Economic Benefits of Multipurpose Hydropower Reservoirs in the United States

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Introduction

The United States is home to over 80,000 dams, of which approximately 3% are equipped with hydroelectric generating capabilities. When a dam serves as a hydropower facility, it provides a variety of energy services that range from clean, reliable power generation to load balancing that supports grid stability. In most cases, the benefits of dams and their associated reservoirs go far beyond supporting the nation's energy demand. As evidenced by the substantial presence of non-powered dams with the ability to store water in large capacities, the primary purpose of a dam may not be hydropower, but rather one of many other purposes. A dam and reservoir may support navigation, recreation, flood control, irrigation, and water supply, with each multipurpose benefit providing significant social and economic impacts on a local, regional, and national level. When hydropower is one of the services provided by a multipurpose reservoir, it is part of an integrated system of competing uses. Operating rules, management practices, consumer demands, and environmental constraints must all be balanced to meet the multipurpose project's objectives.

When federal dams are built, they are authorized by Congress to serve one or more functions. Legislation such as the Water Resources Development Act regulates the operation of the facility in order to coordinate the authorized uses and ensure the dam's intended objectives are being met. While multipurpose reservoirs account for billions of dollars in National Economic Development (NED) every year, no attempt has been made to evaluate their benefits on a national scale. This study is an on-going work conducted by Oak Ridge National Laboratory in an effort to estimate the economic benefits of multipurpose hydropower reservoirs in the United States. Given the important role that federal hydropower plays in the U.S., the first focus of this research will focus on the three main federal hydropower owners —Tennessee Valley Authority, U.S. Army Corps of Engineers, and U.S. Bureau of Reclamation. Together these three agencies own and operate 157 powered dams which account for almost half of the total installed hydropower capacity in the U.S. Future work will include engaging publicly-owned utilities and the private sector in order to quantify the benefits of all multipurpose hydropower reservoirs in the U.S.

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1. Background

The majority of U.S. federal reservoirs serve multiple purposes; including hydropower, navigation, flood control, recreation, irrigation, and municipal and industrial (M&I) water supply. The federal government has been involved in managing reservoir systems since the 19th century, when the Rivers and Harbors Act of 1824 was introduced to improve the inland navigation system. In 1902 Congress passed the Reclamation Act, which funded irrigation projects in 20 states in the West and created the U.S. Bureau of Reclamation (USBR) to administer the program. The act led to rapid construction of dams on almost every major western river. Following a series of floods in every major river basin between 1890 and 1927, intensified concerns over flood damages led to the Flood Control Act of 1936, in which Congress deemed flood management a federal activity. The act appropriated funds for the primary purpose of flood control, and authorized the U.S. Army Corps of Engineers (USACE) to construct hundreds of flood control structures. The Flood Control Act of 1944 helped solidify the federal government's move towards a multipurpose approach: Section 4 authorized the construction, operation, and maintenance of recreation facilities at USACE water resource development projects; Section 5 granted the Secretary of the Interior the authority to sell power generated at federal projects; Section 6 authorized the USACE to provide surplus water at its facilities for M&I use; and Section 8 allowed USACE reservoirs to be used for irrigation purposes (1944 FCA; P.L 78-534). The Water Resources Development Act, a biennial piece of legislation first introduced in 1974, is now the primary statute for federal water resources planning, governing existing water infrastructure and their multiple uses as well as the development of proposed projects.

Federal involvement in water management bolstered the development of hundreds of multipurpose projects throughout the U.S. that are to this day providing services for millions of people in both rural and urban areas. The USACE operates and maintains all federal navigation and flood control facilities. The USBR programs are crucial for irrigation and hydropower generation in the West. The Tennessee Valley Authority (TVA), established by Congress in 1933, provides the Southeast with hydropower, flood control, recreation, among other uses. Together these three agencies own 157 powered dams and account for nearly half of total installed hydropower capacity in the U.S. Most of these dams and their associated reservoirs are authorized for more than one purpose in addition to hydropower generation (Figure 1, left). Each dam's congressionally-authorized purposes are documented in the National Hydropower Asset Assessment Program (NHAAP) database, along with other relevant dam characteristics used in this analysis (NHAAP, 2015). The majority of hydropower reservoirs are authorized for recreational use (119 out of 157, or 76%), while only 42 are authorized for navigation. Over 58% of federal reservoirs help prevent flood damages; of that percentage, two thirds were built for the primary purpose of flood control. The distribution of reservoirs authorized for a given number of purposes reveals a dominant trend (Figure 1, right). Over 80% of all federal reservoirs serve three or more purposes. The multipurpose nature of federal hydropower reservoirs is a distinct characteristic embedded into their authorization, construction, and operation. Since this study only considers reservoirs with hydroelectric generation as an authorized use, the 6.4% of reservoirs authorized for only one purpose are solely authorized for hydropower. The remaining portions of the graph represent a combination of hydropower and another purpose, such as flood control or irrigation.

