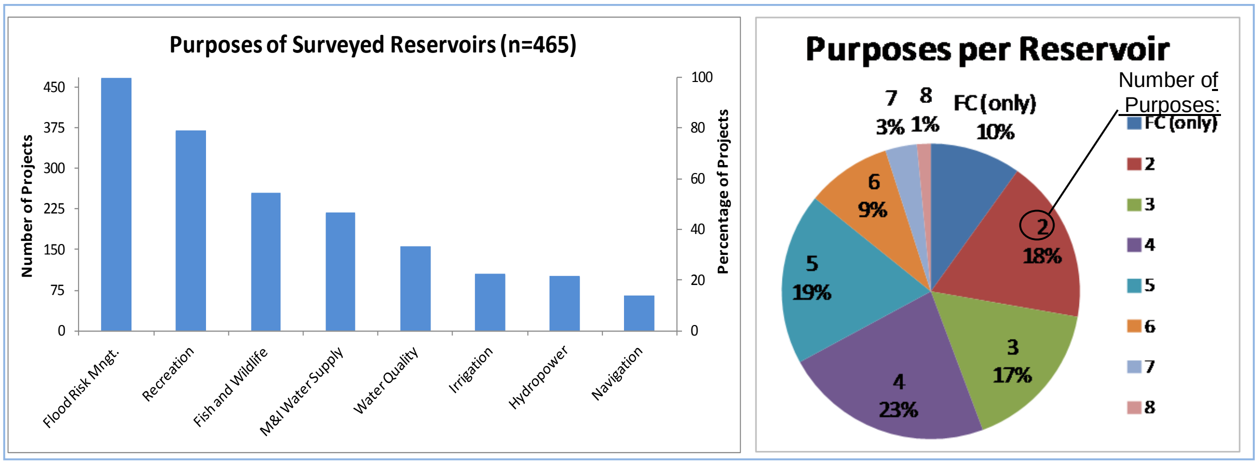
Reservoirs are operated for different purposes. The complexity of operational decision making is generally proportional to the number of authorized purposes. Balancing multiple purposes is a fundamental challenge for water managers and becomes increasingly difficult in times of water scarcity. Purposes for reservoirs with federal government involvement are specified by laws regulating each project's authorization and construction, project-specific laws passed after the project was constructed, and laws that apply generally to all reservoirs with a federal interest (USACE HEC 1992), such as the Clean Water Act (Public Law 92-500) or the Endangered Species Act (Public Law 93-205). Eight purposes were identified for the survey. **Figure 3-6**, on the following page, shows the percentage of projects operated for each purpose, and the number of purposes per reservoir. In the pie chart, the abbreviation "FC," for flood control, is used synonymously with flood risk management.

As federally authorized flood storage was a prerequisite for inclusion, all surveyed reservoirs had flood risk management as an authorized project. Ten percent of projects were single-purpose flood risk management projects. Recreation was the second most common purpose. Multi-purpose reservoirs had a mean average of four purposes per project. The only projects reporting all eight purposes were the six mainstem Missouri River dams: Ft. Peck, Garrison, Oahe, Fort Randall, Big Bend and Gavins Point.

3.3.6. Reservoir Operations

Operational guidance for reservoirs with flood storage is specified in documents called water control manuals. Publication of initial manuals typically lagged completion of the dam by several years. In the intervening period, water managers relied on a

Figure 3-6. Operational Purposes



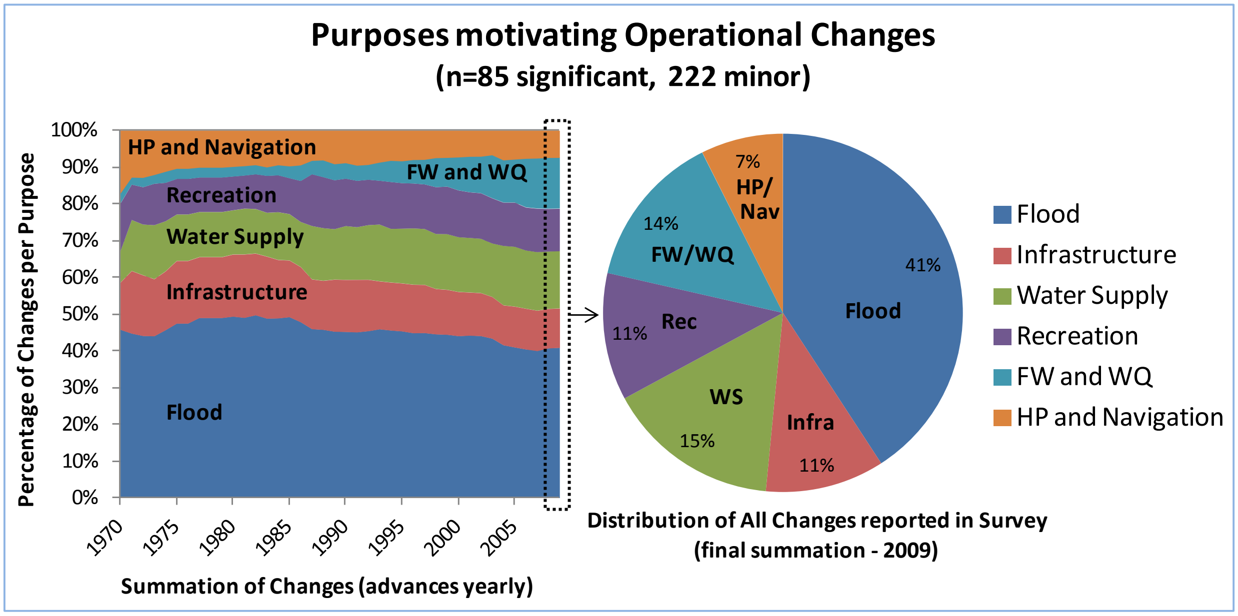
variety of initial guidance (Field Working Agreements, Preliminary or Draft Water Control Manuals, Interim Plans for Regulation of Storage, Design Operating Criteria, etc.) as operational references. Once issued, manuals are updated periodically as operations are adjusted for changing demands or watershed and hydrologic conditions.

The survey compiled information on the evolution of operational guidance. Specifically, operational changes for each edition of a reservoir's water control manual, as well as the purpose or purposes motivating each change, were requested. Changes were then categorized as minor or significant and associated with operational purposes.

Historically, most operational changes from initial guidance to water control manuals and then between subsequent manual editions were motivated by opportunities to improve flood risk management (41%). Enhancements for municipal and industrial or irrigation water supply was the next most common motivation (19%), followed by operational changes for water quality and fish and wildlife management (14%). The distribution of motivating purposes has changed over time, with environmental (water quality and fish and wildlife management) purposes becoming more common. **Figure 3-7**, on the following page, displays the cumulative distribution through each year, and the final distribution of all changes reported in the survey, shown in year 2009.

Operational changes identified as motivated by infrastructure are responses to changing infrastructure conditions. The most common example is an operational change made for an existing dam as additional reservoirs were built in the river system. There were also a few examples of operational changes made as infrastructure condition decayed, for example, the inability to release as much water because the gates were unreliable.

Figure 3-7. Purposes Motivating Operational Changes



3.3.7. Reservoir Releases

Water release decisions from reservoirs are done according to operational guidance for the authorized purposes. Using storage allocations, storage time series, minimum flow requirements, and operational bands for hydropower generation, the time series of reservoir outflows could be generally separated into purposes and plotted as a display that also shows outflows as a function of pool zone. The available data only allowed outflows to be separated into four categories. Outflows were assumed to be released to either meet minimum flow requirements ("environmental" category), generate "hydropower" if released through turbines, or were otherwise ambiguous and categorized as "other". Outflows released to meet minimum flow requirements and to generate hydropower were categorized as "enviro and hydro." No information was collected about water supply deliveries or releases of water for navigation.

In reality, most reservoir outflows serve multiple purposes, which were not fully accounted for in this separation process. Also, a comparison of reservoir inflows and outflows for all reservoirs showed that total outflow only equaled 95% of total inflow, in the period of common data from 1989 to 2008. The reasons for the difference are unknown, though evaporation, seepage, and diversions from the pool or dam could all contribute to the gap.

Storage status was used to track where in the pool releases were made. Storage status was computed based on two main operational modes, flood and conservation, which are split at the top of conservation storage. Each reservoir was considered independently. Categorized outflows were aggregated in 10% intervals within the flood and conservation zones. The process for computing pool status used the logic of **Equation 3-2**:

If S_t >= ToC_t then: $$Status = \left(\frac{S_t - ToC_t}{S_{\max} - ToC_t} \right)$$

Else S_t < ToC_t and: $$Status = \left(\frac{ToC_t - S_t}{ToC_t - S_{\min}} \right)$$ **(Eqn. 3-2)**

Where:

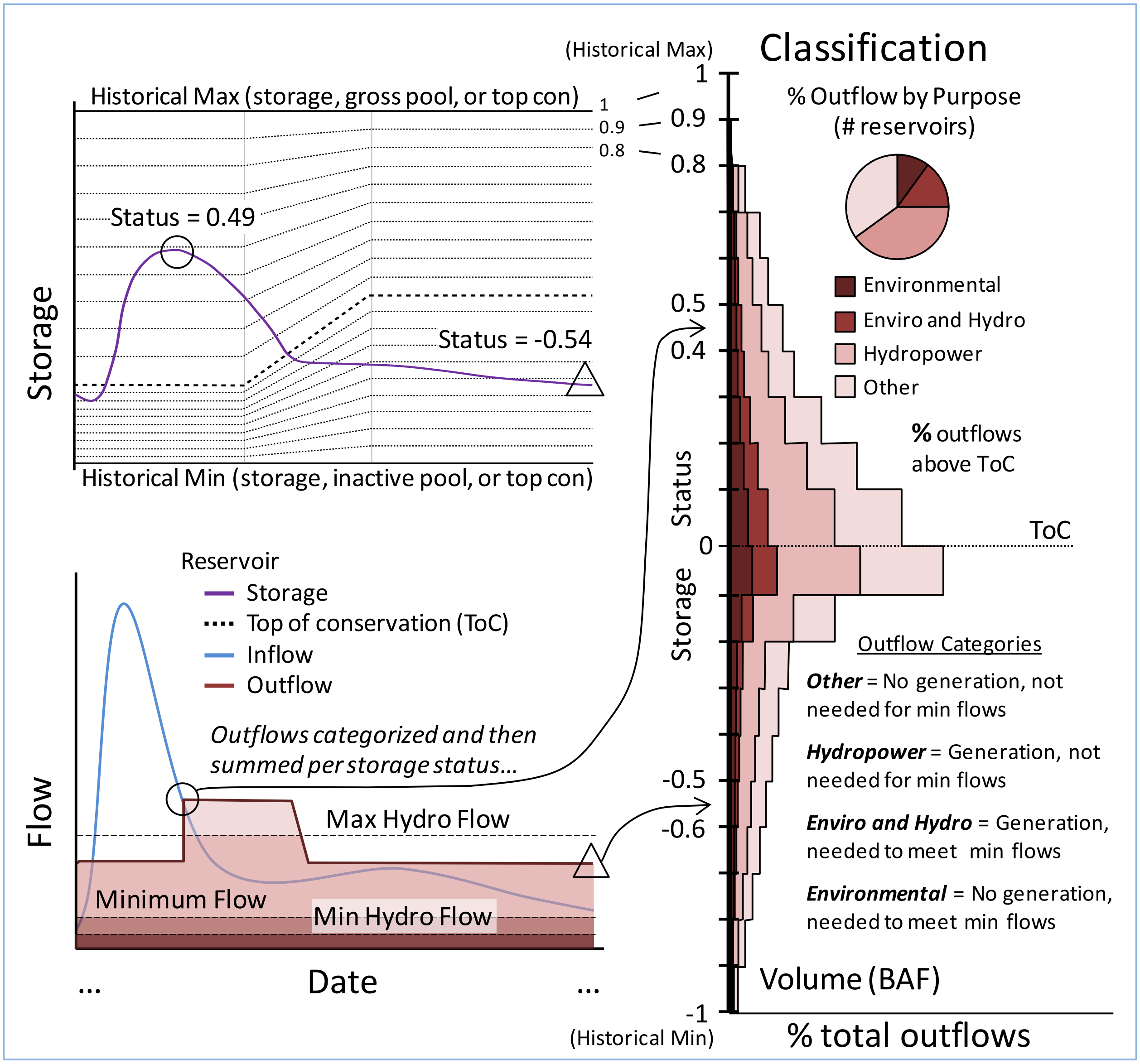
S_{max} is the highest of the maximum historical storage, maximum historical top of conservation storage, or gross pool storage; and

S_{min} is the lowest of the minimum historical storage, minimum historical top of conservation storage, or inactive pool storage.

Figure 3-8, on the following page, details the outflow separation process in relationship to storage status. The resulting displays show from which storage zone reservoir outflows tend to occur and which purposes are typically being served when releases are being made at a particular pool level. This figure is divided into three sections. On the plot to the right side of the figure, the y-axis shows the pool level in relation to top of conservation (ToC). In each percentile above and below ToC, the x-axis shows the percentage of total outflows that were released within that percentile. Furthermore, within each percentile, the contribution of each outflow category to the total is shown by the different colors. The essence is that on any given day when a reservoir is releasing water, those releases were split into purposes (for example, the portion of outflows meeting minimum flow requirements was tallied as environmental), and these daily breakouts have been aggregated for the entire period based on storage status. The plots on the left side of the figure illustrate this concept, with the circle and triangle data points corresponding to examples of two days when the reservoir is either in the flood pool (circle) or in the conservation pool (triangle).

When in the flood zone (positive y-axis), the “other” category is comprised mainly of flood releases not routed through hydropower turbines. When in the conservation zone (negative y-axis), the “other” category corresponds to releases that are not mandated by environmental requirements and are not used to generate hydropower. Since reservoirs typically store when possible (in the conservation zone), those “other” outflows are most likely water deliveries not routed through turbines. The balance between outflows released above and below the top of conservation reflects operational flexibility. Reservoirs are generally managed to maintain storage as close to the top of conservation as possible. As stored waters are released to meet existing obligations such as water supply deliveries and minimum flow requirements, pools are drawn down and operational flexibilities are reduced.

Figure 3-8. Outflow Analysis



Distributions, volumes, and purposes of outflows were assessed between 1989 and 2008 for the three classifications of reservoirs (big river, dry dam and general) as well as a total for all reservoirs. These results are summarized in **Table 3-3**, on the following page.

Table 3-3. Overview of Reservoir Outflows

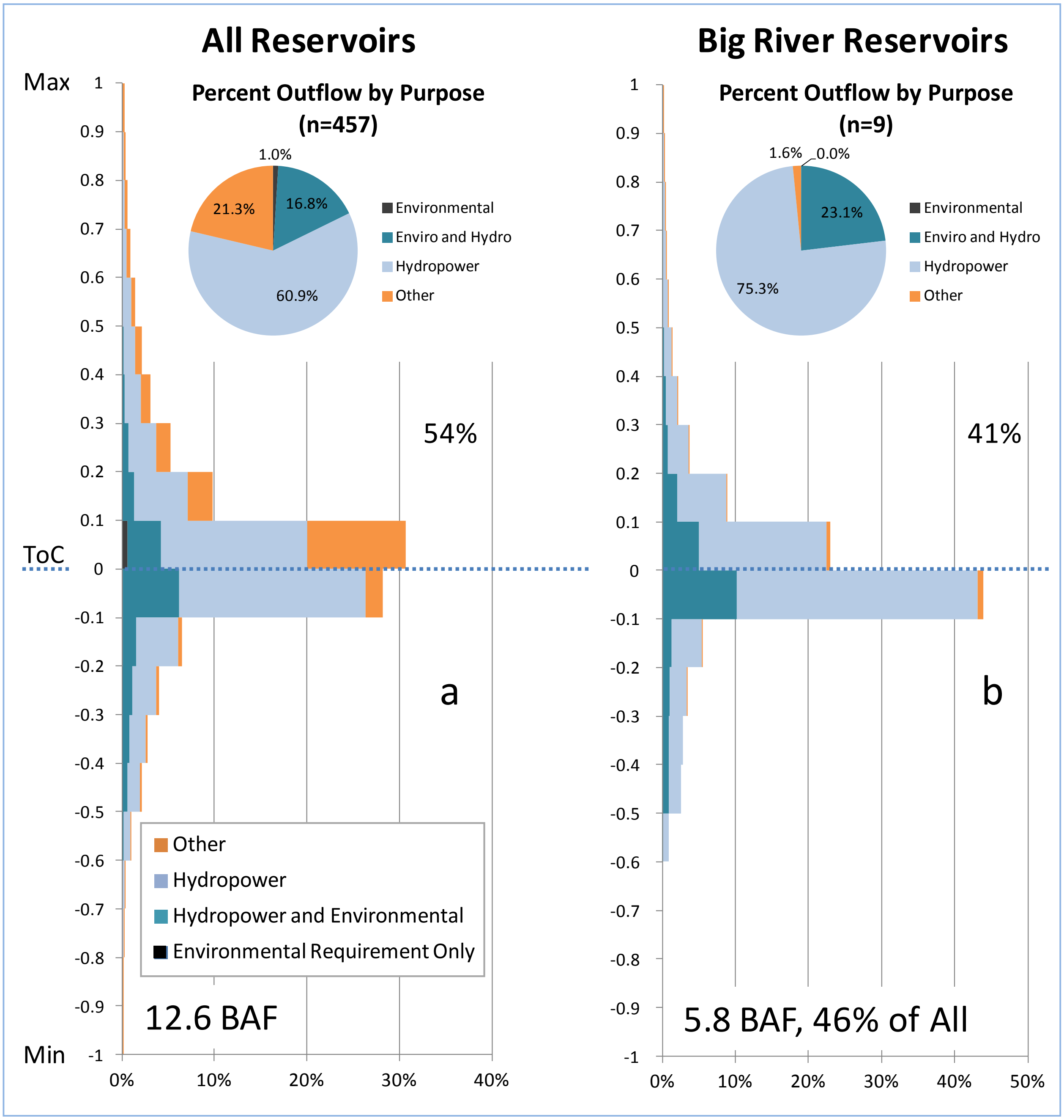
Category Region	Reservoirs		Outflow	Percent Outflow by Purpose				
	Count	w/ Hydro	Volume (BAF)	Enviro and Hydro	Total Enviro [1]	Total Hydro [1]	Other - Con Zone	Other - Flood Zone
All	457	109	12.6	16.8	17.8	77.7	3.3	18.0
Big river	9	9	5.8	23.1	23.1	98.4	0.8	0.8
Dry dam	44	0	0.15	0.0	2.0	0.0	0.2	97.8
General	404	100	6.7	11.7	13.5	61.5	5.6	31.2
LRD	73	10	1.4	9.3	11.3	53.6	3.5	40.8
MVD	32	4	0.55	0.2	6.3	11.8	6.4	75.8
NAD	45	4	0.22	3.8	13.5	14.1	14.2	61.9
SAD	14	9	0.51	15.4	16.1	91.2	1.0	7.4
SPD	55	25	0.62	10.1	10.6	72.6	14.7	12.2
SWD	81	19	1.3	1.1	1.8	50.8	1.9	46.6
NWD-MR	61	6	0.41	19.0	21.4	67.5	8.5	21.5
NWD-CR	43	23	1.7	24.2	24.9	83.7	6.1	9.5

Notes:
[1] “Total” columns correspond to the sum of each category plus the combined “Enviro and Hydro” category. To sum the percentages in a row to 100, the combined “Enviro and Hydro” category must be subtracted from one of the “Total” columns.
[2] Tabulated percentages may not exactly equal 100 or the sum of percentages from figures due to rounding.
[3] Table based on data for the 20-year period of 1989 to 2008.

Similar to **Figure 3-8**, the percentage of outflows by purpose and pool status over the 20-year period of record (1989-2008) are shown in a series of figures for different categories of reservoirs. **Figure 3-9** is divided into the following parts, showing the breakdown for:

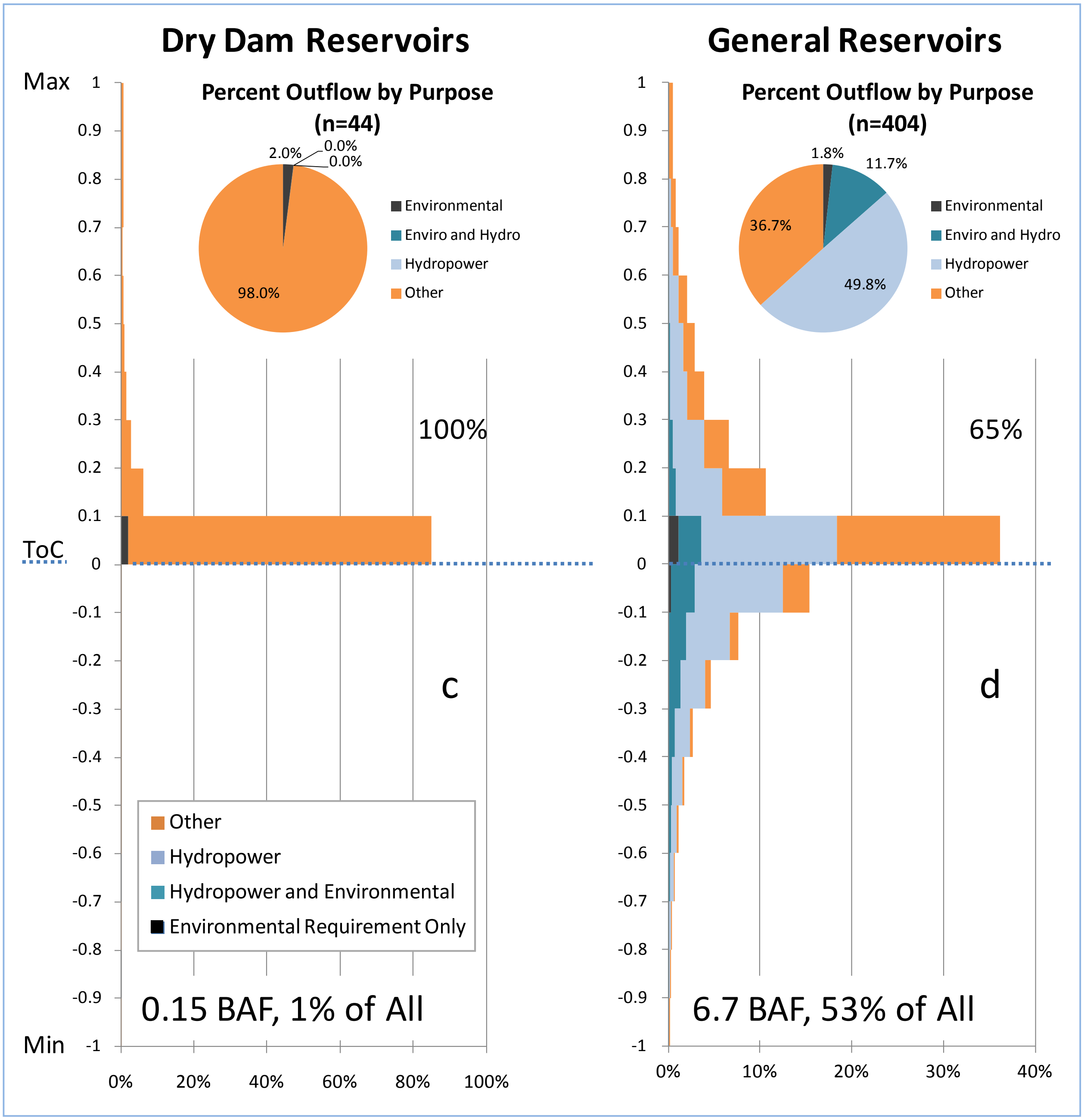
- **a**. All Reservoirs,
- **b**. Big River Reservoirs,
- **c**. Dry Dams,
- **d**. General Reservoirs – All,
- **e**. General – Corps Owned, and
- **f**. General –Non-Corps Owned.

Figure 3-9. Comparison of Outflows by Purpose and Pool Status (a) All Reservoirs and (b) Big River Reservoirs



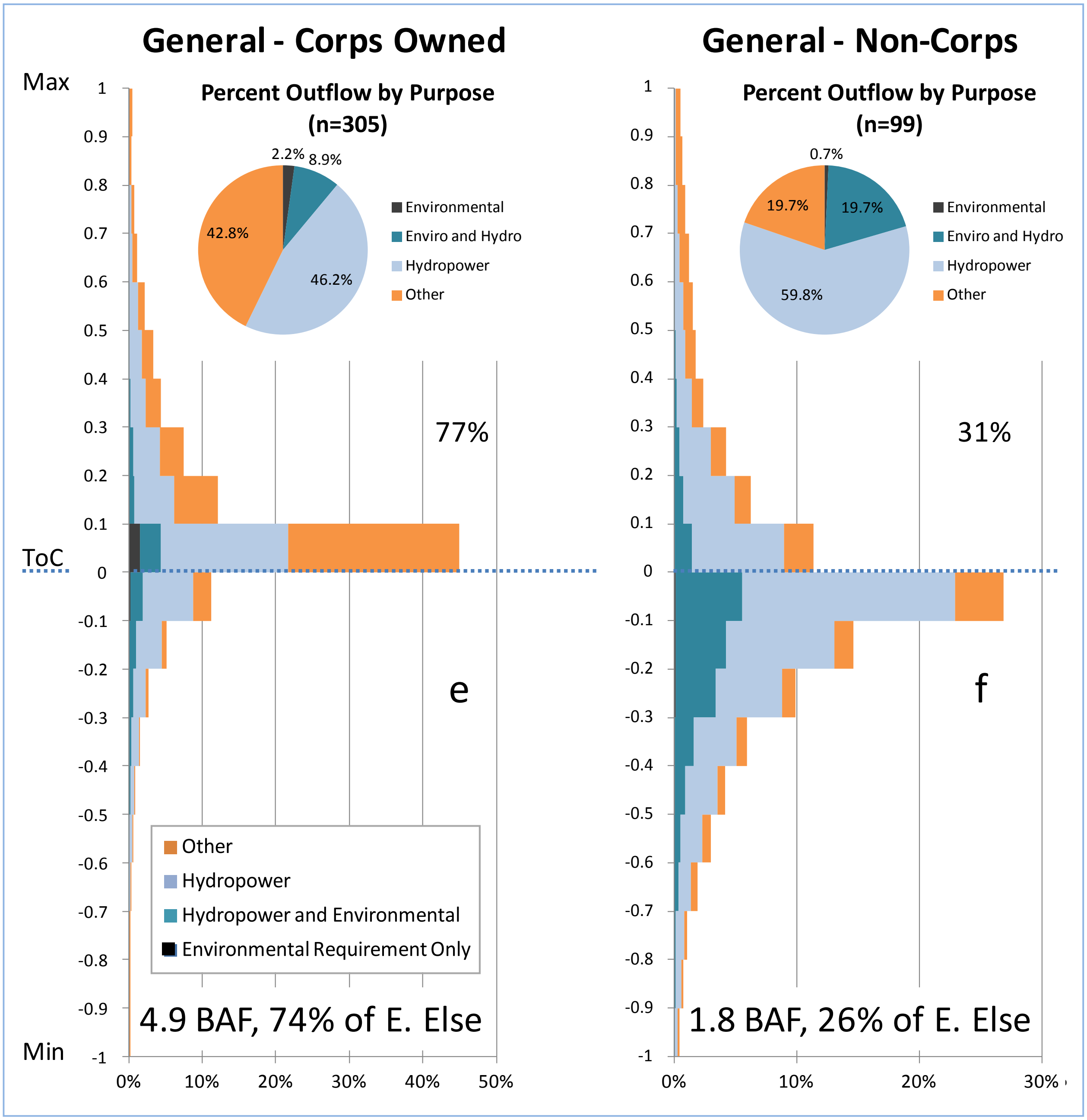
Over the observed 20 years, all surveyed reservoirs released 12.6 billion acre-feet (BAF) of water (**part a**). Big river reservoirs, though only nine in number, accounted for nearly half of the total volume (**part b**). Big river reservoirs were impressively efficient at generating hydropower. 98% of all waters released at those projects spun turbines.

Figure 3-9. Comparison of Outflows by Purpose and Pool Status (c) Dry Dam Reservoirs and (d) All General Reservoirs



Dry dam reservoirs comprised nearly 10% of surveyed reservoirs with time-series data (44 of 457), but regulated only 1% of total outflows (**part c**). No dry dam had hydropower facilities. Two listed minimum flow requirements, though both reported that they were single-purpose, flood risk management reservoirs. A review of the time-series data for these two reservoirs did not indicate that waters were stored to meet minimum flows.

Figure 3-9. Comparison of Outflows by Purpose and Pool Status
(e) Corps-Owned General Reservoirs and (f) Non-Corps General Reservoirs



The general collection of reservoirs accounted for 88% (404 of 457) of all reservoirs and 53% (6.7 of 12.6 BAF) of the outflows (**part d**). This general category of reservoirs can also be separated into those which are Corps-owned (**part e**) and Non-Corps-owned, (**part f**). The Corps-owned general reservoirs account for 39% (4.9 of 12.6 BAF) of total outflows.

3.4. Environmental Flow Management

While environmental strategies at reservoirs can involve management of physical, chemical, and thermal characteristics of in-pool and downstream waters, as well as connectivity of habitats and fluxes of sediment and nutrients, most surveyed reservoirs were limited to flow (61%) or thermal (17%) management strategies. Environmental flow management strategies were formalized mostly in terms of minimum flow requirements. Surveyed reservoirs had minimum flow requirements that totaled to 17.8% and 13.5% of outflows for the “all” projects and “general” categories, respectively (**Table 3-3 and Figure 3-9, parts a and d**). Within the “general” category, reservoirs owned and operated by the Corps had minimum flow requirements totaling to 11.1% of outflows (**part e**).

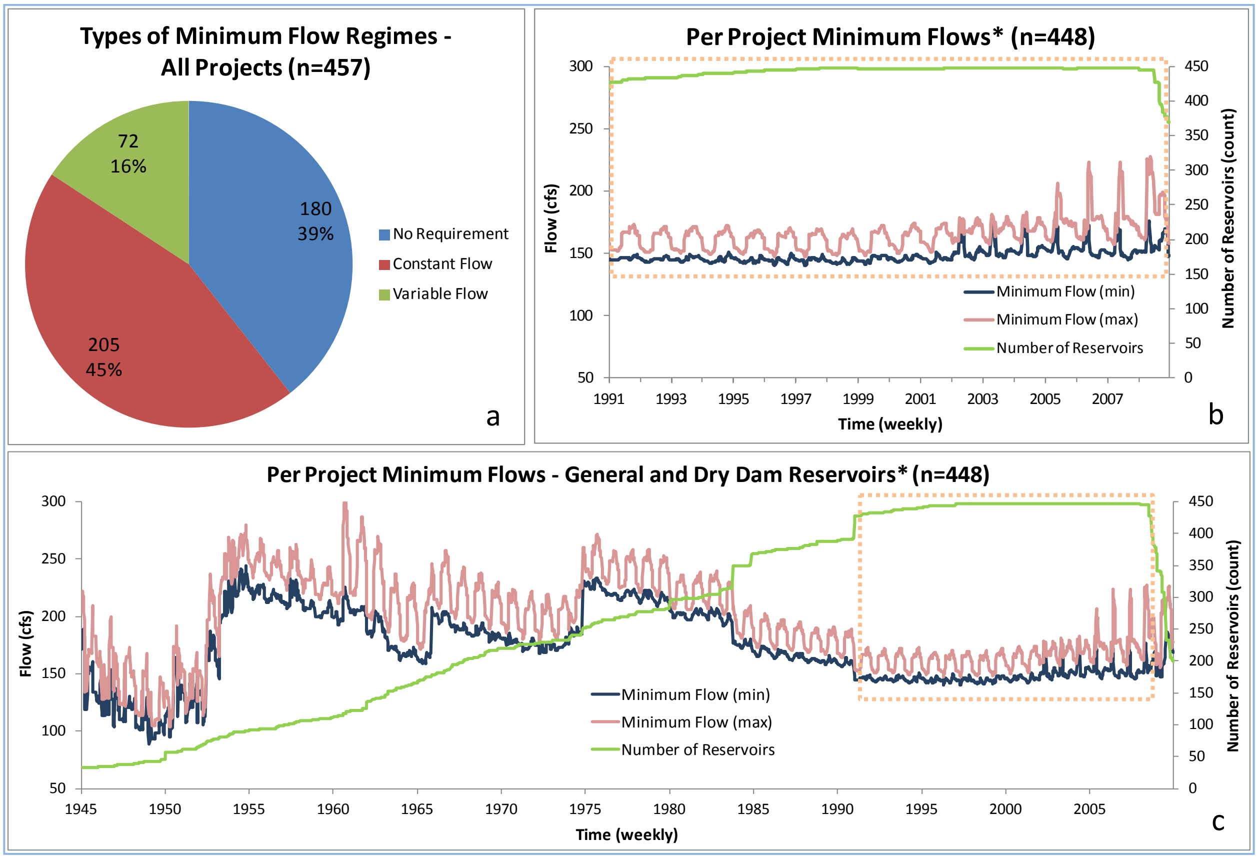
Minimum flow time series were aggregated for all surveyed reservoirs to investigate modes of requirements (**Table 3-4**) and trends in pattern. Of all reservoirs with time-series data, 39% had no requirement. The most common mode (45%) of requirement was a constant minimum flow. The remainder (16%) had a variable flow requirement that fluctuated either seasonally, as a function of condition, or both.

Table 3-4. Summary of Minimum Flow Modes

Category	Total Count	Min Flow Mode (Count)			Min Flow Mode (%)		
		None	Constant	Variable	None	Constant	Variable
All	457	180	205	72	39%	45%	16%
Big river	9	4	4	1	44%	44%	11%
Dry dam	44	42	2	0	95%	5%	0%
General	404	134	199	71	33%	49%	18%

Figure 3-10, on the following page, shows the required outflows for environmental purposes at surveyed reservoirs. Results are shown for the a) type of minimum flow requirement, b) patterns of minimum flow requirements between 1991 and 2008, and c) patterns of minimum requirements between 1945 and 2009. Results of the “Big River” reservoirs on the mainstem Missouri, Columbia, and Colorado Rivers are omitted from this figure for clarity. Between 1991 and 2008, minimum flow requirements were generally stable, though there is a visible trend, beginning in the 2000’s, which shows flow requirements increasing in terms of magnitude and variability.

Figure 3-10. Minimum Flow Requirements



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4. Environmental Conditions

Section 3 discussed the analysis of historical releases made for environmental flow requirements based on the operational time-series data collected in the water management survey. This section discusses two related efforts to evaluate environmental conditions in and around Corps multi-purpose reservoir projects in more detail; both the impact of the projects on affected environments and habitat, and how the physical, chemical and biological conditions in a reservoir impact the authorized purposes.

The Corps Committee on Water Quality (Committee) is a standing technical committee authorized by Congress. The primary charge of the Committee is to provide technical assistance, develop policy guidance and exert leadership in all issues involving water quality and ecological sustainability for the Corps. In 2011, the Committee was funded through the National Portfolio effort to build on the initial assessment of environmental flows made from the water management survey data. Since that time the Committee has produced three products and initiated one additional item in support of the overall assessment of multi-purpose reservoirs. These efforts are described in **Section 4.1.**

The Sustainable Rivers Program (SRP), **described in Section 4.2**, is a collaborative effort between the Corps and The Nature Conservancy (TNC), designed to change dam operations to restore and protect the health of rivers while continuing to serve other project and human needs such as flood control, hydropower and water supply. The program consists of two major efforts, a national program and a project site program. Since 2010, SRP funding has been administered under the umbrella of the National Portfolio.

Appendix D notes the specific projects that have been the subject of the case studies described in this section.

4.1. Committee on Water Quality Products

Since 2011 the Committee has produced three products related to enhancing water quality and promoting ecological sustainability as part of managing multi-purpose reservoir projects:

1) The proceedings of a 2012 workshop documenting the need for technical guidance;

2) A compilation of case studies documenting examples of relatively modest changes in the structural elements and operations of our multi-purpose reservoirs; and

3) An information paper on water quality and ecological threats to multi-purpose reservoir project purposes.

In addition to these three products, the Committee began an online survey to gather information regarding the status of water quality and ecological management concerns at Corps reservoirs. This survey is intended to complement the original three surveys performed as part of the National Portfolio effort.

4.1.1. Technical Guidance on Managing Corps Multi-purpose Reservoir Projects for Improved Water Quality and Ecological Sustainability

The first activity of the Committee under the National Portfolio effort was a 2012 workshop help in Portland, Oregon, to comprehensively discuss the need for, and the new thinking and approaches necessary to manage multi-purpose reservoirs for enhanced water quality and ecological sustainability. The workshop was attended by a cadre of Corps practitioners in water quality and ecological management and organized by Mr. Dave Shepp of Headquarters USACE (since retired) and Dr. John Hickey of the Corps' Hydrologic Engineering Center. The first part of the workshop was focused on a presentation and discussion of fundamental flow concepts. They consist of: 1) the natural flow regime, 2) the ecological impacts of impounding rivers and 3) achieving a naturalized flow regime at Corps multi-purpose reservoirs.

The natural flow regime reflects the characteristics of a pre-impoundment river system with unaffected response to a wide range of hydrologic conditions, from flood to drought. Runoff from rainfall and/or snowmelt is unimpeded, the related flow of nutrients and sediments are unaffected and the mobility and associated life stages of resident and migratory species is unimpeded and unaffected. Where flood intolerant land use occurs, loss of life and property may occur in these unregulated systems.

To realize a range of congressionally authorized benefits (including flood risk management, water supply, navigation, water quality, hydropower, fish and wildlife and recreation) the Corps has designed and constructed and operates a large national portfolio of multi-purpose reservoirs. It is widely understood from decades of study that impounding river systems to achieve such benefits generates a suite of associated ecological impacts. Flow alterations resulting from impounding rivers include: the rate, timing, duration, and volume of flow. Additionally, water temperature, dissolved oxygen concentrations, the flow of nutrients and sediments and the mobility of resident and migratory species may be affected. Further, seasonal flow patterns may be changed, affecting life cycle requirements of native plant and animal species.

A naturalized flow regime reflects efforts to correct or minimize the ecologically altering effects of impounding a free-flowing river system, while simultaneously maintaining the benefits and originally intended purposes of impoundments. To identify goals and objectives associated with achieving a naturalized flow regime, all available pre-impoundment annual hydrographs should be compiled and sorted for high, average and low flow years. In addition to studying annual flow patterns, seasonal flow patterns should be evaluated and related to life-cycle triggers and thresholds for dependent native terrestrial and aquatic species. Where possible, key annual and seasonal flow characteristics of the un-impounded natural flow regime should be reintroduced to the ecosystem affected by the impoundment.

Following discussion of flow concepts, the remainder of the workshop addressed next steps and products. Two products were envisioned: an information paper on the workshop topics and the development of case studies with examples of implemented changes in reservoirs operations specifically targeted to achieve enhanced water quality and ecological sustainability. The information paper that was produced captured the proceedings, findings and recommendations of the workshop. The main recommendation was for the development of technical guidance to provide water managers practical information on new concepts and specific real-world approaches which have been successfully executed to achieve enhanced water quality management and ecological sustainability.

Wherever possible, opportunities for achieving enhanced water quality and ecological sustainability at minimum expenditure of staff time and funding, preferably without incurring deviations from existing Water Control Plans, should be explored and pursued. Using the following compilation of the case studies as a foundation, the Committee recommends the development of technical guidance to present fundamental concepts of flow management, outline associated requirements for ecological sustainability and share practical, applied examples for the districts.

4.1.2. Case Studies

In some situations, achieving goals of improved water quality and ecological sustainability at Corps multi-purpose reservoirs will require complex, programmed multi-year funding, extensive modeling and external expertise as exemplified by The Nature Conservancy's Sustainable Rivers approach. There are many opportunities however that exist throughout the Corps portfolio of multi-purpose reservoirs where substantive improvements in water quality and ecological function and integrity may be achieved with simple adjustments in operations and/or modest structural modifications. These types of improvements can, and have been, realized with modest investments of staff time and capital expenditures usually without triggering a deviation from a given facility's Water Control Plan. The case studies performed as a result of the 2012 Portland workshop reflect a broad range of both simple adjustments in how a given facility is operated and modest structural modifications to a facility to allow increased operational flexibilities. Both approaches reflect a change in thinking about how a given facility could be managed and allow water managers to achieve enhanced water quality and ecological sustainability through their application. The seven case studies investigated are briefly summarized in the following sections.

Dworshak Reservoir, Idaho: Lower Snake River Water Temperatures.

This case study was prepared by the Corps' Walla Walla District. The primary focus of this study was temperature conditions in the four Lower Snake River reservoir projects in Washington State and how they are influenced by project operations at the upstream Dworshak Dam on the North Fork of the Clearwater River in Idaho. The four Lower Snake river reservoir projects, from upstream to downstream, are: Lower Granite, Little Goose, Lower Monumental and Ice Harbor. The case study showed that summer cold-water releases from Dworshak Reservoir are used to decrease Lower Granite Dam tailwater temperatures 80 miles downstream to 20 ºC (68 ºF), or less.

These releases began in 1991 as an experiment to aid salmon migration. The operational changes were later incorporated into the 2000, and subsequent, Federal Columbia River Power System Biological Opinion. A CE-QUAL-W2 model was developed in 2005 as a predictive tool, and has been successfully used to manage the volume and temperature of Dworshak outflows while staying within Idaho's 110% total dissolved gas standard. The cooling effects diminish downstream, but are still evident at the Ice Harbor Dam tailwater monitoring station 100 miles downstream from Lower Granite Dam. One consequence of greater thermal stratification in the Lower Granite forebay is increased thermal differences in the adult fish ladder which can, at times, hinder upstream migration. There are on-going investigations for remedial measures.

Fall Creek Reservoir, Oregon: Modified Operations for Fish Passage.

This case study was prepared by the Portland District. Fall Creek is one of 13 multi-purpose Corps reservoir projects in the Willamette Basin. These dams block access to a majority of the historical spawning habitat for Endangered Species Act-listed fish. Many of the dams were built without downstream fish passage facilities and those facilities that were built have since been abandoned due to lack of functionality. Beginning in 2008, the Corps implemented a series of gradual drawdowns at Fall Creek to improve downstream fish passage per the Willamette Basin Biological Opinion. The purpose of this study was to determine the impacts on fish passage if the project was further drawn down.

Data collected during the drawdown operations implemented from 2010 through 2014 indicate a direct positive effect on the passage and survival of spring Chinook salmon through the dam. Results were positive in terms of other downstream impacts with the exception of cultural resource concerns of the Confederated Tribes of the Grand Ronde. The larger drawdown operations exposed, eroded and damaged culturally significant areas once inundated by the reservoir. The Corps has recognized the potential effects of drawdown operations and have initiated a programmatic agreement with the concerned Native American Indian Tribes.

Detroit Reservoir, Oregon: Operation for Downstream Water Temperature.

This case study was also prepared by the Portland District. This project is located on the North Santiam River in the Willamette River Basin. Detroit Dam is operated for flood risk management, production of hydroelectric power, recreation and fish and wildlife needs. Releases from the dam drive downstream water temperatures in the North Santiam River because of its large, deep pool. In June 2007, an electrical fire broke out at the Detroit powerhouse, damaging power generation equipment and causing a complete shutdown of the powerhouse facility. With the powerhouse out of commission, water was discharged through the surface spillway outlets and deep regulation outlets. Under these atypical operations, regulators and scientists saw improvements to downstream water quality and recognized an opportunity to perform downstream water temperature management.

The Corps then initiated a study to test various operational temperature management strategies and their compatibility with other authorized purposes and the structural and mechanical components of the dam. The study concluded that water temperature management operations were feasible and they have been carried out since. The new operations have had a direct positive effect on the productivity and survival of spring Chinook and winter Steelhead in the river basin. Negative impacts have been felt by hydropower generation, on the order of $2 million per year, and wear and tear on the project's tainter gates has accelerated. A team continues to evaluate the implementation of this plan to determine if it is a viable long-term solution or if a selective withdrawal structure should be constructed.

Tappan Lake, Ohio: Outlet Modifications for Improved Water Quality.

This case study was prepared by the Huntington District. Tappan Dam is an old project, completed in 1936. The outlet structure has three main sluice gates for releasing water and a siphon for low flow control. The outlet structure was not designed with maintenance or improvement of water quality as one of its purposes, therefore the quality of release water is not regulated. Operational concerns included the fact that recreational areas downstream of the dam had to be closed during the summer months, due to high concentrations of hydrogen sulfide, elevated water temperature, low dissolved oxygen, and elevated manganese content. In addition, the concrete liner in the release tunnel was deteriorating much faster than expected; also due to high concentrations of hydrogen sulfide gas in the water. The 2003 study looked at alternatives to mitigate adverse impacts to recreation and fish and wildlife.

The study looked at modifying the intake structure to permit selective withdrawals as well as consideration of regulating the existing low flow system. The least costly alternative was identified as modifying the existing outlet structure to create three wet wells within the current structure with upper level intakes for each well. Funding of the $2.3 million effort was a problem and the modification was put on hold. In 2012 the study was revisited to focus on stopping the concrete deterioration. Managing hydrogen sulfide levels in the outlet tunnel was the best way to slow the rate of concrete deterioration. The recommended solution at a cost of less than $1 million was to replace the one existing trash rack in front of one of the three sluice gates with a combination weir/trash rack. Thus hydrogen sulfide, dissolved oxygen, and manganese objectives of the study would be fully achieved; the temperature objective would be partially achieved; but the objective to control flow through the siphons would not be achieved. It was found that the same design could also be used on four other projects in the Muskingum Basin having similar problems.

Huntington District: Flexible Winter Drawdown for Improved Water Quality.

In accordance with ER 1110-2-240, "Water Control Management" (USACE 1982), the plan of water control management and regulation reflects optimal consideration of each of the project purposes. The Corps environmental mission has two major focus areas: restoration and stewardship. Of the 35 dam projects in the Huntington District, 26 have winter drawdown. The timing of winter drawdown for some projects was in conflict with completion of lake mixing. Thus for those projects with selective withdrawal, blending within the outlet structure was needed to achieve downstream temperature targets. For other projects not having selective withdrawal, a temporary cold water surge was released downstream at a time of the year when warm water was needed. Then later in the year when stream temperatures were decreasing, only warm water was available from the lake.

Use of low flow systems with selective withdrawal to control for temperature downstream was tried as a solution with great success. Unfortunately not all projects had outlet structures with selective withdrawal capability. In addition infrastructure problems caused challenges when different intakes were not available for use due to needed repairs. A more flexible drawdown schedule was needed, and a thorough review of individual water control manuals found that there was more flexibility in operations with regards to the elevation rule curves than previously thought. Rule curves were referred to as "overall schedules" which implied that they could change and further that the optimum date to start drawdown for each project each year would be based on hydrologic conditions. Drawdown schedules at Huntington projects were then revised to be linked to hydrologic conditions with water quality conditions in the lake as the driving factor.

Sutton Lake, West Virginia: Operational and Structural Modifications for Improved Downstream Conditions.

This study, also performed by the Huntington District, looked at operational and structural changes for selective withdrawal. The project is authorized for flood risk management, recreation, pollution abatement, whitewater activities, and fish and wildlife conservation. Due to the design of this project, completed in 1961, turbid water could be released from the lake for weeks at a time after storm events, while other streams within the basin cleared rather quickly. In addition, habitat for the aquatic community was also degraded due to lack of seasonal temperature variations that normally occurred with free flowing streams, since the sluice gates used for releasing water were located at the bottom of the lake.

In the 1970s the district undertook a study to resolve these issues with releases. This study resulted in the construction of a high-level intake that could be operated to increase water temperature and reduce turbidity in the tailwater area, with a subsequent improvement in fishing opportunity. In the area immediately below the dam, the numbers of days with good bass fishing conditions increased dramatically. Operation of the high level intake was closely coordinated with the State of West Virginia through the early 1980s until established priorities and procedures were developed.

In 2009, almost 50 years after dam completion, a biological assessment was performed. The assessment determined that cold-water discharges from the dam were still related to low reproductive rates of native mussels and fish. The West Virginia Department of Natural Resources, the US Fish and Wildlife Service and the Corps reviewed the study findings and jointly decided that water temperature needed a higher priority than in-lake turbidity when releasing water from the existing high level intake, and the water control manual was updated accordingly. With the new guidelines in place cold-water discharges during storm events were reduced considerably, water temperatures in the river below the dam improved and stream conditions returned to more normal.

Kanawha River, West Virginia: Operational Changes in Low Flow Augmentation.

