

Evaluating Need for Adaptation for U.S. Army Corps of Engineers Wilmington District Reservoirs

by

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Executive Summary

The U.S. Army Corps of Engineers (Corps) is a federal agency that owns and operates a network of over 500 reservoirs nationwide. The majority of these projects are 50 years old. Moreover, they were designed with the assumption of a stationary climate and in response to specific community needs. As the agency looks to the future, it is crucial for it to understand which of these assets continue to meet design and operational goals.

This report examines the Corps' reservoir policy and historic operations to assess the reservoirs' need for adaptation, focusing on the Wilmington District in Southeastern U.S. The Corps reservoir policy provides a context for examining operations. Reservoir regulation rules are contained in internal Corps documents called Water Control Plans (WCP). They are updated infrequently due to limited funding and because the Corps relies heavily on its reservoir operators to respond to environmental changes. This condition creates a culture of autonomous management responsive to local needs. It also reflects the Corps' governance structure, where the agency's actors have few limits on their operational discretion.

Using Corps design and operational documents and daily operational data, this analysis quantifies historic reservoir management activities in the Wilmington District by evaluating four operational metrics over 2-3 management periods. Management periods are defined for each reservoir based on major updates to operations, such as an issuance of a new WCP. Changes in external conditions are assessed via inflow and sedimentation metrics, while changes in management approach to meet reservoir purposes are shown via metrics of downstream minimum flow compliance and water supply storage.

The findings are synthesized using a visual "box model." The model allows managers to view reservoirs within the District as a system. Tracing the evolution of external factors affecting reservoirs over time, managers can prioritize facilities for adaptation. However, because Corps documentation contains no guidance on the degree of external change that could trigger adaptation, no thresholds could be set to identify reservoirs in need of adaptation. Falls Lake, however, appears a likely candidate due to its inflows being equal to only 82% of its design inflows during the latest management period (1991-2014). Similarly, the box model helps managers to compare reservoir performance along management

objectives like water supply and water quality maintenance (downstream minimum flows). No thresholds for adaption appear to exist for these metrics, either.

Lastly, the box model allows managers to visualize operational flexibility, or the ability to make short-term operational trade-offs to maximize long-term outcomes. Operational flexibility is measured by the fraction of water remaining available to meet other reservoir purposes. Fluctuations in metrics reflecting reservoir purposes (minimum flows, water supply) across management periods highlight changes in flexibility. Decisions to create flexibility are observed in decreasing percentages of minimum flows met as inflows into Falls Lake are reduced, when more water is retained in the reservoir to provide water supply rather than be released to meet flow requirements. Additional interactions with other reservoir purposes likely exist though they could not be evaluated using the available data. These results point to the Corps' prioritization of water supply over water quality maintenance, though both of those reservoir purposes are equal from the legal standpoint.

Lack of thresholds for adaptation and vague purpose prioritization showcase the degree of operational discretion that the Corps enjoys. Implementing these standards would allow the agency to systematically evaluate the effectiveness of its management approach and clearly signal the need for adaption. Without these set boundaries, the limits of operational flexibility continue to be stretched, and the management approach becomes reactive rather than adaptive. Defining such boundaries, however, would place limits on the Corps' operational flexibility and could impinge on the agency's discretion. This disincentive, in addition to the project-based funding structure, can hinder the Corps' adoption of an effective strategy to manage water resources in the 21st century.

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0.0 Introduction

The U.S. Army Corps of Engineers (Corps) is a federal agency within the Department of Defense that supports critical wartime and peacetime functions. As part of its role in managing national water resources, the Corps owns and operates a network of over 500 dams and adjoining reservoirs nationwide. These reservoirs can provide flood protection, store drinking water, maintain downstream water quality, generate hydroelectric power, and support commercial and recreational navigation, among other functions. The majority of these structures, however, are about half a century old. Moreover, they were designed with the assumption of a stationary climate and in response to specific community needs. As the agency looks to the future, it is crucial for it to understand which of these assets continue to meet their design and operational goals.

This report examines the Corps' reservoir operations to assess the reservoirs' need for adaptation. It comes at a time when the agency has already begun thinking about climate change adaptation on a national level but has yet to translate the broad initiative into specific updates to reservoir operations.¹ The report's methods and findings can be applied to prioritize reservoirs for adaptation and to standardize data collection in support of national response to climate change.

Because of the complexity of the Corps' internal organization and the agency's evolving mission, reservoir operations can only be understood in the context of policy. This report breaks down the question of adaptation potential into two components: Corps reservoir policy and historical operational analysis.

- 1. Corps reservoir policy** section of the report summarizes the Corps' legal authorities, organizational structure, decision-making protocols, and implementation of reservoir management activities.

¹ United States. Army. Corps of Engineers. (2014). *Climate Change Adaptation Plan and Report*. Retrieved from: http://www.corpsclimate.us/docs/USACE_Adaptation_Plan_v50_2014_June_lores.pdf

2. **Historical operational analysis** section is a case study of one Corps District's reservoirs, the Wilmington District in the Southeast U.S. The analysis evaluates reservoir management activities and highlights implications for the future. In attempting to identify the threshold between operational flexibility and the need for adaptation, it points to limitations in the Corps' existing data that could prevent the agency from making a fully informed reservoir adaptation prioritization plan on a district, division, or national scale.

The discussion and synthesis that follow rely on both the policy background and results of the analysis.

This report is part of an ongoing, national-scale project by the Nicholas Institute for Environmental Policy Solutions on Corps reservoir operations.

1.0 U.S. Army Corps of Engineers reservoir policy

The Corps operates its reservoirs in a context both governed by strict hierarchy and permeated with ambiguity. The hierarchy is dictated by the Army's inherent culture of discrete and progressively increasing levels of authority. The ambiguity stems from legislation and internal regulation that attempts to create operational flexibility at levels below the national level. In the context of this report, operational flexibility is defined as the ability to make short-term operational trade-offs to maximize long-term outcomes. In practice, what emerges is a culture of highly autonomous decision-makers who handle daily operations with the least possible intervention from higher authority. This section examines the legal, policy, and practical aspects of Corps reservoir operation and assesses their potential impacts on future adaptation.

1.1 The Corps' authorities

The Corps derives its authority to plan, build, and operate a project from legislature enacted by Congress. Every Corps water control project, such as a dam that creates a reservoir, must be authorized by Congress for specific purposes.² These purposes may be referred to as "original project purposes." Additionally, Congress may modify project purposes after construction via project-specific legislation.³ The original and modified "project-specific purposes" described above are supplemented by "general purposes" that apply to all federal facilities, including all Corps water control projects.⁴

As is evident from the list of project-specific and general purposes outlined in Appendix A, the Corps operates its reservoirs with many layered – and sometimes competing – objectives. As with any federal agency, it is the Corps' responsibility to balance these sometimes contradictory purposes to operate the project as intended by Congress.⁵ The

² 33 C.F.R. §222.5(d)(1)

³ United States. Army. Corps of Engineers. (1994). *Authorized and Operating Purposes of Corps of Engineers Reservoirs*. (PR-19). Retrieved from: <http://www.hec.usace.army.mil/publications/ProjectReports/PR-19.pdf>

⁴ *ibid.*; Whisnant, Richard B. et al. (2009). *Operating Policies and Administrative Discretion at the John H. Kerr Project: A Component of a Study of Operations at the John H. Kerr Project Pursuant to Section 216 of Public Law 91-611*. On file with author.

⁵ *Ibid.*

Corps exercises its agency discretion during project planning and daily activities in an effort to achieve this goal.

Finally, under the Continuing Authorities Program (CAP), the Corps has authority to plan, design, and implement certain types of water projects without project-specific authorization by Congress.⁶ These 10 authorities relate to water resources management but do not directly affect the reservoir operations under consideration in this report (Appendix B).

1.2 Corps documentation and legal requirements

Over decades of constructing and managing the nation's water infrastructure, the Army Corps of Engineers has produced voluminous documentation of its internal processes. However, only some of the Corps' internal regulation is legally binding and enforceable. The Corps, much like other government agencies, creates rules that either (a) translate its understanding of the intent of a legislation or executive order into the agency context; or (b) provide internal guidance on how the intent of the legislation should be carried out in practice.⁷ The former rules (a), termed legislative rules, have the force of law if they have been reviewed via a public process and codified (i.e., appear in the Code of Federal Regulations). The latter rules (b) fall into categories of interpretive rules, general statements of policy, or rules of agency organization, procedures and practice, all of which act merely as internal guidance documents rather than legally enforceable standards.⁸ Agencies tend to produce much more guidance documentation than legislative rules because such documentation does not require a public process and is therefore less administratively burdensome to enact.⁹

⁶ ER 1105-2-100(F-2)(a)

⁷ Jowers, Kay. (2015). *Corps project – Legal/Policy Relevance of Corps Documents & Water Control Plans and the Relationship to Reallocations*. Nicholas Institute of Environmental Policy Solutions, Durham, NC. On file with author.

⁸ *Ibid.*

⁹ *Ibid.*

The Corps produced many types of documentation, such as Engineer Regulations (ER), Engineer Manuals (EM), Engineer Circulars (EC), Engineer Pamphlets (EP), among others. Of these, ER's fall into either category of enforceable and non-enforceable. For example, while ER 1110-2-240 is codified in its entirety in 33 C.F.R. §222.5 and thus has the force of law, that is not the case for the majority of 293 ER's that exist today.¹⁰ For a summary of administrative law in the context of the Corps, please see Appendix C.

The content of an ER generally sets goals and metrics for the Corps' compliance with legislative or executive directives. A guidance document, on the other hand, provides a preferred roadmap for how Corps Divisions and Districts can reach the goals outlined in an ER. For example, ER 1110-2-240 requires the Corps to develop water control plans for all of the water control projects owned and operated by the Corps, while EM 1110-2-3600 conceptually discusses the development of such plans and provides guiding examples. The latter document "should be used as a general guide to water control activities," and the instructions it contains "are sufficiently flexible to permit adaptation to specific regions."¹¹ Thus the Corps internal guidance is sometimes purposefully vague so as to allow Division and District Commanders flexibility in developing water control plans to accommodate the variability in hydrology and community need across the U.S.

1.3 Water control documentation

The Corps is required by law to document its water control operations in a series of hierarchically structured documents, the basic unit of which is the Water Control Plan (WCP).¹² A WCP is a planning document that outlines the goals for how a water control structure, such as a dam, should be operated. It contains information that allows water control managers to put together standing instructions to dam operators, collect and disseminate data, ensure project safety, coordinate operations with other water control projects, and generally operate the reservoir in a way that complies with purposes

¹⁰ Publicly available Corps publications, such as Engineer Regulations, can be found online: <http://www.publications.usace.army.mil/USACEPublications/EngineerRegulations.aspx?>

¹¹ ER 1110-2-240(8)(c); 33 C.F.R. 222.5(h)(3)

¹² 33 C.F.R. 222.5(d), (e)

authorized by Congress as well as with laws that apply to all federal facilities.¹³

Importantly, a WCP also contains the reservoir regulation schedule, or the numeric criteria that govern reservoir storage and releases, that may incorporate seasonal guide curves for reservoir levels, limits of release rates under various conditions, and other quantifiable information that is usually communicated via graphs and tabulations.¹⁴ Some of these criteria, such as maximum release rates, have implications for public safety or the environment and should be closely adhered to by dam operators. Other criteria, such as guide curves, provide mere guidance on ideal reservoir operations.

At the discretion of the District Commander, other water control documents may be produced depending on the needs of the specific reservoir.¹⁵ Multipurpose reservoirs that are authorized for municipal and industrial (M&I) supply, irrigation, hydroelectric power, and/or navigation may necessitate the creation of Annual Water Management Plans to specify guide curves for the coming year based on most recent weather forecasts.¹⁶ At projects that are authorized and constructed to produce hydroelectric power, these Annual Operating Plans are used to plan power production for the coming year.¹⁷

The WCP is translated into practice via a Water Control Manual (WCM), which contains all the information a dam needs to know to safely operate a reservoir under foreseeable conditions.¹⁸ In addition to outlining daily operations, the WCM includes a Drought Contingency Plan (DCP), instructions for regular communication with the National Weather Service regarding river stages, copies of the WCP and any annual plans, and other essential instructions to dam operators.¹⁹

¹³ 33 C.F.R. 222.5(e)(1), (f)

¹⁴ 33 C.F.R. 222.5(e)(2)

¹⁵ 33 C.F.R. 222.5(f)

¹⁶ EM 1110-2-3600, 3-2(c)

¹⁷ EM 1110-2-3600, 4-10(h)(3)

¹⁸ EM 1110-2-3600, 9-5(a)(3)

¹⁹ EM 1110-2-3600, 7-7(a); 33 C.F.R. 222.5(f)(8)

If a reservoir is part of a system of reservoirs, an integrated WCP will outline how its operations should be tied to other reservoirs.²⁰ These joint objectives are translated into daily operations via a Master Water Control Manual (MWCM). Joint objectives may take on different forms, such as several reservoirs being part of a single river system, regional water supply, or – if dams are hydroelectric – regional electrical supply.²¹ For a system that breaches the jurisdictional boundaries of a single Corps District due to these joint operational objectives, the MWCM has to be prepared jointly between several Districts and is reviewed and approved at the higher Division level.²² A MWCM contains long-term operational objectives for a system of reservoirs and may include such items as long-term hydrometeorologic forecasts and system management plans under various conditions, e.g., flood routing through a series of reservoirs and basin drought management plans.²³ For a summary of Corps document types and their relationships, see Appendix D.

1.4 Decision-making for water control projects

According to the agency's internal guidance, decisions within the Army Corps of Engineers follow the strict hierarchical organization of the Corps. As the agency's name implies, it is part of the Department of the Army, which is nested within the Department of Defense in the Executive Branch. The Chief of Engineers, who oversees the agency, reports to Assistant Secretary for Civil Works at the Department of the Army. Under the Chief of Engineers at headquarters are several directorates, including the Directorate of Civil Works that is led by the Director of Civil Works. The agency's civil works governance is split regionally among 8 domestic Divisions, each led by a Division Commander. Each division is made up of Districts, with 38 Districts overall, each led by a District Commander who oversees individual facilities within the District boundaries. Appendix E illustrated the basic hierarchical organization of the Corps.

²⁰ 33 C.F.R. 222.5(e)(1)

²¹ EM 11110-2-3600, 2-1(e)

²² 33 C.F.R. 222.5(g)

²³ EM 1110-2-3600, 7-7(a)

Despite this hierarchical structure, there is evidence that the agency is moving toward formally decentralizing its operations. Starting in 2003, the Corps began a reorganization of its operations via its USACE 2012 plan.²⁴ Among many changes proposed by the plan, one of the greatest alterations affecting daily operations for civil works is the shift toward greater regional management through the diminished role of the Divisions and greater autonomy for the Districts.²⁵ As of the writing of this report, it is difficult to assess the results of this decentralizing effort, though other aspects of the USACE 2012 plan, such as the creation of Regional Business Centers, appear to have been implemented.²⁶ Conversely, in a 2010 report, the Government Accountability Office described the nature of district governance as “autonomous,” pointing to already existing regional decision-making power of Corps districts.²⁷

Information about the Corps’ daily decision-making process in regards to water control activities can be gleaned from Chapter 7 of its 1987 Engineer Manual on “Management of Water Control Systems.”²⁸ Daily reservoir operations are handled exclusively on the facilities level. Water control managers have discretion to rely on the WCM in combination with their best judgment to respond in real time to hydrometeorological conditions and any immediate needs that may arise, especially in cases of emergency.²⁹ Such operations are considered to be normal water management activities. Nevertheless, in cases when a non-emergency water management decision potentially has “far-reaching... adverse impacts on future project regulation activities” and represents a “significant departure” from the WCP, the decision must be “referred to higher echelons for written approval.”³⁰

²⁴ United States. Army. Corps of Engineers. (2003). *USACE 2012: Aligning the U.S. Army Corps of Engineers for Success in the 21st Century*. Retrieved from USACE Digital Library:

<http://cdm16021.contentdm.oclc.org/cdm/ref/collection/p16021coll6/id/60>

²⁵ American Rivers. (2009). *A Citizen’s Guide to the Corps of Engineers*. Retrieved from:

<http://www.americanrivers.org/newsroom/resources/a-citizens-guide-to-the-corps-of-engineers/>

²⁶ United States. Army. Corps of Engineers. (2014). *Sustainable Solutions to America’s Water Resources Needs: Civil Works Strategic Plan 2014-2018*. (EP 1165-2-503). Retrieved from:

http://www.usace.army.mil/Portals/2/docs/civilworks/news/2014-18_cw_stratplan.pdf

²⁷ United States. Government Accountability Office. (2010). *Army Corps of Engineers: Organizational Realignment Could Enhance Effectiveness, but Several Challenges Would Have to Be Overcome*. (GAO-10-819). Retrieved from:

<http://www.gao.gov/products/GAO-10-819>

²⁸ EM 1110-2-3600

²⁹ EM 1110-2-3600, 7-1(a)(2)

³⁰ EM 1110-2-3600, 7-1(a)(3)

The exact meaning of “adverse impacts” and “significant departure” is not elaborated upon, leaving the distinction up to the discretion of water control managers. One can also assume that the nature and severity of the problem will determine the level up the chain of command where the decision on the issue can be made.

Water control managers’ relationship to reservoir guide curves illustrates the Corps’ discretion in operations. The guide curve, as discussed above, shows the ideal lake level throughout the year. It is an integral part of the reservoir regulation schedule, which is a set of numeric criteria derived from engineering studies performed pre- and post-construction to ensure project safety and optimize operations in regards to project purposes. Thus the guide curve, true to its name, serves as a guide that indicates the preferred lake level at which, on the average, all project purposes are operationally in balance. Daily operations, however, are rarely performed in ideal conditions and must respond both to natural variations in streamflow as well as varying community demands, such as water supply, hydroelectric production, and navigation.³¹ Guide curves appear in reservoir WCP’s and WCM’s, both of which are agency guidance documents and do not have the force of law (see section *1.3 Water control documentation*). Therefore, the Corps water control managers are not required by law to strictly adhere to guide curves in their daily operations.

Though the Corps enjoys a rather widely circumscribed discretion in regards to water control activities, Congress still limits the Corps’ overall decision-making ability. Every Corps project is authorized and funded for specific project purposes, and the Corps must balance those and its general purposes to operate the project in the manner intended by Congress (see section *1.1 Corps Authorities*). If, however, operational changes are likely to affect the balance of these authorized purposes, the Corps must seek Congressional approval. This limitation on the Corps’ discretion is outlined in the Water Supply Act of 1958 specifically in regards to water storage for M&I water supply:

³¹ EM 1110-2-3600, 3-3(a)(2)

Modifications of a reservoir project heretofore authorized, surveyed, planned, or constructed to include storage... which would *seriously affect* the purposes for which the project was authorized, surveyed, planned, or constructed, or which would involve *major structural or operational changes* shall be made only upon the approval of Congress as now provided by law.³²

Like the meaning of “adverse impacts” and “significant departure” discussed above, the exact meaning of “seriously affect” and “major structural and operational changes” is left vague in the legislation, possibly to provide the agency with maximum discretion. The interpretation of these phrases by the Corps has evolved over the years and is currently at the crux of the Tri-State Water Conflict litigation between Georgia, Florida, and Alabama over the allocation of Lake Sidney Lanier near Atlanta, GA. Note, however, that here the use of “modification” may imply more permanent and even structural changes to the project when compared to the potentially reversible “decisions” discussed previously.

1.5 Process for operational modification

Due to the wide scope of the Corps’ discretion, operational documents are rarely revised. The Corps chooses instead to rely on the “high efficiency of water control managers” to respond to operational demands.³³ The C.F.R. requires water control documents to be kept current to reflect shifting operational objectives affected by “developments in the project area and downstream, improvements in technology, new legislation and other relevant factors.”³⁴ This directive can be interpreted to mean that, as conditions change, the law intends for the Corps to respond systematically and to keep written records that accurately reflect the reality of operations. Moreover, according to other internal guidance documents, WCP’s “must be reviewed and updated as needed but not less than every 10 years” to keep up with changes in water quality standards.³⁵ The Corps seems to interpret these planning

³² 43 U.S.C. §390b(e), emphasis added.

³³ EM 1110-2-3600, 3-6(a)

³⁴ 33 C.F.R. §222.5(f)(3)

³⁵ ER 1110-2-8154(8): “Specific water quality management objectives must be developed by the districts for each project, and procedures must be outlined and implemented to meet those objectives. These objectives will be included in the project water control plans. These plans must be reviewed and updated as needed but not less than every 10 years.”

directives as a requirement to review water control documentation but not necessarily update it on a regular basis.³⁶ This approach is additionally motivated by “budget and manpower constraints,” which ultimately relegate updating of water control documents to a “very low priority” for management at the District or Division level.³⁷

As a result, the Corps water control managers’ approach to operations assumes a high degree of resiliency from both natural and man-made systems around them: as operators deviate from WCP’s and WCM’s, they assume that changes to which they are responding are temporary and the system is likely to “bounce back” to the average conditions described in the existing documentation.³⁸ This assumption, however, is unlikely to hold true as infrastructure ages, population grows, and climate shifts with time. At some point, the Corps faces a need to adapt its operations, which currently can be done using two mechanisms: revisions of WCP’s and reallocation of reservoir storage.