Federal agencies (U.S. Army Corps of Engineers, Bureau of Reclamation, and the Tennessee Valley Authority) own nearly half of the installed hydropower capacity. The 176 plants they own account for 49% of the capacity but only 8% of the plants. Publicly owned utilities, state agencies, and electric cooperatives own an additional 24% of capacity. The remaining quarter—which corresponds to 62% of the plants—belongs to private owners.

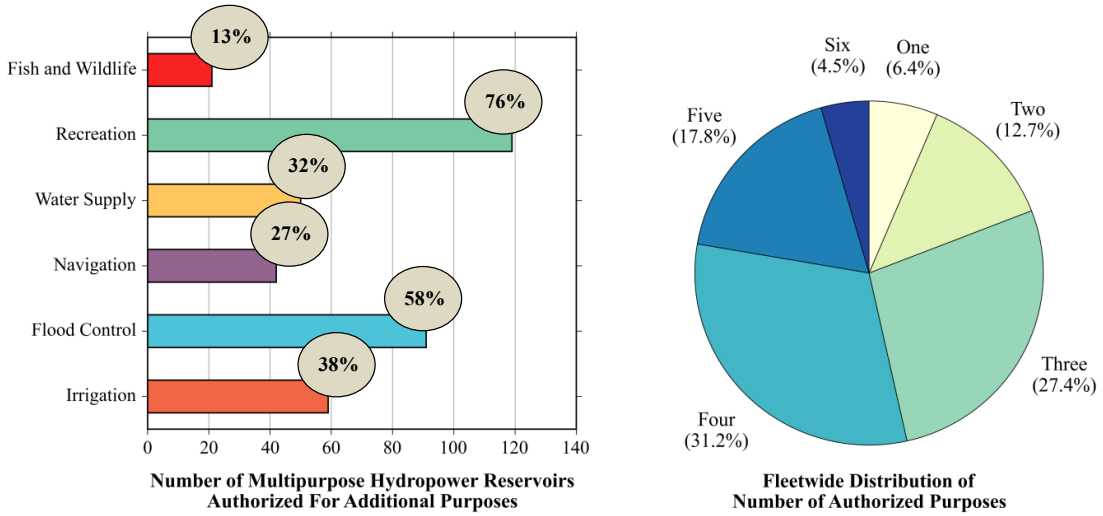

Fig. 1. Distribution of authorized uses for all federal multipurpose hydropower reservoirs. The percentage of multipurpose hydropower reservoirs that are authorized for each respective additional purpose is shown in a circle at the end of each bar (left). Source: NHAAP (2015).

Federal hydropower plants operating at multipurpose reservoirs range in installed capacity, from less than 1 MW to over 6,000 MW. This wide range of generation potential is accompanied by similar variability in reservoir storage volume and surface area, which results in many beneficial opportunities for multipurpose use. The relationship between installed hydropower capacity and number of authorized purposes shows a general trend of greater number of purposes as installed capacity increases (Figure 2). The majority of plants with a capacity greater than 100 MW are authorized for four purposes, while most plants with a capacity lower than 100 MW serve only three purposes. Reservoirs authorized for six uses are almost equally distributed between plants with less than 100 MW, 100-500 MW, and greater than 500 MW installed capacity.