In the 1960s the Huntington District constructed two multi-purpose reservoirs in the Kanawha River Basin, Summersville and Sutton. Local municipalities and industries required a continuous flow of water in the river to dilute pollutants they discharged. At the same time, fish and food chain organisms required a continuous flow of oxygenated water to sustain normal vitality. In the design of the two lakes, there was sufficient seasonal storage to be utilized for pollution abatement to keep dissolved oxygen in the river from falling below the West Virginia standard. At this time, technology to measure real-time dissolved oxygen did not exist, thus a relationship between dissolved oxygen and water temperature was used.

After implementation of the Clean Water Act, the quality of the water in the Kanawha River improved noticeably due to pollutant discharge regulations. As technology for measuring in-situ dissolved oxygen improved, the Corps began to notice an improving dissolved oxygen trend. Summersville and Sutton lakes were releasing more water than needed to maintain the quality of water in the river, and the operating instructions for the project were revised accordingly. Implementation of the new guidelines for managing low flow augmentation in the Kanawha River resulted in less water released from the two dams while at the same time keeping the dissolved oxygen conditions in the river above state standards.

4.1.3. Water Quality and Ecological Threats to Multi-purpose Reservoir Purposes

In 2014 the Committee completed an information paper outlining emerging issues including human activities and natural conditions that, independently and in combination, generally threaten the ability of Corps multi-purpose reservoirs to meet their authorized project purposes. As discussed in **Section 6**, the third National Climate Assessment (Melillo et al. 2014) identified changes to the water cycle, and the impacts of these changes to water resources, as a critical challenge resulting from a warming climate. This change in weather patterns together with an increase in harmful algal blooms, the new pressure on water resources due to the newly-developed unconventional oil and gas extraction and the recent private sector interest in non-Federal retrofit hydropower development have all changed the water resource management landscape in the United States. These topics are discussed in more detail in the following paragraphs.

Corps policy requires that climate change adaption be mainstreamed into all Corps activities to help enhance the resilience of our built as well as the natural water resource infrastructure and reduce their potential vulnerabilities to the effects of climate change and variability. The severe droughts in the last decade, first in the southeastern region and, more recently in the southwest and California, have highlighted the additional pressures that will be placed upon the balance of the Corps' national portfolio of reservoirs which collectively hold about one-third of the nation's constructed reservoir storage (see **Section 3.3**). Increasing demands, and potentially more frequent shortages of water may intensify existing issues and/or create new issues for Corps water managers and reservoir project stakeholders.

An algal bloom is a rapid increase or accumulation in the population of algae in an aquatic system. While some coastal blooms have been attributed to natural upwelling of nutrients, many freshwater and ocean blooms have been found to be directly linked to nutrient pollutants (primarily nitrogen, total phosphorus, and phosphates) from agricultural activities and climate change. A harmful algal bloom (HAB) is an algal bloom that negatively impacts other organisms via production of natural toxins. In the last few years, the incidence of HABs had been increasing throughout the United States including Corps reservoirs.

Following a HAB, water supplies can be compromised and become unfit for human use for weeks or months. There is currently no known control for avoiding or halting HABs. These harmful blooms produce toxins which can cause neurological problems such as paralysis and seizures in humans and animals. These blooms present a growing concern to the non-federal sponsors, citizens, habitat and wildlife served through the Corps' water supply, water quality, recreation and ecosystem restoration missions.

Mineral extraction activities, including coal mining, conventional and unconventional (hydraulic fracturing) oil and gas development, waste disposal and minerals pipelines are exerting increasing pressure on water resources (water quantity and quality, and ecological health) and human health and safety across the nation and at Corps projects. Concerns about the potential for structural and ecological impacts associated with minerals extraction activities led to the development of a Corps interim policy to protect the structural and ecological integrity of our national portfolio of multi-purpose reservoirs. While this policy was developed, it was never implemented and risks are still being managed on a case-by-case basis through the permitting process under the authority of Section 14 of Rivers and Harbors Act of 1899 and codified in 33 U.S.C. §408, commonly referred to as a "Section 408" permit. Mineral extraction activities can potentially compromise human health and safety and the full execution of our authorized project purposes.

A 2012 report produced for the U.S. Department of Energy, "An Assessment of Energy Potential at Non-Powered Dams in the United States" (Hadjerioua et al. 2012), illustrates a growing interest in retrofit of existing dams with new hydropower generation facilities. Retrofit of existing Corps multi-purpose reservoir projects with new non-federal hydropower generation facilities could potentially interfere with Corps water quality and water control interests and responsibilities and compromise the structural and operational integrity of these facilities. In particular, the Committee recommends that water quality and ecological considerations are included in the formulation, development, permitting and operation of non-federal hydropower at Corps Civil Works facilities.

4.1.4. Water Quality Survey

Following completion of the above products, the Committee embarked on a survey effort to better inform the status of water quality and ecological management concerns related to Corps reservoirs. The survey is intended to complement the other three surveys already performed as part of the National Portfolio effort and was formally sent by Headquarters USACE to the appropriate division and district personnel responsible for the water quality mission on 2 August 2013. This survey consists of 24 questions split into two parts: 1) a series of questions directed at Corps Offices and 2) a series of questions pertaining to individual Corps reservoirs. Questions were asked with respect to the district's portfolio of multi-purpose reservoirs on:

- time devoted to water management related to various authorized purposes;
- staffing over various time periods for various classifications of employees related to water management and ecological management activities;
- O&M funding for various business lines as it relates to water quality and ecological management;
- funding over various periods of time for Corps employees and contractual type related to water quality and ecological management;

- how contracted resources are utilized;
- if planning typically involves water quality and ecological management, what type of authority is utilized; and
- if there is a recurring reporting requirement, what mechanism is utilized?

The survey questionnaire is included as **Appendix E**. The survey is still in progress.

4.2. Sustainable Rivers Program

The Sustainable Rivers Program (SRP) is a collaborative effort between the Corps and The Nature Conservancy (TNC) to investigate changes in water management and infrastructure to restore and protect the ecological health of river systems while continuing to serve human needs such as flood risk management, hydropower and water supply. The program grew out of an initial cooperative effort started in 1998 to develop environmental flow recommendations for the Corps' Green River Dam and Lake project in Kentucky. TNC was interested in the Green River as data had showed that changes in the flow regime after construction of the dam in 1969 were having negative effects on fish and mussel species in the river. The Corps and TNC worked together to develop environmental flow recommendations that could be implemented to restore more natural flow and temperature regimes downstream of the dam, while maintaining the flood risk management and recreation benefits provided by the dam and reservoir project. Additional information on TNC's environmental flows efforts is available at https://www.conservationgateway.org/ConservationPractices/Freshwater/EnvironmentalFlows/Pages/environmental-flows.aspx.

As work on the Green River effort proceeded, the Corps and TNC explored ways to expand the partnership, leading to a formal agreement in 2000 identifying common interests and objectives. The agreement focuses on a mutual commitment to improve the sustainable management of the natural resources connected with Corps Civil Works projects. This agreement was the first partnership between the Corps and a non-governmental organization. Since the agreement, TNC has become the largest non-federal sponsor for Corps ecosystem restoration projects, and the organizations are collaborating on a number of water management-related efforts, including reservoir management, removal of non-federal dams, reconnecting rivers and floodplains, and wetland restoration, as well as related work in coastal ecosystems.

The program consists of two major efforts, a national program and work at specific project sites. Corps participation has been managed by Dr. John Hickey of the Corps Institute for Water Resources Hydrologic Engineering Center (HEC). A timeline of activities and milestones for the national program are provided in **Table 4-1**, on the following page. The current project sites are discussed in more detail in **Section 4.2.2** and shown in **Figure 4-4**, on page 63. Since 2010, SRP funding has been included in the overall National Portfolio effort.

The following web sites provide additional information on the program:
http://www.iwr.usace.army.mil/Missions/Environment/SustainableRiversProject.aspx ,
http://www.nature.org/ourinitiatives/habitats/riverslakes/sustainable-rivers-project.xml.

Table 4-1. SRP Program Timeline.

Date	Milestones and Activities
2000	Signature of Memorandum of Understanding defining the SRP program
2003	Joint training begins at the USACE Hydrologic Engineering Center.
2004	First formal staff exchange and joint software development of the Regime Prescription Tool.
2004,2005, 2007, 2009 2010	Dedicated SRP meetings between Corps and TNC staff.
2006	International collaboration includes work on the Yangtze River in China with on-going engagement and multiple trips over the past several years.
2007	First Corps/TNC joint international environmental flows training at 10th River Symposium and Environmental Flow Conference in Brisbane, Australia.
2010	• First dedicated funding stream through the Portfolio in support of SRP. • USACE Environmental Advisory Board (EAB) advises Chief of Engineers in favor of supporting SRP and funding. • Collaboration with Columbian governmental agency appointed with the management of the Magdalena River watershed. • Project Delivery Team (PDT) established to develop draft guidance on the implementation of environmental flows under existing authorities.
2012	• PDT finalizes draft guidance. • USACE EAB holds field and public meetings focused on SRP. • USACE Chief of Engineers expresses support for continuing to fund SRP and potentially using funding through the Corps' Operations and Maintenance program for related work. • TNC publishes "A Practical Guide to Environmental Flows for Policy and Planning."

4.2.1. National Program and Funding

The Memorandum of Understanding signed by the Corps and TNC in 2000 identified seven purposes of the SRP program:

1. Protect or restore freshwater and coastal habitats for native animals and plants and natural communities;
2. Advance our understanding of the distribution and condition of biological diversity associated with our Nation's marine, coastal and riparian waters;
3. Promote non-structural flood protection and other measures to maintain natural ecosystem functions at sustainable levels;
4. Encourage water management measures that benefit native animals and plants and natural communities while meeting human needs;

5. Foster demonstration projects to test promising water management strategies while monitoring their efficacy in meeting multiple objectives;
6. Cooperate in the monitoring and management of rare and endangered species and their habitat potentially affected by related projects and programs;
7. Promote the gathering and sharing of scientific data and research by either entity as it may be related to projects of mutual interest and concern.

Five key strategies have been developed to advance the program: science, technology, outreach, policies and implementation. These strategies are briefly summarized in the following sections.

Science

In recent decades, scientific understanding of river flows and their importance to ecosystem health has grown significantly and outpaced the evolution of operational water management guidelines. The SRP is developing and applying new methods to quantify the environmental flows needed to sustain ecological communities dependent on river flows. These environmental flows are being defined and implemented as part of an adaptive management process that also involves monitoring physical and ecological responses to changes in river flows. Understanding and communicating ecological responses to dam operations is a fundamental scientific challenge for SRP. Environmental purposes are often undervalued because it is difficult to translate changes in management policies to ecosystem responses and associated services to humans. Comparatively, it is far easier to make those connections when considering the benefits of a new hydropower facility or water supply diversion.

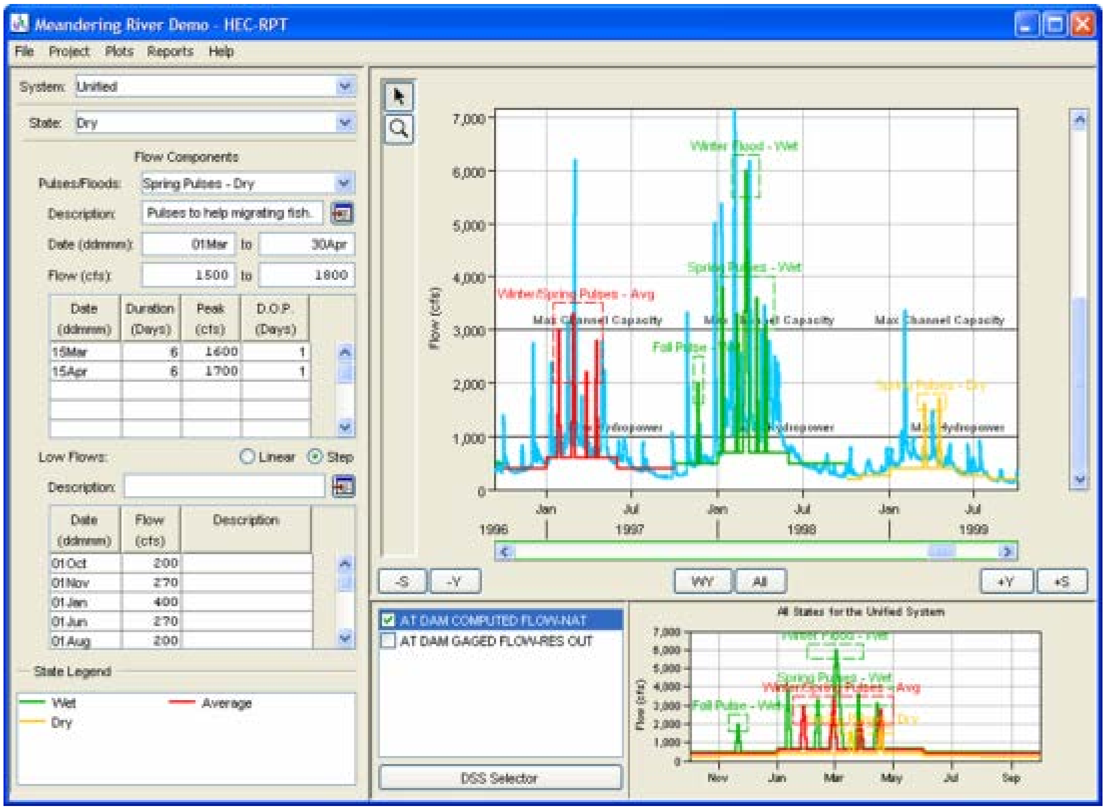
Technology

In concert with the scientific endeavors of SRP, decision support systems are being used to simulate the effects of water resource management scenarios and their associated physical and ecological responses. Key components of these systems are models for reservoir operations, river hydraulics, and ecosystem functions. After validation, these models play an essential role in transitioning the environmental flows recommended by scientists into operating rules for use by water managers. An example of the tools being developed through the program is the Regime Prescription Tool (RPT) developed at the Corps' Hydrologic Engineering Center (HEC) in partnership with TNC.

Development of the RPT started with work on the SRP Savannah River project site. Work on the Savannah River project included a workshop in 2003 with 50 attendees to develop environmental flow recommendations for the river. Throughout the workshop, the participants created, considered, discarded and modified many iterations of hydrographs and it was difficult for the workshop attendees and facilitators to keep track of this work. At the end of the workshop the participants recommended creating a tool to assist in the creation of environmental flow regimes, and, if possible, to interface with other software programs to display historical data and model outcomes.

The original version of RPT was created in less than one year, fulfilling all of these goals, by leveraging existing tools and expertise at the Corps' HEC. RPT facilitates the interactive development of flow time-time series in workshop and public settings. It allows the user to visualize and manipulate historical data, and the results can be exported for use in existing hydrologic simulation programs for river and reservoir system models as well as ecosystem function models. **Figure 4-1** illustrates the program interface.

Figure 4-1. HEC-RPT Version 2.0 Main User Interface



Source: http://www.hec.usace.army.mil/software/hec-rpt/features.aspx

Outreach

SRP is a partnership that requires the participation of multiple groups to succeed. Reaching out to stakeholders, experts, water managers and decision-makers is vital for advancing the program. Incorporating environmental goals with existing reservoir purposes brings community members together to address common challenges. Communities involved with project sites around the country support SRP activities because of their environmental and economic benefits. Through workshops, meetings and outreach efforts, SRP strives to include the input of all groups that live near and rely on rivers. The Corps and TNC have worked together to develop a joint training program, foster staff exchanges, and maintain a presence in important professional venues, including conferences, newsletters, and publications. This work has led to international interest in SRP as indicated in **Table 4-1**, above. For example, TNC collaboration with the China Three Gorges Corporation included use of the HEC-RPT tool to draft proposed environmental flow recommendations to sustain the ecosystems of the Upper Yangtze River's Native Fish Reserve.

Policy

All water management agencies have internal policies that guide the actions of staff and provide a context for decision making. The Corps receives authorizations through the legislative processes of the federal government. In turn, the Corps establishes policy and guidance to ensure compliance with those public laws, as well as executive orders, federal regulations, and existing policies. SRP is working to integrate consideration of environmental flows with existing and developing policies on water and ecosystem management. A 2012 guide prepared by TNC lists the following principles:

- Regionalized environmental flow criteria apply to all the water bodies across a state or large river basin for which site-specific criteria have not yet been established.
- Flow criteria link explicitly to the health of the entire aquatic and riparian ecosystem, and are not limited to specific species.
- Flow regimes mimic natural inter- and intra-annual flow variability.
- The development of environmental flow criteria and the policies for their implementation are closely linked. Defining a clear path to policy implementation from the onset ensures that the ensuing science answers the right management questions.
- Flow criteria are developed through a transparent, inclusive social process informed by sound science. A structured social process for identifying, understanding, and negotiating tradeoffs is critical. (Kendy et al. 2012)

In the Corps, the work by the Corps Committee on Water Quality described above, together with SRP, informed recommendations presented by the Corps Environmental Advisory Board to the Chief of Engineers in 2014. These recommendations include:

- Including instruction on the potential role of Corps dam operations in aquatic ecosystem restoration in classes for new Corps district office leaders;
- Directing Corps districts to include an assessment of the potential for environmental flow operations in periodic reviews of operational guidelines for dam and reservoir projects; and
- Expanding support for SRP with a goal of 20 project sites by the year 2020.

Implementation

Modifying reservoir operations to implement environmental flows is the central objective of SRP. All other strategies contribute directly to implementation. Science and technology show how best to change operations for environmental benefits and the corresponding tradeoffs. Outreach and policy efforts are done to make the atmosphere or conditions in which changes are considered more amenable to their acceptance. SRP efforts to date have affected the patterns of waters released from Corps reservoirs at 5 of the 8 SRP sites. Most have changed operations for parts of the environmental flows quantified and recommended by scientists. Green River is the only site to officially integrate environmental flow strategies with existing operating guidance.

Funding for SRP through the National Portfolio effort totaled approximately $1,700,000 for the period of FY 2010 through 2015. **Figure 4-2** shows the breakout of national and project-level funding among the strategic areas of implementation, science, outreach and technology. To date, the funding has been shared between these areas at about the following percentages: implementation 35%, science 30%, outreach 20%, and technology 15%. Work in the area of policy, as described above, has been performed separately, under other funding sources for each organization.

Science and implementation activities have focused on specific project sites. **Figure 4-3**, on the following page, shows the breakout between national program and project site activities by work area and fiscal year for 2010 through 2015. Overall the share of funding between national program and project site activities has been split about 40% to 60%, respectively. The project sites received the much larger share of the 2010 funding while the national program received the larger share in 2011 and 2012. Since 2013 the project sites have again received the majority of the annual funding.

Figure 4-2. Funding for SRP by Major Work Areas

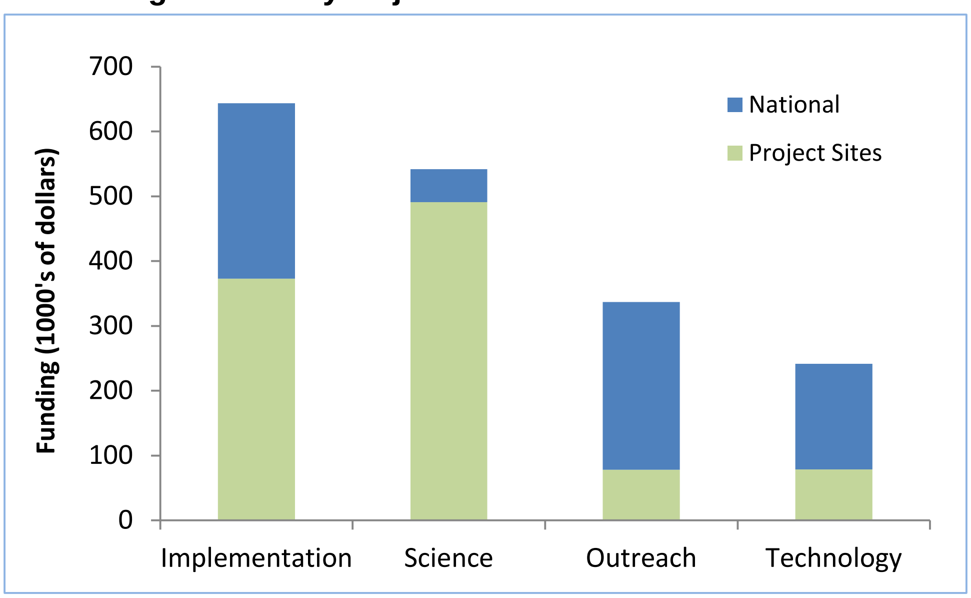
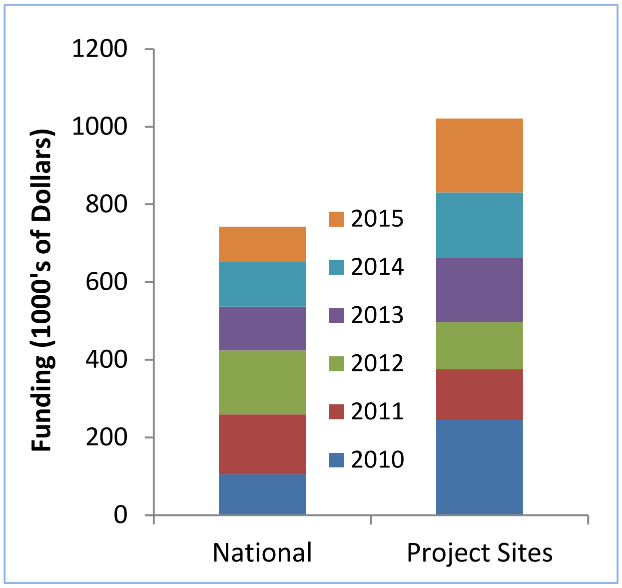


Figure 4-3. SRP National and Project Funding Levels



4.2.2. Project Sites

At SRP sites, citizens, businesses, government agencies, universities and non-governmental organizations all work with the SRP partnership towards goals of enhancing the environment and natural communities while continuing to realize the many benefits that dams provide. The collaborative nature of SRP activities is central to their success throughout the United States. Each site presents unique challenges and opportunities to benefit the people, plants and animals that rely on these rivers. Work at SRP sites currently involves 36 reservoirs in eight river systems. **Figure 4-4**, on the following page, shows the eight SRP river systems. The following sections describe the project work in each system.

Green River, Kentucky

As the first collaboration between the Corps and TNC in reservoir management, activities on the Green River have been a catalyst for the entire Sustainable Rivers Program. TNC first became interested in the Green River because of its biodiversity. With more than 60 species of mussels, 152 species of fish, a host of endemic species and multiple cave systems that are connected to the river, Green River has one of the richest aquatic collections in the United States, including 12 globally rare fish species and 28 imperiled mussel species. After the Corps constructed Green River Dam in 1969 for flood risk management and recreation, changes to natural flow patterns due to the dam operation had negative impacts on the life cycles of many of these species. In particular releases from the dam in the fall, spawning time for many of the fish and mussels, were up to six times higher and significantly colder than the natural flow prior to construction and operation of the dam.

Figure 4-4. Current Sustainable Rivers Project Sites

The Corps and TNC worked together to develop a set of environmental flow recommendations that could be implemented to restore more natural regimes of flow and stream temperature on the river while maintaining the flood risk management and recreation benefits provided by the project. Potential modifications were coordinated with downstream landowners who were willing to change their use of property in the floodplain. The main recommendation was to delay fall releases until after the spawning season, which would also allow for a longer recreation season on the lake. This plan was implemented in 2002 on an interim basis and officially incorporated into the operating plan for Green River Dam in 2006. Today, nearly ten years after the strategies were put into practice, local communities are pleased with the economic benefit of extended recreation seasons, and scientists are reporting increases in the number and diversity of downstream natural communities.

Bill Williams River, Arizona

The Bill Williams River flows through the desert of western Arizona and into Lake Havasu on the Colorado River. The Corps constructed Alamo Dam on the upper Bill Williams River in 1968 for flood risk management, water supply, recreation and fish and wildlife enhancement. Most of the river corridor below Alamo Dam, the only major dam and reservoir in the watershed, is undeveloped and the lower portion of the river, above the confluence with Lake Havasu, runs through the Bill Williams River National Wildlife Refuge. This makes the Bill Williams a river of critical ecological importance and unique scientific opportunity in the Southwestern U.S., where most rivers are highly engineered for human uses.

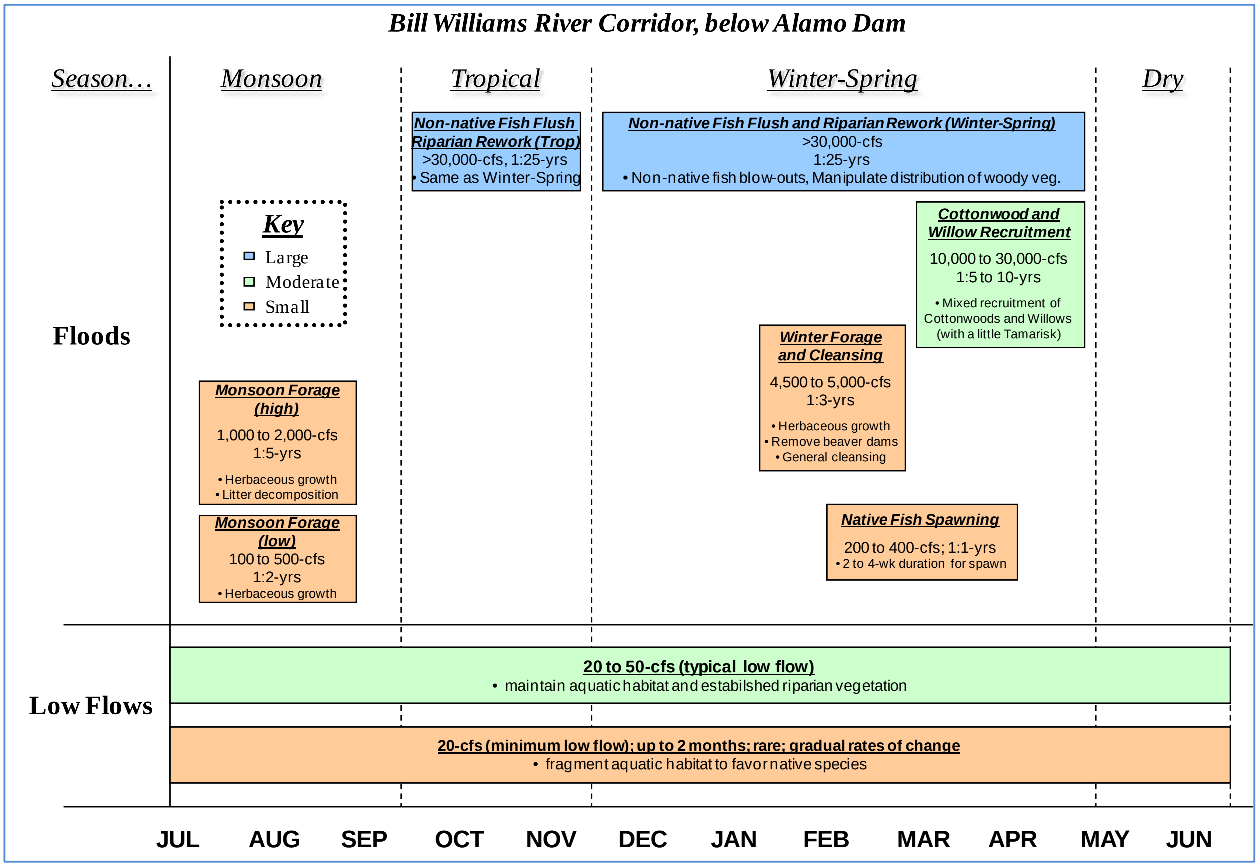
In the desert, many species rely on riparian habitat for survival at some point in their life cycle. After construction of Alamo Dam, changes in the river flows, reduced flows as water was stored behind the dam during drought and extended periods of high flows when floodwaters were releases, began to impact the riparian habitat along the Bill Williams River, and within a few decades most of the forest along the river had disappeared. A committee was formed to study these impacts in the 1990s, and its work evolved into a SRP project site in 2002. An extensive decision support system was developed to support recommendations for water management, with tools for surface and groundwater hydrology, reservoir simulations, single and multidimensional river hydraulics, sediment transport, and ecosystem assessments. **Figure 4-5**, on the following page, illustrates the environmental flow requirements developed through SRP.

In 2003 the Corps issued a new water control manual for Alamo Dam. Changes in dam operations were coordinated with management of the Colorado River, enabling more water to be stored in the Colorado River system during droughts. Implementation has resulted in restored riparian habitat that supports over 350 species of birds and increased tourism along the river. As a result, the Bill Williams River National Wildlife Refuge is the only remaining extensive native riparian forest and plant habitat in the Lower Colorado River basin.

Savannah River, Georgia and South Carolina

The Savannah River drains a watershed over 10,000 square miles in size and flows over 300 miles along the border of Georgia and South Carolina into the Atlantic Ocean through the Port of Savannah. The river provides drinking water for more than one million people, cooling water for nuclear and conventional power plants, hosts numerous endangered, threatened and rare species of plants and animals, and feeds the diverse habitat of the Savannah River estuary which includes the Savannah National Wildlife Refuge. The Corps constructed and manages three dams in the upper basin: J. Strom Thurmond Dam, completed in 1954, Hartwell Dam, completed in 1963, and Richard B. Russell Dam, completed in 1983. Today these projects are operated together as a system to produce flood risk management, navigation, hydropower,

Figure 4-5. Environmental Flow Requirements for the Bill Williams River



water supply, water quality, recreation and fish and wildlife habitat benefits throughout the basin. The lakes are visited by a total of more than one million people annually.

While the Corps projects provide many benefits, regulation of the natural river flows has impacted species that were adapted to the seasonal variations in flow characteristics and water temperature. The Corps and TNC added the Savannah River as a SRP project site in 2002 to develop recommendations to restore more natural environmental flows in the river. Working with other government agencies and academia, the Corps and TNC have taken an adaptive management approach in developing recommendations. The work began with a workshop in 2003 to develop initial recommendations for testing. As discussed above, this workshop led to development of the HEC-RPT tool to assist in formulating recommendations for environmental flows.

The initial recommendations focused on pulse releases made from the reservoir flood pools in spring and measured responses in connected floodplain, shoal and estuary ecosystems. In order to make these releases, the Corps must first store additional water in the flood pool of the reservoirs which creates the potential for increased risks in downstream flooding should a major precipitation event occur. Using existing reservoir system models, the Corps was able to determine that the required water could be stored within acceptable limits of risk. Four spring pulse releases were conducted in 2004, 2005, 2006 and 2007, and monitoring after each event has enabled refinement of recommendations. In 2007, the basin experienced extreme drought conditions, and the existing SRP project and framework for adaptive management in the basin allowed experts to evaluate and improve low-flow requirements and strategies for water conservation.

Big Cypress Bayou, Texas and Louisiana

The Big Cypress Bayou in eastern Texas flows into Caddo Lake on the border of Texas and Louisiana, which was named a globally significant wetland by the Ramsar Convention, one of only 27 such wetlands recognized in the United States. The Ramsar Convention (www.ramsar.org) is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. Caddo Lake is believed to have formed naturally from log jams on the Red River in Louisiana, but clearing of these began in the 19th century, and a dam was constructed in 1914 to continue impounding the lake. In 1959 the Corps constructed Ferrells Bridge Dam and the Lake O' the Pines reservoir upstream of Caddo Lake on the bayou to provide flood risk management, water supply and recreation benefits. Subsequent modifications in the natural cycle of flood and drought flows in the bayou negatively impacted movement of sediment, fish spawning and cypress tree growth.

In 2001, the State of Texas enacted a moratorium on establishing environmental flow protections in water rights permits, instead calling for a study commission that eventually led to an environmental flows study and allocation process that began in 2007. In 2004, Big Cypress Bayou became a SRP project site, in partnership with the Caddo Lake Institute among other organizations. The project has three objectives for environmental flows:

1. Work towards state protection of required environmental flows through the state study and allocation process;
2. Develop strategies to provide the required environmental flows; and
3. Establish a long-term adaptive management program for environmental flows.

After an initial study, recommendations for releases from Lake O' the Pines were implemented on an experimental basis from 2006 to 2011, and the results monitored and evaluated. In 2011 the partners met to refine the flow recommendations and agreed to a five-year trial to the extent that water was available in Lake O' the Pines. A workshop is scheduled in the fall of 2016 to evaluate the five-year trial.

One of the objectives of environmental flows restoration in the bayou is the reintroduction of the threatened American Paddlefish. Paddlefish are the oldest surviving animal species in North America, with fossil records extending back 300 million years. After construction of the Lake O' the Pines, the paddlefish population in the bayou and Caddo Lake began to decline, and by the 1980s they were no longer found in the watershed. A restocking program in the 1990s was unsuccessful. After environmental flow releases began in 2006, a gravel bar was constructed to provide habitat for fish spawning in 2008. Four dozen paddlefish were released into the lake and bayou in 2014 with radio transmitters. Subsequent data collection and the capture and rerelease of six fish in 2015 showed that the fish were healthy and growing.

White River, Arkansas

The White River flows out of the Ozark uplands in western Arkansas and Missouri down into the Mississippi River alluvial valley through the Big Woods region of eastern Arkansas. The Big Woods region is the largest remaining area of bottomland hardwood forest in the Mississippi River alluvial plain north of Louisiana. There are six Corps dam and reservoir projects in the upper basin. Beaver, Table Rock and Bull Shoals Lakes are located in series along the mainstem of the river. Norfork Lake is located on the North Fork tributary, Clearwater Lake on the Black River, and Greers Ferry Lake is located on the Little Red River. These projects were built primarily to reduce flood risks, but also provide hydroelectric power, water supply and recreation benefits in the region.

The Cache River drains the easternmost portion of the White River basin and joins the White River in the Big Woods region downstream of the Corps dams higher in the basin. The Lower Cache-White River area contains three national wildlife refuges, numerous state wildlife management areas and is one of the 27 globally significant wetlands in the United States recognized by the Ramsar Convention. The area is one of the most important remaining bottomland hardwood ecosystems in North America. It is rich in biodiversity and an important stop for migrating birds on the Mississippi Flyway. A Corps project channelized the lower 10 miles of the Cache River in the 1970s in order to prevent flooding and support agriculture in the area.

In 2005 the Corps began a study under the Continuing Authorities Program to restore lost meanders to the Lower Cache River through the Cache River National Wildlife Refuge with TNC as the potential non-federal sponsor. The Corps completed the study in 2010 with a recommendation to restore flows into three isolated meanders that is expected to result in the restoration of nearly 8,000 average annual habitat units for fish and mussel species in the river, and received funding for construction in 2012. Construction was completed in 2013, but available funding was only sufficient to restore flow into two of the three recommended meanders.

In 2015 the Corps completed a draft report for the Cache River Basin Watershed Management Plan as one element of a planned larger White River Basin Comprehensive Watershed Study. The study was conducted pursuant to existing congressional authorities and provides an overview of methods to address problems in the basin as well as potential needs for additional study of federal projects. An interagency team including TNC, as well as other federal, state and local agencies and non-governmental organizations, identified the following vision for the basin: “Maintain and enhance the globally significant Cache River [Bottomland Hardwood] ecosystem within a sustainable agriculture-based landscape to balance ecological, economic and social interests." The draft report identified several short-term, smaller-scale actions that may be undertaken within existing agency programs, and also recommended a larger basin-wide holistic flood risk management and ecosystem restoration study.

Willamette River, Oregon

The Willamette River became a SRP project site in 2006. Nearly 70% of all Oregonians live within 20 miles of the Willamette River, making this waterway crucial to the social and economic well-being of the region. The river historically supported important runs of migratory salmon, trout and other fish species. In 1999 Chinook salmon were listed as a threatened species in the upper Willamette River basin. The Corps constructed and operates 13 dams in the basin that provide numerous benefits including flood risk management, hydropower generation, water supply and recreation. There are also other non-federal dams and water management projects in the basin. These projects alter the timing and volume of river flows in ways that often have negative impacts on stream, riparian and floodplain habitats in the basin. Initial efforts focused on the Coast and Middle Forks of the river, where 6 of the Corps dams are located. The goal was to use these two subbasins as a pilot study to develop experience and recommendations that could be applied throughout the Willamette River basin.

The process of developing environmental flow recommendations began with workshops in 2006 and 2007 that included participants from 34 government agencies, universities and non-governmental organizations. The HEC-RPT tool was found to be extremely useful for displaying data, developing recommendations, and quickly combining the input of separate working groups. The results of these workshops focused on the Middle Fork of the Willamette River from the Corps' Dexter Dam to the confluence with the Willamette River and downstream to Springfield, Oregon. Recommendations for the Middle Fork included (in sequence) small fall pulses, winter bankfull flows, small floods above bankfull flows, larger flood releases, spring pulse flows, spring to summer transition flows, and summer low flows. Each of these recommendations was targeted at the needs of certain aquatic and floodplain species. Testing began with spring pulse flow releases in 2008 and continued through 2010.

Subsequent studies were made of the McKenzie River and Santiam River tributaries to the Willamette River. Workshops were held to develop initial recommendations for the McKenzie River in 2010 and Santiam River in 2012. Both workshops built on the pilot study of the Middle and Coast Forks and subsequent testing of releases from Dexter Dam on the Middle Fork. Results to date from environmental flow trials and monitoring indicate that the releases are improving in-stream and side-channel habitats for salmon species.

Connecticut River, Connecticut, Massachusetts, New Hampshire and Vermont

The Connecticut River basin covers four states and includes 70 large dams and over 2,600 other small dams throughout the basin, dating back to the 17th century. Over two million people live in the river basin. Alteration of natural river flows due to the extensive construction of dams resulted in significant losses in aquatic and floodplain habitats and resources over time. Atlantic salmon are thought to have disappeared from the river in the early 19th century. Ecosystem flow restoration studies under the SRP began with a kick-off meeting in 2008, with partnering meetings continuing over the next several years. A 2011 workshop developed the first environmental flow recommendations for the basin.

A sophisticated decision support system (DSS) was developed to assist in refining the environmental flow recommendations and evaluating them in the future. Water managers and stakeholders will be able to use the DSS to test the environmental and economic outcomes of operational alternatives. Streamflow estimation, reservoir simulation and hydraulic models are linked to a multi-objective optimization model. The optimization model considers flood risk management, hydropower, water supply, recreation and environmental flow objectives in time periods ranging from seasonal to several years.

Five non-federal hydropower dams on the mainstem of the Connecticut River will renew their licenses with the Federal Energy Regulatory Commission in 2018. Hydropower project licenses are typically issued for 30 to 50-year terms, and this is a unique opportunity to evaluate the potential benefits of including environmental flow requirements in the operational plans for these projects. The operator of one of the projects has agreed to use the DSS developed through SRP to support its relicensing application.

Roanoke River, North Carolina and Virginia

The Roanoke is one of the largest rivers in the coastal plain of the Mid-Atlantic region of the country. Its floodplain contains the largest remaining intact bottomland hardwood forest ecosystem in the region and the river and floodplain support habitat for diverse populations of plants, animals, birds and fish. The Corps constructed the John H. Kerr Dam and Reservoir project on the Roanoke in 1953 primarily for flood risk management and hydropower benefits. TNC approached the Corps in 1990 about modifying releases from the dam to minimize extended floodplain inundations that were harming downstream habitat.

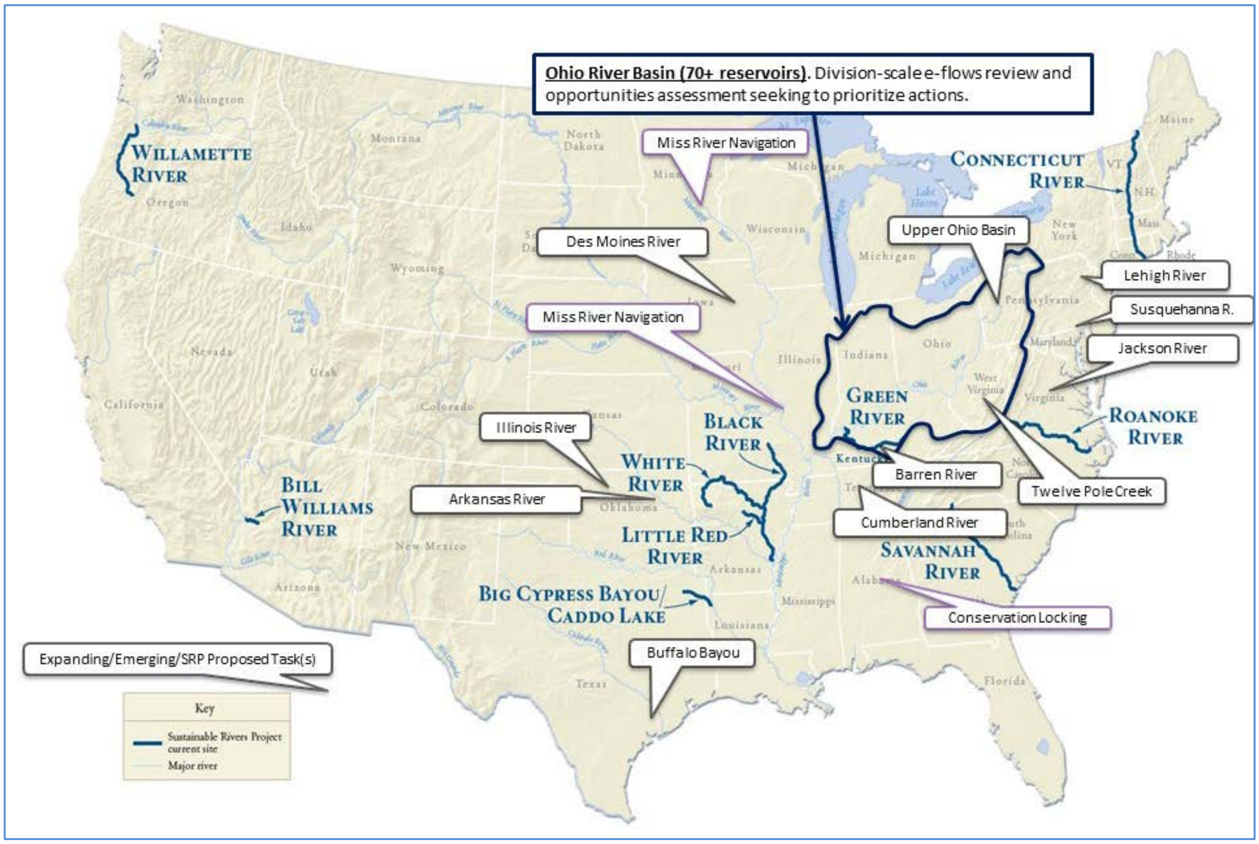
In response to TNC proposals, the Corps began a study in 2000 within its existing congressional authority to review project operations. The study identified operational modifications for a “Quasi Run of River” (QRR) plan that could be made within the Corps existing authority to revise the operating plan for the dam, which was last updated in 1995. The Corps then began a formal process to revise the operating plan for the project, including additional technical evaluations, environmental reviews and public and stakeholder involvement. An Environmental Assessment was completed in late 2015, recommending that the QRR be incorporated into the operating plan for John H. Kerr Dam. The revised operating plan is expected to have long-term benefits in the lower Roanoke River ecosystems, while minimizing potential negative impacts to hydropower production and agricultural lands. A Finding of No Significant Impact was recommended in December of 2015 and is pending public and stakeholder review.

4.2.3. Next Steps for the Sustainable Rivers Program

The mission of SRP is to improve the health and life of rivers by changing dam operations to restore and protect ecosystems, while maintaining or enhancing other project benefits. This is achieved by advancing, implementing, and incorporating environmental flow strategies at Corps reservoirs and utilizing other authorities available for ecosystem restoration. As SRP continues to work and succeed in these endeavors, new sites have expressed an interest in the program, as shown in **Figure 4-6**, on the following page. Some have pressing environmental challenges that are motivating a modernization of operating strategies, others simply recognize the methods applied by SRP as an avenue to additional project benefits. The challenge for SRP is how to engage this interest to best expand the Program geographically and topically.

Currently, 8 rivers and 36 reservoirs are recognized as existing SRP sites. An additional 6 sites and 22 reservoirs have expressed an interest in the Program, including several new requests related to environmental opportunities at navigation-oriented projects (e.g., conservation locking for fish passage and pool level management for habitat creation). These projects are a subset of the 356 reservoirs the Corps owns and operates with federally authorized flood storage (Table 3-2) and of the 181 other Corps reservoirs (USACE 1992) operated for navigation and purposes other than flood risk management.

Figure 4-6. Emerging Sustainable Rivers Project Sites



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5. Reservoir Sedimentation

The results of the 2008 reservoir sedimentation survey were originally reported in a draft paper titled: "Sedimentation in Corps Reservoirs, Results of 2008 Data Call Database Analysis." The authors of the sedimentation paper were Ms. Meg Jonas and Ms. Deborah Cooper, both working at the Corps' Engineer Research and Development Center's Coastal & Hydraulics Laboratory. This report section summarizes the 2008 survey results and findings of the sedimentation paper, and discusses current efforts in collecting sediment data.

5.1. Reservoir Sedimentation Survey Results

The 2008 survey reviewed 378 Corps projects, including reservoirs, dry dams, some lock and dam projects and a few specialized dam projects, such as the Mount St. Helens Sediment Retention Structure. The list of these projects and a tabular summary of the survey results discussed in this section is provided in **Appendix D**. No information was submitted for 25 of these projects, resulting in a total of 353 positive responses.

5.1.1. Percentage of Storage Filled With Sediment

Most notable in this sedimentation survey was the fact that only 15 of the 353 positive responses showed the gross pool or the conservation pool as having a sediment accumulation of greater than 25% of original volume. These 15 reservoirs and the percent storage filled are provided in **Table 5-1**, on the following page. Most of the numbers given in the table for "percent filled" are for the conservation pool, rather than for the gross storage volume as was requested in the survey. The conservation pool is the storage (acre-feet) set aside for the authorized project purposes, other than flood risk management, and is generally a smaller area than the gross pool. The gross pool is the total volume (acre-feet) the project is capable of holding at the crest of the spillway.

5.1.2. Impacts of Sedimentation on Project Purposes

The impacts of sedimentation on project purposes are shown individually in **Appendix D**. It is an important observation that, in most cases, sedimentation impacts to the authorized purposes of at least moderate proportions are seen before depletion of the reservoir storage reaches 25%. The impacts of sediment on the various authorized project purposes are listed as moderate, significant or severe:

- Moderate (MO) – Sediment limits operation of the project for this purpose 10% or more of the time.
- Significant (SI) – Operation for this purpose limited 25% or more of the time.
- Severe (SE) – Operation for this purpose limited nearly all the time.

Table 5-1. Corps Reservoirs with Greater than 25% Filled by Sedimentation

Project	MSC	District	% Filled
Charles Mill Lake, OH	LRD	LRH	25 – 49
Dillon Lake, OH	LRD	LRH	25 – 49
Fishtrap Lake, KY	LRD	LRH	25 – 49
Pleasant Hill Lake, OH	LRD	LRH	25 – 49
Bluestone Lake, WV	LRD	LRH	25 – 49
Lopez Dam, CA	SPD	SPL	25 – 49
Town Bluff Dam/ B.A. Steinhagen Lake, TX	SWD	SWF	25 – 49
Council Grove Lake, KS	SWD	SWT	25 – 49
Heyburn Lake, OK	SWD	SWT	25 – 49
Hulah Lake, OK	SWD	SWT	25 – 49
John Redmond Dam and Reservoir, KS	SWD	SWT	25 – 49
Mount St. Helens Sediment Retention Structure, WA	NWD	NWP	50 – 74
Great Salt Plains Lake, OK	SWD	SWT	50 – 74
Wills Creek Lake, OH	LRD	LRH	75 – 90
Beach City Lake, OH	LRD	LRH	> 90

Impacts to Flood Risk Management

Most of the projects in the survey had a flood risk management (FRM) function. Only 16 projects responded that FRM was not an authorized purposes. Only one project, Beach City Lake in the Huntington District, reported FRM operations severely restricted by sediment. No projects were listed with significant impacts, but 43 reported moderate impacts from sedimentation on FRM operations. Of these 43 projects, 33 are located in the Southwestern Division, and 27 of these are in the Tulsa District. 37 of the 43 projects reporting moderate impacts to FRM operations also reported sediment accumulation of less than 25%.

Impacts to Navigation

Of the 68 Corps reservoir projects that reported navigation as an authorized purpose, only nine reported navigation operations restricted by sedimentation. Of these nine projects, one, the Lower Granite Lock and Dam in Walla Walla District, reported significant restrictions; the other eight reported moderate restrictions. Three of the eight projects reporting moderate impacts were also located in Walla Walla District. Restrictions at these Walla Walla District projects affect navigation on the Snake River in eastern Washington State. Three other reservoir projects reporting moderate restrictions were located in Tulsa District. These projects help regulate flow to assist navigation on the Arkansas River through Oklahoma and Arkansas. All nine projects reporting impacts to navigation operations also reported sediment depletions of less than 25%.