1.5.1 Process for WCP revision

A revision of the WCP may be triggered by external conditions. These conditions include changes in the law, updates to water quality standards, changes in hydrologic, meteorological, or floodplain conditions, and other circumstances external to the Corps to which the agency has to respond.³⁹ Internally, the Corps can also add an operational objective to a reservoir under its general authorities.⁴⁰ Any changes in the WCP should result in a careful balance of operational objectives and ensure that congressionally authorized purposes continue to be met.

³⁶ Jowers (2015)

³⁷ EM 1110-2-3600, 3-6(a)

³⁸ Holling, C.S. (1996). Engineering resilience versus ecological resilience. In *Engineering Within Ecological Constraints* (pp. 31-43). Washington, D.C.: National Academies Press.

³⁹ The Nature Conservancy. (2007). *Handbook for Revisions of Water Control Plans to Improve Environmental Flows Below Dams Operated by the U.S. Army Corps of Engineers and Guide to the Corps Guidance*. Retrieved from: <http://www.caddolakeinstitute.us/docs/flows/Corps%20Modeling/2007-10-30%20ACE%20WCP%20Handbook.pdf>

⁴⁰ According to EP 1165-2-1, 11-7, these objectives are limited to recreation (PL 78-534), M&I water supply (PL 85-200), fish and wildlife conservation (PL 85-624), water quality control (PL 92-500), and preservation of threatened/endangered species (PL 93-205).

Public involvement is a major component of the WCP revision process, which may add to the Corps' reluctance to undertake it. Much like developing the original WCP for a reservoir, revising a WCP requires a public review process that involves all affected stakeholders.⁴¹ However, revisions of the WCP are categorically excluded from compliance National Environmental Policy Act (NEPA) as "activities at completed Corps projects which carry out the authorized project purposes" and "general plans."⁴² The Corps is generally not required to produce an Environmental Assessment (EA) or Environmental Impact Statement (EIS) when revising a WCP that reflects a minor operational change.

Modifications to the WCP can be broken up into two categories depending on their magnitude: minor and major, with these terms being more qualitative than quantitative. Minor modifications are undertaken at the District level and approved by the Division commander upon completion.⁴³ Major modifications, such as adding an authorized purpose or implementing a major facility improvement, must receive congressional authorization and require a feasibility study.⁴⁴ Congress may authorize the Corps to produce such a study; additionally, the Corps has standing authority to perform such studies under §216 of the Flood Control Act of 1970.⁴⁵ This "§216 study" may be initiated by the Corps "due to significantly changed physical or economic conditions" affecting the project.⁴⁶

1.5.2 Water storage reallocation

One condition that typically triggers a revision of the WCP is a permanent reallocation of reservoir storage toward a purpose not authorized by Congress, such as water supply.⁴⁷ It is worth noting that the Corps distinguishes between storage volumes and volume of actual water both in its M&I water supply contracts and its approach to reallocation.⁴⁸ When a

⁴¹ 33 C.F.R. §222.5(f)(9); WRDA 1990, PL 101-640 §310(b)

⁴² ER 200-2-2(9)(a), (d)

⁴³ The Nature Conservancy (2007)

⁴⁴ The Nature Conservancy (2007)

⁴⁵ PL 91-611

⁴⁶ ER 1165-2-199(12)

⁴⁷ Jowers (2015)

⁴⁸ "Under the terms of the 1958 Water Supply Act (WSA) (Title 111 of PL 85-500) the Corps enters into agreements for water supply storage space. The term "storage" conveys the right to store a resource (water)

local partner, such as a municipality, contracts for a given amount of acre-feet of water supply storage in a reservoir or when a district reallocates a reservoir volume toward water supply storage, the contract language focuses on the management of reservoir volumes and does not guarantee of any presence of water associated with those volumes.

The majority of reallocations planned and undertaken to date have been toward M&I water supply.⁴⁹ Much like with WCP revisions, reallocations can be categorized as minor and major, without a clear numeric threshold separating the former from the latter (see section *1.4 Decision-making for water control projects*). Minor reallocations can be performed under the general authority conferred by the Water Supply Act of 1958 and require internal approval based on the magnitude of reallocation (Appendix F).⁵⁰ Nevertheless, the first time a reallocation takes place at a reservoir where water supply is not an authorized purpose, the approval authority lies with the Assistant Secretary of the Army for Civil Works.⁵¹ In this case, the addition of water supply as a new operational objective would not trigger the revision of a WCP since the reallocation is considered minor enough not to affect other operational purposes.

On the other hand, if a reallocation is considered major by the Corps, it must be approved by Congress since it is likely to affect existing authorized project purposes.⁵² The definition of what constitutes a major reallocation toward water supply is currently being debated in the Tri-State Water Conflict litigation over Lake Lanier and the Apalachicola-Chattahoochee-Flint (ACF) river basin regulation by the Corps, as mentioned above. Because it would constitute a modification to reservoir operations, a proposal for reallocation would have to follow the steps for WCP revision that are outlined above.

in a Corps reservoir project. The right to withdraw water from the storage space is a separate water rights issue that is the responsibility of the water user to obtain.” Hillyer, T.M. United States. Army. Corps of Engineers. Institute for Water Resources. (2012). *2011 M&I Water Supply Database*. (Report 2012-R-02). Retrieved from: <http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/2012-R-02.pdf>

⁴⁹ Perry, Meg and Patrick Hunnicutt. (2015). *Nicholas Institute for Environmental Policy Solutions Database of Reallocated U.S.A.C.E. Reservoirs*. Nicholas Institute for Environmental Policy Solutions, Durham, NC. On file with author.

⁵⁰ 43 U.S.C. §390b; ER 1105-2-100 (Table E-31)

⁵¹ ER 1105-2-100 (Table E-31)

⁵² 43 U.S.C. §390b(e)

In addition to permanent storage reallocation, the Corps also has the authority to temporarily reallocate “surplus water” storage at its reservoirs.⁵³ Surplus water has been interpreted by the Corps to mean “(1) water which is not required because the authorized need for the water never developed or the need is reduced by changes which have occurred since authorization or construction and (2) water which would be more beneficially used as M&I water than for the authorized purpose and which, when withdrawn, would not significantly affect authorized purposes over some specified time period.”⁵⁴ The Corps planning guidance states that the authority to declare M&I supply as a more beneficial purpose than an authorized purpose should be used with caution and that such reallocations should be made for limited time periods, normally not exceeding 5 years.⁵⁵ In case of a drought emergency, the Corps also has the authority to temporarily reallocate surplus storage toward water supply.⁵⁶ Appendix F details approval authorities for temporary reallocations.

1.6 Impact of Endangered Species Act on Corps reservoir operations

In addition to the effects of climate change and land use, the Endangered Species Act (ESA) provides a potential limitation on the Corps’ flexibility.⁵⁷ The Corps, like all federal agencies, is prohibited by the ESA from taking any action that negatively affects species listed as endangered or threatened. If a species that inhabits a reservoir or the river below it were to be listed, its protection would become of paramount importance and “likely trump all other requirements of the federal agency,” even if the Corps’ action that endangered the species is explicitly authorized by Congress.⁵⁸ For example, minimum flow standards and maximum reservoir level fall rate requirements, both set in compliance with the ESA, complicate the operation of the Jim Woodruff Dam and the whole system of reservoirs in the contested ACF basin. The ACF river system reaches the Gulf of Mexico at

⁵³ PL 78-534 §6

⁵⁴ United States. Army. Corps of Engineers. (1990). *Modifying Reservoir Operations to Improve Capabilities for Meeting Water Supply Needs During Drought*. (RD-31). Retrieved from: <http://www.hec.usace.army.mil/publications/ResearchDocuments/RD-31.pdf>

⁵⁵ ER 1105-2-100(E-57)(b)(2)(b)

⁵⁶ ER 1105-2-100(E-57)(c)

⁵⁷ 16 U.S.C. 1531-1544, 87 Stat. 884; ESA hereafter

⁵⁸ Whisnant (2009)

the Apalachicola Bay, which home to endangered oysters that are the backbone of the local fishing economy.⁵⁹

Currently, Corps dam operators must maintain minimum flow requirements at a control point below the dam, as prescribed both in reservoir design and operational documents. These requirements are generally put in place for water quality maintenance and are sometimes modified by fish and wildlife concerns.⁶⁰ In practice, the reservoir guide curve and release schedules reflect these requirements.

Unfortunately, the lists of both threatened and endangered species are growing. In regards to this report's area of study, the number of listed species in the Southeastern U.S. is expected to grow in the near future. In the case of the Wilmington District that covers regions of North Carolina and Virginia, almost half of currently petitioned and candidate species listed in its territory are aquatic.⁶¹ Additionally, as ecological science progresses, it is becoming increasingly clear that each healthy ecosystem requires a specific flow regime with variable streamflow magnitudes, durations and frequencies of flow events, timing, and rates of streamflow change.⁶² To protect increasing numbers of endangered species, the Corps will likely need to work more closely with state environmental regulators to establish reservoir regulation schedules that support the needs of the threatened and endangered species. This close and ongoing coordination will add another layer of

⁵⁹ United States. Army. Corps of Engineers. (2012). *Apalachicola-Chattahoochee-Flit (ACF) Remand Modeling Technical Report*. Retrieved from: http://ww3.sam.usace.army.mil/2012ACF_technicalanalysis.pdf

⁶⁰ E.g., see seasonal minimum flow requirements for John H. Kerr reservoir revised WCM (1995).

⁶¹ Of 98 candidate and petitioned species for federal ESA protection in North Carolina and Virginia, 40 are aquatic species (amphibian, crustacean, fish, and mussel taxa). Other taxa, such as birds, insects, snails, and plants that are dependent on aquatic habitats to various degrees during their life cycle, are not tallied here. Ihlo, Christy and Kevin Kun He. (2013). *Nicholas Institute Threatened and Endangered Species Database*. Nicholas Institute for Environmental Policy Solutions, Durham, NC. On file with author.

⁶² Poff, N. Leroy et al. (1997). The natural flow regime: A paradigm for river conservation and restoration. *Bioscience*, 47(11), 769-784; Ecological Flows Science Advisory Board to the North Carolina Department of Environment and Natural Resources. (2013). *Recommendations for Estimating Flows to Maintain Ecological Integrity in Streams and Rivers in North Carolina*. Retrieved from: <http://www.ncleg.net/documentsites/committees/ERC/2013-2014%20ERC%20Documents/Commission%20Meetings/3%20-%20January%2015,%202014/Handouts%20and%20Presentations/8%20T.Reeder-%20Ecological%20Flow%20Rpt.pdf>

complexity to reservoir management and is likely to limit the Corps' discretion and operational flexibility.

1.7 Impact of funding process on Corps' reservoir operations

When a project modification is deemed major and requires congressional approval, it impinges on the Corps' agency discretion and slows down the implementation of changes to project operation. Even if a district finds the necessary funds to undertake a §216 study and the study's recommendations are subsequently authorized by Congress, the implementation of these recommendations may be significantly or indefinitely delayed by the timing of congressional appropriation of funds.⁶³ As of 2014, "the rate of Corps authorizations exceeds the rate of the agency's annual appropriations."⁶⁴ For example, due to various changes in legislation regarding appropriations in the last 20 years, "the majority of studies and construction projects authorized in WRDA [Water Resources Development Act] 2007 remained without federal funding as of 2014."⁶⁵ This backlog of authorized but unfunded projects has caused Congress to enact provisions in the Water Resources Reform and Development Act (WRRDA) 2014 that:

- outline a one-time deauthorization process for projects authorized prior to 2007⁶⁶
- place a limit of seven years on projects authorized in WRRDA 2014 to obtain both federal and local financial support or risk being automatically deauthorized⁶⁷

Currently, the Corps is likely working on its list of projects recommended for deauthorization, as required by WRRDA 2014.⁶⁸ This list will be extensive as the estimated costs of these unfunded projects total \$18 billion.⁶⁹ In addition to lack of federal and non-federal funds for project implementation, the criteria for the project deauthorization

⁶³ The Nature Conservancy (2007)

⁶⁴ U.S. Congressional Research Service. (2014). *Army Corps of Engineers: Water Resource Authorizations, Appropriations, and Activities*. (R41243). Retrieved from: <https://fas.org/sgp/crs/misc/index.html> , hereafter CRS (2014)

⁶⁵ CRS (2014)

⁶⁶ PL 113-121 §6001(a)(1)

⁶⁷ PL 113-121 §6003(a)(1)

⁶⁸ PL 113-121 §6001(b)

⁶⁹ PL 113-121 §6001

include “lack of local support” and recognition that the “authorizing purpose is no longer relevant or feasible.”⁷⁰ These criteria may point to both inefficiencies in the Corps’ operations that inhibit timely response to economic development needs or, conversely, to the federal government’s success at preventing the implementation of projects that may not be needed in the long run.

1.8 Possibility of adaptive management

Adaptive management is a management approach that is structured around a learning process. The adaptive management model allows for iterative changes in planning and management based on continued monitoring and assessment of outcomes.⁷¹ The adaptive management framework can allow increasingly effective resource management in the face of uncertainty and change in boundary conditions (e.g., land use, climate). The Corps and other federal agencies were required to “incorporate adaptive learning so that experience informs and guides adjustments to future actions” by Executive Order 13653 in November 2013.⁷² The Corps is currently implementing several pilot studies that will allow the agency develop internal policies to help incorporate adaptation into existing operations.⁷³

Framing these efforts is the Corps’ past record on organizational change. Organizational realignment efforts, such as Corps 2012 and its predecessors, had limited success due to “(1) inability to gain congressional support, (2) limitations of its funding structure, and (3) the autonomous culture of its districts.”⁷⁴ Support from Congress is lacking because lawmakers may associate the streamlining of operations with job losses in their districts. Additionally, the current means of obtaining funding may limit the Corps’ district discretion in regards to managing projects in an adaptive way. As described above, Corps funding is

⁷⁰ PL 113-121 §6001(a)(1)

⁷¹ Williams, B. K., and E. D. Brown. (2012). *Adaptive Management: The U.S. Department of the Interior Applications Guide*. Adaptive Management Working Group, U.S. Department of the Interior, Washington, DC. Retrieved from: <http://www.usgs.gov/sdc/doc/DOI-Adaptive-Management-Applications-Guide-27.pdf>

⁷² Corps of Engineers. (2014). *Climate Change Adaptation Plan and Report*.

⁷³ *Ibid.*

⁷⁴ United States. Government Accountability Office. (2010). *Army Corps of Engineers: Organizational Realignment Could Enhance Effectiveness, but Several Challenges Would Have to Be Overcome*. (GAO-10-819). Retrieved from: <http://www.gao.gov/products/GAO-10-819>

generally obtained on the project rather than program level. Projects are funded incrementally and based on their planned outcomes. Changing this approach would necessitate a shift in congressional expectations of the Corps on a per-project basis. This shift, however, is unlikely since knowingly funding project that may meet with even a temporary failure in order to increase management knowledge may not be politically feasible for lawmakers.

The last impediment to shift in the Corps' management culture is tied to the age-old difficulty of implementing change in a large organization. This condition is further complicated by the decentralized nature of the agency's day-to-day governance. Thus adaptive management, though a useful tool for natural resource management in an age of uncertainty, may not be a good fit with the Corps' governance, funding, and decision-making approach as it exists today.

1.9 Implications for adaptation

The complexity of the Corps' reservoir management approach stems from the effective decentralization of its normal operations. Decentralized governance allows the Corps to most effectively respond to local needs and conditions. Nevertheless, the direct consequence and drawback of decentralization is the non-standard way in which information is collected at the local level, complicating reporting and comparison of management activities across districts and divisions. Thus decentralization can negatively impact major initiatives, such as climate adaptation, by creating informational heterogeneity. This heterogeneity increases internal uncertainty in national-scale management response by the agency to already uncertain external conditions.

2.0 Analysis of reservoir operations

2.1 Background

The Corps currently faces a systematic challenge in regards to reservoir operations. The majority of Corps reservoirs were designed and constructed approximately 50 years ago. Over this time span, the reservoirs have likely experienced a shift in boundary conditions, such as climate, land use, and local needs. Moreover, Congress has added several general purposes to reservoirs during the last half-century, such as recreation and protection of water quality, endangered species, and the environment (see *1.1 The Corps' authorities* above and Appendix A). The expectation is that these objectives will be balanced with original authorized purposes. Lastly, as infrastructure ages, the Corps must prioritize its limited funding to maintain the structures' integrity. Understanding which reservoirs are most in need of both adaptation and infrastructure updates may allow the agency to allocate its resources most effectively.

Management activities can be evaluated using information generated internally by the Corps. Unfortunately, decentralized governance within the Corps and informational heterogeneity across divisions and districts resulted in a lack of quantitative standards that define operational success even on the district level. (See Appendix G for an evaluation of the Corps' data quality.) This lack of standards can make systematic evaluation of reservoir operations difficult, undermining the Corps' ability to periodically determine whether each facility continues to meet public needs. Additionally, this lack of standards may hinder the agency in its planning for climate adaptation.

This analysis develops a quantitative approach to evaluate a reservoir's continued ability to achieve its authorized purposes using one district as a case study: the Wilmington District in Southeast U.S. The case study approach eliminates the need to account for heterogeneity of hydrology, community needs, and governance approaches among Corps districts across the U.S., which would have added confounding factors to this analysis. The Wilmington District in particular was chosen due to the wide range of reservoir ages and the variety of purposes that its reservoirs serve. As can be seen in Table 1, the five reservoirs in the

district were authorized and constructed between early 1940's and early 1980's. The reservoirs' purposes range from local needs, such as community protection via flood control and storage of local water supply, to state needs, such as water quality protection, to federal needs, such as revenue generation via hydropower. Appendix H shows a map of the reservoirs' location in the states of North Carolina and Virginia.

Table 1. Wilmington District reservoirs background information

Project Name	Basin	Legislation	Year Authorized	Year Completed	Authorized Purposes	Most Recent Operational Objectives	Sources
Falls Dam & Lake	Neuse	PL 89-298	1965	1981	FC, WS, WQ/LF, Rec	FC, WS, WQ/LF, Rec, F&W	DM 1965, MP 2013
B. Everett Jordan Dam & Lake	Cape Fear	PL 88-253	1963	1981	FC, WS, WQ/LF, Rec, "other"	FC, WS, WQ/LF, Rec, F&W	DM 1962, MP 2007, Pert. data 2015
John H Kerr Dam & Reservoir	Roanoke	PL 78-534	1944	1952	FC, Hydro	FC, Hydro, WS, WQ/LF, Rec, F&W	DM 1944, MP 2013
Philpott Dam & Lake	Roanoke	PL 78-534	1944	1951	FC, Hydro, WQ/LF	FC, Hydro, WS, WQ/LF, Rec, F&W	DM 1944, WCP 1992
W. Kerr Scott Dam & Reservoir	Yadkin - Pee Dee	PL 79-526	1946	1962	FC, WS, WQ/LF	FC, WS, Rec, WQ/LF -OR- F&W	DM 1958, WCP 1993, Pert. data 2015

Purposes & Objectives: FC – flood control, Hydro – hydropower, WS – water supply, WQ/LF – water quality/low flow enhancement, Rec – recreation, F&W – fish and wildlife enhancement.

Document Types: DM – Design Memorandum, MP – Master Plan, WCP – Water Control Plan, Pert. Data – pertinent data (from USACE Wilmington website, retrieved in July 2015)

Another reason for selecting Wilmington is that its reservoirs are experiencing external pressures. For example, there is more pressure for additional local water supply due to the region's growing population.⁷⁵ This population growth is also causing a gradual land use changes in the area, which could impact sedimentation of the reservoirs. In the Southeast, changes in land use, climatic shifts, and their interaction also affect streamflow to varying

⁷⁵ An example of this rapid growth is the City of Raleigh, NC. According to the city government website, Raleigh has grown by 49% between 2001 and 2014 (Raleigh Population Estimates, 2001-2014. Retrieved from: <https://www.raleighnc.gov/government/content/PlanDev/Articles/LongRange/RaleighDemographics.html>). In 2014, approximately 82% of Raleigh's mean daily withdrawals for water supply were made from Falls Lake (Surface Water Sources, Local Water Supply Plan for City of Raleigh, 2014. North Carolina Department of Environmental Quality, Division of Water Resources. Retrieved from: http://www.ncwater.org/Water_Supply_Planning/Local_Water_Supply_Plan/report.php?pwid=03-92-010). Raleigh is currently seeking a reallocation of 12,500 acre-feet from the water quality pool of Falls Lake toward water supply (Falls Reallocation Scoping Letter 2015).

degrees.⁷⁶ Thus the Wilmington District serves as a good example of the Corps' management unit that needs to respond to shifting boundary conditions affecting its multipurpose reservoirs.

2.2 Methods

The goal for this analysis is to evaluate reservoir management activities and to identify whether a need for adaptation exists. To accomplish this goal, the author collected data on reservoir design criteria, operational standards, and daily operational data for the district's reservoirs. Based on these data, four metrics to assess reservoir operations were chosen to reflect both external conditions, to which the Corps must respond via operations, and also internal management goals, which are under the Corps' control. These metrics were evaluated based on standards in the Corp's design and operational documents. The latter were assumed to reflect the most up-to-date management goals at the district level. The results of the analysis are synthesized using a model that attempts to visualize the district as a system.