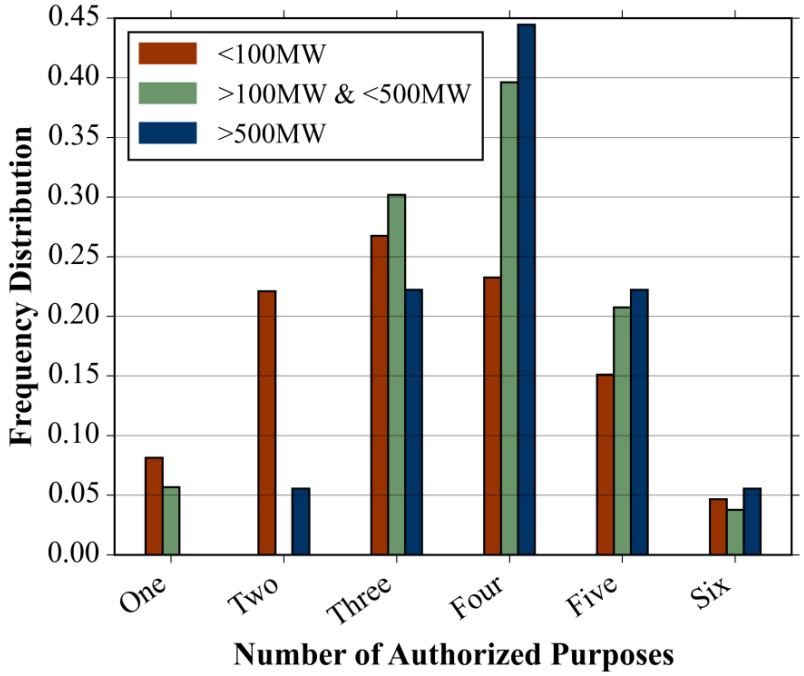

Fig.2. Frequency distribution of authorized uses based on installed hydropower capacity.

The following research is a first attempt at defining a base case of the economic benefits of federal multipurpose hydropower reservoirs. The goal of this study is to inform stakeholders and the general public about the significant socio-economic benefits of multipurpose reservoirs, as well as provide hydropower developers and operators worldwide with an awareness of how the benefits of reservoirs in the U.S. are distributed across multiple uses.

2. Methodology

Though previous studies have been conducted to quantify the economic benefits of multipurpose reservoirs (see e.g., Pizzimenti et al., 2010; Bray et al., 2011), these have been targeted at individual reservoirs or a particular utility or region of the country. The USACE provides a comprehensive valuation methodology in their annual Value to the Nation report, which quantifies the economic benefit of their civil works programs (IWR, 2013). Among the services they provide, flood risk management, navigation, water supply, hydropower, and recreation are quantified in terms of a Net Economic Benefit (NEB), as well as tax revenues generated for the U.S. Treasury. On an international level, Electricité de France (EDF), in partnership with the World Water Council (WWC), released a report as part of their *Multipurpose Water Uses of Hydropower Reservoirs* framework which highlighted the economic benefits of twelve multipurpose reservoirs around the globe (Branche, 2015). Despite these comprehensive evaluations, a scalable valuation methodology for all multipurpose hydropower reservoir benefits has yet to be presented on a national level.

The main objective of a federal water resources project is to contribute to National Economic Development (NED). Methodologies for performing NED cost-benefit analyses are outlined in the *Economic and Environmental Principles and Guidelines for Water Resources Implementation Studies* (P&G), published in 1983 by the U.S. Water Resources Council to provide guidance in evaluating potential federal water resources projects and their alternatives. The P&G has been used since then by USACE, USBR, and TVA. The idea is that a water resources project's NED benefits, or increases in the value of the national output of goods and services following project implementation, must exceed its cost, thus justifying federal investment in the project. NED benefits can be expressed as society's willingness to pay, as is the case with the sale of hydropower generation or the lease of water for M&I purposes, or it could be analyzed from a costs-avoided perspective, used when looking at the benefits of flood control structures. If a project has been authorized by Congress for one or more uses, the NED analysis has to consider all purposes in order to ensure that marginal benefit of use exceeds marginal cost of supply, and that marginal benefit per unit of water (or reservoir storage) is equal across uses (McMahon et al, 2001).

The primary advantage of quantifying benefits in terms of an NED approach is twofold. First, market transactions like hydropower, and non-market transactions including recreation, are valued using measurable financial units that reflect an increase in the national output of goods and services. Second, the principles of NED evaluation represent the federal perspective, rather than region specific valuations, and allow the benefits of the multipurpose reservoirs across the nation to be compared evenly. This advantage trades generality for a loss of specificity, which leads to over- and undervaluation of benefits at certain reservoirs with important secondary and tertiary benefits. For example, the decision to build a manufacturing plant near a river may be driven by the proximity to cheap inland navigation and the improved transportability of physically large products. The local manufacturing benefits and economic impacts are a direct result of the lock, but these benefits are not easily identified or captured in a value analysis. In order to address these issues and map out a framework for identifying an appropriate representative methodology for all benefits, a foundational analysis is needed that represents a base case of economic benefits. This base case seeks to establish an order of magnitude estimate that captures the cumulative benefits distribution across all federal reservoirs.