Hydropower

Of the 77 projects that reported hydropower as an authorized purpose, only eight reported restrictions, and all eight reported moderate restrictions. These eight projects were scattered throughout the nation in four different districts: Detroit (1), Omaha (3), Sacramento (1) and Tulsa (3). All eight of these projects reported less than 25% loss of storage to sedimentation.

Water Supply

The sedimentation survey responses reported 159 projects with a water supply function. This is greater than the number of projects with authorized water supply storage agreements, as discussed in **Section 2**, and may have included reservoir projects where water supply is authorized but no agreements have yet been signed, lock and dam projects with water supply intakes in the pool, and dry dams where flood pool releases are coordinated with downstream water supply needs. One project, Hulah Lake in Tulsa District reported significant restrictions on water supply operations. An additional 36 projects reported moderate restrictions. The majority of projects listing moderate impacts (24) are also reservoir projects in the Tulsa District, serving water supply interests in Kansas, Oklahoma and Texas. The remaining 12 projects reporting moderate restrictions were found throughout the country, in Ft. Worth District (3), Little Rock District (1), Albuquerque District (1), San Francisco District (1), St. Paul District (1), Louisville District (1), Detroit District (1) and Baltimore District (3).

Four of the projects reporting water supply restrictions also reported depletion of storage by sediment in the 25-49% range. These include Hulah Lake, in northeastern Oklahoma, which also reported a significant impacts to water supply operations, as well as Heyburn Lake, also in northeastern Oklahoma, and the Council Grove and John Redmond reservoir projects, both in eastern Kansas. All four of these projects are managed by the Tulsa District. The remaining projects reporting water supply restrictions all either reported sediment depletion at less than 25% of reservoir storage, or, in one case, did not report the estimated sediment loss.

Water Quality

Of the 199 projects that reported a water quality function, 23 reported moderate restrictions due to sedimentation, none reported significant or severe restrictions. Of these 23 projects, 13 are located in the Tulsa District, and three of these reported sediment depletions of between 25% and 49% (Council Grove, Hulah and John Redmond Lakes). St. Paul District reported five projects with moderate restrictions, and the remaining five projects are distributed across the country (Detroit, Baltimore, Kansas City and Seattle districts), and all reported sediment depletions of less than 25%.

Recreation

The majority of projects surveyed reported operation for recreation purposes. Only 43 responded that recreation was not an authorized purpose. The survey identified 58 projects that reported recreation use restricted by sedimentation. One project, Millwood Lake in Arkansas, reported severe restrictions, and one other, Clearwater Lake, also in Arkansas, reported significant restrictions. Both of these reservoir projects are managed by the Little Rock District. The majority of the 57 projects reporting moderate restrictions are located in five districts: Omaha (17), Tulsa (11), Louisville (8), Baltimore (5) and St. Paul (5). The remaining 11 projects are located in seven districts.

Clearwater and Millwood Lakes both reported sedimentation as filling less than 25% of the project storage. 54 of the projects reporting moderate restrictions also reported less that 25% sedimentation filling. Hulah Lake and John Redmond Lake in the Tulsa District reported sedimentation between 25% and 49%. One project, Ft. Peck Dam in the Omaha District, while reporting a moderate impact on recreation did not provide the data on percent filling of the pool.

Fisheries

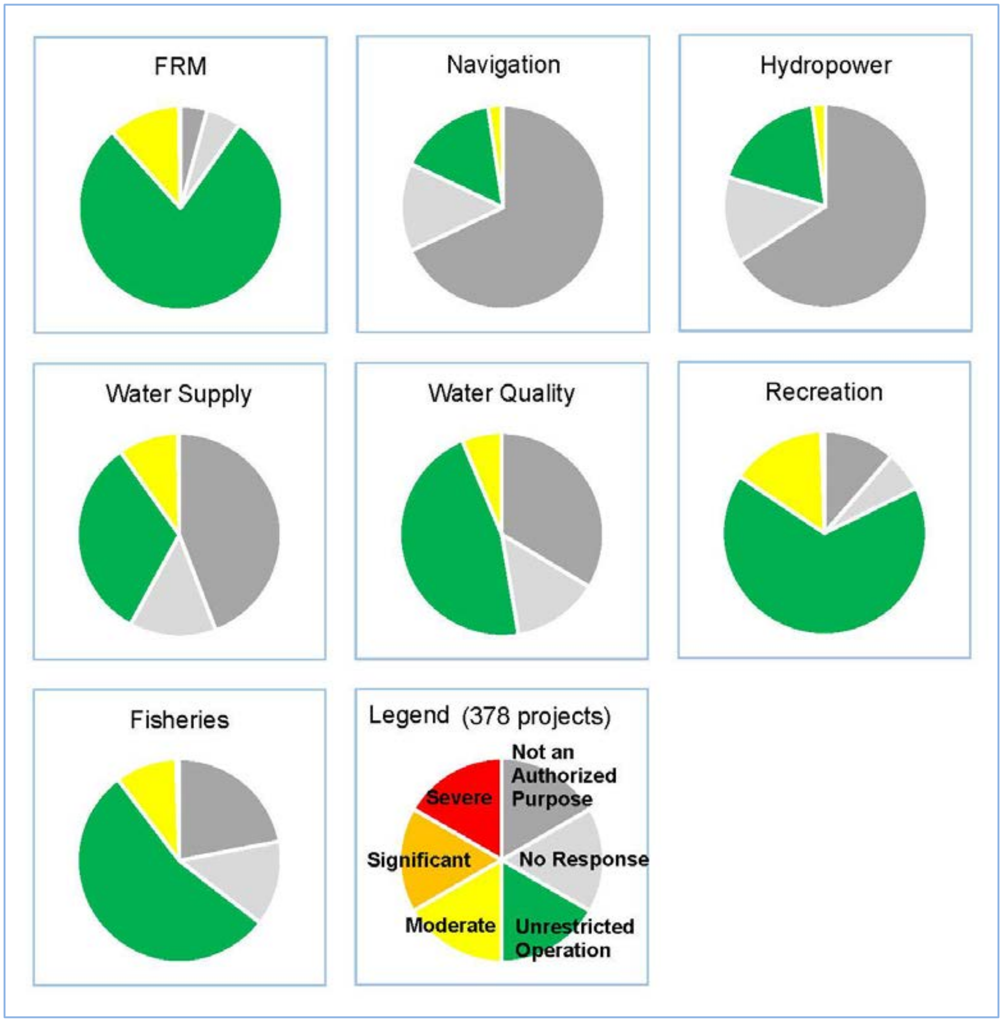
Most projects also reported operation for fisheries, with 83 responding that fisheries were not an authorized purpose. There were 38 projects that reported restrictions on operation for fisheries due to sedimentation. Two projects, Coralville Dam in the Rock Island District and Great Salt Plains Lake in the Tulsa District, reported significant restrictions. The majority of the remaining 36 projects reporting moderate impacts due to sedimentation were managed by two districts: Omaha (15) and Tulsa (10). The other 11 projects are located across the country.

Of the 38 projects reporting restricted fisheries operations, the Great Salt Plains Lake in Tulsa District reported sediment filling between 50 and 74% of storage, and significant restrictions. Two projects, B.A. Steinhagen Lake in Ft. Worth District and Hulah Lake in Tulsa District, reported between 25% and 49% filling, both with moderate restrictions. The Coralville Dam project in Rock Island District reported less than 25% filling and significant impacts. The remaining projects reported less than 25% filling and moderate impacts.

Summary of Impacts to Project Purposes

Figure 5-1, on the following page, provides a graphical summary of the survey reporting on restrictions to project operations due to sedimentation. For each project purpose, the figure shows a pie chart of the survey results for all 378 projects, including those that either did not respond for that purpose, or reported that the project was not authorized to operate for that purpose. The few responses that were received indicating significant or severe restrictions are not visible at the scale of these figures.

Figure 5-1. Summary of Survey Reported Impacts to Project Purposes



Taking into account the projects that either reported a purpose as not authorized or did not report for a purpose, there were a total of almost 1,400 positive responses. Almost 1,200 of the responses (85%) indicated that operations for that purpose at the project were not restricted by sediment accumulation to date. Only seven responses (less than 1%) indicated significant or severe restrictions. About 200 responses (14%) indicated moderate restrictions for operation of one or more purposes at a project. Overall, 97 of the 378 projects surveyed (26%) indicated that project operations for one or more purposes were restricted by some degree due to sedimentation.

Table 5-2, on the following page, summarizes the survey results by district. The table shows the number of projects surveyed and the total number of identified impacts to project operations, by degree, in each district. The South Atlantic Division did not identify any restrictions on project operations due to sedimentation. In all, 13 of the 31 district offices included in the survey did not identify any instances of restricted operations. Sixty (60) percent of the operating restrictions reported, were submitted by two districts: Tulsa and Omaha. These two districts reported operating restrictions at 45 reservoir projects throughout the Great Plains region of the country.

Table 5-2. Count of Project Purposes Impacted By Sedimentation Issues.

MSC	District	Number of Projects in Survey	Number of Project Purposes Impacted (Total for All Projects)		
			Moderate	Significant	Severe
LRD	LRE	1	7		
	LRH	35			1
	LRL	20	9		
	LRN	10	6		
	LRP	16			
MVD	MVR	5		1	
	MVS	5	6		
	MVP	16	13		
	MVK	9			
NAD	NAB	15	10		
	NAE	31			
	NAO	1			
	NAP	5			
NWD	NWK	18	3		
	NWO	30	39		
	NWP	21	1		
	NWS	5	1		
	NWW	8	3	1	
POD	POA	1			
SAD	SAJ	2			
	SAM	5			
	SAS	3			
	SAW	5			
SPD	SPA	9	1		
	SPL	16	1		
	SPK	14	3		
	SPN	1	2		
SWD	SWF	25	12		
	SWG	2			
	SWL	12	4	1	1
	SWT	32	89	2	
TOTAL	**31**	**378**	**210**	**5**	**2**

5.1.3. History of Sediment Surveys

Section K-46 of Engineer Manual (EM) 1110-2-4000, Sedimentation Investigation of Rivers and Reservoirs (USACE 1995b), provides general guidance on reservoir sediment survey frequency. It recommends that reconnaissance surveys of selected key ranges be performed every five years, or after each major flood. The frequency of complete or partial resurveys should be based on findings of reconnaissance surveys, but the guidance recommends that general surveys be performed every 5 to 10 years at the least. Public Law 88-140, enacted in 1963 and referred to as the “permanent rights to water supply storage” law, established an expectation that the rights of non-federal water supply sponsors to utilize reservoir storage would be protected by “equitable” reallocations of storage among project purposes as required due to the impacts of sedimentation. Since the 1980s, Corps water supply storage agreements have contained language indicating that sedimentation surveys will be performed at least every 15 years, unless determined to be unnecessary. In general, current guidance calls for some level of survey to be performed every 5 to 15 years, however, the frequency can and should vary based on project-specific conditions.

The sedimentation 2008 data call captured the year of last sedimentation survey for each of the projects. The draft report cautioned, however, that there were a number of non-responses, surveys never performed or not needed, and that, as the data are good only through 2008; a number of surveys could have been accomplished since that time. The “survey not needed” category includes dry dams, as well as natural lakes and marshes. The year of the last survey and the number and percent of projects in that survey is provided in **Table 5-3**. The early years (1940-1969) are provided in 10-year increments and the latter years in 5-year increments. The percent of reservoirs refers to the percent of positive responses, out of the total of 309.

Table 5-3. Age of Reservoir Sediment Surveys.

Year Increment	Number of Reservoirs	Percentage of Reservoirs	Survey Age Groups (% of Total)
Never surveyed	3	1	19
1940-1949	4	1	
1950-1959	7	2	
1960-1969	17	5	
1970-1979	32	10	
1980-1984	12	4	28
1985-1989	31	10	
1990-1994	42	14	
1995-1999	75	25	25
2000-2004	46	15	28
2005-2008	25	8	
Not needed	15	5	

Using 2008 as a point of reference, these figures show:

- 28% of projects have been surveyed since 2000 or are not needed. These recent surveys should show a relatively good picture of the current sediment conditions.
- 25% of the projects were last surveyed between 1995 and 1999, are from 9 to 13 years old and should show a relatively good picture of sediment conditions.
- 28% of the projects were last surveyed between 1980 and 1994, are from 14 to 28 years old and should be resurveyed if they have not already been resurveyed.
- 19% of the projects were last surveyed between 1940 and 1979 or have never been surveyed. At best, these surveys are at least 29 years old. The sediment conditions at these projects cannot be relied on and should be updated at the earliest possible time.

This distribution indicated that, at the time, the average age of surveys was on the order of 15 years. The above data is best regarded as a snapshot at that time. After the data call was completed, the American Recovery and Reinvestment Act of 2009 provided funding to complete surveys at many projects.

5.1.4. Sediment Survey Methods

Sedimentation surveys are performed using two major methods: rangelines and total bed surveys. Rangeline surveys use survey data taken only at specified cross section (often located and monumented early in the reservoir life). Reservoir volume is computed from the measured area at the cross sections. In general, most Corps reservoirs were originally surveyed using the rangeline method, since this was the most cost-effective, using the technology of the time. Modern survey techniques make total bed surveys increasingly cost-effective. As time goes on, an increasing number of sedimentation surveys will be performed as total bed surveys. The types of survey methods, districts utilizing these methods and the number of applicable projects are shown in **Table 5-4**, on the following page. It is shown that the Rangelines/Cross Sections method was by far the most utilized method, with the Total Bed method the other preferred method. There were 10 districts reporting either "unknown," "never surveyed" or "other" for one or more projects. Finally, there were 15 districts covering 78 projects where an answer was not received.

5.2. Sediment Management

There are a number of sediment management practices that were utilized by the reporting districts. These practices, the number of reservoirs utilizing this practice and the percent of Corps reservoirs is provided in **Table 5-5**, on the following page. As shown, only one survey method was reported for each reservoir. Of the 50 reservoirs reporting other sediment management practices, 13 reported using other practices one time, 18 used other sediment practices sporadically and 19 practiced other sediment practices on an ongoing basis.

Table 5-4. Sediment Survey Methods

Survey Type	Number of Projects
Rangelines/Cross Sections	194
Total Bed Survey	84
Other	5
Unknown	3
Never Surveyed	14
No Answer	78
Total	**378**

Table 5-5. Sediment Management Practices

Sediment Management Practice	Number of Reservoirs Utilizing the Practice	Percent of Reservoirs in the Survey Utilizing the Practice
Minimal Site Specific Sediment Removal	45	12
Periodic Maintenance Dredging	16	4
Periodic Maintenance Dredging with Beneficial Placement of Sediment	8	2
Continual Maintenance Dredging	2	1
Continual Dredging with Beneficial Placement of Sediment	3	1
Sediment Flushing	14	4
Sediment Sluicing	6	2
Other *Sediment Management Practices*	50	13
Sub-total	**144**	**39**
No Sediment Management Practices	73	19
No Response (could imply no other sediment management practices)	161	42
Total	**378**	**100**

Because approximately 60% of the reservoirs reported no sediment management practices, the sedimentation information paper took a closer look at the obstacles to sediment management. This review exposed nine obstacles. These obstacles and a short description are listed on the following page:

- Regulatory. Compliance with the Clean Water Act where sediment cannot be resuspended or added back to the downstream system due to Total Maximum Daily Load (TMTL) restrictions , turbidity problems at water intakes, or tribal concerns.
- Funding. Lack of current operation and maintenance funds sufficient to support the sediment management program.
- Sponsorship. Conflicts with stakeholder and partner objectives for the project, such as water supply holdings, recreation concerns, and cost-sharing through construction general agreements.
- Ownership of Sediments. Debate about actual ownership of mineral rights to deposited sediment.
- Liability. Issues that may be created when relocating sediment from the reservoirs, for example downstream damages caused by flushing/sluicing sediment from the pool or creating geotechnical hazards with dredge spoil piles.
- Ineffectiveness of Management Alternatives. Available management options are not expected to solve any of the problems created by the sediment.
- Technical Understanding of Management Actions. Gaps in technical knowledge that limit decision makers' ability to judge implications and successes of sediment management practices.
- Known or Suspected Chemical Contamination of Sediments. Problems may result from the chemical quality of sediments or resuspended loads.
- Survey age. When the last sedimentation survey was performed decades ago, this presents challenges to sediment management because the current status of sedimentation in these reservoirs is unknown.

The number of projects in each district impacted by each obstacle is provided in **Table 5-6**, on the following page**.** A summary of these obstacles, the number of districts and corresponding projects reflecting these obstacles is provided in **Table 5-7**. A lack of funding was reported as the primary obstacle to sediment management.

Table 5-6. Projects Impacted by each Obstacle

MSC / District	Number of Projects in each Obstacle								
	Regulatory	Funding	Sponsor	Ownership	Liability	Ineffective	Technical	Contamination	Age
LRD									
LRE		1			1	1		1	
LRH									
LRL		16	1						
LRN	4								
LRP		16							
MVD									
MVR	1	1	1			1			
MVS	5	5	5						
MVP	11	14	11	1		12			
MVR		9							
NAD									
NAB		14	3			2		3	
NAE									
NAO									
NAP									
NWD									
NWK		5				4			
NWO	16	20				4	3	1	
NWP	20	1					1		
NWS							1		1
NWW	1	8	1			8	7		
POD									
POA									
SAD									
SAJ									
SAM									
SAS									
SAW	5	5	5	5	2				
SPD									
SPA	2	2				1		1	
SPL	2	1							10
SPK		15							
SPN									
SWD									
SWF		18	17		1				
SWG		2							
SWL	12	11					12		
SWT	7	31	2	5		30	1		1

Table 5-7. Summary of Obstacles to Sediment Management

Obstacle	Number of Districts	Number of Reservoirs
Funding	12	195
Regulatory	12	86
Ineffectiveness of Management Alternatives	9	63
Sponsorship	9	46
Technical Understanding of Management Actions	6	25
Survey Age	3	12
Ownership of Sediments	3	11
Known or Suspected Chemical Contamination of Sediments	4	6
Liability	3	4

5.3. RESSED Database

The Reservoir Sedimentation Database (RESSED) of the Subcommittee on Sedimentation was developed in coordination with the United States Geological Survey (USGS). The Subcommittee on Sedimentation is part of the federal Advisory Committee on Water Information, led by USGS and the Department of the Interior. RESSED was developed in 2009. The database format was based on the Natural Resources Conservation Service's old reservoir sediment data summary form SCS-34. RESSED was first populated by migrating an existing database with historical information on about 1,800 reservoirs. The primary purposes of RESSED are to archive and provide access to historical reservoir survey data, provide a format for expanding the collection of reservoir sedimentation data beyond the original 1,800 projects, and solicit additional information such as accurate location coordinates.

More information on RESSED is available from the Subcommittee on Sedimentation web site at http://water.usgs.gov/osw/ressed/. The Subcommittee acknowledges that the database is a work in progress and that additional development has been restricted by funding limitations. The database structure based on old paper forms is not amenable to capturing all pertinent reservoir survey data produced by today's technologically advanced instruments and methods. Some progress has been made in collecting additional data as the U.S. Bureau of Reclamation uploaded sedimentation information for Reclamation reservoir projects, and the Corps uploaded information for some Corps reservoirs. To augment the RESSED effort, the Corps has proceeded with developing an internal Reservoir Sedimentation Information (RSI) system that is described in the following section.

5.4. Reservoir Sedimentation Information

When a number of new and updated reservoir sedimentation surveys were able to be performed with funding made available through the American Recovery and Reinvestment Act of 2009, the Corps proceeded with development of an internal data collection and analysis system. This effort fell under the Corps Climate Preparedness and Resilience (CPR) Community of Practice as they were working to identify necessary actions to support future reservoir operations in light of the challenges posed by climate change as well as reservoir sedimentation. Changes that have occurred over the 20 years since the last publication of USACE guidance on reservoir sedimentation (USACE 1995b) make it imperative that USACE update its understanding of the current state of reservoir sedimentation by updating reservoir sedimentation information (RSI), including sedimentation surveys, sediment load measurements, and other investigations related to sedimentation in order to support sustainable reservoir management. Reservoir managers are beginning to focus on adapting RSI to account for global and climate change and potential sediment issues associated with these changes.

Sediment quantity is impacted by precipitation and ground state (frozen, thawed, saturated or unsaturated), land cover, and land use practices. Global and climate change can include altered hydrology that manifests as changes in the form (snow vs. rain), intensity (peak, seasonal, average), and duration of precipitation, and can also alter freeze-thaw characteristics. These changes may lead to and/or exacerbate modification of land use and land cover – including changing agricultural practices – that are major contributors to sedimentation in reservoirs. Because USACE manages hundreds of reservoirs, it is essential that the reservoirs are monitored periodically as part of a sustainable management plan.

In typically constrained budget conditions, USACE operations and maintenance priorities have not often funded sediment surveys and studies at the recommended frequency. These limitations come at a critical time for many USACE reservoirs as they near the end of their design life and when global and climate change are altering sedimentation processes in ways that are not easily predicted. As noted in the 2008 survey, sedimentation is beginning to negatively impact the ability of Corps reservoir projects to operate for the authorized project purposes. Therefore, it is essential that USACE establish baseline information on reservoir sediment levels, remaining storage capacity, and determine how future conditions will impact sedimentation. Development of a RSI update and collection strategy will be vital to minimizing reservoir vulnerability to sedimentation impacts.

An interdisciplinary and interagency Project Delivery Team (PDT) is working with the USACE Hydrology and Hydraulics Community of Practice (H&H CoP), USACE Committee on Channel Stabilization, and the Bureau of Reclamation (BOR) to accomplish RSI goals. The current goals are to assess existing knowledge about RSI, prioritize collection of baseline RSI, identify current data gaps and develop a strategy to update RSI, review and update existing methods and policies to support sediment data collection and studies, prioritize needs for reservoir sedimentation studies, and provide a comprehensive summary of USACE reservoir conditions and identify project vulnerabilities to sedimentation. Lessons learned will be incorporated in policies, processes, methods and guidance. To address several of these goals, the PDT developed a RSI web-based portal to centralize sedimentation related data and perform analyses that over time will facilitate the overarching goal of reservoir sustainability. Example uses of the data and portal include, but are not limited to, data gap analysis and correlations to indicators of potential future climate change impacts. Currently the portal only functions inside the USACE network.

Figure 5-2 shows the RSI portal with the home screen and several tabs a user can select from for additional functionality. The Home tab provides an overview of the portal and points the user to additional tools available in the CPR Community of Practice. The Overview tab provides charts and graphics depicting sediment storage loss and allows the user to drill down to specific jurisdictions and reservoir projects in USACE. The Reservoir tab allows one to upload new information, if the user has permissions to edit the data, and provides detailed information specific to a reservoir. The Map tab shows the geographic location of reservoir projects in the system. The Admin tab manages user account permissions. Users can find more information related to the portal on the Help tab.

Figure 5-2. Reservoir Sedimentation Information Web Portal

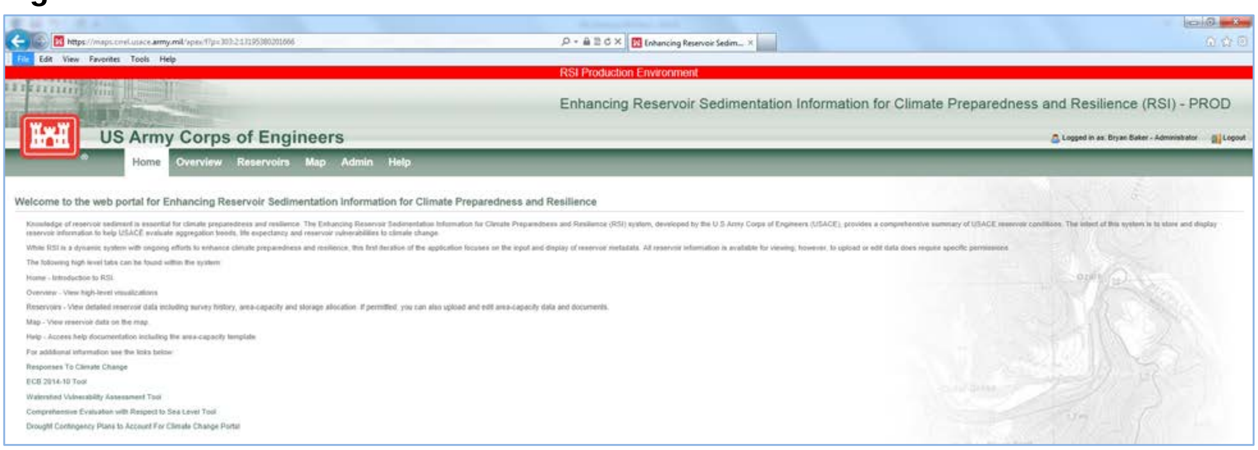
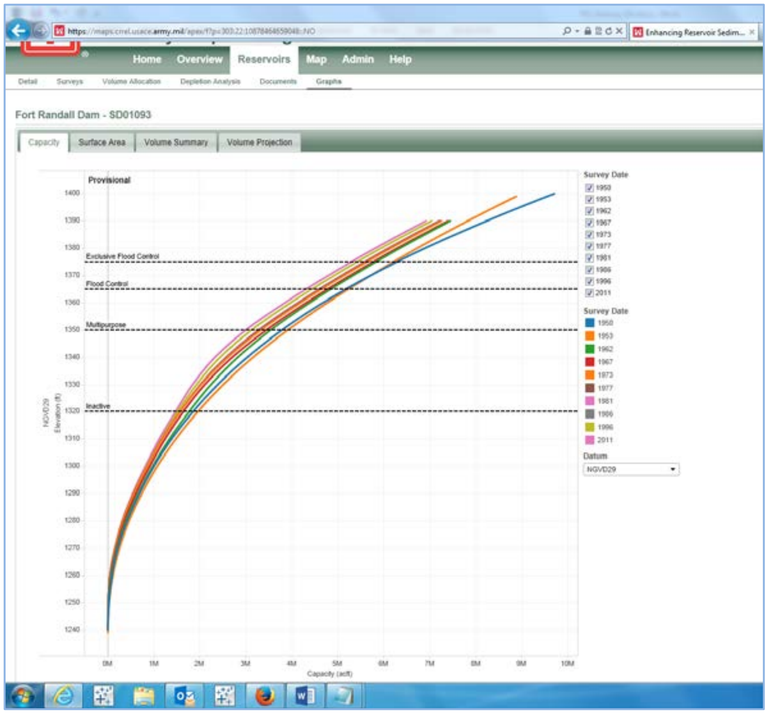


Figure 5-3, on the following page, shows a typical elevation versus capacity chart for a specific reservoir. The user can toggle sediment survey years on or off in the screen. Data can be exported, and the user can create charts to be used in reports. Reservoir life is also computed using standard methods (USACE 1995b) along with other reservoir-specific charts.

Figure 5-3. Example Elevation-Area Chart



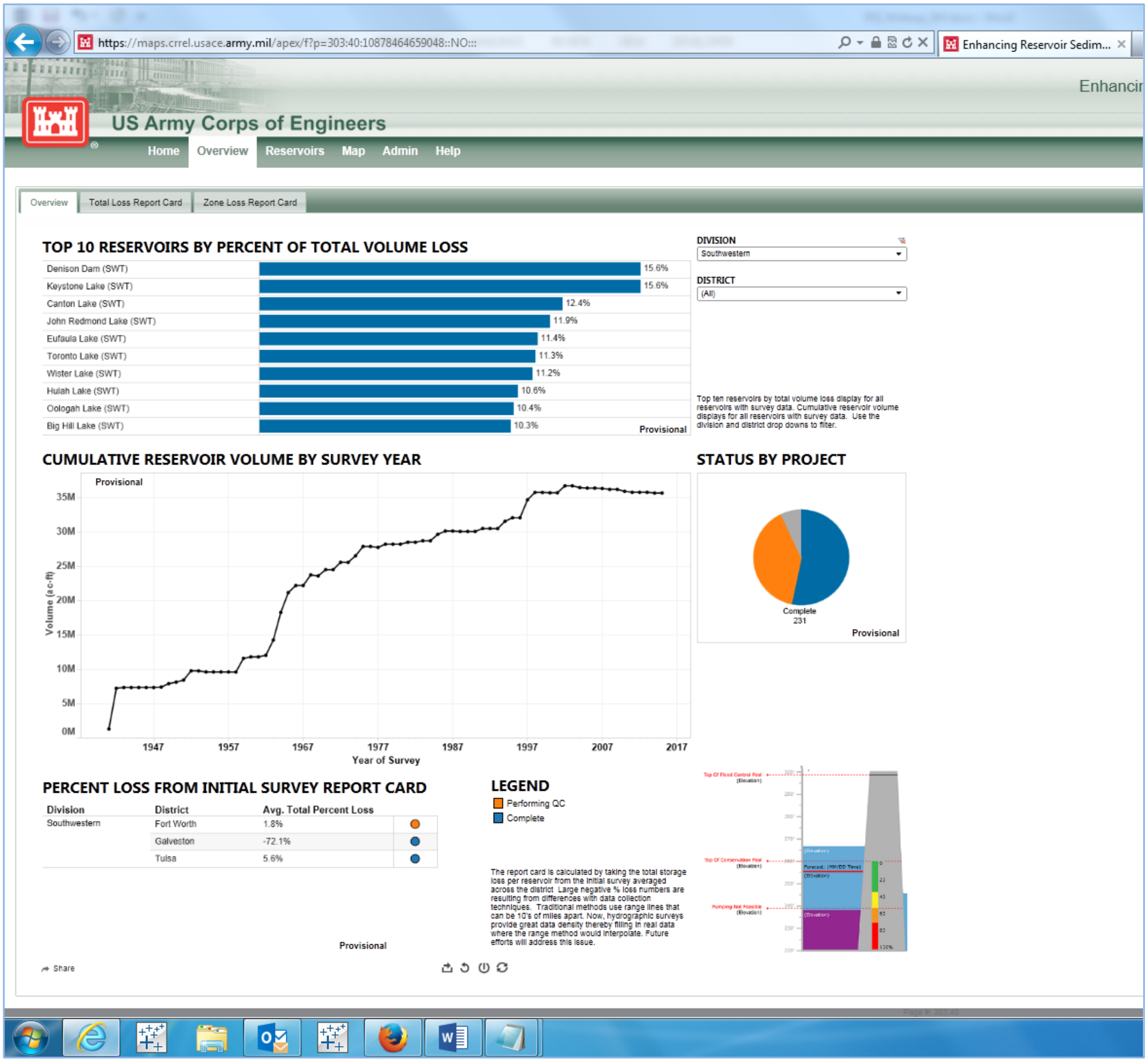
Summary reports and visualizations are available in the Overview section of the portal. There the user can find useful information about sediment depletion in a reservoir. For example, one can see the percent of storage lost in a specific reservoir zone. Other charts show total volume lost ranked at user-defined levels within the USACE organization. In **Figure 5-4**, on the following page, the top bar chart is showing the top ten reservoirs experience total volume loss in the Southwestern Division (SWD) as of the date of the latest information in the database. The middle chart in **Figure 5-4** shows the history of USACE reservoir volume in SWD. Other methods of conveying related information will be added in future version of the tool.

The RSI portal communicates with other enterprise systems, including the National Inventory of Dams, Corps Water Management System, and the newly created Drought Contingency Portal. Moving forward, the PDT will be working on the following tasks:

- establishing sub-teams to perform quality control on reservoir sedimentation data and review new and emerging sediment survey techniques;
- developing a baseline report on climate change impacts to reservoirs and USACE reservoir status; and
- estimating future sedimentation rates and how they change with observed and projected climate change for use in the CPR Community of Practice's Watershed Screening Climate Vulnerability Analysis Tool.

FY 2016 efforts will also address requirements of Executive Order 13653, Preparing the United States for the Impacts of Climate Change, by working with the U.S. Bureau of Reclamation to expand data needed for correlations for climate indicators and streamline reservoir sustainability research needs; and otherwise improve collaboration with, and make reservoir sediment information available to partner agencies. Future enhancements are expected to focus on increasing the value of sediment data and analyses in efforts to improve reservoir sustainability and resiliency with respect to authorized purposes such as flood risk management, hydropower and water supply.

Figure 5-4. Example RSI Portal Reporting



6. Uncertainty in Future Conditions

Uncertainty has always been a factor in the planning, design, operations and maintenance of reservoir projects. With respect to previous sections of this report, there are uncertainties in determining the need to meet new water supply demands through reallocation of reservoir storage space, and the associated impacts on other project purposes as well as the potential for increased safety risks associated with the physical integrity of the dam structure and management of flood events. The Corps has made much progress in operating our reservoir projects in a more environmentally sustainable manner, but more data collection and analysis is needed to evaluate the actions that have been taken and their cost effectiveness, and to inform policy and operational guidance to share the lessons learned. As time passes, reservoir sedimentation will increasingly impact operations, but forecasting trends and planning for mitigation and reduction in impacts remain uncertain.

This section of the report addresses the growing understanding of non-stationarity in hydrologic statistics together with developments in computing power that have enabled water resources planners to begin grappling with questions such as how climate change may impact operations of existing reservoir projects in the future. These areas of uncertainty are not just theoretical. If the construction of new reservoir storage space is no longer feasible, and existing reservoirs continue to lose space to sedimentation, we will increasingly lose our flexibility to respond to changing future conditions, whether those involve increased demand for water, decreasing supplies, increasing extreme flood and drought events, or all of the above. The ability to better forecast uncertain future conditions will be critical in managing the large investments that will be needed to sustain and enhance the benefits that multi-purpose reservoirs currently provide to the nation.

Underlying computational approaches to forecasting future conditions is the need for data. Without adequate data, the most technically sound forecasting method may only increase risks in decision-making due to mathematical uncertainty and statistical error. When adequate data is not available, or uncertainty is too great to recommend definitive changes, it may still be possible to better position reservoir projects to respond to changing future conditions through the development of adaptive approaches and contingency plans. This section explores two related areas where the Corps is working to address uncertainty in future conditions at its multi-purpose reservoir projects: responses to climate change and drought contingency plans.

Various agencies within the Federal Government have been involved in the possible effects of climate change over the last several decades. The U.S. Army Corps of Engineers (USACE) Institute for Water Resources (IWR) conducted its first climate change-related study in 1977 examining projected changes to inland hydrology that could result from temperature changes of up to ±2 degrees. Subsequent work resulted in guidance requiring consideration of sea level rise impacts to coastal projects in 1986 which led to the establishment of the Economic Impacts of Climate Change program.

In 1992 IWR examined warming impacts to reservoir systems throughout the United States. IWR personnel participated in the first Intergovernmental Panel on Climate Change (IPCC) assessments in 1990. Over the course of the next two decades they participated in additional IPCC assessments, conducted the first National Conference on Climate Change and Water Resources Management in 1994, performed a climate analysis study on flow frequencies for the Upper Mississippi River, participated in application of Global Climate Change approaches to the Great Lakes with the International Joint Committee and completed a study and prepared a report to the United States Department of Transportation on the Climate Impacts on Inland Waterways.

USACE reservoir operations and water management control activities will be challenged by future climate change and variability. In order to ensure continued effective and efficient water operations in both the short (5-10 years) and longer term (10-50 years), nationally consistent but regionally tailored water management adaptation strategies and polices are needed. In 2007, IWR initiated the interagency Climate Change and Water Working Group (CCAWWG) to address climate change impacts and adaptation in Federal water resources management. The CCAWWG produced a series of documents that serve as a roadmap for Federal investment in adaptation, including USGS Circular 1331 Climate Change and Water Resources Management: A Federal Perspective (USGS 2009); Addressing Climate Change in Long-Term Water Resources Planning and Management: User Needs for Improving Tools and Information (USACE et al. 2011); and Short-Term Water Management Decisions: User Needs for Improved Climate, Weather and Hydrologic Information (CCAWWG 2013).

6.1. Responses to Climate Change Program

Beginning in 2010, the Responses to Climate Change (RCC) Program, managed by IWR, has tested methods and frameworks for adapting to climate change with respect to specific business management decisions; identification of new policies, methods, and tools; methods to incorporate non-stationarity in the planning process; and to improve adaptation planning at the agency level. USACE established an overarching Climate Change Adaptation Policy Statement and a governance structure to support mainstreaming adaptation in 2011 following the release of Executive Order

13514, Federal Leadership in Environmental, Energy, and Economic Performance, and its implementing instructions. These policies and structures have been refined with the release of the President's Climate Action Plan and Executive Order 13653, Preparing the United States for the Impacts of Climate Change. Current policy requires USACE to mainstream climate change preparedness and resilience in all activities to help enhance the resilience of our built and natural water resources infrastructure; to improve the effectiveness of our military support mission; and to reduce potential vulnerabilities to the effects of climate change and variability. The RCC Program is currently developing additional planning guidance, database tools to standardize how climate change is handled during the USACE planning process, and inventory-level assessments of climate change vulnerabilities at USACE projects nationwide.

Regional climate change and hydrology literature syntheses have been published for all 21 water resources regions designated by USGS, and are on the RCC website at http://www.corpsclimate.us/rccciareport.cfm. Current USACE activities, goals and adaptation strategies are described in the USACE Climate Change Adaptation Plan (USACE 2014a), and planning guidance covering sea level rise and climate change impacts to inland hydrology has been issued, including:

- Engineer Regulation (ER) 1100-2-8162, Incorporating Sea Level Change in Civil Works Program (USACE 2013);
- Engineering Construction Bulletin (ECB) 2014-10 Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects (USACE 2014b);
- Engineer Technical Letter (ETL) 1100-2-1, Procedures to Evaluate Sea Level Change: Impacts, Responses and Adaptation (USACE 2014c); and
- ETL 1100-2-2, Appropriate Application of Paleoflood Information for Hydrology and Hydraulics Decisions (USACE 2014d).

The Third National Climate Assessment in 2013 identified changes to the water cycle, and the impacts of these changes to water resources, as a critical challenge resulting from a warming climate (Melillo et al. 2014). In a warmer world, the location, amount, frequency and form of precipitation are all expected to change. These changes are projected to affect the magnitude and frequency of both floods and droughts, which in turn are likely to impact water supply and flood risk management operations at USACE dams nationwide. Changes in water supply are a particular concern for many regions of the country whose growing populations already stress water resources. As discussed in **Section 2**, 136 USACE multi-purpose reservoir projects currently operate under agreements to provide storage for water supply, and many other USACE projects support water supply uses not directly related to reservoir storage.

6.2. Pilot Studies

Several of the IWR Responses to Climate Change Program pilot studies addressed changes to water supply indirectly, by examining how climate change might impact the rate of sediment deposition behind dams. As a dam gradually fills with sediment, its ability to hold water for downstream users gradually declines. Many of the pilot studies showed limited sedimentation impacts to reservoirs, and in some cases reductions in stream flow under a warmer climate were projected to result in less sediment transport to reservoirs. Two pilot studies conducted by the Tulsa District addressed the water supply issue directly: Utilization of Regional Climate Science Programs in Reservoir and Watershed Risk-Based Assessments, Oologah Lake and Watershed (Oologah Lake) and Climate Change Impacts on Water Supply in the Marion Reservoir Watershed, Kansas (Marion Reservoir).

The Oologah Lake study used data from 112 climate model runs to evaluate future climate conditions in the Oologah Lake watershed, which showed average temperature increases of 4.76°F but little change in precipitation (±10%). Winter precipitation is more likely to fall as rain than currently. Runoff from all seasons was routed through the Oologah Lake watershed to the reservoir using a land surface model. Most of the model ensembles suggested that reservoir firm yield is unlikely to change significantly over time, and the reservoir is well positioned to meet existing water supply obligations in the future. Not considered in the analysis was whether water demand is likely to increase under a warmer climate and, if so, whether the reservoir would still be able to meet these demands.

Originally, the National Portfolio effort did not envision the inclusion of climate change as a primary item of interest. As the study developed into the assessment stage, however, it was recognized that while numerous studies were ongoing with respect to climate change, there were none that directly investigated the effects of climate change on a particular reservoir with M&I water supply storage space. To alleviate this gap, a pilot study was jointly funded by the National Portfolio and RCC program. Climate model forcing data were provided by Dr. Andrew Wood at the National Center for Atmospheric Research. The lead author of the report was Dr. David Williams, Lead Hydraulic Engineer, USACE Tulsa District, and the analyses and findings were developed in collaboration with IWR staff.

The primary objective of this research project was the assessment of vulnerability for water supply and demand at Marion Reservoir in relation to climate change and variability. An initial assessment was performed to assess the reservoir's vulnerability to drought under current conditions. The assessment included the review of the current water supply contracts, customers, and uses. The assessment considered what combination of drought duration and magnitude would cause the reservoir to no longer meet its contracts. The findings of this assessment can be used to consider the water supply customer's potential vulnerability to drought by determining what alternative sources of supply are available, what conservation measures could be employed, and how much water demand exists during drought.

6.3. Summary of the Marion Lake Climate Change Pilot Study

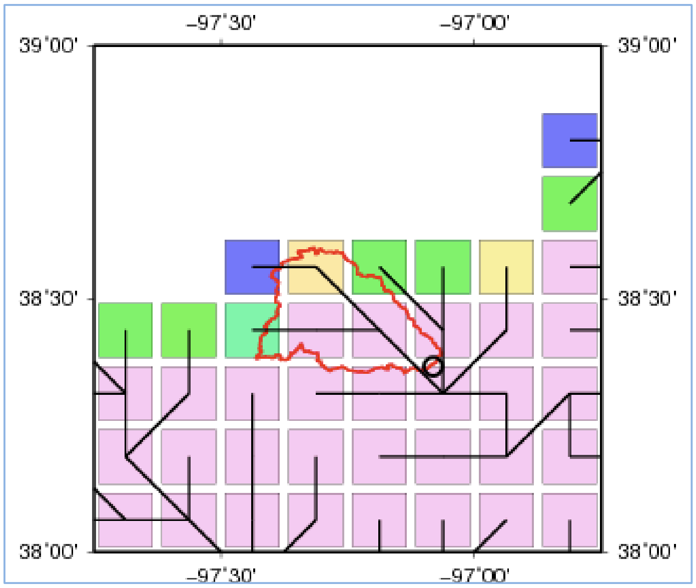
This section provides an overview and summary of the detailed study report, which is reproduced as **Appendix F**. The Marion Lake project was constructed on the Cottonwood River in eastern Kansas in 1968. The watershed above the reservoir is about 70 miles long, averaging about 26 miles in width and draining an area of approximately 1,908 square miles. The lake is one of three projects constructed for flood risk management and low-flow regulation for the Upper Grand River Valley.

The Kansas Water Office (KWO) holds water supply storage agreements with USACE for 50,800 acre-feet (ac-ft) of storage in Marion Lake, or about two-thirds of the project's conservation pool. KWO acts as a wholesale water provider to local interests in the area. However, very little of the water supply storage is currently utilized. KWO currently only contracts for about 1,800 of the available 50,800 ac-ft of storage. Requests for water quality releases for the Cottonwood River are also issued by the Kansas Department of Agriculture, Division of Water Resources, and peak in the summer month. The firm yield of the reservoir storage was last estimated in 1996, using the Corps' HEC-3 model to simulate reservoir routing with recorded streamflow from 1940 and through the critical drought period that occurred in the region during the decade of the 1950s.

Simulations of future streamflows in this pilot study were based on bias-corrected, spatially-disaggregated (BCSD) statistically down-scaled projections of general circulation climate models (GCM) evaluated as part of the World Climate Research Programme's third phase of the Coupled Model Intercomparison Project (CMIP3). The bias correction step involves making adjustments to simulated future variables based on comparison of simulated past variables to observed climate. GCM models are typically run with grid spacings in excess of 1° latitude by 1° of longitude, and the projections had to be spatially disaggregated to a 1/8° spacing for use in the hydrologic model. **Figure 6-1**, on the following page, shows the Marion Reservoir watershed overlaid on the resulting computational grid used in the study. Each grid cell represents an area of 57 square miles. A total of 112 GCM model projections were considered in the study, representing a range of high, medium and low emissions scenarios.

The study developed a method to translate the climate variables derived from the BCSD GCM datasets to runoff and streamflow estimates that could be simulated in a reservoir routing model to calculate firm yield in future scenarios. The Variable Infiltration Capacity (VIC) macroscale hydrologic model developed at the University of Washington was used to translate climate variables to runoff, and a related model used to route runoff estimates from each grid cell to a point simulating the inflow into

Figure 6.1. Computational Grid Cell Arrangement for Marion Reservoir Study

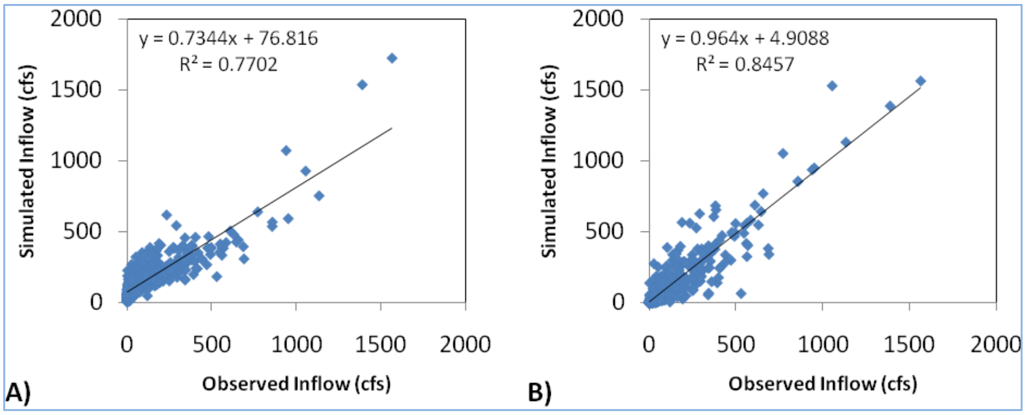


Marion Reservoir. The VIC model was calibrated by comparing the simulated inflow to observed inflow records. Daily values were not well correlated, so the yield calculations were performed using monthly values. The use of monthly values also made the process less cumbersome computationally, and allowed the simulation to neglect flood routing, as it was assumed that storage in the flood pool could be evacuated within a single monthly time step.

A mass balance model was also created to perform the reservoir routing necessary to calculate firm yield. A model was first developed in Microsoft Excel, but, although functional, it was converted to a MATLAB® custom programming application for more efficient computation. The 1996 analysis of reservoir firm yield used the original project design sedimentation rates projected over a 50-year period from construction in 1968 to 2018. For this study, however, data from the most recent bathymetric survey performed in 2010 showed that the actual depletion of storage by sedimentation was only about one-third of original estimates. The mass balance model used elevation-area-capacity relationships based on the 2010 survey data.

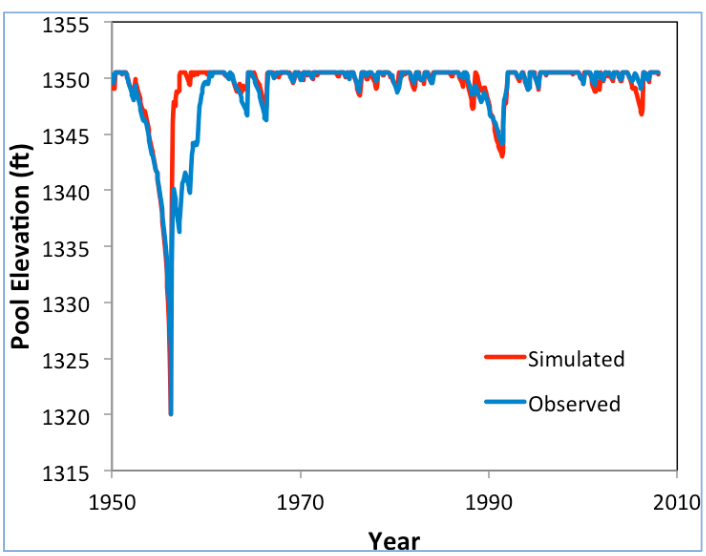
Initial results of the routing model highlighted issues with the remaining statistical bias in the simulated inflows after calibration of the VIC model. The bias was partially corrected by creating cumulative distribution functions (CDF) for each month of the observed inflow data, comparing these to CDFs developed for each month of the simulated inflow dataset, and developing correction factors for each probability. **Figure 6-2**, on the following page, shows the improvement in correlation between observed and simulated historical inflows after this correction. **Figure 6-2, Part A**, shows the correlation before bias correction, and **Part B** shows the improvement in correlation after correction.

