Fish and Wildlife Program Performance Assessment, 1980-2022: Hydrosystem Category

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This is a staff product and has not been reviewed or approved by the Council. This working draft functions as supplementary documentation for the Categorical Assessment presentations and contains information to inform the upcoming amendment process. While elements within this document were developed in collaboration with the region's state and federal fish and wildlife agencies and tribes, the document itself has not been reviewed by anyone other than Council staff and should be considered preliminary. We welcome feedback and/or corrections for future drafts of this documentation.

Northwest **Power** and **Conservation** Council

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Introduction

Purpose and scope of the assessment

The Fish and Wildlife Program of the Northwest Power and Conservation Council was developed to protect, mitigate, and enhance fish, wildlife, and habitat negatively affected by the construction and operation of the hydrosystem. Over the last 40 years, there have been 20 comprehensive or targeted Program amendments and addendums. The intention to have a way to evaluate Program performance has been present since the first Program in 1982, although it was never clearly defined. The Power Act mentions reporting to Congress on the effectiveness of the Fish and Wildlife Program (section 4(h)(12)(A)). This report is submitted annually with updates on Fish and Wildlife and Power. Recently, there has been increased focus in the region and by the Council on understanding outcomes from this significant investment in mitigation.

The Program has undergone numerous advancements and refinements over time, reflecting growing knowledge in the basin, changing priorities, and expanding efforts. Mitigation extends throughout the Columbia Basin and is achieved by implementing a range of actions both at dams and offsite. These actions are referred to as “measures” in the Program. There are thousands of measures directly listed in the Program or included by reference (e.g., to Biological Opinions, or BiOps). Measures on similar topics are grouped by strategy in the Program, and the contemporary 2014/2020 Program has 23 strategies. These measures cover actions related to hydrosystem management, habitat restoration, artificial production, research, and more. The Program is designed so that collective implementation of a range of measures and strategies contributes to achieving shorter-term Program objectives and longer-term Program goals. However, the relationship between measures, strategies, and objectives is not one-to-one. In other words, it may take multiple measures within a strategy, or multiple strategies, to create the conditions needed to achieve a Program objective or goal.

In the 2020 Program addendum, goals and objectives were refined and developed to serve as benchmarks, and performance indicators were developed for each Program strategy. These goals, objectives, and indicators form the core of our performance assessment. However, before we can evaluate Program performance, we must first understand what programs have called for over time and what has been implemented. To do so, we first grouped Program measures by major category of work (Hydrosystem, Artificial Production, Habitat, and Program Adaptive Management) and assessed implementation. These categorical assessments characterize implementation over time relative to identified benchmarks, including goals and objectives, and make use of performance indicators. This approach places data on implementation in the context of the time and space and draws on expertise from fish and wildlife managers throughout the region. Through these categorical assessments, we aim to identify key questions about the Program and its implementation for the region to consider during the next Program amendment.

For this inaugural hydrosystem categorical assessment, we focused on the implementation of measures calling for structures or operations associated with the dams in the mainstem Columbia and Snake Rivers, and the large storage dams in the upper Columbia River Basin. We excluded most tributary projects from this initial assessment due to time limitations but recognize important measures have been called for and implemented in those systems. From an initial 1000+ hydrosystem measures identified in the Program, we focused the assessment on approximately 40 key measures. These actions are organized by (1) juvenile salmon and steelhead, (2) adult salmon and steelhead, (3) mainstem spawning, and (4) resident fish measures, by location. Future assessments will cover expanded content and will be released prior to each Program amendment.

Climate conditions in the Columbia Basin

The Columbia Basin drains an area of 668,000 km^2 encompassing parts of Washington, Oregon, Idaho, Montana, Nevada, Utah, and Wyoming in the U.S., and parts of British Columbia in Canada (Figure 1), and ranges in elevation from sea level to > 4,000 m. In the northern and eastern portions of the basin, the landscape is mountainous, and the hydrology of rivers is dominated by snowmelt. The central portion of the basin is characterized by mid-elevation, arid conditions on the Columbia Plateau. In the southern portion of the Basin in Idaho and along the Oregon border, the landscape is arid, and the hydrograph is dominated by snowmelt. The Cascades mark a rain/snow transition zone; on the West slopes of the Cascades, hydrographs of some tributaries are influenced by snow-melt runoff from the Cascade Range, whereas lower elevation tributaries are primarily influenced by rainfall. Further to the west, the rivers in the low-lying Coast Range are primarily influenced by rainfall.

Across the Basin, precipitation ranges from < 30 cm/year of rain in the Columbia Plateau, to > 13.5 m of snow in Canada at the headwaters of the Columbia River, to > 200 cm of rain at Astoria, Oregon, in the Columbia River Estuary. Changes in the Pacific Decadal Oscillation (PDO) influence precipitation and temperature patterns throughout the Columbia Basin Figure 2).

Figure 1. Map of the Columbia River Basin

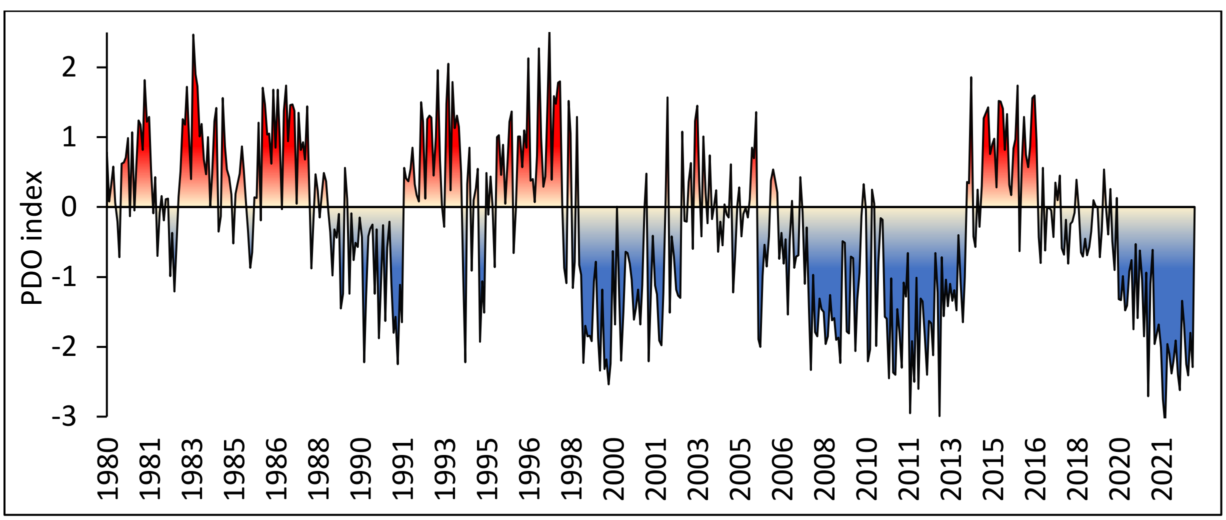


Figure 2. Pacific Decadal Oscillation index (PDO) 1980 - 2022

Development of the hydrosystem

Major mainstem Columbia River dams were constructed between 1933 and 1971 (Figure 3). Dam construction on the mainstem Snake River occurred between 1901 and 1992, although most Snake River dams were constructed between 1952 and 1975. Following disastrous flooding in the lower Columbia in 1948, the Columbia River Treaty was ratified between the U.S. and Canada (1964) and authorized the construction of major storage dams in Canada (Hugh Keenleyside, Mica, Duncan) and one in the U.S. (Libby Dam). These dams were completed between 1967 and 1977. Construction after 1980 was mostly of small hydroelectric facilities that primarily serve other purposes, such as irrigation.

Over the last 130 years, approximately 272 hydroelectric dams were constructed in the U.S. portion of the Columbia Basin; 23 of those dams were eventually removed. In its current configuration, the hydrosystem is comprised of major hydropower producers on the mainstem Columbia River, Snake River, and tributaries, along with dams that produce minimal hydropower, often for local purposes (e.g., diversions or canals). A total of 29 dams in the Columbia Basin (and two dams outside the Basin) comprise the Federal Columbia River Power System (FCRPS) and the largest eight dams have the capacity to produce over 50% of the total power generated by the hydrosystem (Grand Coulee, Chief Joseph, John Day, The Dalles, Rocky Reach, Wanapum, Bonneville, and Boundary).

Major hydropower dams were authorized for multiple purposes in addition to power generation, including flood control, irrigation, municipal water, navigation, and recreation. To meet these various needs, some dams were constructed as storage dams (capable of altering the timing and volume of river flows and power generation seasonally) and others were constructed as run-of-the-river dams (minimal capacity to shape flows). Mainstem dams were also constructed with locks to allow for barging upstream as far as Lewiston, Idaho, an inland seaport located 748 km from the ocean.

CHS, ESRI, GEBCO, Delorme, NaturalVue

Figure 3. Location of major dams (diamonds; red = federally owned, yellow =publicly or privately owned) in the Columbia River Basin, most of which were constructed between 1933 and 1971. Map created in ArcGIS Pro (C) 2020 ESRI. All rights reserved

Operation of the hydrosystem

Management of the hydrosystem requires designing operations at multiple locations to meet different authorizing purposes, fish requirements, and system needs. In the process of power planning, fish operations are incorporated as a firm constraint (i.e., constraints on hydrosystem operations for producing power)- but there are other critical operations to consider before that can happen. There are structural limits to how dams can be operated and there are flood management operations. These are incorporated before fish operations.

In addition to those critical operations and firm constraints, there is also a large role for environmental variation, such as drought or floods, heat domes, and more. When flow levels are low, there is simply less water to shape to meet specific fish operations. There can also be tradeoffs between meeting fish operations for resident and anadromous fish or between listed and non-listed fish. All of this is occurring in the background and is part of the context in understanding how the Program's hydrosystem measures have been implemented over time.

Program strategies, measures, and performance indicators associated with the hydrosystem

The Program calls for a range of operational or structural changes at dams as part of mitigation, including seasonal flows, fish passage, and water quality. Some measures apply broadly to all hydropower dams and others focus on mitigating specific issues at specific dams. Each measure is implemented to improve some kind of biological condition. In general, those purposes cover improving migration conditions for juvenile salmon and steelhead, improving migration conditions for adult salmon and steelhead and all life stages of lamprey, improving conditions for mainstem spawning and rearing salmon, and improving conditions for resident fish in different locations throughout the basin.

Over the last 40 years of Fish and Wildlife Programs, over a thousand measures have called for some kind of action in the hydrosystem. This includes measures identified in Programs, BiOps (actions adopted in Programs), and other plans. Many of these measures are duplicates or modifications of measures from prior programs. Measures exist for dams throughout the basin, with an emphasis on Columbia and Snake River dams and storage dams in tributaries of the upper Columbia, along with major tributaries like the Yakima and Willamette Rivers.

Multiple strategies include measures that relate to the hydrosystem, and they also may include measures that relate to other topics. Of the 23 contemporary Program strategies, seven relate to the hydrosystem and are described in this Categorical Assessment (Table 1). For most of these strategies, Strategy Performance Indicators (SPIs) were developed and provided by managers throughout the Columbia Basin during the 2020 addendum process. These SPIs provide the datasets used to determine how implementation of the Program has proceeded over time. The assessment provides the context needed to interpret the data in the SPIs.

Table 1. Fish and Wildlife Program strategies and strategy performance indicators (SPIs; NPCC 2020) associated with the Hydrosystem Categorical Assessment

Strategy ***SPI***	**Description**
Ecosystem function	Protect and restore natural ecosystem functions, habitats, and biological diversity wherever feasible consistent with biological objectives in the program.
Water quality	Provide flows and habitat conditions of adequate quality and quantity for improved survival of anadromous and native resident fish populations on the mainstem Columbia and Snake rivers, as well as improving water quality in Basin tributaries, to promote healthy and productive populations of anadromous and native resident fish and wildlife.
E2-2/E2-4	Daily average water temperatures at fixed monitoring sites in the mainstem in reference to water quality targets.
E2-5	Total dissolved gas (TDG) during voluntary spill events at Dworshak, Libby, Hungry Horse, Albeni Falls dams, and at Columbia River and Snake River dams compared to the applicable standard.
Mainstem hydrosystem flow and passage	Manage dams and reservoir operations to protect and restore ecosystem function and habitat, and to improve fish passage and survival through the hydrosystem. Analyze the power system effects of operations for fish and recommend adaptations to the power system so that these operations may be delivered in a reliable manner while the region continues to have an adequate, economic and reliable power supply.
S2-1	SARs (smolt-to-adult return rates) for salmon and steelhead, Lower Granite Dam to Lower Granite Dam and uppermost to uppermost dam on the Columbia.
S3-1	PITPH (Powerhouse Encounter Rates) from Lower Granite Dam to Bonneville Dam.
S3-2	Juvenile salmon and steelhead reach survival by year.
S3-3	Number of salmon and steelhead transported in the Snake River.
S3-4/S4-2	Average mortality (%) of juvenile salmon and steelhead at Columbia and Snake River dams.

S4-1	Annual adult salmon and steelhead survival in select Columbia and Snake River reaches.
E3-1	Seasonal flows at specified Columbia and Snake River dams with associated target flows from BiOp.
E3-2	Travel time by release date for salmon and steelhead in Columbia and Snake River Reaches.
E2-3/ E3-4	Daily average flows and water temperatures downstream of McNary Dam in reference to flow and spawning temperature needs for Columbia River White Sturgeon.
E3-5	Reservoir elevation at mainstem reservoirs.
WS1-1	Number of wild female adult White Sturgeon with acoustic tags detected at or above RKM (river kilometer) 246 of the Kootenai River (preferred spawning habitat).
WS4-1	Number of days of streamflow at or above 30 KCFS at Bonners Ferry to support White Sturgeon spawning migration.
Eulachon	Increase understanding, protection, and required restoration of eulachon for the Columbia Basin, estuary, and ocean ecosystems. Better understand how the development and operation of the Federal Columbia River Power System (FCRPS) affects eulachon spawning, survival of eggs and larvae, and migration patterns.
NF-1	Spawning stock biomass of lower Columbia River Eulachon.
Lamprey	Implement actions that result in increased abundance and survival for lamprey, including habitat actions, dam operations and passage, monitoring populations, and research to improve understanding of how the development and operation of the Federal Columbia River Power System affect migration success, survival and growth of lamprey.
L1-4	Abundance of juvenile and larval outmigration tracked at John Day Dam and Bonneville Dam.
L3-1	Adult passage efficiency for each Columbia and Snake mainstem dam (in development).
L4-2	Annual weighted average injury rates for Pacific Lamprey *microphthalmia* at Bonneville, McNary and John Day dams.

Resident fish mitigation		For resident fish and other aquatic species impacted by the hydrosystem, protect and mitigate freshwater and associated terrestrial habitat, and native fish populations.
	R1-1	Bull Trout population abundance by subbasin.
Sturgeon		Implement actions that result in increased abundance and survival for Columbia River Basin green and white sturgeon, including habitat actions, dam operations and passage, hatchery considerations, monitoring populations, and research to improve understanding of how the development and operation of the Federal Columbia River Power System affect survival and growth of sturgeon.
	WS1-8	Kootenai River White Sturgeon adult abundance estimate.

Juvenile migration, Salmon and Steelhead

The purpose of juvenile salmon and steelhead mitigation actions is to improve migration conditions and survival by (1) providing specific water volumes/flows, managing reservoir elevations to speed migration, and creating more natural hydrologic conditions; (2) installing passage structures and implementing seasonal spill to improve transport through the dams and (3) transporting fish around dams to reduce impacts from dam structures and operations.

Seasonal flow management

The development and operation of the hydropower system significantly changed historical flow conditions in the Columbia and Snake Rivers, affecting migration conditions for juvenile salmon and steelhead. Since the beginning, the Council’s Fish and Wildlife Program has focused on enhancing flows to improve in-river conditions for juvenile fish. Providing flows for fish is an important component of water management in the Columbia River Basin.

Table 2. Hydrosystem measures in the Council's Fish and Wildlife Program, and other external agreements guiding water management for juvenile salmon and steelhead, 1982 – 2020

Program	Water Budget and Seasonal Flows	Upper Snake River Flow Augmentation
1982	**NPCC Fish and Wildlife Program Water Budget** Water managed as a total volume to be shaped by the managers at Lower Granite (Snake River) and Priest Rapids (Columbia River) Dams. This was the first time that something like this had been called for in the Columbia Basin. • 20 KCFS for 3 months for a total of 1.19 MAF at Lower Granite Dam. • 58 KCFS per month for 3 months (3.45 MAF) at Priest Rapids Dam.	
1992	**Average monthly flow equivalents for Lower Granite Dam** The flow level required to achieve the same water particle travel time as an equivalent flow at normal average pool elevations at all projects. • 85-140 KCFS average monthly flow equivalent at Lower Granite Dam. • Continued water budget volumes for Priest Rapids Dam.	**Secure water in spring and summer management period** Provide 427 KAF of water from the Upper Snake River Basin through use of uncontracted storage and water marketing to augment flows in the lower Snake River for both spring migrants and summer flow augmentation for temperature reduction.
1994-1998 BiOps	***Seasonal average flow target ranges*** • *85-140 KCFS at Lower Granite Dam.* • *220-260 KCFS at McNary Dam.*	
2000 BiOP	***Continued seasonal average flow target ranges*** • *85-100 KCFS at Lower Granite Dam.* • *220-260 KCFS at McNary Dam.* • *Priest Rapids target set at 135 KCFS.*	
2003	**Seasonal average flow target ranges or point targets** Lower Granite, Priest Rapids, and McNary dams. Program aligned with Biological Opinions. • Lower Granite range 85-100 KCFS, Priest Rapids 135 KCFS target, McNary range 220-260 KCFS.	
2004 NPT Water Rights Settlement and 2005 Upper Snake BiOp		***Secure water in spring and summer management period*** *487 KAF from Upper Snake Basin.*

2009		**Secure water in spring and summer management period** Provide up to 487 KAF of water from BOR projects consistent with the 2008 NOAA Upper Snake Basin BiOp and the NPT Water Rights Settlement Agreement.
2014/2020	**Continue seasonal average flow target ranges or point targets** Lower Granite, Priest Rapids, and McNary Dams. Aligned with Biological Opinions.	**Continue Upper Snake River Flow Augmentation** Aligned with Biological Opinions.

KAF = Thousand acre-feet, MAF = Million acre-feet, KCFS = Thousand cubic feet per second. Rows in italics describe external agreements and associated measures that have been incorporated into the Program. The year listed is the first time a measure appears in a Fish and Wildlife Program.

Water budget and seasonal flows

To begin, flows were based on providing a specified volume of water at key locations, termed a water budget. This idea was first proposed and implemented in the 1980s with the intent to provide minimum flows for at least the middle 80% of the spring outmigration of juvenile salmon and steelhead during low runoff years. The budget was based on the water available and varied both annually and by location.

Summary of implementation

Although initially implemented a few years prior, operations in 1987 tested the idea of a "water budget" in what was considered the first low runoff year. Based on the predicted water availability, the budget was set at 450,000 acre-feet which was substantially lower than the goal of 1.19 million acre-feet for a year with higher runoff. Despite efforts to increase the amount of water via ramping, flows were below the lower limit of the contemporary target of 85 KCFS for 51 of 60 days. The Program flow requirements for fish management purposes were not achieved during a substantial portion of the spring outmigration (Figure 4).

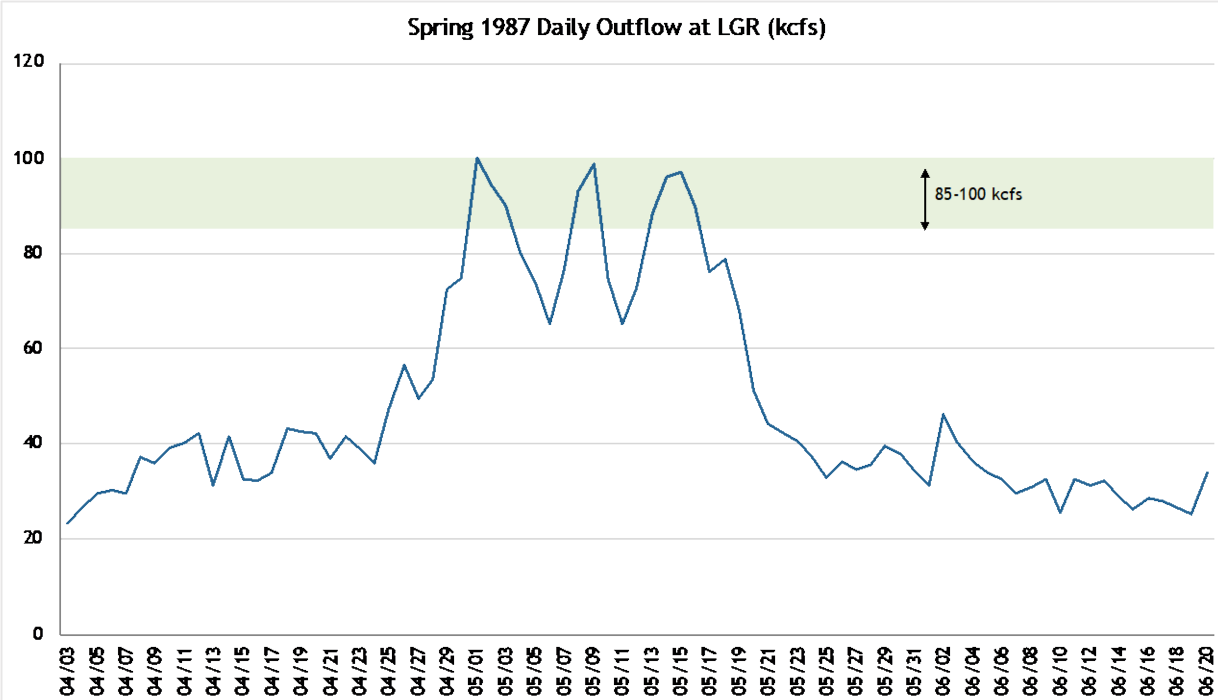


Figure 4. Spring 1987 daily outflow at Lower Granite Dam (KCFS)

Following the Northwest Power Act, competing uses of the hydropower system such as firm power, reservoir refill, and secondary power were not significantly changed from previous operations as fisheries managers hoped they might be, and BPA met all obligations including annual payment to the treasury. This demonstrated that simply having a volume target does not guarantee the appropriate change in flows to meet the needs of the fish. Subsequently, the region proposed and implemented average monthly flow equivalents which were followed by the adoption of weekly and then seasonal average flow target ranges.

Seasonal average flow targets have been relatively consistent since 2000 and are largely driven by annual precipitation. A spring forecast adopted in early April determines the target flow for each year. For dams with a target flow “range”, a point target is selected within the range based on the final spring forecast. McNary and Priest Rapids Dams often meet or exceed spring flow targets while Lower Granite Dam meets or exceeds flow targets less often. Lower Granite Dam on the Snake River is more affected by variation in seasonal precipitation. This is due to the size of the Snake basin and the availability of water upstream compared to Priest Rapids or McNary Dams, which are located on the mainstem Columbia River. These factors together affect the ability of Lower Granite Dam to meet seasonal average flow ranges, particularly in dry years. Despite challenges, managers use adaptive in-season management to work within annual water constraints.

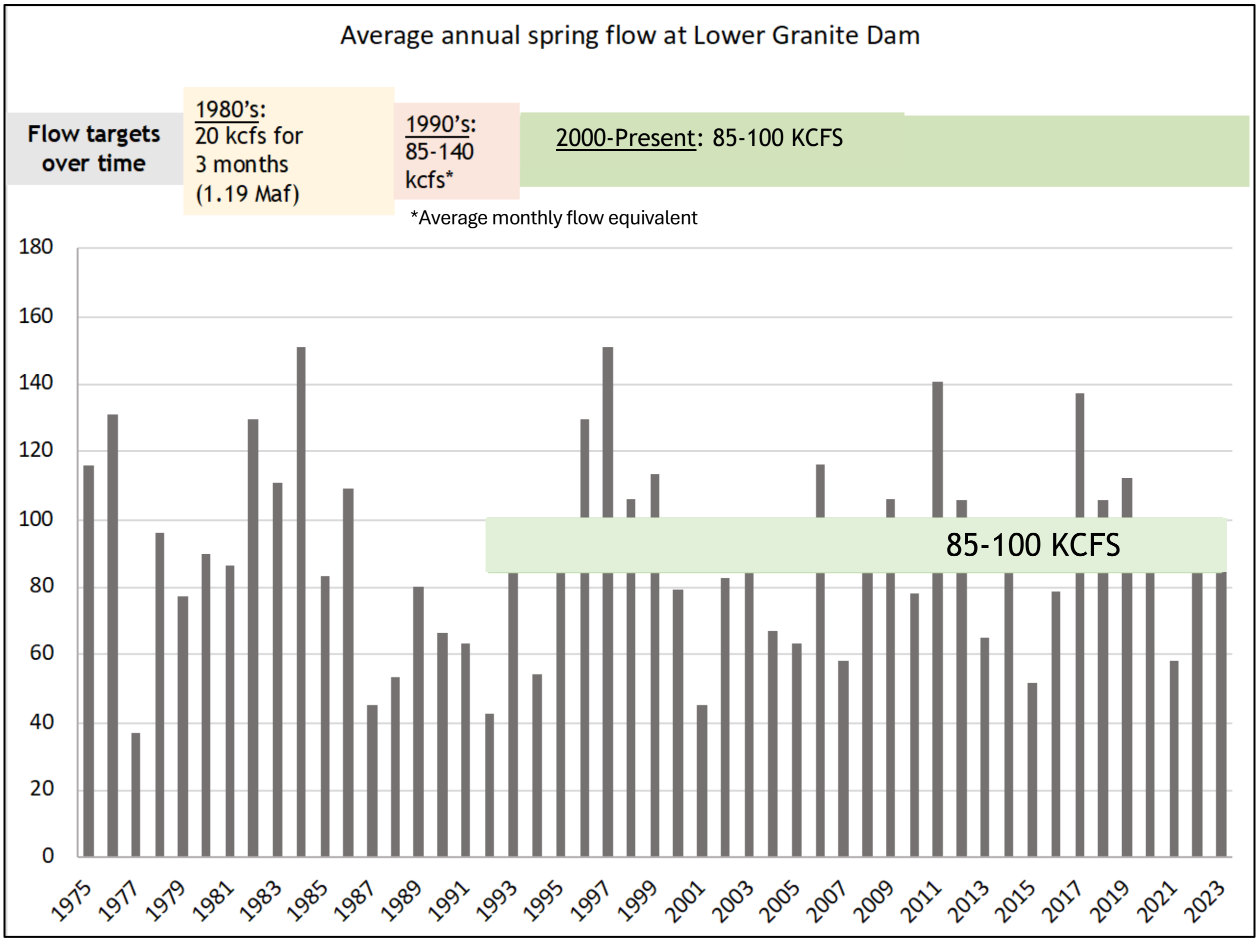


Figure 5. Average spring flow (KCFS) at Lower Granite Dam 1975-2023 with timeline of flow targets

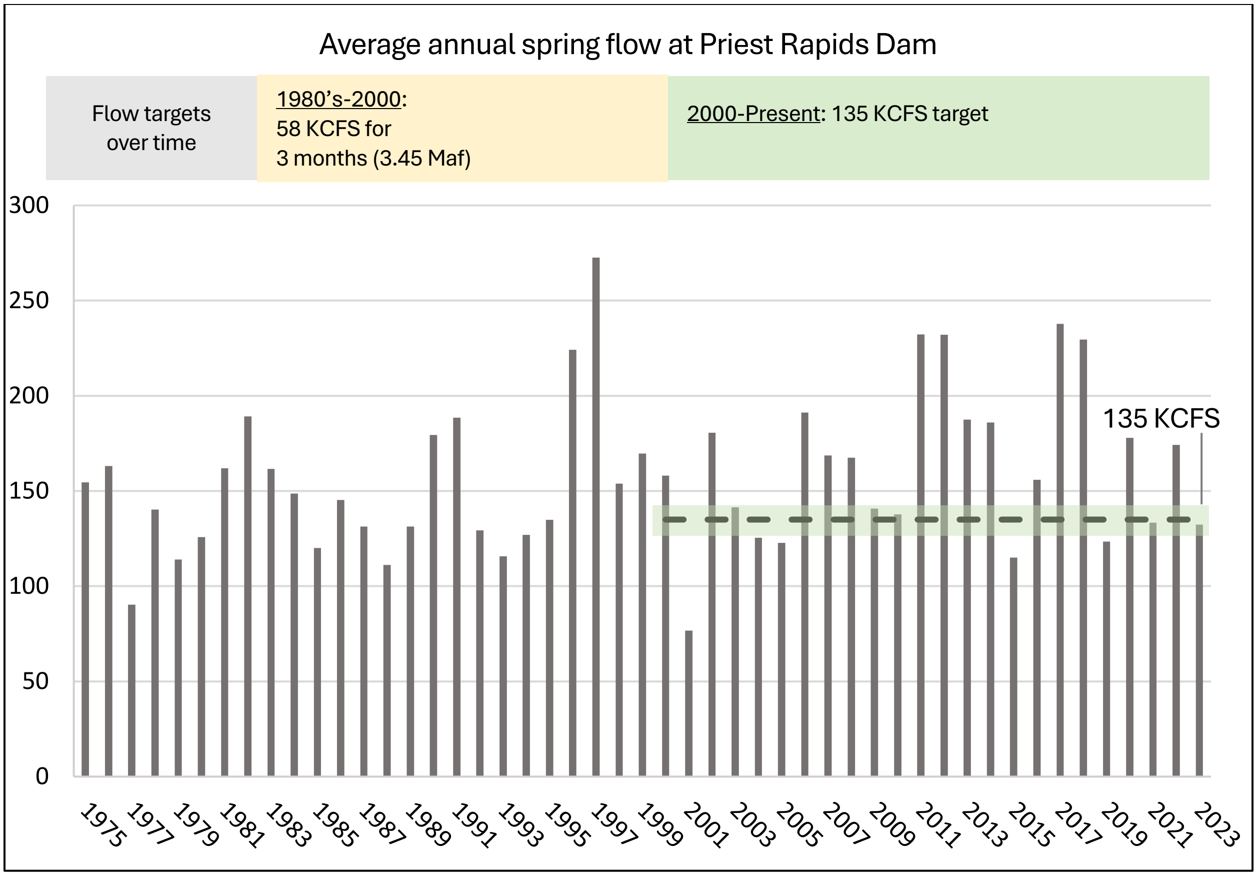


Figure 6. Average spring flow (KCFS) at Priest Rapids 1975-2023 with timeline of flow targets

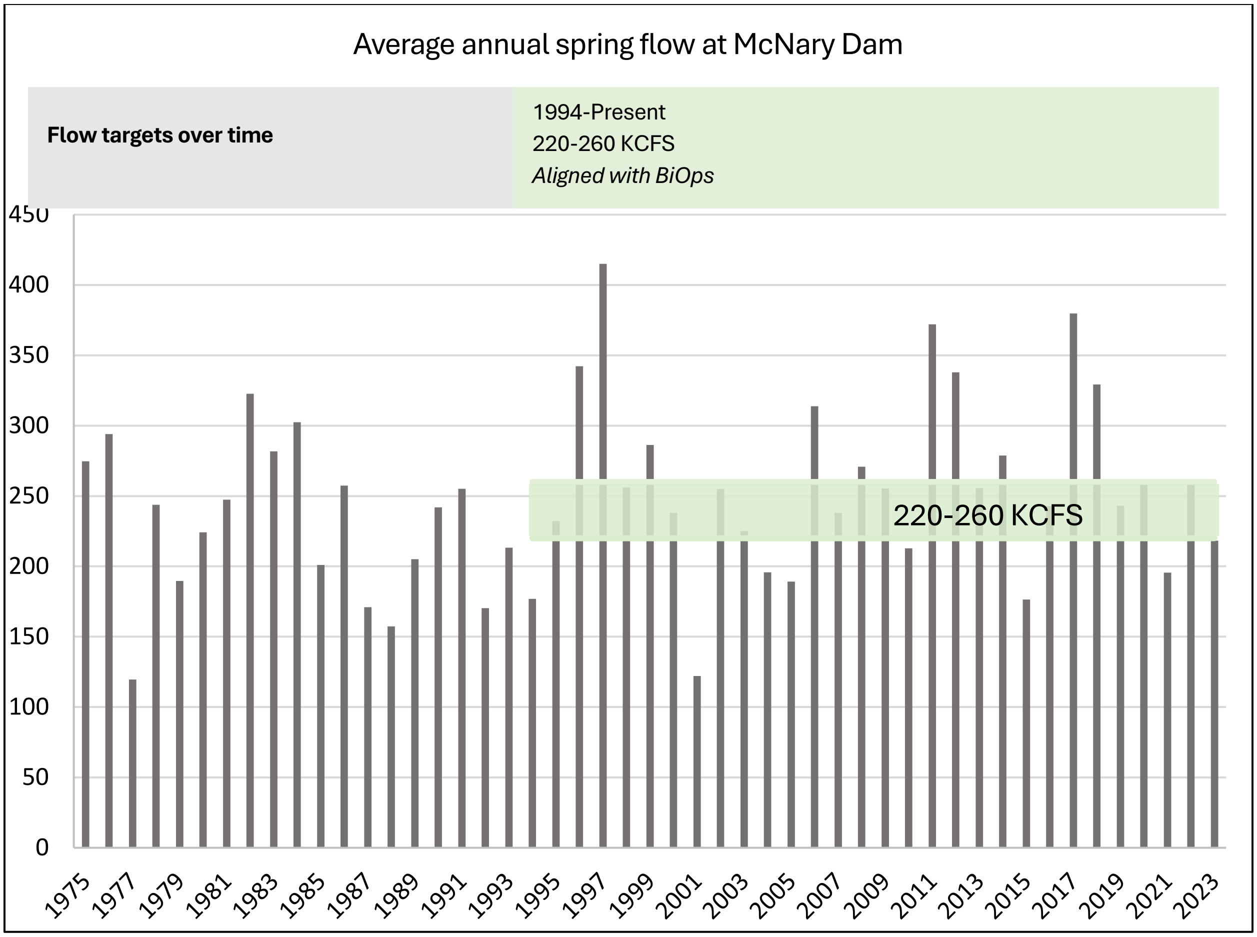


Figure 7. Average spring flow (KCFS) at McNary Dam 1975-2023 with timeline of flow targets

Discussion

The existence of a flow target or target range supports in-season management of flow conditions based on the water available in real-time. Even when the average flow over one full season falls short of the target flow (as seen in the charts here), having a flow target in place allows managers and dam operators to adjust the water at biologically critical windows within the season. Currently, flow point targets and ranges are adaptively managed through processes such as the Technical Management Team (TMT, https://pweb.crohms.org/tmt).

Figure 8 is an example of the data and graphs for the Season Average Flow Strategy Performance Indicator (SPI). This SPI provides weekly average flow and seasonal average flow data and documents how those flows compare to the seasonal average flow target.

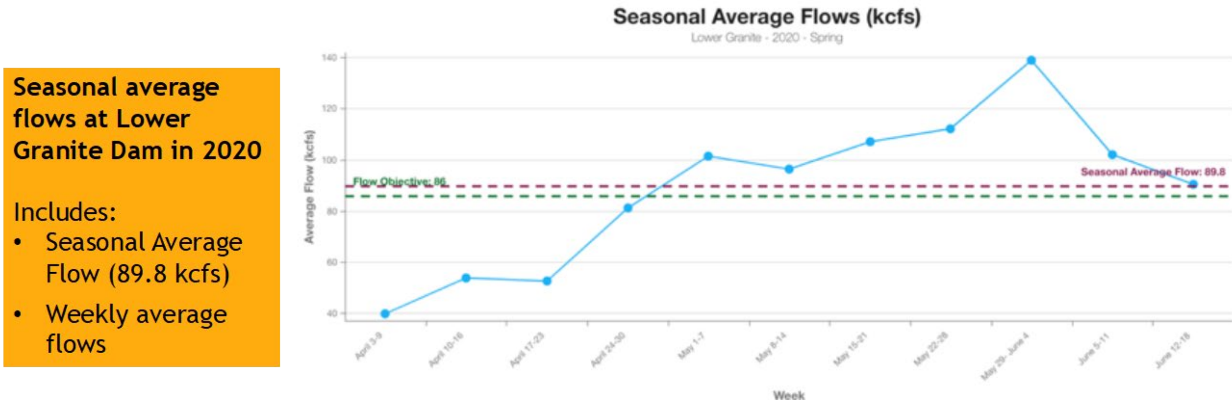


Figure 8. Seasonal average flow data for recent years as presented on the NPCC Program Tracker for Strategy Performance Indicators (SPIs)

References

BiOps: https://www.salmonrecovery.gov/BiologicalOpinions/FCRPSBiOp.aspx

Water Management Plans: https://pweb.crohms.org/tmt

Upper Snake River flow augmentation

The 1992 Council Program called for flow augmentation in the Snake River Basin to provide survival benefits for out-migrating juvenile fall chinook and to help reduce summer water temperatures. The original flow augmentation amount of 427,000 acre-feet was provided beginning in 1993. Following the 2004 Nez Perce Water Rights Settlement (The Snake River Water Rights Act of 2004, Public Law 108-447) and the 2005 Upper Snake Biological Opinion, the flow augmentation amount was increased to 487,000, to be delivered between June and August.