2.2.1 Data collection

The majority of reservoir design criteria, operational standards, and daily operational data for the district's reservoirs was collected from Corps sources. To obtain design criteria and operational standards, the author reviewed 67 USACE documents pertaining to Wilmington District reservoirs that ranged from pre-construction design documents to Water Control Manuals (WCM's) and Plans (WCP's) to proposed changes to reservoir operations (e.g., Congressional Fact Sheets). When documents were not publicly available, such as through the Wilmington District website or academic libraries, they were requested by the author directly from the Wilmington District via the Freedom of Information Act (FOIA) process. Every attempt was made to access every document that presents relevant information about reservoir design and/or management for the Wilmington District. References to

⁷⁶ Patterson, Lauren A, Brian Lutz, and Martin W. Doyle. (2013). Climate and direct human contributions to changes in mean annual streamflow in the South Atlantic, USA. *Water Resources Research*, 49, 7278-7291. <http://dx.doi.org/10.1002/2013WR014618>

project-specific USACE documents reviewed for this report will be made using their abbreviated names listed in the Appendix I.

Daily operational data were publicly available and obtained directly from the Wilmington District website.⁷⁷ These data were compiled, reviewed, and formatted through the work at the Nicholas Institute for Environmental Policy Solutions as part of a larger project on Corps reservoir operations. Streamflow data at control points below each dam were obtained from USGS National Water Information System (NWIS) online database.⁷⁸

Sedimentation rates were extracted from Sedimentation Surveys and Resurveys conducted by the Corps and Corps contractors. Occasionally, sedimentation rate and sediment pool volume information could be found in other Corps documents, such as Environmental Assessments and Master Plans. Design pool volumes and design sedimentation rates came primarily from Design Memoranda. (For an overview of reservoir pools typical of Wilmington District reservoirs, see Appendix J).

The Corps operational documentation was also used to define the management period, a unit of time when the management approach is assumed to be uniform (Figure 1). The management period is the basic unit of analysis in this report. The period is identified as the time between the issuance of two WCP's. (Recall that WCP's define operational rules for the reservoir. See section 1.3 *Water control documentation* for more details.) The exception to that rule is John H. Kerr reservoir, where fishery needs altered flow requirements outside of WCP revisions. The start date of the first management period is the first day of normal reservoir operation after initial lake filling was completed, as reported in Corps documents. The most recent management period ends in May 2014 due to data availability. Falls, Jordan, and W. Kerr Scott lakes have two management periods; John H. Kerr and Philpott lakes have three. Management periods will be discussed further in the context of minimum flows.

⁷⁷ Wilmington District maintains two websites, one for the general public (<http://www.saw.usace.army.mil>) and one containing the technical details of its reservoir operations (<http://epec.saw.usace.army.mil>).

⁷⁸ USGS NWIS database can be accessed via <http://waterdata.usgs.gov/nwis>

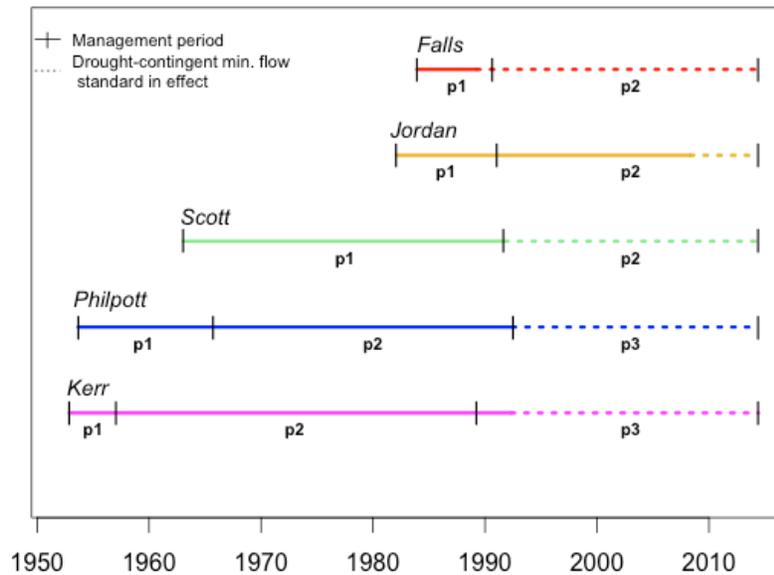


Figure 1. Management periods for Wilmington District reservoirs. Analysis of metrics in this report is based on a unit of time called a management period, designated on the figure with “p[x].” Dashed lines represent the proportions of latter management periods when drought-contingent minimum flow standards were in effect. Sources: Falls – Master Plan 1981, Revised Environmental Assessment 1985, WCP 1990, DCP 1989, DCP 2008; Jordan – Design Memorandum 1962, WCP 1991, DCP 2008; Scott – WCM 1963, WCP 1991, DCP 1991; Philpott – Master Plan 1953, Roanoke Master WCM 1953, WCM 1965, WCP 1992, DCP 1992; Kerr – WCM 1953, WCM 1965 (referencing authorization by Chief of Engineers for fish spawning flows dated 1/30/1957), DCP 1991, WCP 1995 (new fish spawning flow regime implemented 4/1/1989).

2.2.2 Analysis

Using the collected data, four management metrics were developed to assess reservoir operations in the Wilmington District (Table 2). All metrics are evaluated for each management period for all five Wilmington District reservoirs.

Inflow and sedimentation reflect the boundary conditions that shape management decisions externally. Managers have no control over these metrics and must only respond to them. Meeting minimum flow requirements and allocating water supply storage, on the other hand, are entirely under the management’s control. In fact, these metrics represent two of several authorized purposes for which each reservoir must be managed. Additional metrics corresponding to other reservoir purposes are desirable but could not be developed at this time due to limitations of the data.

Data analysis was performed using R Statistical Software.

Table 2. Reservoir management metrics

Type	Element of interest	Indicator	Metric (%)
External parameter	Climate	Reservoir inflow	Inflow / design inflow
External parameter	Land use	Reservoir sedimentation	Sediment pool volume / design sediment pool volume
Internal variable	Local water supply	Volume of water supply storage	Volume of contracted water supply storage / conservation pool volume
Internal variable	Downstream water quality	Downstream minimum flows	(Days mean flows at control point > min. flow requirements) / Total days

2.2.2.1 Inflows

The inflows metric captures changes in the amount of water entering a reservoir due to changes in climate or upstream human activities. The metric compares pre- and post-construction streamflow at the dam site by computing percent deviation above or below the design inflow during the management period.

In addition to mean daily inflows, annual inflows are compared to design annual inflows. Design annual inflows were calculated by multiplying the design daily inflow by the number of days in each year. Actual annual inflows were calculated using the calendar year (January 1 – December 31). The arbitrary mark of 8 months was chosen as the threshold for including or excluding a year from the analysis. For example, if a management period starts in February 1960, the data for the entire year 1960 was included in the analysis. Also, if the break between two management periods split the year into eight months in Period 1 and four months in Period 2, then the whole year’s data was included in Period 1. This designation minimized the exclusion of entire years of data from the analysis, which was important for relatively short management periods of less than 10 years.

The analysis is based on daily data provided by the Wilmington District for each reservoir and design inflows found in Corps documents. The presence of negative values in the

inflow data points to reported values being net daily inflows, which is a sum of all reservoir inflows minus evaporation. It is unclear if the Corps is providing gauged inflow data or modeled inflows. The documentation makes no mention of the Corps maintaining multiple stream gauges to monitor inflows at each branch of a reservoir.

Out of the five reservoirs, analysis of W. Kerr Scott inflows proved most challenging due to how the design inflow is reported in the 1958 Design Memorandum. The design inflow is provided for Wilkesboro, NC, where the drainage area is 492 mi². The drainage area for the dam site is reported as 348 mi² (Design Memoranda 1944, 1949, 1958, 1959; Reservoir Regulation Manual 1960; Sedimentation Resurvey 1979) or 367 mi² (Sedimentation Resurvey 2010, Environmental Assessment 2012, Pertinent Data 2015). The larger value, which was reported later, is presumed to be the more accurate due to advancements in surveying and geographic information system technology over time. Considering that the larger watershed contains the smaller watershed and assuming the same runoff ratio throughout the larger watershed, the design inflow of 771 CFS (0.56 MAF/Yr) as reported at Wilkesboro, NC was rescaled to the actual drainage area for the dam site (367 mi²), yielding 575 CFS (0.42 MAF/Yr).⁷⁹

2.2.2.2 Sedimentation

Sedimentation shows the percentage of the original sediment pool that is free of sediment at the end of each management period. The sediment pool is the volume of water set aside at the bottom of the reservoir that is expected to fill up with sediment over the reservoir's lifetime (see Appendix J). This analysis evaluates sediment pool volumes at the end of each management period using sedimentation rates and sediment pool volumes reported in Corps documentation. Sedimentation rate is an estimate of the amount of sediment deposited into the reservoir per square mile of watershed area over an average year during the reported time period (Figure 2). Sediment pool volume is the functional sediment pool volume that is judged to be free of sediment at the time of the report. For the purposes of

⁷⁹ Leopold, Luna B., M. Gordon Wolman, and John P. Miller. (1964). Hillslope characteristics and processes: Runoff. In *Fluvial Processes in Geomorphology* (pp. 354-357). San Francisco, CA: W.H. Freeman and Company.

this analysis, the sediment pool volume is taken as an indicator of overall reservoir sedimentation.

Sedimentation rates and sediment pool volumes are sourced primarily from Sedimentation Surveys and Resurveys, which were conducted by or on behalf of the Corps since before reservoir construction. Other documents, such as environmental assessments and master plans, occasionally report sedimentation rates. Unfortunately, the dates of these documents typically do not coincide with the end of each management period. Thus sediment pool volumes at the end of each management period are calculated using the following equation:

$$V_m = V_r + R * (Y_m - Y_r) * DA$$

where V_m is volume at the end of the management period, V_r is volume in the year of the report, R is the sedimentation rate for the period following the report (acre-feet/mi²/yr), Y_m is the end year of the management period, Y_r is the year of the report, and DA is the drainage area (mi²). For the most recent management period, which ends in 2014 for the purposes of this analysis, R is the sedimentation rate from the most recent report.

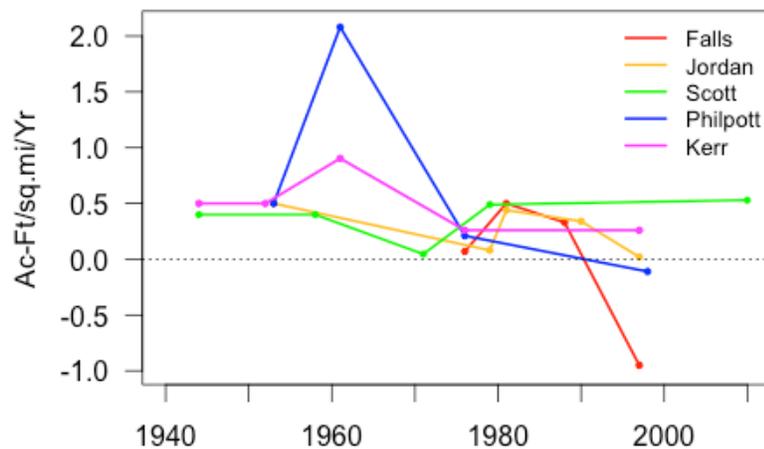


Figure 2. Sedimentation rates for Wilmington District reservoirs. Most recent sedimentation rates are smaller than anticipated in design or early management documents, except for W. Kerr Scott. Negative rates represent a net erosion of the reservoir during the period since the preceding survey. Sources: Falls – Master Plan 1981, Revised Environmental Assessment 1988, Sedimentation Resurvey 1997; Jordan – Sedimentation Resurvey 1997; Scott – Design Memoranda 1944 & 1959, Sedimentation Resurveys 1979 & 2010; Philpott – Master Plan 1953, Sedimentation Resurveys 1961 & 1998; John H. Kerr – Master Plan 1952, Sedimentation Resurveys 1961 & 1997.

Most sedimentation resurveys provide detailed information about the functional pool volumes remaining at the time of the report and the relative rates of sedimentation of each reservoir pool (sedimentation, conservation, flood control). Where sedimentation pool volume is missing from the report (e.g., Scott 1971), it is calculated using the following equation:

$$V_r = V_{r-1} - R_{r-1} * D_s * (Y_r - Y_{r-1}) * DA$$

where V_r is the sediment pool volume in the year of the current report, V_{r-1} is the volume in the year of the previous report, R_{r-1} is the sedimentation rate for the period preceding the year of the report (acre-feet/mi²/yr), D_s is the percentage of the total sediment for the period that was deposited in the sediment pool (from the nearest report), Y_r and Y_{r-1} are the years of the current and previous reports, and DA is the drainage area (mi²).

Sometimes the Resurveys not only report sedimentation rates and pool volumes from previous surveys but also revise preexisting estimates reported in previous documents. Where possible, the original rate estimates were used in this analysis. Additionally, rates that average the results of several surveys are not included, with the exception of:

- Philpott, reported in 1976, which is a compound rate for 1951-1976. This rate that may or may not incorporate the results of the 1961 resurvey (also included).
- Falls, reported in 1997, which is a compound rate for 1982-1997. This rate that may or may not incorporate the rate reported in 1988 revised environmental assessment for modification of operations at Falls Lake (excluded due to lack of other relevant information).

2.2.2.3 Minimum flows

The minimum flows metric evaluates the percent of time minimum flow standards were not met during each management period. The results allow us to determine the compliance of each reservoir with downstream minimum flow requirements set by the state for water quality maintenance. The metric is assessed by analyzing mean daily streamflow at a control point below a dam. A control point is a downstream location at a gauge operated by

the USGS where minimum flow requirements are established. Minimum flow standards typically vary by season and may be relaxed during periods of drought.

Similarly to inflow analysis, the minimum flows analysis also looks at the distribution of excursions from the standard. On days when minimum flow requirements were not met, the difference between the standard and the mean daily flow was calculated. The distributions of these differences (excursions) and their statistics allow us to understand the severity of water quality non-compliance for the reservoir during each management period.

Meeting minimum flow requirements may be more an art than a science for the Corps since river reaches between the dam and the control point may be subject to additional diversions outside of the Corp's control (e.g., local water supply intakes). Nevertheless, each reservoir has a minimum downstream flow standard for the purposes of pollution abatement starting as early as the design documents. Additionally, one of the reservoirs' general purposes is to uphold the Clean Water Act (see section *1.1 The Corps authorities*). Thus the Corps has a responsibility have reservoir management decisions support the meeting of downstream minimum flow standards.

For some reservoirs, streamflow data at the control point came with caveats, such as relocation of the control point. Appendix K summarizes information about control points, their source of data for each date range, and obstacles with data management that had to be resolved to perform this analysis. Missing streamflow data were not an issue at any site except Lillington, NC below Jordan Lake, where 1% of total flow data were missing (10/1/2009 – 2/7/2010).

Minimum flow standards were obtained exclusively from Corps design and management documents. If a standard changed at some point since dam operations began, the date of the Corps document containing the change was taken as the date when the new standard came into effect, unless otherwise noted. Here, the author assumed that the Corps would be the best source of information for operational requirements of the dam. Minimum flow

standards reported in Corps documents were not cross-referenced with other potential sources of information, e.g., NPDES permits and state ecological flows standards.

Analysis of minimum flows was performed for each reservoir management period. A drought-contingent minimum flow standard came into effect at some point during the latest management period for all reservoirs (Figure 1 in section 2.2.1 *Data Collection*). A drought-contingent minimum flow standard is a revision of minimum flow requirements at a control point that incrementally lowers the minimum flow requirement contingent upon the severity of drought. The severity of drought is measured by the volume of water remaining in the reservoir, either as a threshold percentage of the conservation pool remaining or a threshold elevation. Information about drought-contingent minimum flow requirements can be found in Drought Contingency Plans (DCP) for each reservoir. Based on their availability and references to them in other documentation, DCP's do not appear to have existed prior to late 1980's. Additionally, it is likely that DCP 1991 for Jordan Lake may refer to a drought-contingent standard. Because this document could not be located, however, a drought-contingent minimum flow standard downstream of Jordan Lake could not be established for 1991-2008. In this analysis, the regular minimum flow standard continued in effect at Jordan Lake until DCP 2008 came into effect.

Changes in the minimum flow standard in response to reservoir drought conditions varied from reservoir to reservoir. At Jordan and Scott, the minimum flow standard was incrementally decreased during droughts.⁸⁰ At Falls, Philpott, and Kerr, however, the DCP's described how a stakeholder committee would be responsible for prioritizing reservoir operational objectives once the reservoir reaches drought conditions. One possible course of action for the committee could be to "temporarily relax water quality standards."⁸¹ Because documentation of actual committee decisions was unavailable, the effects of possible changes to the minimum flow standard at Falls, Philpott, and Kerr were not evaluated. Since it is possible that minimum flow standards were not relaxed during

⁸⁰ Jordan DCP 2008, Scott DCP 1991, Scott Environmental Assessment 2012.

⁸¹ Falls DCP 1989, 2008.

drought periods, the regular standards in effect during the management period were applied without drought contingency at these three reservoirs.

Despite these limitations, this analysis evaluates the relative benefits to the Corps from adopting the drought-contingent minimum flow standard. The benefits to Corps are measured in the number of violations avoided due to the implementation of the standard. Violations are defined as days when downstream minimum flow standards were not met.

In this analysis, drought is defined only as it pertains to reservoir operations. Thus the presence or absence of landscape-wide drought, as measured by precipitation, or regulatory drought, as declared by state government, is not being considered in this analysis.

2.2.2.4 Water Supply

The water supply metric refers to the percent of total conservation pool contracted for water storage at the close of each management period. The conservation pool is the reservoir volume above the sediment pool that is typically filled with water (refer to Appendix J). The top of the conservation pool is the lake surface.

A water supply storage contract allows a local partner, such as a municipality, to rely on the reservoir to store raw water for the purposes of municipal and industrial (M&I) uses. As mentioned previously, the Corps provides only storage volumes and does not guarantee access to water via these contracts (see section *1.5.2 Water storage reallocation*).

The analysis provides only a broad look at water supply obligations due to inconsistent data among the five reservoirs. Only Corps documentation was used in this water supply storage analysis, though additional sources were considered. For the purposes of evaluating reservoir operations on an annual or periodic basis, it would have been more useful to look at percent of water supply storage actively being used (i.e., water supply releases, active allocations, or demand by contracted entities). Unfortunately, the Corps, NC

Department of Environment Quality, and VA Department of Environmental Quality did not provide sufficient data for such a detailed analysis.

2.3 Results & Discussion

2.3.1 Inflows

When comparing pre- and post-construction inflows, most reservoirs in the Wilmington District have received less water than originally anticipated in their design documents (Table 3). On the average, Falls Lake has received 86% of estimated design inflows, which is the lowest fraction of design inflows of all five reservoirs. Other reservoirs located in the Piedmont (Jordan, Kerr) also received less water than anticipated during the design period. On the other hand, mountain reservoirs (Philpott, Scott) on average received a little over 100% of their design inflows since construction. As mentioned previously, the design inflow for Scott is reported a downstream site in the Design Memoranda (1958, 1959). Thus the design standard was rescaled from 771 CFS as reported in the design documents to the actual reservoir drainage area, yielding 575 CFS.

Table 3. Design and actual mean daily inflows for Wilmington District reservoirs.

Reservoir	BEFORE CONSTRUCTION					AFTER CONSTRUCTION			
	Design mean daily inflow (CFS)	Design period of record	No. Years	Gauge location	Source	Mean daily inflow (CFS)	Inflow period of record	No Years	% of design inflow
Falls	754	1928-1972	45	Northside, NC [reservoir site]	EIS 1974	652	1983-2015	33	86%
Jordan	1616	1929-1974	46	N/A	EIS 1975	1582	1982-2014	34	98%
W. Kerr Scott	575	1920-1957	38	Wilkesboro, NC**	DM 1958, DM1959	616	1963-2014	52	107%
Philpott	252	1931-1939	9	Martinsville, VA*	DM 1944	255	1953-2014	62	101%
John H. Kerr	7960	1912-1940	29	Buggs Island [reservoir site]	DM 1944	7209	1952-2014	63	91%

EIS=Environmental Impact Statement, DM=design memorandum.

* Downstream of dam site; design inflow likely computed, not measured.

** Downstream of dam site; design inflow of 771 CFS is rescaled to 575 CFS using reservoir watershed size.

Pre-construction design inflows were also compared to actual inflows in each management period and on an annual basis (Figure 3). In the latest management periods (approximately 1990–2014), all reservoirs but W. Kerr Scott appear to be below design inflow. The results are mixed for the mid periods (1960's/1980's–1990) and are difficult to compare because of the wide range of years (approximately 10 to approximately 30). Nevertheless, it is interesting to observe that both Fall Lake and John H. Kerr Reservoir have been operating at net deficit for all management periods. This finding is supported by the mean daily inflows at these reservoirs being the lowest fraction of their respective design inflows in the district (Table 3).