Figure 6-2. Bias Correction of Simulated Inflows



Following the bias correction of the simulated hydrograph from the historical overlap period, yield modeling with the simulated dataset was able to accurately reproduce the timing of the critical period, which occurred in 1957. The 1996 study reported a firm yield of 25.6 cubic feet per second (ft^3/s) for the project (both water supply withdrawals and water quality releases), while this study found that the firm yield for the reservoir is 33.5 ft^3/s. The revised estimate of firm yield was considered to be defensible, and explained by the difference in data sources (in addition to the recent sediment survey, the observed inflow data set also differed from that used in the 1996 study), and computational differences between the routing models. **Figure 6-3** shows the resulting favorable comparison of the observed and simulated reservoir pool levels for the calculation of firm yield over the historical period.

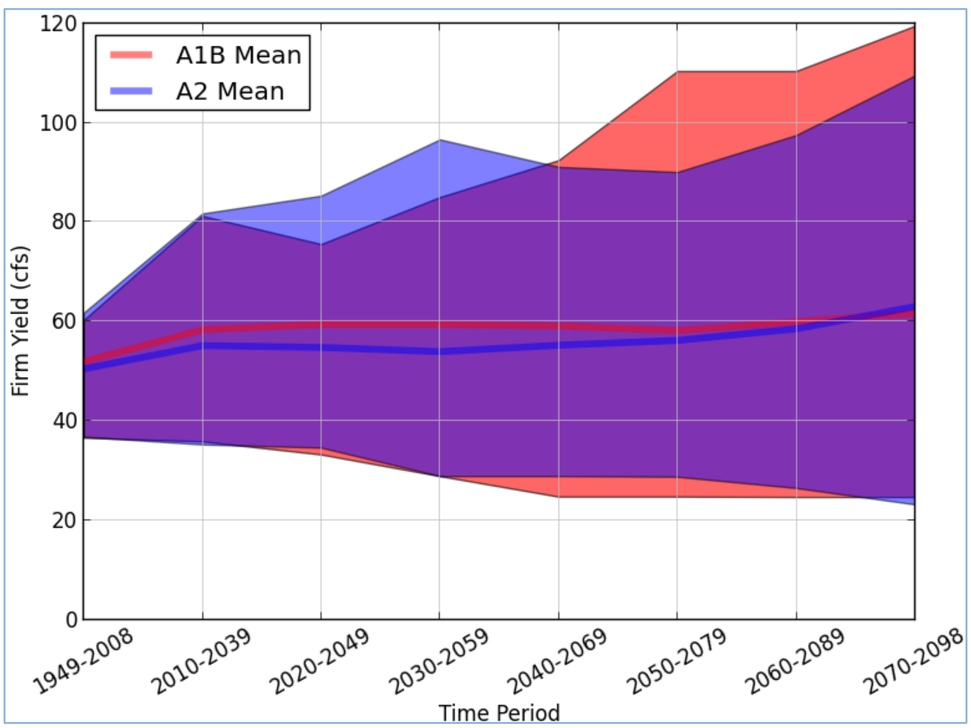
Figure 6-3. Comparison of Observed and Simulated Reservoir Pool Levels over the Historical Period



A snapshot taken in the year 2050 of the GCM projections considered in the study showed that 90% of the simulations forecast a mean temperature increase in the study area of at least 3°F. While the BCSD method of downscaling has been shown to reproduce temperature with better skill than precipitation, the forecasts for precipitation were split, with half of the models predicting more annual rainfall, and the other half predicting less. The majority of the models projected that the change in annual rainfall will be ±20%. Within the Marion Reservoir watershed, this is within ±4 inches, which falls within the current range of annual rainfall variability.

Not all of the 112 scenarios were run through the hydrology modeling. The lower emissions scenarios were omitted because they assumed a greater departure from the current fossil fuel economy and were considered less realistic. The medium and high emissions scenarios were analyzed further in the study and the bias correction factors discussed above were applied to each of the simulated inflow hydrographs generated with the VIC and flow routing modeling. The resulting hydrographs showed no appreciable change in mean streamflow through the year 2098. **Figure 6-4** shows the estimates of firm yield that were then developed with the reservoir routing model.

Figure 6-4. Firm Yield Estimates for Medium (A1B) and High (A2) Emissions Scenarios



The firm yield calculations for the 1949–2008 historical period were higher than the firm yield calculations based on observed records for the same period. Not only were the scenario ensemble mean values higher than the observed 33.5 ft^3/s, but the lower bound computed from all projections was higher than the observed firm yield as well. This was partially explained by remaining bias following the monthly CDF correction. After bias correction, the climate model projections continued to overestimate the Marion Reservoir inflow hydrographs during the summer months. The differential volume over the course of a month was on the order of 10^3 acre-feet, which in turn contributed to the overestimation of firm yield during the overlap period.

The envelope of possible future outcomes suggests that future firm yield will not differ significantly from the current firm yield. The upper and lower bounds of the analysis expand with respect to time due to model uncertainty and differences between the emissions scenarios, but given the nearly stationary behavior of the ensemble means, the model consensus portrays a future in which reservoir yield will be similar to current yields, minus the effect of sediment depletion.

In general, unlike coastal or mountainous areas where changes in sea level or snowpack elevation may be more easily observed, climate impacts on water supply reservoirs in the Great Plains are less obvious. Climate projection ensembles do not show pronounced uniformity in precipitation changes in this region, although the ensemble mean does trend toward more net precipitation. Since mean annual temperature does show an upward trend, the inter-annual distribution of precipitation will be critical, as evaporative losses may increase. Other factors, including soil moisture, base flow, and sedimentation rates, will also affect the water budget of the basin and available storage in reservoirs. All of these variables will require detailed study as the practice of climate prediction evolves, if the long-term impacts on water supply are going to be quantified.

Collaboration on this project with researchers at other Federal agencies was beneficial, given the technical expertise that has been gained through similar efforts. The selection of Marion Reservoir for this pilot study complemented the ongoing modeling efforts of other Federal agencies in the Great Plains region and allowed the use of existing datasets and modeling technology. Based on lessons learned from this pilot and updated climate information, the RCC program, in collaboration with other federal agencies and academic experts, has since made progress in updating analytical methods for similar studies.

6.4. Discussion of Adaptation Approaches

Figure 6-4 illustrates some of the current difficulties and uncertainties in relating climate projections to engineering decisions. Planning for management of reservoirs in drought is concerned primarily with the reliable yield. As discussed, the method for calculating firm yield in the pilot study produced results that were considered to be defensible when observed data were input, in comparison to the previous 1996 estimate and given the differences in sedimentation and inflow data between the two studies. However, the estimate of firm yield using BCSD GCM inputs from the historical period differed significantly from the observed data estimate. In addition, while the mean yield forecasts for future periods remains nearly stationary, the upper and lower bounds vary on the order of plus 100% to minus 50%. The pilot study goes on to discuss further the difficulties in translating results such as those illustrated in **Figure 6-4** into probabilities of future conditions.

The results of this study, however, do support the formulation of important qualitative conclusions with respect to the Marion Lake reservoir, and the study goes on to identify an adaptive approach to ensure the reliability of water supply contracts in the future. As discussed, the available water supply storage at the project is currently under-utilized. The Marion Reservoir watershed is a small, rural area with stagnant growth and water demand. There is no current basis for the expectation of an increase in future demand. When viewed as an ensemble, the GCM projections do not indicate that stream flow will change appreciably during the future. Yield modeling of projected hydrographs shows little change in 30-year mean values. Since the reservoir has existing water supply storage that significantly exceeds the contracted amount, it appears to have a robust capacity to meet future water supply obligations. A prudent approach to managing water supply contracts at Marion Reservoir may therefore include monitoring the firm yield on a regular interval, such as a moving 30-year mean. The existing water supply contracts between KWO and local users expire between years 2021 and 2039, and prior to the expiration and presumable extension of these agreements, the future firm yield can be recomputed, taking advantage of new climate forcings and general improvements in the state of climate modeling.

This type of qualitative assessment and monitoring recommendation is one example of an adaptive approach to managing the project for water supply given future uncertainties. USACE has an existing vehicle to explore and implement other adaptive approaches at multipurpose reservoir projects through drought contingency plans. The current state of these plans, as well as efforts to adapt them for climate change are discussed in the following section.

6.5. Summary of Corps Drought Contingency Plans

USACE reservoir projects and systems of projects are operated according to water control plans and manuals. Water control plans prescribe rules for storing and releasing water under given conditions in order to meet the authorized purposes of the project. As multi-purpose reservoirs must try to balance operations for multiple objectives, and conditions may vary from those foreseen in the water control plan, there are formal processes in place for deviating from an approved water control plan. Following the Western droughts of the 1970s, USACE published ER 1110-2-1941,"Drought Contingency Plans" (USACE 1981), recognizing that drought conditions can be especially challenging for multi-purpose reservoir projects. This ER provides policy and guidance for the preparation of drought contingency plans (DCP) relative to water control management. The intent of the DCPs is to better serve public needs by identifying potential changes to water control plans, within the current project authorities, that would increase the capability to respond to droughts, make provisions for coordination with other appropriate federal, state and local agencies and interests, and identify long-term opportunities to change storage allocations. Since that time, the combination of water control manuals, deviations and DCPs has provided a great deal of flexibility to respond to short-term and long-term needs based on best available information and science.

Consistent with standard engineering practice in the years following the issuance of ER 1110-2-1941, DCPs were prepared based on observed periods of record with regard to temperature, precipitation and drought, and did not address the potential for changes in climate extremes in the future. However, as noted by the US National Climate Assessment (Melillo et al 2014), climate is changing and is projected to continue to change. These changes vary regionally and include warming temperatures, altered precipitation patterns, increasing heat waves (particularly in the West), changing snow patterns (Walsh et al 2014) and droughts (Georgakakos et al 2014). Increases in summer drought are likely across the northern tier of states, including the Northeast, Northwest and Alaska, while increases in drought are likely in the southern Plains, Southeast and Hawai'i. The already arid Southwest is anticipated to see large increases in drought frequency and severity. The Midwest and northern Plains, however, are anticipated to experience little change in drought frequency, and even reductions in drought in northern portions of these regions.

Given these observed and projected changes in drought conditions, USACE has undertaken a project to assess the state of drought contingency planning and develop methods to update DCPs to account for changing climate. A Project Development Team (PDT) was formed to investigate the status of the DCPs at USACE reservoirs. While not funded through the National Portfolio effort, this work is considered very relevant to the issues discussed in this report, and therefore summarized in this section. The full report of this PDT, "USACE Drought Contingency Planning in the Context of Climate Change," (Pinson et al. 2015) was completed recently. The objectives of the report are to:

- Describe how climate change is likely to alter drought intensity and frequency across the United States.
- Review the status of USACE DCPs.
- Compare and contrast DCP contents and methods previously used for forecasting drought frequency and intensity in order to evaluate gaps and robustness develop analytical tools, and to set the stage for future updates to DCPs and DCP guidance if necessary.

The PDT collected and reviewed 142 DCPs covering 301 projects. **Appendix D** lists the specific projects reviewed. The team found that most of the current plans were completed prior to Year 2000, before information on climate change was widely available. None of the DCPs reviewed contained projections on potential future drought conditions in a changing climate. Given this consideration, it is uncertain how robust these plans are, especially in regions considered likely to experience more frequent and/or severe droughts. Other knowledge gaps included identification of specific operating issues and constraints, identification of current resources for short-term forecasting, as well as considerations related to improved understanding of potential long-term climate change.

The next steps to be undertaken by the PDT include conducting pilot studies to test and refine methods for evaluating projects in light of projected short-term and long-term climate data and to update DCPs to account for changing climate. The first step in this process was to select five high priority locations with DCPs requiring updates and perform pilot studies to test methods and approaches to develop updates for these DCPs to account for changing climate. These projects were chosen to represent different Corps divisions and to cover a variety of authorized purposes. Pilot projects are currently planned for the following divisions: Lakes and Rivers, Mississippi Valley, Southwestern, South Pacific and Northwestern. Lessons learned from each of these updates will be applied to subsequent updates and will be included in the guidance developed for dissemination to Corps districts.

7. Conclusions and Next Steps

The National Portfolio effort began in fiscal year (FY) 2008 and has significantly advanced the understanding of our U.S. Army Corps of Engineers (Corps, USACE) reservoir projects. Beginning with a survey of project characteristics and status taken between 2008 and 2009, it has since gone on to develop, or assist in developing a number of products in order to better track status, assess trends, and evaluate challenges to the continuing operation of these important water resources projects. This report section provides a summary of major takeaways from the work completed to date and makes recommendations for next steps in the program. Specific recommendations are identified in bold italics. These recommendations are intended to contribute to the development of an overall framework for funding decisions that ensures Corps reservoir projects continue to maximize the value they provide to the Nation as conditions evolve, and to other goals identified through completed work and Administration budget development as the effort has progressed.

Water Supply Storage Reallocation

Section 2 of the report discussed the water supply mission at multi-purpose Corps reservoir projects. After the 2008 survey, the Corps provided an information paper to the Assistant Secretary of the Army for Civil Works, ASA(CW), that identified 52 priority projects for reallocation studies and three potential alternative funding methods, in accordance with guidance from the Office of Management and Budget. Since those recommendations were made, 15 reallocation studies have received funding through the normal budget process, and others have progressed with contributed or reprogrammed funds. These study efforts have included 26 of the original 52 identified priority projects, as well as 10 other projects identified in the development of subsequent budgets. For alternative funding, one recommendation, to accept voluntarily contributed funding from non-federal sponsors was enacted through legislation and is now permissible under the contributed funds statute, 33 U.S. Code §701h. The other two recommendations have not been adopted.

The completion of the water supply survey complemented contemporary efforts by the Corps' Institute for Water Resources (IWR) to develop a database for water supply storage agreements at Corps projects. As documented most recently in the "2014 Municipal, Industrial and Irrigation Water Supply Database Report" (USACE IWR 2015), the Corps is now able to systematically track over 300 water supply storage agreements at 136 reservoir projects across the country. According to this data, about 9.8 million acre feet of storage in Corps reservoirs is currently allocated to municipal and industrial water supply uses. This represents about three percent of the total gross storage in the 465 projects surveyed in 2008, which themselves represent about half of the total reservoir storage in the nation, according to the National Inventory of Dams. As reservoir storage continues to be lost to sedimentation, and it continues to be difficult to permit, fund and construct new reservoir storage, it is likely that requests will continue to reallocate storage at Corps reservoirs from other purposes to serve increasing water supply needs.

While the Corps has made significant progress in addressing the needs and priorities identified in 2010, to date only two of these studies have resulted in new water supply storage agreements. There are many reasons that a reallocation study might not be completed or result in a final water supply storage agreement, for example, if at any point the proposed reallocation is found not to be economically efficient, or if the non-federal sponsor withdraws in order to pursue other alternatives. However, in general, as demand for water increases, the considerations involved in reallocation studies are becoming more complex and Corps planners must balance needs for more information and detailed characterization of tradeoffs and risks with the need to efficiently manage studies to arrive at a recommendation. This is very similar to ongoing efforts to modernize the Corps planning program and the feasibility study process. In addition, as the Corps' dam safety program has become more formalized and structured, the program has added more oversight to recommendations and actions such as storage reallocation that might alter a project's structure or operations.

Next Steps: More work is needed to provide study teams with the training and tools to complete water supply storage reallocation studies in a timely and cost effective manner.

Finally, while the Corps water supply database now tracks formal water supply storage agreements, other internal reviews have indicated that there are thousands of instances where relatively small (in most cases) water withdrawals are taking place through site-specific real estate instruments or shoreline management permits. At some projects it may be that the sum of these withdrawals could reduce the reservoir yield thought to be available for operations in extreme drought conditions. In many river basins, Corps reservoirs significantly influence the availability of water. As mentioned in **Section 1,** following the initial assessment of water supply and reallocation data it was envisioned that future updates would expand to include forecasted projections of water availability over the next 10, 20 and 50 year periods.

Next Steps: More work is needed to track water withdrawals and forecast availability in order to better inform project planning and sustainable operations.

Water Management Data and Trends

Section 3 of the report discussed the findings of the survey and assessment effort begun in 2008 with respect to water management at Corps reservoir projects, as well as other projects with flood risk management storage managed by USACE. Overall, these 465 projects represented about half of all reservoir storage in the nation. Selected attributes of the data gathered were summarized to help characterize the overall group of projects, understand how project operations have been adjusted in the past in response to changing conditions, and evaluate current environmental operating strategies.

The surveyed reservoirs varied widely in character, but were generally characterized as either “Big River”, “Dry Dam” or “General.” The “Big River” reservoirs included nine mainstem projects on the Missouri, Columbia and Colorado Rivers. “Dry” dams are typically smaller and more single-purpose than other surveyed projects. Most of the 51 projects identified as dry were constructed solely for flood risk management and do not store water under normal conditions. The remaining 405 “General” reservoirs are most representative of typical multi-purpose federal reservoir projects.

Through this survey effort, a database was compiled at the Corps’ Hydrologic Engineering Center including over 37 million daily values, representing over 80 percent of the operational history of the surveyed projects. This was a first-of-its-kind effort and enabled new analyses of reservoir operations. The nine Big River projects alone accounted for nearly half of all water released from the dams in the survey in the period of common data analyzed from 1989 to 2008. At all projects, it was found that, by volume, most releases were identified with hydropower generation, although it was noted that these releases may also serve multiple purposes downstream of the project.

Corps guidance is that water control plans are continually reviewed, updated and adjusted as needed to ensure that the best use is made of available resources in current conditions. The most common motivation for operational changes was found to be improvements in flood risk management, but the percentage of changes for environmental enhancements (water quality and fish and wildlife) has been steadily increasing since the 1980s, and by 2009 represented about 14 percent of all recorded operational changes. At “general” reservoirs, about one-eighth of all releases were identified with environmental purposes. Environmental strategies at most surveyed reservoirs were limited to flow or water temperature management, and were formalized mostly in terms of constant minimum flow requirements.

Next Steps: Develop a recommended scope and frequency for future water management data collection and assessment efforts to continue to build on the one-time assessment documented in this report.

Environmental Considerations

Section 4 of the report discussed efforts to better understand the relationships between multi-purpose reservoir projects and physical, chemical and biological water quality conditions and connected ecosystems; and to evaluate operational and structural changes that could enhance water quality and ecosystems while continuing to serve authorized purposes for human needs. Community support for Sustainable Rivers project sites around the country highlight the benefits of collaboration in efforts such as these to achieve enhanced environmental benefits within the current framework of authorized project purposes. Fifteen case studies were presented where evaluations and modifications have been made for environmental flows involving nearly 70 Corps reservoir projects across the country. The case studies indicate that these mutually beneficial goals can be achieved; however, as noted by the Corps Committee on Water Quality, more work is needed to evaluate outcomes of some of the case studies and to translate lessons learned into practical guidance for water managers around the country.

Next Steps: More work is needed to track results of case studies and develop policy and technical guidance on project modifications to enhance water quality and ecosystems.

The Committee on Water Quality also identified specific challenges to sustaining water quality and ecological conditions tied to Corps reservoir projects. These challenges include: hydrologic nonstationarity and changing climate, mineral extraction activities, harmful algal blooms and non-federal hydropower retrofit projects. The Committee began a survey effort to complement the water supply, water management and reservoir sedimentation surveys completed through the National Portfolio, but this survey has not yet been completed.

Next Steps: Complete the water quality survey and use the results to refine and prioritize the challenges and needs assessment.

Reservoir Sedimentation

Section 5 of the report discussed the findings of the 2008 reservoir sedimentation survey, as well as efforts since then to track and analyze sedimentation data. This survey was by far the best and most extensive review of sedimentation at Corps reservoir projects undertaken to date. It showed that sedimentation is not currently a major issue at most projects, but in isolated cases it is becoming a significant problem. The majority of Corps reservoir projects (338 out of the 378 surveyed) have not experienced more than 25 percent of storage depletion due to sediment.

While a majority of the projects (257) did report that sediment impacts operations for at least one of the authorized purposes (flood risk management, navigation, hydropower, water supply, water quality, recreation and/or fisheries), most of these impacts were characterized as “moderate,” defined as restricting operations from 10 to 25 percent of the time. There were only five projects where a district reported that sediment limits project operations on one or more project purposes 25 percent or more of the time, and only two projects where the district reported sediment impacting project operations nearly all the time. The majority of impacts to project operations were recorded at projects across the Great Plains region of the country. These projects fall under the Tulsa and Omaha district offices.

The 2008 data collected on age of sediment surveys became outdated fairly quickly as many surveys were performed when funding became available under the American Recovery and Reinvestment Act of 2009. The 2008 data did indicate, at the time, that the average age of sediment surveys was on the order of 15 years. Current Corps guidelines suggest that sediment surveys should be performed approximately every 5 to 15 years, although needs are specific to each project. Considering that many surveys were updated or performed after 2009, it appears that the Corps is generally, on average, meeting its internal guidelines for monitoring sedimentation. The data also showed that the majority of surveys were still executed by measuring across rangelines or cross-sections and interpolating between them, but total bed surveys are expected to continue to become more cost effective. The Corps has developed the Reservoir Sedimentation Information (RSI) system to better track sedimentation data and evaluate trends and vulnerabilities.

Responses to the 2008 survey indicated that only 39 percent of the reservoir projects use sediment management practices, and the majority of these reported minimal site specific sediment removal, periodic dredging, or “other” management practices. Sediment flushing and sluicing operations were only reported at six percent of the surveyed projects. Among the obstacles reported to greater use of sediment management practices, regulatory and funding issues were most often cited. As sedimentation continues to reduce the useable storage volume in reservoirs across the country, consequences will increase, and sediment management practices will become more important.

Next Steps: More work is needed to identify and prioritize project risks associated with sedimentation, and understand and explore methods for overcoming obstacles to sediment management.

Uncertainty in Future Conditions

Section 6 of the report discussed efforts to better understand and plan for future uncertainties related to reservoir operations and project benefits. The work discussed in this section focused on the risks and potential vulnerabilities that may arise with changes from historical climate. The report documents one pilot study that developed a method for using downscaled climate model projections to evaluate possible changes in reservoir yield that could be used to inform project modifications or adaptation approaches to sustain or enhance water conservation operations. The report also discusses a related review of reservoir drought contingency plans and efforts to update those plans. Planning for reservoir operations under drought conditions has typically been based on historical data. As our understanding and ability to forecast potential future conditions in a changed climate improve, planning methods should evolve to incorporate future scenarios.

Next Steps: The National Portfolio effort should continue to collaborate with other programs to assess the potential impacts of climate change on multi-purpose reservoir projects.

Unfortunately, climate is just one area of uncertainty facing the Corps as it seeks to sustain its portfolio of aging reservoir projects and continue to operate them for maximum benefits and safety. The Corps is often asked to change project operations to meet changed conditions, or perceived changes, by stakeholders for one project purpose. An example is a non-federal sponsor requesting reallocation of storage to serve new water supply needs. There is often uncertainty regarding the need motivating the requested change and other project conditions that relate to tradeoffs that must be characterized when evaluating project modifications. While the subject of tradeoff analysis has not been a specific area of work under the National Portfolio effort to date, it appears to be very relevant to the assessment of challenges presented in this report.

In addition to the technical challenges in evaluating future conditions and risks related to continuing operations of multi-purpose reservoir projects, the growing dimensions of uncertainty and complexity in interrelationships among them pose a risk to organizational decision-making. The Corps has been addressing similar issues in its efforts to modernize the Civil Works feasibility study planning process for new water resources projects. The Corps will need to be able to define and focus on the most relevant risks and uncertainties in order to make decisions today that will result in more sustainable reservoir projects that are adaptable and resilient to changing conditions in the future.

Next Steps: More work is needed to develop methods, tools and guidance for the complex tradeoff analyses and decision-making involved in evaluating modifications to existing multi-purpose reservoir projects.

In summary, the Corps portfolio of major multi-purpose reservoirs represents a significant portion of the nation's surface water storage and management capacity. Construction of new federal reservoir storage projects peaked in the 1960s, 50 years ago. On average, these projects are at the end of their original planning lives and many now require significant recapitalization, and may require updates to operating plans in order to continue providing benefits while protecting public safety. Increased awareness of the environmental impacts of construction of dams has led to more efforts at mitigation and restoration. Changing conditions and needs are leading to more requests for operational changes.

The current Corps Civil Works Strategic Plan identifies a strategic goal of managing the life-cycle of water resources infrastructure systems in order to consistently deliver sustainable services. This report has presented information related to the current status of the Corps portfolio of multi-purpose reservoir projects and challenges facing the Corps in achieving this goal. The overarching strategy proposed by the Corps is that of integrated water resources management, defined as "a holistic focus on water resources challenges and opportunities that reflects coordinated development and management of water, land and related resources while maximizing economic services and environmental quality, and ensuring public safety while providing for the sustainability of vital ecosystems." Cross-cutting strategies proposed include: taking a systems approach to decision-making, collaboration and partnering, risk-informed decision-making and communication, innovative financing, adaptive management and state-of-the-art technology.

As documented throughout this report, the work completed to date under the National Portfolio effort has demonstrated several of these strategies. Multi-purpose reservoirs, by their nature, exemplify the considerations and benefits of integrated water resources management. The recommendations presented in this section will build on the strategies identified in the Strategic Plan and assist with developing a framework for funding decisions to advance the Corps towards the goal of continuing to sustainably deliver services from its portfolio of multi-purpose reservoir projects in an uncertain future.

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Appendix A. U.S. Army Corps of Engineers Office Abbreviations

Each Corps office has a three-letter abbreviation that is often used to identify the office. These abbreviations are used in tables throughout this report and appendices. Districts having no reservoirs with federally authorized flood space are shaded in grey.

Office	Abbreviation
Great Lakes and Ohio River Division	**LRD**
Buffalo District	LRB
Chicago District	LRC
Detroit District	LRE
Huntington District	LRH
Louisville District	LRL
Nashville District	LRN
Pittsburgh District	LRP
Mississippi Valley Division	**MVD**
Memphis District	MVM
New Orleans District	MVN
Rock Island District	MVR
St. Louis District	MVS
St. Paul District	MVP
Vicksburg District	MVK
North Atlantic Division	**NAD**
Baltimore District	NAB
New England District	NAE
New York District	NAN
Norfolk District	NAO
Philadelphia District	NAP
Northwestern Division	**NWD**
Columbia River Water Management	NWD-CR
Kansas City District	NWK
Missouri River Water Management	NWD-MR
Omaha District	NWO
Portland District	NWP
Seattle District	NWS

Walla Walla District	NWW
Office	**Abbreviation**
Pacific Ocean Division	**POD**
Alaska District	POA
Honolulu District	POH
South Atlantic Division	**SAD**
Charleston District	SAC
Jacksonville District	SAJ
Mobile District	SAM
Savannah District	SAS
Wilmington District	SAW
South Pacific Division	**SPD**
Albuquerque	SPA
Los Angeles	SPL
Sacramento	SPK
San Francisco	SPN
Southwestern Division	**SWD**
Fort Worth District	SWF
Galveston District	SWG
Little Rock District	SWL
Tulsa District	SWT

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Appendix B. 2008 Survey: Definition of Terms and Question Details

This survey, as discussed in **Sections 1, 2, 3 and 5**, was a major undertaking both for the responders and for the people who processed and summarized responses. The following definitions and directions were provided to clarify the scope of information that the survey was intended to collect, and make the effort as straightforward as possible.

Water Supply:

Project Name – The name of the dam and/or lake that is recognized by the Corps.

EROC – Two letter code for the District such as B1 for the Memphis District.

CWIS – Six character project identification code.

Latitude – Latitude of the project's area office.

Longitude – Longitude of the project's area office.

Watershed – Three letter system code name such as MOR for Missouri River.

River – The major river where the project is located.

Congressional District(s) – List all Congressional districts within which the project is located.

Year of Completion – Year project was physically completed and began operations.

Project Dam Safety Action Class – Classification of project infrastructure (1-5) per the national dam safety program.

Authorized Purposes – These are the purposes a reservoir is to serve as specified in laws that either 1) initiated construction of the project, 2) are specific to that project and were passed after construction, and 3) apply generally to all Corps Reservoirs (e.g., the Endangered Species Act, which provides authority for operating projects to protect listed species).

Operating Purposes – These are the purposes for which water management decisions are made at the reservoir. As a general rule, a reservoir is operated for its authorized purposes, but there are exceptions. For example, hydropower may have been authorized but not yet installed.

Drainage Area - The total surface area upstream of the dam where the water from rain and snowmelt flows over the ground surface, back into streams, to finally reach the dam (sq. mi.).

Reservoir Storage Zones – Reservoirs typically have operational zones in which stored water is dedicated to one or more of its authorized purposes. The following series of questions (gross pool through sediment reserve) asks for storage values at zone boundaries. The goal of this series of questions is to define all zone boundaries for each reservoir. If any reservoir has a zone(s) that is not listed below, please use the "Other Zone" option provided in the survey to document any unlisted zone(s). If listed zone boundaries occur at the same storage, please enter that storage for all zones. If a reservoir does not have one of the listed zones, please enter NA (not applicable).

Gross Pool Storage – The definition of "Gross Pool" differs from project to project, but the elevation of gross pool typically coincides with the crest of the reservoir's spillway or the elevation where all flood storage is filled. Gross Pool Storage is the total volume (acre-feet) the project is capable of holding at this pool elevation.

Top of Flood Storage – This applies to reservoirs with authorized space for attenuating flood waters. This is the volume stored (acre-feet) when all of that flood space is filled and may be equal to Gross Pool Storage.

Seasonal Maximum Top of Conservation Storage – The "Top of Conservation" defines seasonal target pool elevations. This is sometimes referred to as a reservoir's guide curve. The "Seasonal Maximum Top of Conservation Storage" represents the maximum volume (acre-feet) a reservoir can store at any time of the year without exceeding the Top of Conservation.

Seasonal Minimum Top of Conservation Storage – This is the minimum volume (acre-feet) a reservoir can store at any time of the year without exceeding the Top of Conservation. The difference between Top of Flood Storage and Seasonal Minimum Top of Conservation should equal the maximum amount of storage dedicated to flood damage reduction.

Hydropower or Conservation Buffer Storage – This is the storage (acre-feet) below which only essential demands (i.e., instream flows or hydropower generation) will be met.

Minimum Hydropower Storage – This is the storage (acre-feet) that corresponds to the minimum pool elevation at which hydropower can be generated.

Inactive Storage – This is the storage (acre-feet) that corresponds to the minimum pool elevation at which water can be released from the reservoir.

Sediment Reserve – This is the volume of reservoir storage (acre-feet) allocated to allow for sediment deposition.

Yield from Conservation Storage – The amount of water the conservation pool is expected to produce (million gallons per day/acre-foot or cfs/acre-foot).

Reallocation Possibilities – The survey provides a series of options regarding the status or potential of reallocation opportunities. One or more options may be selected.

Water Management:

Minimum Flow – Minimum flows define the lowest allowable releases from the reservoir and are typically intended to manage fish, wildlife, and water quality needs. Flows can be seasonal and may be required at multiple locations. The survey requests flow values for all sites and seasons. For complex sets of minimum flows, please use the comments section to note the upstream to downstream order of locations and whether multiple reservoirs are operated as a system to meet the flows for each location. If minimum flows are related to the prevailing hydrologic condition (wet or dry), please tabulate those flows using a header “Location-Hydrologic Condition”. Also, for flow values entered as dd/mm – cfs, please indicate whether flows between date values are held constant (if not, please describe the transition used).

Maximum Power Release – This is an approximation of the maximum flow rate that can be passed concurrently through all turbines generating hydropower at the dam site.

Maximum Release at Minimum Top of Conservation – Flow rate that equals the combined capacity of all outlets at the pool elevation where all of the maximum seasonal flood pool is empty.

Maximum Objective Release – Objective flows are the maximum allowable flows at locations downstream of reservoirs operated for flood damage reduction. This survey requests objective flows and related information for each objective flow location at or downstream of the dam.

Does Objective Release Equal Max Non-Damaging Flow? – In most cases, objective releases are associated with the maximum flow a downstream channel can convey without causing flood damages. If this is not the case, the survey also asks that the maximum non-damaging flow be specified (this flow can be greater or less than the objective flow).

Number of Instances Greater than Max Objective Flow – This should be entered as an integer equal to the number of times that flows at an objective flow location have exceeded allowable maximums.

Date(s) of Instance(s) – Comma separated list of dates (mm/yyyy).

Fish Passage – Ladders, lift devices, and trap-and-haul programs are all examples of fish passage methods at dam sites.

Level of Effectiveness of Fish Passage – This is a qualitative ranking of effectiveness. A ranking of “1” is characterized by near zero success, migratory species are essentially blocked or have been extirpated from system; a “4” indicates partial passage for some species, including migratory species that have been able to sustain reduced populations, a “7” indicates good passage for most species with no loss of migratory species and limited exposure to predation and mortality when navigating the fish passage system, a “10” indicates near zero alteration to fish behavior, passage, and mortalities.

Ability to Manage Outflow Temperatures – Mixed elevation outlets and other temperature control devices give water managers the ability to manage the outflow temperature of waters released from the dam.

Conditions of Dam, Outlets, Gates, etc. – This is a qualitative ranking of infrastructure integrity. A ranking of “1” is characterized by an immediate need to perform intensive rehabilitation of the facility in order to restore or safeguard a facility’s utility to meet its authorized purposes; a “4” indicates an immediate or anticipated need (in the next 5 years) to undertake significant rehabilitation, a “7” an immediate or anticipated need (in the next 5 years) to undertake minor rehabilitation that is or will affect project operations, a “10” indicates that the facility is in good condition and is maintainable in that condition at 2008 funding levels for the next 20 years without affecting project operations.

Database – Series of questions about the flow and reservoir data available in Corps archives. As part of this survey, data for the electronic period of record (preferably at a daily time step) are requested for inflow, outflow, storage, and top of conservation storage. If inflow, storage, or top of conservation storage is limiting the concurrent electronic period of record and could be easily computed based on regulation schedules, pool elevations, or other available electronic data, then those computations should be performed by the district before providing the data. Please provide data in DSS format.

Electronic Period of Record (E-POR) – Range of years where inflow, outflow, storage, and top of conservation storage are available for a daily (or shorter) time step in an electronic database.

Period of Record - Range of years where inflow, outflow, storage, and top of conservation storage are available for a daily (or shorter) time step in any format.

Description of data format(s) pre-E-POR – When the period of record exceeds the electronic period of record (E-POR), please provide a short description of the format(s) of the earlier data.

Water Control Manual Edition – Publication year for each edition of the water control manual.

Changes in this Edition – Each change should be listed and associated with a purpose and motivation for the change. Especially noteworthy are any changes to official policies regarding storage allocations, authorized purposes, objective releases, minimum flows, power generation, water supply, sediment management techniques.

Authorization Required – Position of official signatory or authorizing person.

Purpose/Motivation for Each Change – Brief description of the impetus behind each change.

Testing of Alternatives – Series of questions about how alternative operations are tested at reservoirs. “Tests” are defined as any operations that are not explicitly defined in the water control manuals. Tests would include operations generally followed by reservoir regulators that have not yet been officially incorporated into water control plans or river/reservoir modifications in support of local community events, instream or offstream water use groups, or science activities.

Cooperator(s) – List of any partners of groups associated with the test(s).

Experiment – Brief description of the flow modifications done for the test(s).

Purpose/Motivation – Brief description of the purpose and motivation underpinning the change in operations.

Affect Operations in Long-term? – This question asks whether individual tests have influenced official policies as documented in the water control manuals.

Timeline for Water Management Function – Series of questions about staffing of Corps Water Management groups. Please begin with the current status of the Water Management group and work backwards in time.

Group Name and Organizational Location –

Number of FTEs – Total number of full-time employees. Please include part-time employees in this total as fractional full-time employees. This total should also include any unfilled vacancies (???).

Number of FTEs per Category – Please split the total number of employees into categories the following categories: water manager (direct responsibility for managing reservoir operations), water control data systems, water quality, dam operators, park rangers, administration, other). When an individual has responsibilities that are split amongst these categories, please divide that FTE between the categories according to that person's percent workload.

Years of Experience – Years of experience in the professional arena related to water management for the chief or senior water manager at the beginning of their tenure

Years of Experience in Water Management – Years of experience in the water management field for the chief or senior water manager at the beginning of their tenure

Years of Experience with Corps – Years of experience with the Corps for the chief or senior water manager at the beginning of their tenure.

Years of Experience with Corps Water Management – Years of experience for the chief or senior water manager at the beginning of their tenure

Next Position and Location – Name of position, organization, and location for next assignment at end of tenure as chief or senior water manager.

Sediment Management and Data:

Basin Hydrology – Describe the general hydrology of the contributing basin. We would ask for only on descriptor here (e.g. arid, semi-arid, etc.) A series of push buttons would be good.

Primary Land-Use - Describe the dominate land use in the contributing basin. We would ask for only on descriptor here (e.g. mining, agricultural, etc.) A series of push buttons would be good.

Current Percent Filled Due to Sedimentation

- Percentage of total storage lost due to sedimentation.
- Percent of exclusive flood control storage lost due to sedimentation.
- Percent of multi-purpose storage lost due to sedimentation.
- Percent of permanent storage lost due to sedimentation.
- Percent of dead storage lost due to sedimentation.

Average rate of filling as a percentage of the total storage (enter "NA" if unknown).

Impacts to Authorized Purposes Due to Sedimentation
Definitions
Lost - Project cannot be operated for a particular use due to sedimentation.
Severely Restricted - Due to sedimentation, project can only be operated for a particular use during extreme hydrologic events.
Significantly Restricted - Due to sedimentation, project can only support a particular purpose between 75 and 90% of the time.
Moderately Restricted - Due to sedimentation, project can support a particular purpose more than 90% but less than 100% of the time.
Un-effected - Sedimentation is not impacting a particular use or purpose.

- Project purposes that have been lost due to sedimentation.
- Project purposes that are severely restricted due to sedimentation.
- Project purposes that are significantly restricted due to sedimentation.
- Project purposes that are moderately restricted due to sedimentation.
- Project purposes that are un-effected by sedimentation.

Sediment Management Practices – Please indicate what sort of sediment management practices have been and/or are being practiced.

a. No sedimentation management practices.

b. Minimal site specific dredging or sediment removal for local benefits, such as boat access.

c. Periodic maintenance dredging where the sediments are wasted.

d. Periodic maintenance dredging where the sediments are placed for a beneficial use.

e. Continual maintenance dredging where the sediments are wasted.

f. Continual maintenance dredging where the sediments are placed for a beneficial use.

g. Continual maintenance dredging where the sediments are placed for a beneficial use.

h. Flushing of sediments.

i. Sluicing of sediments.

Please indicate if these are ongoing or one-time practices.

Obstacles to Sediment Management Practices - What are the obstacles to reservoir sediment practices. More than one obstacle may apply to a single lake.

a. Regulatory (Section 404, TMDLs, etc.).

b. Funding

c. Sponsorship

d. Ownership of Sediments

e. Liability

f. Tools (construction, assessment, monitoring, etc.).

g. Other

Dates of Sediment Survey

a. Most Recent Survey Date (year)

b. Total Number of Completed Surveys

c. Initial reservoir survey date (year)

Survey Technique

a. Rangelines and/or average end area methods.

b. Total bed surveying methods

c. Other

d. Please provide a qualitative assessment as to the effectiveness of the various survey techniques relative to being able to operate the project for all uses

Appendix C. Summary of Water Supply and Water Management Survey Results

This appendix provides a tabular summary of some of the water supply and water management data gathered in the 2008 survey effort and subsequent analysis, as discussed in report **Sections 1, 2 and 3**. Reservoir storage volumes are presented in acre-feet (ac-ft), and the estimated reliable yield of the water supply storage in million gallons per day (mgd). The 2010 information paper prepared for the Assistant Secretary of the Army for Civil Works identified projects where there was a potential need for a reallocation study in the near term, and assigned a priority (high, medium or low) to approximately half of those projects based on criteria discussed in **Section 2**. These projects are identified in the table as: (H) high priority, (M) medium, (L) low, or (P) potential. The last column shows those projects at which a reallocation study has either completed or been started since the 2008 survey effort. In all columns, a dash indicates that either the field did not apply to that project or no data was submitted through the survey.

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District	Owner	Project Name	Water Management Survey (Sec. 3)					Water Supply Survey and Database (Sec. 2)			
			Project Classification	Gross Storage (ac-ft)	Flood Storage (ac-ft)	Max. Conservation Storage (ac-ft)	Min. Conservation Storage (ac-ft)	WS Storage (ac-ft)	WS Yield (mgd)	2010 Reallocation Assessment (H / M / L / P)	Recent Reallocation Study (Y)
LRB	Corps	Mount Morris Dam	Dry Dam	301,986	301,986	--	--	--	--	--	--
LRE	Corps	Menasha Lock & Dam - L. Winnebago	General	1,057,586	335,118	908,369	722,468	--	--	--	--
LRH	Corps	Alum Creek Lake	General	134,800	109,800	81,700	25,000	79,200	40.0	--	--
LRH	Corps	Atwood Lake	General	49,700	26,100	23,600	23,600	--	--	--	--
LRH	Corps	Beach City Lake	General	71,700	70,000	1,700	1,700	--	--	--	--
LRH	Corps	Beech Fork Lake	General	38,000	33,800	9,200	4,200	--	--	--	--
LRH	Corps	Bluestone Lake	General	631,000	600,100	38,300	30,900	--	--	--	--
LRH	Corps	Bolivar Dam	Dry Dam	149,600	149,600	--	--	--	--	--	--
LRH	Corps	Burnsville Lake	General	65,900	61,653	14,360	4,247	--	--	--	--
LRH	Corps	Charles Mill Lake	General	88,000	80,600	7,400	7,400	--	--	--	--
LRH	Corps	Clendening Lake	General	54,000	52,200	1,800	1,800	--	--	--	--
LRH	Corps	Deer Creek Lake	General	102,000	95,600	21,000	6,400	--	--	--	--
LRH	Corps	Delaware Lake	General	132,000	123,600	14,000	8,400	--	--	H	--
LRH	Corps	Dewey Lake	General	93,300	93,288	17,200	12	--	--	H	--
LRH	Corps	Dillon Lake	General	274,000	260,900	17,500	13,100	--	--	--	--
LRH	Corps	Dover Dam	Dry Dam	203,000	203,000	--	--	--	--	--	--
LRH	Corps	East Lynn Lake	General	82,500	70,800	17,200	11,700	--	--	--	--
LRH	Corps	Fishtrap Lake	General	164,400	153,900	37,700	10,500	--	--	H	--
LRH	Corps	Grayson Lake	General	119,000	100,261	29,390	18,739	2,538	7.5	H	--
LRH	Corps	John W. Flannagan Lake	General	145,700	133,700	67,500	12,000	3,360	10.0	H	--
LRH	Corps	Leesville Lake	General	37,400	17,900	19,500	19,500	--	--	--	--
LRH	Corps	Mohawk Dam	General	285,000	285,000	--	--	--	--	--	--
LRH	Corps	Mohicanville Dam	Dry Dam	102,000	102,000	--	--	--	--	--	--
LRH	Corps	North Branch of Kokosing Dam	General	14,900	13,857	1,043	1,043	--	--	--	--
LRH	Corps	North Fork of Pound Lake	General	11,300	9,400	3,200	1,900	100	0.3	--	--
LRH	Corps	Paint Creek Lake	General	145,000	136,100	20,300	8,900	1,040	4.0	--	--
LRH	Corps	Paintsville Lake	General	73,500	32,750	40,750	40,750	3,129	6.0	H	Y
LRH	Corps	Piedmont Lake	General	66,700	32,200	36,300	34,500	--	--	--	--

District	Owner	Project Name	Water Management Survey (Sec. 3)					Water Supply Survey and Database (Sec. 2)			
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LRH	Corps	Pleasant Hill Lake	General	88,700	75,200	13,500	13,500	--	--	--	--
LRH	Corps	R.D. Bailey Lake	General	203,700	181,700	34,200	22,000	--	--	--	Y
LRH	Corps	Senecaville Lake	General	88,500	45,100	43,400	43,400	--	--	--	--
LRH	Corps	Summersville Lake	General	413,400	355,500	191,500	57,900	468	4.0	--	--
LRH	Corps	Sutton Lake	General	265,300	264,900	59,700	400	--	--	--	--
LRH	Corps	Tappan Lake	General	61,600	26,500	35,100	35,100	--	--	--	--
LRH	Corps	Tom Jenkins Lake	General	26,900	23,400	3,500	3,500	5,690	8.0	--	--
LRH	Corps	Wills Creek Lake	General	196,000	190,000	6,000	6,000	--	--	--	--
LRH	Corps	Yatesville Lake	General	83,300	78,100	38,100	5,200	--	--	H	--
LRL	Corps	Barren River Lake	General	815,150	749,030	256,400	66,120	1,050	18.0	H	Y
LRL	Corps	Brookville Lake	General	359,600	214,700	184,000	144,900	89,300	82.5	--	--
LRL	Corps	Buckhorn Lake	General	162,570	155,909	26,722	6,661	--	--	--	--
LRL	Corps	Caesar Creek Lake	General	242,200	148,500	102,000	93,700	39,100	37.0	--	--
LRL	Corps	Cagles Mill Lake	General	224,246	197,134	29,264	27,112	--	--	--	--
LRL	Corps	Carr Creek Lake	General	45,898	30,664	21,677	15,234	2,052	2.0	P	--
LRL	Corps	Cave Run Lake	General	614,100	438,500	222,600	175,600	802	3.0	H	--
LRL	Corps	Cecil M. Harden Lake	General	132,800	116,600	51,347	16,200	--	--	--	--
LRL	Corps	Clarence J. Brown Dam & Reservoir	General	63,700	32,900	36,900	30,800	--	--	--	--
LRL	Corps	Green River Lake	General	723,200	532,925	244,100	190,275	4,315	7.5	H	--
LRL	Corps	Huntington Lake	General	169,872	165,772	12,500	4,100	--	--	--	--
LRL	Corps	Lock & Dam #3	--	--	--	--	--	--	--	H	--
LRL	Corps	Mississinewa Lake	General	368,400	345,100	75,200	23,300	--	--	--	--
LRL	Corps	Monroe Lake	General	441,000	258,800	182,200	182,200	160,000	130.0	P	--
LRL	Corps	Nolin Lake	General	609,400	545,560	170,200	63,840	98	1.0	P	--
LRL	Corps	Patoka Lake	General	298,380	153,150	178,730	145,230	129,658	75.0	P	--
LRL	Corps	Rough River Lake	General	334,380	304,580	120,000	29,800	522	4.1	P	--
LRL	Corps	Salamonie Lake	General	263,600	250,500	60,700	13,100	--	--	--	--
LRL	Corps	Taylorsville Lake	General	291,670	211,230	86,420	80,440	--	--	--	--

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LRL	Corps	West Fork of Mill Creek Lake	General	10,721	9,806	915	915	--	--	--	--
LRL	Corps	William H. Harsha Lake	General	284,470	202,270	90,400	82,200	35,534	37.0	P	--
LRN	Corps	Barkley Dam and Lake Barkley	General (ROR)	2,081,900	1,471,800	868,900	610,100	--	--	--	--
LRN	Corps	Center Hill Lake	General	2,092,000	762,000	1,330,000	1,330,000	7,880	23.6	P	--
LRN	Corps	Cheatham Lock & Dam	-- (ROR)	--	--	--	--	--	--	--	--
LRN	Corps	Cordell Hull Lock & Dam	-- (ROR)	--	--	--	--	--	--	--	--
LRN	Corps	Dale Hollow Lake	General	1,706,000	353,000	1,353,000	1,353,000	2,211	2.2	P	--
LRN	Corps	J. Percy Priest Dam and Resrvoir	General	651,500	349,500	399,000	302,000	17,311	63.3	P	Y
LRN	Corps	Laurel River Lake	General	--	--	--	--	1,105	4.3	--	--
LRN	Corps	Martins Fork Lake	General	21,120	17,446	6,758	3,674	--	--	--	--
LRN	Corps	Old Hickory Lock & Dam	-- (ROR)	--	--	--	--	--	--	--	--
LRN	Corps	Wolf Creek Dam - Lake Cumberland	General	6,089,000	2,094,000	3,995,000	3,995,000	--	--	P	Y
LRP	Corps	Berlin Lake	General	86,300	48,000	55,100	38,300	6,260	15.0	--	--
LRP	Corps	Conemaugh River Lake	General	262,700	257,560	5,140	5,140	--	--	--	--
LRP	Corps	Crooked Creek Lake	General	91,100	88,400	2,700	2,700	--	--	--	--
LRP	Corps	East Branch Clarion River Lake	General	84,300	65,300	65,300	19,000	--	--	P	--
LRP	Corps	Kinzua Dam and Allegheny Reservoir	General	1,180,000	834,500	572,606	345,500	--	--	--	--
LRP	Corps	Loyalhanna Lake	General	95,300	94,751	549	549	--	--	--	--
LRP	Corps	Mahoning Creek Lake	General	74,200	9,500	69,700	64,700	--	--	--	--
LRP	Corps	Michael J. Kirwan Dam and Reservoir	General	78,700	56,700	52,900	22,000	--	--	--	--
LRP	Corps	Mosquito Creek Lake	General	97,660	75,960	76,300	21,700	11,000	16.0	--	--
LRP	Corps	Shenango River Lake	General	191,360	41,000	180,280	150,360	--	--	--	--
LRP	Corps	Stonewall Jackson Lake	General	74,650	48,170	48,170	26,480	2,200	3.6	--	--
LRP	Corps	Tionesta Lake	General	128,700	120,900	7,800	7,800	--	--	--	--
LRP	Corps	Tygart River Lake	General	287,700	187,800	278,000	99,900	2,240	1.9	--	--
LRP	Corps	Union City Dam	Dry Dam	47,650	47,650	--	--	--	--	--	--
LRP	Corps	Woodcock Creek Lake	General	19,990	16,020	18,640	3,970	--	--	--	--
LRP	Corps	Youghiogheny River Lake	General	254,000	154,500	151,000	99,500	2,950	5.0	--	--