Summary of implementation

Flow augmentation is provided by the Bureau of Reclamation through a combination of water stored in reservoirs (the use of uncontracted space, water rentals through the State's rental pools, and powerhead space) and natural flow water rights (lease or purchase of natural flow rights) from the Payette, Boise, and Upper Snake Basins (Figure 9).

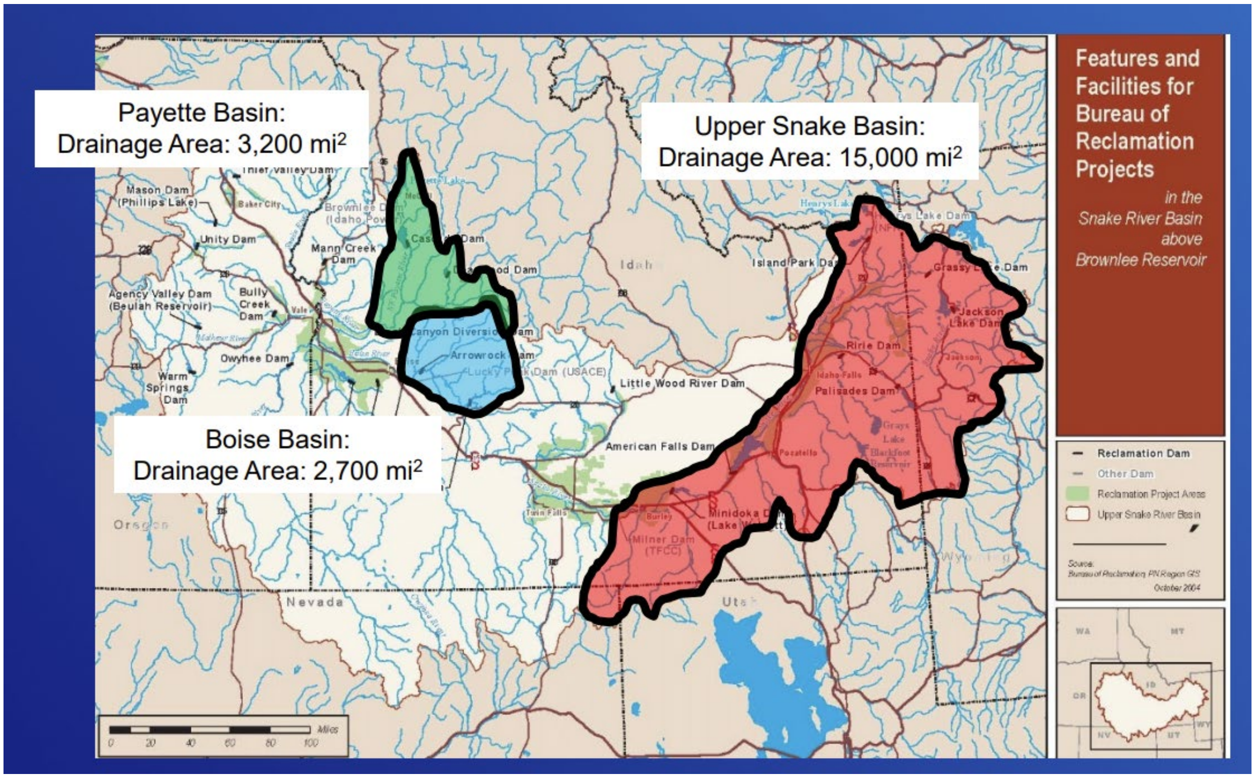


Figure 9. Bureau of Reclamation Flow Augmentation Basins (See: Upper Snake Flow Augmentation)

Figure 10 shows the flow augmentation volumes from 1991-2024. As noted above, the flow augmentation target changed from 427,000 acre-feet to 487,000 acre-feet in 2004. Since that time, flow augmentation in the Upper Snake River above Brownlee Reservoir has met the 427,000 acre-feet target in all years except 2022 and has met the 487,000 acre-feet target 12 out of 20 years.

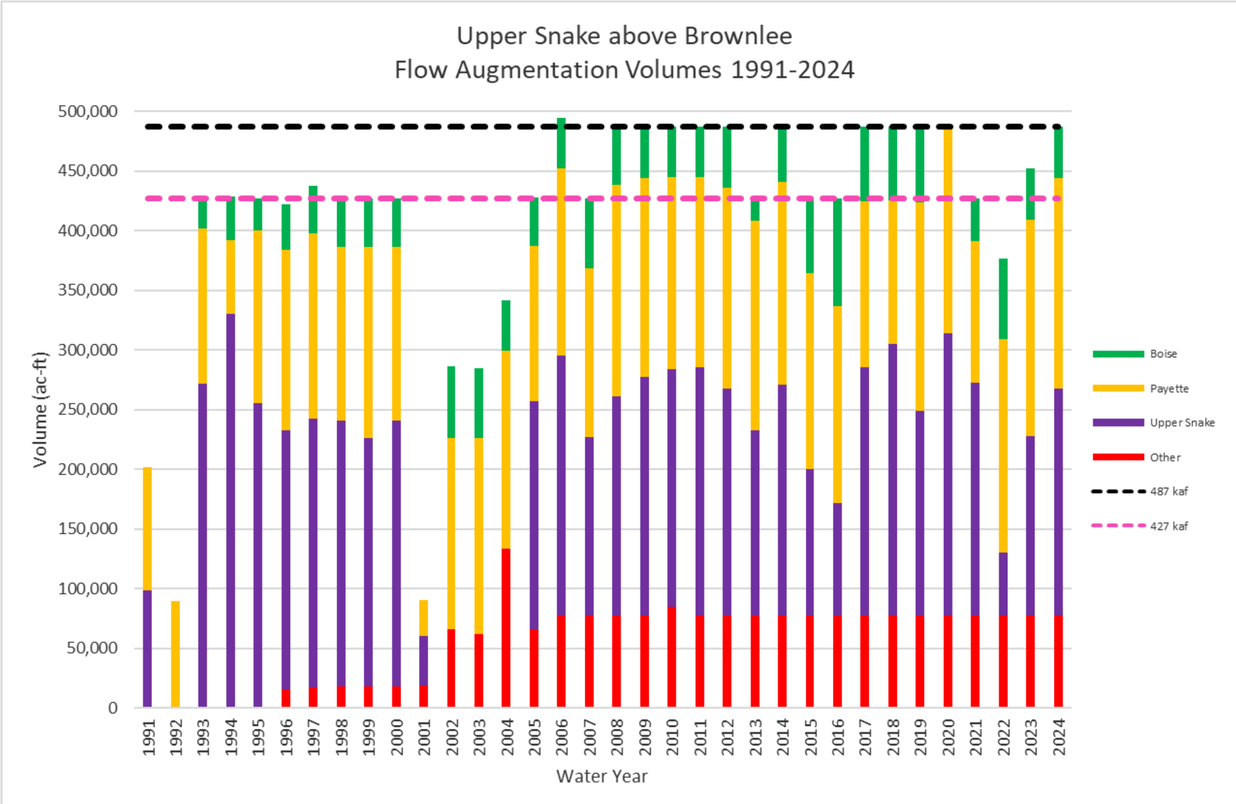


Figure 10. Upper Snake Flow Augmentation Volumes, 1991-2024. Peter Cooper (USBR), personal communication

Discussion

In the 2008 Upper Snake Biological Opinion, the National Marine Fisheries Service recommended that Upper Snake flow augmentation be shifted earlier to provide more benefit to spring and early summer migrants. Recent years have seen a notable shift in the timing of flow releases to somewhat earlier in the season (see for example: 2022 Salmon Augmentation Program Annual Progress Report for the Snake River Basin above Brownlee Reservoir), however, the ability to shift flow augmentation varies depending on the water year type, total flow augmentation volume available, and the amount and timing of water available from each specific basin (BOR, 2022). More detailed information on Snake River Flow Augmentation can be found in the Salmon Augmentation annual reports at Upper Snake Irrigation Project Flow Augmentation, CPN Region .

References

BiOps: https://www.salmonrecovery.gov/BiologicalOpinions/FCRPSBiOp.aspx

Bureau of Reclamation (BOR). 2022. Annual Progress Report 2022 Salmon Flow Augmentation Program and Other Activities Associated with NOAA Fisheries 2008 Biological Opinion and Incidental Take Statement for Operations and Maintenance of Bureau of Reclamation Projects in the Snake River Basin above Brownlee Reservoir. Columbia-Pacific Northwest

Region. Available online at: 2022 Salmon Augmentation Program Annual Report for the Snake River Basin above Brownlee Reservoir (usbr.gov)

The Snake River Water Rights Act of 2004, US Senate Bill 2605 full text: https://www.congress.gov/bill/108th-congress/senate-bill/2605

Nez Perce summary of the Snake River Water Rights Act of 2004: https://idwr.idaho.gov/wp-content/uploads/sites/2/iwrb/2004/20040515-Nez-Perce-Agreement-Summary.pdf

Bureau of Reclamation. Upper Snake Irrigation Project Flow Augmentation presentation, 2021: https://pweb.crohms.org/tmt/agendas/2021/1201_Fenolio_2021-12-01_TMT_2021_YER_Recap_Flow_Aug.pdf

Passage, spill, and transportation

Juvenile fish pass dams via many routes: through spillways and surface passage routes, through juvenile bypass systems (JBS), through turbines, or by collection and transport in barges or trucks downstream. Changes in operations and structural improvements have been implemented to aid downstream migration by reducing the proportion of juvenile fish that pass turbines, decreasing fish travel times and improving chances of overall dam survival. Juvenile fish transportation is an ongoing program designed to improve fish survival by collecting fish from juvenile bypass facilities and transporting them downstream, as needed.

Table 3. Hydrosystem measures in the Council's Fish and Wildlife Program and other external agreements guiding passage and spill for juvenile salmon and steelhead from 1982 – 2020

Program	Passage	Spill	Transportation
1982	**Juvenile bypass systems and screens** Install, operate and evaluate these structures at federal dams. FERC to require installation of collection and bypass systems at Public Utility District dams.	**Spill** as an interim measure until juvenile bypass structures complete. Achieve 80-85% passage efficiency. Allow exceptions to state standards if demonstrated that the risk of fish mortality from exposure to higher levels of dissolved gas is less than the risk of failure to provide the spill regime that may result in such levels. FERC to require PUDs to develop plans for spill at their dams.	Support funding of barges, equipment, facilities, and other expenses necessary to conduct annual smolt transportation program.

1994	**Juvenile bypass systems and screens** Continue to test, install and operate smolt bypass systems at federal dams**.** Improve or install bypass systems and passage at other dams, including PUD dams.	**Spillways and turbines** Operate to enhance fish passage and explore new bypass technologies. Evaluate and modify projects to reduce dissolved gas levels during spill operations and increase spill efficiency. **Spill** to continue at all mainstem dams.	Emphasis on in-river juvenile migration in all but the worst conditions. Improve fish transportation facilities and conduct evaluations of transport versus in-river survival.
1998 Fish Spill MOA		***Spill*** *at all projects that are not equipped with adequate bypass systems.*	
1995-2000 BiOps		***Spill*** *to gas cap and other provisions.*	
2003	**Surface bypass, alternative smolt passage, modify turbines** Test and develop surface bypass and alternative passage structures to increase survival. Relocate bypass outfalls as needed.	**Spillway modifications** Maximize survival. Continue **spill and spill experiments**. Program aligned with Biological Opinions.	Support funding of research to measure the effect of improved in-river migration compared to transportation.
2014/2020	**Surface bypass systems, fish friendly turbines** Continue to refine the operation of these structures.	**Spill and other passage experiments** The Council recognizes value of an experimental approach to salmon recovery in the Northwest. The Council is engaged and tracking newly approved proposals for improving spill and other mainstem operations.	Implement juvenile fish transportation following adaptive management principles that respond to new evidence.

Rows in italics describe external agreements and associated measures that have been incorporated into the Program. The year listed is the first time a measure appears in a Fish and Wildlife Program.

Passage

Not all areas of the Columbia River Basin are accessible to juvenile salmon and steelhead. Some areas are naturally blocked while dams have blocked others (Figure 11). For accessible areas, passage occurs via aforementioned routes including spillways and surface passage routes, juvenile bypass systems (JBS), through turbines, or by collection and transport in barges or trucks (Figure 12).

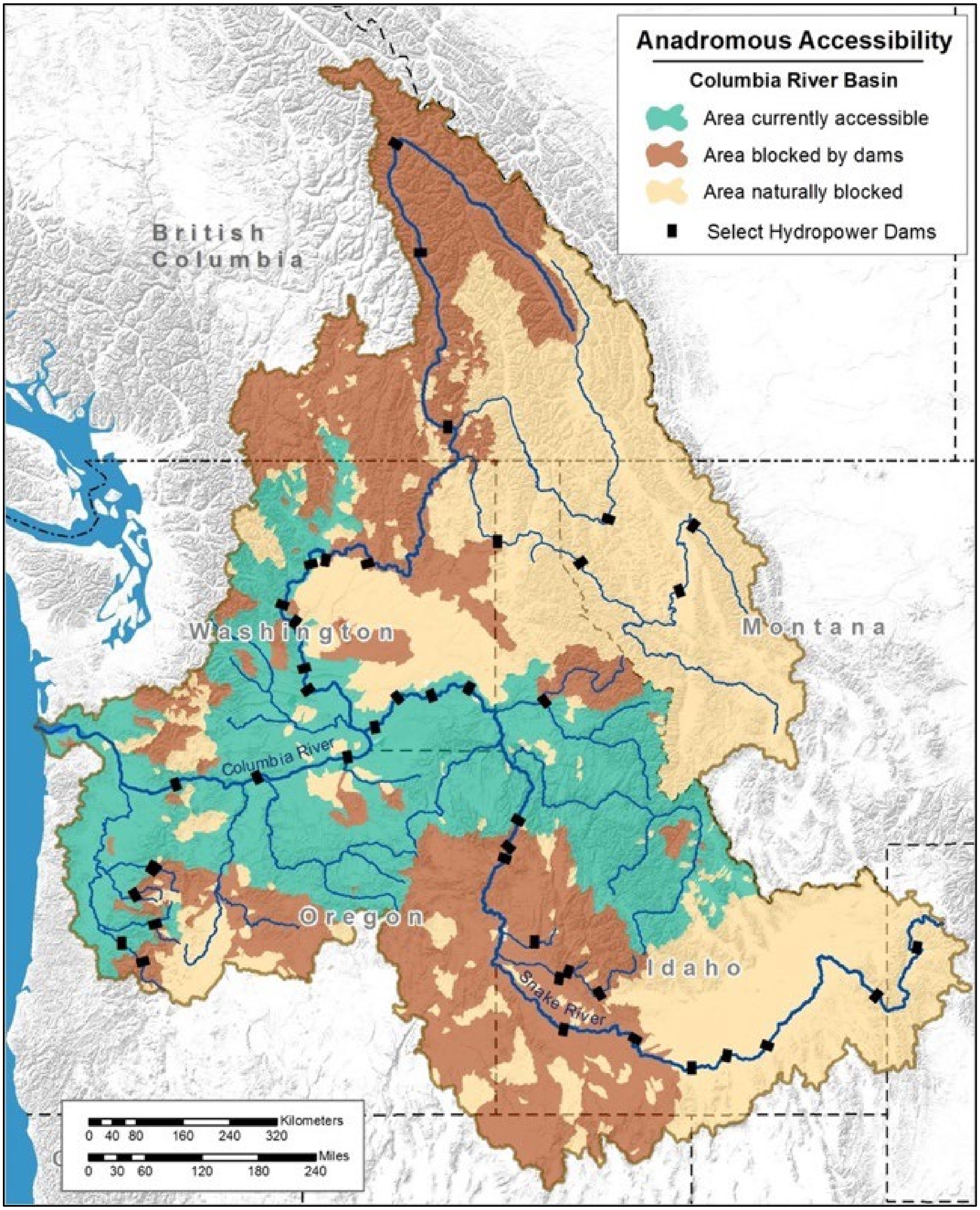


Figure 11. Map of the Columbia River Basin showing areas accessible to anadromous fish via structural or operational passage (green), areas blocked by dams (brown), and areas naturally blocked (beige). Figure from ISAB 2015

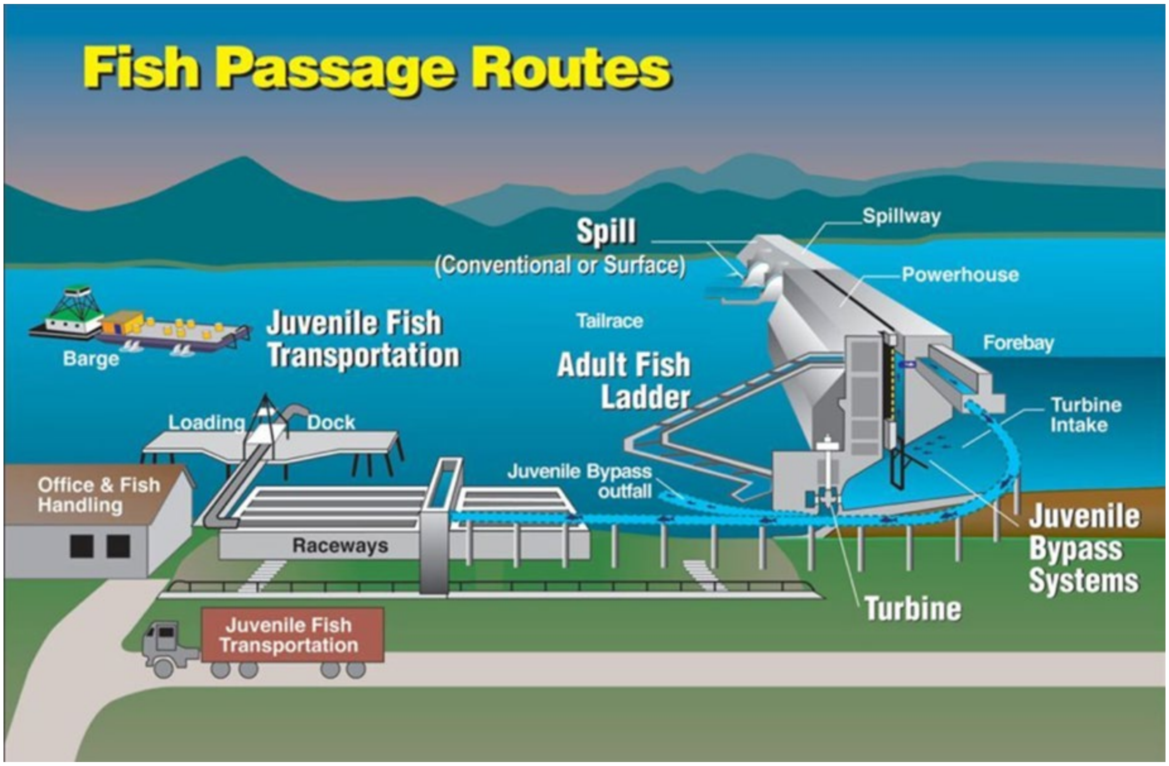


Figure 12. Juvenile and adult fish passage routes at hydropower dams. Figure produced by the U.S. Army Corps of Engineers (USACOE).

Summary of implementation

Operations and structural improvements have been tailored to the specific conditions and structures of each dam to reduce the proportion of juvenile fish that pass turbines, reduce forebay delay, and improve overall dam survival. Juvenile passage improvements to provide surface passage routes (e.g. spillway weirs and sluiceways) have been completed at all eight federal dams on the lower Columbia and lower Snake Rivers (USACOE, 2014). Depending on location, time of year, and species, approximately 76 to 99 percent of the juvenile fish use these non-turbine routes, although some research (CSS 2022 Annual Report) has shown similar impacts to juvenile fish who use juvenile bypass systems as those who travel through turbines. Routes via the spillways are considered to have a higher probability of survival in general. Major changes to dam configuration, spill, and other actions have been completed since 2008 to achieve hydro performance standards and improve fish survival (Figure 13).

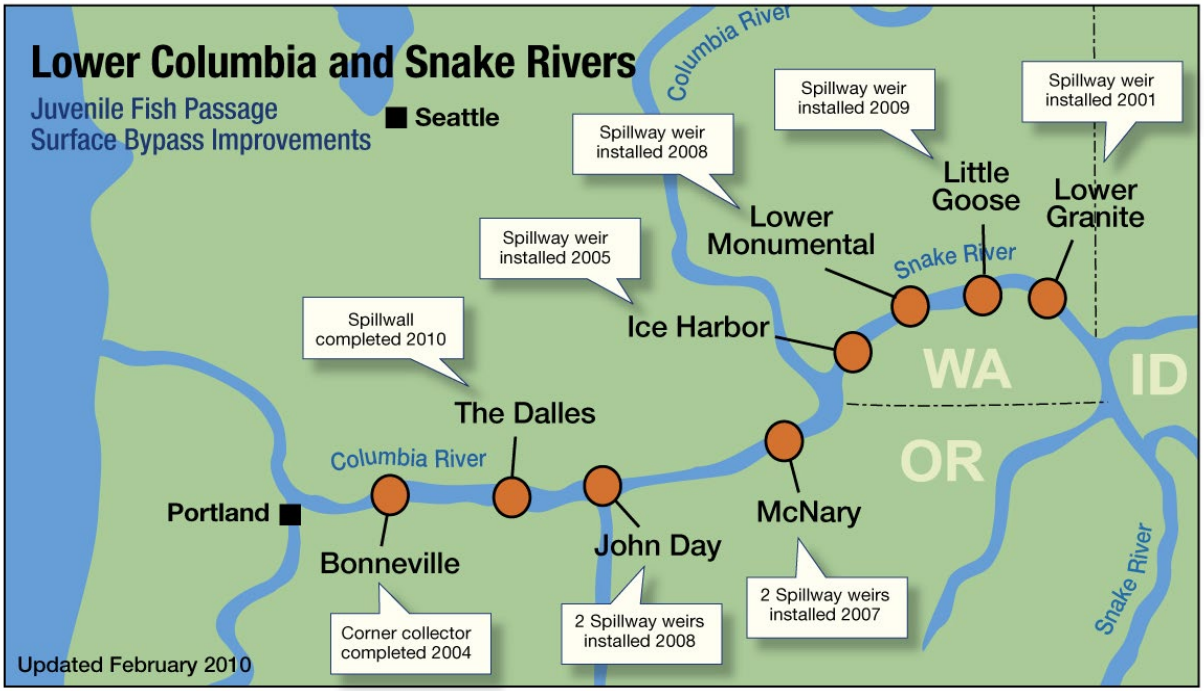


Figure 13. Juvenile fish passage surface bypass improvements through 2010. Figure produced by NOAA

Discussion

Since 2010, further improvements have been made to surface bypass systems and spillway weirs. In addition to the above mapped dams, surface bypass and surface spillway structures have been installed at the mid-Columbia PUD dams.

Passage routes and efficiency can vary at each dam. Annual escapement by species and run timing are reported in the USACOE Annual Fish Passage Report for the dams shown on the map below (Figure 14). The 2022 report can be found here.

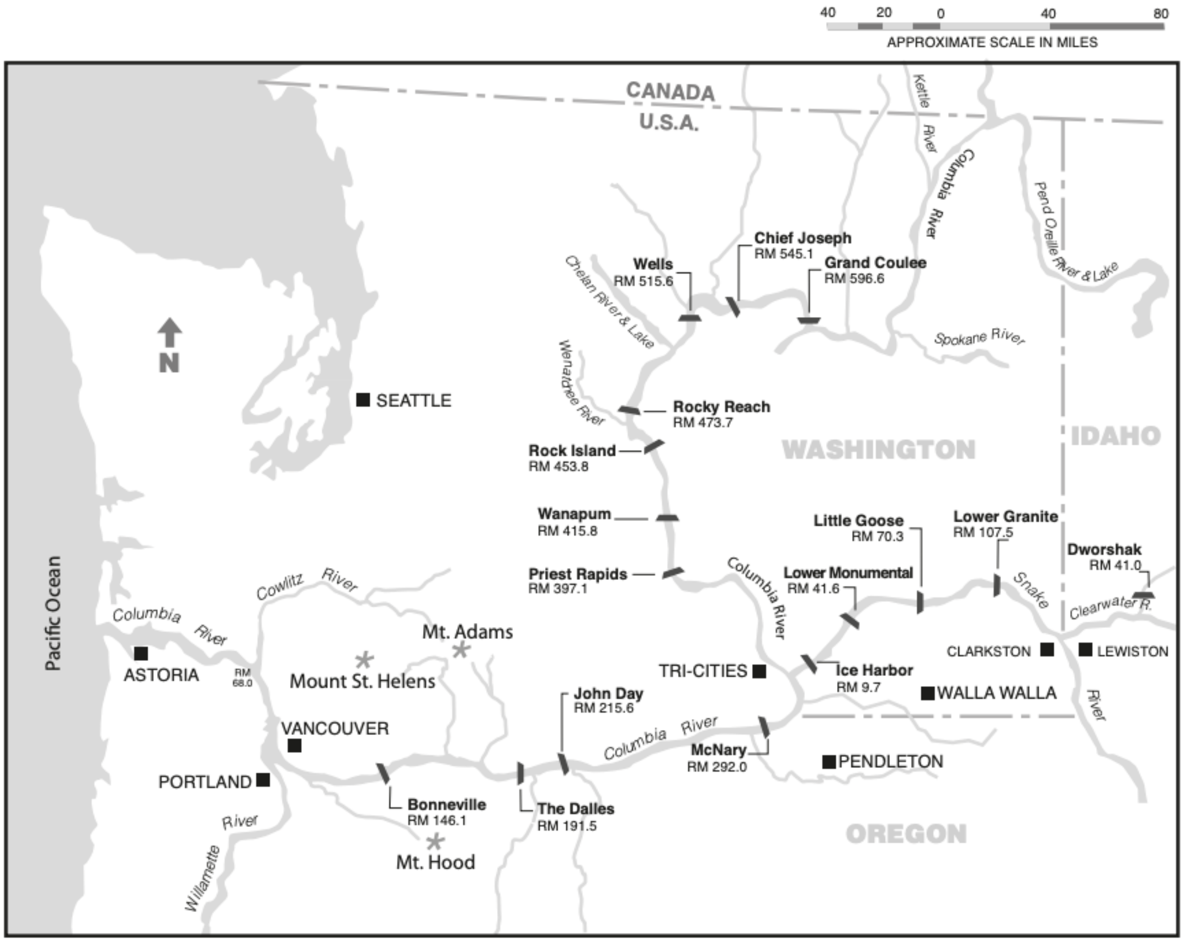


Figure 14. Columbia and Snake River Projects included in USACOE 2022 Annual Fish Passage Report

References

2014 Fish Passage Plan U.S. Army Corps of Engineers Lower Columbia & Lower Snake River Hydropower Projects – Section 1: https://pweb.crohms.org/tmt/documents/fpp/2014/final/FPP14_01_OVE.pdf

Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye 2022 Annual Report (or visit fpc.org): https://www.fpc.org/documents/CSS/CSS%20Final%20Revised%202022.pdf

Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye 2023 Annual Report: https://www.fpc.org/documents/CSS/CSS%20Annual%20Report%202023.pdf

2022 Annual Fish Passage Report: https://usace.contentdm.oclc.org/digital/collection/p16021coll3/id/1009/rec/44

Spill

The 1982 Fish and Wildlife Program recognized the impact of dams on juvenile passage. It called for the development of adequate bypass systems at the Columbia River dams and, until those bypass systems were complete, spill to provide safe passage for juvenile salmonids. The Program also called for exceptions to state standards if the risk of exposure to total dissolved gas (TDG) was less than the risk of not providing adequate spill. These early measures set the stage for future spill experiments paired with TDG monitoring to maximize spillway survival for migrating juvenile salmon. Provisions for spill have been included in Biological Opinions on the operation of the Federal Columbia River Power System beginning in 1992.

Summary of implementation

Spill for fish passage has taken different forms including upper voluntary spill bounds set by total dissolved gas criteria, percentage of total outflow, and fixed volumes. Spill during May (peak juvenile migration) from 1995 – 2017 included the three types of upper bounds listed above, but also included switching between different spill levels during night-time and daytime hours at some dams and a constant voluntary spill level 24 hours per day at other dams (FCRPS, 2022).

Changes in spill can be described in terms of total volume of spill or proportion of spill. Figure 15 shows examples of the total volume of spill (daily average spill in KCFS-days summed over the spring and summer period) and spill as a proportion of total flow. While spill volumes have varied over the years, spill percentage has increased over time.

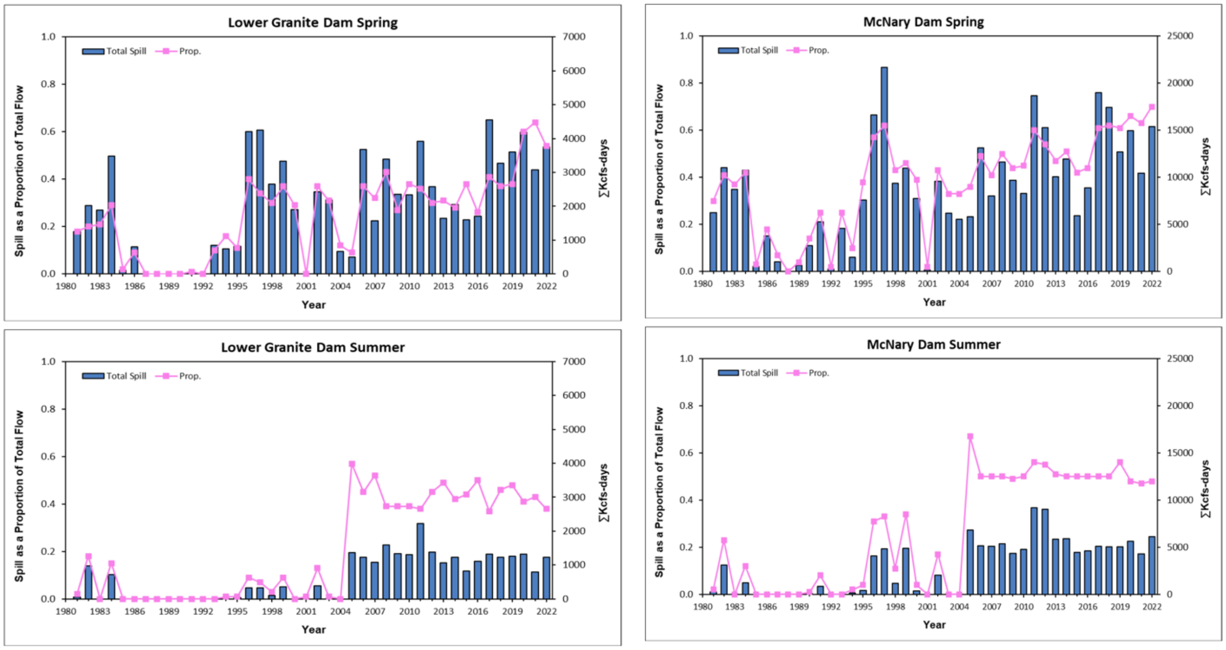


Figure 15. Total spill (∑KCFS-days) for spring (April 3-June 20) and summer (June 21-August 31) at Lower Granite Dam, and spill as a proportion of total flow for the same period (left). Total spill (∑KCFS-days) for spring (April 10-June 30) and summer (July 1- August 31) at McNary Dam, and spill as a proportion of total flow for the same period (right).

Spill at the mainstem Snake and Columbia River Dams can be divided into three primary periods: the pre-Biological Opinion period (1982-1994), the Biological Opinion period (1995-2017), and the Court-Order period (2018-2022) (FPC, 2022). Figure 16 shows the spill percentages during those periods and the differences in spill operations among the mainstem dams. Spill percentages were relatively low prior to 1994. They increased and were relatively stable until implementation of court-ordered spill and subsequent spill agreements. More detailed descriptions of the agreements and spill implementation can be found in CSS, 2022.

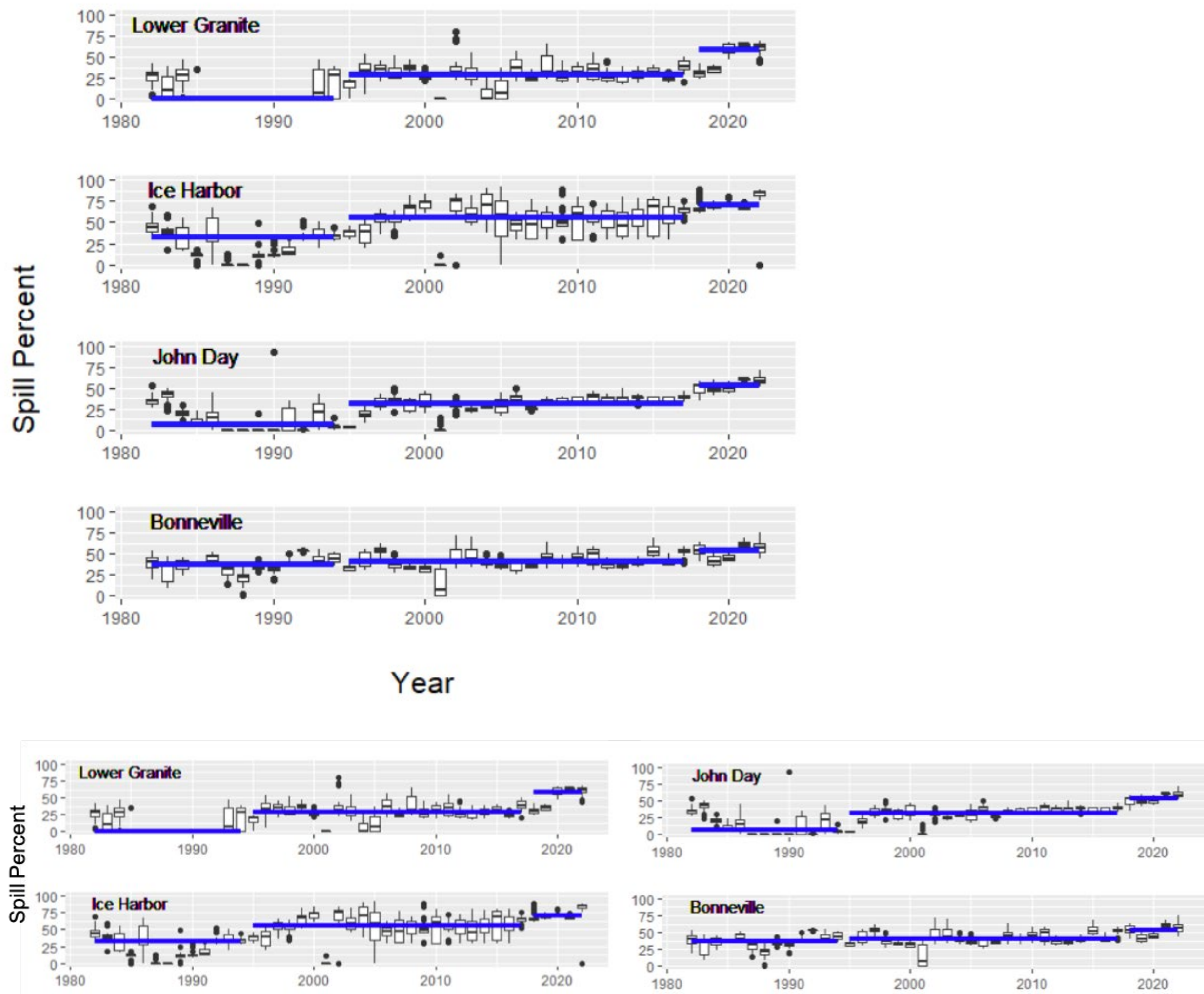


Figure 16. Mean daily spill as a percentage of total outflow from Lower Granite, Ice Harbor, John Day, and Bonneville Dams 1982-2022. Horizontal blue lines denote the yearly median of daily spill percentage (CSS, 2022). The three distinct periods represent distinct eras of spill agreements.