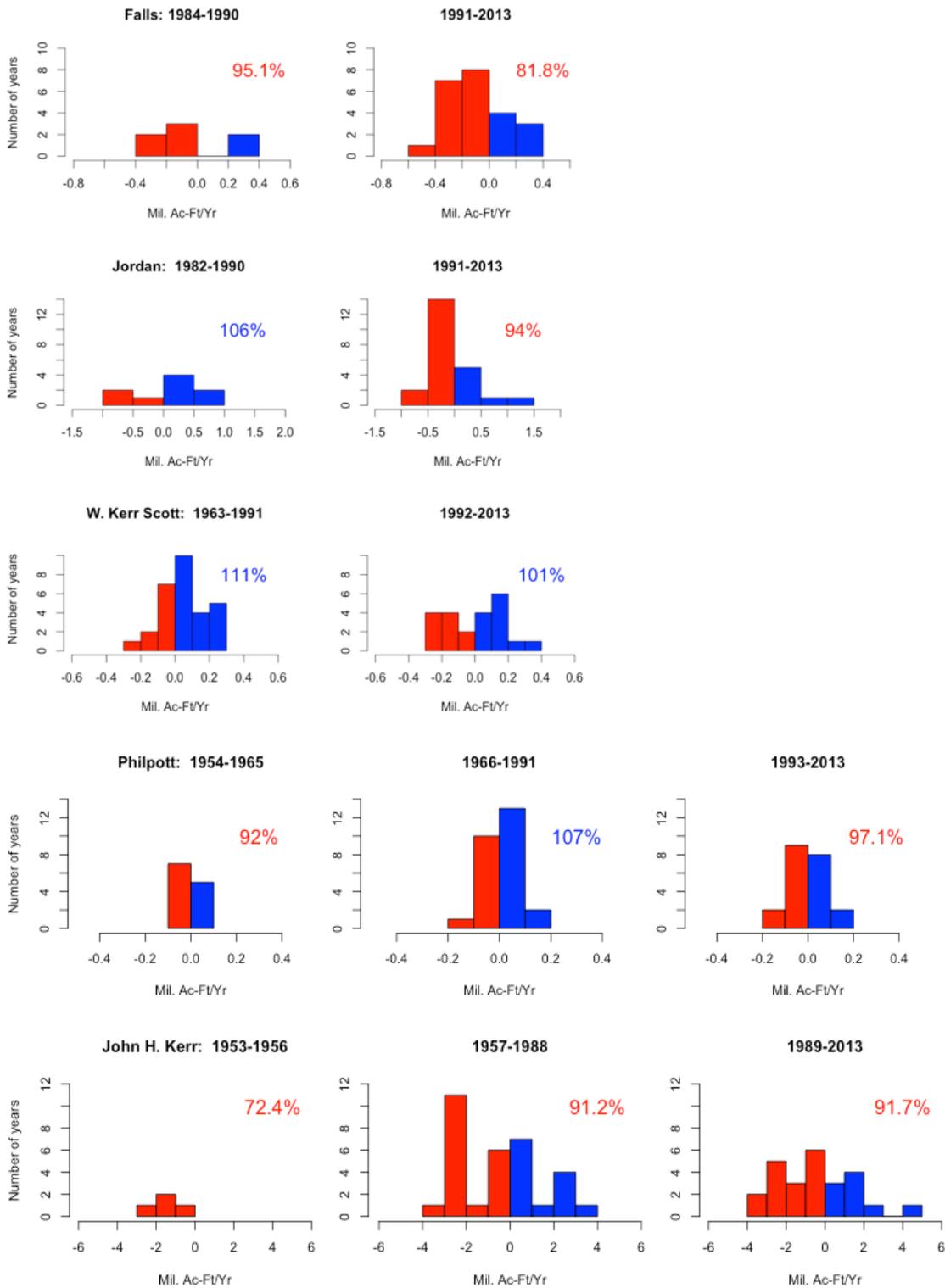


Figure 3. Actual inflows compared to design inflows for each management period. Each graph compares pre-dam conditions (design inflows) to post-construction conditions in a management period. Histograms show distributions of annual inflow anomalies above (blue) or below (red) annual design inflow, which is set at “0.” Percentages indicate the mean daily inflow for the period as compared to the design inflow.

2.3.2 Sedimentation

Sedimentation does not present a limitation to Wilmington District reservoirs (Figure 4). All five reservoirs were designed with a 50-100 year lifespan in mind. Nevertheless, even the oldest reservoirs, like Philpott and John H. Kerr, are not experiencing substantial declines in their sediment pool volumes. Conversely, reservoirs like Falls and Philpott appear to be undergoing net erosion, and the volumes of their sediment pools are increasing compared to design volumes.

Falls Lake represents a special case in this analysis. Due to a surveying error during the design phase, the 1988 Revised Environmental Assessment reduced the estimate of the design sediment pool volume in the reservoir from 38,000 acre-feet to 25,100 acre-feet. Thus the latter value is assumed to be the most accurate estimate of design sediment pool volume. Additionally, we only have one Sedimentation Resurvey (1997) available to extrapolate the volumes at the close of both management periods. That survey reports an increase in all pool volumes (sediment, conservation, and flood control) relative to “as-built” estimates from 1982.

There is a possibility that the results of the 1997 resurvey are not accurate. In that case, extrapolating the erosion (negative sedimentation) rates through 2014 does not yield an true picture of the management situation. Due to lack of evidence to the contrary, however, we have to assume that the Corps has not done another sedimentation resurvey since 1997 and is operating the reservoirs according to the findings of the 1997 Resurvey. This assumption has profound implications during times of severe drought when the Corps can temporarily reallocate sediment pool volumes toward M&I water supply (see section 1.5.2 *Water storage reallocation*). This is especially important at Fall Lake because the reservoir serves as the main source of drinking water for the City of Raleigh, the rapidly growing capital of North Carolina. Overestimates of the functional sediment pool volumes in times of drought can exacerbate a water shortage and could undermine public trust in the Corps.

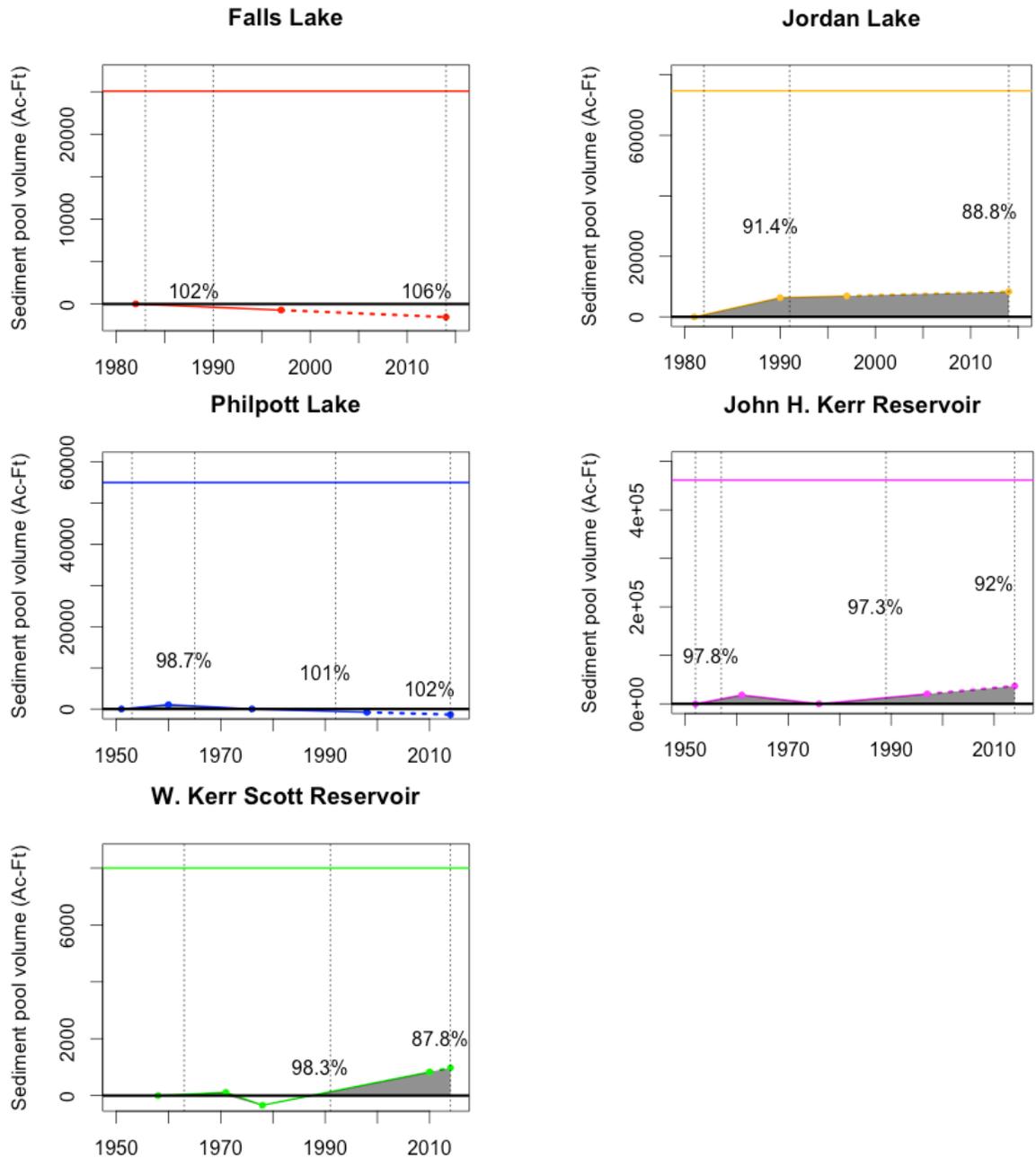


Figure 4. Sediment pool volumes remaining at the end of each management period, shown as percentages of design sediment pool. Vertical dotted lines demark management periods, with the first line marking the beginning of regular reservoir operations. The percentages shown next to second, third, and sometimes fourth dotted lines represent fractions of design sediment pool remaining at the end of each management period. Points on the color lines represent sediment pool volumes reported in Corps documents from the year marked on the x-axis. The sections plotted with dotted color lines represent sedimentation volumes extrapolated to 2014 using the latest available sedimentation pool volume measurements.

2.3.3 Minimum flows

Wilmington District reservoirs have met their downstream minimum flow requirements 90% or more of the time. The exception to this finding is W. Kerr Scott reservoir, which has only met its minimum flow requirements 77% of the time since 1991 (Figure 6). This non-compliance may be tied to Scott being the only non-hydroelectric reservoir in the district that does not have a dedicated water quality pool. Additionally, the Wilkesboro gauge where the minimum flows are measured is located at the confluence of Yadkin River that flows out of the reservoir and Reddies River. The non-compliance may be due to the Corps overestimating flows from Reddies when releasing water from W. Kerr Scott reservoir.

There is no discernible trend from period to period among reservoirs regarding improvement of performance (e.g., higher compliance rate over time). Falls, Jordan, and Scott all had a decrease in the rate of compliance between the first and second management periods. Philpott and Kerr both saw an improvement between the second and third periods, with Philpott only incurring two violations in the third management period. The high rate of compliance at Philpott may be influenced by the minimum flow requirements being in effect for the control point at Bassett, VA only during the summer months as opposed to year-around like for other reservoirs.

There also doesn't appear to be any clear trend from one management period to another in regards to the distribution of excursions below the minimum flow standard (Figure 6). An excursion is the difference between the mean daily flow at the control point and the minimum standard when the flows are below the requirement. The range of excursions increased for both Jordan and Scott from the first to the second period, while it contracted for Falls. It also contracted for Philpott and Kerr from the second to the third management period. Appendix L compares the statistics of excursion distributions between management periods in greater detail.

The implementation of the drought-contingent standard during the latest management period allowed two reservoirs to avoid some minimum flow violations (Figure 5).

Violations are defined as days when downstream minimum flow standards were not met.

At Jordan and W. Kerr Scott, the total number of violations was reduced by 74 days (from 278 to 159 when the drought-contingent standard was in effect) and 359 days (from 2264 to 1905 when the drought-contingent standard was in effect). These values equivalent to approximately 12 and 16 violations avoided per year, respectively. They were calculated by comparing violations incurred using the regular and drought-contingent minimum flow standards for the period.

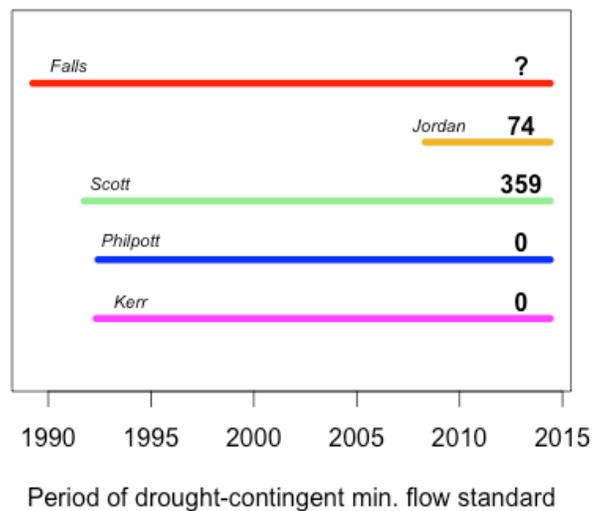


Figure 5. Minimum flow violations avoided during periods of drought-contingent minimum flow standard. Jordan and Scott benefitted the most from the introduction of drought-contingent minimum flow standards during the latest management period. Jordan avoided approximately 12 violations/year while Scott avoided about 16. Philpott never reached reservoir drought during the time period evaluated. Kerr’s minimum flow violations did not occur on days when the reservoir was considered in drought. Due to open-ended guidance on drought contingency and lack of data on the management’s actual response to drought, it was not possible to determine if Falls benefitted from the drought-contingent minimum flow standard.

For other reservoirs, the benefits of the drought-contingent standard are none or unclear. No effects were observed at Philpott and John H. Kerr: Philpott never reached drought conditions as they are defined in the management documents, and at Kerr, no minimum flow violations occurred during periods when the reservoir was considered to be in drought. At Falls Lake the results are inconclusive. At Falls, 45 violations occurred during periods of drought. No information is available about whether and to what degree the minimum flow standards were adjusted during drought periods. Thus it is not possible to determine the number of violations that could have been avoided due to a drought-contingent standard.

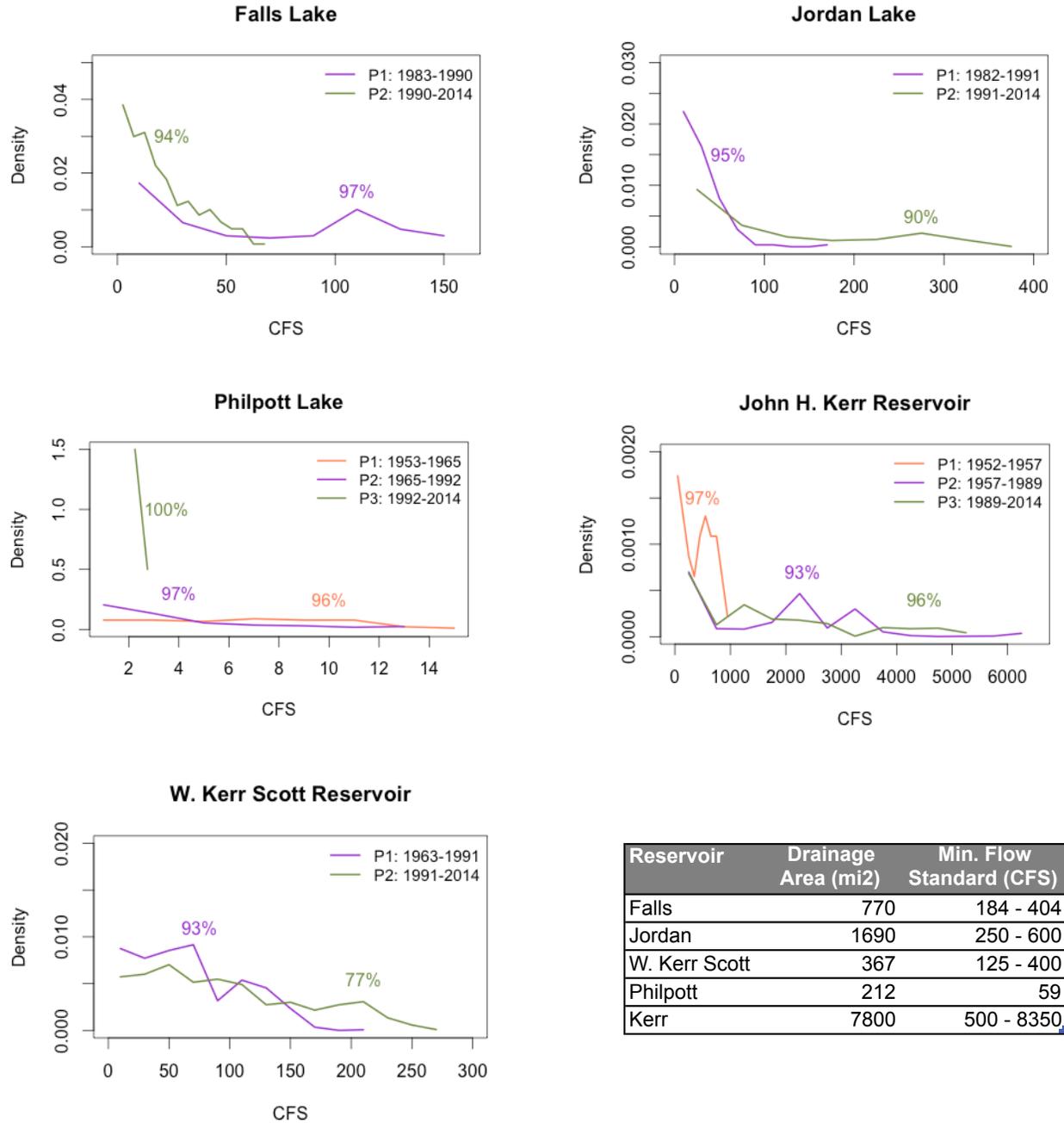


Figure 6. Percent minimum flow requirements met and distributions of excursions below requirements. Percent requirements met is the percentage of days in the management period when the mean daily flow at the downstream control point was equivalent to or exceeded the minimum flow standard. An excursion below the minimum standard is the difference between the mean daily flow at the control point and the minimum standard when the flows are below the standard. The inset table provides a reference for the relative sizes of each reservoir in terms of its drainage area and the range of the minimum flow standard through time. Note the varying ranges of x- and y-axes among reservoirs.

2.3.4 Water Supply

Falls, Jordan, and W. Kerr Scott lakes are authorized for water supply storage from their inception (refer to Table 1 in section *2.1 Background*). A fraction of these reservoirs' conservation pools (Falls, Jordan) and the entirety of the conservation pool (W. Kerr Scott) were allocated to water supply storage starting in the design stage. These water supply volumes were then contracted to local partners, such as City of Raleigh (Falls), the State of North Carolina (Jordan), and City of Winston-Salem and Wilkes County (W. Kerr Scott). Local partners, like the State of North Carolina and Wilkes County, are free to allocate storage volumes to smaller entities, such as local municipalities. Allocation does not necessarily mean that the whole allocated volume is being used every year; rather, it provides the right to the storage volume in a reservoir that yields a specified annual volume of water. The locality can withdraw water up to that amount. The contract lengths for Falls and W. Kerr Scott are 50 years each. The length of Jordan contract is unclear from the available documentation.

Other reservoirs, such as Philpott and John H. Kerr, were not originally authorized for water supply and this did not have a specific fraction of the conservation pool dedicated to water supply. Nevertheless, the Chief of Engineers can reallocate small storage volumes toward water supply, pursuant of Water Supply Act of 1958, as long as the reallocation does not impact other authorized purposes (see section *1.5.2 Water storage reallocation*). Such incremental reallocations took place at John H. Kerr Reservoir starting in early 1980's to provide water storage for state, municipal, and industrial partners in Virginia and North Carolina (Kerr Lake Regional Water System, Dominion-Mecklenburg Power Station, City of Virginia Beach, VA, and State of Virginia Department of Corrections).⁸² The total reallocation at John H. Kerr reservoir constitutes only 2.06% of the total conservation pool volume (Figure 7). No such storage reallocation has yet taken place at Philpott, though one was proposed in 2015 and remains under consideration.⁸³

⁸² Kerr Reallocation Report 2005, Kerr Master Plan 2013.

⁸³ Philpott Congressional Fact Sheet 2015.

The possibility of storage reallocation is not limited to those reservoirs not originally authorized for water supply. Currently, Raleigh is requesting an additional 12,500 acre-feet of water supply storage in Falls Lake, which would need to be reallocated from the water quality pool.⁸⁴ Should it take place, this reallocation would increase Falls Lake’s water supply storage to 54% of the conservation pool volume.