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MVK	Corps	Arkabutla Lake	General	493,800	462,300	122,400	31,500	--	--	P	--
MVK	Corps	Blakely Mountain Dam - Lake Ouachita	General	2,770,174	617,400	2,152,774	2,152,774	1,575	1.0	H	Y
MVK	Corps	Bodcau Lake	General	967,900	967,777	123	123	--	--	--	--
MVK	Corps	DeGray Lake	General	881,900	227,200	654,700	654,700	238,729	152.0	--	--
MVK	Corps	Enid Lake	General	602,400	544,800	270,000	57,600	4,500	10.9	P	--
MVK	Corps	Grenada Lake	General	1,251,700	1,166,000	549,223	85,700	--	--	P	--
MVK	Corps	Narrows Dam - Lake Geeson	General	407,910	128,180	279,730	279,730	--	--	P	--
MVK	Corps	Sardis Dam	General	1,461,900	1,353,900	308,800	108,000	--	--	P	--
MVK	Corps	Wallace Lake	General	96,100	92,160	7,800	3,940	--	--	--	--
MVP	Corps	Big Stone Lake - Whetstone River	General	30,500	27,950	10,800	2,550	--	--	--	--
MVP	Corps	Eau Galle River Lake	General	43,580	42,044	1,536	1,536	--	--	--	--
MVP	Corps	Gull Lake Dam	General	71,000	26,000	61,000	45,000	--	--	--	--
MVP	Corps	Homme Lake and Dam	General	2,847	2,175	2,847	672	--	--	--	--
MVP	Corps	Lac Qui Parle Lakes	General	162,300	109,250	60,550	53,050	--	--	--	--
MVP	Corps	Lake Ashtabula - Baldhill Dam	General	101,300	70,300	70,600	31,000	--	--	--	--
MVP	Corps	Lake Traverse - Reservation Control D.	General	165,000	75,000	106,000	90,000	--	--	--	--
MVP	Corps	Lake Traverse - White Rock Dam	General	85,000	78,500	6,500	6,500	--	--	--	--
MVP	Corps	Leech Lake Dam	General	1,043,000	689,000	609,000	354,000	--	--	--	--
MVP	Corps	Orwell Lake	General	17,750	16,550	8,300	1,200	--	--	--	--
MVP	Corps	Pine River Dam - Cross Lake	General	188,000	138,900	105,000	49,100	--	--	--	--
MVP	Corps	Pokegama Dam	General	158,000	103,000	102,000	55,000	--	--	--	--
MVP	Corps	Red Lake River	General	2,690,000	1,020,000	1,810,000	1,670,000	--	--	--	--
MVP	Corps	Sandy Lake Dam	General	118,000	74,000	64,000	44,000	--	--	--	--
MVP	Corps	Winnibigoshish Dam and Lake	General	1,151,000	651,000	716,200	500,000	--	--	--	--
MVR	Corps	Coralville Dam	General	1,054,800	1,039,100	28,100	15,700	--	--	--	--
MVR	Corps	Farmdale Dam	Dry Dam	15,500	15,500	--	--	--	--	--	--
MVR	Corps	Foundulac Dam	Dry Dam	3,780	3,780	--	--	--	--	--	--
MVR	Corps	Red Rock Dam and Lake Red Rock	General	2,366,300	2,177,300	189,000	189,000	--	--	--	--

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MVR	Corps	Saylorville Lake	General	1,525,000	1,451,400	73,600	73,600	14,900	13.3	--	--
MVS	Corps	Carlyle Lake	General	982,900	748,200	283,000	234,700	32,692	24.5	--	--
MVS	Corps	Clarence Cannon Dam - Mark Twain L.	General	1,428,000	1,153,740	274,260	274,260	20,000	16.0	--	--
MVS	Corps	Lake Shelbyville	General	684,000	533,200	210,000	150,800	24,714	17.0	--	--
MVS	Corps	Rend Lake	General	294,000	201,755	92,245	92,245	109,000	70.0	--	--
MVS	Corps	Wappapello Lake	General	582,200	551,100	62,700	31,100	--	--	--	--
NAB	Corps	Almond Lake	General	14,005	12,900	1,105	1,105	--	--	--	--
NAB	Corps	Alvin R. Bush Dam	General	75,000	73,260	1,740	1,740	--	--	--	--
NAB	Corps	Arkport Dam	Dry Dam	7,950	7,950	--	--	--	--	--	--
NAB	Corps	Aylesworth Creek Lake	General	1,764	1,700	64	64	--	--	--	--
NAB	Corps	Cowanesque Lake	General	84,930	52,330	32,600	32,600	25,600	70.0	--	--
NAB	Corps	Curwensville Lake	General	119,625	110,085	9,540	9,540	5,360	50.0	--	--
NAB	Corps	East Sidney Lake	General	33,494	31,794	3,350	1,700	--	--	--	--
NAB	Corps	Foster Joseph Sayers Dam	General	99,000	92,700	28,800	6,300	--	--	P	--
NAB	Non-Fed	George B. Stevenson Dam	General	75,800	73,500	2,300	2,300	--	--	--	--
NAB	Corps	Jennings Randolph Lake	General	130,928	36,221	94,707	94,707	40,995	120.0	P	--
NAB	Corps	Raystown Lake	General	762,000	248,000	514,000	514,000	--	--	P	--
NAB	Non-Fed	Savage River Dam	General	19,500	12,499	19,500	7,001	--	--	--	--
NAB	Corps	Stillwater Lake	General	12,000	11,657	343	343	--	--	--	--
NAB	Corps	Tioga-Hammond Lakes	General	62,307	52,362	9,945	9,945	--	--	P	--
NAB	Corps	Whitney Point Lake	General	86,500	81,300	12,740	5,200	--	--	--	--
NAB	Corps	York Indian Rock Dam	Dry Dam	28,000	27,998	2	2	--	--	--	--
NAE	Corps	Ball Mountain Lake	General (ROR)	54,690	54,450	2,240	240	--	--	--	--
NAE	Corps	Barre Falls Dam	General	24,000	24,000	490	--	--	--	--	--
NAE	Corps	Birch Hill Dam	Dry Dam	49,900	49,900	--	--	--	--	--	--
NAE	Corps	Black Rock Lake	General (ROR)	8,755	8,451	304	304	--	--	--	--
NAE	Corps	Blackwater Dam	Dry Dam	46,000	46,000	--	--	--	--	--	--
NAE	Corps	Buffumville Lake	General (ROR)	11,480	9,840	1,640	1,640	--	--	--	--

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NAE	Corps	Colebrook Lake	General	97,700	50,230	47,470	47,470	50,200	116.3	--	--
NAE	Corps	Conant Brook Dam	Dry Dam	3,740	3,740	--	--	--	--	--	--
NAE	Corps	East Brimfield Lake	General	32,220	29,782	2,438	2,438	--	--	--	--
NAE	Corps	Edward Macdowell Lake	General (ROR)	12,950	12,800	150	150	--	--	--	--
NAE	Corps	Everett Lake	General (ROR)	92,500	91,500	1,200	1,000	--	--	--	--
NAE	Corps	Franklin Falls Dam	General	150,600	147,792	2,808	2,808	--	--	--	--
NAE	Corps	Hancock Brook Lake	General (ROR)	4,030	3,855	175	175	--	--	--	--
NAE	Corps	Hodges Village Dam	Dry Dam	13,250	13,250	--	--	--	--	--	--
NAE	Corps	Hop Brook Lake	General (ROR)	6,970	6,850	120	120	--	--	--	--
NAE	Corps	Hopkinton Lake	General (ROR)	70,800	70,100	1,360	700	--	--	--	--
NAE	Corps	Knightville Dam	General	49,000	49,000	870	--	--	--	--	--
NAE	Corps	Littleville Lake	General	32,400	23,000	9,400	9,400	9,400	17.5	--	--
NAE	Corps	Mansfield Hollow Lake	General (ROR)	49,650	47,935	3,450	1,715	--	--	--	--
NAE	Corps	North Hartland Lake	General (ROR)	71,100	68,750	2,350	2,350	--	--	--	--
NAE	Corps	North Springfield Lake	General (ROR)	50,500	49,893	607	607	--	--	--	--
NAE	Corps	Northfield Brook Lake	General (ROR)	2,430	2,321	109	109	--	--	--	--
NAE	Corps	Otter Brook Lake	General (ROR)	18,320	17,450	870	870	--	--	--	--
NAE	Corps	Surry Mountain Lake	General (ROR)	33,011	31,696	1,874	1,315	--	--	--	--
NAE	Corps	Thomaston Dam	Dry Dam	42,000	42,000	--	--	--	--	--	--
NAE	Corps	Townshend Lake	General (ROR)	33,700	32,164	1,536	1,536	--	--	--	--
NAE	Corps	Tully Lake	General (ROR)	22,025	21,500	1,500	525	--	--	--	--
NAE	Corps	Union Village Dam	General	38,000	38,000	650	--	--	--	--	--
NAE	Corps	West Hill Dam	Dry Dam	12,440	12,440	--	--	--	--	--	--
NAE	Corps	West Thompson Lake	General (ROR)	26,800	25,200	1,600	1,600	--	--	--	--
NAE	Corps	Westville Lake	General (ROR)	11,100	10,900	200	200	--	--	--	--
NAO	Corps	Gathright Dam and Lake Moomaw	General	421,520	297,781	123,739	123,739	--	--	P	--
NAP	Corps	Beltzville Lake	General	68,254	27,031	41,223	41,223	27,880	42.0	--	--
NAP	Corps	Blue Marsh Lake	General	50,006	32,383	22,897	17,623	8,000	35.5	P	--

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NAP	Corps	Francis E. Walter Reservoir	General	109,608	107,815	1,793	1,793	--	--	P	--
NAP	Corps	General Edgar Jadwin Dam & Reserv.	Dry Dam	24,500	24,500	--	--	--	--	--	--
NAP	Corps	Prompton Reservoir	General	52,000	48,500	3,500	3,500	--	--	P	--
NWD-CR	Corps	Bonneville Lock & Dam	-- (ROR)	--	--	--	--	--	--	--	--
NWD-CR	Non-Fed	Brownlee Dam and Lake	General	1,420,062	975,362	975,318	444,700	--	--	--	--
NWD-CR	USBR	Grand Coulee	Big River	9,107,422	5,185,455	5,185,455	3,921,967	--	--	--	--
NWD-CR	USBR	Hungry Horse Dam and Lake	General	3,586,783	3,100,783	3,161,000	486,000	--	--	--	--
NWD-CR	Corps	John Day Lock and Dam - L. Umatilla	Big River	2,523,900	534,000	2,523,900	1,989,900	--	--	--	--
NWD-CR	Corps	Kerr Dam and Flathead Lake	General	1,917,600	1,344,800	1,219,000	572,800	--	--	--	--
NWD-MR	Corps	Big Bend Dam - Lake Sharpe	Big River	1,798,000	177,000	1,738,000	1,621,000	--	--	M	Y
NWD-MR	Corps	Fort Peck Dam - Fort Peck Lake	Big River	18,463,000	3,675,000	17,492,000	14,788,000	--	--	M	Y
NWD-MR	Corps	Fort Randall Dam - Lake Francis Case	Big River	5,418,000	2,294,000	4,433,000	3,124,000	--	--	M	Y
NWD-MR	Corps	Garrison Dam - Lake Sakakawea	Big River	23,821,000	5,711,000	22,332,000	18,110,000	54,390	18.8	H	Y
NWD-MR	Corps	Gavins Point Dam - Lewis and Clark L.	Big River	470,000	149,000	411,000	321,000	--	--	M	Y
NWD-MR	Corps	Oahe Dam - Lake Oahe	Big River	23,137,000	4,303,000	22,035,000	18,834,000	--	--	M	Y
NWK	Corps	Blue Springs Lake	General	26,557	15,715	10,842	10,842	--	--	--	--
NWK	USBR	Bonny Dam and Reservoir	General	170,160	128,820	41,340	41,340	--	--	--	--
NWK	USBR	Cedar Bluff Dam and Reservoir	General	364,342	191,890	172,452	172,452	--	--	--	--
NWK	Corps	Clinton Lake	General	394,117	268,783	139,060	125,334	89,200	17.4	--	--
NWK	USBR	Enders Dam and Reservoir	General	72,958	30,048	42,910	42,910	--	--	--	--
NWK	Corps	Harlan County Lake	General	814,111	500,000	314,111	314,111	--	--	--	--
NWK	Corps	Harry S. Truman Dam and Reservoir	General	5,187,032	4,005,392	1,181,640	1,181,640	283	0.7	M	--
NWK	USBR	Harry Strunk Lake - Medicine Creek Dam	General	87,361	52,714	34,647	34,647	--	--	--	--
NWK	Corps	Hillsdale Lake	General	159,840	92,343	80,465	67,497	53,000	5.2	--	--
NWK	USBR	Hugh Butler Lake - Red Willow Dam	General	85,070	48,846	36,224	36,224	--	--	--	--
NWK	Corps	Kanopolis Lake	General	418,752	369,278	67,751	49,474	12,500	12.9	--	--
NWK	USBR	Kirwin Dam and Reservoir	General	313,290	215,136	108,909	98,154	--	--	--	--
NWK	Corps	Long Branch Lake	General	64,516	37,127	34,189	27,389	24,400	7.1	M	--

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NWK	Corps	Longview Lake	General	46,944	24,810	22,134	22,134	--	--	--	--
NWK	USBR	Lovewell Dam and Reservoir	General	86,131	50,465	38,104	35,666	--	--	--	--
NWK	Corps	Melvern Lake	General	360,258	221,591	161,941	138,667	50,000	7.2	--	--
NWK	Corps	Milford Lake	General	1,145,485	801,382	426,545	344,103	300,000	111.0	--	--
NWK	USBR	Norton Dam - Keith Sebelius Lake	General	133,740	99,230	39,472	34,510	--	--	--	--
NWK	Corps	Perry Lake	General	722,079	535,569	231,474	186,510	150,000	74.6	--	--
NWK	Corps	Pomme De Terre Lake	General	644,177	406,821	257,461	237,356	--	--	--	--
NWK	Corps	Pomona Lake	General	240,331	183,562	72,237	56,769	33,000	7.4	--	--
NWK	Corps	Rathbun Lake	General	570,553	349,193	238,389	221,360	6,680	2.0	M	--
NWK	Corps	Smithville Lake	General	243,443	115,565	146,700	127,878	95,200	28.8	M	--
NWK	Corps	Stockton Lake	General	1,650,953	776,066	950,792	874,887	50,000	30.0	--	Y
NWK	USBR	Swanson Lake - Trenton Dam	General	246,291	134,077	112,214	112,214	--	--	--	--
NWK	Corps	Tuttle Creek Lake	General	2,150,872	1,905,744	339,308	245,128	50,000	57.8	--	--
NWK	USBR	Waconda Lake(Glen Elder Dam)	General	942,408	722,988	232,233	219,420	--	--	--	--
NWK	USBR	Webster Dam and Lake	General	259,510	183,353	85,318	76,157	--	--	--	--
NWK	Corps	Wilson Lake	General	772,732	539,148	247,075	233,584	--	--	H	--
NWO	Corps	Bear Creek Dam and Lake	General	30,586	28,704	1,882	1,882	--	--	P	Y
NWO	Corps	Bowman-Haley Dam and Lake	General	91,482	72,717	18,765	18,765	15,500	1.9	--	--
NWO	USBR	Boysen	General	892,226	294,861	741,594	597,365	--	--	--	--
NWO	Non-Fed	Bull Hook - Scott Coulee Dams	Dry Dam	6,500	6,500	--	--	--	--	--	--
NWO	USBR	Canyon Ferry	General	1,992,977	895,378	1,891,888	1,097,599	--	--	--	--
NWO	Non-Fed	Cedar Canyon Dam	Dry Dam	136	123	13	13	--	--	--	--
NWO	Corps	Chatfield Dam	General	234,207	214,586	27,428	19,621	--	--	P	Y
NWO	Corps	Cherry Creek Dam and Lake	General	133,134	120,329	12,805	12,805	--	--	P	--
NWO	USBR	Clark Canyon	General	253,442	129,282	174,367	124,160	--	--	--	--
NWO	Corps	Coldbrook Dam and Lake	General	7,200	6,680	520	520	--	--	--	--
NWO	Corps	Cottonwood Springs Dam and Lake	General	8,385	7,730	655	655	--	--	--	--
NWO	USBR	Glendo	General	789,402	271,917	517,485	517,485	--	--	--	--

District	Owner	Project Name	Water Management Survey (Sec. 3)					Water Supply Survey and Database (Sec. 2)			
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NWO	USBR	Heart Butte	General	214,169	147,027	67,142	67,142	--	--	--	--
NWO	USBR	Jamestown	General	220,978	192,621	31,510	28,357	--	--	--	--
NWO	Non-Fed	Kelly Road Dam	Dry Dam	360	360	--	--	--	--	--	--
NWO	USBR	Keyhole	General	334,215	140,462	193,753	193,753	--	--	--	--
NWO	USBR	Pactola	General	99,029	43,057	55,972	55,972	--	--	--	--
NWO	Corps	Pappillion Creek Dam #11	General	16,907	13,853	3,054	3,054	--	--	--	--
NWO	Corps	Pappillion Creek Dam #16	General	4,782	3,571	1,211	1,211	--	--	--	--
NWO	Corps	Pappillion Creek Dam #18	General	10,512	7,596	2,916	2,916	--	--	--	--
NWO	Corps	Pappillion Creek Dam #20	General	8,611	6,042	2,569	2,569	--	--	--	--
NWO	Corps	Pipestem Dam and Lake	General	142,107	133,163	8,944	8,944	--	--	P	--
NWO	Corps	Salt Creek Dam #10	General	7,468	5,839	1,629	1,629	--	--	--	--
NWO	Corps	Salt Creek Dam #12	General	9,415	7,607	1,808	1,808	--	--	--	--
NWO	Corps	Salt Creek Dam #13	General	7,182	5,021	2,161	2,161	--	--	--	--
NWO	Corps	Salt Creek Dam #14	General	27,597	20,097	7,500	7,500	--	--	--	--
NWO	Corps	Salt Creek Dam #17	General	6,628	5,845	783	783	--	--	--	--
NWO	Corps	Salt Creek Dam #18	General	96,759	71,671	25,088	25,088	--	--	--	--
NWO	Corps	Salt Creek Dam #2	General	4,957	3,857	1,100	1,100	--	--	--	--
NWO	Corps	Salt Creek Dam #4	General	9,660	7,129	2,531	2,531	--	--	--	--
NWO	Corps	Salt Creek Dam #8	General	8,375	6,595	1,780	1,780	--	--	--	--
NWO	Corps	Salt Creek Dam #9	General	5,864	4,413	1,451	1,451	--	--	--	--
NWO	USBR	Shadehill	General	350,176	230,004	120,172	120,172	--	--	--	--
NWO	USBR	Tiber	General	1,328,723	661,510	925,649	667,213	--	--	--	--
NWO	Non-Fed	Westerly Creek	Dry Dam	4,150	4,150	--	--	--	--	--	--
NWO	USBR	Yellowtail	General	1,328,360	498,673	1,070,029	829,687	--	--	--	--
NWP	Corps	Applegate Lake	General	83,300	78,150	76,200	5,150	--	--	--	--
NWP	Corps	Big Cliff Dam	--	--	--	--	--	--	--	H	Y
NWP	Corps	Blue River Lake	General	89,520	85,520	83,000	4,000	--	--	H	Y
NWP	Corps	Cottage Grove Lake	General	32,900	29,800	31,800	3,100	--	--	H	Y

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NWP	Corps	Cougar Lake	General	200,000	147,800	189,000	52,200	--	--	H	Y
NWP	Corps	The Dalles Lock & Dam	-- (ROR)	--	--	--	--	--	--	--	--
NWP	Corps	Detroit Lake	General	472,600	318,200	436,000	154,400	--	--	H	Y
NWP	Corps	Dexter Dam and Reservoir	--	--	--	--	--	--	--	H	Y
NWP	Corps	Dorena Lake	General	77,500	70,400	72,100	7,100	--	--	H	Y
NWP	USBR	Emigrant Lake	General	46,700	26,170	40,530	20,530	--	--	--	--
NWP	Corps	Fall Creek Lake	General	125,000	115,400	117,800	9,600	--	--	H	Y
NWP	Corps	Fern Ridge Lake OR	General	111,400	108,600	97,320	2,800	--	--	H	Y
NWP	Corps	Foster Dam	General	60,800	29,700	55,900	31,100	--	--	H	Y
NWP	Non-Fed	Galesville Lake	General	41,870	20,940	41,870	20,930	--	--	--	--
NWP	Corps	Green Peter Lake	General	428,000	268,000	410,000	160,000	--	--	H	Y
NWP	Corps	Hills Creek Lake	General	356,000	200,600	350,000	155,400	--	--	H	Y
NWP	Corps	Lookout Point Lake	General	455,800	337,000	443,000	118,800	--	--	H	Y
NWP	Corps	Lost Creek Lake	General	465,000	315,000	465,000	150,000	10,000	16.7	L	--
NWP	Non-Fed	Mayfield Lake	General	133,700	21,400	133,700	112,300	--	--	--	--
NWP	Non-Fed	Mossyrock Dam	General	1,696,000	370,000	1,686,000	1,326,000	--	--	--	--
NWP	Corps	Mt. Saint Helens Sediment Retention Struct.	--	--	--	--	--	--	--	--	--
NWP	USBR	Ochoco Lake	General	54,000	52,480	32,220	1,520	--	--	--	--
NWP	USBR	Prineville Lake	General	233,100	231,210	94,790	1,890	--	--	--	--
NWP	USBR	Scoggins Dam	General	56,230	23,230	53,600	33,000	--	--	--	--
NWP	Corps	Willamette Falls Locks	-- (ROR)	--	--	--	--	--	--	--	--
NWP	Corps	Willow Creek Lake	General	14,091	11,542	6,249	2,549	--	--	P	--
NWS	Corps	Albeni Falls Dam	General	1,561,000	1,042,400	1,561,000	518,600	--	--	--	--
NWS	Corps	Chief Joseph Dam - Rufus Woods Lake	-- (ROR)	--	--	--	--	--	--	--	--
NWS	Corps	Howard A. Hanson Dam	General	105,650	104,430	30,395	1,220	20,000	33.6	--	--
NWS	Corps	Libby Dam - Lake Koocanusa	General	5,869,392	4,980,000	4,469,390	889,392	--	--	--	--
NWS	Corps	Mud Mountain Dam	Dry Dam	106,275	106,275	--	--	--	--	--	--
NWS	Non-Fed	Ross Dam	General	1,434,796	120,000	1,434,796	1,314,796	--	--	--	--

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NWS	Non-Fed	Upper Baker	General	285,625	74,003	269,607	211,622	--	--	--	--
NWS	Non-Fed	Wynoochee Dam	General	69,405	36,951	45,443	32,454	--	--	--	--
NWW	USBR	Agency Valley Dam	General	59,900	59,900	59,900	--	--	--	--	--
NWW	USBR	Anderson Ranch	General	493,182	452,182	493,182	41,000	--	--	--	--
NWW	USBR	Arrowrock	General	286,600	286,337	286,600	263	--	--	--	--
NWW	USBR	Bully Creek Dam	General	31,650	30,000	31,650	1,650	--	--	--	--
NWW	Corps	Dworshak Dam and Reservoir	General	3,468,000	2,016,000	3,468,000	1,452,000	--	--	--	--
NWW	Corps	Ice Harbor Lock & Dam	-- (ROR)	--	--	--	--	--	--	--	--
NWW	USBR	Jackson Lake Dam	General	2,847,000	847,000	2,847,000	2,000,000	--	--	--	--
NWW	Corps	Little Goose Lock & Dam	-- (ROR)	--	--	--	--	--	--	--	--
NWW	USBR	Little Wood	General	30,000	30,000	30,000	--	--	--	--	--
NWW	Corps	Lower Granite Lock & Dam	-- (ROR)	--	--	--	--	--	--	--	--
NWW	Corps	Lower Monumental Lock & Dam	-- (ROR)	--	--	--	--	--	--	--	--
NWW	Corps	Lucky Peak Reservoir and Dam	General	307,043	278,276	307,043	28,767	--	--	--	--
NWW	USBR	Mason Dam	General	95,500	90,500	78,500	5,000	--	--	--	--
NWW	Corps	McNary Lock & Dam	-- (ROR)	--	--	--	--	--	--	--	--
NWW	Corps	Mill Creek Flood Control Project	General	9,437	9,337	100	100	--	--	--	--
NWW	USBR	Palisades Dam	General	1,401,000	1,200,000	1,401,000	201,000	--	--	--	--
NWW	USBR	Ririe Dam	General	100,541	90,541	90,541	10,000	--	--	--	--
NWW	USBR	Warm Springs Dam	General	169,700	168,300	82,800	1,400	--	--	--	--
POA	Corps	Chena River Lakes	Dry Dam	200,000	200,000	--	--	--	--	--	--
SAJ	Non-Fed	Cerrillos Dam and Reservoir	General	46,810	15,975	30,835	30,835	--	--	--	--
SAM	Corps	Allatoona Lake	General	670,047	467,278	367,471	202,769	19,511	21.4	M	--
SAM	Corps	Buford Dam - Lake Sidney Lanier	General	3,850,000	1,933,000	1,955,200	1,917,000	--	--	M	--
SAM	Corps	Carters Dam and Lake	General	472,756	95,683	383,565	377,073	818	2.0	M	--
SAM	Corps	Okatibbee Lake	General	142,350	113,190	46,060	29,160	13,100	25.0	P	--
SAM	Corps	West Point Dam and Lake	General	774,800	332,512	604,500	442,288	--	--	M	--
SAS	Corps	Hartwell Dam and Lake	General	2,842,700	508,900	2,549,600	2,333,800	26,574	37.8	M	Y

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SAS	Corps	J. Strom Thurmond Dam and Lake	General	2,900,000	670,000	2,510,000	2,230,000	3,833	12.2	P	--
SAS	Corps	Richard B. Russell Dam and Lake	General	1,166,166	139,922	1,026,244	1,026,244	872	15.9	P	--
SAW	Corps	B. Everett Jordan Dam and Lake	General	1,646,560	1,431,430	215,130	215,130	45,800	100.0	L	--
SAW	Corps	Falls Lake	General	1,020,980	895,040	125,940	125,940	45,000	66.0	P	Y
SAW	Corps	John H. Kerr Dam and Reservoir	General	3,364,500	2,086,600	1,590,700	1,277,900	21,115	41.0	P	--
SAW	Corps	Philpott Lake VA	General	318,300	159,265	164,745	159,035	--	--	P	--
SAW	Corps	W. Kerr Scott Dam and Reservoir	General	306,000	265,000	41,000	41,000	33,000	150.0	P	--
SPA	Corps	Abiquiu Dam	General	1,192,800	1,008,919	183,881	183,881	178,000	--	--	--
SPA	USBR	Brantley Dam and Reservoir	General	1,008,219	846,887	161,332	161,332	--	--	--	--
SPA	Corps	Cochiti Lake	General	582,019	532,019	50,000	50,000	--	--	--	--
SPA	Corps	Conchas Lake	General	513,903	198,168	315,735	315,735	--	--	--	--
SPA	Corps	Galisteo Dam	Dry Dam	89,468	89,468	--	--	--	--	--	--
SPA	Corps	Jemez Canyon Dam	Dry Dam	97,425	97,425	--	--	--	--	--	--
SPA	Corps	John Martin Reservoir	General	793,400	459,488	333,912	333,912	--	--	--	--
SPA	USBR	Navajo Dam	General	1,701,300	1,039,500	1,701,300	661,800	--	--	--	--
SPA	USBR	Platoro Dam	General	59,571	59,571	53,571	--	--	--	--	--
SPA	USBR	Pueblo Dam and Reservoir	General	527,626	270,677	322,949	256,949	--	--	--	--
SPA	Corps	Santa Rosa Dam and Lake	General	438,364	179,288	259,076	259,076	--	--	--	--
SPA	USBR	Sumner Dam and Reservoir	General	227,683	183,915	43,768	43,768	--	--	--	--
SPA	Corps	Trinidad Lake	General	180,000	108,976	71,024	71,024	--	--	--	--
SPA	Corps	Two Rivers Dam	Dry Dam	163,775	163,775	--	--	--	--	--	--
SPK	Corps	Bear Dam	Dry Dam	7,700	7,700	--	--	--	--	--	--
SPK	Non-Fed	Big Dry Creek Dam	Dry Dam	33,300	33,100	200	200	--	--	--	--
SPK	Corps	Black Butte Lake	General	136,200	129,560	136,200	6,640	--	--	--	--
SPK	USBR	Blue Mesa Dam	General	940,800	748,500	780,000	192,300	--	--	--	--
SPK	USBR	Boca Dam	General	41,100	8,000	41,100	33,100	--	--	--	--
SPK	Corps	Buchanan Dam - H.V. Eastman Lake	General	150,000	45,000	150,000	105,000	--	--	--	--
SPK	Corps	Burns Dam	Dry Dam	6,700	6,700	--	--	--	--	--	--

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SPK	Non-Fed	Camanche Dam	General	430,900	200,000	430,900	230,900	--	--	--	--
SPK	Non-Fed	Don Pedro Dam	General	2,030,000	340,000	2,030,000	1,690,000	--	--	--	--
SPK	USBR	East Canyon Dam	General	51,200	48,000	51,200	3,200	--	--	--	--
SPK	USBR	Echo Dam	General	73,942	73,942	73,942	--	--	--	--	--
SPK	Corps	Farmington Dam	Dry Dam	52,000	52,000	--	--	--	--	--	--
SPK	USBR	Folsom Dam	General	977,000	400,000	977,000	577,000	--	--	--	--
SPK	USBR	Friant Dam	General	520,500	520,500	520,500	--	--	--	--	--
SPK	Corps	Hidden Dam - Hensley Lake	General	90,000	65,000	90,000	25,000	--	--	--	--
SPK	Non-Fed	Indian Valley Dam	General	300,600	40,000	300,600	260,600	--	--	--	--
SPK	Corps	Isabella Lake	General	568,100	568,100	568,100	--	--	--	--	--
SPK	USBR	Jordanelle Dam	General	321,927	107,912	314,004	214,015	--	--	--	--
SPK	USBR	Lemon Dam	General	40,146	39,030	40,146	1,116	--	--	--	--
SPK	Non-Fed	Little Dell Dam	General	20,500	20,500	17,500	--	--	--	--	--
SPK	USBR	Los Banos Dam	General	34,600	14,000	34,600	20,600	--	--	--	--
SPK	USBR	Lost Creek Dam	General	22,510	20,000	22,510	2,510	--	--	--	--
SPK	Corps	Mariposa Dam	Dry Dam	15,000	15,000	--	--	--	--	--	--
SPK	Corps	Martis Creek Lake	General	20,400	19,600	800	800	--	--	--	--
SPK	Non-Fed	Mountain Dell Dam	General	3,200	3,200	2,200	--	--	--	--	--
SPK	Non-Fed	New Bullards Bar Dam	General	966,000	170,000	966,000	796,000	--	--	--	--
SPK	Non-Fed	New Exchequer Dam	General	1,024,600	400,000	1,024,600	624,600	--	--	--	--
SPK	Corps	New Hogan Lake	General	317,100	165,000	317,100	152,100	105,000	10.3	--	--
SPK	USBR	New Melones Dam	General	2,420,000	450,000	2,040,000	1,970,000	--	--	--	--
SPK	Non-Fed	Oroville Dam	General	3,538,000	750,000	3,538,000	2,788,000	--	--	--	--
SPK	Corps	Owens Dam	Dry Dam	3,500	3,500	--	--	--	--	--	--
SPK	USBR	Paonia Dam	General	15,978	15,418	15,978	560	--	--	--	--
SPK	Corps	Pine Flat Lake and Kings River	General	1,000,000	1,000,000	1,000,000	--	--	--	--	--
SPK	USBR	Pineview Dam	General	110,149	110,149	110,149	--	--	--	--	--
SPK	USBR	Prosser Dam	General	29,800	20,000	29,800	9,800	--	--	--	--

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SPK	USBR	Red Fleet Dam	General	26,000	18,000	26,000	8,000	--	--	--	--
SPK	USBR	Ridgway Dam	General	84,410	59,396	84,410	25,014	--	--	--	--
SPK	USBR	Shasta Dam	General	4,552,000	1,300,000	4,552,000	3,252,000	--	--	--	--
SPK	USBR	Stampede Dam	General	226,500	22,500	226,500	204,000	--	--	--	--
SPK	USBR	Starvation Dam	General	167,310	152,330	167,310	14,980	--	--	--	--
SPK	Corps	Success Lake	General	82,300	82,300	82,300	--	--	--	P	--
SPK	Corps	Teminus Dam - Lake Kaweah	General	195,630	195,630	185,630	--	--	--	--	--
SPK	Non-Fed	Tulloch Dam	General	67,000	10,000	67,000	57,000	--	--	--	--
SPK	USBR	Vallecito Dam	General	129,678	116,340	129,678	13,338	--	--	--	--
SPK	USBR	Wanship Dam	General	62,120	62,120	62,120	--	--	--	--	--
SPL	Corps	Alamo Lake	General	995,300	672,923	322,377	322,377	--	--	--	--
SPL	Corps	Brea Dam	Dry Dam	3,888	3,888	--	--	--	--	--	--
SPL	Corps	Carbon Canyon Dam	Dry Dam	6,438	6,438	--	--	--	--	P	--
SPL	Corps	Fullerton Dam	Dry Dam	764	764	--	--	--	--	--	--
SPL	Corps	Hansen Dam	Dry Dam	33,348	33,348	--	--	--	--	P	--
SPL	USBR	Hoover Dam	Big River	27,377,000	5,350,000	25,877,000	22,027,000	--	--	--	--
SPL	Corps	Lopez Dam	Dry Dam	197	197	--	--	--	--	--	--
SPL	Corps	Mathews Canyon Dam	Dry Dam	6,271	6,271	--	--	--	--	--	--
SPL	USBR	Modified Roosevelt Dam	General	3,432,408	1,779,365	1,653,043	1,653,043	--	--	--	--
SPL	Corps	Mojave River Reservoir	Dry Dam	89,669	89,669	--	--	--	--	--	--
SPL	Corps	Painted Rock Dam	Dry Dam	2,336,169	2,336,169	--	--	--	--	--	--
SPL	Corps	Pine Canyon Dam	Dry Dam	7,747	7,747	--	--	--	--	--	--
SPL	Corps	Prado Dam	Dry Dam	187,600	187,600	--	--	--	--	P	--
SPL	Corps	San Antonio Dam	Dry Dam	9,303	9,303	--	--	--	--	--	--
SPL	Corps	Santa Fe Dam	Dry Dam	30,887	30,887	--	--	--	--	P	--
SPL	Corps	Sepulveda Dam	Dry Dam	18,129	18,129	--	--	--	--	--	--
SPL	Non-Fed	Seven Oaks Dam	Dry Dam	147,969	147,969	--	--	--	--	--	--
SPL	BIA	Tat Momolikat	Dry Dam	487,066	487,066	--	--	--	--	--	--

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			Project Classification	Gross Storage (ac-ft)	Flood Storage (ac-ft)	Max. Conservation Storage (ac-ft)	Min. Conservation Storage (ac-ft)	WS Storage (ac-ft)	WS Yield (mgd)	2010 Reallocation Assessment (H / M / L / P)	Recent Reallocation Study (Y)
SPL	USBR	Twitchell Dam	General	391,265	278,817	112,448	112,448	--	--	--	--
SPL	Corps	Whitlow Ranch Dam	Dry Dam	356,178	356,178	--	--	--	--	--	--
SPL	Corps	Whittier Narrows Dam	Dry Dam	30,465	30,465	--	--	--	--	P	--
SPN	Corps	Coyote Valley Dam	General	116,500	48,100	86,400	68,400	70,000	62.0	P	--
SPN	Non-Fed	Del Valle Dam	General	77,000	38,000	40,000	39,000	--	--	--	--
SPN	Corps	Warm Springs Dam-Lake Sonoma	General	381,000	136,000	245,000	245,000	212,000	186.4	--	--
SWF	Corps	Aquilla Lake	General	206,694	162,117	44,577	44,577	33,600	9.7	H	Y
SWF	Corps	Bardwell Lake	General	131,640	85,145	46,495	46,495	42,800	11.2	--	--
SWF	Corps	Belton Lake	General	1,079,348	644,114	435,234	435,234	360,700	101.3	--	--
SWF	Corps	Benbrook Lake	General	255,945	170,313	85,632	85,632	72,500	6.7	--	--
SWF	Corps	Canyon Lake	General	733,602	354,703	378,899	378,899	366,400	89.8	--	--
SWF	Corps	Cooper Lake	General	428,570	129,687	298,883	298,883	273,000	105.9	--	--
SWF	Corps	Ferrell's Bridge Dam - Lake O'The Pines	General	828,241	586,870	269,946	241,371	250,000	155.0	P	--
SWF	Corps	Granger Dam and Lake	General	231,022	178,494	52,528	52,528	37,900	16.2	P	Y
SWF	Corps	Grapevine Lake	General	407,536	242,758	164,778	164,778	161,250	20.7	--	--
SWF	Corps	Hords Creek Lake	General	24,734	16,622	8,112	8,112	5,780	1.1	--	--
SWF	Corps	Joe Pool Lake	General	362,725	185,830	176,895	176,895	142,900	14.2	--	--
SWF	Corps	Lavon Lake	General	649,367	192,841	456,526	456,526	380,000	92.0	P	Y
SWF	Corps	Lewisville Lake	General	886,732	314,806	571,926	571,926	331,000	165.0	--	--
SWF	USBR	Marshall Ford	General	1,951,380	779,792	1,171,588	1,171,588	--	--	--	--
SWF	Corps	Navarro Mills Lake	General	206,185	149,222	56,963	56,963	53,200	15.5	--	--
SWF	Corps	North San Gabriel Dam - Georgetown L.	General	130,737	93,719	37,018	37,018	29,200	10.3	--	--
SWF	Corps	O.C. Fisher Dam and Lake	General	392,686	276,943	115,743	115,743	78,793	3.6	--	--
SWF	Corps	Proctor Lake	General	370,407	314,770	55,637	55,637	31,400	13.9	--	--
SWF	Corps	Ray Roberts Lake	General	1,261,460	461,712	799,748	799,748	799,600	112.5	--	--
SWF	Corps	Sam Rayburn Dam and Reservoir	General	4,305,138	1,442,758	2,862,380	2,862,380	43,000	1,328.7	P	--
SWF	Corps	Somerville Lake	General	495,455	347,447	148,008	148,008	143,900	36.2	--	--
SWF	Corps	Stillhouse Hollow Lake	General	620,757	394,663	226,094	226,094	204,900	63.2	--	--

District	Owner	Project Name	Water Management Survey (Sec. 3)					Water Supply Survey and Database (Sec. 2)			
			Project Classification	Gross Storage (ac-ft)	Flood Storage (ac-ft)	Max. Conservation Storage (ac-ft)	Min. Conservation Storage (ac-ft)	WS Storage (ac-ft)	WS Yield (mgd)	2010 Reallocation Assessment (H / M / L / P)	Recent Reallocation Study (Y)
SWF	Corps	Town Bulff Dam - B.A. Steinhagen Lake	--	--	--	--	--	--	--	--	--
SWF	USBR	Twin Buttes	General	632,212	454,369	177,843	177,843	--	--	--	--
SWF	Corps	Waco Lake	General	735,754	529,986	205,768	205,768	151,626	94.6	--	--
SWF	Corps	Whitney Lake	General	1,926,778	1,372,300	554,478	554,478	50,000	17.6	P	--
SWF	Corps	Wright Patman Dam and Lake	General	2,607,112	2,484,318	305,852	122,794	76,663	50.0	P	Y
SWG	Corps	Addicks Dam	Dry Dam	200,800	200,800	--	--	--	--	--	--
SWG	Corps	Barker Dam	Dry Dam	209,000	209,000	--	--	--	--	--	--
SWL	Corps	Beaver Lake	General	2,182,500	518,300	1,692,800	1,664,200	160,148	132.5	H	Y
SWL	Corps	Blue Mountain Lake	General	653,480	628,840	34,130	24,640	1,550	2.0	--	--
SWL	Corps	Bull Shoals Lake	General	6,013,000	2,965,000	3,186,000	3,048,000	12,613	8.0	H	Y
SWL	Corps	Clearwater Lake	General	911,150	889,230	21,920	21,920	--	--	--	--
SWL	Corps	DeQueen Lake	General	370,600	335,700	34,900	34,900	17,885	22.0	--	--
SWL	Corps	Dierks Lake	General	221,600	191,900	29,700	29,700	10,100	13.3	--	--
SWL	Corps	Gillham Lake	General	283,310	250,280	33,030	33,030	20,600	41.8	--	--
SWL	Corps	Greers Ferry Lake	General	3,313,000	1,388,700	1,956,100	1,924,300	31,308	25.6	H	Y
SWL	Corps	Millwood Lake	General	2,618,750	2,413,780	204,970	204,970	150,000	265.0	P	--
SWL	Corps	Nimrod Lake	General	851,275	822,265	41,020	29,010	143	0.3	--	--
SWL	Corps	Norfork Lake	General	2,108,700	857,500	1,318,200	1,251,200	2,400	3.0	H	--
SWL	Corps	Table Rock	General	4,075,000	1,373,000	2,789,000	2,702,000	--	--	H	--
SWT	USBR	Altus Lake	General	152,430	19,600	132,830	132,830	--	--	--	--
SWT	USBR	Arbuckle Lake	General	108,800	36,400	72,400	72,400	--	--	--	--
SWT	Corps	Arcadia Lake	General	92,020	64,450	27,570	27,570	23,090	11.0	--	--
SWT	Corps	Birch Lake	General	59,030	39,805	19,225	19,225	7,630	3.0	--	--
SWT	Corps	Broken Bow Lake	General	1,368,245	450,155	946,740	918,090	152,440	170.3	P	--
SWT	Corps	Canton Lake	General	377,100	266,000	111,100	111,100	90,000	4.6	--	--
SWT	USBR	Cheney Lake	General	247,930	80,860	167,070	167,070	--	--	--	--
SWT	Corps	Copan Lake	General	221,491	186,857	34,634	34,634	7,500	2.0	--	--
SWT	Corps	Council Grove Lake	General	238,695	190,030	48,665	48,665	32,400	6.7	--	--

District	Owner	Project Name	Water Management Survey (Sec. 3)					Water Supply Survey and Database (Sec. 2)			
			Project Classification	Gross Storage (ac-ft)	Flood Storage (ac-ft)	Max. Conservation Storage (ac-ft)	Min. Conservation Storage (ac-ft)	WS Storage (ac-ft)	WS Yield (mgd)	2010 Reallocation Assessment (H / M / L / P)	Recent Reallocation Study (Y)
SWT	Corps	Denison Dam - Lake Texoma	General	5,061,062	2,689,679	2,668,595	2,371,383	300,001	292.5	--	--
SWT	Corps	El Dorado Lake	General	301,104	144,054	157,050	157,050	142,800	11.0	--	--
SWT	Corps	Elk City Lake	General	284,458	240,954	43,504	43,504	34,300	12.2	--	--
SWT	Corps	Eufaula Lake	General	3,825,400	1,681,085	2,144,315	2,144,315	56,909	51.0	--	--
SWT	Corps	Fall River Lake	General	254,876	232,249	22,627	22,627	--	--	--	--
SWT	USBR	Fort Cobb Lake	General	135,900	62,070	73,830	73,830	--	--	--	--
SWT	Corps	Fort Gibson Lake	General	1,284,400	919,200	365,200	365,200	--	--	--	--
SWT	Corps	Fort Supply Lake	General	100,770	88,531	12,240	12,240	--	--	--	--
SWT	USBR	Foss Lake	General	436,530	258,630	177,900	177,900	--	--	--	--
SWT	Corps	Great Salt Plains Lake	General	241,695	215,584	26,111	26,111	--	--	--	--
SWT	Corps	Heyburn Lake	General	56,303	50,802	5,501	5,501	2,000	1.7	--	--
SWT	Non-Fed	Hudson Lake	General	444,510	244,210	200,300	200,300	--	--	--	--
SWT	Corps	Hugo Lake	General	960,323	819,283	188,535	141,040	47,600	57.6	--	--
SWT	Corps	Hulah Lake	General	285,897	263,332	22,565	22,565	19,800	12.4	--	--
SWT	Corps	John Redmond Dam and Reservoir	General	574,918	524,417	50,501	50,501	44,900	56.2	--	--
SWT	Corps	Kaw Lake	General	1,327,155	961,289	406,540	365,866	171,200	167.1	--	--
SWT	Corps	Keystone Lake	General	1,672,613	1,167,232	505,381	505,381	20,000	14.5	--	--
SWT	Non-Fed	Lake Kemp	General	578,275	332,841	245,434	245,434	--	--	--	--
SWT	USBR	Lake Meredith	General	1,358,594	462,136	896,458	896,458	--	--	--	--
SWT	USBR	Lake Thunderbird	General	196,260	76,660	119,600	119,600	--	--	--	--
SWT	Corps	Marion Lake	General	141,802	61,213	80,589	80,589	50,800	9.2	--	--
SWT	USBR	McGee Creek	General	225,769	111,820	113,949	113,949	--	--	--	--
SWT	Corps	Oologah Lake	General	1,559,279	1,007,060	552,219	552,219	342,600	136.6	P	--
SWT	Corps	Optima Lake	General	382,500	253,500	129,000	129,000	--	--	--	--
SWT	Corps	Pat Mayse Lake	General	182,942	64,833	118,109	118,109	109,600	55.0	P	--
SWT	Corps	Pearson-Skubitz - Big Hill Lake	General	42,564	15,595	26,969	26,969	25,700	8.5	--	--
SWT	Non-Fed	Pensicola Dam / Grand Lake O' The Cheroke	General	2,197,000	525,000	1,672,000	1,672,000	--	--	--	--
SWT	Corps	Pine Creek Lake	General	465,780	412,030	72,860	53,750	28,800	49.0	M	--

District	Owner	Project Name	Water Management Survey (Sec. 3)					Water Supply Survey and Database (Sec. 2)			
			Project Classification	Gross Storage (ac-ft)	Flood Storage (ac-ft)	Max. Conservation Storage (ac-ft)	Min. Conservation Storage (ac-ft)	WS Storage (ac-ft)	WS Yield (mgd)	2010 Reallocation Assessment (H / M / L / P)	Recent Reallocation Study (Y)
SWT	Corps	Sardis Lake	General	468,057	193,724	274,333	274,333	297,200	140.0	--	--
SWT	Corps	Skiatook Lake	General	543,626	220,903	322,723	322,723	62,900	14.5	P	--
SWT	Corps	Tenkiller Ferry Lake	General	1,230,800	576,700	654,100	654,100	25,853	12.2	H	--
SWT	USBR	Tom Steed Lake	General	117,825	20,305	97,520	97,520	--	--	--	--
SWT	Corps	Toronto Lake	General	200,839	179,807	21,032	21,032	400	--	--	--
SWT	Corps	Waurika Lake	General	451,107	260,907	190,200	190,200	151,400	36.2	H	--
SWT	Corps	Wister Lake	General	427,485	366,062	61,423	61,423	13,819	19.5	--	--

Appendix D. Summary of Reservoir Sedimentation Survey, Case Studies and Drought Contingency Plan Reviews

This appendix provides a tabular summary of some of the reservoir sedimentation data gathered in the 2008 survey effort, as discussed in report **Section 5.** The table presents the type of project and gross reservoir storage (see **Section 3**), and the estimated percentage of storage filled by sedimentation, as of the 2008 survey. “NR” indicates that no response was received for estimated sediment depletion at that project. “NS” indicates that there was no record of a survey at the project. It should be noted that a few projects estimated the level of sediment depletion while noting that there were no records of a survey at the project.