Three federal agencies, USACE, USBR, and TVA, own and operate 42% of the installed capacity of the U.S. hydropower fleet. Raw data was requested from each agency for the six benefit categories. Because various economic evaluations are employed by each agency in their proprietary cost-benefit analyses and annual reports, additional data analysis was completed before NED benefits could be quantified and compared across agencies. Further, data collected from an agency may cover project, unit, or division level operations, and it may represent the aggregate of multiple reservoirs, of which only a fraction possess hydroelectric generating capability. Additional research, literature review, data collection, and methodology development were completed to allocate larger-scale data to individual reservoirs.

Based on the availability of both public and proprietary data, a total of six reservoir purposes are analyzed within the NED framework: power generation, navigation, flood control, recreation, municipal water supply, and irrigation.

2.1 Power Generation

The NED methodology used to quantify hydropower generation is relatively straightforward. The annual kilowatt-hours generated from a power plant is multiplied by the average wholesale rate at which it is sold to regional utilities. Depending on their business model, each agency provided an average rate for either an individual plant or a group of plants. The unit price for energy varies between and within the agencies as they cater to different regions of the nation, each with unique energy markets and demand.

2.2 Navigation

Inland navigation in the United States is responsible for the transportation of over 500 million tons of cargo every year. The inland waterway system—consisting of 192 lock sites and 235 chambers, 68 powered locks, 124 non-powered locks —extends through 12,000 miles and touches 38 states. Inland navigation serves a vital role in the transportation of goods throughout the U.S. The USACE maintains and operates the majority of navigation infrastructure on inland waterways and records usage statistics at the Waterborne Commerce Statistics Center (WCSC). The WCSC provided essential data needed for the 68 locks located at multipurpose hydropower reservoirs to calculate the NED navigation benefit. This benefit is manifested as shipper savings (S.S), or the amount of money saved by shippers who send commodities by barge (typically the cheapest shipping option) rather than by truck or rail (usually the second least expensive option). A national value of S.S. was provided by the Planning Center of Expertise for Inland Navigation.

To estimate the NED navigation benefit, the tonnage passed through a powered lock is multiplied by the national S.S. value. The S.S. units are given in dollars per ton, reflecting the dollar value saved over the entire length of a shipment. A typical shipment passes through multiple locks and, consequently, the raw tonnage value at each lock cannot be used directly to estimate the navigation benefit as it would result in double counting over the trajectory of a shipment. In an effort to eliminate the double counting of goods passing through multiple locks, the individual lock tonnage is divided by the total tonnage passed through all locks. This fraction of the national tonnage is multiplied by the national reduced tonnage (i.e. the total tonnage without double counting), provided by the USACE Institute of Water Resources, to arrive at an annual lock tonnage that excludes double counting. This tonnage is multiplied by the national S.S. to generate the NED navigation benefit for each lock.

2.3 Flood Control

Flood control benefits are quantified as damages avoided, or the dollar estimate of damages that would have occurred had the structure not been in place. Since the benefit for preventing these natural events can be substantial, each agency performs a proprietary analysis to estimate damages avoided based on derived flood-stage-damage relationships for particular regions. This value is commonly assigned to an entire river system or agency project incorporating the flood benefits of multiple reservoirs with and without hydropower. To obtain the amount of benefit from a single reservoir, the fraction of total system flood storage provided by an individual reservoir is multiplied by the damages prevented.

Flood plain curves, using geographic and local data, allow both the acreage and depth of a prevented flood to be estimated. When a dam regulates a flooding event, the volume stored is used in the flood plain model. A fraction of the value of land, buildings, goods, and activities that lie within the flood plain and would have been destroyed are assigned to the flood event based on its severity. This ultimately allows a dollar amount of potential damages to be reached. This method is an estimation and its accuracy could vary based on many factors that go into this process.

2.4 Recreation

Reservoirs are popular destinations for a wide variety of recreation activities including fishing, boating, camping, swimming, water sports, and wildlife observation. To estimate the economic benefit of recreation, most agencies rely on visitor counts to reservoirs and related recreation areas obtained through an agency survey or provided by state and national park services. The number of annual visitors to a reservoir is multiplied by a daily spending average, resulting in the total recreation economic benefit. In most cases either the average spending amount or the

number of visitors contain regional and temporal multipliers to capture spending trends in a specific region and account for the amount of time each visitor spends while carrying out recreation activities.