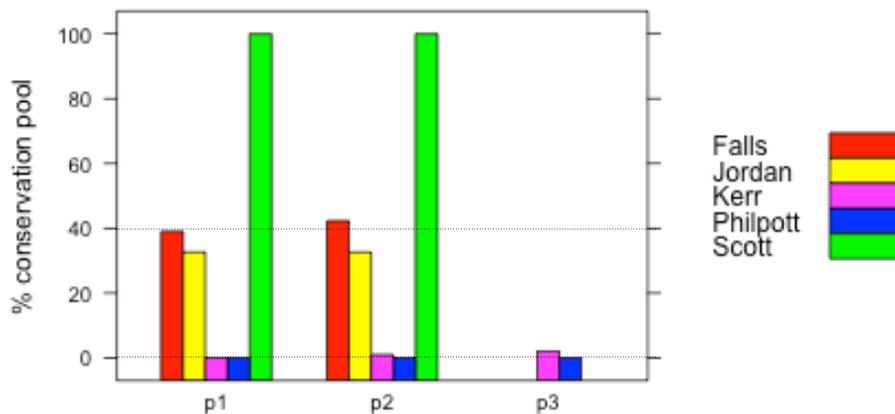


Figure 7. Percent of conservation pool contracted for water supply storage at the end of each management period. Falls, Jordan, and W. Kerr Scott were originally authorized for water supply storage. At John H. Kerr Reservoir, a hydroelectric dam, water supply storage was gained via reallocation from the power pool. Philpott, which is also hydroelectric, currently has no storage volumes dedicated to water supply. At the reservoirs where water supply storage exists, the entirety of the water supply pool has been contracted to local partners. Sources: Falls – Environmental Impact Statement 1974, WCP 1990, Master Plan 2013; Jordan – WCP 1992, Master Plan 2007, Drought Contingency Plan 2008; Scott – Water Supply Contract 1960, Drought Contingency Plan 1991, Congressional Fact Sheet 2015; Philpott – WCP 1991, Congressional Fact Sheet 2015; Kerr – WCP 1992, WCP 1995, Reallocation Report 2005, Master Plan 2013.

It is worth noting that the small increase for Falls Lake between the two management periods appears to be not due to a reallocation but due to a recalculation of the conservation pool volume (Figure 7). The total volume allocated to Raleigh’s drinking water storage has remained at 45,000 acre-feet. However, sometime between 1994 and 2008 the percentage of the total conservation pool that this volume constitutes changed from 39% to 42.3%. This increase points to a reevaluation of the conservation pool volume sometime during that period, resulting in a decrease of the total conservation pool storage.

⁸⁴ Falls Lake Reallocation Study 2015

The reevaluation is unlikely to have been due to the results of the 1997 Sedimentation Resurvey since that report found a net increase of the conservation pool compared to the “as-built” volume. Other reasons for the reevaluation are unclear based on Corps documentation.

2.4 General Discussion & Synthesis

The Wilmington District water managers have been operating reservoirs since 1952. Between then and now, the District hasn’t faced dramatic long-term changes compared to design assumptions for the majority of its reservoirs. The boundary conditions of climate and land use have not exerted a pressing need for systematic change in the District. Looking back on the history of reservoir operations allows us to ask the question: what could be the threshold for managers to consider systematic changes for a reservoir or the District’s overall management approach?

2.4.1 Inflows

Reservoir inflows are a reflection of climate. Inflows into four of five Wilmington reservoirs (Falls, Jordan, Philpott, and Kerr) were below the design inflows for the latest management period (approximately 1990-2014). For the majority of Wilmington Reservoirs, design inflows were based on approximately 30 years or more of pre-construction streamflow data (see Table 3 in section 2.3.1. *Inflows*). Because 20 years is the preferred length of record for predictably estimating future streamflow, these records yielded trusted estimates under assumption of climate stationarity.⁸⁵ Deviations from pre-dam design flows could indicate a permanent shift in climate. Alternatively, they could occur in response to a long-term natural climate oscillation.⁸⁶ Regardless of the causes, inflows that are consistently lower than design inflows may compromise the operators’ ability to effectively manage the reservoir for all of its operational objectives. It is possible that a

⁸⁵ Gan, K.G., T.A. McMahon, and B.L. Finlayson. 1991. Analysis of periodicity in streamflow and rainfall data by Colwell’s indices. *Journal of Hydrology*, 123, 105-118. [http://dx.doi.org/10.1016/0022-1694\(91\)90072-P](http://dx.doi.org/10.1016/0022-1694(91)90072-P)

⁸⁶ Patterson, Lauren A, Brian Lutz, and Martin W. Doyle. (2012). Streamflow changes in the south Atlantic, United States during the mid- and late-20th century. *Journal of the American Water Resources Association*, 48(6), 1126-1138. <http://dx.doi.org/10.1111/j.1752-1688.2012.00674.x>

threshold for a minimum daily, annual, or decadal inflow exists that allows managers to ensure that all of the reservoir's operational objectives will be reached. No mention of it, however, exists in the Corps documents reviewed for this report.

2.4.1.1 Reservoirs of interest: Falls Lake and John H. Kerr Reservoir

Mean inflows at Falls Lake and John H. Kerr Reservoir consistently have been below the reservoirs' respective design inflows across all management periods (see Figure 3 in section 2.3.1 *Inflows*). This deviation may be partially explained by the influence of regional climate since both reservoirs and the majority of their watersheds are located in the Piedmont region. For Falls Lake, the deviation has been especially dramatic during the latest management period, coming in at 82% of design inflow. This metric is likely influenced by several droughts of record in the early 2000's and 2007-2008. Inflows to Falls Lake are of concern to the City of Raleigh, the local partner that receives the majority of its water supply from Falls Lake. At John H. Kerr, the deviation may impact the reservoir's electric generation capacity.

2.4.2 Sedimentation

Sedimentation does not present a systematic concern to the Wilmington District reservoirs. According to this analysis, all reservoirs have 88% or more of their sediment pool capacities free of sediment as of 2014. This metric exceeds even the most conservative design estimates, according to which the sediment pool of each reservoir would be expected to completely fill with sediment over 50-100 years. If sedimentation rates in the region do not change, Wilmington District reservoirs will be minimally affected by sedimentation. This condition, however, may be subject to change as the region's population grows and alterations to land use may affect sedimentation rates. A threshold for sediment pool volume or sedimentation rates may exist in order for the reservoir to continue meeting its operational objectives. Nevertheless, it could not be located in the documents reviewed.

2.4.2.1 Reservoir of interest: Falls Lake

Sediment pool estimates at Falls Lake are based on the results of a single Sedimentation Resurvey from 1997. The findings of that resurvey were surprising as they indicated net erosion of the lake as a whole, including the sediment pool. Given the troubled history of accurately estimating reservoir volumes at this location and the reservoir's importance as a source of drinking water for the rapidly growing state capital, a verification of these results is desirable. Inaccurate estimates of sediment pool volumes could exacerbate a drought emergency when local partners may be counting on a temporary reallocation of the sediment pool toward water supply storage (see section *1.5.2 Water storage reallocation*).

2.4.3 Minimum flows

Four of five reservoirs in the Wilmington District (Falls, Jordan, Philpott, and Kerr) have been able to meet downstream minimum flow requirements at 90% or more success rate for each management period. No clear trend exists from management period to management period or among reservoirs regarding shifts in the rate of compliance or variability of excursions below the minimum flow standard. Only two of five reservoirs (Jordan and Scott) definitively benefitted from implementing drought-contingent minimum flow standards during the latest management period.

Minimum flow requirements are currently driven primarily by pollution abatement needs. However, increasing pressure from local stakeholders and growing numbers of aquatic species coming under the protection of the Endangered Species Act may be putting pressure on the Corps to revise its flow requirements to mimic ecological flow regimes (see section *1.6 Impact of Endangered Species Act on Corps reservoir operations*).

2.4.3.1 Reservoirs of interest: W. Kerr Scott and John H. Kerr Reservoirs

W. Kerr Scott was able to meet its downstream minimum flow requirements only 77% of the time in the latest management period. This metric accounted for the drought-contingent minimum flow standard. This flexible standard allowed Scott to avoid an

additional 359 violations that would have occurred if the regular standard had been in effect during periods of drought at the reservoir (Figure 5). This low rate of compliance may be driven by two factors: (a) the reservoir lacking a dedicated water quality pool; and (b) managers overestimating flows from the Reddies River, which enters the Yadkin River near the USGS gauge at the control point. In order to increase the rate of compliance with the minimum flow standard, water managers could consider the impact of these two factors on operations. Additionally, this example introduces the question of whether a threshold should exist for the minimal fraction of the conservation dedicated specifically to water quality maintenance.

John H. Kerr Reservoir is currently undergoing a revision of its WCP to change its operations to the Quasi-Run-of-River approach. The proposed changes “would more closely mimic the unregulated river discharges and would be considered the maximum extent of what could be changed operationally, without drastically altering reservoir levels and the flood footprint.”⁸⁷ The proposed WCP, included in the Environmental Assessment, refers to the needs of downstream striped bass fishery and estuary ecological needs. This change demonstrates the Corps’ moving towards a broader definition of downstream flow requirements by considering ecological flows in addition to minimum flows necessary for pollution abatement.

2.4.4 Water Supply

Four of five Wilmington District reservoirs (Falls, Jordan, Scott, and Kerr) have a portion of their conservation pool allocated toward water supply storage. Unlike other federal agencies that manage water resources (e.g., Bureau of Reclamation), the Corps only provides storage volumes in their reservoirs but does not guarantee water availability. In reservoirs where water supply pools exist, they were contracted out to local sponsors in their entirety at the end of each management period. Reservoirs are either authorized for water supply storage at their inception or can reallocate small amounts of storage toward

⁸⁷ Kerr EA - WCP Revision 2015.

water supply pursuant of the Water Supply Act of 1958 (see section 1.5.2 *Water storage reallocation*).

Water supply has grown in importance as a management objective for Corps reservoirs over the last 60 years. The oldest reservoirs in the Wilmington District (Philpott, Kerr) that were authorized in 1944 did not include water supply as a discrete authorized purpose. Scott was originally conceived for the purposes of flood control and hydropower, and water supply only appeared as an authorized purpose in the reservoir's final design document in 1958, the year of the passage of the federal Water Supply Act.⁸⁸ The designs of Jordan and Falls were motivated by water supply storage from the beginning. Kerr underwent reallocations toward water supply over time, though its conservation pool is still primarily dedicated to hydropower generation.

2.4.4.1 Reservoirs of interest: Falls and Philpott Lakes

Currently, water supply is still growing in importance as a management objective. Both Philpott and Falls are currently undergoing review for reallocation toward water supply. At Philpott, Henry County Public Service Authority is seeking a 50-100% increase of releases for its water supply downstream, which is prompting a storage reallocation study on the part of the Corps. The volume of this potential reallocation is yet unknown. At Falls, the reallocation would be coming from the water quality pool and would increase the reservoir's water supply pool from 42% to 54% of the conservation pool volume.

These requests for reservoir storage reallocation toward M&I water supply are part of a national trend that is best explained in the Corps' M&I Supply Database Report (2011): "As the Corps has not been constructing new multipurpose reservoir projects that could include M&I water supply storage for a number of years, an increasing necessity to meet the demands of state and local interests is through reallocations."⁸⁹ Additionally, the trend

⁸⁸ Scott Design Documents 1944 & 1958

⁸⁹ United States. Army. Corps of Engineers. Institute for Water Resources. (2012). *2011 M&I Water Supply Database* (2012-R-02). Retrieved from: <http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/2012-R-02.pdf>

is not recent in the Southeast: the Wilmington District is part of the South Atlantic Division, which was one of the earliest implementers of reallocation toward M&I purposes.⁹⁰ This trend raises the question of a potential maximum fraction of the conservation pool that is dedicated to water supply storage. It is possible that such a threshold exists to prevent the Corps from compromising its ability to meet other reservoir operational objectives, though no specific mention of this threshold could be found in Corps documentation.

2.5.5 Synthesis

2.5.5.1 Defining operational success

The Corps has several competing and sometimes conflicting priorities for its reservoir operations. In the Wilmington District, each reservoir has between five and six operational purposes (see Table 1 in section 2.1 *Background*). Some of these purposes can be at odds with one another, like water supply storage and downstream minimum flow requirements during times of drought. Under these contradictory priorities, it may be especially important to define operational success to ensure that reservoirs are being managed to achieve the maximum public good.

We can approximate the degree of operational success by evaluating management metrics from the public's and the Corps' point of view. We assume that the public wants to see the Corps put reservoir storage to maximum productive use. Thus one measure of success would be having the water supply portion of the conservation pool 100% allocated to various municipal and industrial users. In addition, the public wants to maintain river quality at acceptable standards, so another measure of success would be for the Corps to be in compliance with minimum flow requirements 100% of the time. This approach approximates the legal requirements that the Corps faces to meet all of the reservoirs' operational objectives equally well.

From the point of view of Corps operation, the outlook may be different. Multi-objective optimization of operations can balance the objectives, but it is unlikely to result in a high

⁹⁰ *ibid.*, Table 7.

degree of success for all objectives. Prioritizing some objectives over others, temporarily or permanently, can create operational flexibility that allows short-term trade-offs to achieve long-term priority objectives. Additionally, prioritization reduces the number of operational targets to be achieved, improving the chances of successful operations.

Legally, some reservoirs have very little or no operational flexibility. An example is a reservoir that has 100% of its water supply storage allocated and aims to meet 100% of its downstream minimum flow requirements. The Wilmington District considers Falls and Jordan Lakes to be such projects. Both of these reservoirs have 100% of their water supply pools contracted to local sponsors, like the City of Raleigh and State of North Carolina, respectively. The remainders of their conservation pools serve as water quality pools, which are considered to be under the authority of the State of North Carolina. Legally, “flexibility within the conservation pool between water supply and water quality would have to be initiated and addressed by the State of North Carolina” for Jordan Lake.⁹¹ In this case, creation of flexibility is likely referring to a formal process by which operations or conservation pool allocations would be changed to achieve a different balance of objectives. In practice, however, the Corps is still responsible for daily releases that may be used to create short-term operational flexibility that allows priority objectives to be achieved.

Operational success can be defined by comparing metrics, such as those evaluated in this report, against accepted standards. Pre-defined thresholds may act as such standards. A threshold may be defined at the district level and influenced by regional conditions (climate, land use), or they may be adjusted for each reservoir to optimally balance its operational objectives. Exceeding a threshold can be used to trigger the need for adaptation at a reservoir. Current adaptation mechanisms include WCP revision to continue to meet reservoir purposes and reallocation of storage volumes to respond to external influences on reservoir operations.

⁹¹ Jordan DCP 2008

2.5.5.2 Box model methods

To synthesize the results of this analysis and visualize the roles of thresholds and flexibility in reservoir operations, the author developed a “box model.” One model was produced for each of the management periods for all five reservoirs in the Wilmington District. The model relies on the metaphor of a box, a physical object that has a location and contents.

The location is defined by two metrics of reservoir parameters, also known as external influences on reservoir operations. These metrics make up axes of the Cartesian plain, with percent sediment pool on the x-axis and percent design inflow on the y-axis. Thus the location of the box synthesizes the results of the metrics shown in sections 2.3.2. Sedimentation and 2.3.1 Inflows, respectively.

Visualizing the reservoir parameters as a location allows us to introduce the idea of thresholds. The Wilmington District may establish thresholds for both inflows and sedimentation beyond which the reservoir would need to adapt. A possible scenario may be that the threshold for inflows is +/- 25% of design inflows and for sedimentation is +/- 75% of design sediment pool (Figure 8, left).

The contents of the box are comprised of reservoir variables, which represent operational objectives like water supply storage and downstream water quality maintenance. Each metric is represented by a bar graph measuring 0-100%. Thus the contents of the box synthesize the results of metrics shown in sections 2.3.4 Water Supply and 2.3.3 Minimum Flows, respectively.

The metrics inside the box may also have thresholds (Figure 8, right). They could represent the maximum percent of the conservation pool that may be allocated to water supply storage without compromising other reservoir objectives, and the minimum percent of downstream minimum flow requirements that should be met in a management period (or month, year). Additionally, these metrics – or rather the negative white space created by the bars inside the box – allow us to visualize operational flexibility, or the water remaining

and available to meet additional reservoir purposes. In the case of this example, water supply storage takes up 25% of the conservation pool, and the managers have 75% of the reservoir conservation pool available to achieve other objectives. If, however, the remainder of the conservation pool is allocated toward water quality, like in Jordan and Falls Lakes, that volume will be managed to meet a primary objective: downstream minimum flows. Nevertheless, other reservoir objectives may intervene, such as fish and wildlife enhancement that requires the lake levels be kept at a certain elevation for a period of time. In this case, the managers can artificially create short-term flexibility by missing some daily minimum flow requirements in order to help maintain a species population for the year.

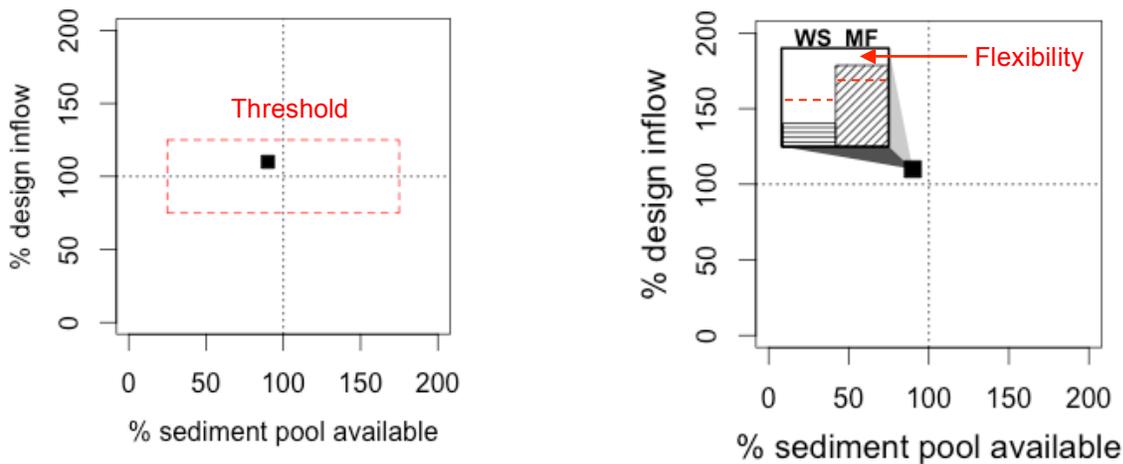


Figure 8. Visualizing operational thresholds and flexibility via the box model. Dashed lines represent possible thresholds of (left) +/- 25% of design inflows and +/- 75% of design sediment pool; and (right) 50% of conservation pool allocated to water supply (WS) and 75% of minimum flows met (MF). Flexibility is visualized as the empty space inside the box contents (right). Flexibility can be artificially created by, for example, not meeting daily minimum flow requirements, as in this example where about 15% of requirements were not met during a management period. This flexibility may be necessary to achieve other operational objectives in the Wilmington District not captured by these metrics, such as flood protection, recreation, fish and wildlife enhancement, and hydropower.

2.5.5.3 Box model results and discussion

The box model allows us to evaluate the assumption of stationarity under which the Wilmington District reservoirs were originally designed. While the reservoir designers expected the sediment pool to fill up over time, nothing in the design documents indicates

that they allowed for the possibility of reservoir erosion. Additionally, climate change and its impact on water availability has only become a recent concern to water managers. Thus it is unlikely that the reservoir designers in 1940's-1970's anticipated significant deviations from their hydrologic estimates over the reservoirs' lifetimes. Thus, according to reservoir design assumptions, we should only be able to see the reservoir "location" shift to the left (<100 on the % sedimentation axis) and remain close to zero over the long-term average (% design inflows axis).

Using the location function of the box model allows us to easily visualize how the external parameters influencing reservoir operations have changed over time (Figure 9). This figure provides a means to assess the potential needs of Wilmington reservoirs as a system, allowing managers to prioritize projects of potential concern. For example, Jordan's, Scott's, and Kerr's locations are moving to the left over time, showing sediment accruing in the manner anticipated by designers. Philpott and Falls, however, appear to be experiencing net erosion over time (moving to the right). Because this is an unusual result, it could trigger another round of Sedimentation Resurveys for Philpott and Falls to confirm the accuracy of previous resurveys' results.

Another cause for concern may be the location for Falls Lake Period 2 (red p2). It represents an obvious outlier compared to other most recent management periods. Moreover, if the Wilmington District had an inflows threshold in place equivalent to +/- 15% of design inflows, Falls p2 would have been outside that threshold. This simple visualization can trigger an evaluation of the reservoir for adaptive measures. Regardless of the existence of the threshold, presently Falls Lake is at a higher risk than other Wilmington reservoirs for not being able to consistently achieve all of its authorized and operational purposes.

The contents of the boxes reveal the role that the need for short-term flexibility may play in multipurpose reservoir operations (Figure 10, a and b). As mentioned previously, practical flexibility at Falls and Jordan Lakes stems from only a fraction of their conservation pools being contracted for water supply, leaving the rest available for other purposes. The

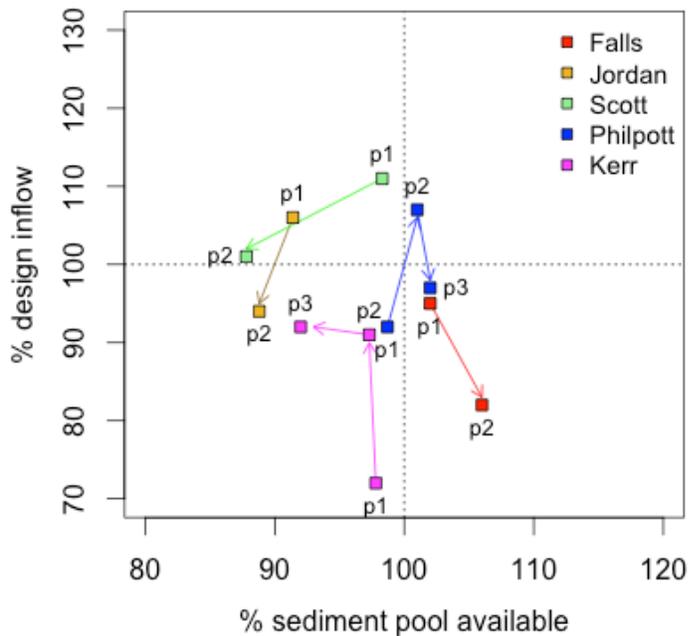


Figure 9. Box model locations for all management periods for Wilmington District reservoirs. The squares show the locations of the box representing each management period for all reservoirs (2-3 per reservoir). The arrows point in the directions of the shift through time. Note that if a +/- 15% design inflow threshold existed for management period inflows, Falls Lake would be a candidate for adaptation based on the location of its box for Period 2 (red p2). (The axes range was changed for ease of visualization.)

variability of minimum flows met in each management period attests to the fact that the managers are taking advantage of that flexibility. Conversely, the lack of flexibility at Scott may be impacting the high rate of non-compliance with minimum flow requirements in the second management period. In this case, managers may be foregoing minimum flows in order to balance water supply and other objectives. Lastly, Philpott and Kerr appear to have a large degree of flexibility due to minimal storage dedicated to water supply. However, both of these reservoirs are operated for hydroelectric generation, which may have an impact on their ability to meet minimum flows 100% of the time.