As discussed in **Section 5**, impacts to project purposes from sedimentation were reported as either Moderate (MO), Significant (SI), or Severe (SE). A moderate impact indicates that sediment limits project operation for that purpose 10% or more of the time; significant 25% or more of the time, and severe nearly all of the time. A dash indicates either that no restriction was reported or no response was received for that purpose at that project.

The table also indicates which projects were the subjects of the case studies for environmental considerations and future uncertainty, as discussed in report **Sections 4 and 6**.

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District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)								(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage	Storage Filled	Impacts (MO / SI / SE)							Case Studies	DCP Review
				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries	(Y)	(Y)
LRE	Corps	Menasha Lock & Dam - L. Winnebago	General	1,057,586	NR	MO	MO	MO	MO	MO	MO	MO	--	--
LRH	Corps	Alum Creek Lake	General	134,800	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Atwood Lake	General	49,700	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Beach City Lake	General	71,700	>90	SE	--	--	--	--	--	--	Y	Y
LRH	Corps	Beech Fork Lake	General	38,000	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Bluestone Lake	General	631,000	25 - 49	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Bolivar Dam	Dry Dam	149,600	NS	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Burnsville Lake	General	65,900	NR	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Charles Mill Lake	General	88,000	25 - 49	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Clendening Lake	General	54,000	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Deer Creek Lake	General	102,000	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Delaware Lake	General	132,000	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Dewey Lake	General	93,300	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Dillon Lake	General	274,000	25 - 49	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Dover Dam	Dry Dam	203,000	NS	--	--	--	--	--	--	--	Y	Y
LRH	Corps	East Lynn Lake	General	82,500	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Fishtrap Lake	General	164,400	25 - 49	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Grayson Lake	General	119,000	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	John W. Flannagan Lake	General	145,700	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Leesville Lake	General	37,400	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Mohawk Dam	General	285,000	NS	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Mohicanville Dam	Dry Dam	102,000	NS	--	--	--	--	--	--	--	Y	Y
LRH	Corps	North Branch of Kokosing Dam	General	14,900	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	North Fork of Pound Lake	General	11,300	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Paint Creek Lake	General	145,000	<25	--	--	--	--	--	--	--	Y	Y

District	Owner	Project Name	Water Management Survey (Sec. 3)	Sedimentation Survey (Sec. 5)									(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage	Storage Filled	Impacts (MO / SI / SE)							Case Studies	DCP Review
				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries	(Y)	(Y)
LRH	Corps	Paintsville Lake	General	73,500	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Piedmont Lake	General	66,700	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Pleasant Hill Lake	General	88,700	25 - 49	--	--	--	--	--	--	--	Y	Y
LRH	Corps	R.D. Bailey Lake	General	203,700	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Senecaville Lake	General	88,500	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Summersville Lake	General	413,400	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Sutton Lake	General	265,300	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Tappan Lake	General	61,600	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Tom Jenkins Lake	General	26,900	<25	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Wills Creek Lake	General	196,000	75 - 90	--	--	--	--	--	--	--	Y	Y
LRH	Corps	Yatesville Lake	General	83,300	<25	--	--	--	--	--	--	--	Y	Y
LRL	Corps	Barren River Lake	General	815,150	<25	--	--	--	--	--	MO	--	--	--
LRL	Corps	Brookville Lake	General	359,600	<25	--	--	--	--	--	--	--	--	--
LRL	Corps	Buckhorn Lake	General	162,570	<25	--	--	--	--	--	MO	--	--	--
LRL	Corps	Caesar Creek Lake	General	242,200	<25	--	--	--	--	--	--	--	--	--
LRL	Corps	Cagles Mill Lake	General	224,246	<25	--	--	--	--	--	MO	--	--	--
LRL	Corps	Carr Creek Lake	General	45,898	<25	--	--	--	--	--	--	--	--	--
LRL	Corps	Cave Run Lake	General	614,100	<25	--	--	--	--	--	--	--	--	--
LRL	Corps	Cecil M. Harden Lake	General	132,800	<25	--	--	--	--	--	--	--	--	--
LRL	Corps	Clarence J. Brown Dam & Reservoir	General	63,700	<25	--	--	--	--	--	--	--	--	--
LRL	Corps	Green River Lake	General	723,200	<25	--	--	--	--	--	--	--	Y	--
LRL	Corps	Huntington Lake	General	169,872	<25	--	--	--	--	--	--	--	--	--
LRL	Corps	Mississinewa Lake	General	368,400	<25	--	--	--	--	--	MO	--	--	Y
LRL	Corps	Monroe Lake	General	441,000	<25	--	--	--	--	--	MO	--	--	--
LRL	Corps	Nolin Lake	General	609,400	<25	--	--	--	--	--	MO	--	--	--

District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)								(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage	Storage Filled	Impacts (MO / SI / SE)							Case Studies	DCP Review
				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries	(Y)	(Y)
LRL	Corps	Patoka Lake	General	298,380	<25	--	--	--	--	--	--	--	--	--
LRL	Corps	Rough River Lake	General	334,380	<25	--	--	--	MO	--	MO	--	--	--
LRL	Corps	Salamonie Lake	General	263,600	<25	--	--	--	--	--	--	--	--	Y
LRL	Corps	Taylorsville Lake	General	291,670	<25	--	--	--	--	--	MO	--	--	Y
LRL	Corps	West Fork of Mill Creek Lake	General	10,721	<25	--	--	--	--	--	--	--	--	--
LRL	Corps	William H. Harsha Lake	General	284,470	<25	--	--	--	--	--	--	--	--	--
LRN	Corps	Barkley Dam and Lake Barkley	General	2,081,900	<25	--	--	--	--	--	--	MO	--	Y
LRN	Corps	Center Hill Lake	General	2,092,000	<25	--	--	--	--	--	--	--	--	Y
LRN	Corps	Cheatham Lock & Dam	--		<25	--	--	--	--	--	--	MO	--	Y
LRN	Corps	Cordell Hull Lock & Dam	--		<25	--	--	--	--	--	--	--	--	Y
LRN	Corps	Dale Hollow Lake	General	1,706,000	NR	--	--	--	--	--	--	--	--	Y
LRN	Corps	J. Percy Priest Dam and Resrvoir	General	651,500	<25	--	--	--	--	--	--	--	--	Y
LRN	Corps	Laurel River Lake	General		<25	--	--	--	--	--	--	--	--	Y
LRN	Corps	Martins Fork Lake	General	21,120	<25	--	--	--	--	--	MO	MO	--	--
LRN	Corps	Old Hickory Lock & Dam	--		<25	--	--	--	--	--	MO	MO	--	Y
LRN	Corps	Wolf Creek Dam - Lake Cumberland	General	6,089,000	<25	--	--	--	--	--	--	--	--	Y
LRP	Corps	Berlin Lake	General	86,300	<25	--	--	--	--	--	--	--	--	Y
LRP	Corps	Conemaugh River Lake	General	262,700	<25	--	--	--	--	--	--	--	--	--
LRP	Corps	Crooked Creek Lake	General	91,100	<25	--	--	--	--	--	--	--	--	--
LRP	Corps	East Branch Clarion River Lake	General	84,300	<25	--	--	--	--	--	--	--	--	--
LRP	Corps	Kinzua Dam and Allegheny Reservoir	General	1,180,000	<25	--	--	--	--	--	--	--	--	Y
LRP	Corps	Loyalhanna Lake	General	95,300	<25	--	--	--	--	--	--	--	--	--
LRP	Corps	Mahoning Creek Lake	General	74,200	<25	--	--	--	--	--	--	--	--	Y
LRP	Corps	Michael J. Kirwan Dam and Reservoir	General	78,700	<25	--	--	--	--	--	--	--	--	Y
LRP	Corps	Mosquito Creek Lake	General	97,660	<25	--	--	--	--	--	--	--	--	Y

District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)								(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage	Storage Filled	Impacts (MO / SI / SE)							Case Studies	DCP Review
				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries	(Y)	(Y)
LRP	Corps	Shenango River Lake	General	191,360	<25	--	--	--	--	--	--	--	--	Y
LRP	Corps	Stonewall Jackson Lake	General	74,650	<25	--	--	--	--	--	--	--	--	Y
LRP	Corps	Tionesta Lake	General	128,700	<25	--	--	--	--	--	--	--	--	--
LRP	Corps	Tygart River Lake	General	287,700	<25	--	--	--	--	--	--	--	--	Y
LRP	Corps	Union City Dam	Dry Dam	47,650	<25	--	--	--	--	--	--	--	--	--
LRP	Corps	Woodcock Creek Lake	General	19,990	<25	--	--	--	--	--	--	--	--	Y
LRP	Corps	Youghiogheny River Lake	General	254,000	<25	--	--	--	--	--	--	--	--	Y
MVK	Corps	Arkabutla Lake	General	493,800	<25	--	--	--	--	--	--	--	--	--
MVK	Corps	Blakely Mountain Dam - Lake Ouachita	General	2,770,174	NR	--	--	--	--	--	--	--	--	--
MVK	Corps	Bodcau Lake	General	967,900	<25	--	--	--	--	--	--	--	--	--
MVK	Corps	DeGray Lake	General	881,900	<25	--	--	--	--	--	--	--	--	--
MVK	Corps	Enid Lake	General	602,400	<25	--	--	--	--	--	--	--	--	--
MVK	Corps	Grenada Lake	General	1,251,700	<25	--	--	--	--	--	--	--	--	--
MVK	Corps	Narrows Dam - Lake Geeson	General	407,910	<25	--	--	--	--	--	--	--	--	--
MVK	Corps	Sardis Dam	General	1,461,900	<25	--	--	--	--	--	--	--	--	--
MVK	Corps	Wallace Lake	General	96,100	<25	--	--	--	--	--	--	--	--	--
MVP	Corps	Big Stone Lake - Whetstone River	General	30,500	<25	--	--	--	--	--	--	--	--	--
MVP	Corps	Eau Galle River Lake	General	43,580	<25	--	--	--	--	--	--	--	--	--
MVP	Corps	Gull Lake Dam	General	71,000	<25	--	--	--	--	MO	MO	--	--	--
MVP	Corps	Homme Lake and Dam	General	2,847	<25	MO	--	--	MO	--	--	--	--	--
MVP	Corps	Lac Qui Parle Lakes	General	162,300	<25	--	--	--	--	--	--	MO	--	Y
MVP	Corps	Lake Ashtabula - Baldhill Dam	General	101,300	<25	--	--	--	--	--	--	--	--	Y
MVP	Corps	Lake Traverse - Reservation Control D.	General	165,000	<25	--	--	--	--	--	--	--	--	Y
MVP	Corps	Lake Traverse - White Rock Dam	General	85,000	<25	--	--	--	--	--	--	--	--	Y
MVP	Corps	Leech Lake Dam	General	1,043,000	<25	--	--	--	--	MO	MO	--	--	--

District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)									(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage	Storage Filled	Impacts (MO / SI / SE)								Case Studies	DCP Review
				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries		(Y)	(Y)
MVP	Corps	Marsh Lake	--	--	NR	--	--	--	--	--	--	--		--	--
MVP	Corps	Orwell Lake	General	17,750	<25	--	--	--	--	--	--	--		--	--
MVP	Corps	Pine River Dam - Cross Lake	General	188,000	<25	--	--	--	--	--	--	--		--	--
MVP	Corps	Pokegama Dam	General	158,000	<25	--	--	--	--	MO	MO	--		--	--
MVP	Corps	Red Lake River	General	2,690,000	<25	--	--	--	--	--	--	--		--	--
MVP	Corps	Sandy Lake Dam	General	118,000	<25	--	--	--	--	MO	MO	--		--	--
MVP	Corps	Winnibigoshish Dam and Lake	General	1,151,000	<25	--	--	--	--	MO	MO	--		--	--
MVR	Corps	Coralville Dam	General	1,054,800	<25	--	--	--	--	--	--	SI		--	Y
MVR	Corps	Farmdale Dam	Dry Dam	15,500	NR	--	--	--	--	--	--	--		--	--
MVR	Corps	Foundulac Dam	Dry Dam	3,780	NR	--	--	--	--	--	--	--		--	--
MVR	Corps	Red Rock Dam and Lake Red Rock	General	2,366,300	NR	--	--	--	--	--	--	--		--	Y
MVR	Corps	Saylorville Lake	General	1,525,000	NR	--	--	--	--	--	--	--		--	Y
MVS	Corps	Carlyle Lake	General	982,900	<25	--	--	--	--	--	MO	MO		--	Y
MVS	Corps	Clarence Cannon Dam - Mark Twain L.	General	1,428,000	<25	--	--	--	--	--	--	--		--	Y
MVS	Corps	Lake Shelbyville	General	684,000	<25	--	--	--	--	--	MO	MO		--	Y
MVS	Corps	Rend Lake	General	294,000	<25	--	--	--	--	--	MO	MO		--	Y
MVS	Corps	Wappapello Lake	General	582,200	<25	--	--	--	--	--	--	--		--	--
NAB	Corps	Almond Lake	General	14,005	<25	MO	--	--	--	--	MO	--		--	Y
NAB	Corps	Alvin R. Bush Dam	General	75,000	<25	--	--	--	--	--	MO	--		--	Y
NAB	Corps	Arkport Dam	Dry Dam	7,950	<25	--	--	--	--	--	--	--		--	--
NAB	Corps	Aylesworth Creek Lake	General	1,764	<25	--	--	--	--	--	--	--		--	--
NAB	Corps	Cowanesque Lake	General	84,930	<25	--	--	--	MO	--	--	--		--	Y
NAB	Corps	Curwensville Lake	General	119,625	<25	--	--	--	MO	--	MO	--		--	Y
NAB	Corps	East Sidney Lake	General	33,494	<25	--	--	--	--	--	--	--		--	--
NAB	Corps	Foster Joseph Sayers Dam	General	99,000	<25	--	--	--	--	--	MO	--		--	Y

District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)								(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage	Storage Filled	Impacts (MO / SI / SE)							Case Studies	DCP Review
				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries	(Y)	(Y)
NAB	Corps	Jennings Randolph Lake	General	130,928	<25	--	--	--	MO	MO	--	--	--	--
NAB	Corps	Raystown Lake	General	762,000	<25	--	--	--	--	--	--	--	--	Y
NAB	Corps	Stillwater Lake	General	12,000	<25	--	--	--	--	--	--	--	--	Y
NAB	Corps	Tioga-Hammond Lakes	General	62,307	<25	--	--	--	--	--	MO	--	--	Y
NAB	Corps	Whitney Point Lake	General	86,500	<25	--	--	--	--	--	--	--	--	Y
NAB	Corps	York Indian Rock Dam	Dry Dam	28,000	<25	--	--	--	--	--	--	--	--	Y
NAE	Corps	Ball Mountain Lake	General	54,690	<25	--	--	--	--	--	--	--	Y	--
NAE	Corps	Barre Falls Dam	General	24,000	<25	--	--	--	--	--	--	--	Y	--
NAE	Corps	Birch Hill Dam	Dry Dam	49,900	<25	--	--	--	--	--	--	--	Y	--
NAE	Corps	Black Rock Lake	General	8,755	<25	--	--	--	--	--	--	--	--	Y
NAE	Corps	Blackwater Dam	Dry Dam	46,000	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	Buffumville Lake	General	11,480	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	Colebrook Lake	General	97,700	<25	--	--	--	--	--	--	--	Y	--
NAE	Corps	Conant Brook Dam	Dry Dam	3,740	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	East Brimfield Lake	General	32,220	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	Edward Macdowell Lake	General	12,950	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	Everett Lake	General	92,500	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	Franklin Falls Dam	General	150,600	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	Hancock Brook Lake	General	4,030	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	Hodges Village Dam	Dry Dam	13,250	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	Hop Brook Lake	General	6,970	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	Hopkinton Lake	General	70,800	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	Knightville Dam	General	49,000	<25	--	--	--	--	--	--	--	Y	--
NAE	Corps	Littleville Lake	General	32,400	<25	--	--	--	--	--	--	--	Y	--
NAE	Corps	Mansfield Hollow Lake	General	49,650	<25	--	--	--	--	--	--	--	--	Y

District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)								(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage	Storage Filled	Impacts (MO / SI / SE)							Case Studies	DCP Review
				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries	(Y)	(Y)
NAE	Corps	North Hartland Lake	General	71,100	<25	--	--	--	--	--	--	--	Y	--
NAE	Corps	North Springfield Lake	General	50,500	<25	--	--	--	--	--	--	--	Y	--
NAE	Corps	Northfield Brook Lake	General	2,430	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	Otter Brook Lake	General	18,320	<25	--	--	--	--	--	--	--	Y	Y
NAE	Corps	Surry Mountain Lake	General	33,011	<25	--	--	--	--	--	--	--	Y	--
NAE	Corps	Thomaston Dam	Dry Dam	42,000	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	Townshend Lake	General	33,700	<25	--	--	--	--	--	--	--	Y	--
NAE	Corps	Tully Lake	General	22,025	<25	--	--	--	--	--	--	--	Y	--
NAE	Corps	Union Village Dam	General	38,000	<25	--	--	--	--	--	--	--	Y	--
NAE	Corps	West Hill Dam	Dry Dam	12,440	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	West Thompson Lake	General	26,800	<25	--	--	--	--	--	--	--	--	--
NAE	Corps	Westville Lake	General	11,100	<25	--	--	--	--	--	--	--	--	--
NAO	Corps	Gathright Dam and Lake Moomaw	General	421,520	<25	--	--	--	--	--	--	--	--	--
NAP	Corps	Beltzville Lake	General	68,254	<25	--	--	--	--	--	--	--	--	Y
NAP	Corps	Blue Marsh Lake	General	50,006	<25	--	--	--	--	--	--	--	--	Y
NAP	Corps	Francis E. Walter Reservoir	General	109,608	<25	--	--	--	--	--	--	--	--	--
NAP	Corps	General Edgar Jadwin Dam & Reserv.	Dry Dam	24,500	<25	--	--	--	--	--	--	--	--	--
NAP	Corps	Prompton Reservoir	General	52,000	<25	--	--	--	--	--	--	--	--	--
NWD-CR	Corps	Bonneville Lock & Dam	--	--	<25	--	--	--	--	--	--	--	--	--
NWD-CR	Corps	John Day Lock and Dam - L. Umatilla	Big River	2,523,900	<25	--	--	--	--	--	--	--	--	--
NWD-MR	Corps	Big Bend Dam - Lake Sharpe	Big River	1,798,000	<25	--	--	MO	--	--	MO	MO	--	Y
NWD-MR	Corps	Fort Peck Dam - Fort Peck Lake	Big River	18,463,000	NR	--	--	--	--	--	MO	MO	--	Y
NWD-MR	Corps	Fort Randall Dam - Lake Francis Case	Big River	5,418,000	<25	--	--	MO	--	--	MO	MO	--	Y
NWD-MR	Corps	Garrison Dam - Lake Sakakawea	Big River	23,821,000	<25	--	--	--	--	--	MO	--	--	Y
NWD-MR	Corps	Gavins Point Dam - Lewis and Clark L.	Big River	470,000	<25	--	--	--	--	--	MO	MO	--	Y

District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)								(Sections 4 & 6)	(Sec. 6)
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				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries	(Y)	(Y)
NWD-MR	Corps	Oahe Dam - Lake Oahe	Big River	23,137,000	<25	--	--	MO	--	--	MO	--	--	Y
NWK	Corps	Blue Springs Lake	General	26,557	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Clinton Lake	General	394,117	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Harlan County Lake	General	814,111	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Harry S. Truman Dam and Reservoir	General	5,187,032	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Hillsdale Lake	General	159,840	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Kanopolis Lake	General	418,752	<25	--	--	--	--	MO	MO	MO	--	--
NWK	Corps	Long Branch Lake	General	64,516	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Longview Lake	General	46,944	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Melvern Lake	General	360,258	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Milford Lake	General	1,145,485	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Perry Lake	General	722,079	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Pomme De Terre Lake	General	644,177	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Pomona Lake	General	240,331	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Rathbun Lake	General	570,553	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Smithville Lake	General	243,443	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Stockton Lake	General	1,650,953	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Tuttle Creek Lake	General	2,150,872	<25	--	--	--	--	--	--	--	--	--
NWK	Corps	Wilson Lake	General	772,732	<25	--	--	--	--	--	--	--	--	--
NWO	Corps	Bear Creek Dam and Lake	General	30,586	<25	--	--	--	--	--	--	--	--	Y
NWO	Corps	Bowman-Haley Dam and Lake	General	91,482	<25	--	--	--	--	--	--	--	--	Y
NWO	Non-Fed	Bull Hook - Scott Coulee Dams	Dry Dam	6,500	<25	--	--	--	--	--	--	--	--	--
NWO	Non-Fed	Cedar Canyon Dam	Dry Dam	136	<25	--	--	--	--	--	--	--	--	--
NWO	Corps	Chatfield Dam	General	234,207	<25	--	--	--	--	--	--	--	--	Y
NWO	Corps	Cherry Creek Dam and Lake	General	133,134	<25	--	--	--	--	--	--	--	--	Y

District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)								(Sections 4 & 6)	(Sec. 6)
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				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries	(Y)	(Y)
NWO	Corps	Coldbrook Dam and Lake	General	7,200	<25	--	--	--	--	--	--	--	--	--
NWO	Corps	Cottonwood Springs Dam and Lake	General	8,385	<25	--	--	--	--	--	--	--	--	--
NWO	Non-Fed	Kelly Road Dam	Dry Dam	360	<25	--	--	--	--	--	--	--	--	--
NWO	Corps	Pappillion Creek Dam #11	General	16,907	<25	--	--	--	--	MO	MO	MO	--	Y
NWO	Corps	Pappillion Creek Dam #16	General	4,782	<25	--	--	--	--	--	--	--	--	Y
NWO	Corps	Pappillion Creek Dam #18	General	10,512	<25	--	--	--	--	--	--	--	--	Y
NWO	Corps	Pappillion Creek Dam #20	General	8,611	<25	--	--	--	--	--	--	--	--	Y
NWO	Corps	Pipestem Dam and Lake	General	142,107	<25	--	--	--	--	--	--	--	--	Y
NWO	Corps	Salt Creek Dam #10	General	7,468	<25	--	--	--	--	--	MO	MO	--	Y
NWO	Corps	Salt Creek Dam #12	General	9,415	<25	MO	--	--	--	--	MO	MO	--	Y
NWO	Corps	Salt Creek Dam #13	General	7,182	<25	MO	--	--	--	--	MO	MO	--	Y
NWO	Corps	Salt Creek Dam #14	General	27,597	<25	--	--	--	--	--	MO	MO	--	Y
NWO	Corps	Salt Creek Dam #17	General	6,628	<25	--	--	--	--	--	MO	MO	--	Y
NWO	Corps	Salt Creek Dam #18	General	96,759	<25	--	--	--	--	--	MO	MO	--	Y
NWO	Corps	Salt Creek Dam #2	General	4,957	<25	--	--	--	--	--	MO	MO	--	Y
NWO	Corps	Salt Creek Dam #4	General	9,660	<25	MO	--	--	--	--	MO	MO	--	Y
NWO	Corps	Salt Creek Dam #8	General	8,375	<25	--	--	--	--	--	MO	MO	--	Y
NWO	Corps	Salt Creek Dam #9	General	5,864	<25	--	--	--	--	--	MO	MO	--	Y
NWP	Corps	Applegate Lake	General	83,300	<25	MO	--	--	--	--	--	--	--	--
NWP	Corps	Big Cliff Dam	--	--	<25	--	--	--	--	--	--	--	Y	--
NWP	Corps	Blue River Lake	General	89,520	<25	--	--	--	--	--	--	--	Y	--
NWP	Corps	Cottage Grove Lake	General	32,900	<25	--	--	--	--	--	--	--	Y	--
NWP	Corps	Cougar Lake	General	200,000	<25	--	--	--	--	--	--	--	--	--
NWP	Corps	The Dalles Lock & Dam	--	--	<25	--	--	--	--	--	--	--	--	--
NWP	Corps	Detroit Lake	General	472,600	<25	--	--	--	--	--	--	--	Y	--

District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)								(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage	Storage Filled	Impacts (MO / SI / SE)							Case Studies	DCP Review
				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries	(Y)	(Y)
NWP	Corps	Dexter Dam and Reservoir	--	--	<25	--	--	--	--	--	--	--	Y	--
NWP	Corps	Dorena Lake	General	77,500	<25	--	--	--	--	--	--	--	Y	--
NWP	Corps	Fall Creek Lake	General	125,000	<25	--	--	--	--	--	--	--	Y	--
NWP	Corps	Fern Ridge Lake OR	General	111,400	<25	--	--	--	--	--	--	--	Y	--
NWP	Corps	Foster Dam	General	60,800	<25	--	--	--	--	--	--	--	Y	--
NWP	Corps	Green Peter Lake	General	428,000	<25	--	--	--	--	--	--	--	Y	--
NWP	Corps	Hills Creek Lake	General	356,000	<25	--	--	--	--	--	--	--	Y	--
NWP	Corps	Lookout Point Lake	General	455,800	<25	--	--	--	--	--	--	--	Y	--
NWP	Corps	Lost Creek Lake	General	465,000	<25	--	--	--	--	--	--	--	--	--
NWP	Corps	Mt. Saint Helens Sediment Retention Struct.	--	--	50-74	--	--	--	--	--	--	--	--	--
NWP	Corps	Willamette Falls Locks	--	--	<25	--	--	--	--	--	--	--	--	--
NWP	Corps	Willow Creek Lake	General	14,091	<25	--	--	--	--	--	--	--	--	--
NWS	Corps	Albeni Falls Dam	General	1,561,000	<25	--	--	--	--	--	--	--	--	--
NWS	Corps	Chief Joseph Dam - Rufus Woods Lake	--	--	<25	--	--	--	--	--	--	--	--	--
NWS	Corps	Howard A. Hanson Dam	General	105,650	<25	--	--	--	--	MO	--	--	--	--
NWS	Corps	Libby Dam - Lake Koocanusa	General	5,869,392	<25	--	--	--	--	--	--	--	--	--
NWS	Corps	Mud Mountain Dam	Dry Dam	106,275	<25	--	--	--	--	--	--	--	--	--
NWW	Corps	Dworshak Dam and Reservoir	General	3,468,000	<25	--	--	--	--	--	--	--	Y	--
NWW	Corps	Ice Harbor Lock & Dam	--	--	<25	--	MO	--	--	--	--	--	--	--
NWW	Corps	Little Goose Lock & Dam	--	--	<25	--	MO	--	--	--	--	--	--	--
NWW	Corps	Lower Granite Lock & Dam	--	--	<25	--	SI	--	--	--	--	--	--	--
NWW	Corps	Lower Monumental Lock & Dam	--	--	<25	--	MO	--	--	--	--	--	--	--
NWW	Corps	Lucky Peak Reservoir and Dam	General	307,043	<25	--	--	--	--	--	--	--	--	--
NWW	Corps	McNary Lock & Dam	--	--	<25	--	--	--	--	--	--	--	--	--
NWW	Corps	Mill Creek Flood Control Project	General	9,437	<25	--	--	--	--	--	--	--	--	--

District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)								(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage	Storage Filled	Impacts (MO / SI / SE)							Case Studies	DCP Review
				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries	(Y)	(Y)
POA	Corps	Chena River Lakes	Dry Dam	200,000	<25	--	--	--	--	--	--	--	--	--
SAJ	Non-Fed	Cerillos	--	--	NR	--	--	--	--	--	--	--	--	--
SAJ	Non-Fed	Portugues Dam	--	--	NR	--	--	--	--	--	--	--	--	--
SAM	Corps	Allatoona Lake	General	670,047	<25	--	--	--	--	--	--	--	--	Y
SAM	Corps	Buford Dam - Lake Sidney Lanier	General	3,850,000	NR	--	--	--	--	--	--	--	--	Y
SAM	Corps	Carters Dam and Lake	General	472,756	NR	--	--	--	--	--	--	--	--	Y
SAM	Corps	Okatibbee Lake	General	142,350	NR	--	--	--	--	--	--	--	--	Y
SAM	Corps	West Point Dam and Lake	General	774,800	NR	--	--	--	--	--	--	--	--	Y
SAS	Corps	Hartwell Dam and Lake	General	2,842,700	NR	--	--	--	--	--	--	--	Y	--
SAS	Corps	J. Strom Thurmond Dam and Lake	General	2,900,000	NR	--	--	--	--	--	--	--	Y	--
SAS	Corps	Richard B. Russell Dam and Lake	General	1,166,166	NR	--	--	--	--	--	--	--	Y	--
SAW	Corps	B. Everett Jordan Dam and Lake	General	1,646,560	<25	--	--	--	--	--	--	--	--	Y
SAW	Corps	Falls Lake	General	1,020,980	<25	--	--	--	--	--	--	--	--	Y
SAW	Corps	John H. Kerr Dam and Reservoir	General	3,364,500	<25	--	--	--	--	--	--	--	Y	Y
SAW	Corps	Philpott Lake VA	General	318,300	<25	--	--	--	--	--	--	--	--	Y
SAW	Corps	W. Kerr Scott Dam and Reservoir	General	306,000	<25	--	--	--	--	--	--	--	--	Y
SPA	Corps	Abiquiu Dam	General	1,192,800	<25	--	--	--	MO	--	--	--	--	Y
SPA	Corps	Cochiti Lake	General	582,019	<25	--	--	--	--	--	--	--	--	Y
SPA	Corps	Conchas Lake	General	513,903	<25	--	--	--	--	--	--	--	--	Y
SPA	Corps	Galisteo Dam	Dry Dam	89,468	<25	--	--	--	--	--	--	--	--	--
SPA	Corps	Jemez Canyon Dam	Dry Dam	97,425	<25	--	--	--	--	--	--	--	--	Y
SPA	Corps	John Martin Reservoir	General	793,400	<25	--	--	--	--	--	--	--	--	Y
SPA	Corps	Santa Rosa Dam and Lake	General	438,364	<25	--	--	--	--	--	--	--	--	Y
SPA	Corps	Trinidad Lake	General	180,000	<25	--	--	--	--	--	--	--	--	Y
SPA	Corps	Two Rivers Dam	Dry Dam	163,775	<25	--	--	--	--	--	--	--	--	Y

District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)								(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage	Storage Filled	Impacts (MO / SI / SE)							Case Studies	DCP Review
				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries	(Y)	(Y)
SPK	Corps	Bear Dam	Dry Dam	7,700	<25	MO	--	--	--	--	--	--	--	--
SPK	Corps	Black Butte Lake	General	136,200	<25	MO	--	--	--	--	--	--	--	Y
SPK	Corps	Buchanan Dam - H.V. Eastman Lake	General	150,000	<25	--	--	--	--	--	--	--	--	Y
SPK	Corps	Burns Dam	Dry Dam	6,700	<25	--	--	--	--	--	--	--	--	--
SPK	Corps	Farmington Dam	Dry Dam	52,000	<25	--	--	--	--	--	--	--	--	--
SPK	Corps	Hidden Dam - Hensley Lake	General	90,000	<25	--	--	--	--	--	--	--	--	Y
SPK	Corps	Isabella Lake	General	568,100	<25	--	--	MO	--	--	--	--	--	Y
SPK	Corps	Mariposa Dam	Dry Dam	15,000	<25	--	--	--	--	--	--	--	--	--
SPK	Corps	Martis Creek Lake	General	20,400	<25	--	--	--	--	--	--	--	--	--
SPK	Corps	New Hogan Lake	General	317,100	<25	--	--	--	--	--	--	--	--	Y
SPK	Corps	Owens Dam	Dry Dam	3,500	<25	--	--	--	--	--	--	--	--	--
SPK	Corps	Pine Flat Lake and Kings River	General	1,000,000	<25	--	--	--	--	--	--	--	--	Y
SPK	Corps	Success Lake	General	82,300	<25	--	--	--	--	--	--	--	--	Y
SPK	Corps	Teminus Dam - Lake Kaweah	General	195,630	<25	--	--	--	--	--	--	--	--	Y
SPL	Corps	Alamo Lake	General	995,300	<25	--	--	--	--	--	--	--	Y	Y
SPL	Corps	Brea Dam	Dry Dam	3,888	<25	--	--	--	--	--	--	--	--	Y
SPL	Corps	Carbon Canyon Dam	Dry Dam	6,438	<25	--	--	--	--	--	--	--	--	Y
SPL	Corps	Fullerton Dam	Dry Dam	764	<25	--	--	--	--	--	--	--	--	Y
SPL	Corps	Hansen Dam	Dry Dam	33,348	<25	--	--	--	--	--	--	--	--	Y
SPL	Corps	Lopez Dam	Dry Dam	197	25-49	MO	--	--	--	--	--	--	--	Y
SPL	Corps	Mathews Canyon Dam	Dry Dam	6,271	<25	--	--	--	--	--	--	--	--	--
SPL	Corps	Mojave River Reservoir	Dry Dam	89,669	<25	--	--	--	--	--	--	--	--	--
SPL	Corps	Painted Rock Dam	Dry Dam	2,336,169	<25	--	--	--	--	--	--	--	--	Y
SPL	Corps	Pine Canyon Dam	Dry Dam	7,747	<25	--	--	--	--	--	--	--	--	--
SPL	Corps	Prado Dam	Dry Dam	187,600	<25	--	--	--	--	--	--	--	--	Y

District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)								(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage (ac-ft)	Storage Filled (%)	Impacts (MO / SI / SE)							Case Studies (Y)	DCP Review (Y)
						FRM	NAV	Hydro	WS	WQ	REC	Fisheries		
SPL	Corps	San Antonio Dam	Dry Dam	9,303	<25	--	--	--	--	--	--	--	--	Y
SPL	Corps	Santa Fe Dam	Dry Dam	30,887	<25	--	--	--	--	--	--	--	--	Y
SPL	Corps	Sepulveda Dam	Dry Dam	18,129	<25	--	--	--	--	--	--	--	--	Y
SPL	Corps	Whitlow Ranch Dam	Dry Dam	356,178	<25	--	--	--	--	--	--	--	--	--
SPL	Corps	Whittier Narrows Dam	Dry Dam	30,465	NR	--	--	--	--	--	--	--	--	Y
SPN	Corps	Coyote Valley Dam	General	116,500	<25	--	--	--	MO	--	MO	--	--	Y
SPN	Corps	Warm Springs Dam-Lake Sonoma	General	381,000	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Aquilla Lake	General	206,694	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Bardwell Lake	General	131,640	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Belton Lake	General	1,079,348	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Benbrook Lake	General	255,945	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Canyon Lake	General	733,602	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Cooper Lake	General	428,570	NR	--	--	--	--	--	--	--	--	--
SWF	Corps	Ferrell's Bridge Dam - Lake O'The Pines	General	828,241	<25	--	--	--	--	--	--	--	--	--
SWF	Corps	Granger Dam and Lake	General	231,022	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Grapevine Lake	General	407,536	<25	MO	MO	--	MO	--	--	--	--	Y
SWF	Corps	Hords Creek Lake	General	24,734	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Joe Pool Lake	General	362,725	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Lavon Lake	General	649,367	<25	MO	--	--	MO	--	MO	MO	--	Y
SWF	Corps	Lewisville Lake	General	886,732	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Navarro Mills Lake	General	206,185	<25	MO	--	--	MO	--	MO	MO	--	Y
SWF	Corps	North San Gabriel Dam - Georgetown L.	General	130,737	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	O.C. Fisher Dam and Lake	General	392,686	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Proctor Lake	General	370,407	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Ray Roberts Lake	General	1,261,460	<25	--	--	--	--	--	--	--	--	Y

District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)								(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage	Storage Filled	Impacts (MO / SI / SE)							Case Studies	DCP Review
				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries	(Y)	(Y)
SWF	Corps	Sam Rayburn Dam and Reservoir	General	4,305,138	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Somerville Lake	General	495,455	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Stillhouse Hollow Lake	General	620,757	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Town Bulff Dam - B.A. Steinhagen Lake	--	--	25-49	--	--	--	--	--	--	MO	--	Y
SWF	Corps	Waco Lake	General	735,754	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Whitney Lake	General	1,926,778	<25	--	--	--	--	--	--	--	--	Y
SWF	Corps	Wright Patman Dam and Lake	General	2,607,112	<25	--	--	--	--	--	--	--	--	--
SWG	Corps	Addicks Dam	Dry Dam	200,800	<25	--	--	--	--	--	--	--	--	--
SWG	Corps	Barker Dam	Dry Dam	209,000	<25	--	--	--	--	--	--	--	--	--
SWL	Corps	Beaver Lake	General	2,182,500	<25	--	--	--	--	--	--	--	Y	Y
SWL	Corps	Blue Mountain Lake	General	653,480	<25	MO	--	--	--	--	--	--	--	Y
SWL	Corps	Bull Shoals Lake	General	6,013,000	<25	--	--	--	--	--	--	--	Y	Y
SWL	Corps	Clearwater Lake	General	911,150	<25	MO	--	--	--	--	SI	--	Y	Y
SWL	Corps	DeQueen Lake	General	370,600	<25	--	--	--	--	--	--	--	--	--
SWL	Corps	Dierks Lake	General	221,600	<25	--	--	--	--	--	--	--	--	--
SWL	Corps	Gillham Lake	General	283,310	<25	--	--	--	--	--	--	--	--	--
SWL	Corps	Greers Ferry Lake	General	3,313,000	<25	--	--	--	--	--	--	--	Y	Y
SWL	Corps	Millwood Lake	General	2,618,750	<25	MO	--	--	MO	--	SE	--	--	--
SWL	Corps	Nimrod Lake	General	851,275	<25	--	--	--	--	--	--	--	--	Y
SWL	Corps	Norfork Lake	General	2,108,700	<25	--	--	--	--	--	--	--	Y	Y
SWL	Corps	Table Rock	General	4,075,000	<25	--	--	--	--	--	--	--	Y	Y
SWT	Corps	Arcadia Lake	General	92,020	<25	MO	--	--	MO	--	--	--	--	Y
SWT	Corps	Birch Lake	General	59,030	<25	MO	--	--	MO	--	--	--	--	Y
SWT	Corps	Broken Bow Lake	General	1,368,245	<25	--	--	--	--	--	--	--	--	Y
SWT	Corps	Canton Lake	General	377,100	<25	MO	--	--	--	--	--	--	--	Y

District	Owner	Project Name	Water Management Survey (Sec. 3)		Sedimentation Survey (Sec. 5)									(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage	Storage Filled	Impacts (MO / SI / SE)								Case Studies	DCP Review
				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries		(Y)	(Y)
SWT	Corps	Copan Lake	General	221,491	<25	MO	--	--	MO	MO	--	--		--	Y
SWT	Corps	Council Grove Lake	General	238,695	25 - 49	MO	--	--	MO	MO	--	--		--	Y
SWT	Corps	Denison Dam - Lake TeXoma	General	5,061,062	<25	MO	--	MO	MO	MO	MO	MO		--	Y
SWT	Corps	El Dorado Lake	General	301,104	<25	MO	--	--	MO	MO	--	--		--	--
SWT	Corps	Elk City Lake	General	284,458	<25	MO	--	--	MO	MO	MO	MO		--	--
SWT	Corps	Eufaula Lake	General	3,825,400	<25	MO	MO	MO	MO	--	MO	MO		--	Y
SWT	Corps	Fall River Lake	General	254,876	<25	MO	--	--	MO	MO	MO	--		--	--
SWT	Corps	Fort Gibson Lake	General	1,284,400	<25	--	--	--	--	--	--	--		--	Y
SWT	Corps	Fort Supply Lake	General	100,770	<25	MO	--	--	--	--	--	--		--	Y
SWT	Corps	Great Salt Plains Lake	General	241,695	50 - 74	MO	--	--	--	--	--	SI		--	Y
SWT	Corps	Heyburn Lake	General	56,303	25 - 49	--	--	--	MO	--	--	--		--	Y
SWT	Corps	Hugo Lake	General	960,323	<25	MO	--	--	MO	MO	--	--		--	Y
SWT	Corps	Hulah Lake	General	285,897	25-49	MO	--	--	SI	MO	MO	MO		--	Y
SWT	Corps	John Redmond Dam and Reservoir	General	574,918	25 - 49	MO	--	--	MO	MO	MO	--		--	Y
SWT	Corps	Kaw Lake	General	1,327,155	<25	MO	--	--	MO	--	--	--		--	Y
SWT	Corps	Keystone Lake	General	1,672,613	<25	MO	MO	MO	MO	--	MO	--		--	Y
SWT	Corps	Marion Lake	General	141,802	<25	MO	--	--	MO	--	--	--		Y	Y
SWT	Corps	Oologah Lake	General	1,559,279	<25	MO	MO	--	MO	--	MO	MO		Y	Y
SWT	Corps	Optima Lake	General	382,500	<25	--	--	--	--	--	--	--		--	Y
SWT	Corps	Pat Mayse Lake	General	182,942	<25	MO	--	--	MO	--	--	--		--	Y
SWT	Corps	Pearson-Skubitz - Big Hill Lake	General	42,564	<25	MO	--	--	MO	--	MO	MO		--	--
SWT	Corps	Pine Creek Lake	General	465,780	<25	MO	--	--	MO	MO	--	--		--	Y
SWT	Corps	Sardis Lake	General	468,057	<25	MO	--	--	MO	--	--	--		--	Y
SWT	Corps	Skiatook Lake	General	543,626	<25	MO	--	--	MO	MO	--	--		--	Y
SWT	Corps	Tenkiller Ferry Lake	General	1,230,800	<25	--	--	--	--	--	--	--		--	Y

District	Owner	Project Name	Water Management Survey (Sec. 3)	Sedimentation Survey (Sec. 5)									(Sections 4 & 6)	(Sec. 6)
			Project Classification	Gross Storage	Storage Filled	Impacts (MO / SI / SE)							Case Studies	DCP Review
				(ac-ft)	(%)	FRM	NAV	Hydro	WS	WQ	REC	Fisheries	(Y)	(Y)
SWT	Corps	Toronto Lake	General	200,839	<25	MO	--	--	MO	MO	MO	MO	--	--
SWT	Corps	Waurika Lake	General	451,107	<25	MO	--	--	MO	MO	MO	MO	--	Y
SWT	Corps	Wister Lake	General	427,485	<25	MO	--	--	MO	--	--	--	--	Y

Appendix E. Water Quality Survey Questionnaire

As discussed in **Section 4**, this survey is intended to complement the 2008 surveys of water supply, water management and sedimentation information, and consists of 24 questions that are split into two parts: 1) a series of questions directed at Corps offices and 2) a series of questions pertaining to individual Corps reservoirs. Only Corps reservoirs (see **Appendix C**) are of interest to the survey. The following detailed directions discuss the intent and terms for each survey question.

<u>Office-specific Questions</u>:

1) This question seeks to characterize the average time spent in support of congressionally authorized reservoir purposes. Percentages should reflect a current and typical workload for the entire responding office, for its whole portfolio of survey reservoirs, and for a long enough time period (i.e., at least annually) to provide accurate estimates of the overall relationship between effort and purpose. Percentages may be entered for as many of the listed (or other) purposes as appropriate, but should total to 100%.

Staffing - Questions 2-6 focus on past, current, and anticipated staffing levels.

2) This question requests the total number of employees focused on water quality/ecological management in your office over time. Partial FTE's (full-time employees) are fine. Responses will be used to determine current status and trends in staffing levels. FTE's reported here should be regular Corps staff. Please do not include vacant FTE's in the tallies.

3) This question separates current FTE's into professional disciplines. The FTE total for this question should equal the number reported for "This Year" in question 2. Partial FTE's are fine. FTE's reported here should be regular Corps staff. Please do not include vacant FTE's in the tallies.

4) This question requests the total number of developmental or exchange staff focused on water quality/ecological management in your office over time. Partial FTE's are fine. FTE's reported here should include relevant interns, co-op students, Department of the Army interns, Pathways Internship Program participants, IPA's (staff shared through Intergovernmental Personnel Act), and otherwise shared or exchanged staff.

5) This question requests the total number of external staff focused on water quality/ecological management for your office over time. Partial FTE's are fine. FTE's reported here should include contractors.

6) This question separates current external FTE's into categories of support. The FTE total for this question should equal the number reported for "This Year" in question 5. Partial FTE's are fine. FTE's reported here should include contractors.

Funding - Questions 7-10 focus on past, current, and anticipated funding levels:

7) This question requests tallies of funding per source that supported your office's water quality and ecological management activities for FY 2013. Funds reported should be related to reservoir operations. Please provide values in increments of $100K or smaller when appropriate and comment as necessary.

8) This question requests total funding that supported your office's water quality and ecological management activities for FY 2003, FY2008, FY 2012, FY 2013, and FY2016 that was budgeted for water quality/ecological management pertaining to reservoir operations. Responses will be used to determine trends in funding for Water Quality/Ecological Management pertaining to reservoir operations over time. The value for 2013 should equal the sum of per source funding from question 7.

9) This question requests how much of your office's total funding (from Question 8) was contracted outside of the Corps. Responses will be used to determine trends in contracting outside the Corps for water quality/Ecological Management pertaining to reservoir operations over time.

10) This question details the per purpose amount contracted support used for water quality/ecological management activities for FY 2013. Please provide values in increments of $100K or smaller when appropriate and comment as necessary.

11) This question requests whether planning is involved with your office's water quality/ecological management. If planning is involved, the question then requests the types of planning support your office does.

12) This question requests whether recurring reporting is done for your office's water quality/ecological management. If recurring reporting is done, specify the type of reporting that is done. This could be on an annual basis (Annual Report), as needed basis (Special Studies), within updates to Water Control Manuals, or some other reporting mechanism.

Reservoir-specific Questions:

13) The question is about physical factors affecting water quality/ecological management at each reservoir. It is separated into 3 parts: upstream, in-reservoir, and downstream. For each part, there is a list of categories (industry, agriculture, etc.) and factors for each category (waste disposal, thermal, etc.).

Answer the question by rating the degree to which each factor affects water quality/ecological management at the reservoir. Options are provided for High, Medium, Low, or NA (Not Applicable). If a factor does not apply, please select "NA".

Factors are described briefly below:

Upstream

Industry:

- Waste disposal – effluent from factory – usually a pipe
- Thermal influences – effluent temperature much warmer than normal stream temperature – typical for power plants, but also other industries
- Water withdrawals – removal of water from stream – pump or divert

Agriculture:

- Nutrients – fertilizers and animal waste
- Upland erosion – sediment from field transported to stream
- Channel erosion – stream/bank sediments transported downstream
- Pesticides – chemicals used for insect control
- Water withdrawals – removing water for irrigation – pump or divert

Urbanization/ Suburbanization:

- Impervious surfaces – paved surfaces – causes increased runoff
- Nutrients – fertilizers
- Water withdrawals – removing water from the stream – pump or divert

Mineral Exploration/ Extraction:

- Water withdrawals – removing water from the stream – pump or divert
- Wastewater disposal – discharging of wastewater to a stream
- Tailings – Waste material from mine
- Contaminated runoff from mining – water passing through mine or tailings before entering stream

Forestry:

- Practices – policies used in managing a forest that may cause water quality/ecological problems with the stream
- Range/forest fires – problems associated with fires (range or forest) e.g. increased sedimentation due to lack of ground cover

Legacy pollutants – Abandoned properties in the headwaters where there are pollutants resulting from discontinued land-use practices

<u>Reservoir</u>

Recreation:

- In-lake fisheries – typically sport fisheries management
- Bacterial contamination – water quality at beaches and other locations
- Wave erosion – sediment problems related to wind or boat wakes
- Petroleum contamination – surface sheens
- Pool level maintenance – recreational and sometimes seasonal pool level management
- Algal blooms – problematic or nuisance concentrations of algae

Water quality concerns:

- Dissolved oxygen concentrations – low oxygen or anoxic conditions related to fish kills, temperature management, and hydrogen sulfide
- Thermal conditions – How much does water temperature affect water quality/ecological conditions
- pH – acidity affects fish populations and in-pool productivity levels

Sediment quality – Sediment inputs affect algal dynamics, turbidity or thermal dynamics

Fish passage – If yes, please report the degree to which fish passage affects management. If no, please respond with “NA”.

Legacy pollutants – Existing pollutants in reservoir sediment can limit operational flexibilities and degrade in pool recreation opportunities

<u>Downstream</u>

Ecological Flows – If special releases are made for downstream ecological purposes, please report the degree to which these operations affect management. If not, please respond with “NA”.