Most recreation data represents an estimate based on trends observed at sites around the country. When survey data is not available at a particular site, it is common for agencies to estimate a number for that site based on other national recreation areas with similar characteristics. This approach, in combination with the diverse activities and preferences of recreationists at reservoirs, lends itself a great deal of uncertainty in number of visits and spending amounts per activity. In a pure economic benefits analysis, this uncertainty cannot be easily quantified. To mitigate the uncertainty in a national level analysis, the approach used in this report restricts valuation to two metrics and relies primarily on data provided by individual agencies.

2.5 Municipal Water Supply

Approximately 62 billion gallons of water per day are used for public, municipal, and industrial uses in the U.S. (excluding mining and livestock), accounting for 17% of total surface- and groundwater withdrawals (Maupin et al., 2014). Many multipurpose reservoirs assign a percentage of their total storage to water supply and are equipped with facilities to release or withdraw stored water. In 2011, approximately 35% of USACE multipurpose reservoirs included a water supply purpose (IWR, 2013).

To produce the NED benefit of M&I uses, the volume of water stored for municipal and industrial use is multiplied by the national average price of water per unit volume. In general, contractors and municipalities reserve a volume of water under contract to be made available each year for their consumption. This data is largely found within project operating plans that outline the storage allocations of each reservoir.

2.6 Irrigation

Most of the irrigated farmland in the U.S. sits west of the Mississippi River, where water is procured and distributed for irrigation largely by BOR through the Department of the Interior (DOI). The irrigation benefit is pronounced in arid regions where lower rainfall necessitates irrigation infrastructure such as pumping stations, diversion dams, and canals. These systems are capable of transporting stored water from a reservoir to farmland anywhere from less than a mile to hundreds of miles away.

The NED benefit for irrigation is quantified by multiplying the total acres of land irrigated by the value of crops grown on those acres. These values were provided by the BOR, which keeps yearly data on the number of acres, types of crops, and regional value of those crops for each of their projects authorized for irrigation.

2.7 Methodology Exceptions

While the results are presented largely as point estimates, it is important to note that significant engineering judgement and interpretation have been applied at all levels of the data analysis and collection, and many estimates contain a high level of uncertainty. In cases when a reservoir is authorized for a given purpose and no data is available to quantify the economic benefit of that purpose, the reservoir is omitted from the analysis. Pumped-storage hydropower plants were also excluded due to the increased complexity of valuing power generation benefits. Including exceptions, the analysis captured 33 (BOR), 49 (USACE), and 26 (TVA) conventional hydropower plants representing 96%, 74%, and 98% of federal agency conventional installed capacity, respectively.

3. Results

The benefits distribution of multipurpose hydropower reservoirs at each federal agency is presented in Figure 3. TVA and USACE reservoirs show a similar benefits structure, with recreation comprising the largest overall benefit (nearly 40% of the total economic benefit of all reservoirs) and navigation providing the smallest benefit[1]. Power generation provides between 25% and 15% of the total benefit, ranking as the second and third largest benefit for TVA and USACE, respectively. USACE hydropower reservoirs show a small but notable increase in flood control and water supply benefit over TVA. Nearly 73% of USACE multipurpose hydropower reservoirs are authorized for flood control compared to 79% for TVA. Though TVA has a higher percentage of reservoirs providing flood

[1] While a total of 16 USACE multipurpose hydropower reservoirs are authorized for irrigation, no data was available to quantify any irrigation benefit.

control, the benefit is slightly less per reservoir, with the difference being made up in navigation and power benefits. A significant departure in benefits distribution is seen with BOR reservoirs, where 60% of the economic benefit is tied to irrigation. BOR dams are predominantly located in the western U.S., where irrigation is the primary source of water for many farmers and an authorized use for nearly all reservoirs. The remaining representative benefits are nearly equally distributed amongst power, water supply, and recreation.