Other metrics representing the remaining reservoir purposes are desirable for this analysis. These metrics could not be developed based on the information that the Corps collects in its management documents or tracks on a daily basis. Understanding how flood control, recreation, fish and wildlife enhancement, and hydropower interact with water supply and minimum flow metrics would have provided a more complete picture of reservoir operations. Moreover, it would have facilitated an evaluation of which metrics represent high-priority objectives and which are treated as constraints subject to an occasional breach.

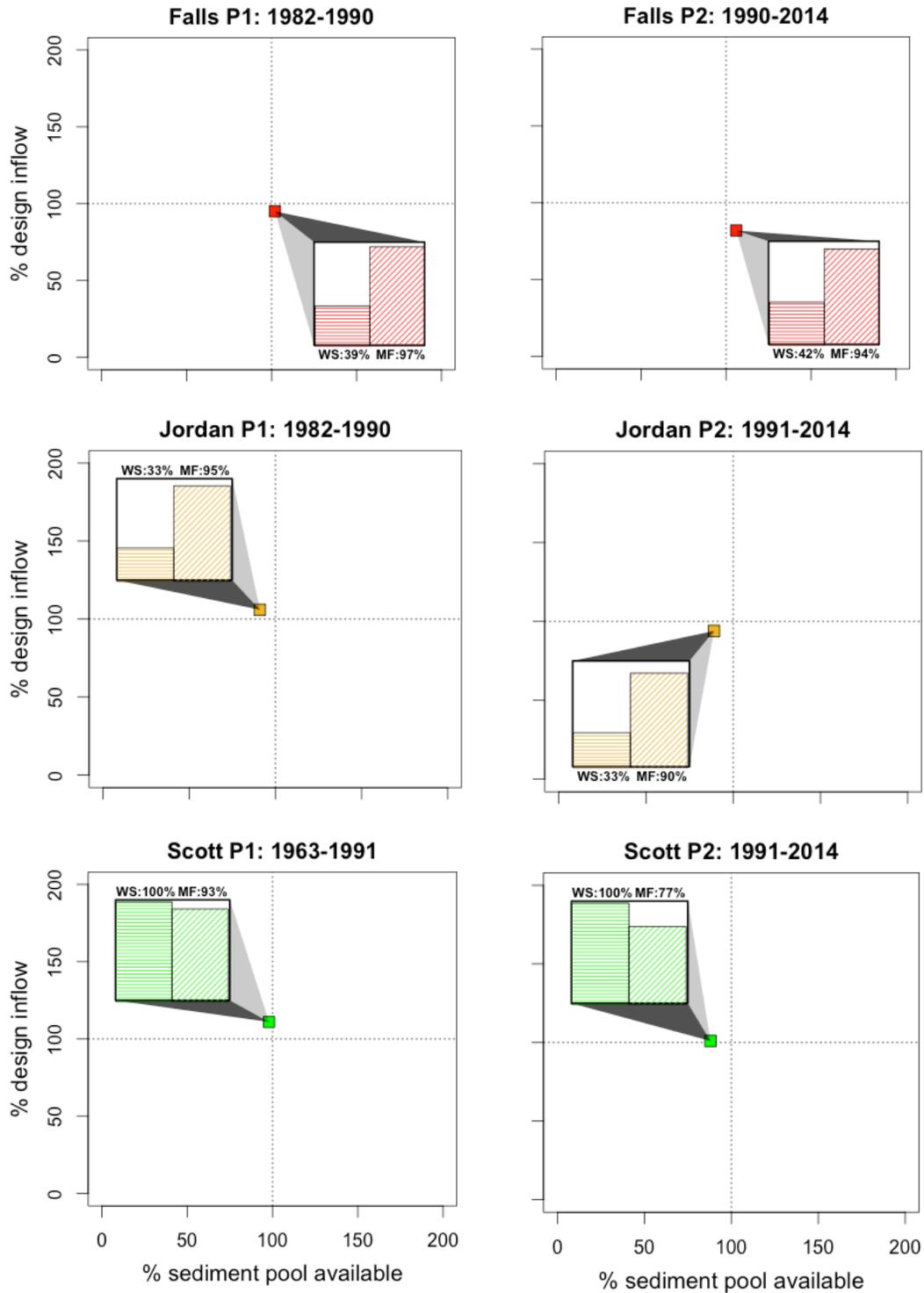


Figure 10a. Box models of Falls, Jordan, and W. Kerr Scott Reservoirs.

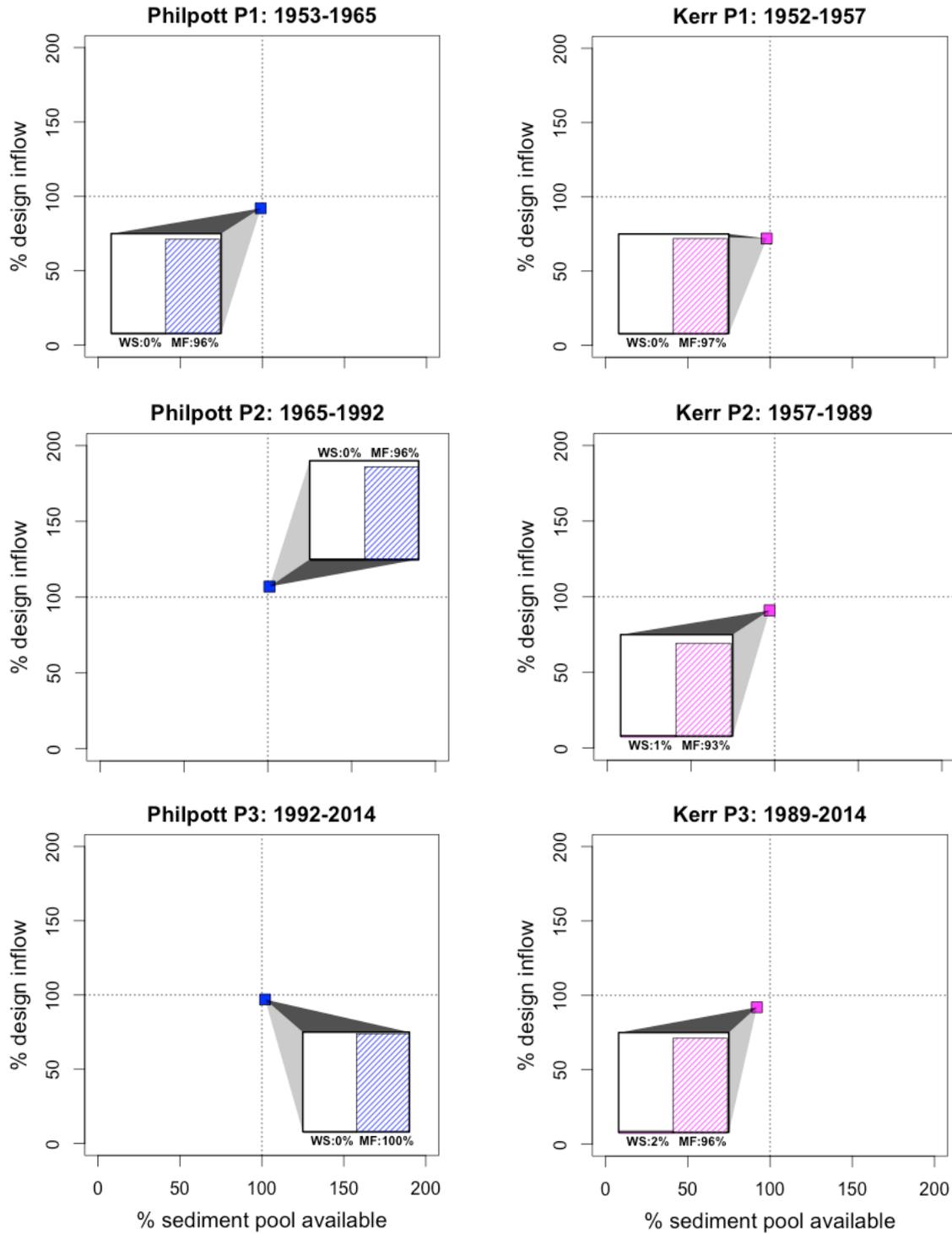


Figure 10b. Box models of Philpott Lake and John H. Kerr Reservoir.

In daily operations, it is important to distinguish high-priority objectives from constraints that are treated as guidance. An example of such a distinction is the difference between how water supply and minimum flows are treated in operations. When it was found that, due to a surveying error, Falls Lake's conservation pool did not contain the volume contracted to Raleigh for water supply, the reservoir went through a reallocation process that raised the lake level to ensure that the terms of the contract could be met.⁹² On the other hand, minimum flow requirements that maintain downstream water quality are either relaxed or have the option to be relaxed during drought periods.⁹³ This relaxation of the standard likely increases operational flexibility when water levels are low. The contrasting treatment of two operational objectives that have equal weight in the eyes of the law points to water supply being of a higher practical priority for the Corps than water quality maintenance in day-to-day operations.

Currently, the Corps appears to be legally constrained from making a distinction between objectives and constraints: all authorized purposes seem to have equal force of law because Congress doesn't assign priorities to its authorizations. Nevertheless, the Corps, like other federal agencies, is responsible for interpreting the law via its internal regulations (see section 1.2 *Corps documentation and legal requirements*). Understanding the distinction between objectives and constraints may help the managers at the District or Division level to better assess the realities of reservoir operations under their command. The Corps' legal counsel may be able to locate additional flexibility in the law in order to allow the agency to structure its regulations in a way that more closely reflects operational reality.

2.5.5.4 Implications of the absence of thresholds

The Corps as an agency enjoys a large degree of discretion in its operations. Part of that discretion comes from Congress traditionally deferring to federal agencies on the details of implementation of the law because the agencies are considered subject-matter experts. Nevertheless, other ambiguities exist in the law, allowing decision-making to happen

⁹² Falls Revised EA 1988, EA 1994

⁹³ Falls DCP 1990, Scott DCP 1991, Philpott DCP 1992, Kerr DCP 1992, Jordan DCP 2008

almost on a case-by-case basis and upholding the agency's discretion. A specific example in regards to the Corps is the generic wording of the Water Supply Act of 1958 that does not set a clear threshold between the Corps' and Congress' authorities for storage reallocation (see section *1.5.2 Water storage reallocation*).

Much like the lack of specific thresholds in the law maximizes the Corp's discretion, the agency also foregoes setting specific triggers for adaptation in its internal regulations. For example, the Corps relies on the skill of their reservoir operators to meet with expected and unexpected challenges in operations instead of regularly updating its water control documents as conditions change (see section *1.5 Process for operational modification*). While operational documentation is subject to review on a periodic basis, no clear guidance exists on a threshold that would trigger the need for revision. Thus it is apparent that the Corps' management culture is averse to thresholds that may impinge on the discretion of the agency, a management unit, or even an individual operator. Specifying thresholds for adaptation may oblige the Corps to adapt when those thresholds are reached, which may be difficult to plan for and difficult to implement given the agency's dwindling fiscal resources (see section *1.7 Impact of funding process on Corps' reservoir operations*).

As we have seen, the culture of preserving the agency's local discretion creates an intentional ambiguity in Corps' internal regulation on the national scale. This regulatory ambiguity allows maximum local flexibility of operations and a high degree of autonomy from district to district and perhaps even reservoir to reservoir. Currently, that flexibility is being stretched to its limit. In some places this ambiguity may even be disguising the need for adaptation, as we have seen with reservoirs like Falls Lake and W. Kerr Scott in the Wilmington District.

It is true that adaptation in the form of storage reallocation is currently being considered at Falls Lake. Nevertheless, the initiative emerged from a request for additional water supply by a local sponsor instead of being initiated by the Corps because of an internal recognition. This outcome illustrates the first downside of the Corps' management approach, as it tends to be focused and reactive as opposed to being strategic and proactive. Reservoir managers

who are making decisions on the daily, weekly, or monthly scale by responding to weather events and local needs hardly have the time to think about long-term strategic objectives. Operations remain focused on balancing current needs as opposed to achieving strategic goals.

Managers at the District or Division level who could be undertaking long-term planning do not have a clear enough picture of daily operations based on the information in the Corp's own documentation. This reveals the second shortcoming of the current management approach: the lack of systematic preservation and sharing of institutional knowledge. Such knowledge can not only make higher-level managers more effective in regards to long-term planning, but also can allow operators across the country to share best practices.

Lastly, the third drawback of the current management approach is perhaps the most important for the future of the Corps' as the country's premier water resources manager. Under the disjointed culture of operations fostered by the existing management approach, implementation of national initiatives, such as the Climate Change Adaptation Plan, may prove to be especially challenging.⁹⁴ Not only do various Districts operate quite autonomously across the country, but also the higher-level managers who will be considering the details of implementation do not have the means to accurately assess the realities of current operations. In this scenario, estimating the best ways to pivot operations will likely be based on tenuous data and may not yield the readiness to manage adaptively in response to a changing climate.

⁹⁴ Corps of Engineers. (2014). *Climate Change Adaptation Plan and Report*.

3. Conclusion

The policy framework and historic operations provide an insight into the Corps' approach to reservoir management in the Wilmington District. Due to a lack of accepted criteria for evaluating various metrics, the analysis raises more questions than provides answers about the reservoirs' need to adapt.

Most reservoirs in the Wilmington District continue to meet their operational goals to date. However, because the Corps does not have established thresholds for evaluating operations, it is difficult to say whether the reservoirs that are meeting only 77% of the minimum flow requirements (Scott) or are receiving less than 85% of their design inflows (Falls) are in need of adaptation. Additionally, not all reservoir purposes could be evaluated for operational success due to a lack of consistent data that would allow the development of appropriate metrics.

Future directions for this analysis could include further exploration of relevant data and the Corps' management culture. More data could be obtained from the Corps regarding hydropower generation, annual fishery management, recreational activities at the reservoirs, value of flood damages avoided, and others to help evaluate operational success along reservoir purposes not captured by this analysis. Additionally, it could be useful to interview reservoir managers to better understand which purposes constitute high-priority objectives and whether operational thresholds exist in practice though they may remain undocumented. Lastly, more investigation may be needed into the Corps' management culture and funding mechanisms to understand the underlying institutional barriers to adaptive management.

The methods and findings of this report can be used to consider the Corps' data collection and management practices and to perform similar evaluations along the inflow, sedimentation, minimum flows, and water supply metrics for other Corps districts. They also can be used to highlight potential outliers within a management unit and prioritize funding accordingly. The lack of clearly established high-priority objectives and accepted

standards against which metrics can be evaluated makes the assessment for adaptation difficult at this time. The Corps is encouraged to consider how the lack of these objectives and standards at the District or Division level may impact the agency's ability to adapt to external pressures of the 21st century.

4. Appendices

APPENDIX A. Corps reservoir purposes

Project-specific purposes:⁹⁵

- Flood Control
- Navigation
- Hydropower
- Irrigation
- Municipal and/or Industrial Water Supply
- Fish and Wildlife Conservation
- Recreation
- Low Flow Augmentation or Pollution Abatement
- Quality or Silt Control

General purposes:⁹⁶

- Discretionary recreation and water supply from surplus water (FCA 1944)
- Discretionary water supply (WSA 1958)
- Mandatory coordination to conserve fish & wildlife (FWCA 1958)
- Mandatory consideration of recreation during planning (Water Project Recreation Act 1965)
- Mandatory water quality protection (CWA, 1972 amendment)
- Mandatory protection of endangered species (ESA 1973)
- Mandatory environmental protection as project primary purpose (WRDA 1990, PL 101-640 §306(a)): “The Secretary shall include environmental protection as one of the primary missions of the Corps of Engineers in planning, designing, constructing, operating, and maintaining water resources projects.”⁹⁷

⁹⁵ 33 C.F.R. §222.5, Appendix E

⁹⁶ Corps of Engineers. (1994). *Authorized and Operating Purposes of Corps of Engineers Reservoirs*; Whisnant et al. (2009). *Operating Policies and Administrative Discretion at the John H. Kerr Project*.; TNC. (2007). *Handbook for Revisions of Water Control Plans*.

⁹⁷ Whisnant (2009) discusses the ambiguity of this directive. He cites *Raymond Proffitt Foundation v. USACE*, 343 F.3d. 199, 207 (3rd Cir. 2003), stating that the case discussed without concluding whether environmental protection is project-specific or a general purpose of the Corps. It is also unclear whether this directive is to be applied retroactively.

APPENDIX B. Continuing Authorities Program

Reproduced with edits from ER 1105-2-100, appendix F, table F-2.

Authority	U.S. Code	Project Purpose
Flood Control Act (hereafter FCA) of 1946, §14, as amended	33 U.S.C. 701r	Streambank and shoreline erosion protection of public works and non-profit public services
Rivers and Harbors Act (hereafter RHA) of 1962, §103, as amended	33 U.S.C. 426g	Beach erosion; hurricane and storm damage reduction
RHA 1960 §107, as amended	33 U.S.C. 557	Navigation improvements
RHA 1968 §111, as amended	33 U.S.C. 426i	Shore damage prevention or mitigation caused by Federal navigation projects
Water Resources Development Act (hereafter WRDA) of 1976, §145, as amended	33 U.S.C. 426j	Placement of dredged material on beaches
WRDA 1992 §204, as amended	33 U.S.C. 2326	Beneficial uses of dredged material
FCA 1948 §205, as amended	33 U.S.C. 701s	Flood control
WRDA 1996 §206, as amended	33 U.S.C. 2330	Aquatic system restoration
FCA 1954 §208, as amended (amends FCA 1937 §2)	33 U.S.C. 701g	Removal of obstructions, clearing channels for flood control
WRDA 1986 §1135, as amended	33 U.S.C. 2309a	Project modifications for improvement of the environment

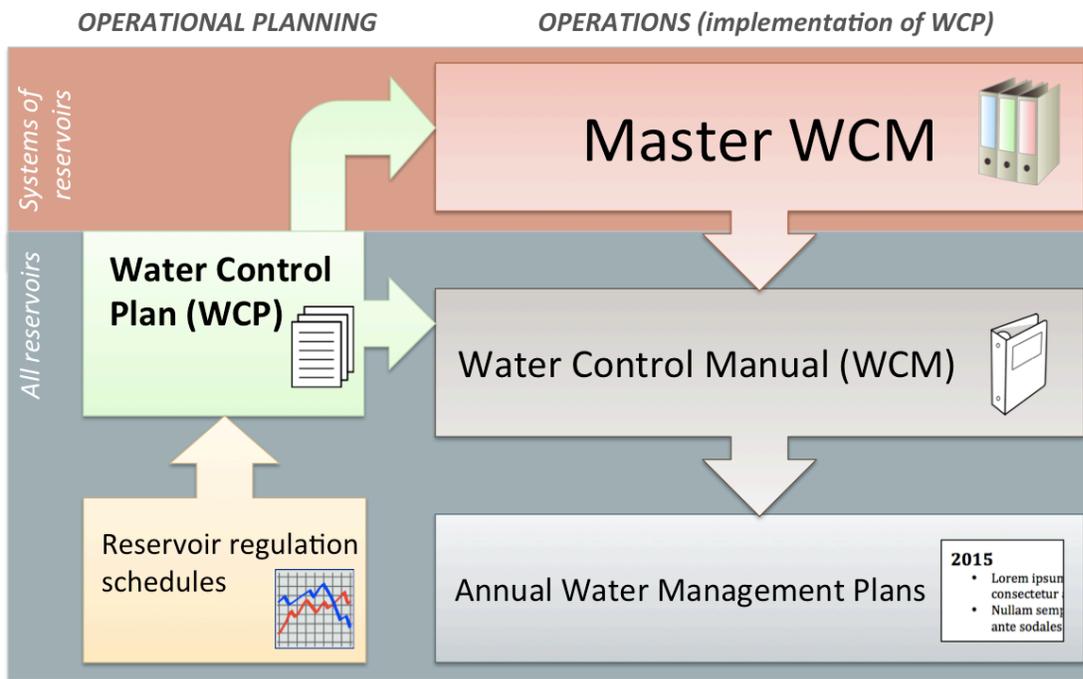
APPENDIX C. Administrative law and the Corps.

Based on Jowers (2015).