Temperature Management – If reservoir outflows are managed for downstream water temperature considerations, please report the degree to which these operations affect management. If not, please respond with “NA”.
Dilution – If reservoir outflows are made for dilution of pollutants, please report the degree to which these operations affect management. If not, please respond with “NA”.
Recreation:

- Rafting - If special releases are made in support of boating, please report the degree to which these operations affect management. If not, please respond with “NA”.
- Fisheries - If special releases are made in support of downstream fisheries, please report the degree to which these operations affect management. If not, please respond with “NA”.

14) This question focuses on the institutional factors that influence reservoir operations related to water quality and environmental management. For example, if this reservoir is authorized for Fish and Wildlife, please respond with a measure of how impactful that authorization is regarding operations for water quality and environmental management. Similarly, categories are provided for other authorized purposes, contractual agreements, Corps principles, federal and state laws, and tribal considerations.

Answer the question by rating the degree to which each factor affects water quality/ecological management at the reservoir. Options are provided for High, Medium, Low, or NA (Not Applicable). If a factor does not apply, please select “NA”.

15) This question focuses on the operational influence of the Clean Water Act (CWA) and the Endangered Species Act (ESA). The CWA section consists of two overview questions and considerations for non-point source and point source pollutants.

<u>CWA - Overview questions</u>:

Is any part of the reservoir or downstream water bodies within the range of management of the dam listed as 303d impaired? For the purposes of the survey, the range of management is defined as the longer of 1) the river distance to the most downstream operating location or 2) 5 to 50 river miles depending on reservoir influence related to overall watershed and river characteristics. Resources provided by EPA might be useful references for this question, including http://iaspub.epa.gov/waters10/attains_nation_cy.control?p_report_type=T.

Does this law influence operations of this reservoir (Y-N)? If yes, please note as such and continue with this question. If no, please note as such and proceed to the Endangered Species Act section.

CWA - Nonpoint source pollutants. A series of likely pollutants related to reservoir management are provided, including temperature, dissolved oxygen (DO), total dissolved gas (TDG), metals, sediment, toxins, nutrients, and others. Please report any existing or pending TMDL (total maximum daily load) permits that affect operations of this reservoir.

CWA - Point source pollutants. As authorized by the CWA, the National Pollutant Discharge Elimination System (NPDES) Permit Program controls water pollution by regulating point sources (e.g. pipes or ditches) that discharge pollutants into waters of the United States. Please report any existing or pending NPDES permits that affect operations of this reservoir.

The ESA section consists of an overview question and requests information for all endangered species that influence operations of this reservoir.

ESA - Overview question: Does this law influence operations of this reservoir (Y-N)? If yes, please note as such and continue with this question. If no, please note as such and proceed to question 16.

ESA – Endangered Species. This section is related to endangered species that affect operations of this reservoir. For each species, please enter the name and approximate year when ESA considerations began to influence reservoir operations and select from options regarding threat, location relative to reservoir, and status of process. Please note any multiple threats or unlisted options in the comment field.

16) The intent of this question is to identify the management issues that are driving water quality/ecological management operations at each of your reservoirs, both at the reservoir (16a) and downstream of the reservoir (16b). These issues could be Emerging (potential management issues that are still being identified), Existing (identified management issues) and Operational (issues that have been and are being managed for). For Operational issues, the question requests the level of significance (Low, Medium or High) of each issue from an operational perspective. Significance is used in the survey as a general and relative measure of effort. The significance of an issue increases as that issue demands higher amounts of time, budget, consultations with counsel, etc. Low indicates issues with minor operational influence and management burden. Medium indicates issues that affect operations with regularity and

impose modest burdens. High indicates issues that exert significant operational influence and burden. The types of management issues are described briefly below:

Recreation:

- Primary contact recreation-direct contact with the water e.g. swimming
- Secondary contact recreation-indirect contact with the water e.g. boating
- Harmful algal bloom

Biotic/natural resource

- Wetlands associated with pool-
- Fisheries-resident and migratory fish
- Environmental flows-reservoir releases required for environmental purposes
- T&E-threatened and endangered species
- Invasive Species –non-native species

Water quality

- Circulation
- Nutrients
- Hydrogen sulfide
- Thermal management of pool
- Dissolved oxygen
- Pharmaceuticals
- Contaminants and bioaccumulation
- Metals (please note metals of concern in comments)

Structural

- Outlet structure modification
- Private modifications to hydropower
- WQ Management during construction/rehab

Water supply and climate

- Drought Management
- Climate change
- Snowpack Management

Mineral

- Coal
- Mineral extraction activities:
    - Oil
    - Gas
    - Sand and Gravel
    - Water extraction
    - Groundwater contamination
    - Surface/groundwater interaction
    - Total dissolved solids (TDS)

17) This question requests an estimation of time devoted annually, in terms of percentage to each congressionally authorized purposes of the reservoir. Percentages should total to 100%.

18) This question requests the annual time, in terms of percentage, currently devoted to flood risk management operations (18a), water quality/ecological management programs (18b), and the annual percentage of time that could potentially be devoted to water quality/ecological management programs based on current operational flexibilities (18c). The percentages here do not need to add to 100%, but should not exceed 100%.

19) The intent of this question is to identify reservoir management practices that are currently being used (part a) and those that are unused, but desired for use (part b) to benefit water quality and environment management. Any practices cited as desired for use should reflect both applicability for this reservoir and a management interest in implementation, which has been unrealized due to other constraints. Each part of the question contains a list of management measures, some of which are defined below:

Life stage support. A reservoir operation intended to benefit a critical period of an organism's life cycle. Can include not only reservoir elevations, but also inflow and outflow timing/volume.

Geomorphic processes. Flow and sediment provision for processes that influence how rivers change and build forms over time.

Flushing flows. Peaks in the natural flow regime of a stream that typically occur during spring runoff and heavy rainfall, and are necessary to maintain ecological integrity.

Pulse flows. A controlled release intended to simulate natural storm events that occur during the late summer and early fall to improve water quality without detrimental effects to the fishery.

Variable flow management. A program that attempts to control flooding while also releasing water during the refill period to mimic natural flow patterns. This can means storing more water behind the dam in the winter to provide higher river flows when threatened and endangered fish spawn in the spring. The technique depends heavily on long-range weather forecasts.

Seasonal flow management. Seasonal flows that represent a typical range for each month and are useful for describing characteristic variation between seasons (i.e., summer and fall) or between among years (i.e., a wet summer compared to a dry summer).

Low-flow enhancement. Low flows, also called base flows maintain adequate habitat, temperature, dissolved oxygen, and chemistry for aquatic organisms; drinking water for terrestrial animals; and soil moisture for plants.

Dilution flows. Augmenting stream flow to meet pollution dilution requirements (can be associated with low flow periods).

Stream restoration. Includes restoration projects outside the project boundaries.

Nutrient management. Includes (a) reducing watershed nutrient inputs, (b) nutrient enhancement programs for blue-green algae control or fish productivity, and (c) internal nutrient cycling.

20) As a follow-up to question 19.b, this question focused on the constraints that limit water quality and environmental management at this reservoir. Options are provided for High, Medium, Low, or NA (Not Applicable). If a constraint does not apply, please select "NA". The question concludes by asking responders to list key WQ and environmental management opportunities at this reservoir. Opportunities should be currently unused or under-used at this reservoir. Associating gaps with opportunities is sometimes difficult, but examples that may apply to your project are opening avenues for partnering with other agencies, leveraging funds, or other collaborative efforts.

21) This question seeks information about the water quality monitoring program at this reservoir, including:

a. Active WQ monitoring can include annual and/or rotational water quality monitoring activities associated with bacteria monitoring at beaches, recreation area monitoring for compliance with the Safe Drinking Water Act, and general water quality monitoring of reservoirs at multiple locations. Please indicate whether there is an active WQ monitoring program for this reservoir. If yes, please note and proceed. If no, please note and go to question 22.

b. Identify and characterize the objectives of your WQ monitoring program. Options are provided for High, Medium, Low, or NA (Not Applicable). If your monitoring program is used to meet objectives that are not listed, please specify those objectives under "other".

c. Identify the sources of funding used in your WQ monitoring programs.

d. Identify the functional areas within the District/Division conducting WQ monitoring activities

e. Identify and characterize the types of data collected through your WQ monitoring activities.

f. Indicate if laboratory results are generated by in-house analyses, contract/commercial laboratories, and/or ERDC laboratories. If in-house, please specify the organizational section.

g. Identify the primary instrumentation used in your WQ programs (e.g., YSI multi-parameter sondes, HydroLab multi-parameter sondes, light meters, etc.)

22) This question seeks information regarding the water quality and environmental data management for this reservoir, including:

a. Use of data management tools. DASLER (Data management and Analysis System for Lakes, Estuaries, and Rivers), Aquarius (), are Microsoft Access are queried directly. If other data management tools are used please include them in the “other” row or mention in the comments.

b. Public access to data. Please indicate yes or no and specify how and which data types are made available.

c. Non-telemetry data to EPA databases. EPA maintains the STORET and WQX national water quality databases. Please indicate whether non-telemetry data (e.g., grab samples) for this reservoir are input to those databases.

d. Telemetry data to databases. DSS (Data Storage System – HEC-DSS) and CWMS (Corps Water Management System) are or include databases commonly used by reservoir managers to store operational information. Please indicate whether telemetry data, collected by gages and transmitted electronically, are stored in these or other software.

e. Funding. Please provide a breakdown of the amount and source of funding used to support water quality and environmental data management.

23) This question seeks information about hardware and software being used in support of water quality and environmental management at this reservoir, including:

a. Water quality management hardware and software. Please note whether and, if so, describe any innovative, unique, and potentially transferable methods that are being used for this reservoir.

b. Decision support. Please note whether and, if so, describe any modeling tools being used to support management of this reservoir.

24) Droughts often create unique and challenging water quality and environmental management concerns. Please report whether this reservoir has a drought contingency plan and, if so, the year of the current version.

Appendix F. Marion Lake Climate Change Pilot Study Report

This appendix reproduces the 2013 report discussed in **Section 6** that was prepared for the National Portfolio effort, “Climate Change Impacts on USACE Water Supply Reservoirs: A Pilot Study of the Marion Reservoir Watershed in Kansas."

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US Army Corps of Engineers

Institute for Water Resources

Climate Change Impacts on USACE Water Supply Reservoirs: A Pilot Study of the Marion Reservoir Watershed in Kansas

August 2013

EXECUTIVE SUMMARY

Marion Reservoir, located on the Cottonwood River in Marion County, Kansas, was selected for an assessment of its water supply and demand vulnerabilities in relation to climate change and variability. The water supply in this reservoir (44,730 acre-feet) is owned by the State of Kansas. The water supply contract held by the State of Kansas was originally approved in 1976, with a subsequent reallocation of additional water supply storage in 1996. The Kansas Water Office currently has water marketing contracts totaling 1,834 acre-feet that extend through the year 2039.

There have been three prolonged periods of drought recorded in the Cottonwood River basin. The most prolonged (and most severe) occurred between 1952 and 1957. The average monthly inflow during this period was 12% of the period average (1922–1988), and it included 6 months of zero inflow. The lowest Palmer Drought Severity Index (PDSI) value during this period was –6.06, which is considered to be an extreme drought.

Prior to beginning this study, a gridded dataset of bias-corrected, spatially disaggregated (BCSD) statistically downscaled climate projections was obtained from a joint archive maintained by several Federal and academic partners, including the U.S. Army Corps of Engineers (Brekke et al., 2013). A subset of this data, extracted for the Marion Reservoir watershed, was converted from a native general circulation model (GCM) grid cell size and redistributed into 1/8° (latitude by longitude) spacing (A. Wood, personal communication, 2011). The resulting grid cells, each with an area of 57 square miles, were superimposed across the Marion Reservoir watershed; 10 grid cells were used in the analysis.

Hydrographs were developed from the BCSD dataset by running simulations in the Variable Infiltration Capacity (VIC) model (Liang, 1994). Several steps were required, including incorporation of the vegetation and soil dataset for the watershed, generation of the computational grid for the watershed by overlaying watershed polygons and extracting grid cells, compilation of the source code for VIC and routing models, definition of the state variables and pathnames for VIC and routing models, execution of the VIC model and generation of cell flux output, and execution of the routing model and generation of time series hydrographs for the watershed.

Numerical routing was then used to project each of the hydrographs into a long-term simulation of pool elevations so that droughts could be identified and the critical period for each could then be identified. A mass balance approach was used, and iteration proceeded automatically through all time steps in the spreadsheet until an outflow value was found that resulted in a single minimum pool elevation of 1,320.0 feet, which constituted the occurrence of both the critical period and the firm yield.

The VIC simulation, with historical data as input, accurately reproduced the critical period. The timing and duration of historical droughts, including the 1952–1957 drought of record, were generally correct. However, the VIC simulation did not replicate firm yield. Differences between

the observed and simulated firm yield were minimized when the simulated hydrograph was bias corrected to the observed hydrograph for the historical overlap period (1949-2008).

All model projections were in agreement that future conditions will be warmer over the Marion Reservoir watershed, with a median increase in temperature of +4.76°F by the year 2050. No consensus existed with respect to future precipitation trends in the Marion Reservoir watershed. Half of the models in the BCSD dataset predicted an increase in annual rainfall by the year 2050, while the other half predicted a decrease in annual rainfall. Most of the models fall within a ±20% range by the year 2050 based on current climatology.

This study provides a methodology from which climate change can be included as a factor when planning for long-term water supply use. The results of this study suggest that mean annual temperature will increase across the basin while mean annual precipitation will remain about the same. Yield modeling of projected hydrographs shows little change in 30-year mean values. Furthermore, the capacity for additional water supply contracts currently exists. Although future demand was not considered, the Marion Reservoir watershed is a small, rural area with stagnant demand growth. There is no current basis for the expectation of an increase in future demand. Since the reservoir has existing water supply capacity that significantly exceeds the contracted amount, it appears to be well positioned to meet future water supply obligations.

PURPOSE

The primary objective of this project was to assess the vulnerability of water supply and demand at Marion Reservoir in relation to climate change and variability.

An initial assessment was performed to assess the reservoir's vulnerability to drought under current conditions. The assessment included the review of the current water supply contracts, customers, and uses. The assessment considered what combination of drought duration and magnitude would cause the reservoir to no longer meet its contracts. The findings of this assessment can be used to consider the water supply customer's potential vulnerability to drought by determining what alternative sources of supply are available, what conservation measures could be employed, and how much water demand exists during drought.

This project was completed with funding from the U.S. Army Corps of Engineers (USACE) Institute for Water Resources (IWR) and was prepared for Mr. Ted Hillyer, Manager of the Water Supply Business Line. Climate model forcing data were provided by Dr. Andrew Wood, Development and Operations Hydrologist, National Oceanographic and Atmospheric Agency (NOAA), National Weather Service (NWS), Northwest River Forecast Center. The analysis and findings in this report were developed in collaboration with Dr. David Raff, Senior Hydraulic and Hydrologic Engineer, USACE IWR Climate and Global Change Team.

We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modelling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy.

Any questions regarding the technical information contained in this report should be directed to the author, Dr. David Williams, Lead Hydraulic Engineer, USACE Tulsa District.

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INTRODUCTION

The U.S. Army Corps of Engineers (USACE) has numerous water supply contracts at reservoirs in the Tulsa District (SWT). Among these multi-purpose projects is Marion Reservoir, located on the Cottonwood River in Marion County, Kansas. This reservoir was chosen for a pilot study that assessed the vulnerability of water supply and demand to climate variability based on the following criteria:

- The reservoir provides water supply as an allocated purpose.
- The watershed associated with the reservoir is relatively small.
- The reservoir is not a downstream project in a system.

Marion Reservoir met these criteria since it has a small total capacity, it maintains a contracted water supply allocation to the State of Kansas, and it is a headwater reservoir in a watershed of a manageable size. Additionally, a long observed and simulated period of record is available from USACE (Tulsa District).

Downscaled climate change projections derived from the World Climate Research Programme's third phase of the Coupled Model Intercomparison Project (CMIP3) were used as the basis for the analysis. This study utilized the Variable Infiltration Capacity (VIC) hydrologic model to examine a range of climate change scenarios to determine whether or not the Federal water supply contractual obligations will be met during future climate conditions. In other words, how vulnerable is the water supply contract at Marion Reservoir to climate change?

Answering this question required not only hydrologic climate modeling using VIC, but also reservoir simulation using numerical routing methods. Operational rules contained in the Marion Reservoir water control manual were used to simulate pool elevations in conjunction with the inflow hydrograph that was computed with the VIC model. Development of water supply reservoir modeling with projected climate variables provides an opportunity for USACE to assess the vulnerability of these projects with modified precipitation and runoff parameters.

Collaboration on this project with researchers at the U.S. Bureau of Reclamation (USBR) and the National Oceanic and Atmospheric Administration (NOAA) was beneficial, given the technical expertise that has been gained through similar efforts. The selection of Marion Reservoir for this pilot study complements the ongoing modeling efforts of other Federal agencies in the Great Plains region and allows the use of existing datasets and modeling technology.

PROJECT DESCRIPTION

Marion Reservoir is located at mile 126.7 on the Cottonwood River, about 3 miles northwest of Marion in Marion County, Kansas (Figure 1). It is a multi-purpose project for flood control, water quality control, recreation, and water supply. Marion Reservoir, Council Grove Lake, and John Redmond Reservoir are integral components in a three-unit system. This system is part of the multi-purpose plan for flood control, hydroelectric power generation, navigation, and allied water uses on the Arkansas River and tributaries in Kansas, Arkansas, and Oklahoma.

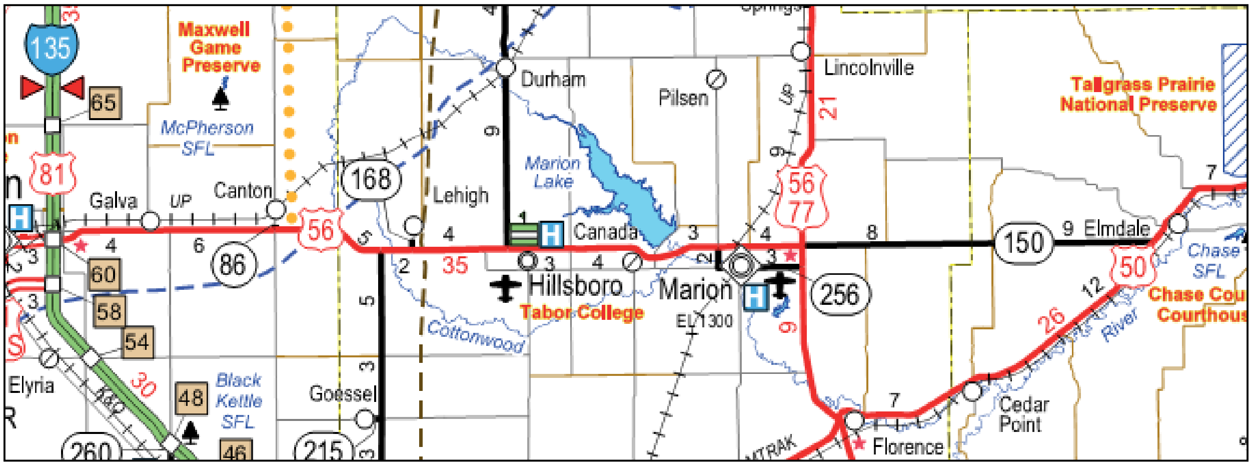

FIGURE 1: Map of region surrounding Marion Reservoir (from Kansas Department of Transportation).

The Cottonwood River, a principal tributary in Kansas, rises in east central Kansas near Marion and flows in a general easterly direction from its source to its confluence with the Neosho River at mile 382.8. The watershed is about 70 miles long, averaging about 26 miles in width and draining an area of approximately 1,908 square miles, which is 70% of the total drainage area above the confluence of the Cottonwood and Neosho Rivers.

The climate of the Cottonwood River watershed is characterized by moderate winters and comparatively long summers with relatively high temperatures. Summer rains generally occur as thunderstorms with very intense rainfall of short duration and limited areal coverage. The winter rains are generally of low intensity but cover a large area and are of considerably longer duration. The Gulf of Mexico is the source of much of the precipitation that falls on the basin.

Most of the flood-producing storms over the watershed above Marion Reservoir have been from 3 to 8 days duration and have occurred in the spring and fall months. The longer storms have generally been made up of two or three periods of intense precipitation, with moderate precipitation on the intervening days saturating the watershed and resulting in a high percentage of runoff from subsequent periods of heavy precipitation.

Maximum rainfall occurs in May and June, with a noticeable decrease in the average rainfall in November, December, January, and February (Figure 2). The maximum storm over the watershed above Marion Dam during the period of record was 10.16 inches over four days in July 1951. Over the period of record, about 71.8% of the rainfall occurred during the months of April through September. The averages were computed from published precipitation records of rainfall recorded for the basin. These records do not necessarily report the center of intense storms. Antecedent precipitation, season of the year, and many other factors influence storm runoff, and floods have frequently followed periods of relatively small amounts of recorded rainfall. Conversely, some storms with greater amounts of recorded rainfall have caused only minor flooding.

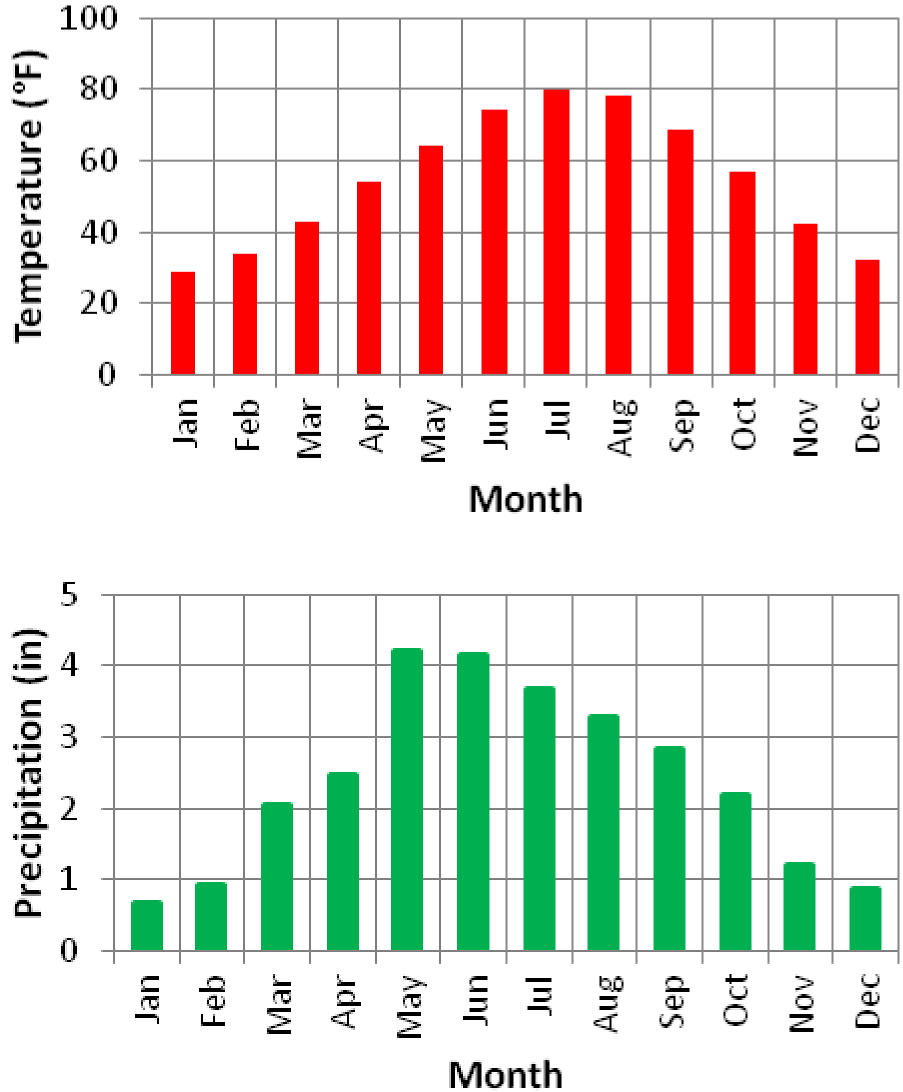

FIGURE 2: Average monthly temperature and precipitation climatology for the Marion Reservoir watershed, 1949–2008 (from Guttman and Quayle, 1996; NCDC, 2013).

There have been three prolonged periods of drought recorded in the Cottonwood River basin. The most severe occurred between 1952 and 1957 (Figure 3). The average monthly inflow during this time period was 12% of the period average (1922–1988), and it included 6 months of zero inflow. The lowest Palmer Drought Severity Index (PDSI) value during this period was –6.06, which is considered to be an extreme drought. The second-most severe drought of record occurred during 1963–1964. The average monthly inflow during this time period was 14% of the period average. The lowest PDSI value during this period was –4.89, also classified as an extreme drought. The third-most severe drought occurred between 1932 and 1934. The average monthly inflow during this time period was 25% of the period average. The lowest PDSI value during this period was –4.5. In addition to these exceptional droughts, there have been many years with consecutive dry months.

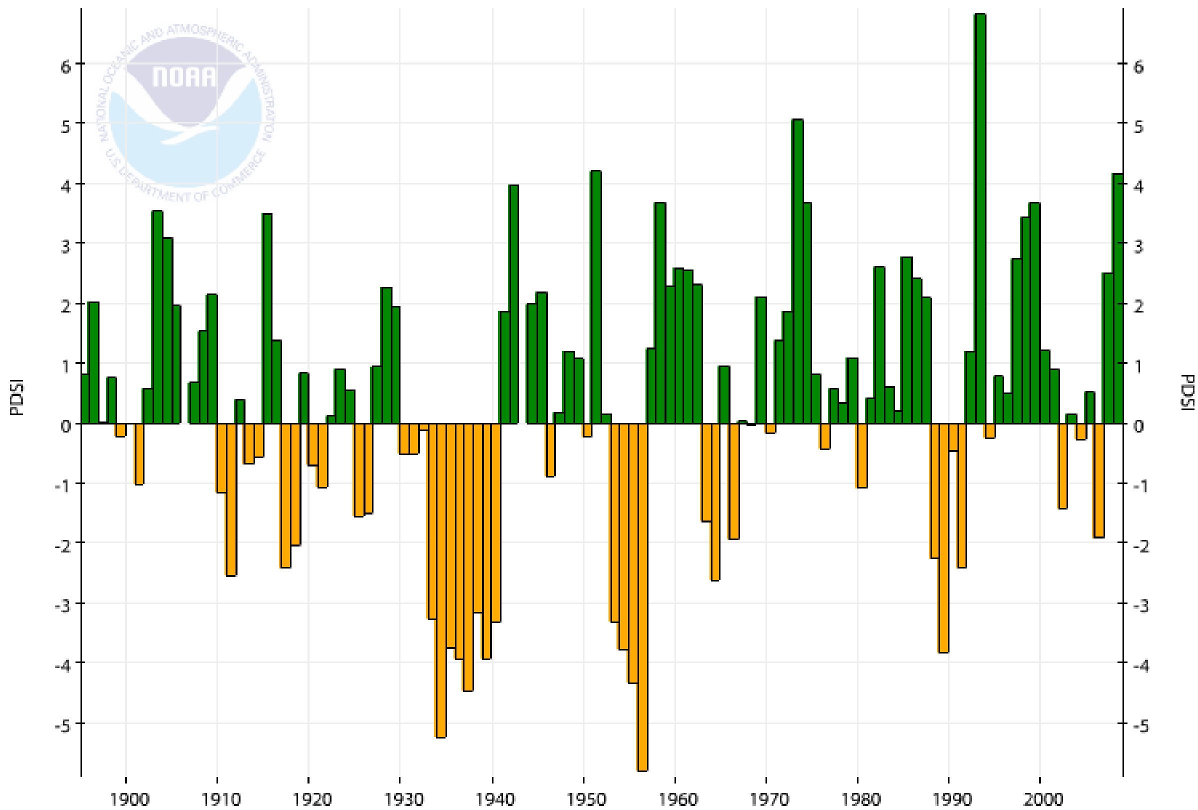

FIGURE 3: Historical PDSI for the Marion Reservoir watershed, 1895-2008 (from Guttman and Quayle, 1996; NCDC, 2013).

The drought of 1952–1957 occurred across much of the Great Plains. Conditions during the "Dust Bowl" of the 1930s were more severe in many locations, but that drought pre-dated stream flow records across much of the region. The 1950s drought affected an area ranging from the Texas panhandle to central and eastern Colorado, western Kansas and central Nebraska; all of these areas experienced prolonged drought conditions. Kansas experienced severe drought conditions during much of the five-year period, which peaked in 1956. The PDSI reached a record low in September 1956. The recurrence interval for the 1950s drought was greater than 25 years across most of Kansas. As a result of its severity, the 1952–1957 drought is defined as the critical drought for water supply studies at Marion Reservoir and many other reservoirs across Kansas.

Construction of Marion Reservoir was authorized by the Flood Control Act of 17 May 1950 (Public Law 516, 81st Congress, 2nd Session). Excavation began in 1964, and embankment closure occurred in 1968. The initial fill (maximum conservation storage) occurred in February 1969. At the time of construction, 38,300 acre-feet of conservation storage was designated for water supply, while 44,600 acre-feet of storage was reserved for water quality. Yields corresponding to these volumes were developed based on the 1950s drought (Figure 4).

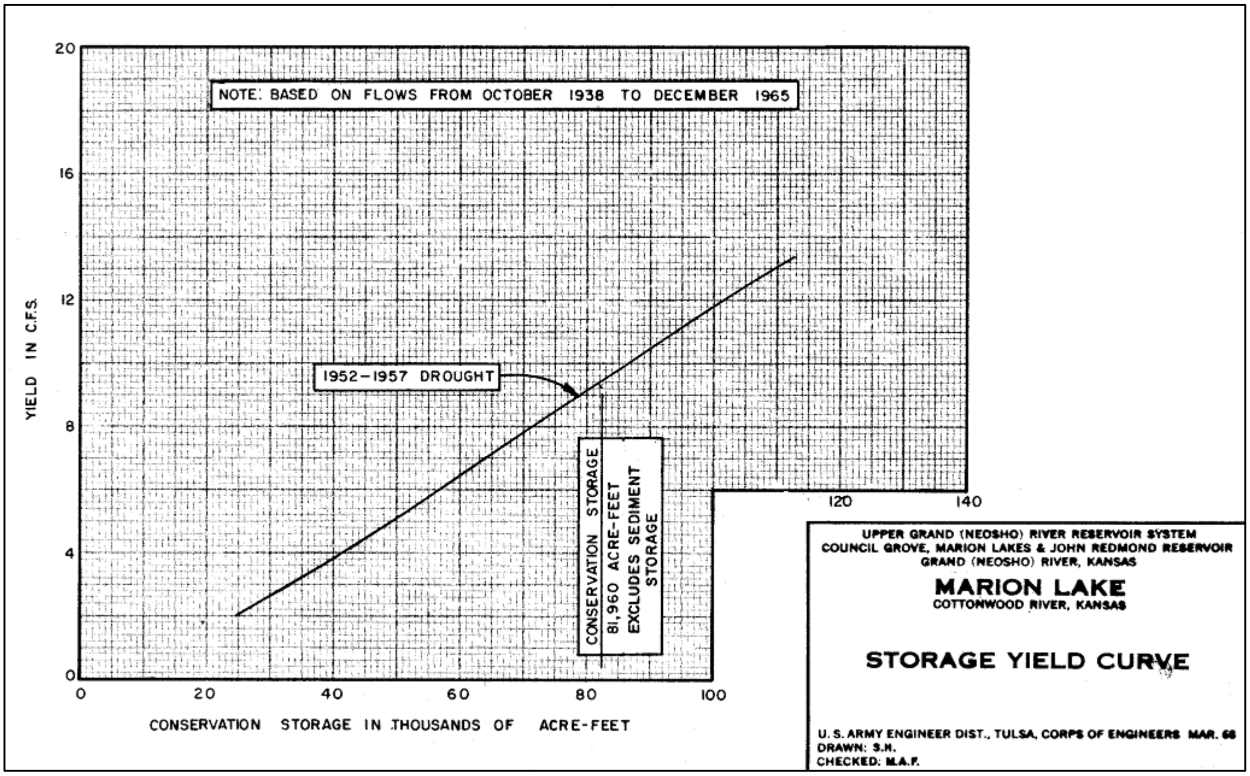

FIGURE 4: Original computation of firm yield for Marion Reservoir (from USACE, 1974).

The original water control manual for Marion Reservoir, published in 1974, reported the contract yield as 3,359 acre-feet (4.6 ft^3/s) and the water supply yield as 3,924 acre-feet (5.4 ft^3/s) for a firm yield of 7,283 acre-feet (10.0 ft^3/s). It is interesting to note that the corresponding storage-yield curve published in the 1974 manual indicates that the originally calculated firm yield was 6,805 acre-feet (9.4 ft^3/s), slightly lower than the tabulated value reported in the same document.

The Kansas Water Office, acting on behalf of the State of Kansas, entered into a contractual agreement with the U.S. Army Corps of Engineers in March 1976 for the right to utilize water supply storage in Marion Reservoir. This agreement gave the State of Kansas exclusive rights to 46.20% of the total storage space in the reservoir within the conservation pool. As defined in the agreement, this storage was to be used for municipal and industrial water supply purposes. The Federal government retained rights to the other 53.80% of the conservation storage volume for "such purposes as the United States may deem desirable," with water quality being the typical use. Use of the water supply storage commenced in December 1981.

Following the initial agreement between the U.S. Army Corps of Engineers and the State of Kansas in 1976, a second agreement was signed in June 1996 that allocated an additional 17.92% (12,500 acre-feet) of storage for the purposes of water supply, bringing the total allocation to 64.12% (44,730 acre-feet). This reallocation was the result of a study that was authorized following a memorandum of understanding signed by both parties in December 1985. A simulation of pool routing and corresponding storage was developed using a HEC-3 model with period-of-record inflow data beginning in 1940. This study, which captured the exceptional 1950s drought, assumed a conservation pool volume of 69,770 acre-feet, the projected year 2018 storage resulting from sedimentation losses (USACE 1996). A contract yield of 12.5 ft^3/s (9,074 acre-feet) resulted from the HEC-3 model computation. Since a water quality low-flow requirement of 13.1 ft^3/s exists during each July–August period, the firm yield established during this study is 25.6 ft^3/s (18,534 acre-feet).

Water quality releases for the Cottonwood River are issued by the Kansas Department of Agriculture, Division of Water Resources. Releases from Marion Reservoir are made at the request of the Kansas Water Office to satisfy these requirements. The largest water quality releases from Marion Reservoir are required during the summer months (Table 1).

TABLE 1: Seasonal water quality release schedule (ft^3/s) for Marion Reservoir.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.0	1.0	1.0	2.3	6.5	9.0	13.1	13.1	9.0	6.5	2.4	1.0

CLIMATE MODELING TECHNIQUES

Several general circulation models (GCMs) have been evaluated as part of the World Climate Research Programme's third phase of the Coupled Model Intercomparison Project (CMIP3). Each of these models has been run based on climate scenarios that differ based on the magnitude and timing of CO_2 emissions. Therefore, over 100 final model runs are available for analysis. Each GCM varies based on physical processes and feedbacks. Since future conditions are unknown, a robust set of models should be analyzed to fully capture the range of possible scenarios.

In the Intergovernmental Panel on Climate Change (IPCC) *Special Report on Emissions Scenarios*, four emissions "storylines" were defined to represent plausible economic, population, and technological scenarios for the 21st century (Nakicenovic & Swart, 2000). These scenarios can be used to bracket future climate conditions. The four scenario families are A1, A2, B1, and B2:

A1: Rapid economic growth, global population peak in the mid-21st century, global emphasis, and the rapid introduction of new and efficient technologies.

A2: Slow economic growth, continuously increasing population, regional emphasis, and slow technological change.

B1: Rapid economic growth, global population peak in the mid-21st century, global emphasis, reductions in material intensity, and introduction of ecologically friendly technology.

B2: Intermediate economic growth, continuously increasing population, regional emphasis, and fragmented technological change.

Scenario A1 has been further subdivided into three groups: A1FI, A1T, and A1B. The differences between these subgroups are based on energy technologies. Specifically, energy use for A1FI is deemed to be fossil fuel intensive, A1T is biased toward renewable energy, and A1B is a compromise between fossil fuels and renewable energy sources (Figure 5).

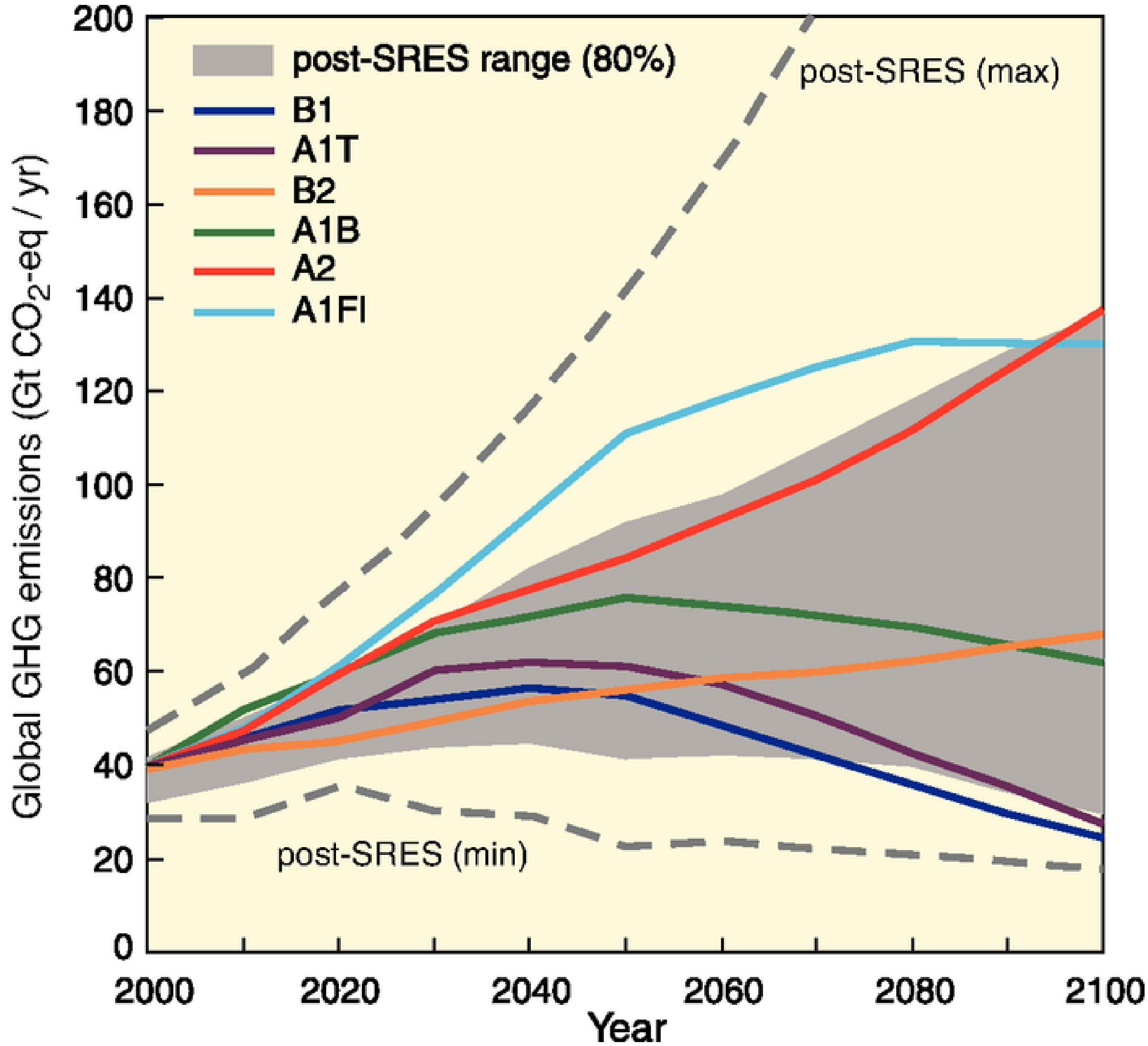

FIGURE 5: Emissions projections of IPCC scenarios (from Pachuari & Reisinger, 2007).

GCM simulations in the CMIP3 archive used in this study were typically run with grid spacing in excess of 1° latitude by 1° of longitude, which is too coarse for water resources modeling with the exception of the planet's largest river systems. For example, 1° (latitude by longitude) spacing in the central United States covers an area equal to nearly 4,000 square miles. By contrast, the watershed that contributes runoff to Marion Reservoir has an area equal to 200 square miles. It is therefore necessary to resample GCM output at a finer resolution to produce meaningful data for a reservoir and its upstream basin.

Watershed studies typically use GCM output scaled to 1/8°. Based on 1/8° (latitude by longitude) spacing, the Marion Reservoir watershed occupies all or part of 10 grid cells. The grid cell arrangement was developed for previous studies and encompasses the contiguous United States.

One technique used for downscaling GCM climate variables utilizes statistical methods. Statistical downscaling re-samples coarse GCM output to a scale appropriate for watershed studies by determining empirical relationships between large-scale processes and local variables. This type of downscaling relies on accepted statistical methods and has been widely implemented in climate studies.

In contrast to statistical downscaling, dynamic methods can also be used to translate GCM output into meaningful data on a scale appropriate for watershed studies. Dynamic downscaling uses regional climate models (RCMs), which are nested in GCM simulation output domains and simulate the finer scale physical hydrometeorological processes. This technique is computationally intensive when compared with statistical downscaling.

Although dynamic downscaling offers a physically based approach to GCM downscaling, it requires more knowledge of the underlying processes and is significantly more complex than empirically based statistical downscaling. Therefore, statistical downscaling was selected for this study, even though several disadvantages exist, including a translation of bias from the GCM, no change in the empirical relationship of the variables (stationarity), and no feedback within the climate system (Werner, 2011). Despite these drawbacks, statistical downscaling has enjoyed widespread implementation in hydrologic climate modeling studies and was deemed appropriate for this study.

According to Brekke et al. (2010), a statistical downscaling technique chosen for analysis should be:

- Well tested and documented, especially in applications in the United States.
- Automated and efficient enough to feasibly permit the downscaling of many 21st century climate projections, thereby permitting more comprehensive assessments of regional to local climate projection uncertainty.
- Capable of producing output that statistically matches historical observations.
- Capable of producing spatially continuous, fine-scale gridded output of precipitation and temperature suitable for water resources and other watershed-scale impacts analysis.

Prior to beginning this study, a gridded dataset of bias-corrected, spatially disaggregated (BCSD) statistically downscaled climate data was obtained from Dr. Andrew Wood (personal communication, 2011; Brekke et al., 2013). This dataset, which was customized for the Marion Reservoir watershed, was converted from a native GCM grid cell size and redistributed into 1/8° (latitude by longitude) spacing. The resulting grid cells, each with an area of 57 square miles, were superimposed across the Marion Reservoir watershed so that a total of 10 grid cells were used in the analysis (Figure 6).

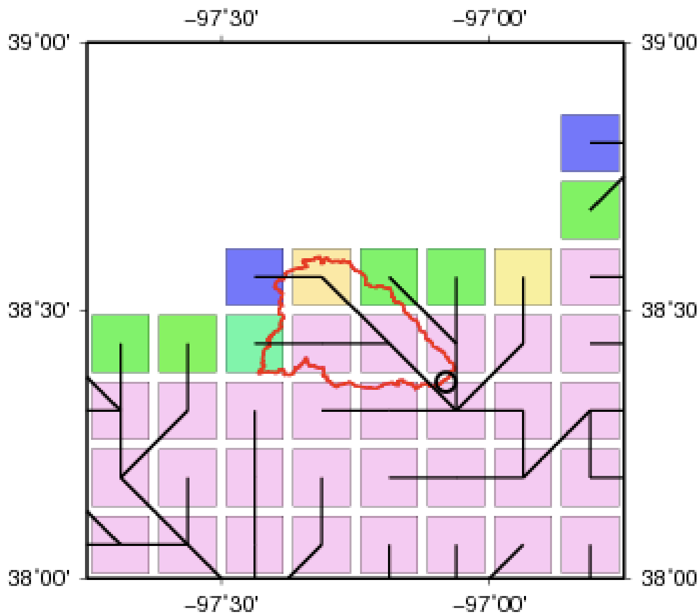

FIGURE 6: Computational grid cell arrangement for VIC analysis of the Marion Reservoir watershed.

What advantages do the BCSD outputs provide for this study? As implied by its name, BCSD is a two-step process in which the data are first corrected for bias in the GCM simulation followed by the interpolation of GCM output to a 1/8° grid cell (Wood et al., 2004). The bias-correction step operates at the GCM (2°) scale, where adjustment is made to the simulated future variables based on the overlap between simulated past variables and observed climate.

The BCSD dataset includes GCM output from the A2, A1B, and B1 emissions scenarios, as these represent high, medium, and low emissions, respectively. A total of 16 GCMs were provided for the Marion Reservoir watershed study, and output from several of the primary models included multiple generations in which adjustments were made to the underlying parameters. A total of 112 GCM model projections were analyzed in this study.

TABLE 2: Summary of GCM output included in BCSD dataset (adapted from Werner, 2011).

Model	Agency
BCCR-BCM2.0	Bjerknes Centre for Climate Research (Norway)
CGCM3.1	Canadian Centre for Climate Modeling and Analysis
CSIRO-Mk3.0	CSIRO Atmospheric Research (Australia)
CNRM-CM3	Centre National de Recherches Meteorologiques (France)

ECHO-G	Meterological Institute of the University of Bonn (Germany) and the Meteorological Institute of KMA, Model and Data Group (Korea)
GFCL-CM2.0	NOAA Geophysical Fluid Dynamics Laboratory (United States)
GFCL-CM2.1	NOAA Geophysical Fluid Dynamics Laboratory (United States)
GISS-ER	NASA Goddard Institute for Space Studies (United States)
INM-CM3.0	Institute for Numerical Mathematics (Russia)
IPSL-CM4	Institut Pierre Simon Laplace (France)
MIROC3.2 (medres)	Center for Climate System Research, University of Tokyo, and the National Institute for Environmental Studies, Frontier Research Center for Global Change (Japan)
MRI-CGCM2.3.2	Meterological Research Institute (Japan)
ECHAM5/MPI-OM	Max Planck Institute for Meteorology (Germany)
CCSM3	National Center for Atmospheric Research (United States)
PCM	National Center for Atmospheric Research (United States)
UKMO-HadCM3	Hadley Centre for Climate Prediction and Research (United Kingdom)

Several options exist for selecting a statistical analysis method for use in a watershed study, including period-change (delta) approaches as well as transient methods. Period-change approaches, which compare differences between observed and simulated datasets, are generally categorized as follows:

- Delta method
- Hybrid-Delta method
- Ensemble-informed method

The most straightforward of these techniques is a simple delta period-change method. This technique analyzes the change in variables (temperature, pressure) between and overlapping observed and simulated climate time periods (e.g., 1950–1999) and then applies the change to a future time period (e.g., 2030–2059). The Delta method is applied on a monthly basis (Brekke et al., 2010).

Another technique similar to the Delta method is the Hybrid-Delta method, where adjustment factors are also computed based on an analysis between changes in the overlapping observed and simulated climate time periods. Unlike the Delta method, the Hybrid-Delta method uses adjustment factors that are based on monthly variability (instead of monthly means) (Brekke et al., 2010). Therefore, monthly climate changes are treated differently by year type.

Ensemble-informed methodology is nearly identical to the Hybrid-Delta method except for one key point: variable distributions are constructed from an ensemble of all simulations instead of from individual model runs (Brekke et al., 2010). Climate projections are categorized by type (e.g., warm and dry, hot and dry, etc.). Each class of ensembles (typically four categories plus a central tendency) is then analyzed in the same manner as the Hybrid-Delta method.

One significant drawback of the period-change approaches discussed so far is their inability to represent climate variation in the context of a continuous time series. Instead, the period-change approached provide “snapshots” of some future period as compared with the present. This is a distinct limitation when investigating the impact of climate change on hydrologic processes, which are generally expressed in the form of a time series.

An alternative to the period-change approach is the transient (time-evolving) method of analysis. Unlike the period-change approach, transient analysis does not capture the step change in climate variables between two specific time periods. Instead, it captures the envelope of possibility over the duration of the simulation (Gangopadhyay & Pruitt, 2011). This approach is advantageous for a dynamic system such as reservoir storage and water supply because it incorporates time-series information into the analysis.