Discussion

Increases in spill proportions have contributed to decreases in travel times for fish through the hydropower system and decreases in the number of powerhouse encounters experienced by juvenile fish. Figure 17 shows PITPH, an index used to describe the number of powerhouse encounters experienced by a group of juvenile fish (McCann et al. 2015 Appendix J). PITPH is a system level descriptor that incorporates spill proportions, the spill passage efficiencies at individual dams, and the river discharges at which a group of fish migrates (McCann, 2022). As can be seen in this graph, powerhouse encounters have decreased over time. The Columbia River system is operated to minimize generation of TDG during spill. Standards vary at different dams throughout the basin and have changed over time as part of the spill agreements. TDG can be tracked against these standards using SPI E2-5.

As of 2024, an updated short-term spill agreement with the U.S. Government has been put in place. The monitoring of potential changes to downstream survival due to these changes will be crucial to understanding the impacts of these changes (USG, 2023).

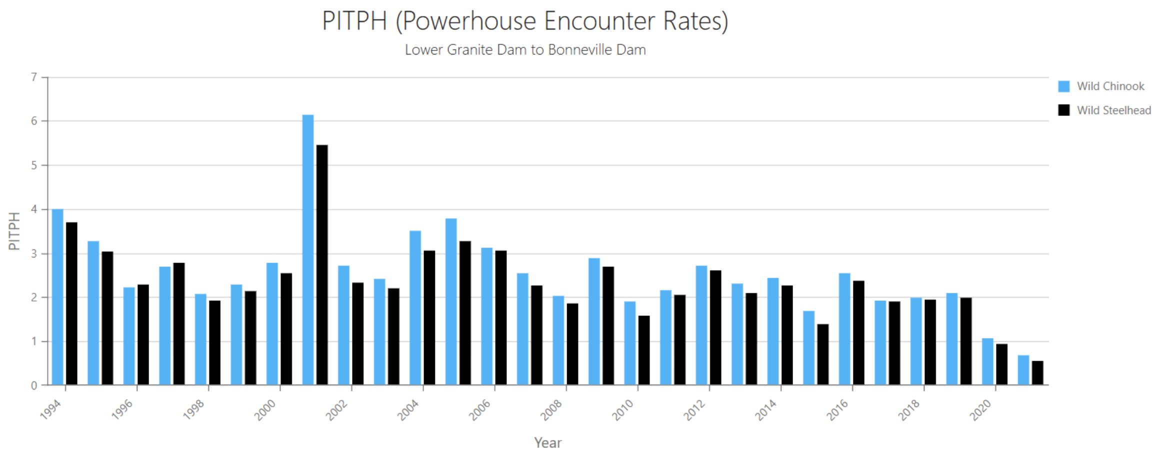


Figure 17. Estimated cumulative PITPH at all dams in the LGR to BON reach. Estimated PITPH can be found here in the Council's Strategy Performance Indicators (SPI's).

Total Dissolved Gas graphs and data for multiple years and locations, and Fish Travel Time graphs and data for multiple species and years can be found in the Council's Strategy Performance Indicators (SPI's).

References

2022 FPP: https://pweb.crohms.org/tmt/documents/fpp/2022/final/FPP22_Final_08-11-22.pdf

2022 CSS: https://www.fpc.org/documents/CSS/CSS%20Final%20Revised%202022.pdf

2023 U.S. Government Commitments in Support of the "Columbia Basin Restoration Initiative" and in Partnership with the Six Sovereigns: https://earthjustice.org/wp-content/uploads/2023/12/snake-river-litigation-usg-commitments.pdf

Transportation

Since the beginning of the Council's Fish and Wildlife Program, transportation has been accepted as a strategy to be implemented only when in-river migrant survival is unacceptably risky or low for juvenile salmon and steelhead. Three dams on the Snake River- Lower Granite, Little Goose, and Lower Monumental- are currently equipped with facilities that permit the collection and transport of migrating salmon. Until 2013, juvenile fish were also collected and transported at McNary Dam on the lower Columbia River.

Summary of implementation

Transportation generally begins in April, though start dates have shifted over time (CSS 2022). The percentage of fish transported each year has also changed and is generally lower now than in the 1990s through the early 2000s (Figures 18 and 19). Studies are continuing to evaluate the benefits of transportation on juvenile survival and adult returns. More detailed information on the transportation program, changes over time, and effects on salmon can be found in annual reports from the Fish Passage Center, the Comparative Survival Study, USACOE annual Fish Passage Plans, and NOAA/NMFS Annual Survival Estimate Reports.

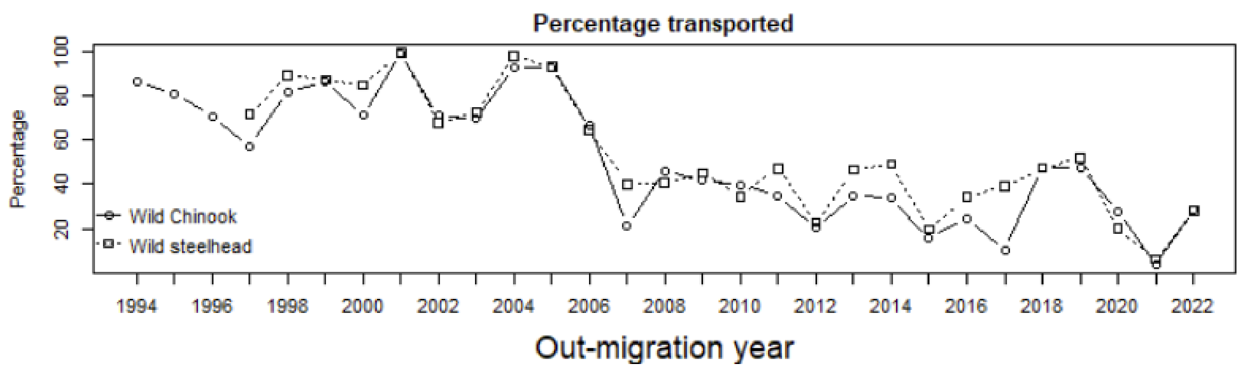


Figure 18. Proportion of wild Snake River stocks transported 1994-2022 included in the 2022 CSS Annual Report. Note: the proportion of wild Chinook and Steelhead transported for migration year 2022 was estimated for this report

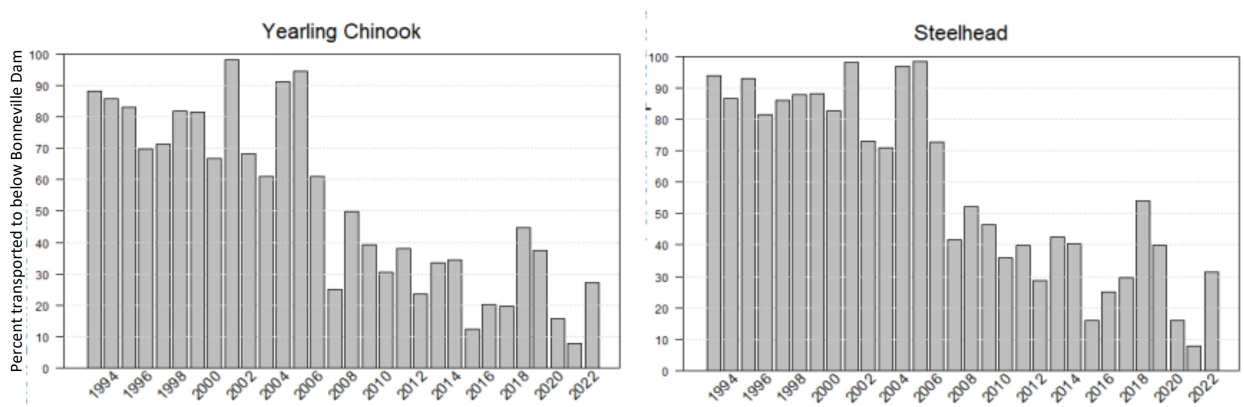


Figure 19. Annual estimates of the percentage of yearling Chinook salmon and steelhead smolts (mean of estimates for hatchery and wild smolts) that arrived at Lower Granite Dam that were subsequently transported, either from Lower Granite Dam or downstream from Little Goose or Lower Monumental Dam to below Bonneville Dam (1993-2022). From annual NOAA/NMFS report.

Discussion

Transportation has decreased in frequency for both yearling Chinook and juvenile steelhead. Transportation continues to be a strategy to encourage juvenile survival in situations where downstream passage is unavailable or considered a higher risk for mortality. The Program has continued to call for research and innovations to improve in-river downstream passage whenever possible.

An average of 33% of the Snake River spring Chinook and 35% of the Snake River steelhead runs have been transported in recent years. Before 2008, those stocks were transported at an average rate of 75% and 83% respectively. Spill through surface passage increases the proportion of fish migrating in-river, which is preferred to transportation methods. The installation of surface passage structures in spillways, operational changes that attract fish to the spillways, and variable arrival timing of juveniles have all contributed to the reduced transportation rates.

Transportation data for contemporary years can be found in the Council's [Strategy Performance Indicators (SPI's) .](#) Figure 20 is an example of the data and graphs for the Transportation SPI.

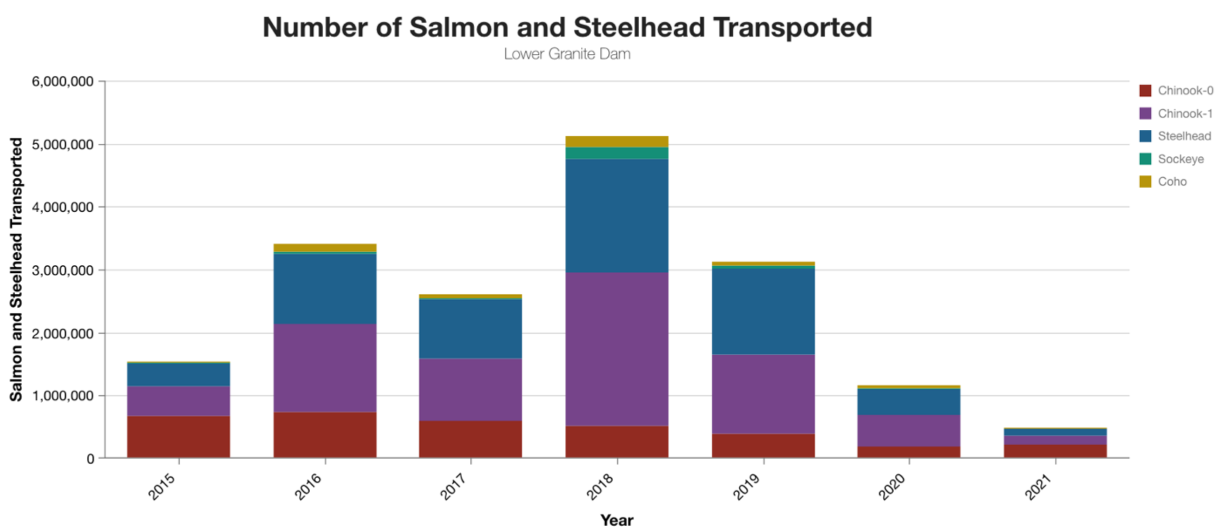


Figure 20. Number of Salmon and Steelhead Transported at Lower Granite Dam 2015-2021

References

Fish Passage Center. 2023. Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye 2023 Annual Report:https://www.fpc.org/documents/CSS/CSS%20Final%20Report%20Revised.pdf

Northwest Fisheries Science Center. 2022. Preliminary survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs: https://pweb.crohms.org/tmt/agendas/2022/1116_2022_Preliminary_Survival_Estimates_Memo_finalv2.pdf

NOAA. 2021. Survival Estimates for the Passage of Spring-Migrating Juvenile Salmonids Through Snake and Columbia River Dams and Reservoirs: https://repository.library.noaa.gov/view/noaa/49078/noaa_49078_DS1.pdf

US Army Corps of Engineers Annual Fish Passage Plans: https://pweb.crohms.org/tmt/documents/fpp/

Adult migration of anadromous species

Mitigation actions in the Program intended to aid adult migration of anadromous species aim to (1) improve migration conditions for salmon and steelhead in the mainstem through managing flow and reservoir elevation, maintaining suitable temperatures, installing and operating adult passage structures and trap-and haul, and (2) improve migration conditions for other native species in the mainstem through managing flow, and designing, installing, and operating lamprey-specific passage structures (benefiting all life stages of lamprey), providing passage for bull trout at Albeni Falls, and installing structures to minimize the entrainment of sturgeon.

Salmon and steelhead

Table 4. Hydrosystem measures in the Council's Fish and Wildlife Program, and other external agreements guiding flow, temperature, and passage for adult salmon and steelhead, 1982 – 2020

Program	Seasonal Flows – Summer Flows and Flow Augmentation	Temperature Management	Passage
1982			**Fishway operations** U.S. Army Corps of Engineers shall implement existing criteria for all USACOE projects on the Columbia River. FERC shall require Grant, Chelan, and Douglas County PUDs to conduct studies and develop fishway operating criteria for optimum fish passage for the Fishway operating mid-Columbia project(s).
1992	**Secure water in spring and summer management period**	**Reservoir operations** Release cool water during August and	

	Provide 427 Kaf of water from the Upper Snake River Basin through the use of uncontracted storage and water marketing to augment flows in the lower Snake River for both spring migrants and summer flow augmentation[1] for temperature reduction.	September from both Dworshak and Hells Canyon Complex dams to reduce lower Snake River water temperatures. Evaluate methods for decreasing water temperature in mainstem fish ladders and apply. Start of September, release up to 200 KAF of cool water from Dworshak Reservoir, as needed for the temperature control evaluation.	
1994	**Average monthly flow equivalents at Lower Granite Dam** The flow level required to achieve the same water particle travel time as an equivalent flow at normal average pool elevations at all projects. • 50 KCFS at Lower Granite Dam. **Reservoir operations** Allow Dworshak to draft to elevation 1,520 feet by the end of July, if needed to assist in meeting the summer basin flow and velocity objectives. Allow Grand Coulee to draft to an elevation of 1,280 feet by the end of August, if needed to meet the summer flow objective.		**Fish passage facilities** Upgrade existing adult passage facilities including additional adult ladders, increased attraction water for fish ladder collection channels and entrances, adult fishway modifications and improvements.
2003	**Seasonal average flow target ranges or point targets[1]** Lower Granite and McNary Dams • Lower Granite (50-55 KCFS) and Priest Rapids target set at 200 KCFS. **Reservoir operations** Draft Lake Roosevelt evenly to target no lower than 1283 feet by the end of August.		**Fish Passage Improvements** Expedite schedules to design and install improvements to fish passage facilities, install adult PIT tag detectors, improve fish counting.
2009	**Reservoir operations** Operate Dworshak Dam consistent with the provisions of the 2008 FCRPS Biological Opinion. Draft Dworshak to elevation 1,535 feet by the end of August and to elevation 1,520 feet by the end of September, unless		

	modified per the agreement between the United States and the Nez Perce Tribe. Subject to in-season management, draft Lake Roosevelt to the target elevations of 1,278 or 1,280 feet by the end of August. **Secure water in spring and summer management period** Provide up to 487 KAF of water from the BOR projects consistent with the NOAA Fisheries' 2008 Upper Snake Basin BiOp and the NPT Water Rights Settlement Agreement.		
2014/2020	**Continue seasonal average flow target ranges or point targets** Lower Granite and McNary. *Aligned with Biological Opinions.* Continue Upper Snake River Flow Augmentation[1] *Aligned with Biological Opinions*		**Fish Passage Improvements** Improve adult fish passage facilities at mainstem dams, install adult PIT tag detectors, improve fish counting.

[1] Seasonal average flow targets and Snake River Flow Augmentation discussed in Chapter 1. The year listed is the first time a measure appears in a Fish and Wildlife Program.

Summer flows

Summer flows were first called for in the 1990s by the Council's Fish and Wildlife Program as average monthly flow equivalents. They now mirror the spring framework of seasonal average flow target ranges or point targets. Summer flow targets are met less frequently than spring flow targets due to competing priorities, including providing flows to move juvenile migrants downstream during the spring season. In years both pre- and post-BiOp adoption, the chance of meeting or exceeding summer flow targets at Lower Granite Dam has been 27-28% since 1975 (Figure 21).

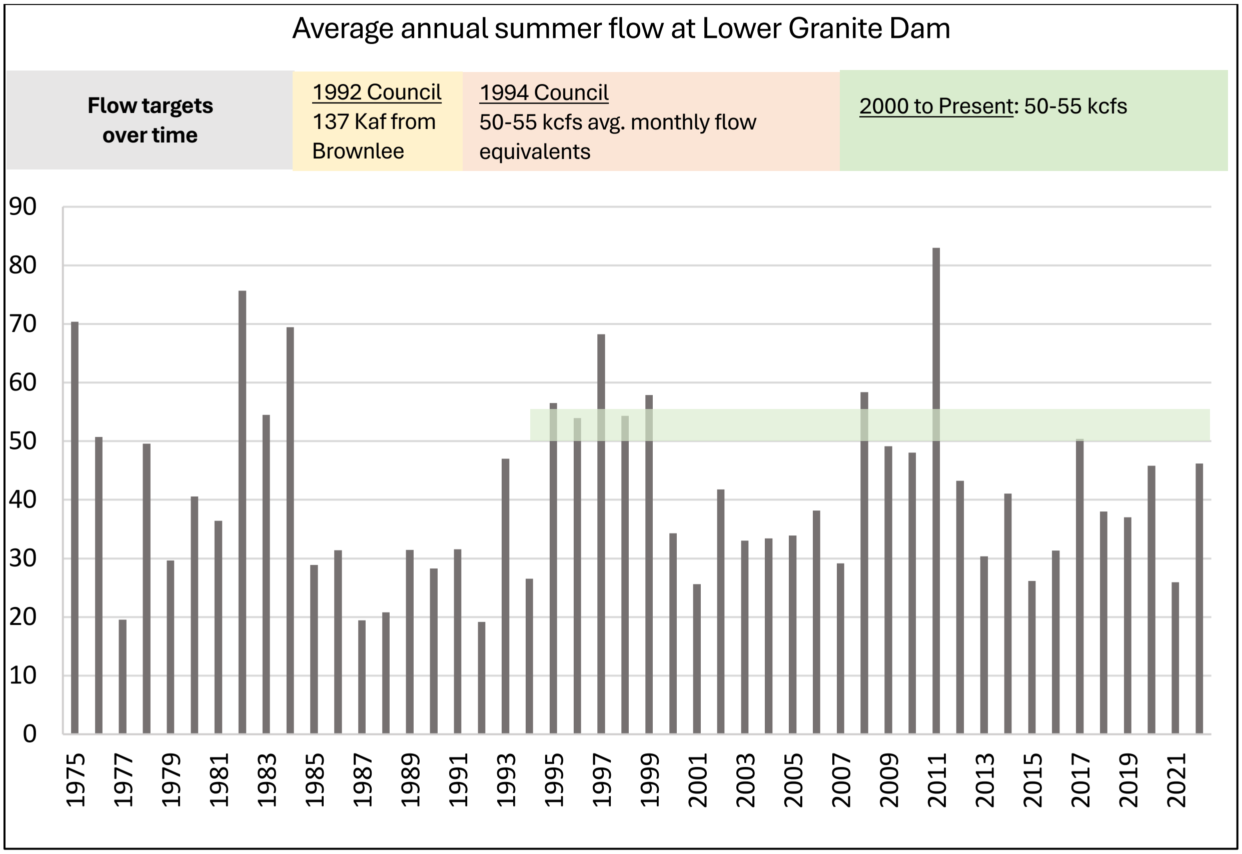


Figure 21. Average annual summer flow at Lower Granite Dam with timeline of target flows. The contemporary average summer flow target at Lower Granite Dam is 50-55 kcfs

Across all years since 1975, the chance of meeting or exceeding summer flow targets at McNary Dam has been 24%. Since the 1994 BiOp, the chance of meeting of exceeding summer flow targets has been 21% (Figure 22).

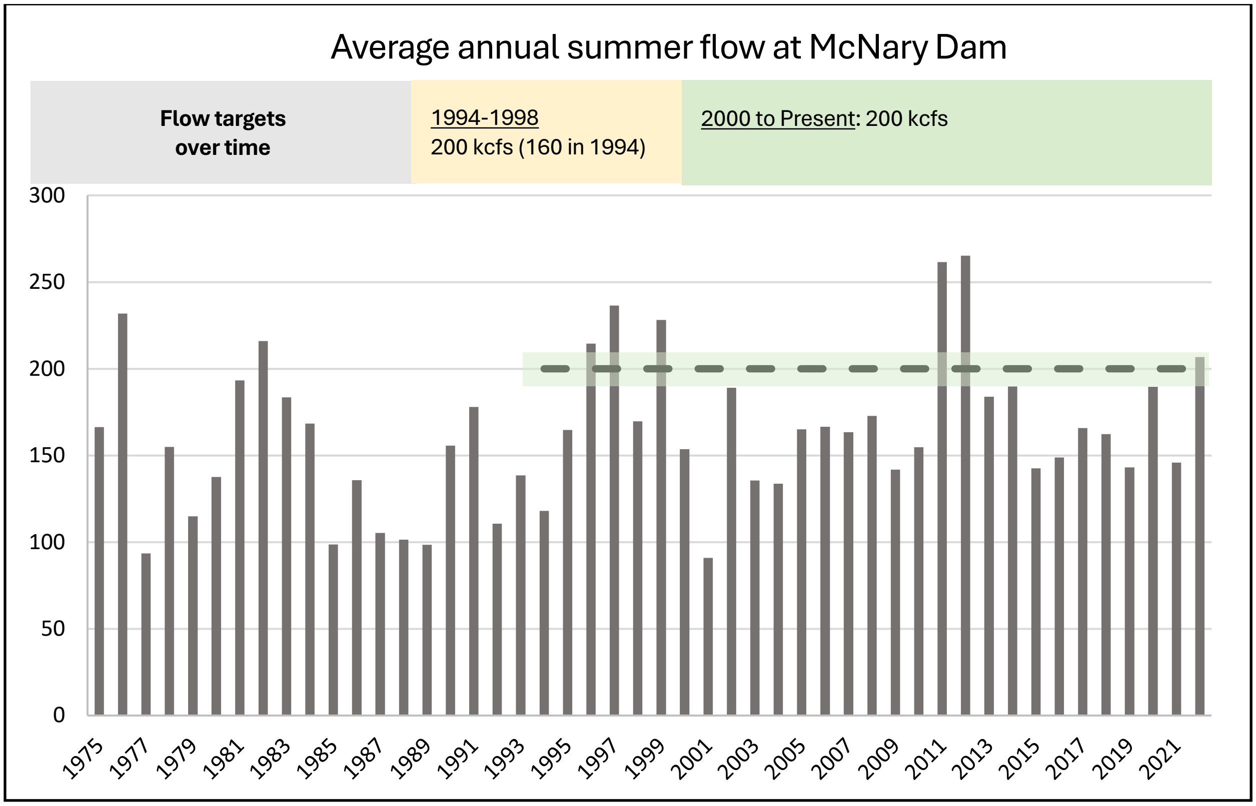


Figure 22. Average annual summer flow at McNary Dam with timeline of target flows. The contemporary average summer flow target at Lower Granite Dam is 200 KCFS

Summary of implementation

To meet summer basin flow and velocity objectives, water is drafted from upstream reservoirs including Grand Coulee (Lake Roosevelt) and Dworshak Dams.

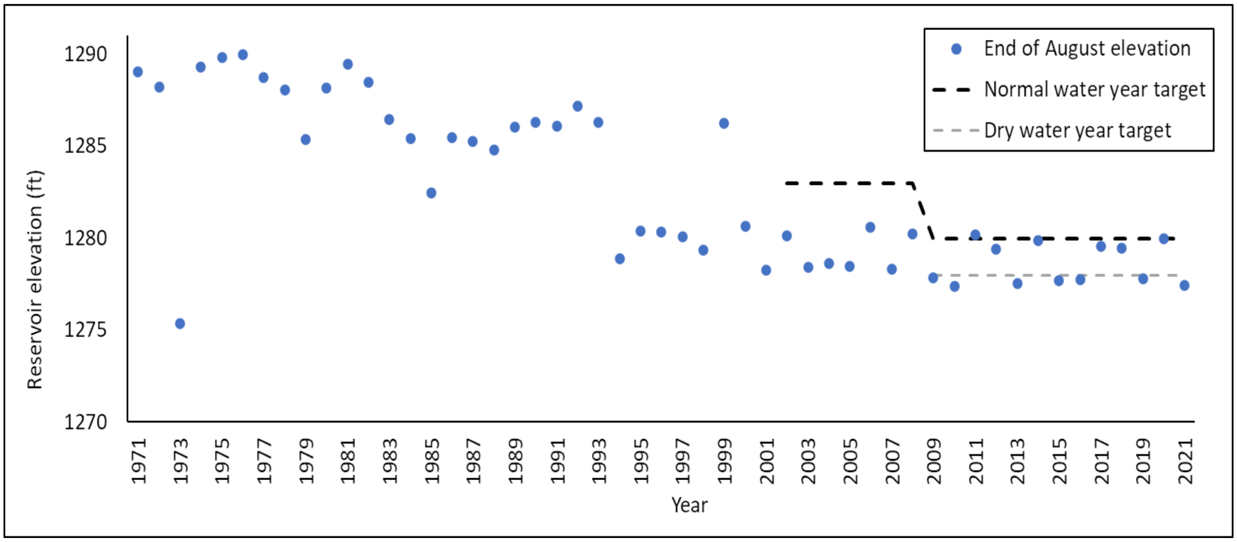


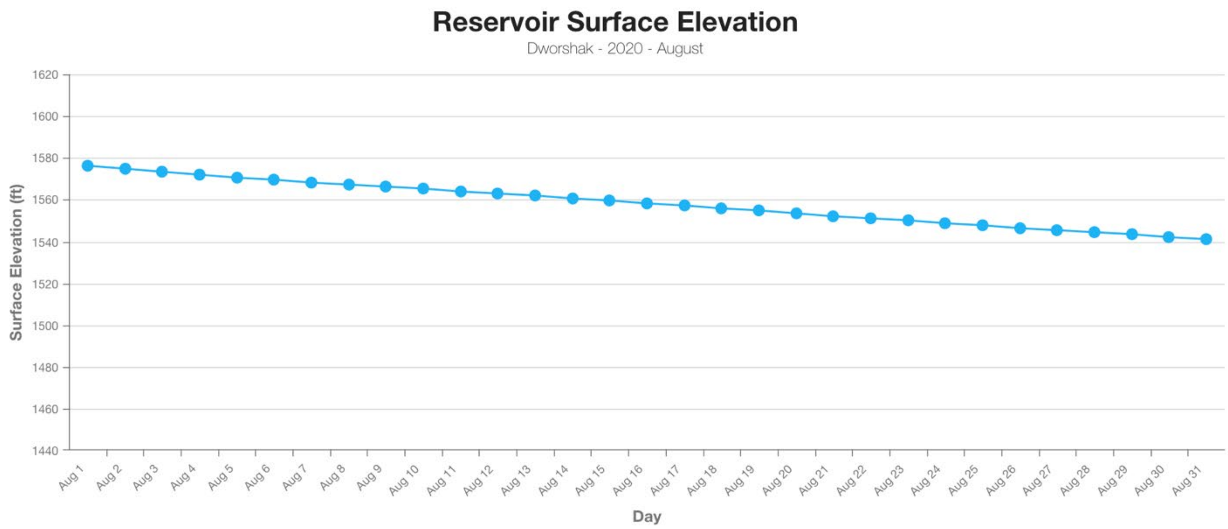
Figure 23. Reservoir elevation (ft; blue dots) at the end of August relative to draft limit (black dash), at Lake Roosevelt, Grand Coulee Dam, 1971 – 2021. Beginning in 2003, the Program called for drafting evenly to, but not below, the draft limit of 1283 ft. In 2009, the Program was amended to call for a draft limit of 1278-1280 ft, reflecting an operational change that had already been implemented

Beginning in 2003, the Program called for even drafting at Lake Roosevelt to the end of August elevation, while remaining above 1283 feet. In 2009, the Program was amended to call for an end of August elevation of 1280 ft in normal water years, and 1278 in dry years. That operation was already in place and the 2009 amendment brought the Program in line with management. While the 1283 standard was never met, the 1280 or 1278 standard is more frequently met. Moreover, elevation changes from the end of June to the end of August have been gradual, as required.

Discussion

Over time there has been a decrease in the end of August target elevations at Lake Roosevelt. The first decrease in elevation occurred around the time the water budget was first initiated. The second, larger decrease in elevation occurred in conjunction with ESA-listings and further mandates for flow augmentation.

To provide summer flows and manage downstream temperatures, the Program has called for target end of summer elevations at Dworshak Dam. In these SPI examples from 2020 (Figure 24), you can see Dworshak Dam operations meeting the target of 1,535 feet elevation by the end of August and 1,520 feet elevation by the end of September.



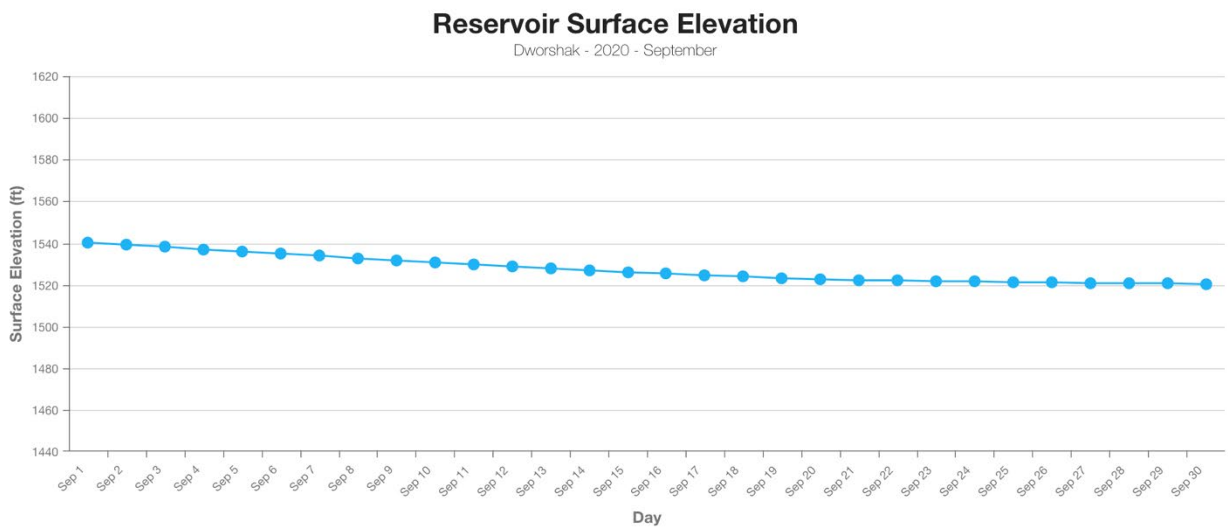


Figure 24. Reservoir elevation data for contemporary years can be found in the Council's Strategy Performance Indicators (SPI E3-5)

Temperature management

Since the early 1990s Dworshak has been operated to control temperature at Lower Granite Dam, with a target temperature at the dam of 68° F (20°C). Typically, target water release temperatures have varied from 48°F (8.9°C) to 51° F (10.6°C) during July and August. The target water temperatures are selected as a balance between fish production at the downstream Dworshak National Fish Hatchery and anadromous fishery needs in the lower Snake River. Cool summer releases from Dworshak Dam typically contribute from 25 to 45% of the Snake River flow. High flows in July and August are desirable to downstream migrants, while high flows and low temperature are best for adult fall Chinook in September (EPA, 2003).

Temperature data for contemporary years can be found in the Council's Strategy Performance Indicators (SPI's).

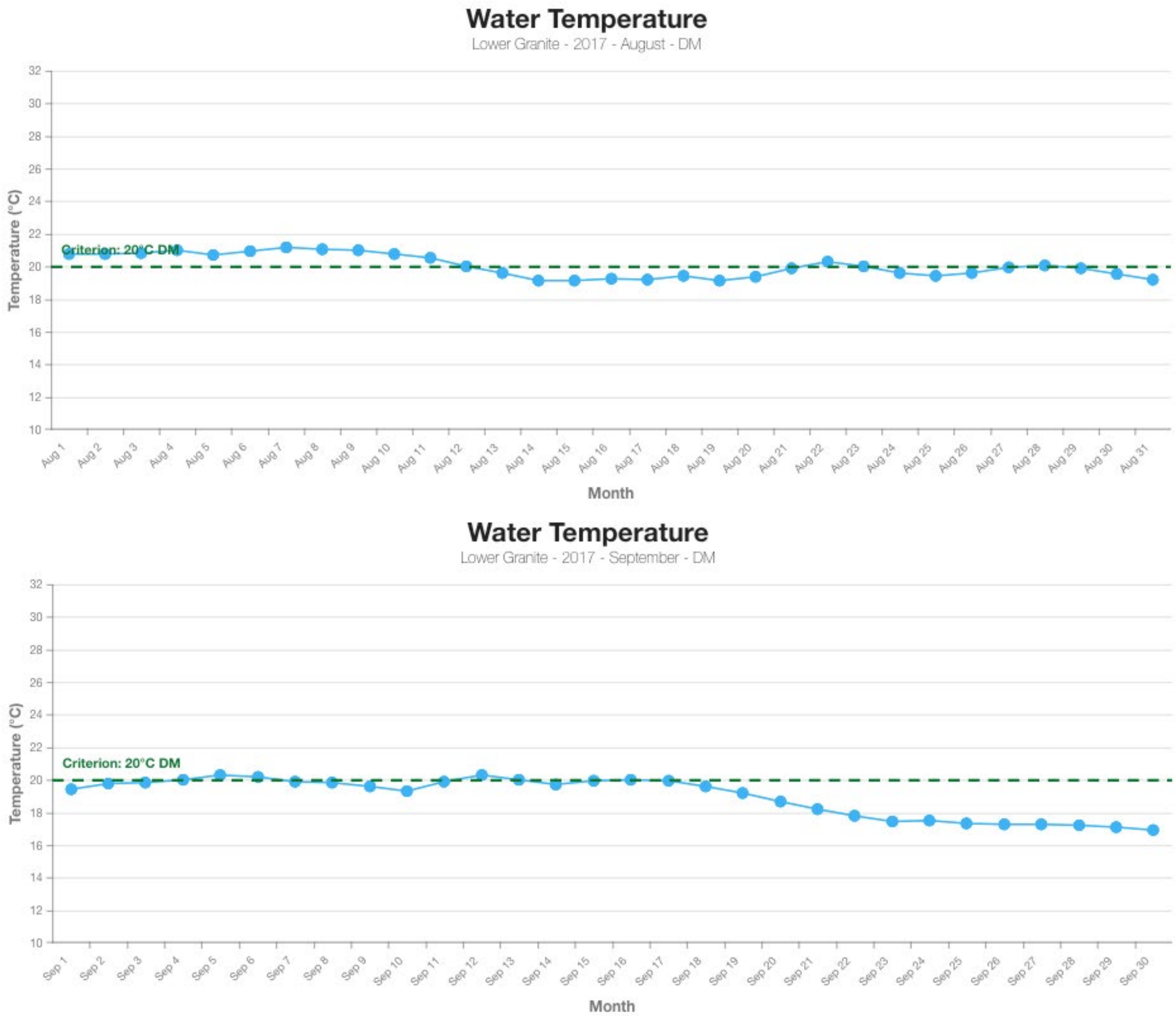


Figure 25. Reservoir surface temperatures at Lower Granite Dam in August and September during 2017. SPI: E2-2 and E2-4

Of note is that the 2017 August reservoir elevation was lower than some years. The temperature criterion of 20°C was exceeded for part of August before dropping again. Temperature decrease patterns are directly related to the upstream release of water from behind Dworshak Dam in the same months.

Discussion

Temperature management is a crucial way to improve migration conditions for adult migrants often traveling long distances from the ocean back to spawning grounds, especially for those prioritized by the Program traveling above Bonneville Dam. As climate change continues to be a growing concern in conjunction with changing hydropower operations, the need for cool water will continue. The region has already observed the devastating consequences of extreme hot weather events when they overlap with the peak of an adult return. For example, in 2015 a combination of drought conditions and unusually warm weather led to half of the anticipated sockeye run dying before having a chance to spawn. Other species such as sturgeon were also negatively impacted by this isolated event but situations like this could become more frequent in the future. Because cool summer releases from Dworshak Dam typically contribute from 25 to 45% of the Snake River flow, they will likely continue to play a role in a changing basin.