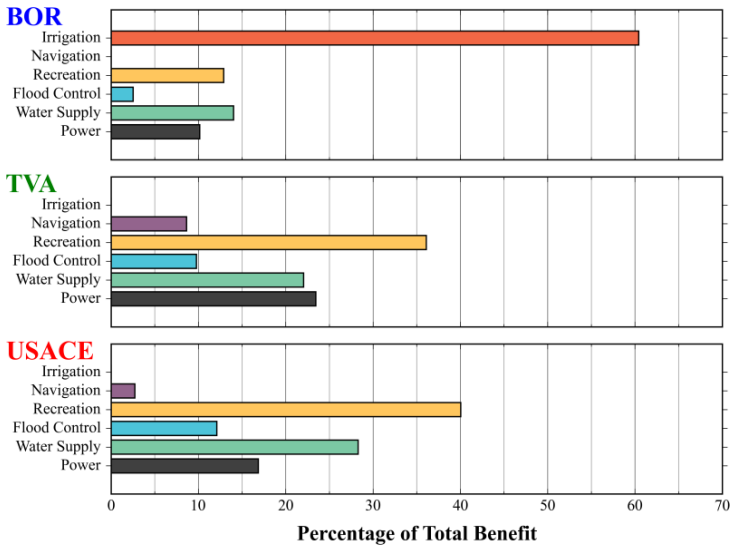

Fig.3. Distribution of economic benefit per use per agency.

As the number of quantifiable purposes of a reservoir increases, the respective percentage of power benefit decreases based on installed capacity (Figure 4). For reservoirs with two purposes, the hydropower benefit increases significantly with installed capacity. Large plants with >500MW of capacity provide the substantial majority of economic benefit when there is only one other quantifiable benefit. This trend is also prevalent for reservoirs with three purposes. For reservoirs with four and five purposes, hydropower tends to provide a slightly disproportionately smaller percentage of the total benefit in most cases. This is interesting to note in the context of Figure 2, which shows that as installed capacity increases, the number of authorized purposes tends to increase. Reservoirs with installed hydroelectric capacity of less than 100MW tend to have fewer quantifiable uses, and hydropower tends to make up a smaller portion of the total benefit. On the other end of the spectrum, large hydroelectric dams are also more likely to be part of a large multipurpose project. The greater the number of alternate purposes, the smaller the representative contribution of hydropower towards the total benefit.

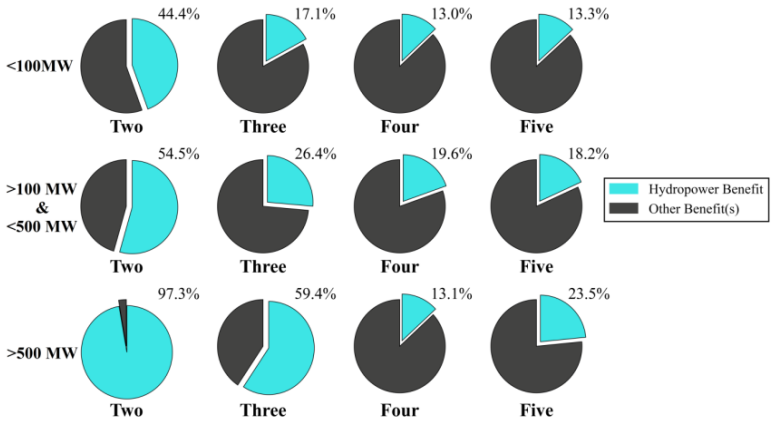

Fig.4. Average percentage of power benefit per reservoir. Columns depict the number of quantifiable purposes, while rows represent a range of installed capacity.

The benefits structure of multipurpose hydropower reservoirs varies with installed capacity (Figure 5). As installed capacity decreases from 500MW to less than 100MW, the economic benefit of power generation as a portion of overall benefits is reduced 50%. This is attributable both to a decrease in revenue from power generation and the relative increase in the benefit of additional purposes. Notable is recreation, which tends to increase as a benefit as installed capacity is reduced. Many reservoirs with low to mid-size installed capacity are characterized by substantial miles of shoreline and surface area that consistently attract a variety of recreationists. When these reservoirs are located close to metropolitan areas, the recreation benefit can make up a large majority of the overall reservoir benefit (Hadjerioua et al., 2015).

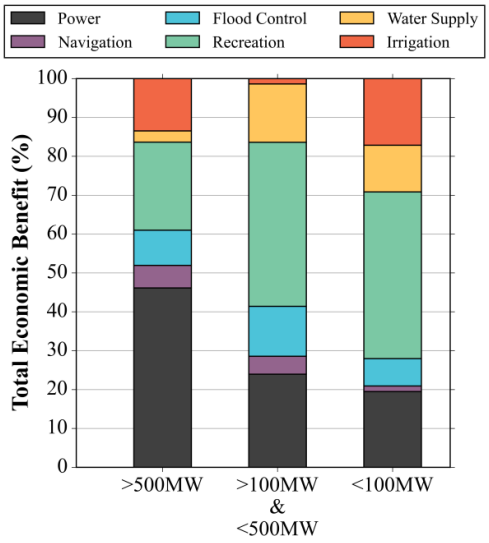

Fig.5 .Breakdown of economic benefits by installed capacity.