Government Enactment	Example	Purpose	Have the force of law?	Public comment process	Potential for litigation against agency for violations of enactment	Notes
Statute	Legislation by Congress	Give authority to agency to create rules to carry out legislation	Yes	No	Yes, if agency actions are inconsistent with the statute	
Executive order (EO)	EO by President		Yes	No		
Rule: legislative (i.e., regulation)	Corps' Engineer Regulations <i>that are codified in Code of Federal Regulations (C.F.R.)</i>	Created by agency to outline what is its understanding of the directives given in a statute or EO in more concrete terms	Yes, agency's actions must be consistent with statute	Yes, formal, during both adoption and amendment	Yes, if agency actions are inconsistent with its own regulation	
Rule: interpretive	Corps' Engineer Regulations <i>that are not codified in C.F.R.</i> ;	Provide guidance through recommendations, examples, handbooks, templates or suggestions on how to turn the agency's interpretation of legislation, EO's, and regulation into agency action	No, unless followed by an administrative order, court order, or consent decree	No	No, but could be useful as persuasive authority by outside groups to spur agency action	Less time consuming due to less public involvement, so used more frequently by agencies than legislative rules
General statement of policy	Engineer Manuals, Circulars, Directives, Pamphlets;			No		
Rule of agency organization, procedure, or practice	interpretive information on agency website that does not refer to a codified regulation			No		

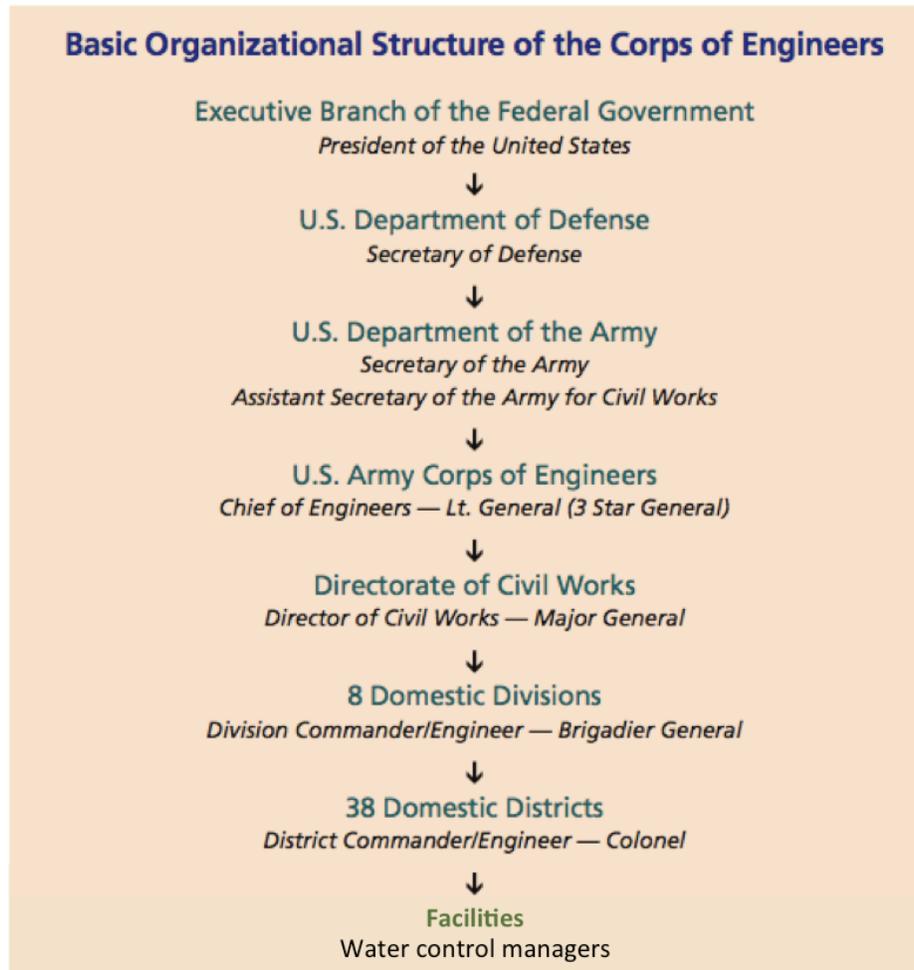
APPENDIX D. Water control documentation hierarchy

See generally EM 1110-2-3600.



APPENDIX E. Corps organizational and decision-making structure.

From *American Rivers*. (2009). A Citizen's Guide to the Corps of Engineers.



APPENDIX F. Approval authorities for permanent and temporary reallocations

Reproduced from ER 1105-2-100.

ER 1105-2-100
22 Apr 2000

Table E- 31 Water Supply Storage Agreement Approval Authority [1]

Drafts				
Acre – Feet [2]		Storage Agreements [3]		Reallocation Reports [5]
From	To	Without Reallocation	With [4] Reallocation	
0	99	District [6]	District [6]	District
100	499	Division [6]	Division [6]	Division
500	999	Division [6]	ASA(CW)	HQUSACE [7]
1000	& up	ASA(CW)	ASA(CW)	HQUSACE [7]
Finals [8]				
Acre – Feet [2]		Storage Agreements		
From	To	Without Reallocation	With [4] Reallocation	
0	499	District	District	
500	999	District	HQUSACE	
1000	& up	HQUSACE	HQUSACE	

Footnotes:

- [1] A copy of all approved agreements will be provided to ASA(CW).
- [2] In any particular agreement, the acre-feet of storage needed to produce the water under agreement on a dependable basis.
- [3] At projects where storage agreements have been previously approved. The first storage agreement on any project will be approved by the ASA(CW).
- [4] For reallocations which do not require Congressional approval, i.e., no significant effect on other authorized purposes and/or no major structural or operational changes.
- [5] When the cumulative amount of storage reallocated exceeds the lesser of 4000 ac-ft of 10% of available storage, reports will be submitted to ASA(CW) prior to approval.
- [6] When using approved model or approved model with editorial changes only. Agreements involving other changes will be submitted to ASA(CW) for approval.
- [7] Submitted to ASA(CW) with the draft agreement prior to approval.
- [8] When using the approved draft agreement and local signature within six months of draft approval. If beyond six months or if changes are made, the final agreement will be resubmitted for approval to the office with approval authority for the draft. If the proposed agreement involves changes other than editorial changes, the agreement will be submitted to ASA(CW) for approval. The ASA(CW) reserves the right to retain approval authority of any final agreement he approved as a draft. In cases where that right will be exercised in advance, the draft agreement will so note.

Table E- 32 Surplus Water Agreement Approval Authority [1]

Drafts			
Acre - Feet [2]		Agreement [3]	Letter Report [4]
From	To		
0	99	District [5]	District
100	499	Division [5]	Division
500	999	Division [5]	HQUSACE [6]
1000	& up	ASA(CW)	HQUSACE [6]
Finals [7]			
Acre - Feet [2]		Agreement [3]	
0	499		
0	499	District	
500	999	District	
1000	& up	HQUSACE	

Footnotes:

- [1] A copy of all approved agreements will be provided to the ASA(CW).
- [2] The storage needed to produce the agreed to water on a dependable basis.
- [3] Not affecting authorized purposes (water not being used for an authorized purpose). When surplus water agreements involve water being used for an authorized purpose, they will be treated like a reallocation agreement and report (See Table E-31).
- [4] When the cumulative amount of storage reallocated exceeds the lesser of 4000 acre-feet or 10% of available storage, reports will be submitted to ASA(CW) for approval.
- [5] When using approved model or approved model with editorial changes only. Agreements involving other changes will be submitted the ASA(CW) for approval.
- [6] Submitted to ASA(CW) with the draft agreement prior to approval.
- [7] When using the approved draft agreement and local signature within six months of draft approval. If beyond six months or if changes are made, the final agreement will be resubmitted for approval to the office with approval authority for the draft. If the proposed agreement involves changes other than editorial changes, the agreement will be submitted to ASA(CW) for approval. The ASA(CW) reserves the right to retain approval authority of any final agreement he approved as a draft. In cases where he will exercise that right in advance, the draft agreement will so note.

APPENDIX G. Evaluation of the Corps' data quality

The U.S. Army Corps of Engineers operates eight divisions in the U.S. that are broken up into 38 districts (see section *1.4 Decision-making for water control projects*). Due to their relative autonomy of operations, the districts collect data independently of each other. Additionally, the agency does not appear to have a universal data reporting standard across districts that would allow for easy comparisons of reservoir operations.

This problem manifested itself even within the documentation for a single district (Wilmington). There, few data were reported in a standard way both historically for a single reservoir and laterally among several reservoirs. Changes in data reporting standards in time and among reservoirs made it difficult to develop more than four meaningful metrics to evaluate reservoir operations despite much data being collected. Moreover, metrics could only be developed for only two of five or six authorized purposes at each reservoir.

The problem of lack of specificity is best illustrated by comparing reservoirs with static and seasonal guide curves (Table G1). When a guide curve fluctuates seasonally, the associated conservation and flood control pool volumes fluctuate with it. Nevertheless, few documents on design and operation of reservoirs with seasonal guide curves reported the associated seasonal changes in volume for the conservation and flood control pool. Moreover, seasonal ranges for guide curves were never accompanied by ranges of pool volumes. Pool volumes were always presented as static.

The problem of lack of consistency manifested itself in several ways. The most puzzling and most easily avoidable is the inconsistent terminology used to describe similar and perhaps equivalent metrics, e.g. conservation pool v. maximum power pool (for reservoirs with hydroelectric dams). Very few of the reviewed documents provided definitions for the reported metrics. When definitions were provided, however, it was not always clear whether these definitions for one reservoir at a particular point in time could be applied to another reservoir at another point in time.

Table G1. Errors in data quality observed in Wilmington design and operational documents

Category of error	Type of error	Example
Precision	Specificity of data	Single values for pool volumes but seasonally fluctuating guide curve; Changes in spillway design flood magnitudes (reason: unclear)
Precision	Unclear terminology	Conservation pool, active pool, power pool, effective power pool may or may not be the same volume in a reservoir
Consistency	Type of data reported among reservoirs	Metrics reported in “pertinent data” varied from reservoir to reservoir; Pre-dam monthly inflow statistics reported for all but Jordan
Consistency	Type of data reported over time (same reservoir)	Start of normal operations reported on different dates for both Philpott and John H. Kerr; Flood of record for same date reported differently over time; Metrics reported in earlier documents do not appear in later documents and <i>vice versa</i>
Consistency	Temporal ranges of data	Mean streamflow at dam site reporting for just pre-dam flows, just post-construction flows, or mean flows pre-dam to present

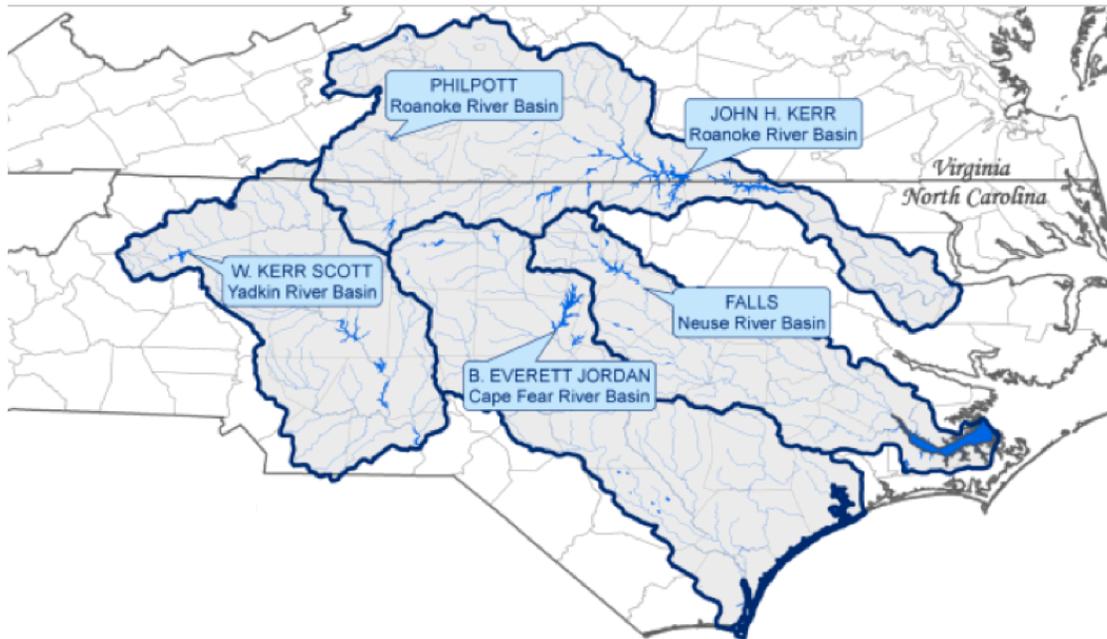
A lack of consistency across documents through time may be discounted somewhat due to changing standards and incorporation of the organization’s learning over time into its operational documentation. Nevertheless, in some cases, these inconsistencies appear as omissions due to the essential nature of the missing information to reservoir operations. A great example of such an omission is the disappearance of monthly inflow statistics from design and operational documents sometime in the 1970’s. Monthly inflows at dam site were reported in operational documents for older reservoirs (John H. Kerr, Phillipott, W. Kerr Scott) in the 1950’s and 1960’s. They were also reported in the Environmental Impact Statement (EIS) for Falls Lake in 1974. The author was not able to locate them in any design documents for Jordan Lake even though the EIS for Jordan Lake was released in 1971, prior to the EIS for Falls Lake. Monthly inflow statistics were not reported in any documents after 1980 for any reservoir in Wilmington District.

Wilmington District reservoir design and management documentation is filled with interesting and useful data that, unfortunately, appears only once and cannot be used to compare reservoir operations through time or between reservoirs. One instance where the documentation avoids this pitfall is the reporting of sedimentation rates. In all but one instance (Jordan Lake EIS supplement, 1975), the reports state the metrics consistently so that their evolution may be easily tracked through time. This consistency may be attributed to specific demands by the Corps to complete “Engineering Form 1787” as part of the sedimentation resurvey process, references to which are made in several sedimentation resurveys that were reviewed. According to USACE Publications database (www.publications.usace.army.mil), Engineering Form 1787 was first published in 1966 and does not have an expiration date listed.

Aside from inconsistency in data reporting in design and management documentation, the author was exposed to another discrepancy, this one on a larger scale: the inconsistency between districts to respond to request for information from members of the public. One reason for choosing the Wilmington District reservoirs for analysis was the district’s responsiveness via the FOIA process. When a similar request was put in with another district, the receipt was acknowledged but no information was ever transmitted. This inconsistency between two districts may not only reflect the difference in corporate culture from district to district, but also point to differing levels of data retrieval and sharing infrastructure at the district level. Such infrastructure may be expressed both as systems, such as digital databases and information retrieval protocols, as well as allocation of resources like staff time.

APPENDIX H. Map of Wilmington District reservoirs

From <http://epec.saw.usace.army.mil>



APPENDIX I. Wilmington District operational documents reviewed

Tables A2 and A2 provide an overview of the project-specific Corps documents reviewed in preparation of this report. The list of references provides the formal names of the documents. The references are sorted by reservoir project name and follow the chronological order of the tables.

Design memoranda deserve a special note. A reservoir design memorandum that is reviewed by Congress prior to authorization enters the congressional record as House Document (HD) XX-YYY, where XX is the Congress number and YYY is the house document number. House documents containing design documents are referred to by their call number in the authorizing legislation. House documents can be retrieved by their call number using the U.S. Congressional Serial Set, 1817-1994 database (accessible through Duke University library). Typically, house documents contain the main reports and not the appendices that detail hydrology, population projections, etc. The relevant appendices were requested from the Wilmington District separately and are listed as such.

The majority of the remaining documents were accessed through a formal request process pursuant of the Freedom of Information Act (FOIA). Several documents for Falls, Jordan, and Kerr reservoirs were accessed in hard copy via the Duke University library system (marked with *). Lastly, references for the documents available online contain hyperlinks.

Table A1. Project-specific documents reviewed for Falls, Jordan, and W. Kerr Scott reservoirs.

FALLS LAKE		B. EVERETT JORDAN LAKE		W. KERR SCOTT RESERVOIR	
Year	Type of Report	Year	Type of Report	Year	Type of Report
1965	Design memorandum	1962	Design memorandum	1944	Design memorandum
1965	Design memorandum, appendices	1971	EIS	1949	Design memorandum
1974	EIS	1975	EIS Supplement vol. 2	1958	Design memorandum
1981	Master Plan	1992	Revised WCP	1959	Design Memorandum (Hydrology)
1988	Revised EA	1997	Sedimentation Resurvey	1960	Water supply contract
1990	WCP	2007	Master Plan	1963	WCM
1990	Drought Contingency Plan	2008	Drought Contingency Plan	1979	Sedimentation resurvey
1994	Environmental Assessment	2015	Pertinent Data (USACE website)	1991	Drought Contingency Plan
1997	Sedimentation Resurvey	2015	USACE website	1993	WCP
2008	Drought Contingency Plan			2010	Sedimentation resurvey
2008	EA - Drought Contingency Plan			2012	EA - Water intake
2013	Master Plan			2015	Pertinent Data (USACE website)
2015	Pertinent Data (USACE website)			2015	Congressional Fact Sheet 1
2015	Congressional Fact Sheet 1			2015	Congressional Fact Sheet 2
2015	Congressional Fact Sheet 2				
2015	Reallocation Scoping Letter				

Table A2. Project-specific documents reviewed for John H. Kerr and Philpott reservoirs.

JOHN H. KERR RESERVOIR		PHILPOTT LAKE	
Year	Type of Report	Year	Type of Report
1944	Design memorandum	1944	Design memorandum
1952	Master Plan	1953	Master Plan
1953	Roanoke Master WCM	1961	Sedimentation Resurvey
1953	WCM	1962	Power Potential and Rule Curves
1961	Sedimentation Resurvey (summary)	1964	Master Plan
1961	Sedimentation Resurvey	1965	WCM (exerpts)
1962	Power Potential and Rule Curves	1992	WCP
1965	WCM	1992	Drought Contingency Plan
1965	Roanoke Master WCM	1998	Sedimentation Resurvey
1992	Drought Contingency Plan	2015	Pertinent Data (USACE website)
1992	WCP	2015	Congressional Fact Sheet
1995	WCP		
1997	Sedimentation Resurvey		
2005	Reallocation Report		
2013	Master Plan		
2015	Pertinent Data (USACE website)		
2015	EA - WCP revision		

EA – Environmental Assessment

EIS – Environmental Impact Statement

WCM – Water Control Manual

WCP – Water Control Plan

Falls Lake:

1. United States. Army. Corps of Engineers. (1965). *Neuse River Basin, North Carolina* (House Document 89-175). Washington, DC: U.S. Government Printing Office.
2. United States. Army. Corps of Engineers. (1965). *Neuse River Basin, North Carolina: Appendices I (Hydrology), IV (Economic Base Survey), V (Water Supply & Water Quality Control)*.
3. United States. Army. Corps of Engineers. (1974). *Final Environmental Statement (revised), Falls Lake, Neuse River Basin, North Carolina*.*
4. United States. Army. Corps of Engineers. Wilmington District. (1981). *Master plan for the development, use, and management of Falls Lake, North Carolina* (Design Memorandum 27).
5. United States. Army. Corps of Engineers. Wilmington District. (1988). *Revised Environmental Assessment, Falls Lake, North Carolina: Modification to operation*.
6. United States. Army. Corps of Engineers. Wilmington District. (1990). VII. Water Control Plan. In *Falls Lake Water Control Manual, Falls Lake Project*.
7. United States. Army. Corps of Engineers. Wilmington District. (1990). Appendix B: Drought Contingency Plan, September 1990. In *Falls Lake Water Control Manual*.
8. United States. Army. Corps of Engineers. Wilmington District. (1994). *Environmental Assessment, Falls Lake, North Carolina: Raising the top of conservation pool elevation to 251.5 ft*.*
9. United States. Army. Corps of Engineers. Wilmington District. (1997). *Report of sedimentation resurvey, Falls Lake project, Neuse River basin, North Carolina*.
10. United States. Army. Corps of Engineers. Wilmington District. (2008). Appendix A: Falls Lake, Neuse River Basin, NC, Drought Contingency Plan, updated March 2008. In *Falls Lake Water Control Manual*.
11. United States. Army. Corps of Engineers. Wilmington District. (2008). *Environmental Assessment, Falls Lake, North Carolina: Drought Contingency Plan (revised March 2008)*.
12. United States. Army. Corps of Engineers. Wilmington District. (2013). *Falls Lake Master Plan, Neuse River Basin*. Retrieved from: <http://www.saw.usace.army.mil/Portals/59/docs/recreation/fallslake/Images/Falls%20Lake%20Master%20Plan%20JUNE%2021%202013%20FINAL.pdf>
13. United States. Army. Corps of Engineers. Wilmington District. (2015). *Falls Lake Project, Neuse River Basin, NC: Pertinent Data*. Retrieved from: <http://epec.saw.usace.army.mil/FALLPERT.TXT>
14. United States. Army. Corps of Engineers. Wilmington District. (2015). *Falls Lake, NC Non-Federal Hydropower Add-On* (Congressional Fact Sheet 1). Retrieved from: http://www.saw.usace.army.mil/Portals/59/docs/review_plans/2016%20Congressional%20Fac%20Sheets/Falls%20Lake,%20NC%20Non-Federal%20Hydropower%20Add-On.pdf
15. United States. Army. Corps of Engineers. Wilmington District. (2015). *Falls Lake, NC Reallocation Study* (Congressional Fact Sheet 2). Retrieved from: http://www.saw.usace.army.mil/Portals/59/docs/review_plans/2016%20Congressional%20Fac%20Sheets/38%20-%20Falls%20Lake%20%20NC%20Reallocation%20Study_WSA%201958.pdf