References

DART. 2021. DART - Columbia River DART, Columbia Basin Research, University of Washington. Columbia Basin Conditions.

Environmental Protection Agency. 2003. EPA: A Preliminary Analysis of the Thermal Regime of Dworshak Reservoir, 2003

NPCC. 2015. Warm Water Blamed for Huge Columbia River Sockeye Die-off.

Passage structures and operations

Figure 11 shows the areas that are currently accessible to salmon and steelhead. Improvements to passage at dams with existing adult passage structures have continued to occur over time. These improvements include modifications to ladders, flow releases and structural changes to decrease water temperatures in the ladders, and sea lion excluder devices (SLEDS). Additionally, counting facilities have improved to support efforts to improve fishway conditions and increase passage success.

Starting in 1982, the Council called for the USACOE to implement existing criteria for all USACOE projects on the Columbia River. Since 2001, the USACOE has invested $1.8 billion in fish passage improvements at the FCRPS dams which has resulted in significant survival improvements. Some examples of new and modified actions include additional ladders installed to give fish options or in the case that one ladder fails or is closed for maintenance, automated monitoring systems to avoid handling, and temperature reduction in the ladders during warm parts of the year.

The Council also called for FERC to require Grant, Chelan, and Douglas County PUDs to conduct studies and develop fishway operating criteria for optimum fish passage for the operating mid-Columbia project(s).

References

CRITFC, 2014. Spirit of the Salmon - Adult Fish Migration. https://plan.critfc.org/2013/spirit-of-the-salmon-plan/technical-recommendations/adult-salmon-passage/

PNNL, 2006. Optimizing Dam Operations for Power and for Fish. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-SA-51033.pdf

Salmonrecovery.gov, 2022. Documents and Reports.
https://salmonrecovery.gov/crtf.html#panel-docs

Pacific Lamprey

Different types of passage structures are needed for lamprey, which pass dams by creating suction with their mouths against structures and working their way up and over (as opposed to swimming up ladders). Although research needs for lamprey passage at mainstem Columbia River dams were called for as early as the 1994 Fish and Wildlife Program, significant changes in lamprey management followed the signing of the 2008 MOA under the Columbia Basin Fish Accords which guaranteed at least 10 years of research and passage improvements (USACOE, 2018). Pacific lamprey abundance reached historic lows in the Columbia Basin between 2009-2010, which prompted discussions about the need for state and federal protections (USFWS, 2012). Since 2013, activity has been focused on the Lamprey Conservation Agreement Regional Implementation Planning Conservation Team (CT), the USFWS Pacific Lamprey Data Clearinghouse, and efforts to improve mainstem adult passage by the USACOE and others.

Table 5. Hydrosystem measures in the Council's Fish and Wildlife Program, and other external agreements guiding passage for Pacific lamprey, 1982 – 2020. Rows in italics describe measures referenced and implemented as mitigation through the Program that were first described in external documents. The year listed is the first time a measure appears in a Fish and Wildlife Program.

Program	Passage	General Measures
1994	**Call for research** Evaluate needs for passage.	
2004	**Assess and improve passage** through mainstem and tributary dams, culverts, irrigation diversions, flow and thermal barriers, etc. for all life stages.	Assess abundance, biology and ecology, genetic structure, habitat requirements, and need for restoration activities.
2009	**Identify structural improvements** Improve adult Pacific lamprey passage survival and reduce delays in migration by identifying specific fish passage structures and developing and implementing lamprey passage aids at known obstacles. ***2008 MOA Columbia Basin Fish Accords - USACOE*** *Guarantee at least 10 years of research and passage improvements.*	**Monitoring** Evaluate lamprey passage at mainstem hydropower dams to inform passage improvement actions and to identify passage problem areas.
2014/2020	**Install lamprey-friendly passage structures**	**Improve lamprey fish counting**

	Both adult and juvenile lamprey. Implement improvements to adult fish passage facilities at mainstem dams. Install adult PIT tag detectors. ***2013 Pacific Lamprey Conservation Agreement***	

The enumeration of adult lamprey at mainstem Columbia River Dams is one way that passage improvements (including lamprey specific passage structures and trap and haul methods) have seen increased efficiency over time. Lamprey are typically more active at night and the USACOE has monitored nighttime passage at count windows using video technology. Due to concerns about the quality of nighttime count data, Figure 26 excludes said counts. As such, passage estimates shown in this report should be considered minimum estimates. Lamprey were not consistently counted at Columbia River System (FCRPS) dams from 1970-1998 (Starke and Dalen 1995 as cited in Keefer et al. 2009). Currently, the Fish Passage Center provides about 50% of the reported counts, DART another 25% of counts, and the Lamprey Passage Structures provide additional numbers.

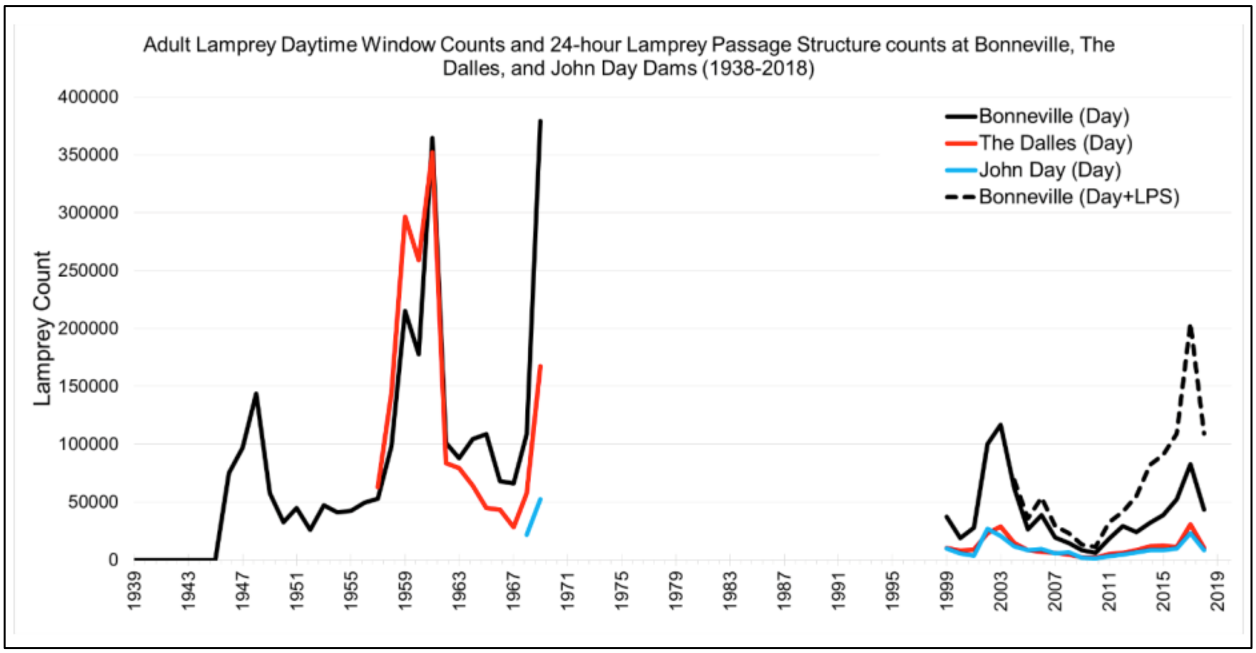


Figure 26. Estimated number of adult Pacific lamprey passing count station windows within fish ladders (daytime only) and Lamprey Passage Structure (LPS) passage estimates. No DART counts included.

Improvements to lamprey passage at mainstem dams are ongoing. Some examples of how traditional fish ladders are modified include rounding corners, the installation of plating in problem areas to allow lamprey to attach and rest, and the installation of small refuge boxes on the fish ladder floors to provide resting areas. In addition, modifications to gratings on fish ladder floors to keep lamprey from entering dead-end areas are important. More recently, specific Lamprey Passage Structures (LPS) have been installed at some dams to target the species. These ramp-like flume systems help move adult Pacific lamprey around passage bottlenecks characterized by high velocity and turbulent flows. In addition, managers have worked to get LPS installed away from salmon attractants and closer to intuitive entrances for Lamprey when they noticed that lamprey were going through picket leads and ending up in auxiliary water channels. They are also working with the USACOE to lift picket leads by 1.5” to encourage lamprey to use these channels more than previously. Paired with the LPS structures are design features that improve fishway entrance success and conditions within the fishways themselves (USACOE, 2018). This aerial map (Figure 27) of Bonneville Dam highlights lamprey specific passage systems in addition to the standard fish ladders that are included.

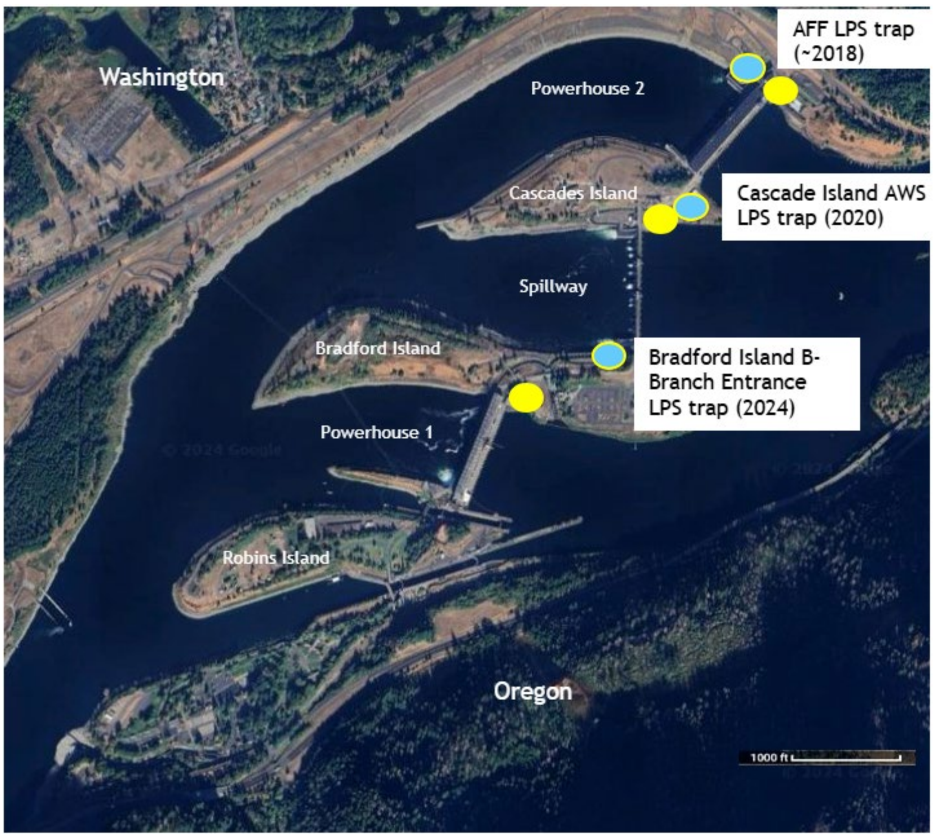


Figure 27. Location of Lamprey-specific passage systems at Bonneville Dam

To understand the impacts of improved passage structures and monitoring, passage investigations using radiotelemetry, PIT tags, and video and acoustic imaging have been conducted since 2008. These studies have helped to prioritize future fishway modifications and report passage efficiencies at the lower Snake River dams (Stevens et al., 2014).

Summary of implementation

The enumeration of lamprey passing mainstem dams has varied over time. Counting has been more consistent since 1996, although it is still considered incomplete overall due to counting times and data quality issues and is therefore considered a minimum count at Bonneville, The Dalles, and John Day dams. Importantly, Lamprey Passage Structures allow lamprey to be collected and transported upstream of the dam and are therefore not captured in passage indices (counts) (USACOE, 2018). This could be a space for improvement both for on-the-ground counting and in the Council's Strategy Performance Indicators.

The hydraulic requirements for lamprey have been studied in the past 10 years through the efforts described above, which has led to a better understanding of the swimming modes and capacities of lamprey in relation to the hydraulic, structural, and biological conditions encountered in fishways (USACOE, 2015).

Discussion

Since 2008, there have been large improvements in structures and counting methods at mainstem dams in the Columbia River to benefit Pacific lamprey. Generally, counts have trended upward at Bonneville Dam, but overall passage indices have not changed appreciably. Bottlenecks are still occurring at the upstream extent of the fishways and fishway entrances continue to be a challenge for the fish. Although many of the structural improvements in the Columbia have been widely adopted, there is much more work to be done as funding becomes available.

References

Stevens, P., I. Courter, C. Peery, and C. Caudill. 2015. Evaluation of adult Pacific lamprey passage at lower Snake River Dams, 2014. Final report to the U.S. Army Corp of Engineers, Walla Walla District. Walla Walla, WA.

USFWS, 2012: U. S. Fish and Wildlife Service. 2012. Conservation agreement for Pacific lamprey in the states of Alaska, Washington, Oregon, Idaho, and California. Retrieved from U.S. Fish and Wildlife Service; https://www.fws.gov/pacificlamprey/AgreementMainpage.cfm.

USACOE, 2015: Design Guidelines for Pacific Lamprey Passage Structures: https://www.pacificlamprey.org/wp-content/uploads/2022/02/Zobott-et-al-2015-5-LPS-Design-Criteria_FINAL.pdf

USACOE, 2018: Summary Report: Columbia Basin Fish Accords Pacific Lamprey Passage Improvements: 2009-2018

Mainstem spawning and rearing (salmon)

The purpose of mainstem spawning and rearing actions for salmon in the Program is to improve spawning and rearing conditions below mainstem dams through management of flow and ramp rates during (1) spawning, (2) incubation, and (3) emergence. We reviewed mainstem spawning and rearing measures meant to benefit fall Chinook salmon in the Hanford Reach and chum salmon (listed in 1999) in the Columbia River below Bonneville Dam. Implementation of these measures is guided by Water Management Plans and subject to in-season management and input from managers.

Hanford Reach – Fall Chinook

Prior to construction of Priest Rapids Dam in 1961, the local hydrograph was similar to elsewhere in the Columbia River – a large peak flow in June and low flows throughout the rest of the year (Figure 28). After construction, the peak flow was reduced and winter flows were increased (Figure 28). In the early years of operation, power peaking and flow fluctuations at that dam degraded spawning and rearing conditions for fall Chinook salmon in the downstream, free-flowing Hanford reach. Dewatering occurred post-spawning, resulting in egg desiccation and very low juvenile production. In the 1970s, the Grant County PUD funded studies (e.g., Chapman et al. 1983) on how flow controls might benefit the fall Chinook spawning and rearing in the Hanford reach. These studies were subsequently called for in the Fish and Wildlife Programs and resulted in the Vernita Bar Settlement Agreement (VBSA 1988) and subsequent Hanford Reach Fall Chinook Protection Program Agreement (HRCPPA 2004).

Table 6. Hydrosystem measures in the Council's Fish and Wildlife Program, and other external agreements guiding mitigation for Hanford Reach Fall Chinook Salmon, 1982 – 2020

Program	Hanford Reach Fall Chinook
1982 – 1984	**Call for studies to determine the effect of varying flows on the spawning, incubation, and rearing of fall chinook salmon.**
1987	**Develop a flow plan to protect natural propagation of fall chinook salmon on Vernita Bar in the Hanford Reach.**
1988 Vernita Bar Settlement Agreement (VBSA)	*Formalizes protections for spawning Chinook Salmon and egg incubation* *-Spawning period- minimize formation of redds above 70 KCFS* *-Incubation period – minimum flows based on observed spawning elevation*
2003	Suitable and stable flows

2004 Hanford Reach Fall Chinook Protection Program Agreement (HRFCPPA)	*Expands VBSA protections to include emergence and rearing* *-Emergence period–maintain water over Vernita Bar above elevation where spawning occurs* *-Rearing period- limit flow fluctuations to reduce stranding*
2009 – 2020	**Continue to implement HRFCPPA**

Rows in italics describe measures referenced and implemented as mitigation through the Program that were first described in external documents. The year listed is first time measures appear in a Fish and Wildlife Program.

Summary of implementation

Operations for Hanford Reach Fall Chinook focus on four life stages: spawning, incubation, emergence, and rearing (Figure 28). For the first stage, a critical elevation for flow is established to minimize formation of redds in gravel beds that become wetted when flows exceed 70 KCFS. This prevents egg desiccation at these higher elevation beds, later in the year. In the next stage, minimum flow levels are established at the highest level where spawning occurred to protect eggs during incubation. These flow levels are carried through the emergence period. In the rearing period, flow constraints are imposed to limit daily flow fluctuations so that juveniles do not become stranded. These four operations occur from approximately Oct 1 – mid June (Figure 28). Since their implementation, the hydrograph in the Hanford reach has a more naturally timed, albeit lower, peak flow and elevated winter flows, along with constrained daily fluctuations.

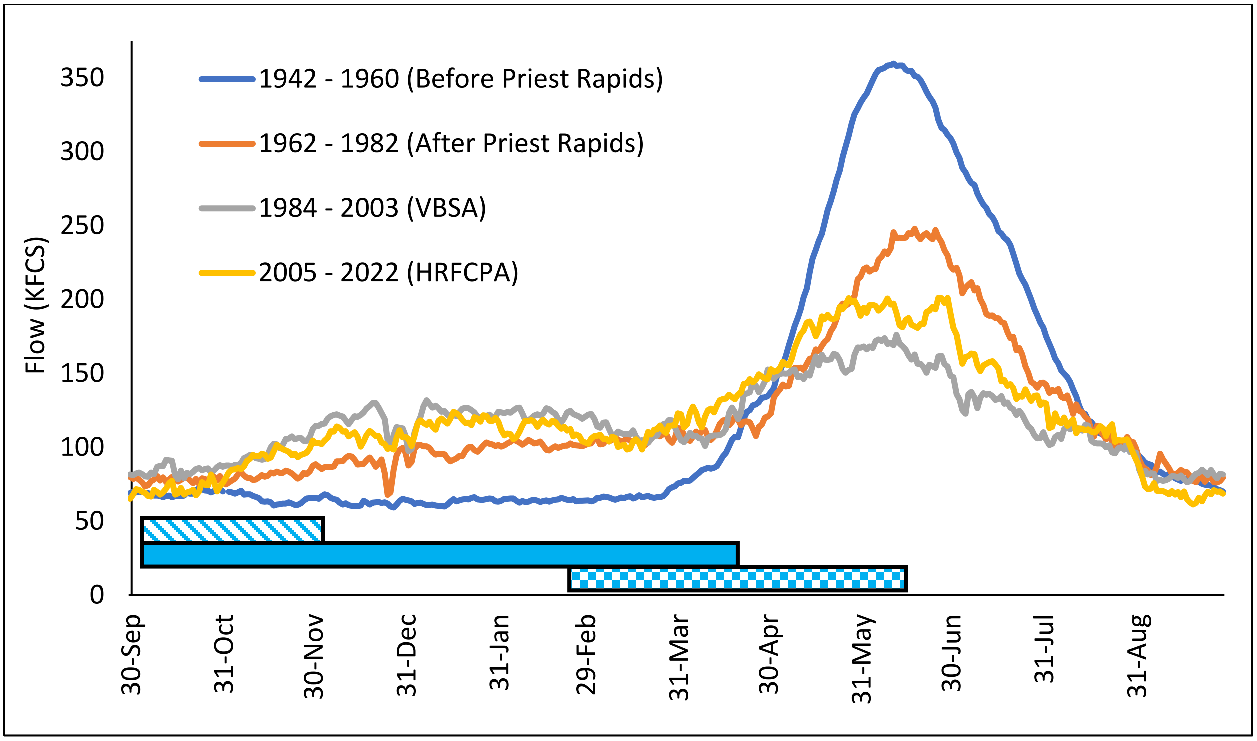


Figure 28. Average daily flows at Priest Rapids Dam (USACE Gage PRD) during four time periods: prior to construction of Priest Rapids Dam (1942 – 1960; blue line), after construction of Priest Rapids but before protective flows for Fall Chinook were in place (1962 – 1982; red line), during flow operations guided by Vernita Bar Settlement Agreement (VBSA, 1984 – 2003; grey line), and during contemporary operations guided by Hanford Reach Fall Chinook Protection Agreement (HRFCPA, 2005 – present, yellow line). Flows are shown relative to approximate management periods for Fall Chinook: spawning (blue dashed bar), incubation (blue solid bar), and emergence/ rearing (blue checkered bar).

From 1988 – 2021, the critical elevation for spawning flows has ranged from 50 to 70 KCFS, with 70% of years having elevations set at flows ≥ 65 KCFS. The highest redd counts occur in years with these critical elevation levels.

Since 2004, there has been an increase in the percent of daily flow constraints met each year during rearing and emergence, ranging from 64.4% met in 2004, to > 97% consistently met since 2012.

Discussion

Implementation of flow controls from spawning through emergence is meant to increase the amount of spawning habitat that remains inundated, thus increasing egg survival and juvenile production. Harnish and Hoffarth (2022) evaluated freshwater productivity in the Hanford Reach, beginning prior to implementation of VBSA and extending to the present. Over this period, production of juveniles (surviving through the rearing stage) increased from an average of 14 million annually (prior to flow controls) to over 52 million annually.

Harnish and Hoffarth (2022) further estimated that current production exceeds juvenile carrying capacity, noting that competition for limited resources appears to limit smolt size and results in lower survival in the ocean to age 2. They proposed that management to limit high escapement could produce larger smolts that survive better in the ocean. In combination with favorable ocean conditions, this could result in more adults returning to the basin.

References

Chapman, D. W., D. E. Weitkamp, T. L. Welsh, and T. H. Schadt. 1983. Effects of Minimum Flow Regimes on Fall Chinook Salmon Spawning at Vernita Bar 1978 - 1982. Report to Grant County Public Utility District No. 2, Doc. No. 83-0715-0080, prepared by Don Chapman Consultants, Inc., McCall, Idaho, and Parametrix Inc., Bellevue, Washington. 123 pp. (Available at Columbia Basin F&W Library).

Data on critical elevations and flow constraints from annual report by Grant County PUD: https://www.grantpud.org/templates/galaxy/images/2022_Hanford_Reach_Fall_Chinook_Salmon_Protection_Program_Report_For_the_2021-2022_Protection_Season_2.pdf

Hanford Reach Fall Chinook Protection Agreement- Accessed online at: https://pweb.crohms.org/tmt/documents/wmp/2006/draft/app7.pdf

Harnish, R.A. and P. Hoffarth. 2022. Hanford Reach Fall Chinook Salmon Productivity Analysis, Brood Years 1975-2016. Available from: https://www.researchgate.net/publication/368533886_Hanford_Reach_Fall_Chinook_Salmon_Productivity_Analysis_Brood_Years_1975-2016#fullTextFileContent [accessed Dec 14 2023]."

Vernita Bar Settlement Agreement 1988. Approved by FERC on Dec 9, 1988.

Columbia River below Bonneville Dam – Chum Salmon

Chum salmon were listed as threatened under the ESA in 1999 (NMFS 1999). There are only two stable populations of chum salmon in the Columbia Basin, one of which spawns in the mainstem and tributaries downstream of Bonneville Dam in November and December. When flows are too low, spawners cannot access certain tributaries and there is reduced mainstem spawning habitat available. Researchers have identified minimum flow levels required to maintain tributary access and keep mainstem habitat watered throughout the spawning, incubation, and emergence periods. Implementing these flows requires sufficient water be available at Grand Coulee, which also provides water earlier in the year for juvenile salmon and steelhead and Hanford Reach Fall Chinook.

Table 7. Hydrosystem measures in the Council's Fish and Wildlife Program, and associated BiOp measures guiding mitigation for threatened chum salmon below Bonneville Dam, 1982 – 2020

Program	Chum salmon below Bonneville Dam
1994	**Call to identify populations of chum salmon and adopt rebuilding targets.**
2000 BiOp	*Water releases to protect spawning and incubating chum salmon in the Columbia River below Bonneville Dam.* • *Spawning- releases begin Nov 1; objective = 125 KCFS.* • *Incubation- winter and spring protection flows.* *Flow levels contingent on sufficient water supply to maintain tailwater elevation through incubation and emergence.*
2003	**Operate Grand Coulee to implement chum salmon seasonal flows.** Adopt 2000 BiOp actions as measures in Program.
2004 BiOp, 2008 BiOp	*Specific tailwater elevations for spawning (and access to tributaries), incubation, and emergence; operations coordinated through TMT.*
2009 -2020	Adopt 2004/8 BiOp actions as measures in Program.
2020 BiOp	• *Spawning – if water supply sufficient, provide Bonneville Dam tailwater elevation of ~ 11.5 feet beginning first week of Nov (or when spawners arrive) and ending late Dec; maintain tailwater elevations between 11.3 – 13.0 feet during chum salmon spawning on Ives/Pierce Islands.* • *Incubation and emergence – tailwater elevation set in late Dec based on observed redd depth and forecasted ability to maintain tailwater elevation through Apr 10.*

Rows in italics describe measures referenced and implemented as mitigation through the Program that were first described in external documents. Year listed is the first time measures appear in a Fish and Wildlife Program

Summary of implementation

Operations for chum salmon appear in the Fish and Wildlife Program and the BiOp and are coordinated through the TMT. Originally, operations were based on a flow target (125 KCFS); this quickly transitioned to an elevation target at Tanner Creek below Bonneville Dam (11.3 or 11.5 ft). Since the adoption of spawning elevation requirements, the minimum water level below Bonneville has consistently remained above the annual standard during the management timeframe (Figure 29). There has also been less variation among years in minimum spring elevations (January – March), with the exception of extreme low water years; minimum water levels consistently remain above 11 ft and are often much higher (Figure 30).

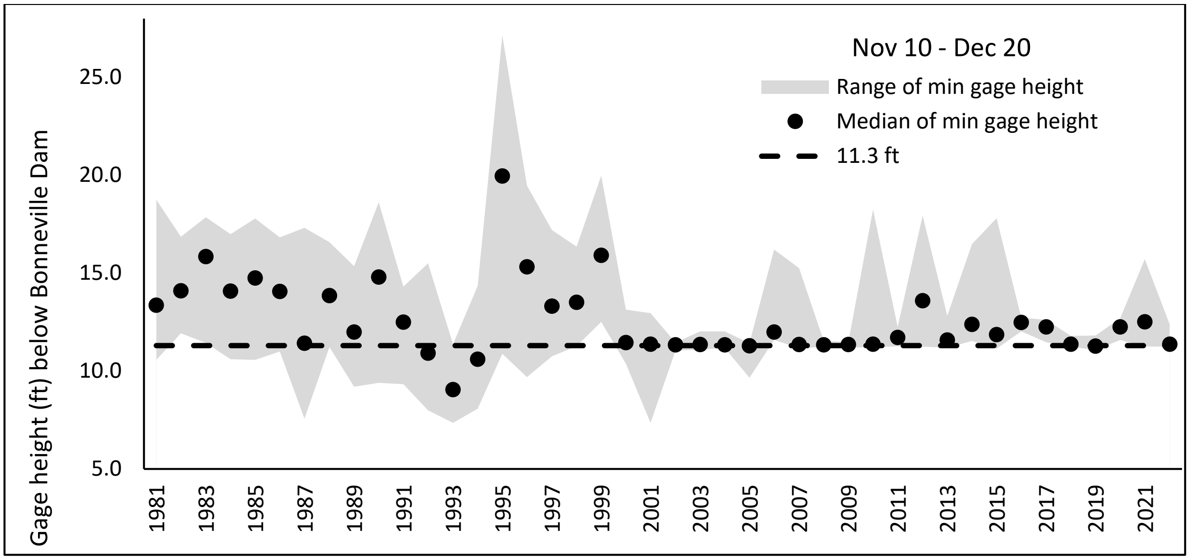


Figure 29. Range (grey) and median (black dots) of the minimum gage height at Tanner Creek (USGS gage #14128870) below Bonneville Dam during dates (Nov. 10 – Dec. 20) that consistently occur within the chum salmon spawning season, prior to listing (1982 – 1999) and post listing (2000 to present). The dashed line at 11.3 feet is the contemporary standard in the Biological Opinion for chum salmon.

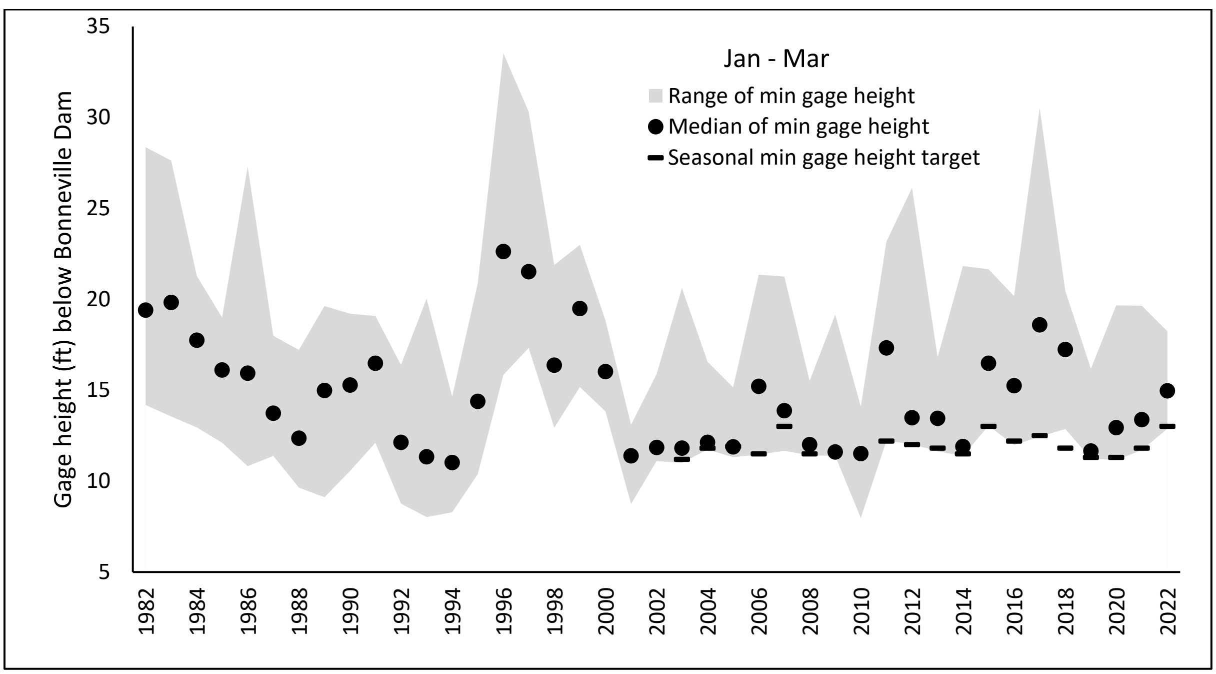


Figure 30. Range (grey) and median (black dots) of the minimum gage height at Tanner Creek (USGS gage #14128870) below Bonneville Dam during dates (January – March) that consistently occur within the chum salmon incubation and emergence season prior to listing (1982 – 1999)

and post listing (2000 – present). Seasonal minimum elevation targets for incubation/emergence vary among years and are shown as discontinuous lines.

Discussion

Chum salmon have more consistent access to spawning tributaries because of the maintenance of tailwater elevations below Bonneville. Implementation of flows for chum salmon occurs when there is sufficient water available in the system in the fall to be able to meet high priority fish operations (flood risk management, minimum flow and ramp rate criteria, refill at storage facilities, spring flow objectives for juvenile salmon and steelhead, and in some years- Hanford Reach Fall Chinook) and maintain water levels below Bonneville Dam through the chum salmon spawning and rearing season. In drought years, flow may not be provided. As described in the 2023 Water Management Plan (BPA et al. 2023), "The 2020 NMFS BiOp…stated that chum salmon spawning operations generally have a lower priority than achieving spring flow objectives or summer refill…". Because chum operations depend on water availability after meeting higher priority operations, they may be especially vulnerable to climate change, increasing water demands, or new hydro operations, including potential changes to flood management under the revised Columbia River Treaty. It may be necessary to investigate whether a lower frequency of providing these tailwater elevations could affect productivity in the long term in the population of chum salmon below Bonneville.

Tailwater elevations are provided during the first week of November or once chum salmon are observed on spawning grounds. Chum salmon regularly appear in fish counts at Bonneville Dam beginning in October (FPC.org), signifying that they are present below Bonneville Dam before they are observed on spawning grounds. By waiting to increase flows until chum salmon are observed, there is the potential that early spawners may be delayed in accessing their spawning tributaries. Poirier et al. 2012 identified that the timing of spawning flows affected the initiation timing and duration of spawning behavior. Spawn timing is one component of life history diversity that can affect survival, so maintaining the greatest diversity possible may be key for preserving adaptive capacity of chum salmon in a changing environment.

At the Hanford reach, data on juvenile production can be related to flow and is an indicator of the biological response to operations. For chum salmon in the mainstem below Bonneville dam, data exist on the timing of emergence (van der Naald et al. 2006) but data on mainstem egg-to-fry survival do not exist. However, increasing tailwater elevations does allow access to spawning tributaries that would be otherwise inaccessible in dry or low water years. Likewise, tailwater elevations are maintained to allow for egg incubation and emergence on Pierce and Ives Islands, which should result in increased survival.

References

BPA, USACE, and BOR. 2023. Final Water Management Plan. Accessed from: https://pweb.crohms.org/tmt/documents/wmp/2023/Final/20221231_2023_WMP_Final.pdf

NMFS (National Marine Fisheries Service). 1999. Endangered and threatened species: threatened status for two ESUs of chum salmon in Washington and Oregon. Federal Register. 64 (57):14508–14517.

NMFS. 2020. Biological Opinion for the Federal Columbia River Power System. Available online at: https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/federal-columbia-river-power-system-biological-opinion

Poirier, J.M., T. A. Whitesel, and J. R. Johnson. 2012. Chum salmon spawning activity in tributaries below Bonneville Dam: the relationship with tailwater elevation and seasonal precipitation. River Research and Applications 28(7): 882-892.

van der Naald, W., C. Duff, T. A. Friesen, R. R. Brooks, and L. M. Tomaro. 2006. Evaluation of Fall Chinook and Chum Salmon Spawning Below Bonneville Dam. Annual Report 2004-2005. ODFW, Clackamas, OR. Available online at: https://www.dfw.state.or.us/fish/OSCRP/CRI/docs/Chum%20Annual%20Report%202004-2005%20Final.pdf

Resident fish measures, by location

The purposes of resident fish measures in the Program are to improve spawning and rearing conditions below mainstem dams and within reservoirs. This is accomplished through (1) management of flow and water quality (temperature and TDG), (2) minimizing ramp rates to protect resident fish and aquatic prey and to decrease bank erosion and increase stability of flow, and (3) managing reservoir elevations.

These measures are designed to benefit multiple species, including bull trout (ESA listed in 1998/1999), white sturgeon, Kootenai River white sturgeon (ESA listed in 1995), kokanee salmon, cutthroat trout, rainbow trout, and all levels of the foodweb, including shoreline vegetation. We reviewed resident fish measures in five locations: Columbia River (white sturgeon), Libby Dam, Hungry Horse Dam, Grand Coulee Dam, and Albeni Falls Dam. Implementation of these measures is guided by annual Water Management Plans and is subject to in-season management and input from managers.

Columbia River Sturgeon

White sturgeon are a long-lived anadromous species inhabiting the Columbia Basin from the estuary upstream to the upper Columbia and Upper Snake Rivers. Historically, white sturgeon migrated long distances to find productive habitats for spawning. Because white sturgeon do not spawn every year, migrations were critical for ensuring they spawned in the best habitat available in any particular year to maximize survival of their offspring. Construction of the hydrosystem has blocked these migrations and resulted in isolated pools with habitat quality that varies geographically and sometimes among years. In pools with poor habitat, spawning may not occur. In pools with available habitat, the success of spawning depends on environmental conditions in a given year. If spawning conditions are poor, sturgeon are unable to migrate to better habitat.