Flood control and navigation benefits tend to contribute less to the overall reservoir benefit as installed capacity is reduced. The navigation benefit is tied directly to the tonnage of commodities shipped through a lock, which correlates with the width of the lock and the ability of a river to physically support barge traffic. It follows that larger rivers with greater hydropower potential also provide the largest navigation benefit. The flood control benefit is also intuitively linked to dam size, as the ability to store surface water and mitigate natural disasters also translates into the ability to store large amounts of water for hydroelectric generation. Water supply and irrigation do not show any readily apparent trends in relation to installed capacity. These benefits are largely location dependent, where proximity to water consumers is a driving factor in benefits distribution.

The relative weighting of the hydropower benefit compared to alternate multipurpose benefits is shown in Figure 6. In each figure, the size of the points represents installed capacity at the individual reservoir. Several observations provide insight into the dynamics of benefit distributions based on hydropower plant characteristics. The hydropower benefit is much larger than the recreation benefit for run-of-river dams with large installed capacity (Figure 6, top left). The recreation benefit tends to dominate most dams with smaller relative installed capacity, while peaking dams with larger installed capacities tend to group towards the bottom left, where both hydropower and recreation benefits are small. Many larger peaking dams show a substantial irrigation benefit (Figure 6, bottom left). These dams tend to be located in the western U.S., with large storage capacity that is used primarily for agriculture. Few run-of-river dams have substantial capacity to provide a significant irrigation benefit, and the ones that do trend towards a smaller installed capacity.