MODEL DEVELOPMENT

The basis of the relationship between storage volume and yield is that stream flow is variable over time, and to provide water for a continuous flow rate (demand) that is at times greater than stream flow, water must be stored when stream flow is greater than demand (surplus) for use when stream flow is less than demand (deficit). *Firm yield* is defined as the largest consistent demand that can be provided throughout a period of record of stream flow (USACE, 2011). The storage requirement is based on the demand of water supply coupled with the variability of stream flow. The ability to store water increases firm yield by allowing demand to be met using water held as conservation storage when stream flow falls below the level of demand. Diversion of the firm yield brings the stored water volume exactly to zero once during the period of record, during what is defined as the *critical period* for that yield and storage capacity (USACE, 2011). The periods that require the use of stored water occur multiple times during the period of record, with the most extreme occurrence constituting the critical period.

The development of a yield model for Marion Reservoir began with the analysis of a statistically downscaled BCSD dataset for the Marion Reservoir watershed. The gridded 1/8° cells were disaggregated to a daily time step. Even with the downscaling of the climate variables, the Marion Reservoir watershed is sufficiently small that it only occupies all or part of 10 grid cells.

Disaggregation of the climate model output to a daily time step is a key process in the development of a hydrologic model. Also, since the ultimate goal was an analysis of the firm yield of the reservoir based on future climate, the period-change methods of analysis (e.g., the Delta method) were deemed inappropriate for this study. Instead, a time-transient analysis was chosen. Transient analysis is particularly useful for a long-term hydrologic analysis because it treats the simulation as a time series instead of a snapshot in time. This distinction is especially important for a reservoir yield study because firm yield is defined by a critical period in either the observed past or the simulated future, which can only be determined by analyzing a continuous time series. If a period-change approach were used instead, the critical period could be missed.

The Variable Infiltration Capacity (VIC) model, which has been used in many previous hydrologic climate studies, was chosen for this study. This model is distributed and physically based, and it treats evapotranspiration and infiltration as separate processes instead of lumping them together as a single loss category. An advantage of the VIC model is that it treats the subsurface soil layers as distinct horizons instead of a single zone. Other attributes include energy balance and aerodynamic calculations for evapotranspiration and nonlinear recession for base flow (AMEC, 2011).

Development of the VIC model began over a decade ago in the Climate Studies Group at the University of Washington, where the source code continues to be maintained (Liang, 1994). The model is written for UNIX/LINUX operating systems and must be compiled before running.

One important aspect of the VIC model is that it operates on a daily time step. As previously noted, downscaled GCM output was disaggregated to a daily interval for this reason. Requirements for grid cell spacing are variable, and a 1/8° grid cell size is acceptable.

Evapotranspiration and infiltration losses are computed on a cell-by-cell basis. To account for these processes, vegetation and soil parameters must be input for each cell. These parameters, which were developed during the North American Land Data Assimilation System (NLDAS) project (Mitchell et al., 2004), were also obtained from Dr. Andrew Wood (personal communication, 2011).

Once the VIC model was compiled and set up for scenario processing, it was necessary to determine which (if any) of the 112 statistically downscaled BCSD climate model scenarios should be culled from the dataset in order to manage the large amount of data available for analysis.

A significant obstacle that precludes any quick decisions about trimming the list of scenarios is the inability to weight the scenarios. In fact, the basis for culling is weak (Gangopadhyay & Pruitt 2011). Relevant literature suggests that all scenarios be carried forward in an analysis because no sound basis exists for favoring one scenario or a collection of scenarios over any of the others (Gangopadhyay & Pruitt, 2011; Werner, 2011). All scenarios were therefore included in this analysis.

The following steps (in chronological order) were required to develop Marion Reservoir inflow hydrographs using each of the 112 available climate simulations from the BCSD dataset:

1. Obtain a statistically downscaled BCSD climate dataset for the Marion Reservoir watershed.
2. Obtain the NLDAS vegetation and soil dataset for the watershed.
3. Generate a computational grid for the watershed by overlaying the watershed polygons and extracting grid cells.
4. Compile the source code for the VIC and routing models.
5. Define the state variables and pathnames for the VIC and routing models.
6. Run the VIC model and generate the cell flux output.
7. Run the routing model and generate the time series hydrographs for the watershed.

If 112 climate scenarios or even a large subset are to be analyzed, these seven steps will quickly become time consuming, as steps 5–7 must be repeated for each scenario. It is recommended that scripting be used to automate these tasks and minimize the repetitive input that must be completed. The Marion Reservoir watershed model was run on a LINUX machine, and Bourne Again Shell (BASH) scripting minimized the repetitive effort by changing pathnames, creating new subdirectories, and running the VIC and routing models automatically for each scenario.

The output for each grid cell within the VIC model is treated independently, but in a watershed study, the cumulative hydrograph at some point within the basin is of greatest interest. To compute inflow hydrographs for Marion Reservoir, a separate modeling routine developed by Lohmann et al. (1998) was required. The routing model source code, also written for UNIX/LINUX and also requiring compilation prior to running, takes VIC runoff output for each grid cell (termed "flux") and generates a combined hydrograph for the period of analysis.

The observed and simulated inflow hydrographs were calibrated by adjusting parameters in the VIC model. Specifically, the main control parameters that were adjusted included base flow (b_i), soil depth (w_s), and infiltration (d_s). These parameters were adjusted based on tolerances provided in the online documentation for the VIC model. Once calibration was performed, calibration (measured as R^2) was maximized at 0.86 for the annual data. Monthly inflows were calibrated so that a maximum value of $R^2 = 0.77$ was achieved while remaining within VIC model parameter guidelines (Figure 7).

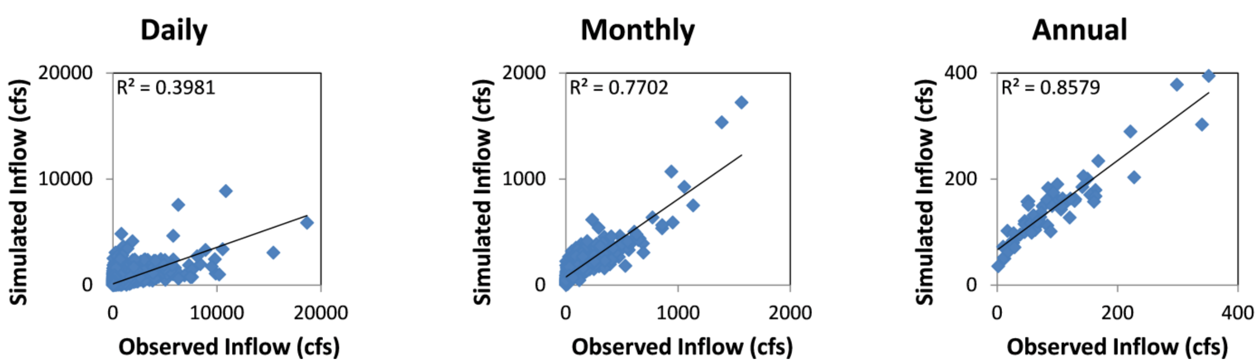

FIGURE 7: Correlation between daily, monthly, and annual observed and simulated inflow for Marion Reservoir.

Daily observed and simulated inflow was found to be the least correlated dataset ($R^2 = 0.40$) following calibration. However, the overall degree of correlation was deemed acceptable because of the decision to model reservoir yield as a monthly variable. A certain amount of bias nonetheless remained in the VIC model calibration as evidenced by $R^2 = 0.77$, and this residual bias likely resulted from an imperfect representation of soil physics in the model (USBR, 2012). Since the Marion Reservoir watershed is small, small-scale processes are going to be more important than they would be in a large basin. Relevant literature suggests that the VIC model has been used most extensively to model very large watersheds (Abdulla et al., 1996; Wood et al., 1997; Hamlet et al., 1999; Nijssen et al., 2001; USBR, 2012).

Output from the VIC (and routing) model was required for the determination of reservoir firm yield. For the Marion Reservoir water supply study, these hydrographs were used to create a mass balance depicting storage:

$$\text{Storage}(t) = \max[\text{Storage}(t - 1) + \text{Inflow}(t) - \text{Release}(t), \text{storage capacity}] \quad (1)$$

In theory, this mass balance equation results in a simple computation of firm yield based on the simulated hydrographs coupled with an elevation-storage function for the reservoir. In practice, however, this step is both time consuming and computationally intensive (USACE, 2011).

Iterative simulation is required to evaluate Equation 1 for the reservoir over a period of simulation. Each time step depends not only on its variables but also on the variables carried over from the previous time step. Although construction of Marion Reservoir wasn't completed until 1968, simulated pool elevations dating to 1940 were available from USACE (Tulsa District). The historical BCSD dataset used in this study begins in 1949, however, so the initial date of the routing simulation was set as the first day of that year (01 Jan 1949). Daily ordinates were modeled through an ending date of 31 Dec 2098. Therefore, nearly 55,000 daily records were analyzed.

During the 1996 water supply reallocation study performed for Marion Reservoir, 50-year planning conditions were modeled, assuming a conservation pool volume of 69,770 acre-feet (USACE, 1996). This condition was assumed to result from continuous sedimentation beginning at the time of project completion (1968) through a 50-year planning horizon ending in 2018. The computation that was used assumed a loss of 16,626 acre-feet of conservation storage.

Since incremental losses were previously estimated for every year from 1983 through 2067, the development of this pilot study provided a good opportunity to revisit the assumed sedimentation loss rate and determine if conservation storage really has decreased as quickly as predicted. The 1996 reallocation study assumed that the conservation pool would have 72,205 acre-feet of conservation storage remaining by 2010, a loss of 12,742 acre-feet to sedimentation. The reservoir underwent a bathymetric resurvey in 2010, however, and the conservation storage was estimated to be 80,659 acre-feet, or a 4,288 acre-foot loss. The loss of available conservation storage due to sedimentation is clearly much lower than it what was assumed to have been, and it is clear that the volume adopted for the 1996 reallocation study is significantly lower than what will be observed at the end of the 50-year planning horizon in 2018.

For this study, firm yield was recalculated using elevation-area-capacity data generated from the 2010 Marion Reservoir bathymetric survey (Figure 8). Mass balance routing was used in conjunction with a monthly time step and an assumption that during the course of any given month, flood operations would lower the reservoir elevation to the conservation pool. A simulated inflow hydrograph, which was originally developed for the USACE (Tulsa District) RiverWare model that includes Marion Reservoir, was used for the routing computation. The data were provided as a daily time step and subsequently re-averaged to a monthly time step. It is important to note that the inflow hydrograph dataset used for the development of water supply routing in this study differs from the dataset that was used in the 1996 reallocation study.

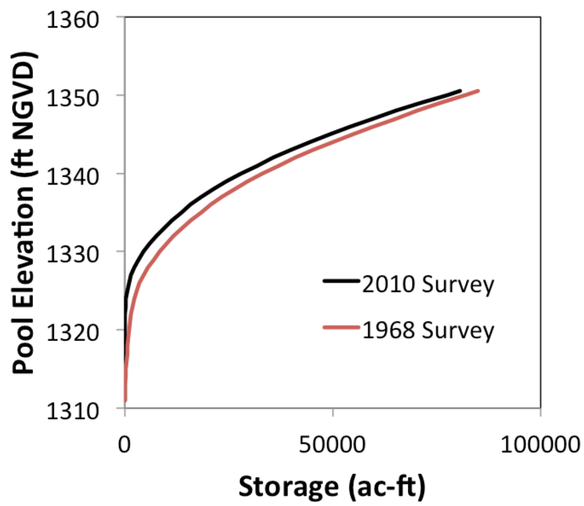

FIGURE 8: Storage curve for Marion Reservoir.

An elevation of 1,350.5 feet was entered for the first day of the routing simulation (01 Jan 1949), since this is the elevation at which 100% of conservation storage is filled. The initial storage value was calculated through linear interpolation by comparing the initial elevation with the elevation-capacity curve, and each subsequent storage value was computed as a mass balance combining the storage, precipitation, evaporation, and differential flow volumes from the previous time step. Once the storage value was determined for the current time step, elevation was calculated through linear interpolation by comparing the storage value (as volume) with the elevation-area-capacity curve. The iterative calculation then continued step-by-step to the next successive time ordinate.

Since significant changes in reservoir storage tend to occur on the order of days or even weeks, a decision was made to carry out the analysis using a monthly time step. This decision was supported in part by the assumption that flood storage in Marion Reservoir could be neglected during the analysis because the pool would likely only remain above the top of the conservation pool for periods of time not exceeding one month. By adopting a monthly time step, in other words, the total number of records could be significantly reduced while justifying the exclusion of flood control rules from the simulation. The number of records was consequently reduced from nearly 55,000 to 1,800.

Since the mass balance for any given monthly record relies on the previous month for calculation, a change to any of the 1,800 monthly records requires that the remaining records be recalculated as well. The only practical ways in which this analysis could be carried out were by 1) using a simulation model such as HEC-ResSim or WSROUT, 2) using a spreadsheet method, or 3) using a specialized mathematical programming and analysis environment such as MATLAB. All data were available in record form, so Microsoft Excel was initially selected as the method of choice, and a spreadsheet model was created.

After consideration of possible ways to automate the iterative calculation process in Microsoft Excel, it was determined that the goal-seek function offered the most practical way to calculate firm yield. Each spreadsheet was set up so that the column of pool elevations calculated in an iterative step-by-step process was included in a MIN function. The bottom of the conservation pool (which is the minimum allocated storage of the reservoir) is at elevation 1320.0 feet. By setting up the column of outflow values with the goal-seek function and assigning the same outflow value to all time steps (since firm yield is a constant value), iteration was performed between the outflow column and the pool elevation so that the elevation defined by the MIN function was equal to 1,320.0 feet. Iteration then proceeded automatically through all time steps in the spreadsheet until an outflow value was found that resulted in a single minimum pool elevation of 1,320.0 feet. This outflow value is the constant rate of withdrawal from the conservation pool that is required to meet water supply allocation, which is by definition the firm yield.

Even with the number of records for each of the 112 scenarios pared down substantially by converting the output to a monthly time step, spreadsheet modeling in Microsoft Excel was cumbersome and time consuming. Conversion of the spreadsheet files from XML (*.xlsx) to binary format (*.xlsb) was useful in keeping the files manageable as it significantly reduced the file size.

Ultimately, even the conversion of data to a binary format did not result in optimal performance of the routing computations within the spreadsheet, given the size of the data files and the number of iterative calculations required. Although the spreadsheet routing did, in fact, work for the purposes of this study, it became increasingly cumbersome and was eventually abandoned in favor of MATLAB. Dr. David Raff (USACE) wrote a numerical routing script that was used, along with the assumptions developed for the spreadsheet routing, to construct the water supply yield model.

Once the routing results were computed using the MATLAB model, a discrepancy was noted between the observed and simulated inflow hydrographs, highlighting the imperfect match of physical processes between the VIC model and the actual processes that occur in the watershed. Since significant bias remained in the simulated inflow hydrograph following the VIC model calibration, additional bias correction was necessary. This correction was performed by independently taking the observed and simulated inflow hydrographs from the historical overlap period (1949–2008) and developing a cumulative distribution function (CDF) for each. The CDF was constructed by taking the full hydrograph for the observed dataset, binning the data by month, and then assigning probabilities (P) to the data by applying the Weibull formula:

$$P = \frac{m}{n+1} \tag{2}$$

This expression requires that the data be sorted so that rank (m) is compared to the total number of data points in the series (n). The calculation is performed for each of the data points, resulting in a CDF for each of the monthly datasets. The same procedure was then repeated for the simulated dataset. Following the development of both cumulative distribution functions for each of the monthly datasets, each of the simulated monthly CDFs was then compared with the observed monthly CDFs. A ratio between the observed and simulated value for each probability pair was then computed, and this ratio was designated as the bias correction factor corresponding to the specific probability (Figure 9).

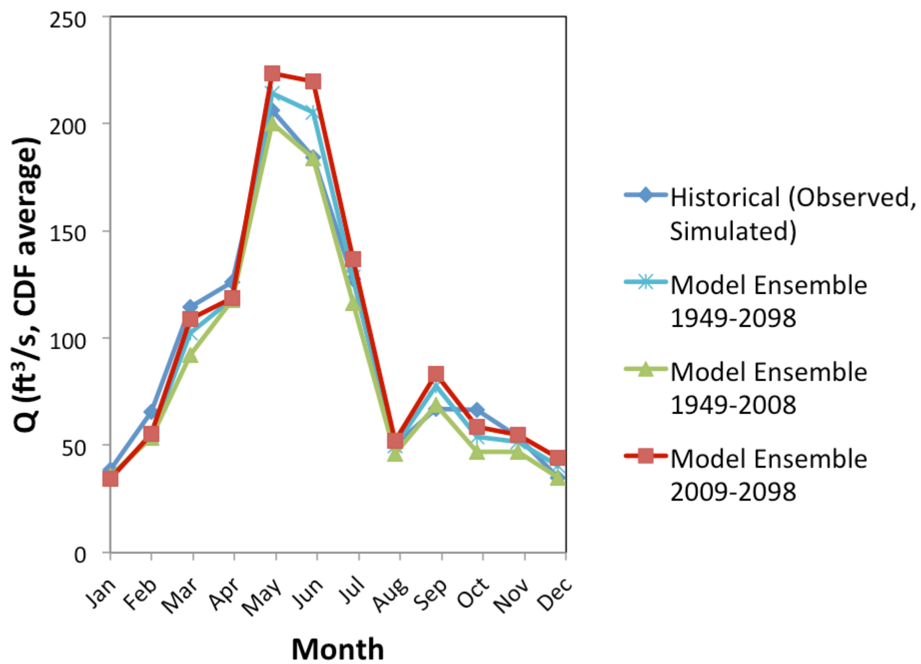

FIGURE 9: Inflow hydrograph ordinates for Marion Reservoir plotted as monthly CDF averages; the historical observed and historical simulated distributions, which overlap, have been bias corrected, and the resulting correction factors have been applied to the model projections.

After the bias correction factors were computed for the range of probabilities of each of the monthly distributions, they were then applied to the ordinates of the historical simulation hydrograph. Although residual bias remained in the modeling process after calibration, the timing of observed inflow was for the most part replicated accurately in the VIC simulation (Figure 10).

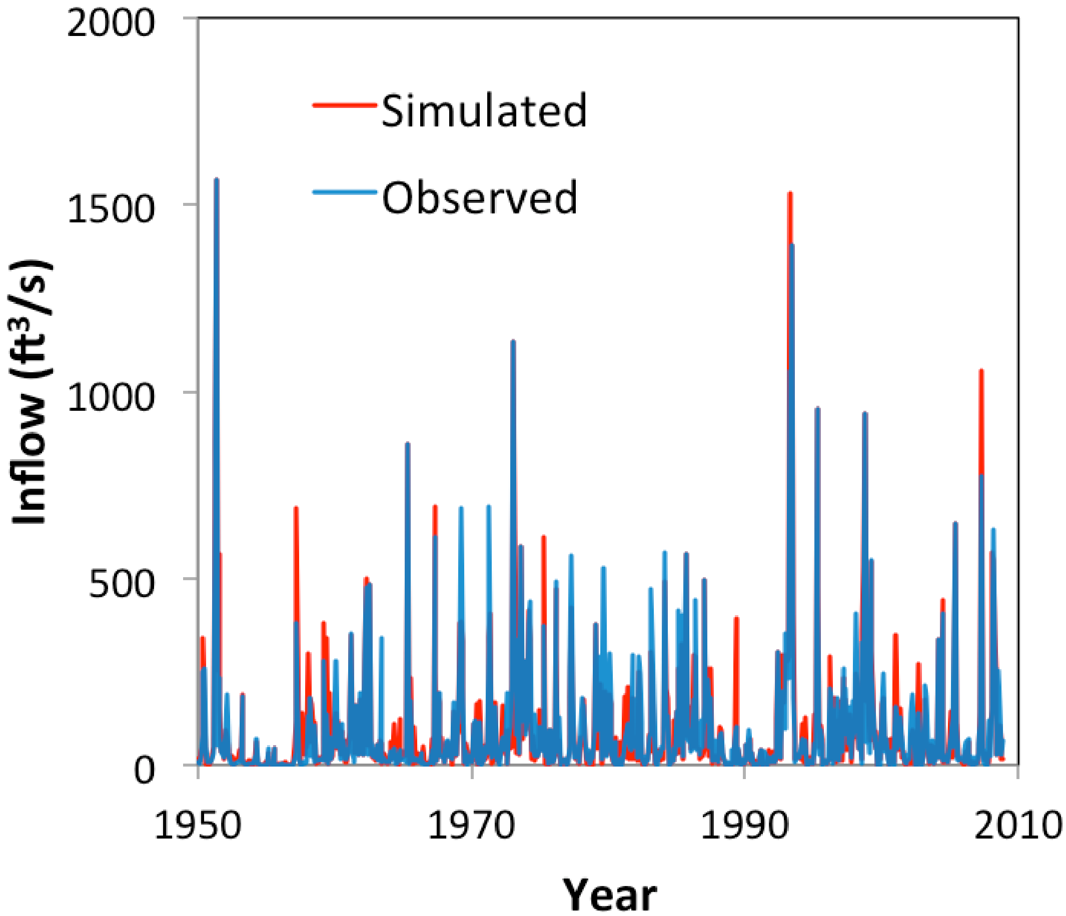

FIGURE 10: Monthly observed and simulated inflows for Marion Reservoir, 1949–2008.

Application of the bias correction factors to the simulated hydrograph period within the historical overlap period improved the correlation between the two datasets (Figure 11). Although some bias remains, the adjustment to the simulated hydrograph during the historical overlap period compares favorably with the computed firm yield from the observed dataset (33.5 ft^3/s), resulting in a difference of 2,244 acre-feet of water.

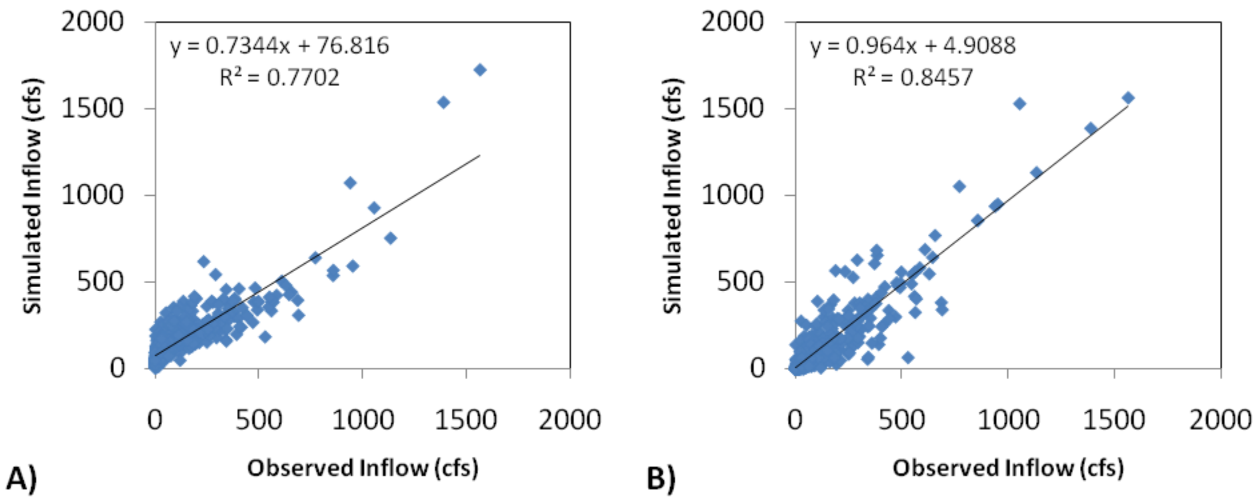

FIGURE 11: Improvement in correlation between A) the historical observed and VIC simulated monthly hydrographs without additional bias correction, and B) the historical observed and VIC simulated monthly hydrographs with additional bias correction developed from cumulative distribution functions of monthly-binned ordinates.

Following the bias correction of the simulated hydrograph from the historical overlap period, yield modeling with the simulated dataset was able to accurately reproduce the timing of the critical period, which occurred in 1957 (Figure 12). The 1996 study reported a firm yield of 25.6 ft^3/s for the project (contract yield and water quality release), while this study found that the firm yield for the reservoir is 33.5 ft^3/s. The difference between the two results is not inconsequential, as it equates to a volume of 5,719 acre-feet over a one-year period. This can be explained by the difference in data sources and by computational differences between this study and the HEC-3 routines used in the 1996 study. Since the inflow record taken from the USACE (Tulsa District) RiverWare model is considered to be the most recent dataset, and since the bathymetric survey used in this study is also the most current data available, the computed firm yield of 33.5 ft^3/s is considered to be a defensible calculation and therefore carried forward in this study.

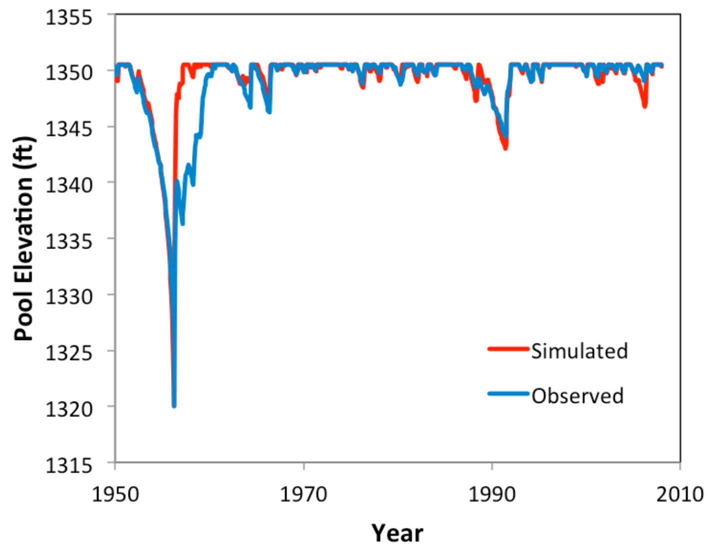

FIGURE 12: Monthly observed and simulated Marion Reservoir firm yield calculations (as critical period), 1949–2008.

Bias correction factors were then applied to each of the hydrographs generated with VIC from the 112 unique climate projections that were analyzed in the study. Specifically, all time series data in each of the 112 climate projection hydrographs were assigned correction factors from the appropriate monthly CDF corresponding to each ordinate. Since the correction factors were distributed across a range of probabilities, linear interpolation was used to develop the corrected hydrographs.

RESULTS AND DISCUSSION

Projected temperature and precipitation trends from each of the 112 BCSD model projections were analyzed to support conclusions drawn from the A2, B1, and A1B emissions scenarios yield studies. To look at a "snapshot" of these variables, a planning horizon of 40 years was chosen. Both of these variables were analyzed based on the year 2050.

Temperature provided the most straightforward analysis with regard to climate variability across the Marion Reservoir watershed. All models projected an increase in mean temperature through the year 2050, and based on Weibull position plotting, the median increase in mean temperature is projected to be +4.76°F (Figure 13). A mean temperature increase of at least 2.96°F was projected by 90% of the simulation models. Maurer and Hidalgo (2008) found that the BCSD method reproduces temperature with greater skill than precipitation.

Precipitation simulations for the year 2050 are evenly split, with half of the models projecting more annual rainfall and the other half projecting less. The majority of the models project that the change in annual rainfall will be ±20%. Within the Marion Reservoir watershed, this is within ±4 inches, which falls within the current range of annual rainfall variability. The Marion Reservoir watershed receives (on average) approximately 20 inches of snowfall a year, which equates to 2–3 inches of liquid equivalent precipitation. Although a seasonal analysis was not performed, it is assumed that the model consensus trend to a warmer climate by year 2050 may shift some of this precipitation to rainfall.

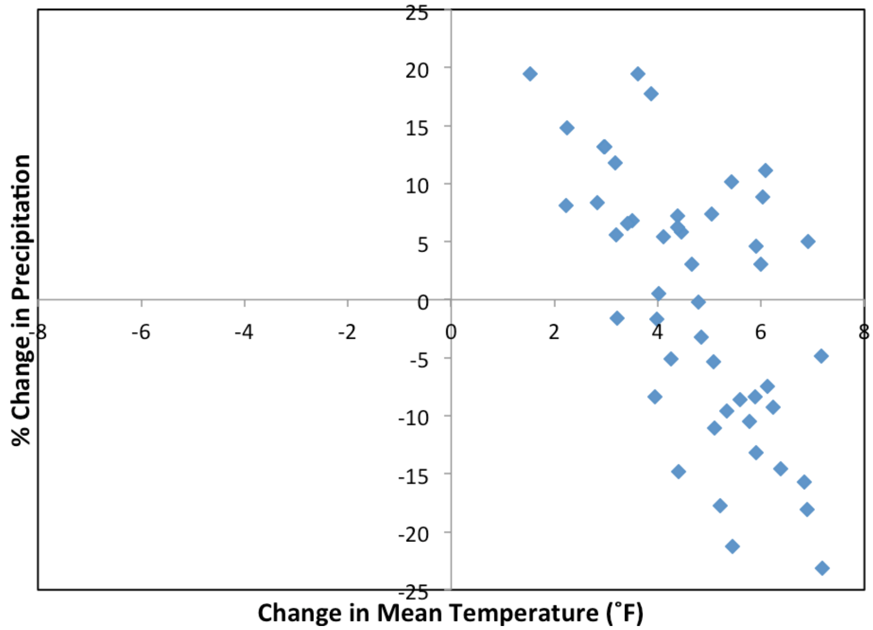

FIGURE 13: Quadrant plot of year 2050 temperature and precipitation for the Marion Reservoir watershed denoting “cooler, wetter,” “cooler, drier,” “warmer, wetter,” and “warmer, drier” conditions. Change is measured from the 1961-1990 baseline average (from Maurer et al., 2007; Zganjar et al., 2009).

The A1B projections, which represent a balance between fossil fuels and “green” energy resources, were further investigated for future trends in temperature and precipitation within the Marion Reservoir watershed. These projections all simulate warmer temperatures through the end of the study period. The change in annual mean air temperature (from present conditions) by year 2098 across the model ensemble ranges from +2°C to +8°C (Figure 14).

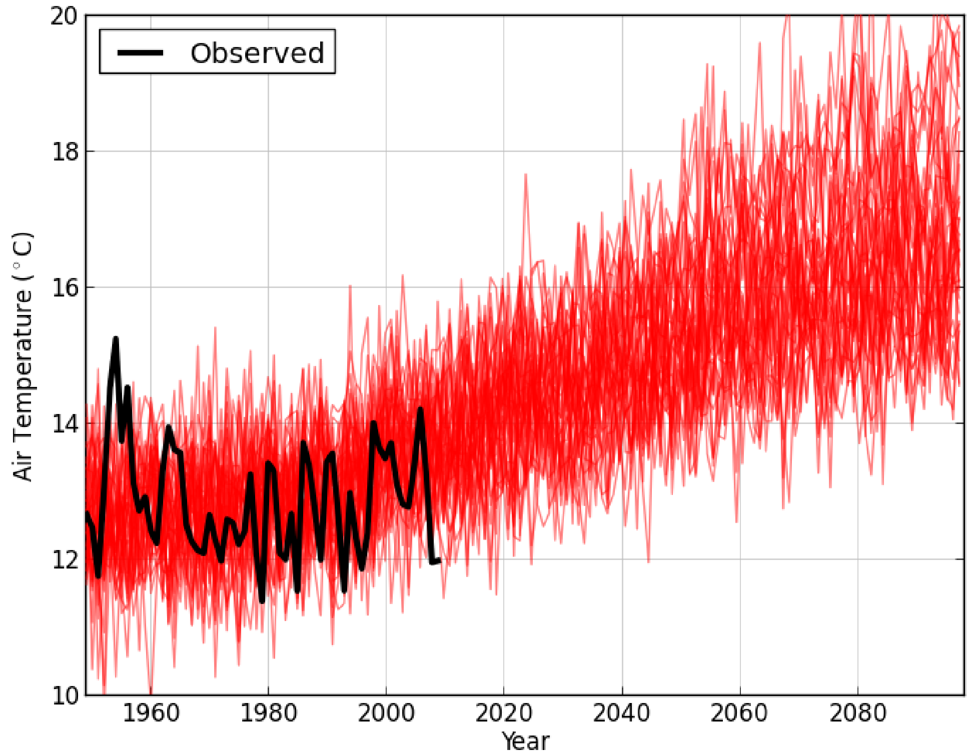

FIGURE 14: A1B emissions scenario model projections for annual mean air temperature through the year 2098. The observed temperature trend is plotted through 2009.

Model results are less straightforward with respect to future precipitation trends. It has been demonstrated with the A1B projections that the climate models project a warmer future in the watershed above Marion Reservoir. However, no clear precipitation trend emerges from the ensemble of A1B projections, which is consistent with the findings that were presented in Figure 13. The A1B ensemble mean does increase by 50 mm/year over the duration of the simulation, which is equivalent to an increase of 2 inches of annual precipitation (Figure 15).

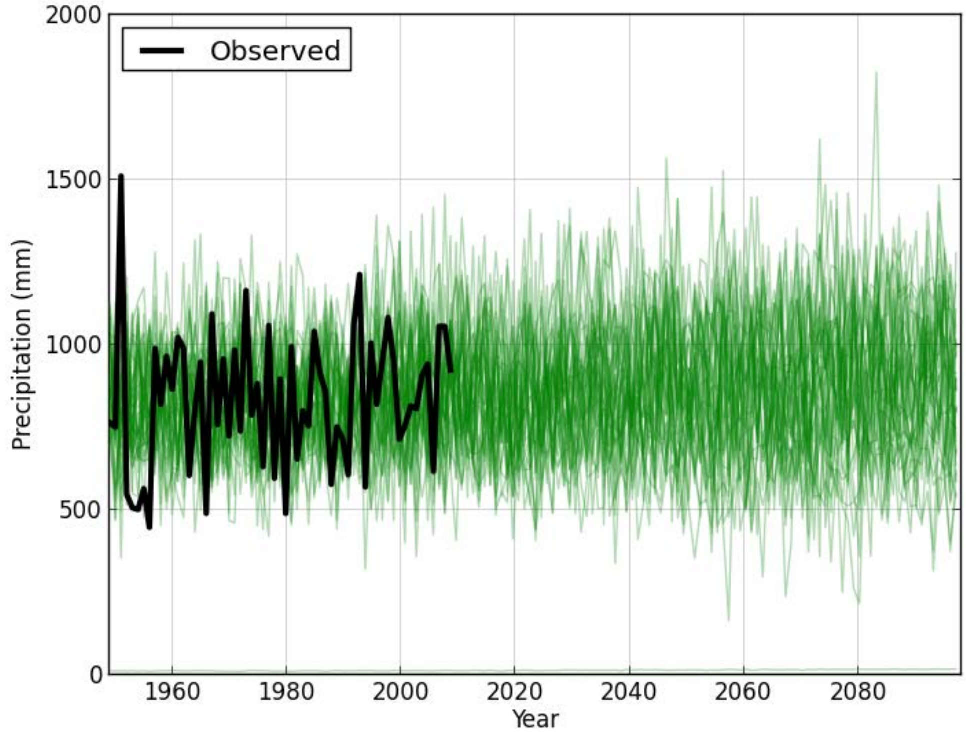

FIGURE 15: A1B emissions scenario model projections for annual precipitation through the year 2098. The observed precipitation trend is plotted through 2009.

Results from the A2 emission scenario are more extreme than the A1B scenario with respect to the rise in mean annual air temperature during the future simulation period. This does not necessarily imply an increased vulnerability to drought in the Marion Reservoir watershed, however, as many of these model projections also forecast a wetter future.

Each of the A1B and A2 model projection hydrographs, generated by running the VIC output through the routing code developed by Lohmann et al. (1998), were then adjusted using the CDF procedure discussed in the previous section. Results for the B1 emissions scenario were omitted from the yield analysis since it represents a greater departure from a fossil fuel economy than either the A2 or A1B scenarios, so it may be less realistic than the latter two scenarios. The resulting hydrographs show no appreciable change in mean stream flow through the year 2098 (Fiqure 16).

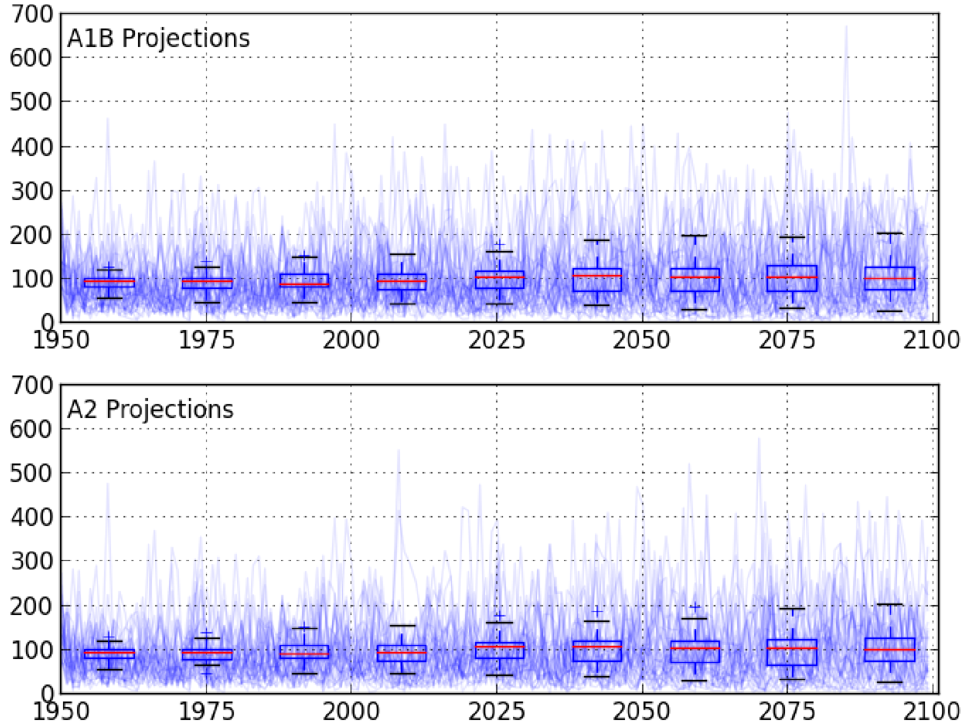

FIGURE 16: Inflow hydrographs (annual mean) computed for Marion Reservoir from the A1B and A2 model projections. Box plots depict 30-year period means.

The current water supply storage owned by the State of Kansas in Marion Reservoir is 44,730 acre-feet, and the contracted annual amount is 1,834 acre-feet. These contracts, which deliver water for municipal use, require a dependable yield of 2.53 ft^3/s. The existing contract yield of 20.4 ft^3/s can clearly meet the demand of the current water supply contracts. Does this hold true, however, for future yield?

A limited analysis to help inform an answer to this question was conducted with the A1B and A2 hydrographs presented in Figure 16 routed through the yield model for the entire study period ending in the year 2098. Future demand was not considered in this study. The watershed is small and rural; demand growth has been stagnant, and there is no reason to assume that this will change. Aside from temperature and precipitation, no other water supply variables were considered.

Changes in precipitation in conjunction with changes in evapotranspiration and hydrologic runoff produced ensembles that, for the most part, indicate no major changes in firm yield (Figure 17). The A1B and A2 model projections simulate a slight increase in firm yield through the year 2098. Ensemble mean values of firm yield for the two emissions scenarios range from 50 to 60 ft^3/s (approximately) through the year 2098.

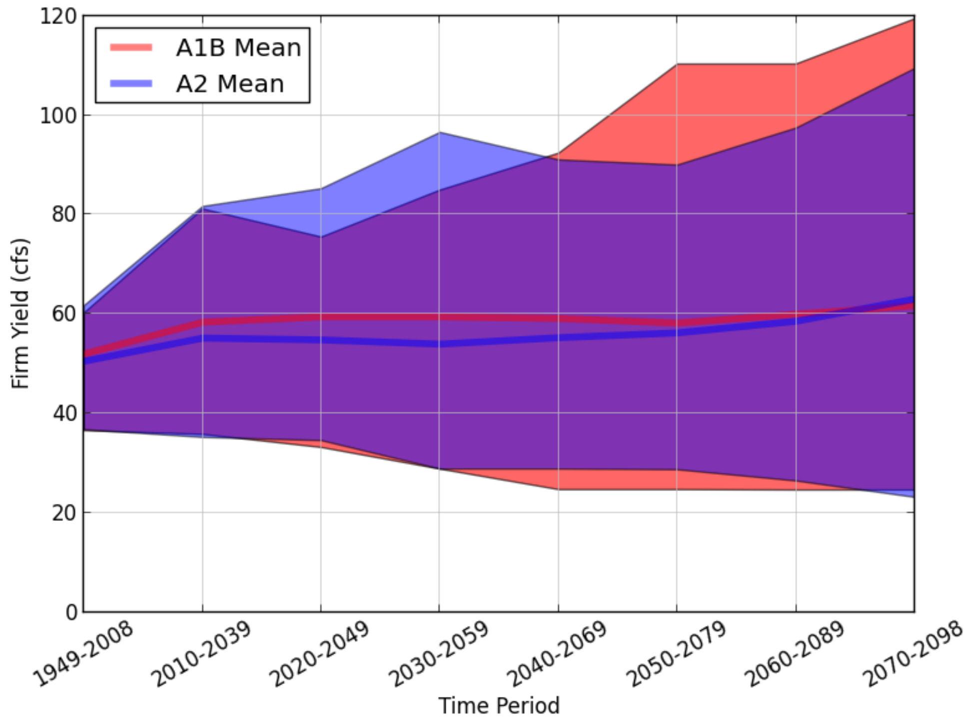

FIGURE 17: Firm yield for the A1B and A2 emissions scenarios, calculated as 30-year ensemble mean values; the upper and lower bounds of 30-year firm yields for all A1B and A2 emissions scenarios are plotted as shaded areas.

Ensemble firm yield calculations for the 1949–2008 historical period are higher than the observed firm yield for the same period. It is not surprising that the ensemble mean value is higher than the observed 33.5 ft^3/s, but the lower bound computed from all projections is higher than the observed firm yield as well. This can be partially explained by remaining bias following the monthly CDF correction discussed in the previous section. The climate model projections are overestimating the Marion Reservoir inflow hydrographs during the summer months (see Figure 10). The differential volume over the course of a month is on the order of 10^3 acre-feet, which in turn contributes to the overestimation of firm yield during the overlap period.

Mean ensemble values of firm yield are too general for water supply planning. Firm yield is event driven (i.e., historical drought), and knowledge of whether or not a dependable volume of water can be delivered to a customer is a key element in planning and executing the terms of a water supply contract. Projections of the mean firm yield do provide insight about model trends (in this case, firm yield computed from both emissions scenarios remains nearly stationary).

Water supply planning is well suited for risk-based analysis, and the interpretation of results from this type of study would ideally be characterized in terms of probability. Contracts are based on the dependable yield that a reservoir can deliver, which is derived from an analysis of historical droughts. If drought(s) of greater magnitude may occur in conjunction with future climate conditions, it would be important to plan for these. Likewise, if future climate conditions are likely to be less susceptible to drought, renegotiating existing contracts with an increase in dependable yield may be a viable option.

Characterization of the ensemble of climate model projections used in this study in terms of absolute risk would require a random sample of the entire range of possible outcomes. As has previously been stated, however, this is not the case. The individual members of the ensemble are mutually dependent. Any statistical analysis of the ensemble therefore reveals characteristics that pertain to the models themselves, not to the true risk as applied to the range of all possible outcomes.

Unfortunately, climate projections cannot be used to characterize absolute risk. Each climate model represents an outcome from state-of-the-art knowledge, or in other words, a "best guess." Even when a collection of models is analyzed as an ensemble, which in the case of this study is 112 climate projections generated from a combination of 16 GCMs and 3 emissions scenarios, the results must be considered as a collection of best guesses and not a robust sampling of possible outcomes. What can be addressed, however, is the *relative* confidence in being able to meet existing water supply contracts. Since absolute risk cannot be quantified for future dependable yield, the results of the study must be characterized either in terms of consensus-based risk or in terms of specific outcomes.

Existing contracts at Marion Reservoir, which deliver water for municipal use, require a dependable yield of 2.53 ft^3/s. Since the current firm yield of the reservoir is 33.5 ft^3/s, or 24,250 acre-feet, existing contracts with the City of Hillsboro, City of Marion, and City of Peabody will be met, and additional contracts may be viable (Table 3). Since only 1,834 acre-feet of water supply storage is currently utilized, over 22,000 acre-feet remains available for potential use.

TABLE 3: Terms of existing Marion Reservoir water supply contracts.

Contract No.	Customer	Ending Date	Ann. Contract (ac-ft)	Dependable Yield (ft^3/s)
80-1	City of Hillsboro	12/22/2021	921	1.27
81-4	City of Marion	10/3/2023	729	1.01
99-1	City of Peabody	4/9/2039	184	0.25

The envelope of possible future outcomes, based on T and P projections from the A1B and A2 scenarios, suggests that future firm yield will not differ significantly from the current firm yield. The upper and lower bounds of the analysis expand with respect to time due to model uncertainty and differences between the emissions scenarios (the upper bound more aggressively than the lower bound), but given the nearly stationary behavior of the ensemble means, the model consensus portrays future water supply conditions that look similar to present conditions. Based on the model results, the existing contracts at Marion Reservoir appear to be sustainable through the lifetime of the agreements with additional contract capacity that is not currently utilized.

A prudent approach to managing water supply contracts at Marion Reservoir may therefore include monitoring the firm yield on a regular interval, such as a moving 30-year mean. The existing water supply contracts expire between 2021 and 2039, and prior to the expiration and presumable extension of these agreements, the future firm yield can be recomputed, taking advantage of new climate forcings and general improvements in the state of climate modeling. Upper and lower firm yield thresholds can be set that trigger analysis, either because additional contracts are sought or because changing conditions have jeopardized existing contracts. If, for example, a firm yield threshold on the lower bound is reached, then an individual projection or collection of projections that track closely with the threshold criteria can be analyzed in greater detail to make informed decisions about future water supply contracts.

Unlike coastal or mountainous areas where changes in sea level or snowpack elevation may be more easily observed, climate impacts on water supply reservoirs in the Great Plains are less obvious. Climate projection ensembles do not show pronounced uniformity in precipitation changes in this region, although the ensemble mean does trend toward more net precipitation. Since mean annual temperature does show an upward trend, the inter-annual distribution of precipitation will be critical, as evaporative losses may increase. Other factors, including soil moisture, base flow, and sedimentation rates, will also affect the water budget of the basin and available storage in Marion Reservoir. All of these variables will require detailed study as the practice of climate prediction evolves if the long-term impacts on water supply at Marion Reservoir (or any USACE-owned dam at which water supply is an authorized purpose) are going to be quantified.

The results of this study do support the formulation of important qualitative conclusions with respect to the Marion Reservoir watershed. Climate model projections unanimously simulate warmer temperatures in the future. Half of them predict in increase in annual precipitation. Most of the model projections indicate that future precipitation will remain within ±10% of current annual values. When viewed as an ensemble, the model projections do not indicate that stream flow will change appreciably during the future. Yield modeling of projected hydrographs shows little change in 30-year mean values. . Although future demand was not considered, the Marion Reservoir watershed is a small, rural area with stagnant demand growth. There is no current basis for the expectation of an increase in future demand. Since the reservoir has existing water supply capacity that significantly exceeds the contracted amount, it appears to be well positioned to meet future water supply obligations.

SUMMARY OF FINDINGS

- The VIC model can be successfully applied to a study of future water supply yield that incorporates climate change, even in a watershed as small as the one that contributes to Marion Reservoir.
- All projections were in agreement that future conditions will be warmer over the Marion Reservoir watershed, with a median increase in temperature among all models of +4.76°F by the year 2050.
- No consensus existed with respect to future precipitation trends in the Marion Reservoir watershed through the year 2050. Some of this variation can be attributed to differences in the emissions scenarios. Most of the models fall within a ±20% range of the current annual mean by the year 2050 based on current climatology.
- Unlike coastal or mountainous areas where changes in sea level or snowpack elevation may be more easily observed, climate impacts on water supply reservoirs in the Great Plains are less obvious.
- The Marion Reservoir watershed receives (on average) approximately 20 inches of snowfall a year, which equates to 2–3 inches of liquid equivalent precipitation. It can be assumed that the model consensus trend to a warmer climate by year 2050 will shift some of this precipitation to rainfall.
- The VIC simulation using historical data exhibited good skill when replicating the critical period. The timing and duration of historical droughts, including the 1952–1957 drought of record, were generally correct.
- The VIC simulation using historical data initially exhibited poor accuracy when replicating firm yield, but this improved significantly with additional bias correction using a monthly CDF derived from the historical and simulated overlap period, which was then applied to the hydrographs from all projections.
- A consensus of model projections suggests that stresses resulting from simulated changes in T and P at Marion Reservoir will not increase over time.
- Based on the modeling results, Marion Reservoir appears to be well positioned to meet future water supply obligations, particularly since no future additional allocations are contracted.

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