Table 8. Hydrosystem flow and passage measures in the Council's Fish and Wildlife Program guiding mitigation for Columbia River white sturgeon, 1982 – 2020

Program*	General Measures	Passage
1982	**Research on a range of topics related to hydrosystem effects on sturgeon.**	
1995		**Research feasibility of additional sturgeon passage opportunities at The Dalles Dam by restoring existing fish lock facilities.**
2009		**Research on how presence/ absence of removable spillway weirs (RSWs) affects downstream passage, passage mortality, and whether dams isolate populations and if that can be mitigated.**
2014/ 2020	Seek opportunities to operate the FCRPS to **provide flow consistent with the needs of productive sturgeon populations**, including increased spring and summer flows, reduced flow fluctuations during spawning season, and spill where feasible. **Evaluate whether alternative flow regimes might increase sturgeon productivity and recruitment in the lower Columbia below McNary Dam** and if so, whether and how operations could be altered to provide those flow regimes without compromising protection for salmon, steelhead and lamprey.	The USACOE, in collaboration with the state, federal agencies and tribes, should **continue to implement improvements to the adult fish passage facilities at mainstem dams to benefit salmon and steelhead, Pacific lamprey, white sturgeon, and bull trout**.

The year listed is the first time measures appear in a Fish and Wildlife Program.

Flow and temperature

Summary of implementation

The Program has called for research on the relationship between sturgeon survival and the hydrosystem and a better understanding of seasonal flow or temperature requirements. Results of modeling and empirical data indicate that spawning and productivity in the Columbia River, below McNary Dam, are positively associated with the number of days when temperature is in the range of 12 – 18°C while flow exceeds 250 KCFS during May – July (Parsley et al. 1993; CBWSPF 2013). Since 1995 (the period of record for temperature), there has been a relatively consistent number of days between 12 – 18°C, but there has been a shift toward fewer days colder than 12°C and more days warmer than 18°C.

In contrast, over time there has been a decrease in the number of days with flow > 250 KCFS between May and July each year. From 1942 to 1972, there was an average of 72 days and since 1973, that average has dropped to 37.3 days. Several storage projects became operational during the early to mid-1970s. These include John Day, Libby, and Dworshak. In addition, during the late 1960s and early 1970s, large storage projects in Canada were filled. The decrease in days with flow > 250 KCFS was not a result of any decrease in runoff volume during the same months each year. From 1949 to present, there has been a slight decrease in runoff volume as runoff has occurred earlier in the year and in combination with certain consumptive uses of water, like agriculture. However, no abrupt change in volume occurred after 1972, when there was a significant decrease in the number of days flow exceeded 250 KCFS.

Over the last three decades, there has been a range of temperature and flow conditions observed in the mainstem below McNary Dam. Since 1995, *both* temperature and flow were suitable for sturgeon spawning between 0 and 68 days (average = 33.5 days) each season. There is no trend over time in the number of days these conditions are met annually (Figures 31 and 32). Some years, like 2001 and 2015, there were no days with suitable spawning temperatures and flows. These were severe drought years. Other years, like 1997 and 2012, there were over two months of suitable spawning conditions. These years were characterized by substantial snowpack and runoff. It is not clear if there is a minimum threshold of days with appropriate temperature and flow conditions that is required for successful spawning. The Program and water management plans do not identify a benchmark for a minimum or average number of days each season when conditions should be achieved.

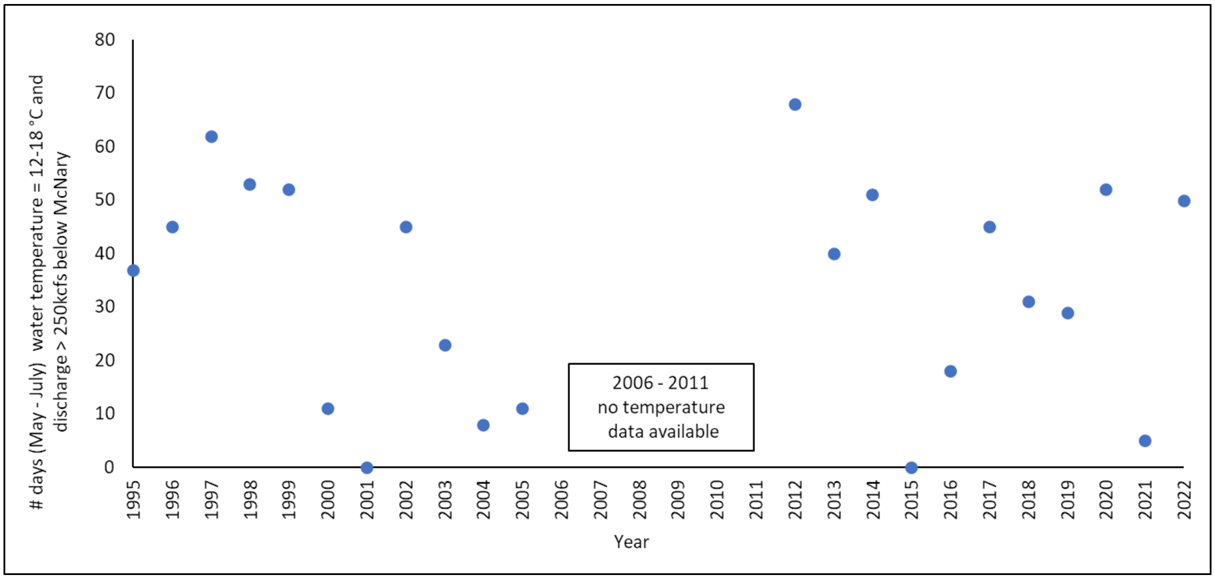


Figure 31. Number of days with a combination of average temperature within the range of 12 – 18°C and average flow > 250 KCFS, May – July, below McNary Dam, 1995 – 2022. Hourly flow data obtained from gage MCN (McNary Lock and Dam). Hourly temperature data obtained from gage MCPW (Columbia River below McNary Dam near Umatilla). Temperature data between 2006 and 2011 were not available at this gage.

Annual data on average flow and temperature downstream of McNary Dam can be found in the Council's Strategy Performance Indicators (SPI's). Figure 32 is an example of data for May 2000.

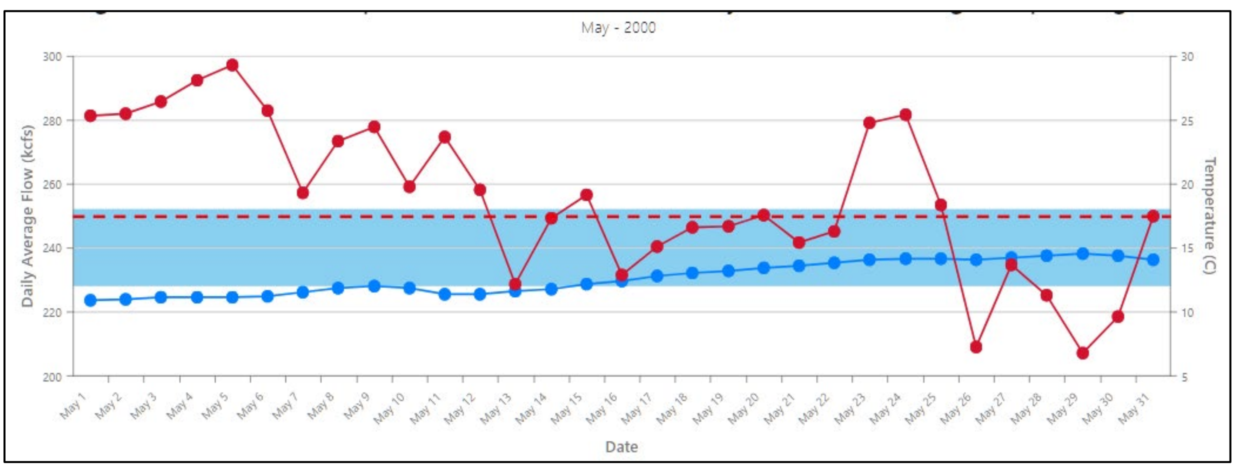


Figure 32. Data on average flow (red line) and water temperature (blue line) downstream of McNary in relation to standards for temperature (12 – 18 °C; blue bar) and flow (> 250 KCFS; red dashed line) identified for white sturgeon (Parsley et al. 1993; CBWSPF 2013). Data available on NPCC Program Tracker, Strategy = Hydrosystem Flow and Passage, Indicator = E3-4.

Passage

Summary of implementation

Sturgeon passage has not been constructed for the hydrosystem. Historically, there are accounts of adult white sturgeon passage through fish locks (an elevator-type structure) at Bonneville Dam (Warren and Beckman 1992), but these have not been operated since 1971. Even when operated, they were designed for salmon and steelhead and could only pass sturgeon < 4.5 feet in length because of the size of the locks (Warren and Beckman 1992).

More recent research has documented adult passage upstream through The Dalles Dam. In 1995, a total of 943 sturgeon were counted using the east fish ladder, compared to 104 in the north ladder (Parsley et al. 2007; USGS 2008). This disparity in ladder use was also observed in a telemetry study where of 148 tagged fish, 19 passed through The Dalles- either upstream or downstream, and sometimes multiple times (Parsley et al 2007). Most upstream passage occurred through the east fish ladder whereas downstream passage occurred through the spillway. Researchers suggest “differences in construction between the north and east fish ladders may account for the greater success of the east fish ladder in passing sturgeon upstream” (Parsley et al. 2007).

Discussion

Currently the Fish and Wildlife Program calls for researching and implementing ideal flows for sturgeon while not negatively impacting other species. Without a specific description of how to operate the hydrosystem to achieve those flows, no specific flows for sturgeon are implemented. Any beneficial flow for sturgeon occurs either because there was a large runoff volume in a particular water year or because of operations meant to benefit other species- particularly salmon and steelhead.

The number of days with both suitable temperature and flow conditions is primarily limited by flow. However, there has been an increase in the number of days that are above 18 °C and a decrease in days below 12 °C. If this continues, temperature may become a more limiting factor and there may be a further decrease in the number of days each year when both conditions are in range.

Temperature and flow are not the only factors controlling spawning success. Some reservoirs have suitable habitat and others do not. Sturgeon passage between reservoirs is limited and primarily occurs in a downstream direction. This occurs when adults migrate over the spillway or through the locks, or when juveniles pass downstream through turbines, the spillway, and the ice and trash sluice. Research has shown that the loss of individuals to downstream reservoirs may affect the abundance and contemporary genetic diversity of upstream populations (CBWSPF 2013 and references contained therein).

No implementation of passage measures has occurred. Rather, measures to address the loss of upstream population abundance and genetic diversity focus on artificial production. These will be further described in the Artificial Production Categorical Assessment.

References

Columbia Basin White Sturgeon Planning Framework (CBWSPF). 2013. Prepared by CRITFC, WDFW and ODFW for the Northwest Power and Conservation Council. R. Beamesderfer and P. Anders editors. 285 pp.

Parsley, M.J., L. G. Beckman, and G. T. McCabe Jr. 1993. Spawning and rearing habitat use by White Sturgeon in the Columbia River downstream from McNary Dam. TAFS 122: 217-227.

Parsley, M. J., C.D. Wright, B. K. Van Der Leeuw, E.E. Kofoot, C.A. Peery, and L. Moser. 2007. White sturgeon (*Acipenser transmontanus*) passage at the Dalles Dam, Columbia River, USA. Journal of Applied Ichthyology. Accessed online at: https://onlinelibrary.wiley.com/doi/10.1111/j.1439-0426.2007.00869.x

USGS. 2008. White Sturgeon Passage at The Dalles Dam. USGS Fact Sheet 2008-3081. Available online at: https://pubs.usgs.gov/fs/2008/3081/

Warren, J. J. and L. G. Beckman. 1992. Fishway Use by White Sturgeon to Bypass Mainstem Columbia River Dams, Report F, in Status and habitat requirements of the white sturgeon populations in the Columbia River downstream from McNary Dam, Beamesderfer, R.C. and A.A. Nigro, editors. Final Report of Research Volume I July 1986 - September 1992. Project No. 86-50. Available online: https://docs.streamnetlibrary.org/BPA_Fish_and_Wildlife/63584-6.pdf

Libby Dam and Hungry Horse Dam, operations downstream of the dams

Libby and Hungry Horse Dams are operated to provide suitable flow and temperature conditions for resident fish downstream of the dams and to maintain productive conditions within the reservoirs. Some of these operations are meant to benefit ESA-listed resident fish (Kootenai River white sturgeon, listed in 1995; bull trout, listed in 1998 and 1999). Other operations are in response to operations for ESA-listed salmon or steelhead that negatively impacted resident fish. In 2017, Montana Fish, Wildlife, and Parks and the Montana office of the NPCC, in consultation with the Confederated Salish and Kootenai Tribes, reviewed operations at Libby and Hungry Horse dams (MFWP et al. 2017). In this section, we build off that review and describe the implementation of operations meant to benefit resident fish in the river, including minimum flows, flows for sturgeon, seasonal flows for bull trout, ramp rates, temperature, and total dissolved gasses.

Table 9. Hydrosystem measures in the Council's Fish and Wildlife Program, and associated BiOp measures guiding mitigation for resident fish downstream of Libby Dam and Hungry Horse Dam, 1982 – 2020

Program	Libby Dam/ Kootenai River	Hungry Horse Dam/ SF Flathead River
1982	**Minimum flows year-round** • Normal water year = 4 KCFS • Dry water year = 3 KCFS **Spawning flows Kokanee**	**Instantaneous flows (Columbia Falls):** • Oct 15 – Dec 15: 3.5 – 4.5 KCFS • Dec 15 – Apr 30: min = 3.5 KCFS • Jul 1 – Oct 15: min = 3.5 KCFS
1991 – 1993		**Selective withdrawal** **Instantaneous flows (Columbia Falls):** • Oct 15 – Dec 15: 3.5 – 4.5 KCFS • Dec 15 – Oct 15: min = 3.5 KCFS
1994		**Selective withdrawal installed in 1996**
1995	**Supplemental flow releases for Kootenai River white sturgeon spawning, May – July.**	
2000 BiOp	*Tiered flows for Kootenai River white sturgeon* *Bull trout flows* • *May – Sep min = 6 KCFS* • *Jul – Aug variable min 6– 9 KCFS, depending on forecast* *Daily and hourly ramp rates* *Minimize spill / do not exceed 110 % MT standard*	*Bull trout flows* *Minimum flows, based on forecast* • *HGH min outflow = 0.4 – 0.9 KCFS* • *Columbia Falls min flow =3.2 – 3.5 KCFS* *Daily and hourly ramp rates* *Minimize spill / do not exceed 110 % MT standard*
2003	**Adoption of bull trout BiOp requirements and ramp rates.**	**Adoption of bull trout BiOp requirements and ramp rates.**
2006 Libby BiOp	*Sturgeon and bull trout requirements*	
2009	**Implement 2003 amendments, actions in BiOps**	**Same as Libby**
2014	**Operations no longer experimental. Continue refinements.**	**Same as Libby**
2020	**Implement refinements**	**Same as Libby**

Rows in italics describe measures referenced and implemented as mitigation through the Program that were first described in external documents. The year listed is first time measures appear in a Fish and Wildlife Program.

Libby Dam

Summary of implementation

Annual minimum flow

Minimum daily outflows have been called for in the Program since 1982. Flows were meant to exceed 4 KCFS in 80% of water years and 3 KCFS in drier years. Although minimum flows were meant to be achieved 365 days a year, from 1982 until 1989, the 4 KCFS minimum standard was not met between 50 and 150+ days a year (Figure 33). The 3 KCFS standard was met much more frequently, but still not 100% of the time. Since the early 1990s there has been a general increase in the minimum flow released annually, to a point in the last 10 years when the 4 KCFS standard is almost always met. There have been very few days when flow dropped below the standard, for reasons including maintenance and in-stream rescue operations.

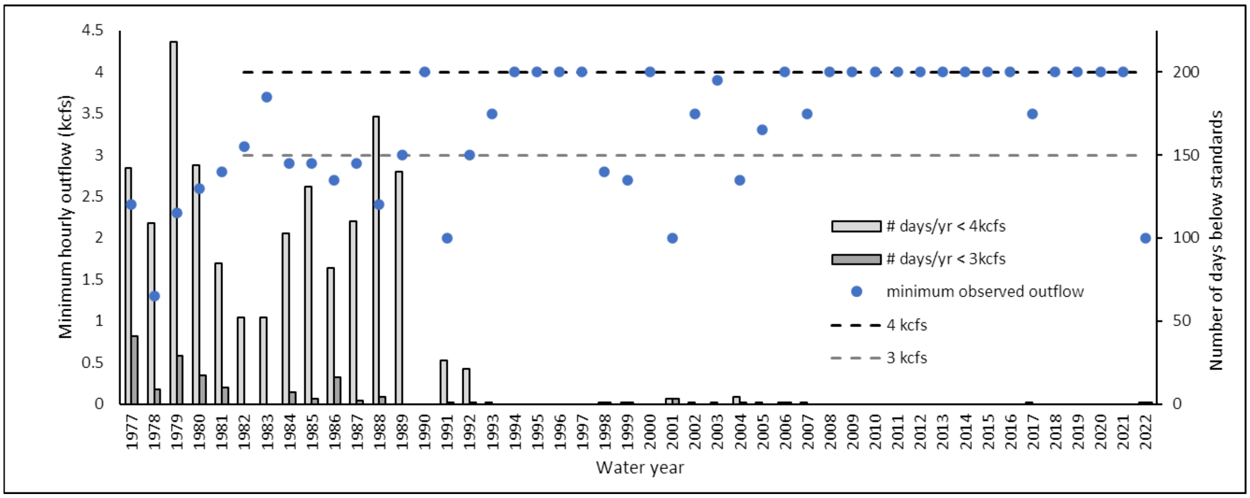


Figure 33. Lowest observed instantaneous (hourly) outflow (blue dots; KCFS) each year relative to minimum outflow standards (dashed lines) at Libby Dam, water years 1977 – 2022. Bars represent the number of days each year that the minimum daily outflow falls below 3 KCFS (dark grey) or 4 KCFS (light grey). Figure excludes single hourly value of 0 KCFS in 1992 and 2006.

Seasonal flows for Kootenai River white sturgeon

The Program and BiOp call for flow to be released from Libby Dam to support Kootenai River white sturgeon spawning. Supplemented flows are typically released from mid-May until the end of June and the selected volume (using Tiered Flow chart; Figure 34) is added to the bull trout minimum flow of either 4 or 6 KCFS, depending on the date the flows begin (see bull trout section, below). In the late 1990s, the objective was to release as much water as possible for sturgeon to emulate the 1974 water year. However, this could cause floods that were of concern to downstream communities. The contemporary objective is to achieve ≥ 30 KCFS for as many days as possible each year during the spawning and incubation period, as recorded at Bonners Ferry (river kilometer [RKM 246] on the Kootenai River). A second objective is to meet a particular water elevation at Bonners Ferry to maximize habitat.

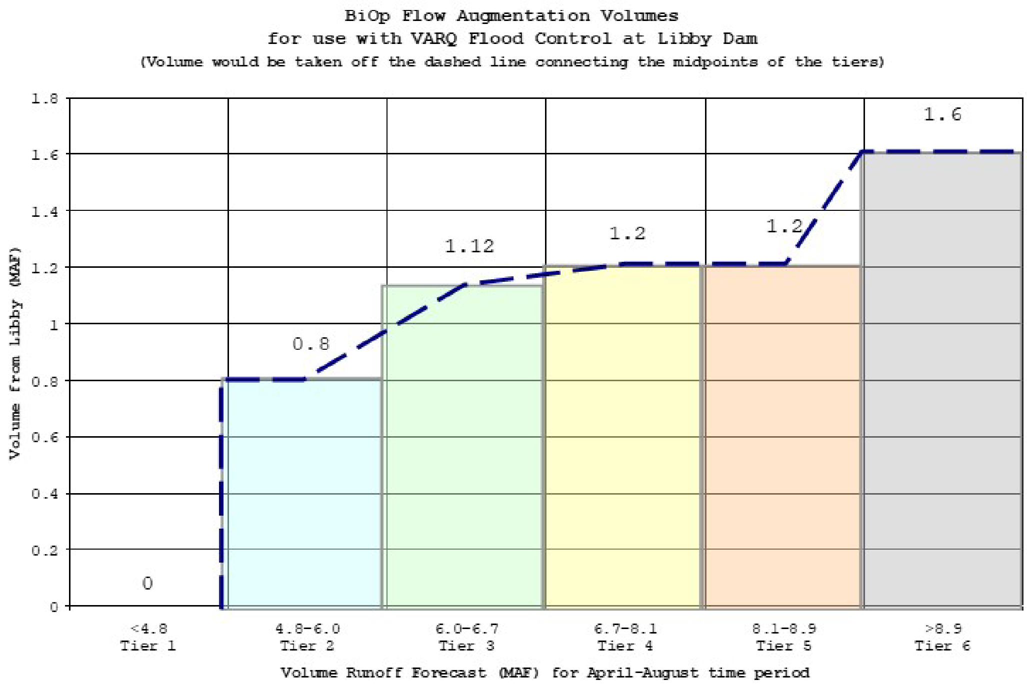


Figure 34. Supplemental flow releases from Libby Dam for sturgeon selected from tiers 1 – 6 depending on local forecast runoff volume. Actual flow releases are shaped according to seasonal requests from the USFWS and in-season management

Since the beginning of sturgeon flows in 1995, late May and June flows are consistently higher (average = 17.4 KCFS) than in the period from 1977 – 1994 (average = 6.6 KCFS; Figure 35). The exception to this is very dry years, like 2001, when no sturgeon pulse could be released.

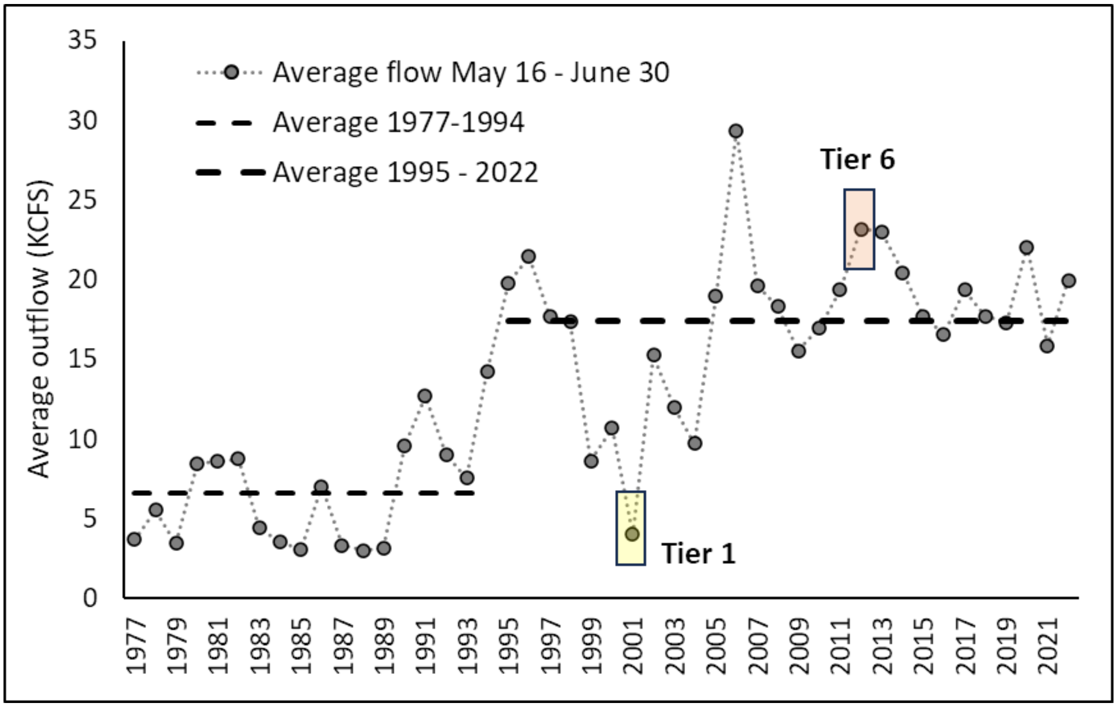


Figure 35. Average outflow (KCFS) May 16 – June 30 at Libby Dam, 1977 to 2022 (dots) and interannual average for 1977 – 1994 and 1995 – 2022 (dashed lines). Specific flow management for sturgeon commenced in 1995 following ESA listing; flow pulses typically released mid-May through the end of June. Annual release volume currently determined from sturgeon tiered flow chart, using the final May forecast for Apr – August runoff volume at Libby Dam. Yellow box highlights tier 1 year (no pulse released) and orange highlights a tier 6 release (highest tier).

Flow pulses are meant to cue migration by sturgeon to productive spawning grounds.

Researchers have identified that a greater number of fish migrate with an increasing number of days of average flow ≥ 30 KCFS at the Bonners Ferry gage (Hardy and McDonnell, 2020). The number of days of average flow ≥ 30 KCFS at Bonners Ferry has occurred with variable frequency from 2005 to present, but there has been a general negative trend in flows since 2017 (Figure 36).

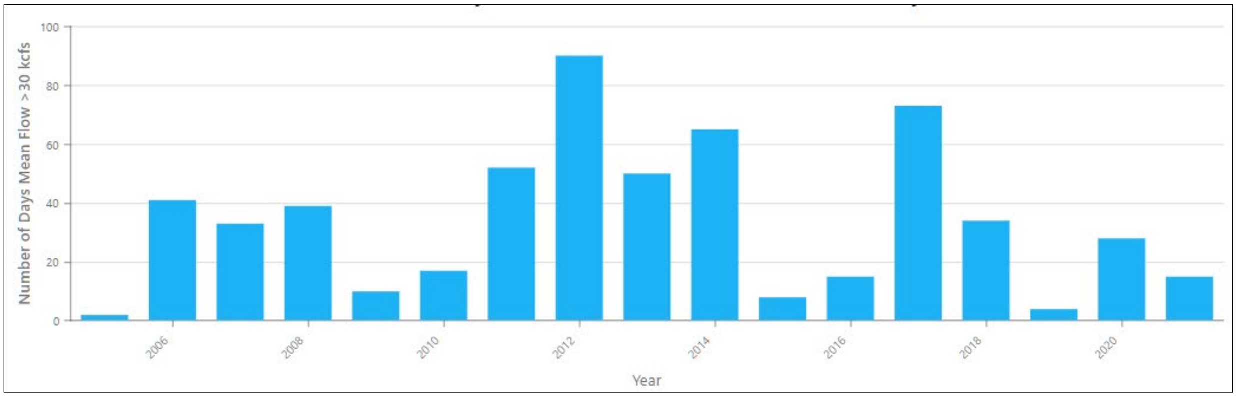


Figure 36. Number of days of stream flow at or above 30 KCFS at Bonners Ferry to support white sturgeon spawning migration, 2005 – 2021. Data available on NPCC Program Tracker, Strategy Performance Indicator WS1-1/ WS4-1

The area of the Kootenai River beginning at Bonners Ferry (RKM 246) and extending upstream is considered high quality spawning habitat. Sturgeon can access habitat upstream to Kootenai Falls (RKM 310), which is 42 km downstream of Libby Dam (RKM 352). Researchers track the number of females migrating to this habitat (Sean Wilson, IDFG, personal communication; Fosness et al. 2017) as one way to determine how sturgeon are responding to flow pulses. From 2006 – 2017 there was an increasing trend of females migrating to or above RKM 246 but since 2018, the trend has been negative (Figure 37). In 2021, 4 females were observed migrating- identical to the numbers observed in 2006 and 2007. Data on flow pulses and migrating females are available on NPCC Program Tracker, Strategy Performance Indicator WS1-1/ WS4-1.

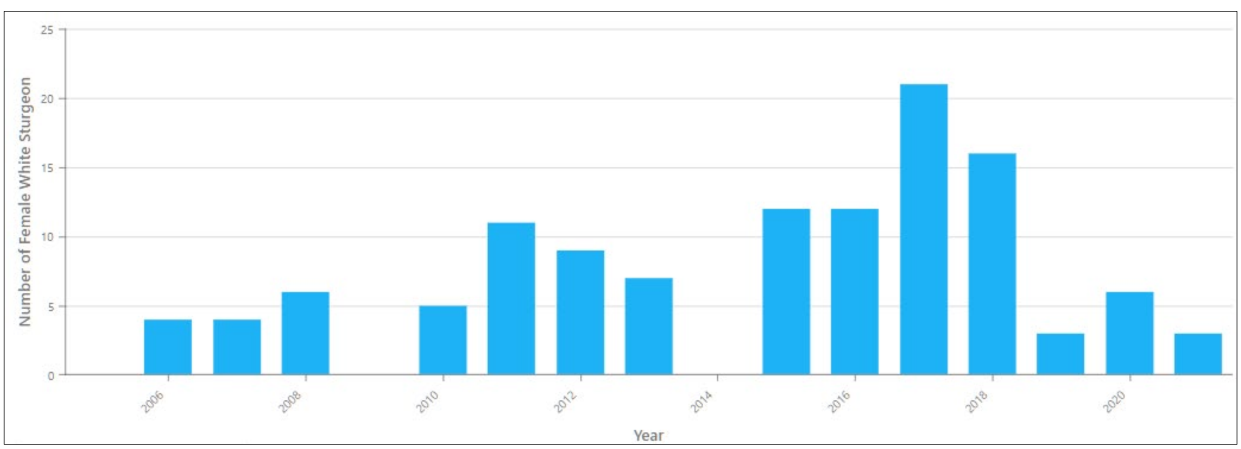


Figure 37. Number of wild female adult white sturgeon with acoustic tags detected at or above RKM 246 of the Kootenai River, an area of preferred spawning habitat, 2005-2021. Data available on NPCC Program Tracker, Strategy Performance Indicator WS1-1/ WS4-1.

The estimated number of adult sturgeon in the Kootenai River (between Kootenay Lake and Kootenai Falls) has declined consistently since 1990 (Figure 38). Early estimates exceeded 2,750 adults and the most recent estimate (2017) was 1,750 adults, according to data provided by IDFG and reported on Program Tracker. It is challenging to relate the number of sturgeon migrants or spawners to particular flow regimes because sturgeon do not spawn every year. Conditions for spawning may be ideal, but if spawners have not regained their fecundity following a prior spawning event, they may not be biologically ready to take advantage of those conditions.

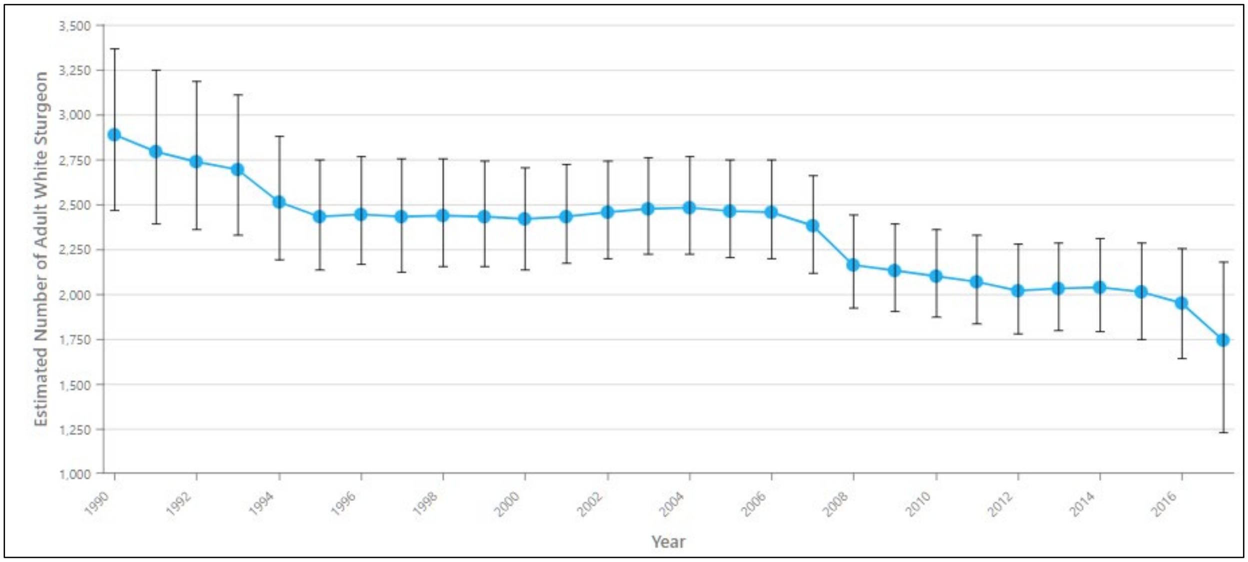


Figure 38. Estimated number of adult white sturgeon in the Kootenai River, 1990 – 2017. Data available on NPCC Program Tracker, Strategy Performance Indicator WS1-8.

Minimum seasonal flows for bull trout May 15 – Sept. 30 and July 1 – Aug. 31

Minimum flows for bull trout (6 KCFS, May 15 – Sept. 30; 6 – 9 KCFS, June 1 – July 31) were called for in the 2000 BiOp and subsequently in the 2003 mainstem amendments. Prior to this, minimum flows during spawning were governed by the annual minimum standard of 3 – 4 KCFS. From 2000 to approximately 2010, minimum outflow dropped below 6 KCFS at some point between May 15 and September 30, up to ~ 50 days per year (Figure 39). Beginning in 2011, minimum outflows were much closer to, or exceeded, the 6 KCFS minimum for all but 1 or 2 days per season, each year. During July and August, minimum flows have almost always been met, with the exception of 1 or 2 days per year (Figure 40). In the first few years of implementation, minimum flow frequently exceeded 9 KCFS. In the last decade, minimum flows have typically ranged between 6 and 9 KCFS.

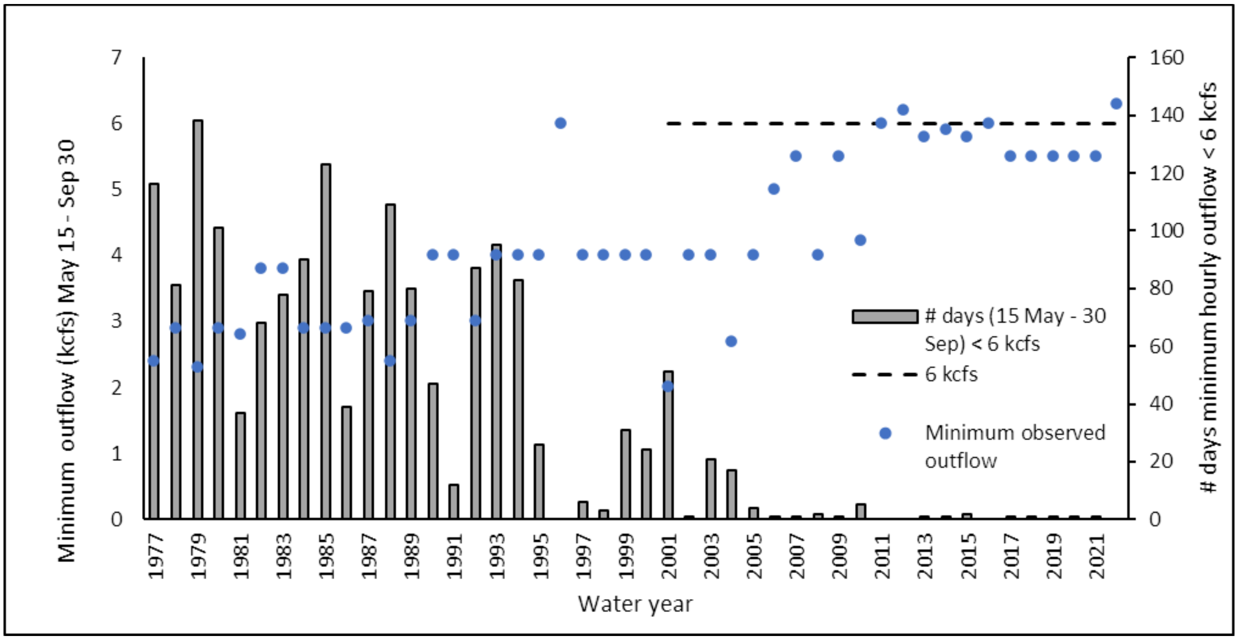


Figure 39. Lowest observed instantaneous (hourly) outflow (blue dots; KCFS) May 15 – Sept. 30 each year relative to minimum outflow standard (dashed line) at Libby Dam, 1977 – 2022. Grey bars represent number of days/season with minimum hourly outflow < 6 KCFS. Figure excludes single hourly value of 0 KCFS in 1992.