16. United States. Army. Corps of Engineers. Wilmington District. (2015). *Falls Lake, NC Reallocation Scoping Letter, November 25, 2015.*

Jordan Lake:

17. United States. Army. Corps of Engineers. (1962). *Cape Fear River Basin, North Carolina* (House Document 87-508). Washington, DC: U.S. Government Printing Office.
18. United States. Army. Corps of Engineers. Wilmington District. (1971). *New Hope Lake, North Carolina, Environmental Impact Statement, Volume I.**
19. United States. Army. Corps of Engineers. Wilmington District. (1975). *New Hope Lake, North Carolina, Environmental Impact Statement, Supplement, Volume II.**
20. United States. Army. Corps of Engineers. Wilmington District. (1992). VII. Water Control Plan. In *Water Control Manual, B. Everett Jordan Lake Project.*
21. United States. Army. Corps of Engineers. Wilmington District. (1997). *Report of sedimentation resurvey, B. Everett Jordan Dam and Lake, Cape Fear River basin, North Carolina.*
22. United States. Army. Corps of Engineers. Wilmington District. (2007). *B. Everett Jordan Dam and Lake Master Plan Update Draft Report, July 2007.* Retrieved from: ftp://ftp.chathamnc.org/Chatham_ConservationPlan_GIS/Plans_Policies_Ordinances_USACoE_Jordan%20Lake%20Master%20Plan%20Update.pdf
23. United States. Army. Corps of Engineers. Wilmington District. (2008). Appendix A: B. Everett Jordan Dam and Lake, Cape Fear River Basin, NC, Drought Contingency Plan, updated May 2008. In *B. Everett Jordan Dam and Lake Water Control Manual.*
24. United States. Army. Corps of Engineers. Wilmington District. (2015). *B. Everett Jordan Dam and Lake Project, Cape Fear River Basin, NC: Pertinent Data.* Retrieved from: <http://epcc.saw.usace.army.mil/BEJPERT.TXT>
25. United States. Army. Corps of Engineers. Wilmington District. (2015). *Hydropower at Jordan Lake* (USACE Website). Retrieved from: <http://www.saw.usace.army.mil/Locations/DistrictLakesandDams/BEverettJordan/Hydropower.aspx>

W. Kerr Scott Reservoir:

26. United States. Army. Corps of Engineers. (1944). *Yadkin-Pee Dee River and Its Tributaries, North Carolina and South Carolina* (House Document 78-652). Washington, DC: U.S. Government Printing Office.
27. United States. Army. Corps of Engineers. (1949). *Yadkin-Pee Dee River and Its Tributaries, North Carolina and South Carolina* (House Document 81-31). Washington, DC: U.S. Government Printing Office.
28. United States. Army. Corps of Engineers. Charleston District. (1958). *Wilkesboro Reservoir, Yadkin River, North Carolina, General Design Memorandum.*
29. United States. Army. Corps of Engineers. Charleston District. (1959). *Wilkesboro Reservoir, Yadkin River, North Carolina, Design Memorandum No. 3: Hydrology.*

30. United States. Army. Corps of Engineers. (1960). *Contract Between the United States of America and the County of Wilkes, N.C., and the City of Winston-Salem, N.C. for Water Storage Space in Wilkesboro Reservoir* (Contract DA-38-081-CIVENG-60-17).
31. United States. Army. Corps of Engineers. Charleston District. (1963). *W. Kerr Scott Reservoir, Reservoir Regulation Manual, Yadkin-Pee Dee River Basin, Yadkin River, North Carolina* (R5-1-64).
32. United States. Army. Corps of Engineers. Charleston District. (1979). *Report on Sedimentation resurvey, W. Kerr Scott Reservoir*.
33. United States. Army. Corps of Engineers. Wilmington District. (1991). Exhibit B: W. Kerr Scott Dam and Reservoir, Yadkin River Basin, NC, Drought Contingency Plan. In *W. Kerr Scott Reservoir Water Control Manual*.
34. United States. Army. Corps of Engineers. Wilmington District. (1993). VII. Water Control Plan. In *W. Kerr Scott Reservoir Water Control Manual*.
35. United States. Army. Corps of Engineers. Wilmington District. (2010). *Report of Sedimentation 2010 Resurvey, W. Kerr Scott Reservoir, Yadkin-Pee Dee River Basin, North Carolina*.
36. O'Brien & Gere Engineering. (2012). *Environmental Assessment – W. Kerr Scott Reservoir Raw Water Project, Wilkes County, North Carolina*.
37. United States. Army. Corps of Engineers. Wilmington District. (2015). *W. Kerr Scott Dam and Lake Project, Yadkin-Pee Dee River Basin, NC: Pertinent Data*. Retrieved from: <http://epec.saw.usace.army.mil/WKSPERT.TXT>
38. United States. Army. Corps of Engineers. Wilmington District. (2015). *W. Kerr Scott Dam and Reservoir, Wilkes County Water Intake Project, Wilkes County, NC* (Congressional Fact Sheet 1). Retrieved from: http://www.saw.usace.army.mil/Portals/59/docs/review_plans/2016%20Congressional%20Fac%20Sheets/41%20-%20W%20Kerr%20Scott%20Dam%20and%20Reservoir%20Water%20Intake%20Project.pdf
39. United States. Army. Corps of Engineers. Wilmington District. (2015). *W. Kerr Scott Lake, NC, Non-Federal Hydropower Add-On* (Congressional Fact Sheet 2). Retrieved from: <http://www.saw.usace.army.mil/Portals/59/docs/FactSheets/40%20rev%207%20Oct%2015-%20W%20Kerr%20Scott%20Non-Fed%20Hydropower%20add-on%20clean.pdf>

John H. Kerr Reservoir:

40. United States. Army. Corps of Engineers. (1944). *Roanoke River, VA. and N.C.* (House Document 78-650). Washington, DC: U.S. Government Printing Office.
41. United States. Army. Corps of Engineers. Norfolk District. (1952). *Master Plan for John H. Kerr Reservoir, Roanoke River Basin, VA and NC.**
42. United States. Army. Corps of Engineers. Norfolk District. (1953). *Reservoir Regulation Manual, Roanoke River Basin, VA.-N.C.* (Roanoke Master WCM).
43. United States. Army. Corps of Engineers. Norfolk District. (1953). *Reservoir Regulation Manual, Appendix Section A, Roanoke River Basin, VA.-N.C.* (Kerr WCM).

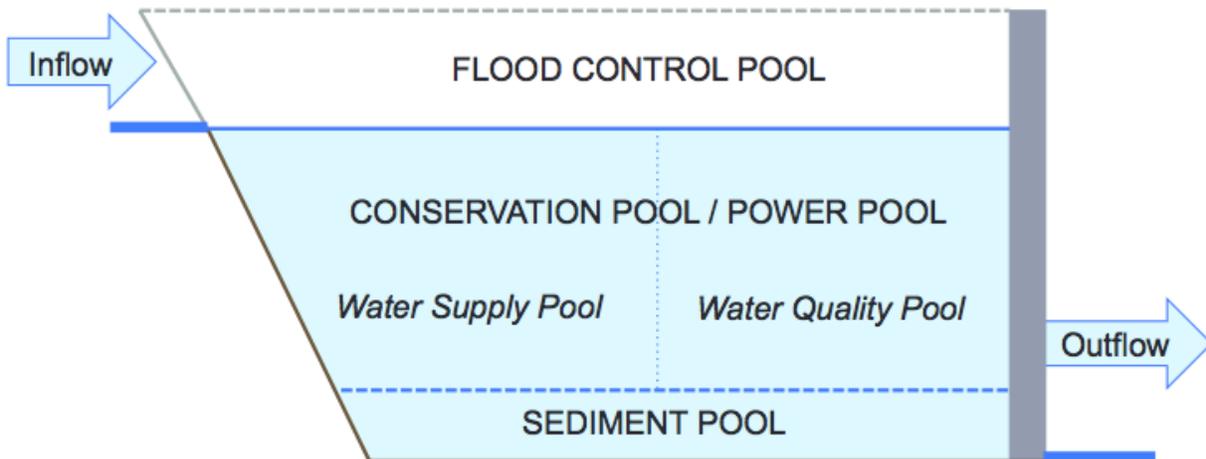
44. United States. Army. Corps of Engineers. Norfolk District. (1961). *John H. Kerr Reservoir Sedimentation Resurvey Data Summary*. Retrieved from: <http://water.usgs.gov/osw/ressed/datasheets/6-11.pdf>
45. United States. Army. Corps of Engineers. Norfolk District. (1961). *Report of Sedimentation Resurvey, John H. Kerr Reservoir, Roanoke River Basin*.
46. United States. Army. Corps of Engineers. Wilmington District. (1962). *Roanoke River Basin, Kerr and Philpott Reservoirs: Power Potential and Reservoir Rule Curves*.
47. United States. Army. Corps of Engineers. Wilmington District. (1965). *Reservoir Regulation Manual, Roanoke River Basin, VA.-N.C.* (Roanoke Master WCM).
48. United States. Army. Corps of Engineers. Wilmington District. (1965). *Reservoir Regulation Manual, Appendix A: Kerr Reservoir, Roanoke River Basin, VA.-N.C.* (Kerr WCM).
49. United States. Army. Corps of Engineers. Wilmington District. (1992). John H. Kerr dam and reservoir, Roanoke River Basin, VA-NC: Drought Contingency Plan. In *John H Kerr Reservoir Water Regulation Manual*.
50. United States. Army. Corps of Engineers. Wilmington District. (1992). Water Control Plan for John H. Kerr dam and reservoir. In *John H Kerr Reservoir Water Regulation Manual*.
51. United States. Army. Corps of Engineers. Wilmington District. (1995). Water Control Plan for John H. Kerr dam and reservoir. In *John H Kerr Reservoir Water Regulation Manual*. Retrieved from: <http://epec.saw.usace.army.mil/KERRWCP.TXT>
52. United States. Army. Corps of Engineers. Wilmington District. (1997). *Report of Sediment Resurvey, John H. Kerr Reservoir, Roanoke River Basin, Virginia – North Carolina*.
53. United States. Army. Corps of Engineers. Wilmington District. (2005). *Reallocation Report: John H. Kerr Reservoir Water Supply Storage Reallocation Request for the City of Henderson, North Carolina*. Retrieved from: <http://epec.saw.usace.army.mil/Henderson0505R.pdf>
54. United States. Army. Corps of Engineers. Wilmington District. (2013). *John H. Kerr Dam and Reservoir Master Plan, Roanoke River Basin*. Retrieved from: http://www.saw.usace.army.mil/Portals/59/docs/recreation/Master%20Plan/Kerr%20Master%20Plan_FINAL%20JAN%202013.pdf
55. United States. Army. Corps of Engineers. Wilmington District. (2015). *John H. Kerr Project: Pertinent Data*. Retrieved from: <http://epec.saw.usace.army.mil/KERRPERT.TXT>
56. United States. Army. Corps of Engineers. Wilmington District. (2015). *Environmental Assessment, John H. Kerr Dam and Reservoir Water Control Plan Revision, Virginia and North Carolina*. Retrieved from: http://www.saw.usace.army.mil/Portals/59/docs/ecosystem_restoration/Kerr%20Water%20Control%20Plan%20Update%20EA%2012-15-2015%20V2.pdf

Philpott Lake:

57. United States. Army. Corps of Engineers. (1944). *Roanoke River, VA. and N.C.* (House Document 78-650). Washington, DC: U.S. Government Printing Office.

58. United States. Army. Corps of Engineers. Norfolk District. (1953). *Philpott Dam and Reservoir Master Plan, Smith River, Virginia, Roanoke River Basin, VA.- N.C.*
59. United States. Army. Corps of Engineers. Norfolk District. (1961). *Philpott Reservoir Sedimentation Resurvey Data Summary*. Retrieved from:
<http://water.usgs.gov/osw/ressed/datasheets/6-12.pdf>
60. United States. Army. Corps of Engineers. Wilmington District. (1962). *Roanoke River Basin, Kerr and Philpott Reservoirs: Power Potential and Reservoir Rule Curves*.
61. United States. Army. Corps of Engineers. Wilmington District. (1964). *The Master Plan for Philpott Dam and Reservoir, Smith River, Roanoke River Basin, Virginia* (Design Memorandum No. 1B).
62. United States. Army. Corps of Engineers. Wilmington District. (1965). *Reservoir Regulation Manual, Appendix B: Philpott Reservoir, Roanoke River Basin, VA.-N.C.*
63. United States. Army. Corps of Engineers. Wilmington District. (1992). Water control plan for Philpott Lake. In *Water Control Manual, Philpott Lake*. Retrieved from:
<http://epec.saw.usace.army.mil/PhilpottWCP.pdf>
64. United States. Army. Corps of Engineers. Wilmington District. (1992). Exhibit D. Philpott Lake, Roanoke River Basin, VA. Drought Contingency Plan. In *Philpott Lake Water Control Manual*.
65. United States. Army. Corps of Engineers. Wilmington District. (1998). *Report of Sedimentation Resurvey, Philpott Reservoir, Roanoke River Basin, Virginia*.
66. United States. Army. Corps of Engineers. Wilmington District. (2015). *Philpott Project: Pertinent Data*. Retrieved from:
<http://epec.saw.usace.army.mil/PHILPERT.TXT>
67. United States. Army. Corps of Engineers. Wilmington District. (2015). *Philpott Lake, VA, Henry County Water Withdrawal Agreement* (Congressional Fact Sheet). Retrieved from:
http://www.saw.usace.army.mil/Portals/59/docs/review_plans/2016%20Congressional%20Fac%20Sheets/34%20-%20Philpott%20Lake%20VA%20Henry%20County%20Water%20Supply%20Agreement.pdf

APPENDIX J. Typical reservoir pools



The Corps breaks up a multipurpose reservoir into “pools,” or volumes that have different purposes. The flood control pool is kept empty to provide extra storage in case of a flood. The conservation pool always contains water. The top of the conservation pool is the lake surface, which can fluctuate throughout the year following a guide curve. If the reservoir dam has hydroelectric generation capabilities, the conservation pool is usually referred to as the power pool.

The uses of water in the reservoir depend on the reservoir purposes. These uses determine the names of the sub-pools of the conservation pool. For example, water supply pool and water quality pool exist in a reservoir that is authorized for water supply and downstream water quality maintenance.

Lastly, the sediment pool (or the inactive pool) is a volume at the bottom of the reservoir that is set aside to fill up with sediment over the reservoir’s lifetime.

Appendix K. Minimum flow control points for Wilmington District reservoirs

Reservoir	Control point	Date range	Gauge
Falls	Smithfield, NC	12/7/83 – 9/30/91	USGS 02087570 Neuse River at Smithfield, NC
	Clayton, NC	10/1/91 – 5/31/14	USGS 02087500 Neuse River at Clayton, NC
Jordan	Lillington, NC	2/4/82 – 5/31/14	USGS 02102500 Cape Fear River at Lillington, NC
Philpott	Bassett, VA	9/7/1953 – 5/31/14	USGS 02072500 Smith River at Bassett, VA
	Martinsville, VA	9/7/1953 – 5/31/14	USGS 02073000 Smith River at Martinsville, VA
John H. Kerr	Roanoke Rapids, NC	11/18/1952 – 5/31/14	USGS 02080500 Roanoke River at Roanoke Rapids, NC
W. Kerr Scott	Wilkesboro, NC	1/19/1963 – 5/31/14	USGS 02112000 Yadkin River at Wilkesboro, NC

At Falls Lake, the control point was relocated in 1991 to Clayton, NC, slightly upstream of the original control point at Smithfield, NC, and with a drainage area that is 4.6% smaller.⁹⁸ The minimum flow standard, however, was not updated with the relocation.

At Philpott Lake, minimum flow requirements are provided both for Bassett (Stanleytown), VA and Martinsville, VA. Because the control point at Martinsville is below the Martinsville reservoir (not operated by USACE), flows at Bassett were used for minimum flows analysis. Flows at Bassett had a minimum flow standard only for the summer months (June-August).

Design Memorandum 1944 for Philpott lists Bassett, VA as the control point for minimum flows. Subsequently, the control point is listed as “Stanleytown, VA” in the Corps documents from 1962 through 1992 (most recent available). However, the USGS doesn’t maintain a gauge on the Smith River at Stanleytown, VA while it does maintain one in Bassett, only 2-3 miles upstream. In this analysis, it was assumed that the locations were equivalent. See Figure A1 below showing the location of the Bassett gauge relative to Stanleytown, VA.⁹⁹

⁹⁸ Drainage area information from USGS NWIS database, <http://waterdata.usgs.gov/nwis>

⁹⁹ “Site Map for the Nation: USGS 02072500 Smith River at Bassett, VA.” Retrieved from http://waterdata.usgs.gov/nwis/nwismap/?site_no=02072500&agency_cd=USGS on April 19, 2016.

Site Map for the Nation USGS 02072500 SMITH RIVER AT BASSETT, VA

Available data for this site Location map GO

Henry County, Virginia
Hydrologic Unit Code 03010103
Latitude 36°46'12", Longitude 80°00'04" NAD27
Drainage area 259 square miles
Gage datum 752.28 feet above NAVD88

Location of the site in Virginia

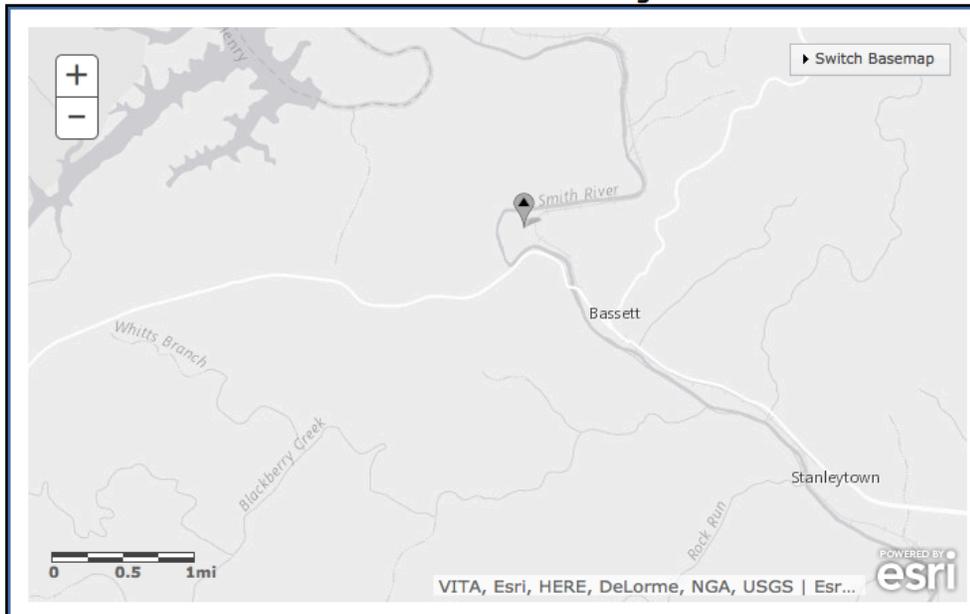


Figure A1. Location of USGS gauge at Bassett, VA relative to Stanleytown, VA. Stanleytown is listed as the control point for minimum flows from Philpott starting in 1962. Due to the proximity of the two towns and the establishment of design minimum flows at Bassett, VA, the locations were judged to be equivalent for the purposes of this analysis. Source: NWIS database website: http://waterdata.usgs.gov/nwis/nwismap/?site_no=02072500&agency_cd=USGS

Lastly, At John H. Kerr reservoir, the control point at Roanoke Rapids is separated from the John H. Kerr dam by two other reservoirs (Lake Gaston and Roanoke Rapids Lake, also not operated by USACE). Here, however, no alternative control point existed, and flows at Roanoke Rapids were used to analyze minimum flows.

Appendix L. Statistics of excursions below a minimum flow standard

Reservoir & management period	% Time Min. Flows Met	Min Excursion (CFS)	Max Excursion (CFS)	Mean Excursion (CFS)	Std. Dev. (CFS)	CV
Falls p1: 1983-1990	97%	1	151	62	51	0.83
Falls p2: 1990-2014	94%	1	62	19	15	0.77
Jordan p1: 1982-1991	95%	1	167	29	23	0.81
Jordan p2: 1991-2014	90%	1	395	105	103	0.98
W. Kerr Scott p1: 1963-1991	93%	1	206	67	43	0.63
W. Kerr Scott p2: 1991-2014	77%	1	263	96	66	0.68
Philpott p1: 1953-1965	96%	1	15	7	4	0.56
Philpott p2: 1965-1992	96%	1	15	7	4	0.56
Philpott p3: 1992-2014	100%	2	3	2	1	0.22
Kerr p1: 1952-1957	97%	10	920	433	275	0.64
Kerr p2: 1957-1989	93%	1	6360	1696	1415	0.83
Kerr p3: 1989-2014	96%	10	5060	1593	1467	0.92