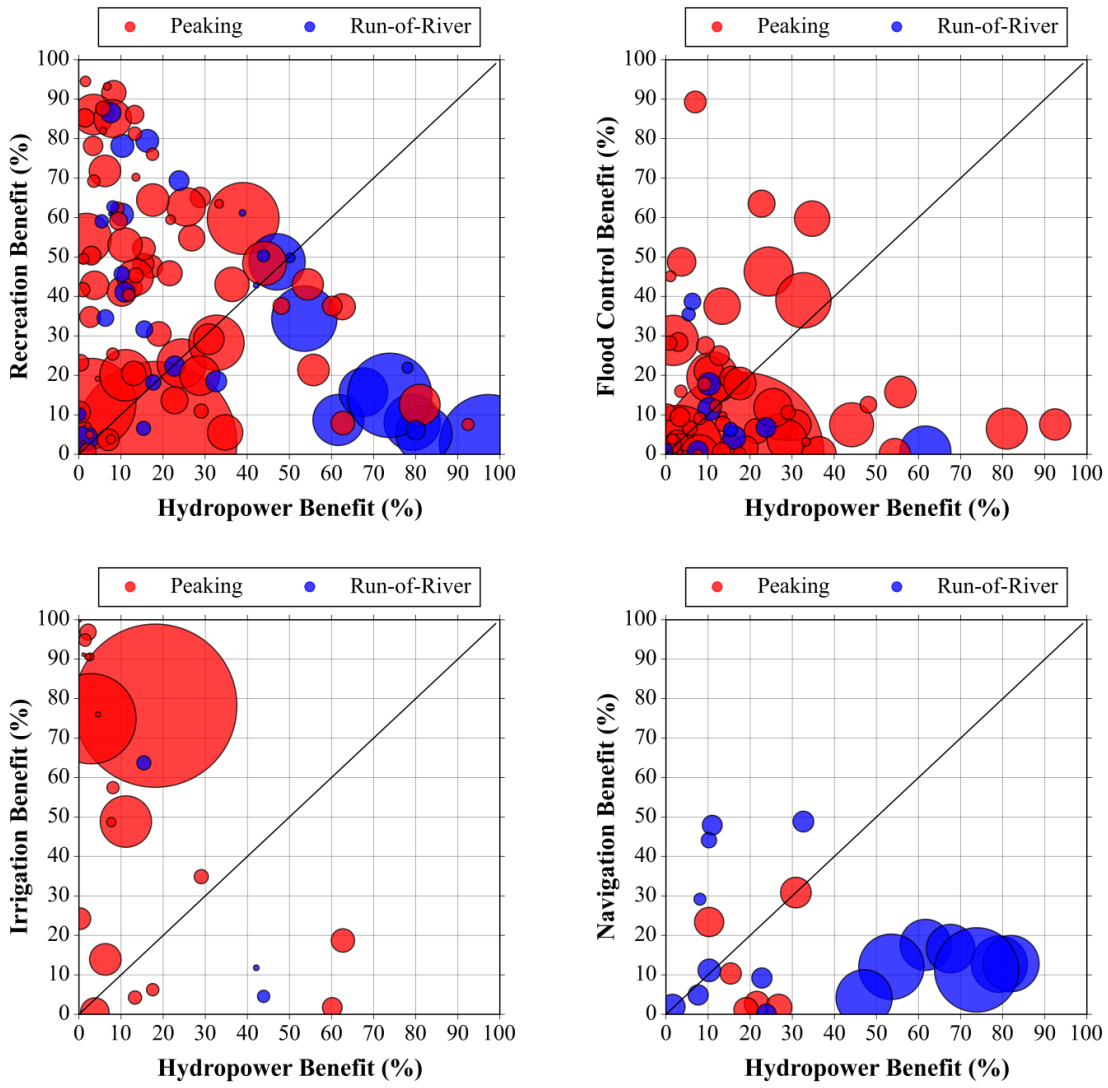

Fig.6. Weighting of hydropower benefit versus an alternate multipurpose benefit. In each case, the solid black line indicates an even split between benefits. Any points below the line indicate the hydropower benefit is greater, while points above the line indicate the respective benefit is greater than the hydropower benefit. Points are colored by mode of operation (NHAAP, 2015) and sized by installed capacity.

The weighting of flood control benefits versus hydropower benefits (Figure 6, top right) shows a grouping near the lower left corner where both purposes represent a small percentage of the total benefit for the full spectrum of installed capacity. Only a handful of peaking or storage dams show a flood control benefit greater than 50% of the total benefit. Many dams with the smallest installed capacities show a slight but notable trend towards flood control benefits over hydropower benefits. The navigation benefit is dominated by run-of-river dams, many of which have larger installed capacities (Figure 6, lower left). Most of these dams are located in the Pacific Northwest, where high flows and wider rivers increase the weighting of the hydropower benefit over navigation. In the southeastern U.S., the navigation benefit increases for run-of-river dams that are located on smaller rivers near regions with notable barge traffic.

4. Conclusions

Federal hydropower dams in the U.S. support the grid with over 276,000 GWh of annual clean, renewable electricity[2]. Over 80% of these dams are multipurpose projects, congressionally authorized for additional purposes including flood control, irrigation, navigation, water supply, and recreation. Each of these purposes has a significant and oftentimes quantifiable economic benefit. The magnitude of the benefit, measured here as an NED contribution, depends on the reservoir volume, geography, allocated storage, and installed capacity, among many other factors.

The benefits analysis revealed that, while a critical component of many multipurpose projects, power generation does not contribute the largest NED benefit in most cases. Rather, recreation and irrigation provided the largest economic benefit for federal multipurpose reservoirs. The contributing factors towards these benefit distributions include recreation visitors and spending, and the value of irrigated crops. For TVA and USACE reservoirs, recreation opportunities on surface waters and surrounding land attract millions of visitors annually. Most BOR reservoirs are located in the western U.S., where they are the primary supplier of water for irrigated crops, farmland, and livestock. These purposes contribute significant economic benefits to the multipurpose nature of hydropower reservoirs.

As hydropower installed capacity at a reservoir is increased, the benefit of hydropower is significant when only one or two additional purposes are present. For true multipurpose projects with four to five quantifiable uses, hydropower benefits represent a disproportionately smaller percentage of the total economic benefit. Large projects often benefit many stakeholders, and the most valuable multipurpose use is a function of many competing inputs, including location, mode of operation, and authorized use.

This research is part of an ongoing effort to quantify the economic benefits of multipurpose hydropower reservoirs in the U.S. This analysis is representative of the best available data, which at times is challenging to gather as federal agencies, as well as offices within these agencies, do not have a systematic method for collecting and reporting dam and reservoir data. The present methodology was developed to standardize and quantify, as best as possible, the economic benefits of federal reservoirs. The ultimate objective of this research is to engage publicly-owned utilities and private sector hydropower dam owners so a complete national estimate of multipurpose benefits can be obtained.

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