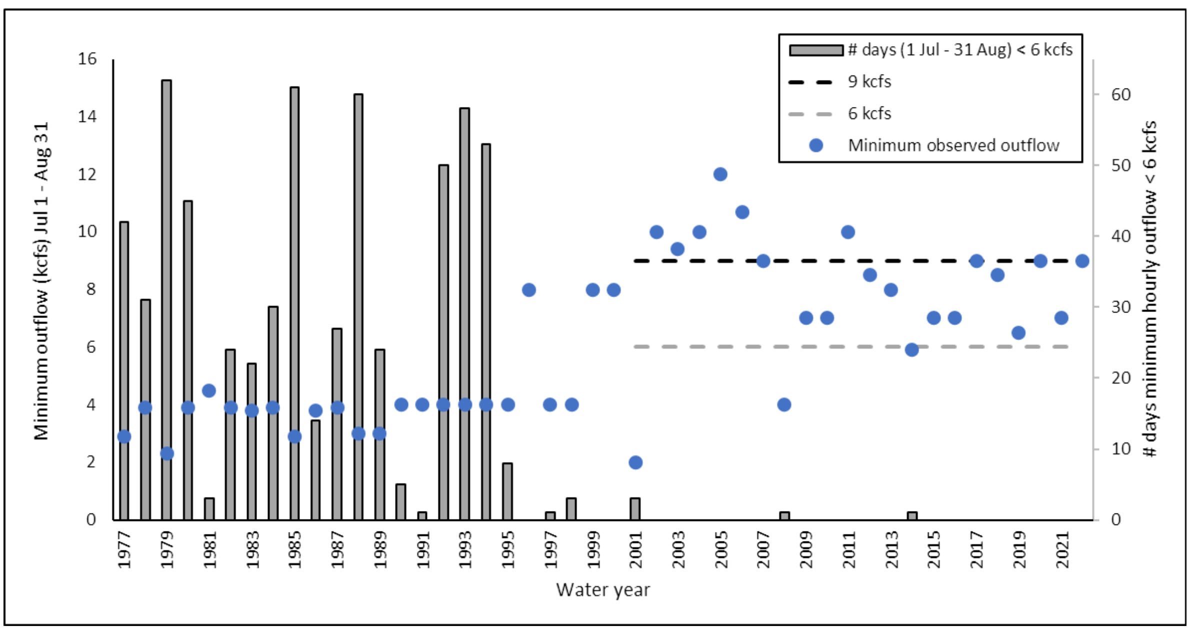


Figure 40. Lowest observed instantaneous (hourly) outflow (blue dots; KCFS) Jul 1 – Aug 31 each year relative to minimum outflow standards (dashed lines) at Libby Dam, 1977 – 2022. Grey bars represent number of days/season with minimum hourly outflow < 6 KCFS. Figure excludes single hourly value of 0 KCFS in 1992.

Ramp Rates

Ramp rates are carefully followed by project operators and problems in implementing these rates have not been reported. Ramp rates contribute to the stability of flow conditions in the reaches downstream of dams; this is a high priority for management. To describe stability, we calculated the annual average and max of the daily delta (the daily max – min flow). In years with a lot of variation in flow (ramping up and ramping down) the annual average of daily changes would be higher than a year with minimal flow changes and a big peak flow event. Likewise, the annual max describes the biggest ramp rate of the year and relates to peak flows.

Beginning with the ramp rates called for in 2000 BiOp and 2003 Program, the annual average of daily changes in ramp rates has ranged from 250 – 1,390 CFS (Figure 41). In the mid 1990s, the annual average of daily deltas ranged from 1,060 – 2,799 CFS. Since 2000, the annual max delta in outflows has ranged from 6,233 – 17,998 CFS. This compares with a range of 16,191 – 19,347 CFS in the mid 1990s.

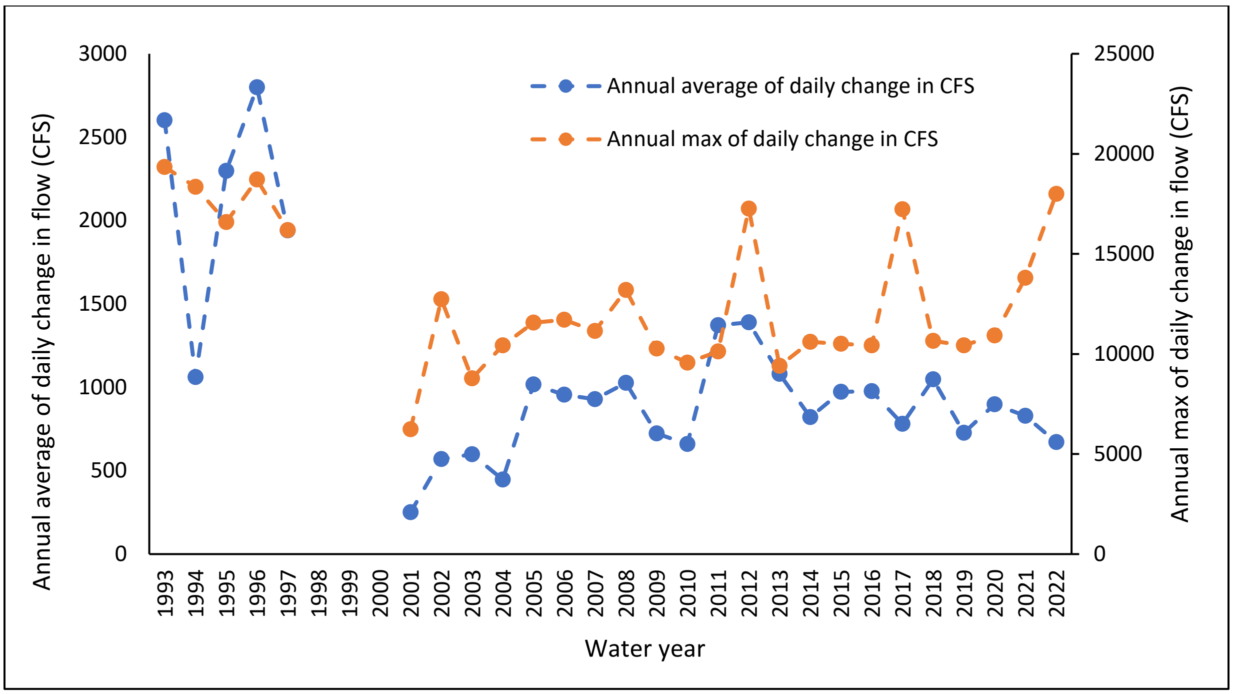


Figure 41. Annual average (blue dots) and annual maximum (orange dots) of daily changes in flow (CFS; daily max flow – daily min flow) on the Kootenai River below Libby Dam (USACE gage LIBM), 1993 – 2022.

Water Temperature

The temperature of water released from Libby Dam affects the productivity of organisms in that habitat. Selective withdrawal was installed on Libby Dam in 1972 and the Program calls for operating selective withdrawal to approximate natural water temperatures. Using degree days (calculated as the sum of mean daily temperature (°C) July – Sept.), an indicator of the growing conditions over a season, we calculated a range of 1,035 – 1,352 degree days (°C) during July – Sept., 1986 to present (Figure 42). Prior to the construction of Libby dam, an average of 1,388 degree days were accumulated during that same period (Sylvester et al. 2019). In general, a greater number of degree days provides for better growing conditions for resident fish provided that temperatures do not rise so high that they become a stressor on the river system and aquatic organisms.

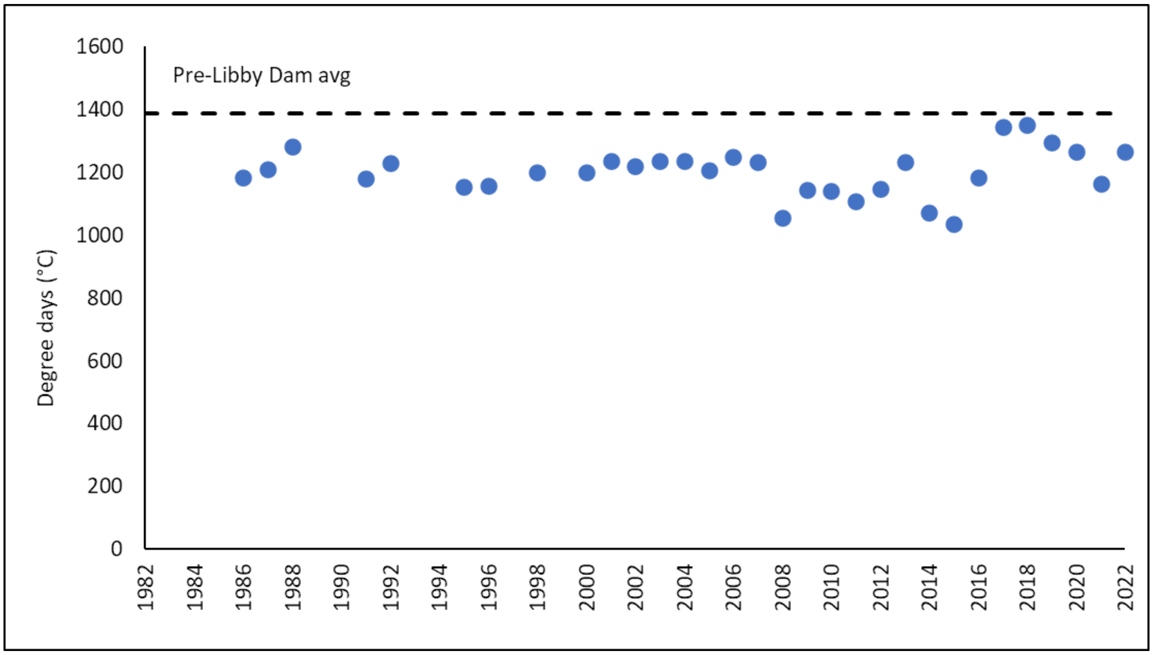


Figure 42. Total degree days, July – September (calculated as sum of mean daily temperature (°C) July – September) at the Kootenai River, below Libby Dam (blue dot; USACE gage LIBM)) relative to average degree days (July – September) prior to construction of Libby Dam (dashed line; data on pre-dam temperatures from Table 2-9 in Sylvester et al. 2019). In years with ≤ 4 missing daily values, temperature values were interpolated from adjacent days. Years with > 4 missing daily values were excluded.

TDG

Gas bubble trauma (GBT) in fish depends on the level of gas supersaturation, how long a fish is exposed, and the depth characteristics in the river environment downstream. Symptoms include split fins and bubbles in tissue, eyes, and the lateral line. The state of Montana limits TDG to 110% to avoid causing GBT. That standard pre-dated the development of TDG operational requirements at Libby Dam during the 2000 BiOp. From 2010 – 2012, court-ordered spill tests occurred and resulted in elevated TDG (Figure 43). During these tests, the 110% standard was temporarily waived.

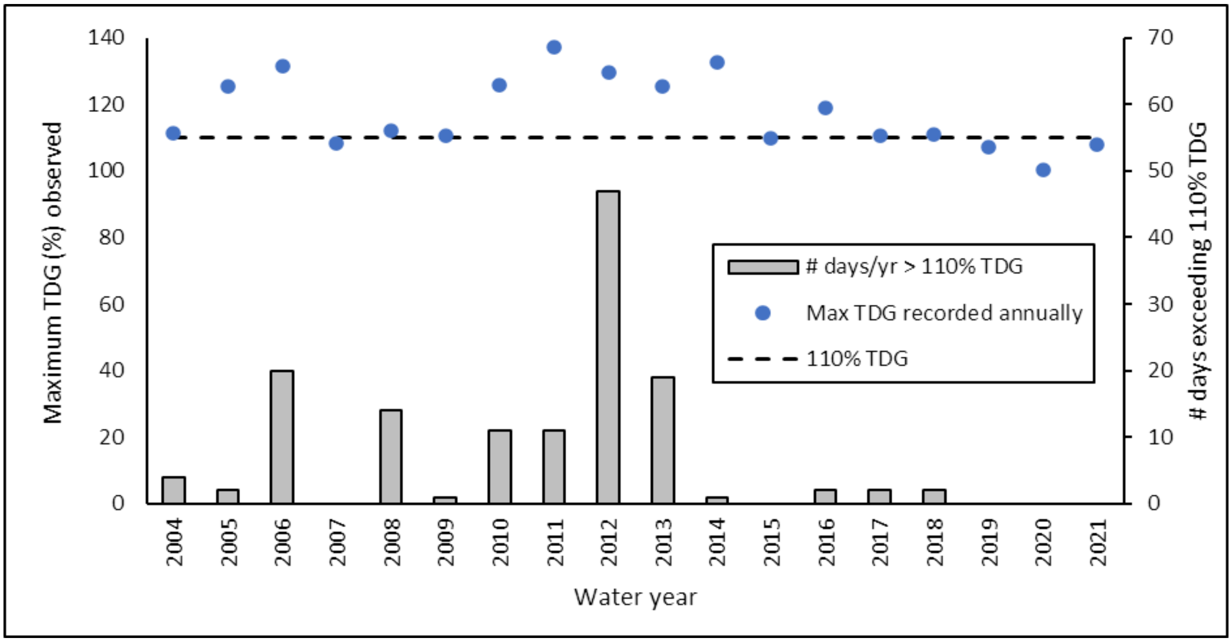


Figure 43. Maximum total dissolved gas (TDG) observed each water year below Libby Dam (USACE gage LIBM), 2004 – 2021, relative to Montana water quality standard of 110% TDG. Grey bars represent the number of days each year when TDG > 110%. Contemporary data available on NPCC Program Tracker, Strategy Performance Indicator E2-5.

Hungry Horse Dam

Summary of implementation

Minimum flow

Prior to 2000, the minimum outflow requirement at Hungry Horse Dam was 145 CFS. Although the flow standard is for instantaneous flows, data during this period are daily averages and not hourly flows. Daily average flows consistently met the standard of 145 CFS. In 1999, bull trout were listed and in 2000 a BiOp was released calling for an increased minimum flow interpolated between 400 – 900 CFS, depending on the final March forecast for runoff. There has been a trend toward increasing the minimum outflows (hourly data not shown). Since 2001, there have only been three days when an hourly outflow observation dropped below 400 CFS (Figure 44).

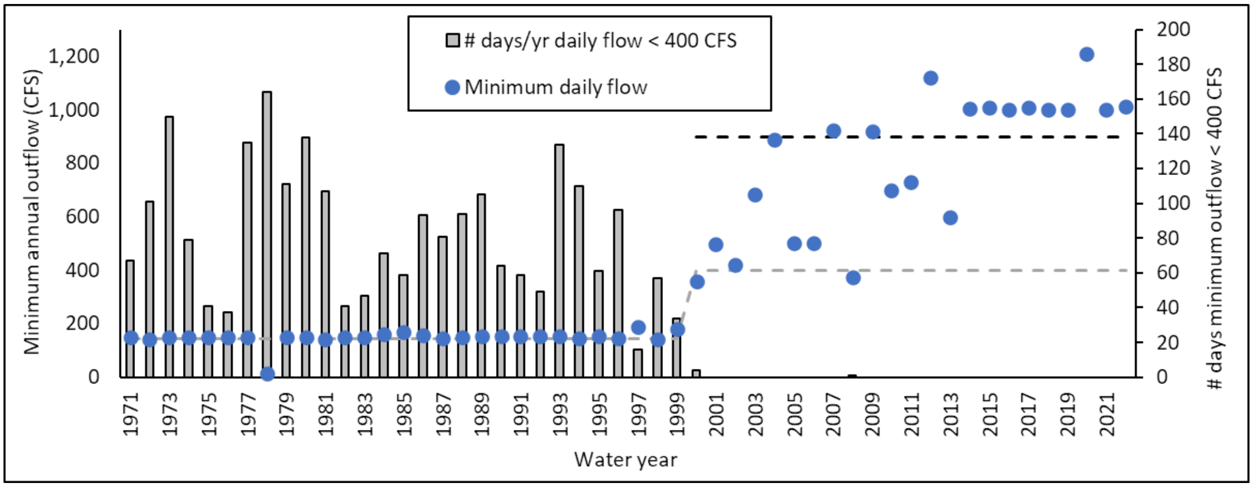


Figure 44. Lowest observed daily outflow (blue dots; CFS) each year relative to minimum outflow standards (dashed lines) at Hungry Horse Dam, 1971 – 2022. Grey bars represent # days/ year daily outflow < 400 CFS. Minimum outflow standard changed from 145 CFS to 400 – 900 CFS in 2000.

Beginning in 1982, the Program called for seasonal minimum flows to support kokanee spawning and summer rearing of other resident species like bull trout, cutthroat trout, and mountain whitefish. From Oct. 15 – Dec. 15, there was a lower and upper limit to flows and for the remainder of the year there was a minimum flow standard. Since the 2000 BiOp and 2003 mainstem amendments, there has been an annual minimum standard that is interpolated between 3,200 and 3,500 CFS, depending on the final March forecast for runoff. There is no longer an upper range to flows during the fall.

Flow data at Columbia Falls began in 1996. From this point, there has been generally consistent implementation of minimum flow standards (Figure 45). In 1999, 2001, and 2005, minimum flow dropped slightly below the standard of 3,200 CFS for a total of 10 days. In 2011 and 2013, flows in the 2,500 – 2,800 CFS range were observed for a total of 8 days.

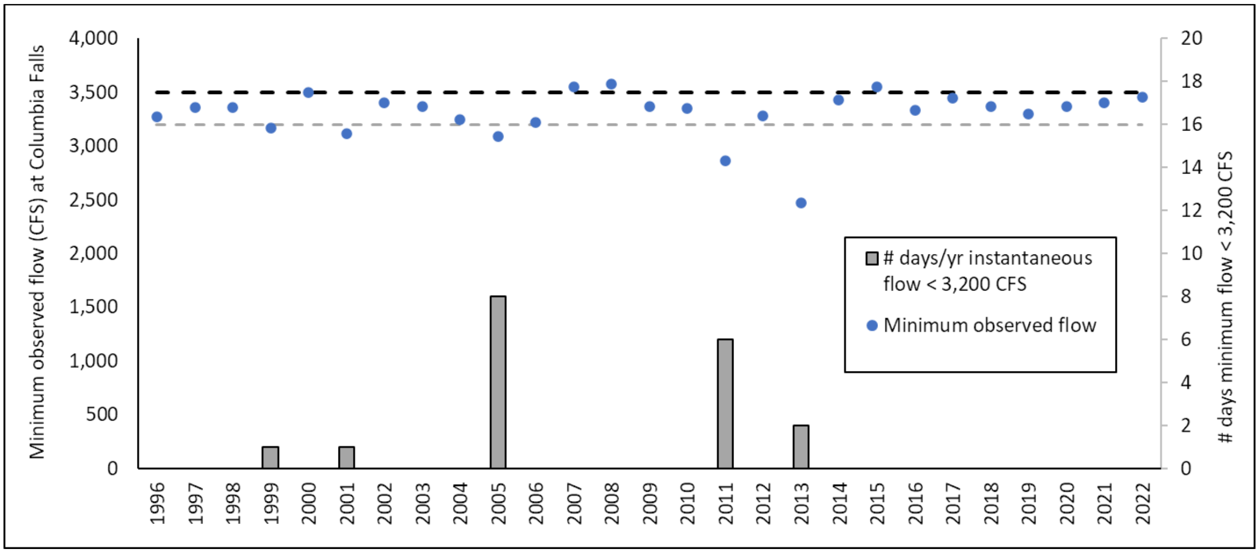


Figure 45. Lowest observed instantaneous (hourly) flow on the Flathead River at Columbia Falls (blue dots; CFS) each year relative to minimum outflow standards (dashed lines), 1996 – 2022, using data from USGS gage 12363000. Grey bars represent # days / year minimum daily flow < 3,200 CFS.

Ramp rates

The flow range at Columbia Falls determines the ramp up and ramp down limits at Hungry Horse Dam. If flows drop too quickly, there may be fish stranded on the banks and if flows increase too rapidly, there may be scour.

Ramping rates are carefully followed by project operators and problems in implementing these rates have not been reported. As with Libby Dam, the stability of flow conditions in the reaches downstream of the dam is a high priority. Beginning with the ramp rates called for in the 2000 BiOp and 2003 Program, the annual average of daily changes in ramp rates has ranged from 126 – 451 CFS (Figure 46). Hourly data needed to calculate this daily change in flows did not exist prior to 2001, so it is not possible to evaluate how these ramp rates compare to those prior to the change in operations associated with the BiOp. The annual max of daily change in outflows has ranged from 1,800 – 9,900 CFS.

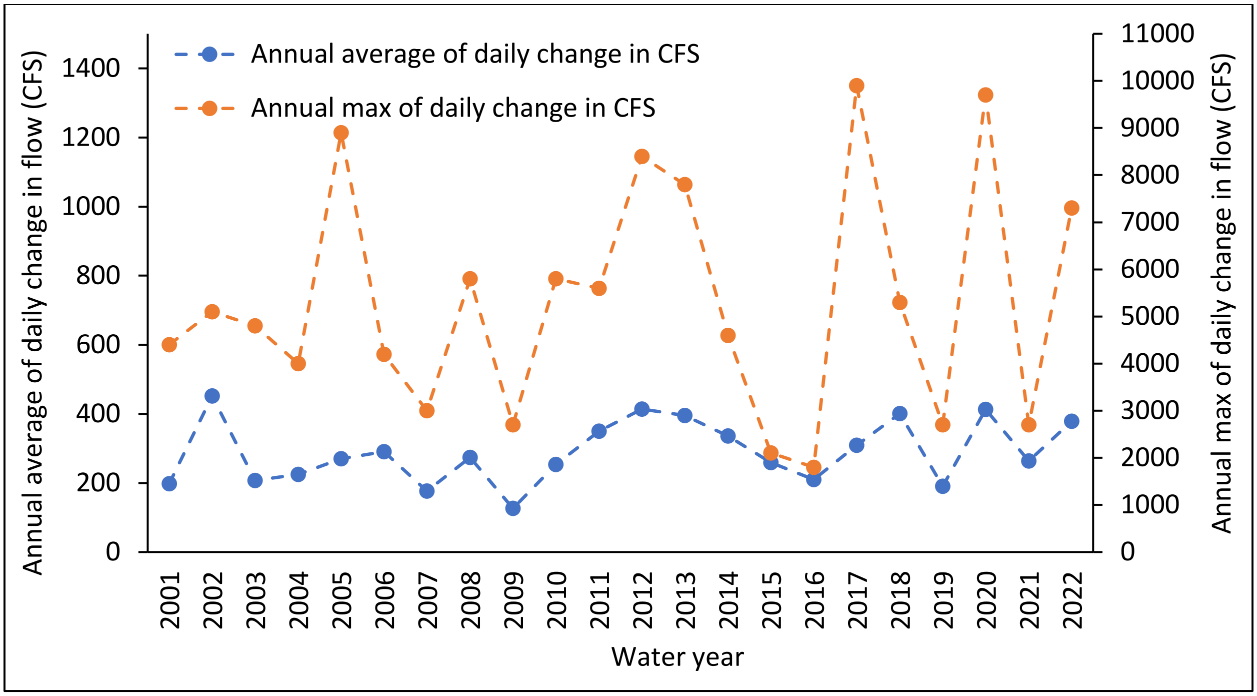


Figure 46. Annual average (blue dots) and annual maximum (orange dots) of daily changes in outflow (CFS; daily max flow – daily min flow) from Hungry Horse Dam, water years 2001 – 2022

Water temperature

Selective withdrawal was installed at Hungry Horse Dam in 1996 and is operated each year between June and September with the objective of maintaining more normative stream temperatures in the South Fork Flathead, downstream of the Dam. We describe these temperatures using degree days, which are an indicator of conditions that affect primary productivity. Temperature data (°C) collected from 1978 to 1981 indicated that degree days- the sum of daily temperatures from July – September- were in the ~400 – 500 range. In contrast, the estimated optimal total degree days for July – September is 1,308 (optimal temperature modeled by Marotz et al. 1996 and daily data published in Vermeyen 2006). Once selective withdrawal was installed in 1996, summer degree days were approximately three times higher and have ranged from 1,138 – 1,375 (Figure 47).

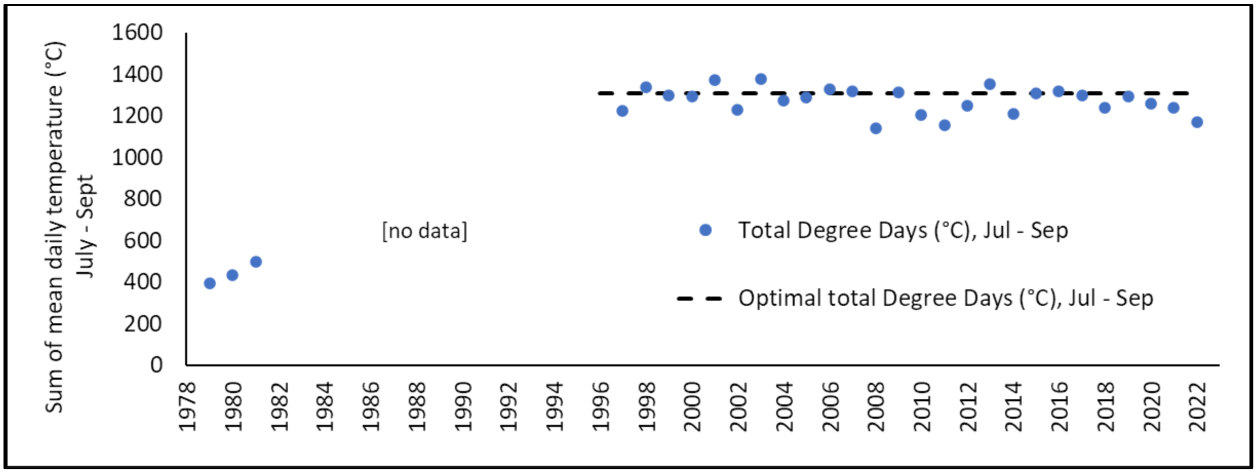


Figure 47. Total degree days, July – September (calculated as sum of mean daily temperature (°C) July – September) on the South Fork Flathead River before and after installation and operation of the selective withdrawal structure at Hungry Horse Dam, relative to optimal total degree days for fish growth, 1978 – 2022. Data in 1978 – 1981 were collected from Cavigli 2007, whereas data from 1997 – present were obtained from USGS gage 12362500. Optimal temperatures modeled by Marotz et al. 1996 and daily data available in Vermeyen 2006.

TDG

As with at Libby Dam, the Montana TDG standard of 110% was adopted in the 2000 BiOp. Since 2004, max TDG has ranged from 107 – 120% (Figure 48). In 2022, spill was necessary because turbines were down for the Hungry Horse Dam Modernization project. When spill occurs, flow is balanced through the outlet tubes to minimize TDG. During this spill event, TDG never exceeded 112%. Information on why elevated TDG occurred between 2013 and 2017 was not available at the time of this report.

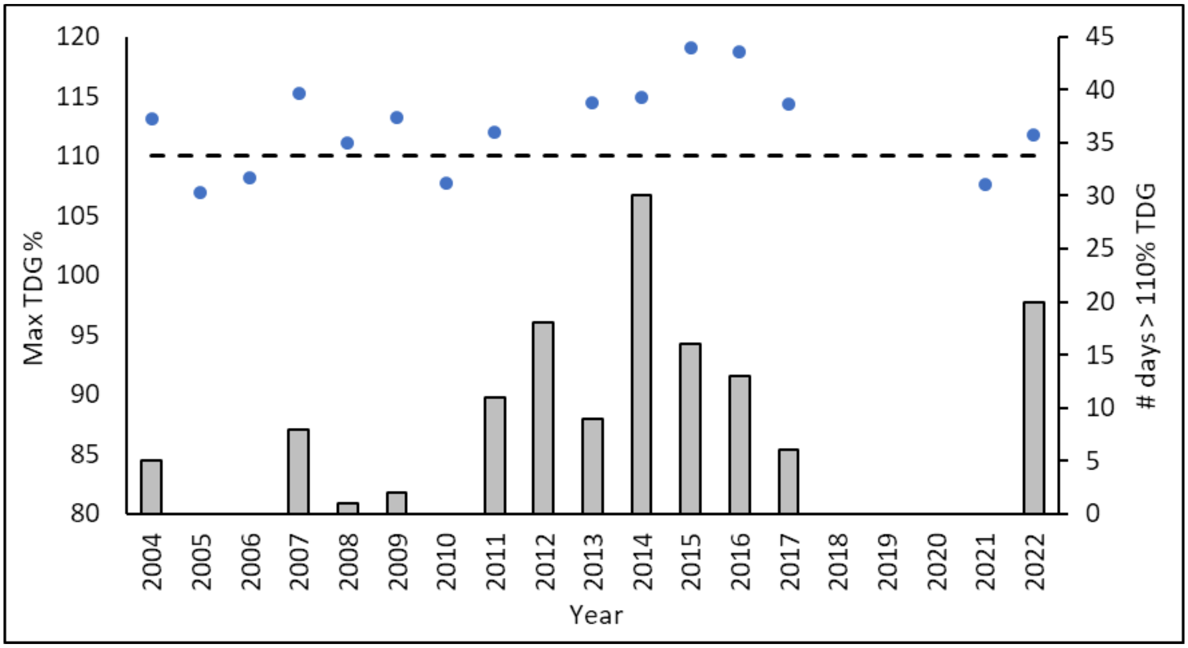


Figure 48. Maximum total dissolved gas (TDG) observed each year below Hungry Horse Dam (USACE HGHM), 2004 – 2022, relative to Montana water quality standard of 110% TDG. Grey bars represent the number of days each year when TDG exceeds 110%. Contemporary data ava

Discussion

Since 1982, there has been a growing list of measures implemented at Libby and Hungry Horse Dams for the benefit of resident fish in the Kootenai River and Flathead River, downstream of the dams. Key advances in operations occurred with BiOps in 1995, 2000, and 2006, and refinements in the 2003 mainstem amendments, all culminating in a set of operations referred to as the Montana Operations. With some exceptions, these have been fully implemented to the degree possible since approximately 2010.

Minimum flow requirements for Libby and Hungry Horse Dams have appeared in the Program since 1982. These minimum standards generally have been implemented, especially since 2001. Maintaining minimum flow is a high priority because the river environment is more sensitive than the reservoir. This means that in low flow years, if there is insufficient water to meet operations in both environments, the river will be prioritized.

Despite decades of measures on flows for Kootenai River white sturgeon, there has been no successful recruitment regardless of how much water is released and adult abundance continues to decline. This is a result of multiple factors, including habitat quantity and quality, food availability, and entrainment of juveniles in Libby Dam. Released water cues migrations to better upstream habitat, but the water temperature in that habitat is quite cold and not ideal for development of larvae.

In the first few years of implementation of bull trout flows at Libby Dam, minimum flow frequently exceeded 9 KCFS. In the last decade, minimum flows have typically ranged from 6 to 9 KCFS. Habitat connectivity and quality improve as flows exceed 9 KCFS. In particular, years of lower flows in the Kootenai River, combined with a natural transport of sediment down tributaries, have resulted in sediment accumulating in tributary deltas. When flow exceeds 9 KCFS, there is connectivity between the mainstem and tributaries, and some of that sediment can be transported away from the deltas.

Ramp rates are controlled to protect productivity and to minimize stranding or desiccation when flows decrease. Figures 40 and 45 show ramp rates using the daily and max change (or delta) in flow. Variability in the annual max of daily delta documents that in high water years or during peak flows, the outflow is allowed to ramp up rapidly, whereas variation in average daily delta reflects less stable flows. More variation in average daily deltas is observed at Libby than at Hungry Horse.

At both Libby and Hungry Horse Dams, the Program calls for using selective withdrawal to approximate normative temperature conditions downstream. Cold temperatures on the Kootenai River occur despite the operation of selective withdrawal, indicating that there is only so much warming that is possible (to create more productive downstream conditions) when conditions are otherwise cold. Selective withdrawal works when the upper 25 ft of the reservoir are sufficiently warm. It takes time for the reservoir volume to warm and begin to stratify each spring. This creates challenges in achieving established temperature targets, particularly in the spring when it is often physically impossible to release warm water through the selective withdrawal system.

The installation of selective withdrawal at Hungry Horse Dam in 1996 has allowed maintenance of more normative stream temperatures in the South Fork Flathead downstream of the dam. Summer degree days are now approximately three times higher than in the pre-selective withdrawal period and currently range from 1,138 – 1,375.

Libby and Hungry Horse Dams are managed to minimize spill and not exceed the Montana water quality standard of 110% TDG. However, differences in the structure of the dams and the characteristics of the downstream river environments result in different levels of TDG. At Libby Dam, if the sluice gate is used, TDG can reach high levels very quickly. Downstream of the spillway basin, the Kootenai River is relatively shallow. In deep water, fish can depth compensate for excess TDG by entering deeper water; TDG levels decrease by 10% for every 1 m below the water surface. However, when fish re-enter shallow water, e.g., when feeding, GBT symptoms increase rapidly. From 2010 – 2012, court-ordered spill for sturgeon caused excessive TDG; just a few KCFS of spill (>2 KCFS) can cause substantial increases in TDG. Keeping Lake Koocanusa (Libby Dam) at less than full pool decreases likelihood of having to spill.

At Hungry Horse Dam, the spillway does not seem to produce substantially elevated TDG. In addition, the Flathead River is quite deep below Hungry Horse Dam, so when there is excess spill, fish have the ability to access deeper water with less TDG. However, just as with Libby Dam, if they return to shallow water, they experience TDG and potentially GBT.

References

Cavigli, J. 2007. The Influence of Selective Withdrawal Operation at Hungry Horse Dam on the Benthos and Water Temperature of the South Fork Flathead and Main Stem Flathead Rivers, FWP report for Hungry Horse Fisheries Mitigation Project

Fosness, R. L., T. J. Dudunake, R. R. McDonald, R. S. Hardy, S. Young, S. Ireland, and G. C. Hoffman. 2017. Kootenai River White Sturgeon (Acipenser transmontanus) Fine-scale habitat selection and preference, Kootenai River near Bonners Ferry, Idaho. Available online at: https://pubs.usgs.gov/sir/2021/5132/sir20215132.pdf

Hardy, R., and McDonnell, K., 2020, Kootenai River resident fish mitigation—White sturgeon, burbot, native salmonid monitoring and evaluation—Annual progress report, May 1, 2017–April 30, 2019: Idaho Fish and Game Report Number 20-11, 157 p.

Marotz, B. L., C. Althen, B. Lonon, and D. Gustafson. 1996. Model development to establish integrated operational rule curves for Hungry Horse and Libby Reservoirs- Montana. Final Report to BPA, Project # 83-467.

Montana Fish, Wildlife, and Parks, Montana office of NPCC, and Confederated Salish and Kootenai Tribes. 2017. Montana operations at Libby and Hungry Horse dam. Available online at: https://www.nwcouncil.org/reports/montana-operations-libby-and-hungry-horse-dams

Sylvester, R. M., B. C. Stephens, and J. T. Frye. 2019. Mainstem Columbia Amendments Research at Libby Dam, 1/1/2018 - 12/31/2018 Annual Report, 2006-008-00. Report prepared by Montana Fish, Wildlife & Parks for Bonneville Power Administration. February 2019. Available at: https://www.cbfish.org/Document.mvc/Viewer/P164102

Vermeyen, T. B. 2006. Hungry Horse Selective Withdrawal System Evaluation 2000-2003. Hydraulic Laboratory Report HL-2006-06. Bureau of Reclamation, Denver, CO. Available online at https://www.usbr.gov/research/projects/researcher.cfm?id=20

Libby and Hungry Horse Dams – operations within the reservoirs

Libby and Hungry Horse Dams are operated to provide suitable flow and temperature conditions for resident fish downstream of the dams and to maintain productive conditions within the reservoirs. These operations are meant to balance water requirements for listed salmon and steelhead in the Columbia River and listed (bull trout, Kootenai River white sturgeon) and non-listed species in the reservoirs. In 2017, Montana Fish, Wildlife, and Parks and the Montana office of the NPCC, in consultation with the Confederated Salish and Kootenai Tribes, reviewed operations at Libby and Hungry Horse dams (MFWP et al. 2017). In this section, we build off that review and describe implementation of operations meant to maintain productive conditions within the reservoirs. We describe the development of Integrated Rule Curves, and operations for drawdown, refill, summer conditions, fall draft.

Table 10. Hydrosystem measures in the Council's Fish and Wildlife Program, and associated BiOp measures guiding mitigation for resident fish in Lake Koocanusa (above Libby Dam) and Hungry Horse Reservoir, 1982 – 2020

Program	Libby Dam/ Lake Koocanusa	Hungry Horse Dam/ Reservoir
1982	**Drawdown limits** to protect resident fish in normal (110 feet from full pool) and dry (90 ft from full pool) water years.	**Drawdown limits** to protect resident fish (85 ft from full pool).
1990s	**Integrated Rule Curves (IRCs) developed for Libby Dam** • Based on forecast, curves specify annual drawdown, refill, and draft operations. • Refill to full pool by end of July.	**IRCs developed for Hungry Horse Dam** • Based on forecast, curves specify annual drawdown, refill, and draft operations. • Refill to full pool by end of June.
1994	**Adopt IRCs in Program**	**Same as Libby**
1995 BiOp	• *Augment flows for juvenile salmon and steelhead.* • *Draft reservoir < 20 feet by end of Aug to provide downstream flows.*	• *Augment flows for juvenile salmon and steelhead* • *Draft < 20 feet by end of Aug*
2003	**Stable/ decreasing flows** to eliminate double peak in summer reservoir elevation. • IRCs adopted as experimental. • Refill within 5 ft at greater frequency than historically. • Fall draft date changes to end of Sep to increase stability over summer • Additional fall draft target- < 10 ft from full pool- added for normal water years; normal/dry year determined by inflow forecast at The Dalles Dam	Same as Libby
2008 BiOp	• *Incorporate above operations*	*Same as Libby*
2009	• Implement 2003 amendments • Implement IRCs • Implement actions in BiOps	Same as Libby
2014	• Operations no longer experimental • Continue refinements	Same as Libby

2020	Recommendations received from MTFWP and KTOI adopted in Program. Include: • Sep 30 draft limits for normal/ dry years now determined from local inflow forecast • Fixed fall draft replaced with variable draft (normal years = 5 ft, interpolating down to 20 ft in dry years) • Refill within 5 ft of full pool	Recommendations adopted in Program. Include: • Sep 30 draft limits for normal/ dry years now determined from local inflow forecast • Fixed fall draft replaced with variable draft (normal years = 10 ft, interpolating down to 20 ft in dry years)

Rows in italics describe measures referenced and implemented as mitigation through the Program that were first described in external documents. The year listed is the first time measures appear in a Fish and Wildlife Program

Integrated rule curves

Reservoir elevations at Libby and Hungry Horse are managed seasonally to create conditions in the reservoir and downstream of the reservoir using integrated rule curves (Figure 49). Rule curves describe a set of adjustable drawdown and refill elevation targets that are selected according to the water supply forecast. Drawdown, which generally occurs in the late winter and early spring, is the lowest elevation the reservoir reaches during the year to create space for incoming runoff. In a dry year, less drawdown is needed, and the reservoir can be refilled earlier in the year. Refill is the highest target elevation for the reservoir. During the late spring and early summer months, the reservoir is refilled, and that elevation is maintained at a constant level to promote productive reservoir rearing conditions. Draft means lowering the reservoir elevation in general. In the late summer and early fall, the reservoir is drafted to augment flows downstream of the dam for both resident and anadromous fish. Each seasonal operation- early spring drawdown, spring/summer refill, end of summer/early fall draft is connected. If targets for one season are not met in a given year, it is more difficult to reach the targets for the next seasonal operation.

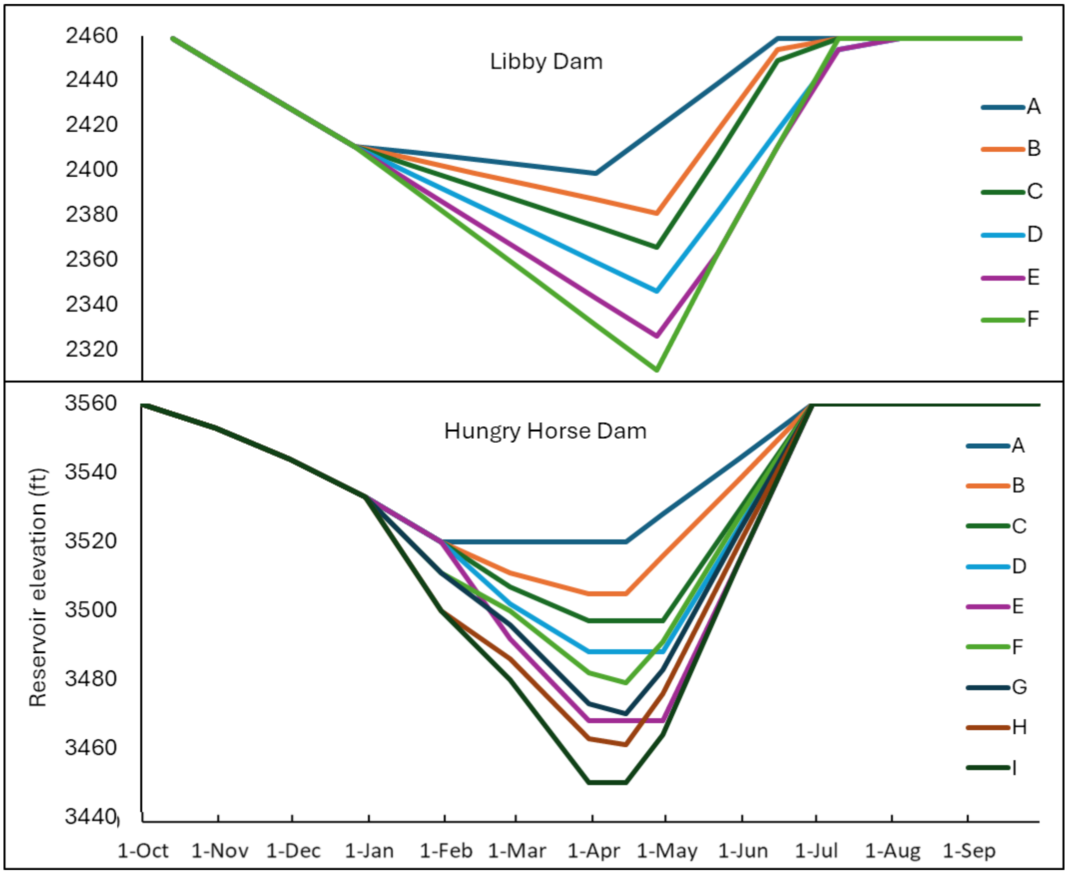


Figure 49. Integrated Rule Curves for Libby Dam (upper panel) and Hungry Horse Dam (lower panel) indicating adjustable drawdown and refill targets dependent on water supply forecast. Each of the lines represents a different kind of water year, ranging from a dry year (curve A) to a very wet year (curve E). Curves A – E apply to the first year of a critical period. During the second – fourth years of an extended drought, curves B – F (Libby Dam) and C - I (Hungry Horse Dam) allow for additional draft.

Libby Dam/ Lake Koocanusa

Summary of implementation

Drawdown

Reservoir drawdown is meant to be no deeper than the curve selected for a given year. In the late 1970s through early 1990s, Lake Koocanusa was frequently drawn very low. Since full implementation of the IRCs, there has been an end to very deep drawdowns and now more water is kept in the reservoir over time (Figure 50; Table 11). This water is available to support other fish operations in the reservoir and downstream.

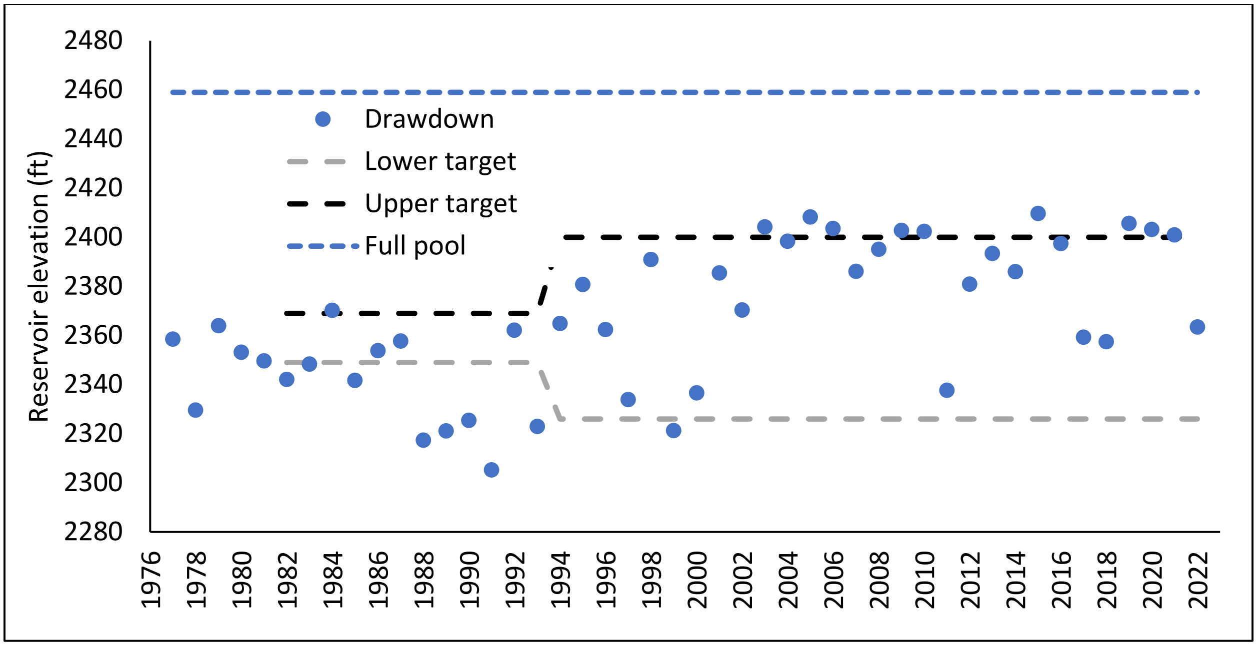


Figure 50. Lowest annual reservoir elevation (ft; blue dots) at Lake Koocanusa, 1977 – 2022, relative to full pool (blue dash), and corresponding upper (black dash; dry years) and lower (grey dash; wet years) drawdown limits. From 1982 – 1993, limits were 90 – 110 feet from full pool. From 1994 – present, drawdown limits were described as curves in the Integrated Rule Curve (upper and lower rule curves shown).

Table 11. Percent of time minimum reservoir elevation is at or above drawdown limit during three time periods: 1982 – 1993, 1994 – 2022, and 2010 – 2022 (the period when operations fully implemented) at Lake Koocanusa. Statistics correspond to data in Figure 50.

% time target met	1982 – 1993	1994 – 2022	2010 – 2022
Upper Target	8.3%	31%	38.5%
Lower Target	33.3%	96.6%	100%

Refill

In the 1980s and 1990s, there was pressure to achieve full pool each year. Now refill is considered to be 5 feet from full pool. Refill targets are typically not met at Lake Koocanusa (Figure 51; Table 12). Downstream operations for sturgeon, salmon, and steelhead result in less water being available to reach the refill target.

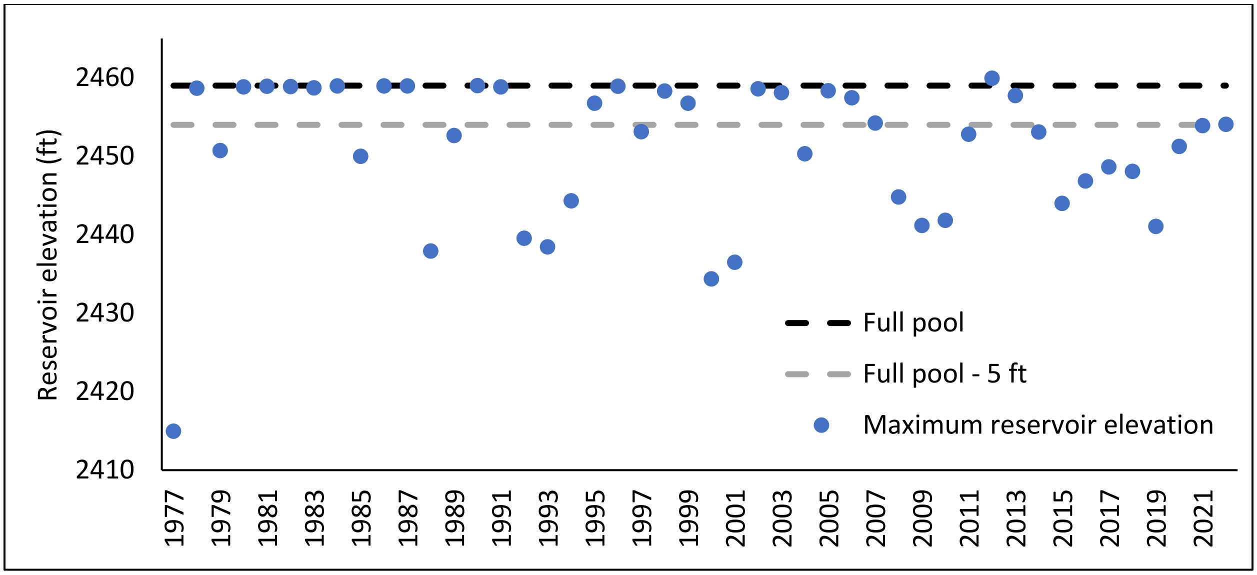


Figure 51. Maximum reservoir elevation (ft; blue dots) in July at Lake Koocanusa, 1977 – 2022, relative to full pool (black dash) and full pool – 5 feet (grey dash). From 1994 – 2002, the objective for summer operations was to refill to full pool by the end of July. In 2003, an additional objective was to refill within 5 feet of full pool at a greater frequency than historically achieved. Contemporary operations seek to achieve five feet from full pool and to maintain that level for the duration of the summer.

Table 12. Percent of time targets for reservoir refill or refill within 5 feet met from 1982 – 1993, 1994 – 2002, 2003 – 2022, and 2010 – 2022 (the period when operations fully implemented) at Lake Koocanusa. Statistics correspond to data in Figure 51.

% time target met	1982 – 1993	1994 – 2002	2003 – 2022	2010 – 2022
Refill to full pool	33.3%	0%	5%	7.7%
Refill w/in 5 ft of full pool	58.3%	55.6%	35%	23.1%

Stable summer conditions

After the reservoir achieves its highest summer elevation, the Program calls for maintaining stable or slightly decreasing reservoir elevations over the summer. In a year when refill could only be achieved for a short period of time, operations would prioritize instead reaching a lower reservoir elevation that could be held for a longer period of time to create optimal conditions for reservoir productivity.

In the mid to late 1990s, ESA listings triggered biological opinions describing operations that at times pitted resident fish priorities against salmon and steelhead. From 1995 – 2002, Libby Dam was operated to create a spring high flow event to benefit sturgeon spawning and then operated later in the summer to augment flows for migrating juvenile salmon and steelhead. This created a double pulse both downstream of the reservoir and in the reservoir, which proved disastrous for resident fish. As a result, the 2003 amendments incorporated measures calling for stable or consistently declining flow conditions and reservoir elevations through the productive summer months.

Since full implementation of the Montana operations around 2010, there has been increased stability in summer reservoir elevations. In addition, there has been a general increase in the amount of water held in reservoirs over time and a decrease in the annual variability in reservoir elevation. This reflects improved maintenance of stable flows.

End of summer draft

The water drafted from the reservoir at the end of September is used to augment flows for migrating salmon and steelhead and to maintain flow conditions downstream for resident species like bull trout. In normal water years, less water needs to be drafted to meet downstream flow requirements because reservoir inflows can be passed through. Drafting is not meant to be any lower than the limit for a given water year.

In recent years, most drafting occurs between the dry year and normal year targets at Libby Dam; draft is rarely on or near the normal year target, where it is meant to be approximately 80% of the time (Figure 52; Table 13). Beginning in 2020, a variable draft limit was put in place for the end of September. Draft is now interpolated based on water year between 5 and 20 ft from full pool.

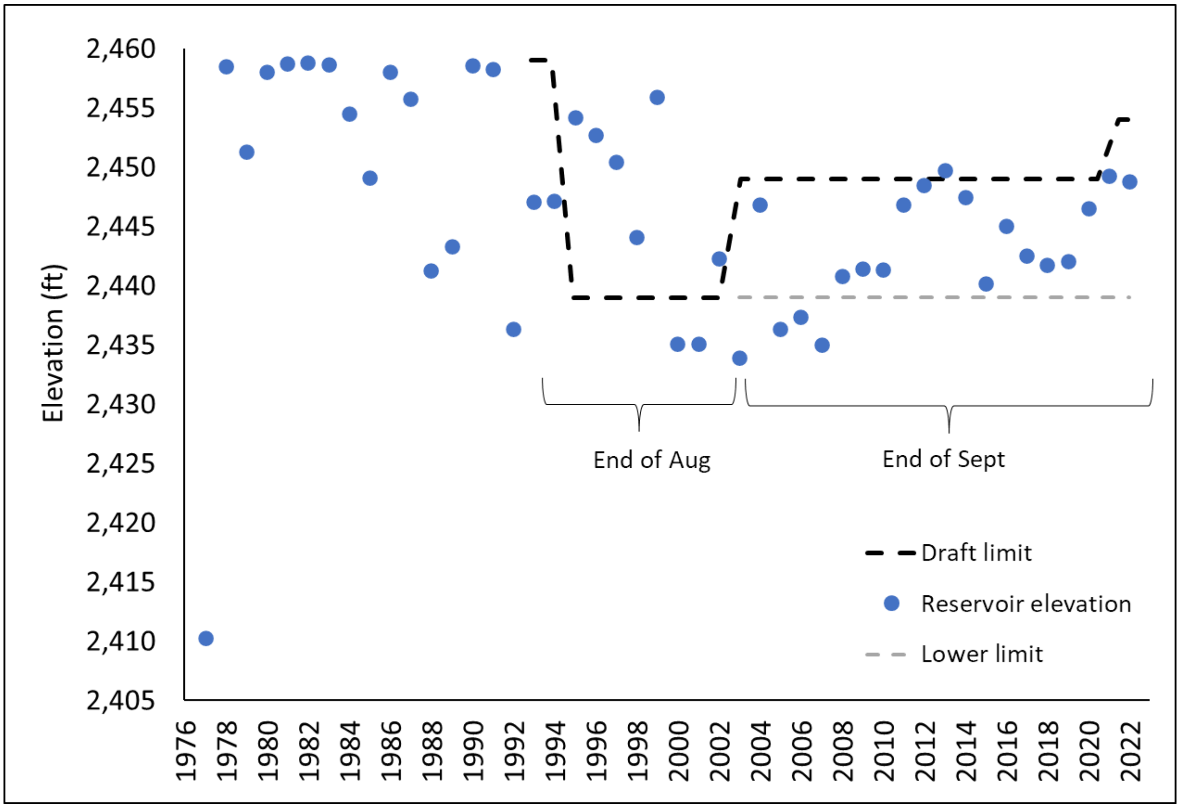


Figure 52. Reservoir elevation (ft; blue dots) at the end of August (1993 – 2002) or September (2003 – present) relative to normal water year draft target (black dash) and low water year draft target (grey dash) at Libby Dam, compared to the period of record, 1977 – 2022.

Table 13. Percent of years end of August/September reservoir elevations remain at or above draft targets during 1993 – 1994, 1995 – 2002, 2003 – 2022, and 2010 – 2022 (the period when operations fully implemented) at Lake Koocanusa. Statistics correspond to data in Figure 52.

Targets	1993 – 1994 (Aug)	1995 – 2002 (Aug)	2003 – 2022 (Sep)	2010 – 2022 (Sep)
Normal water year	0%	100%	60%	92.3%
Low water year	-	-	90%	100%

Hungry Horse Reservoir

Summary of implementation

Drawdown

Over the last 10 years, there has been substantially less drawdown at Hungry Horse than in either the early period of the Program (1982 – 1993) or prior to the Program (Figure 53; Table 14). The general decrease in drawdown reflects the slow implementation of the IRCs from 1994 until ~2010.

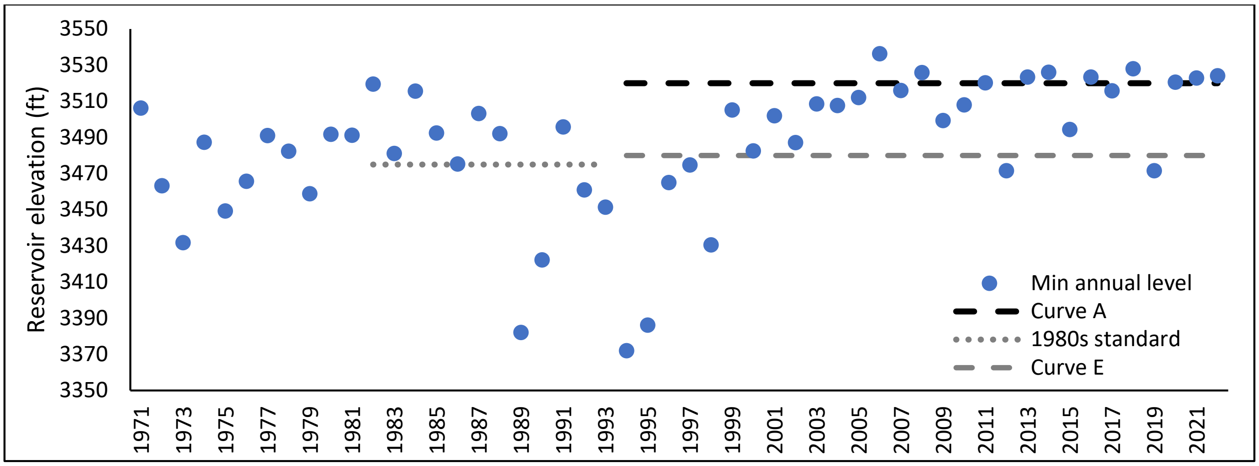


Figure 53. Lowest annual reservoir elevation (ft; blue dots) at Hungry Horse Reservoir, 1972 – 2022, relative to corresponding upper (black dash) and lower (grey dash) drawdown targets. From 1982 – 1993, the target was 85 feet from full pool. From 1994 – present, drawdown targets were described as curves in the Integrated Rule Curve (targets shown for curve A (black dash) and curve E (grey dash)

Table 14. Percent years that minimum reservoir elevation at or above drawdown target during three time periods: 1982 – 1993, 1994 – 2022, and 2010 – 2022 (the period when operations fully implemented) at Hungry Horse Reservoir. Statistics correspond to data in Figure 53. Normal year target corresponds to Curve A or the 1980s standard, and wet year target corresponds to Curve E.

% time target met	1982 – 1993	1994 – 2022	2010 – 2022
Normal year target	66.6%	34.5%	61.5%
Wet year target	-	75.9%	84.6%

Refill

Aside from low water years, refill consistently occurs within 5 feet of full pool (Figure 54; Table 15). This is a marked departure from operations prior to the mainstem amendment, when refill within 5 feet of full pool was achieved only 25% of years.

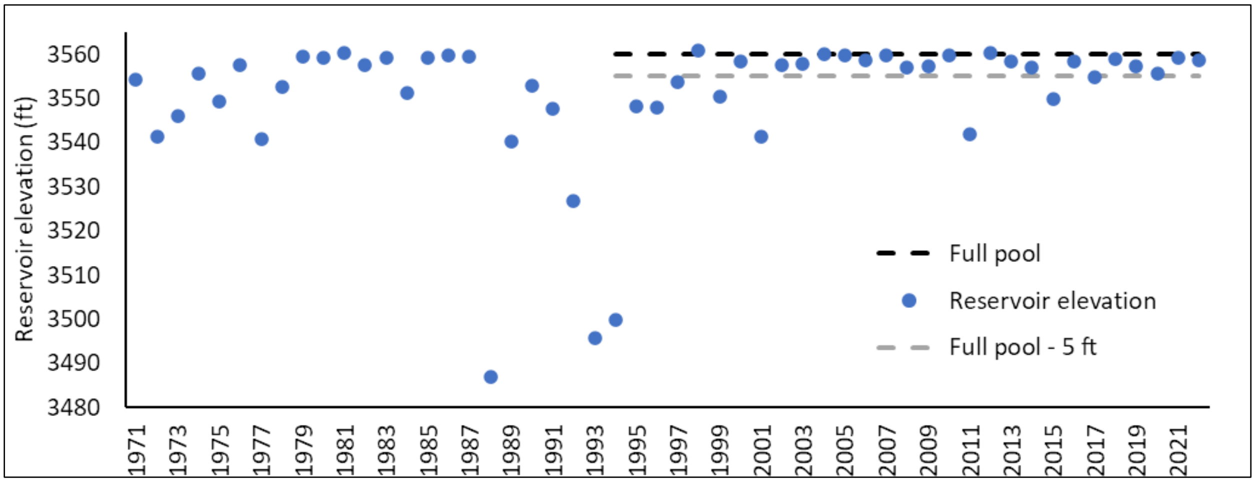


Figure 54. Maximum reservoir elevation (ft; blue dots) in June at Hungry Horse Reservoir, 1972 – 2022, relative to full pool (black dash) and full pool – 5 feet (grey dash). From 1994 – 2002, the objective for summer operations was to refill to full pool by the end of June. In 2003, an additional objective was described as refilling within 5 feet of full pool at a greater frequency than historically achieved.

Table 15. Percent of time targets for reservoir refill or refill within 5 feet met from 1982 – 1993, 1994 – 2002, 2003 – 2022, and 2010 – 2022 (the period when operations fully implemented) at Hungry Horse Dam. Statistics correspond to data in Figure 54.

% time target met	1994 – 2002	2003 – 2022	2010 – 2022
Refill to full pool	11.1%	5%	7.7%
Refill w/in 5 ft of full pool	25%	85%	76.9%

Stable summer conditions

After the reservoir achieves its highest summer elevation, the Program calls for maintaining stable or slightly decreasing reservoir elevations over the summer. As with Libby Dam, this measure began in 2003 in response to the double flow pulse that was occurring to provide flows for both sturgeon and migrating juvenile salmon and steelhead. Since full implementation of the Montana operations, there has been increased stability in summer reservoir elevations, a general increase in the amount of water held in reservoirs over time, and a decrease in the annual variability in reservoir elevation.

End of summer draft

At Hungry Horse Dam, drafting typically remains above the normal year target, particularly since operations were fully implemented (Figure 55; Table 16).

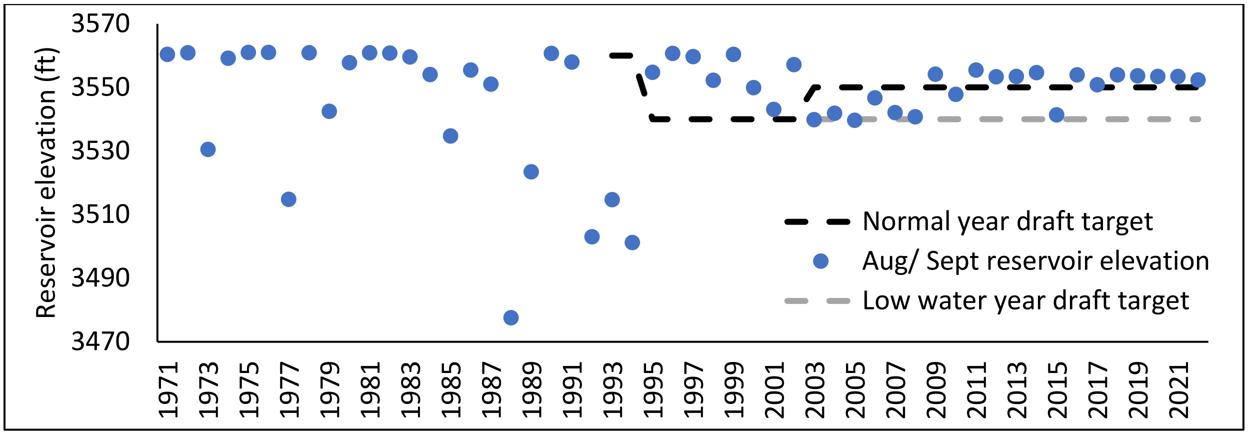


Figure 55. Reservoir elevation (ft; blue dots) at the end of August (1993 – 2002) or September (2003 – present) relative to normal water year draft target (black dash) and low water year draft target (grey dash) at Hungry Horse Dam, compared to the period of record, 1971 – 2022.

Table 16. Percent of years end of August/ September reservoir elevations remain at or above draft targets during 1993 – 1994, 1995 – 2002, 2003 – 2022, and 2010 – 2022 (the period when operations fully implemented) at Hungry Horse Dam. Statistics correspond to data in Figure 55.

Targets	1993 – 1994 (Aug)	1995 – 2002 (Aug)	2003 – 2022 (Sep)	2010 – 2022 (Sep)
Normal water year	0%	100%	60%	92.3%
Low water year	-	-	90%	100%

Discussion

Montana operations were adopted as experimental in the 2003 amendments and complete implementation did not occur until ~2009/2010. In general, implementation of these operations at Libby Dam has been variable because local and downstream operations for resident and anadromous species compete for the same water. In contrast, implementation at Hungry Horse Dam has been more consistent. This is primarily due to fewer constraints on flows (e.g., no sturgeon operations).

Integrated Rule Curves were adopted in the Program in 1994. The Council played a large role in helping these operations gain regional support and implementation. After the IRCs were adopted, the USACOE developed a new flood risk management strategy, termed “VarQ” (variable discharge) based on the IRCs. The intention was to avoid excess drawdowns while managing flood risk. When modeling demonstrated that VarQ would not negatively impact standard flood risk management, it was embraced by both the BOR and USACOE. The VarQ strategy was reviewed under NEPA and after approval was ramped up into full implementation.

At both Libby and Hungry Horse, full implementation of IRCs has resulted in less drawdown and more water kept in the reservoirs. This water is available to support other fish operations or uses of the hydrosystem.

Refill targets (within 5 feet of full pool) are typically not met at Libby Dam but are met at Hungry Horse Dam. Achieving operations for Kootenai River white sturgeon and downstream flow targets affect the ability to achieve the refill target at Libby Dam (Sylvester et al. 2019). Although the official refill target at Libby Dam is still full pool and achieving refill within 5 feet more frequently than historically, the management target has shifted to define refill as 5 ft from full pool. Managers identified that the Lake Koocanusa ecosystem was better served by maintaining slightly lower reservoir elevations in the summer for several reasons. First, when achieving full pool, the band of warm water in the reservoir occurs at a higher elevation because it tracks with the surface elevation; as the warm water rises, aquatic insects are left in cold, less productive, water below the warm band. Second, in lower flow years, it is better to reach a refill level and maintain it for at least a month (to spur productivity), than to briefly reach full pool but then draft to a lower level. Third, keeping the elevation of Lake Koocanusa slightly lower in the summer decreases the potential for involuntary spill, which can rapidly elevate TDG downstream of Libby Dam. Lastly, the revised refill operation allows for better stabilization of river flows as the reservoir approaches full pool. These changes reflect adaptive management implemented through the water management plans.

Stable reservoir elevations are achieved July – August with increasing frequency. These are important for creating a productive environment in the reservoir. They also contribute to stable flow conditions downstream. If a tradeoff needs to occur between meeting reservoir elevation targets and downstream flow targets, the priority is downstream flow because the river is a more sensitive environment than the reservoir.

If refill is not achieved, there is less water available to meet the September draft limit. Draft is frequently above dry year limit, especially post 2010, but most draft falls below normal year limit. In a dry year, more draft is required to achieve minimum flows downstream.

Water forecasts are developed to estimate how much runoff will come down the river. Based on that forecast, rule curves are selected to manage reservoir elevations across the year. Forecasts are developed at Libby Dam by the USACOE and at Hungry Horse Dam by the BOR for the April – August time period and are finalized in May. Once the forecast is generated, it is utilized in decisions regarding timing and magnitude of fish operations for each year. The accuracy of forecasts affects implementation of reservoir management for multiple objectives, including flood risk management and fish operations.

There is tremendous variation in water temperature and precipitation patterns throughout the Columbia Basin, often over short geographic distances. This variation in temperature and precipitation contributes to challenges in forecasting the amount of water that is expected to be available each year and the specific fish operations that can be implemented given those runoff conditions. When conditions are drier than forecast, it is possible that the reservoir may be drawn down too deep and this can make it difficult to achieve refill. When conditions are wetter than forecast, there may be insufficient storage space for flood risk management and excess flow may have to be spilled. At some large storage dams, this can create issues with total dissolved gasses.

Until 2020, decisions about normal or dry year operations at Libby and Hungry Horse Dams were made using the water forecast at The Dalles. In general, there was good agreement between forecast and observed runoff volume at The Dalles (Figure 56). However, when contrasting forecasts at The Dalles vs observed conditions at Libby and Hungry Horse Dams, it was clear that there were years when more or less water was available in the upper basin than would be predicted at The Dalles.

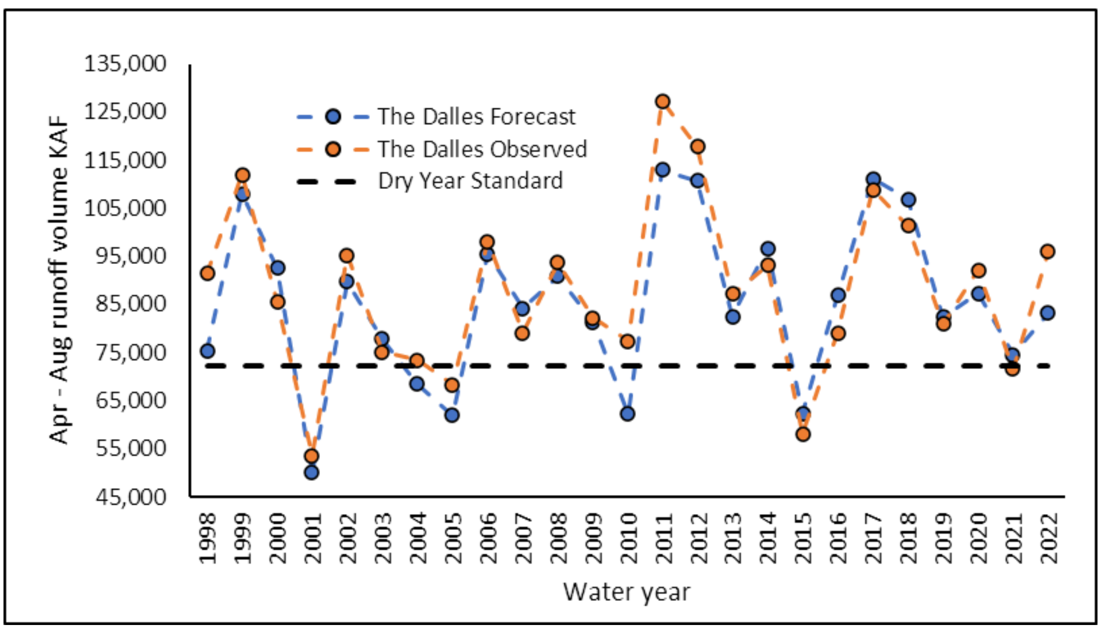


Figure 56. Final May forecast for April – August runoff volumes (blue dots) compared to observed April – August runoff volumes (orange dots) at The Dalles Dam, 1998 – 2022. Dashed line represents runoff volume that triggers dry-year operations at Libby Dam, with values occurring below the line approximately 20% of water years.

In 2020, at the request of managers in Montana, local runoff forecast volumes, rather than forecasts at The Dalles, were used to determine annual operations at Libby and Hungry Horse. The use of local forecasts addressed regional differences in runoff patterns. However, it has also highlighted how the temperature and precipitation patterns in the basin are shifting, often in ways that make forecasting more challenging (Hoffman, personal communication; Marotz, personal communication). At Libby Dam, there has been a shift in the last decade where observed runoff is lower than forecast runoff (Figure 57). Forecasts assume that summer precipitation (as rainfall) will be average and that the majority of runoff is determined by snowmelt at a typical time of year (Hoffman, personal communication; Marotz, personal communication). In recent years, summer precipitation has been below average, more precipitation has been falling as rain, and runoff at lower elevations has occurred earlier in the year (Sylvester et al. 2019; Marotz personal communication).

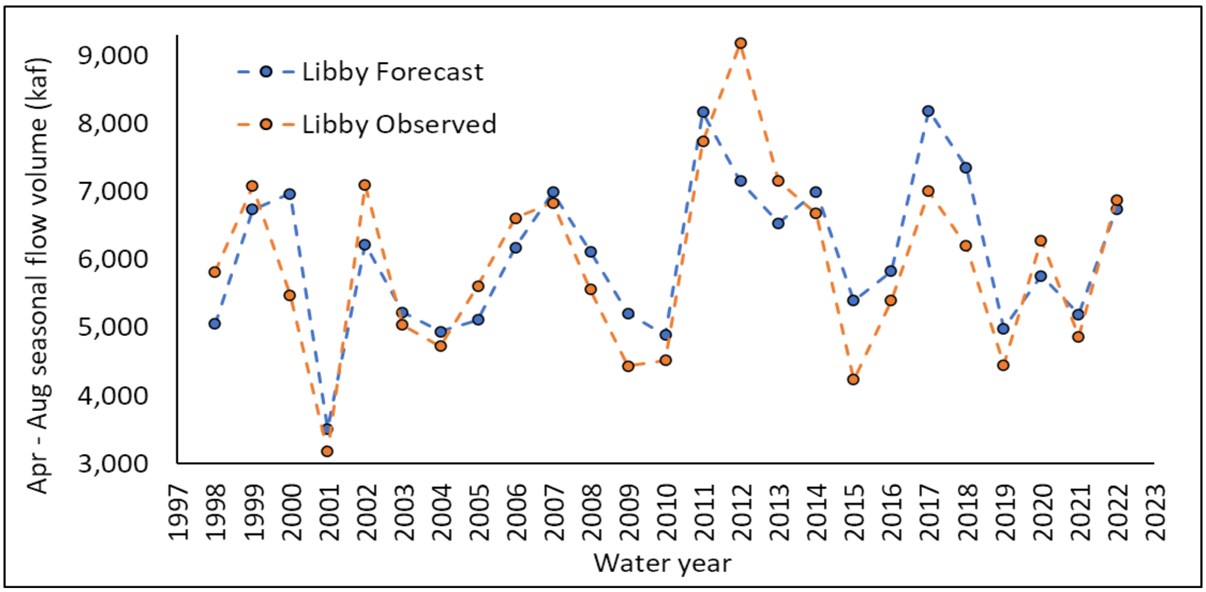


Figure 57. Final May forecast for April – August runoff volumes (blue dots) compared to observed April – August runoff volumes (orange dots) at Libby Dam, 1998 – 2022.

In seven of the last nine years, observed runoff has been drier than what was forecasted (Figure 58). In some cases, this has resulted in larger flow volumes being released for sturgeon than would have been supported by the observed flow. This can make it challenging to achieve refill and draft limits later in the year.

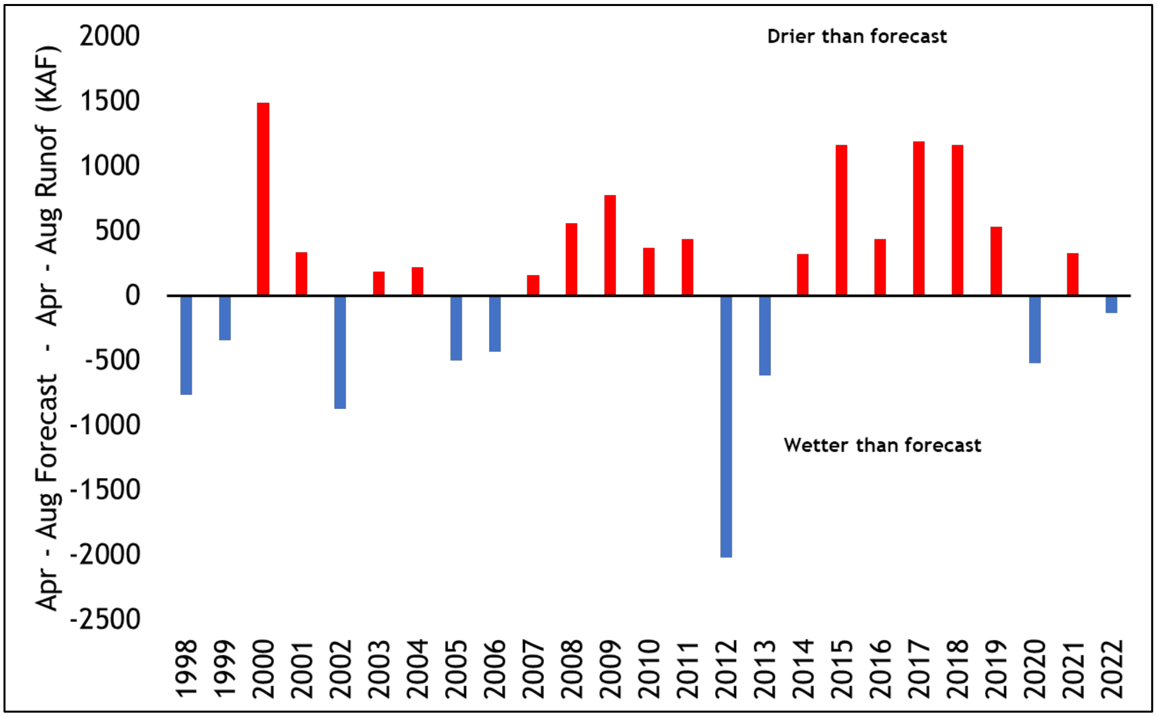


Figure 58. Final May forecast for April – August runoff volume (KAF) at Libby Dam compared to observed runoff volume, 1998 – 2022. Values calculated as *forecast runoff - actual runoff*. Positive (red) values indicate drier years than forecast (less runoff), negative (blue) values indicate more runoff than expected.

Managers have developed tools to improve in-season management as they seek improvements in models. One change has been to add an additional review of the forecast in June to account for potential deficits in expected summer precipitation (2024 Water Management Plan). Through adaptive management, adjustments can be made in-season if inflows are lower than expected. When comparing the May forecast to the June forecast and the observed runoff for May – September, it is clear that this additional forecast review in June better reflects observed runoff patterns and minimizes the chance of overcommitting water resources (Figure 59). Another tool that has been developed is the use of a variable draft limit of 5 to 20 ft to avoid the abrupt transition in reservoir elevation that could occur in water years approaching the dry year cutoff.

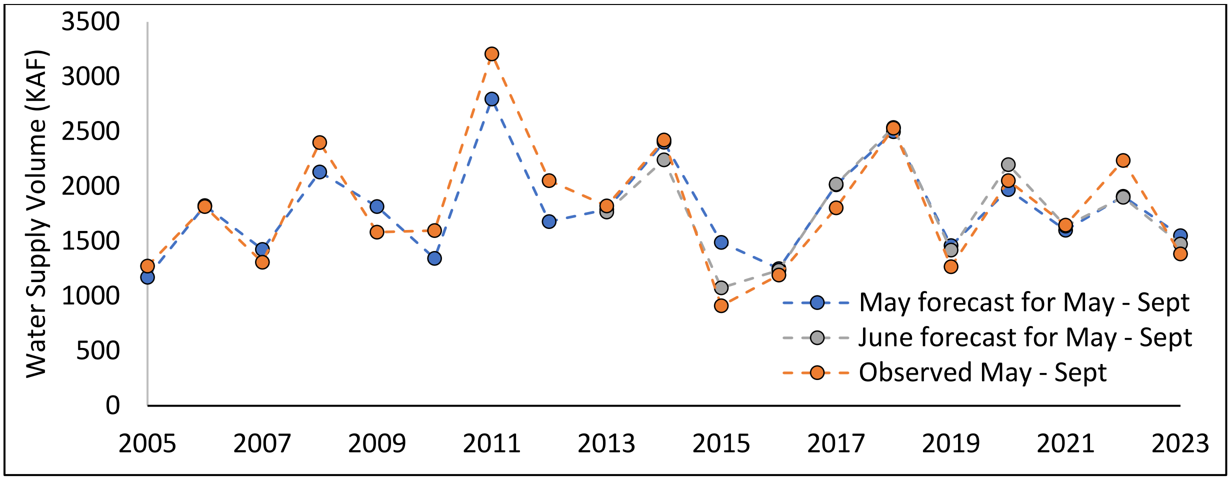


Figure 59. Final May forecast (blue dots) and June forecast (grey dots) for May – September runoff volumes compared to observed May – September runoff volumes (orange dots) at Hungry Horse Dam, 2005 – 2022.

References

Boyer, M. 2023. Personal communication with K. Homel

Hoffman, G. 2023. Personal communication with K. Homel.

Marotz, B. 2023. Personal communication with K. Homel.

Montana Fish, Wildlife, and Parks, Montana office of NPCC, and Confederated Salish and Kootenai Tribes. 2017. Montana operations at Libby and Hungry Horse dam. Available online at: https://www.nwcouncil.org/reports/montana-operations-libby-and-hungry-horse-dams

Sylvester, R. M., B. C. Stephens, and J. T. Frye. 2019. Mainstem Columbia Amendments Research at Libby Dam, 1/1/2018 - 12/31/2018 Annual Report, 2006-008-00. Report prepared by Montana Fish, Wildlife & Parks for Bonneville Power Administration. February 2019. Available at: https://www.cbfish.org/Document.mvc/Viewer/P164102

Water Management Plan. 2024. Available online at: https://pweb.crohms.org/tmt/documents/wmp/2024/Draft_1_October_1/Comments/20230929_2024_WMP_Draft_1_NMFS.pdf

Grand Coulee / Lake Roosevelt

Grand Coulee Dam became operational in 1942. It was constructed to be a major power producer and a source for irrigation water in the basin. As a storage reservoir, it also has an important role in flood risk management. Grand Coulee Dam impounds Lake Roosevelt and water from that reservoir is also pumped into a neighboring basin to fill Banks Lake. Grand Coulee operations contribute to many anadromous and resident fish needs in the basin, as previously described. Here we describe two operations specifically targeting resident fish: (1) maximizing water retention times and (2) maintaining a minimum elevation to protect kokanee spawners.

Table 17. Hydrosystem measures in the Council's Fish and Wildlife Program guiding mitigation for resident fish in Lake Roosevelt above Grand Coulee Dam, 1982 – 2020

Program	Measures
1994	**Water retention times** • No significant reduction in water retention times Jun 15 – Sep 30
1995	**Water retention times** • Max water retention times possible, with a min of 40 days Jun 15 – Sep 30
2003	**Water retention times** • Maximize water retention times from Jun – Dec of 40 – 60 days • Sep-Dec min elevation = 1283 feet to protect kokanee access and spawning. • Across each season and each day minimize reservoir fluctuations.
2009	**Sep – Dec: maximize water retention times** • Protect kokanee access and spawning **Stable reservoir elevations**
2014	**Revised water retention times** **Stable reservoir elevations**

The year listed is first time measures appear in a Fish and Wildlife Program.

Water retention time describes the amount of time it takes for a particle of water to travel from the reservoir inflow to the outflow. There are considerable year to year differences in water retention times. However, average monthly retention times frequently fall below the minimum standard of 40 days, especially during the summer (Table 18). When comparing average monthly values pre-1995 and post-1995, there has been a consistent reduction in retention times during the months of June, July, and August, an increase in retention times for September and October, and no appreciable difference in retention times for November and December (Table 18).

Table 18. Average monthly water retention times for June – December averaged across years prior to (1971 – 1994) and post (1995 – 2021) adoption of monthly minimum retention standard of 40 days

Years	June	July	August	September	October	November	December
1971 - 1994	33.4	41.4	47.3	58.6	58.0	51.4	43.6
1995 - 2021	29.6	38.0	42.5	63.5	66.1	51.7	43.8

Beginning in 2003, the Program called for maintaining a minimum elevation of 1283 ft to protect kokanee salmon during spawning. During the four-month season when this standard applies, elevations are typically at or above that minimum for 2 – 3 months and within five feet of the elevation for the remainder of the season (Figure 60). Prior to the establishment of the minimum elevation, fall elevations were frequently held above 1283 ft but there could be considerable interannual variation in elevation, with some years dropping to 1251 or 1260 ft.

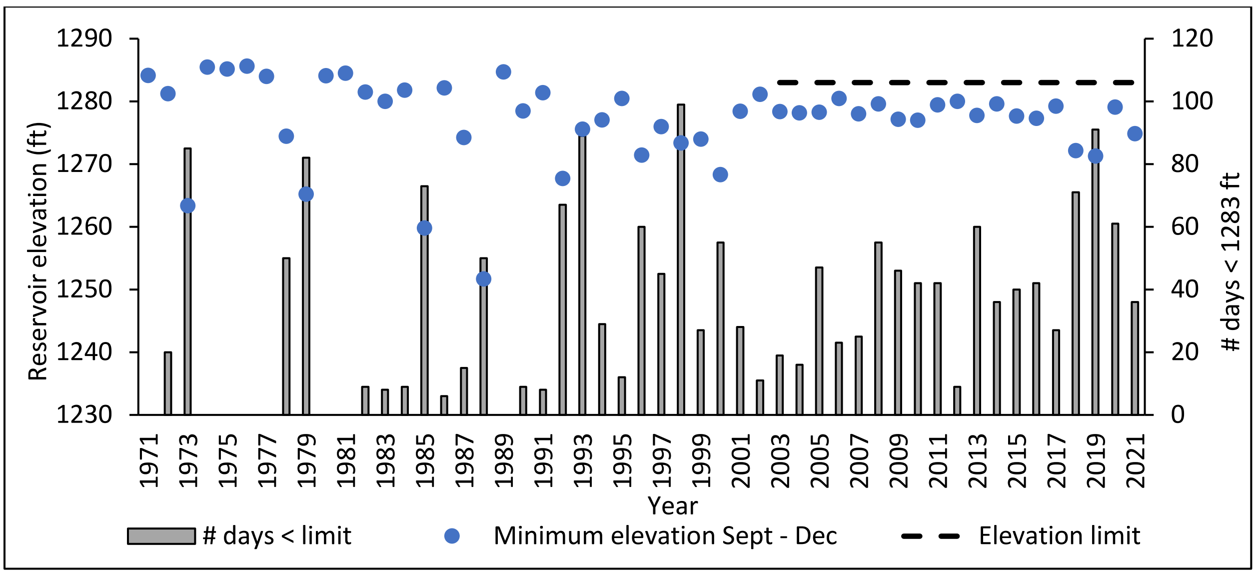


Figure 60. Reservoir elevation (ft; blue dots) September - December relative to minimum elevation target of 1283 ft (black dash) called for in the 2003 Program for protection of kokanee salmon, at Lake Roosevelt, Grand Coulee Dam, 1971 – 2021. Bars represent the number of days during the season when reservoir elevations fell below the minimum elevation target.

Reservoir managers try to minimize reservoir fluctuations as much as possible across seasons and within days. From 1971 until approximately 2002, there was substantial interannual variation in July, August, and September reservoir elevations. For example, in some years summer reservoir elevations dropped almost 20 feet from full pool and in others, elevations remained at almost full pool for the entire summer. During this period, the lowest elevations would occur in July with refill achieved in August and drafting beginning in September.

That pattern changed abruptly around 2003. Refill was targeted for the end of June, maintained through July, and then drafting began between July and August down to a minimum level of 1278-1280 feet. In September, further drafting could occur, which would bring the reservoir below the established minimum levels and affect water availability for Kokanee spawners. Over the last 50 years, there has been a slight increase in average annual reservoir elevation, indicating that Lake Roosevelt is not drawn down as deeply as it has been in the past.

Discussion

Grand Coulee is primarily operated for purposes other than resident fish. At times it is possible to achieve beneficial operations for reservoir rearing fish, but that is a function of flow conditions in each water year and not a change in priorities. Despite limited implementation of reservoir rearing measures, those measures still function as benchmarks describing ideal reservoir conditions.

Maximizing water retention times is most critical during the warm, productive summer months. Where retention times are longer, the reservoir can stratify, although that is extremely limited at Lake Roosevelt (Knudson and Kain 2021). Over time, there has been a reduction in retention times during the months of June, July, and August, and retention times frequently fall below the minimum standard of 40 days. This may create challenging conditions for primary and secondary productivity in the reservoir (Knudson and Kain 2021).

Beginning in 2003, the Program called for maintaining a minimum elevation of 1283 ft to protect kokanee salmon during spawning. Reservoir elevations are typically at or above that minimum for 2 – 3 months and within five feet of the elevation for the remainder of the four-month spawning season.

References

Knudson, T. and A. Kain. 2021. Lake Roosevelt Fisheries Evaluation Program 2020 Annual Limnological Assessment. Prepared for BPA by the Spokane Tribe of Indians under project #1994-043-00. Available online at: https://www.cbfish.org/Document.mvc/Viewer/P190993

Albeni Falls/ Pend Oreille

Albeni Falls Dam was constructed in 1955 and regulates the upper 11.5 feet of Lake Pend Oreille. Kokanee salmon were introduced into Lake Pend Oreille to support a fishery. They also function as prey for threatened bull trout. The Program called for research in the 1980s to understand how lake elevations at Pend Oreille affected survival and production of kokanee. Historical winter operations resulted in low lake elevations and it was thought these might affect the availability of spawning habitat. Furthermore, Albeni Falls Dam does not have fish passage, and dam construction fragmented productive habitat for migratory bull trout in the Pend Oreille River and Lake ecosystem.

Table 19. Hydrosystem measures in the Council's Fish and Wildlife Program guiding mitigation for resident fish in Lake Pend Oreille and bull trout in the Pend Oreille ecosystem, 1982 – 2020

Program/ event year	Measure
1982 Program	Evaluate degree to which Albeni Falls affects Lake Pend Oreille fishery.
1991 – 1993 Programs	Experiment with winter lake levels to benefit kokanee spawning.
1994 Program	Investigate changing winter lake levels to benefit kokanee; begin in 1995.
1995 Amendment	Fund kokanee/ Pend Oreille bull trout study.
2000 BiOp	*Call for feasibility study for upstream and downstream passage.*
2009	Provide trap and haul transportation for bull trout around Albeni Falls while dam upgrade options are investigated.
2014/2020	USACOE in collaboration with state and federal agencies and tribes, should continue to implement improvements to the adult fish passage facilities at mainstem dams to benefit salmon and steelhead, Pacific lamprey, white sturgeon, and bull trout.

The year listed is first time measures appear in a Fish and Wildlife Program.

Summary of implementation

Winter lake levels

A minimum control elevation (MCE) is established each year in November and December to protect spawning kokanee salmon; Lake Pend Oreille cannot be drafted below the MCE. The MCE has ranged from 2051 to 2055 ft during experimental operations to protect spawners and understand how lake elevations affect productivity. Established MCEs are consistently met (Figure 61).

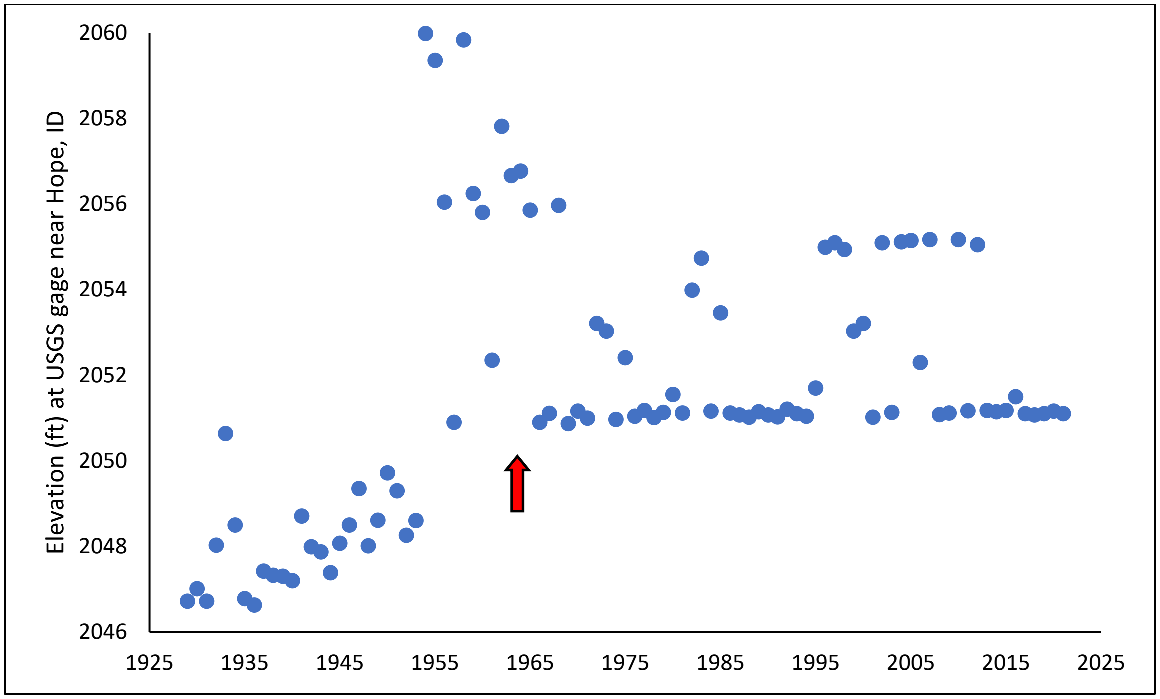


Figure 61. Minimum elevation of Lake Pend Oreille, Nov. 15 – Dec. 31, as recorded at USGS gage 12392500 at Hope, ID. Albeni Falls Dam (red arrow) was constructed in 1955 and regulates the upper 11.5 feet of Lake Pend Oreille.

Bull Trout

The 2000 USFWS BiOp called for researching the feasibility of installing fish passage at Albeni Falls for bull trout and the 2009 Program called for implementing trap and haul while feasibility was assessed. Trap and haul was instituted through a project implemented by the Kalispel Tribe. Monitoring data suggested that fish transported above the dam did not fall back and continued upstream migrations into spawning tributaries (Paluch et al. 2009). Bull trout populations in the Pend Oreille subbasin are monitored through redd counts in multiple streams. Passage for bull trout at Albeni Falls is currently being studied. Installing passage at Albeni Falls will allow for increased life history diversity and improve connectivity among populations, which vary in abundance throughout the subbasin (Figure 62).

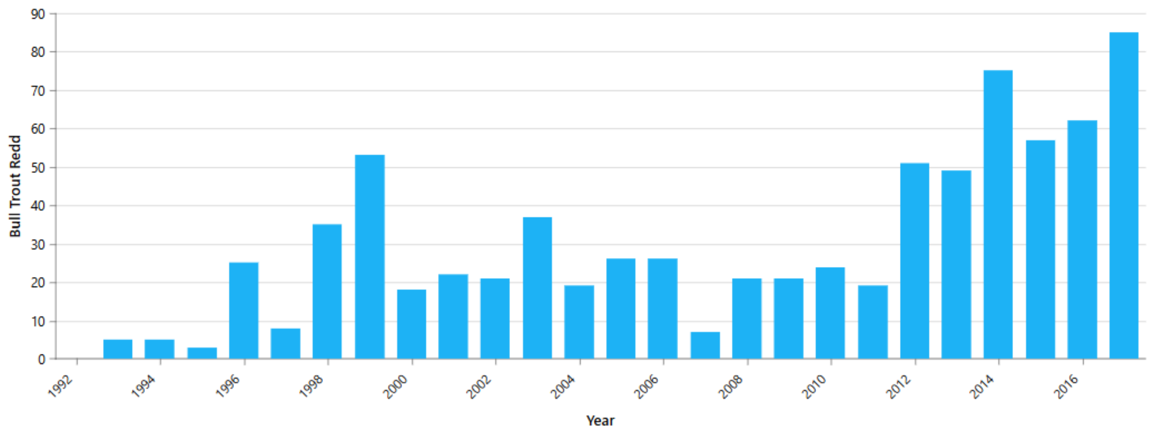


Figure 62. Bull trout abundance (redd counts) in the upper Priest River within the Pend Oreille subbasin. Redd count data for all surveyed streams available on NPCC Program Tracker, Strategy Performance Indicator R1-1.

Discussion

The MCE is consistently implemented at Lake Pend Oreille to protect kokanee salmon redds between Nov. 15 and Dec. 31. In the late 1990s, a decision tool was developed to set annual winter water levels between 2051 and 2055 ft to maximize spawning habitat for kokanee (Maiolie et al. 2002). Annual monitoring data were collected throughout the 2000s and in 2012, IDFG determined that there was not a clear relationship between winter elevations at 2055 ft and improved productivity. As such, operations reverted to a winter lake level of about 2051 ft to protect redds from desiccation.

The USACOE has completed an Environmental Impact Statement (EIS) for passage restoration and is in a design phase. In December of 2023, the USACOE posted a request for feedback on their two-way passage designs.

References

Maiolie, M. A., K. Harding, W. Ament, and W. Harryman. 2002. Lake Pend Oreille fishery recovery project. Idaho Department of Fish and Game, Completion Report to Bonneville Power Administration, Contract 1994-047-00. Portland, Oregon.

NMFS. 2014 FCRPS BiOp. Available online at: https://www.salmonrecovery.gov/doc/default-source/FCRPS-BiOp/2014/2014-apr_section-2_9-30-15_final.pdf?sfvrsn=2

Paluch, M. A. Scholz, H. McLellan, and J. Olson. 2009. Temporary Restoration of Bull Trout Passage at Albeni Falls Dam. Report submitted to BPA. Project Number 2007-246-00. Available online at: https://digital.library.unt.edu/ark:/67531/metadc932459/m1/2/

USACE and BPA. 2011. Albeni Falls Dam, Flexible Winter Power Operations Bonner County, Idaho, Final Environmental Assessment October 2011. Available online at:

https://www.energy.gov/sites/default/files/2013/10/f4/EA-1894_Albeni_Falls_Dam_10-2011.pdf

Conclusion – Key points

The region is changing, the climate is changing, and the human population of the Northwest is increasing. All of these changes place additional demands on the hydrosystem. How does our program best prepare for these changes? What opportunities exist for climate adaptation? Where have investments lacked? What other strategies might be critical in the future to take this program into the next 40 years?

- Adaptive management
  - Key to implementing hydro operations, given multiple priorities and environmental conditions
  - Targets function as sideboards but actual implementation requires ongoing management decisions including in-season
  - Programs called for adaptive management from beginning, called for evaluation, identified who could participate, set up processes for coordination
- Priorities
  - Program typically does not contain priorities for how to implement multiple fish operations
  - Water management plans do contain priorities (ex: reservoir refill vs seasonal flows)
  - Program called for forums where in-season priorities could be determined
- Challenges in implementation
  - Changing environmental conditions (drought/fire/early runoff/more precipitation as rain)
  - Changing demands and operation of system
  - Forecasting models (upon which all fish decisions rely)
  - Entrainment of resident fish at storage reservoirs
- Improvements that have occurred
  - Better modeling
  - Lessons learned from 40 years of implementation
  - Adaptive management systems now established
  - In-season operations refined
- What do we need to think about leading up to the next amendment?

    - Which fish operations are implemented differently than what is described in the program?
    - Which fish operations may be most or least affected by climate change?
- As the priorities or conditions of the Basin change, are operations adaptable?

New operations are emerging through the USG commitments and the Columbia River Treaty negotiations, although the specifics are not finalized. Details on the processes can be found at the following links:

- https://www.state.gov/summary-of-the-agreement-in-principle-to-modernize-the-columbia-river-treaty-regime/
- https://engage.gov.bc.ca/columbiarivertreaty/agreement-in-principle/#:~:text=Canada%20and%20the%20U.S.%20have,and%20ecosystems%20in%20both%20countries.
- https://engage.gov.bc.ca/columbiarivertreaty/
- USG Commitments: https://www.whitehouse.gov/briefing-room/statements-releases/2023/12/14/fact-sheet-bid[...]duction-increase-resilience-and-provide-energy-stability-i/

How do these operations relate to existing fish operations under the Program?

- Called upon flood management could result in deeper drafts at Grand Coulee and this could potentially affect water availability for Hanford and chum operations, along with water supplementation for salmon and steelhead migration.
- Which fish operations are likely to remain about the same regardless
- Which fish operations may change?

Appendix A. Refill at storage reservoirs

Albeni Falls

- Reach full pool by end of June (this date is primarily related to having sufficient water available for other operations)
  - Full pool = 2062.5 (dam can control upper 11.5 feet in elevation at Pend Oreille)
  - Hope, ID gage is noted as a control point.

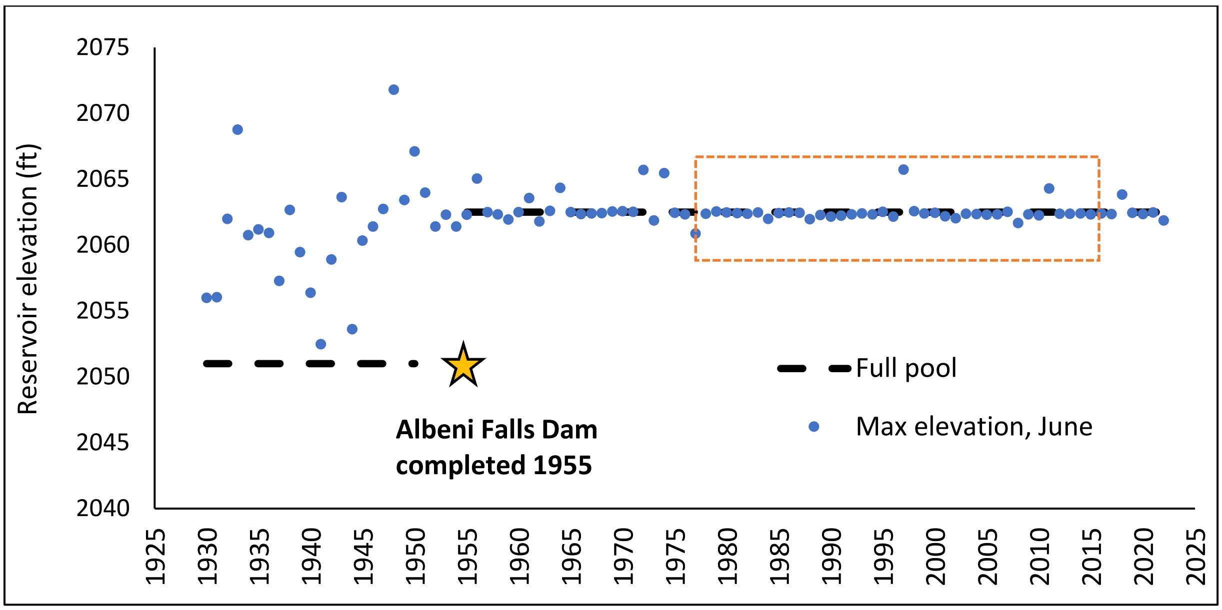


Figure A1. Maximum reservoir elevation in June at Pend Oreille, as recorded at Hope, ID USGS gage, 1925 - 2022. Datapoints shown relative to full pool (black dash). Orange box highlights recent years shown in Figure A2, below.

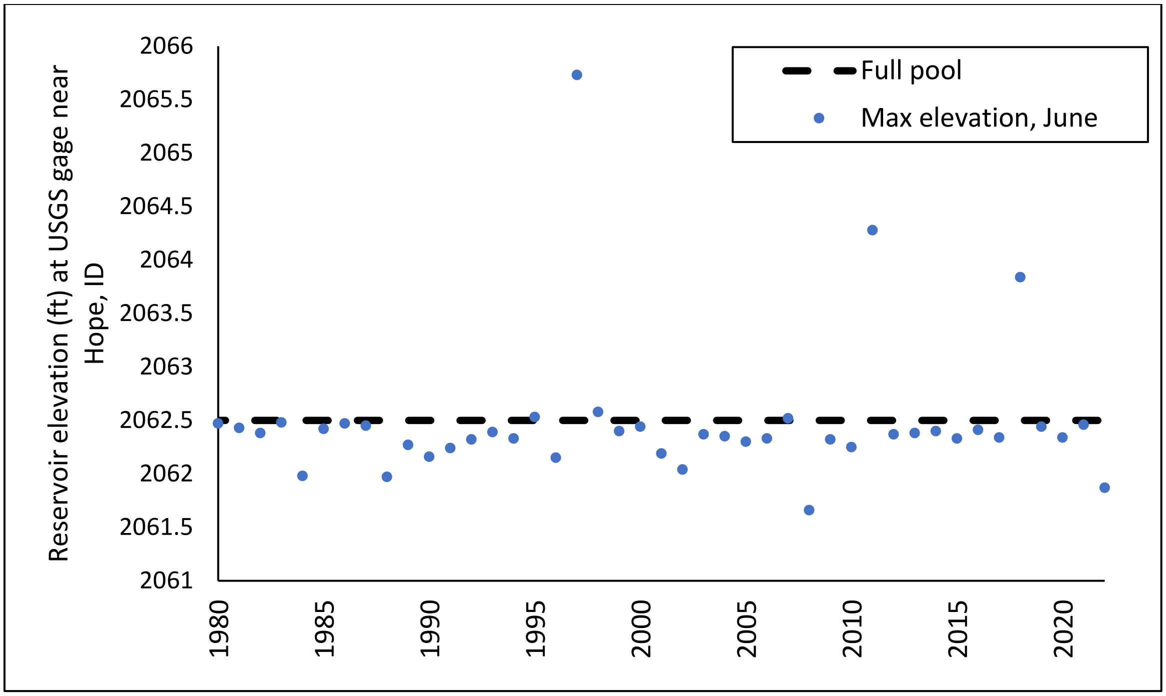


Figure A2. Maximum reservoir elevation in June at Pend Oreille, as recorded at Hope, ID USGS gage, 1980 - 2022. Datapoints shown relative to full pool (black dash).

Grand Coulee

- Refill should be a high priority for spring operations at … Grand Coulee [Dam] so that the reservoir has the maximum amount of water available during the summer. On average the target date for refill should be the end of June for Grand Coulee, [but] the system operators should work to adjust the actual refill date based on reservoir conditions and inflow forecasts.

From 1971 until 2022, there has been a decrease in the interannual variability in end of June reservoir elevations (Figure A3). However, the refill target of 1290 ft has never been met. Since 2001, the reservoir has consistently filled to 1280 - 1287 feet.

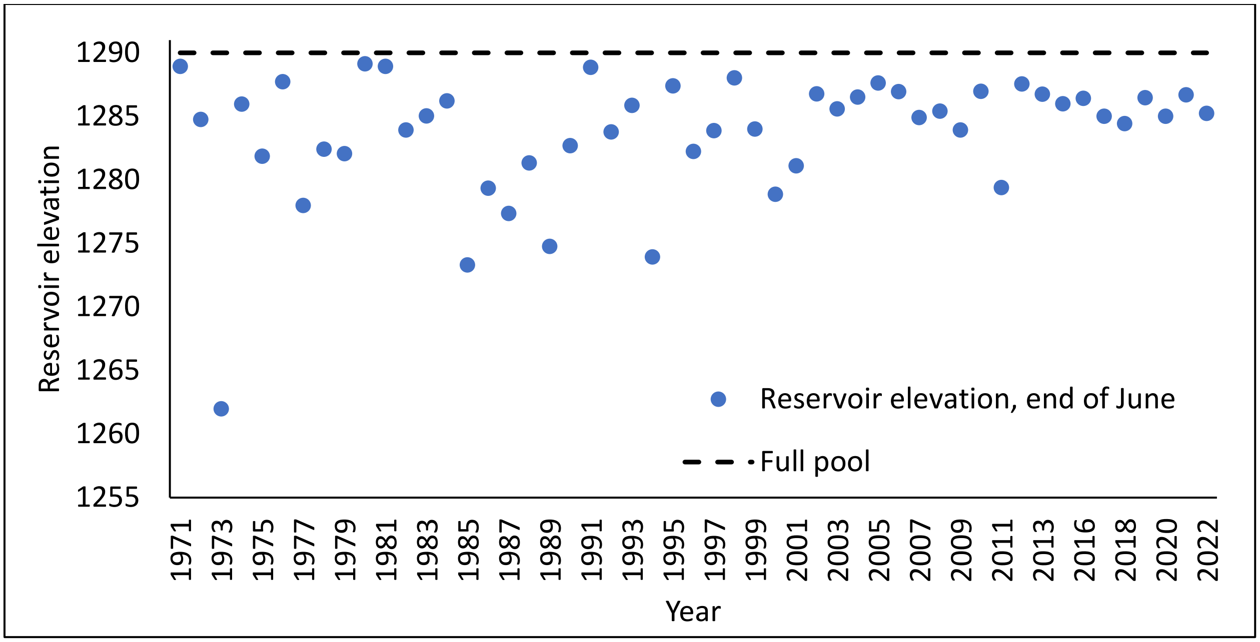


Figure A3. Maximum reservoir elevation (ft; blue dots) in June at Lake Roosevelt above Grand Coulee Dam, 1971 – 2022, relative to full pool (black dash). Beginning in 2003, refill by the end of June was described as a high priority.

Grand Coulee Dam / Lake Roosevelt is managed to provide water for several downstream fish operations, including juvenile flows, Hanford Reach Fall Chinook, and Chum Salmon. It is also managed for significant power production and flood risk management, along with irrigation and filling Banks Lake. Each of these operations requires water and impedes the ability of the reservoir to refill by the end of June.

Dworshak

Dworshak Dam is consistently operated to achieve full pool by the end of June (Figure A4). From 1975 through 2001, a drought year, there were occasional very deep summer drafts but in recent years, there have been no deep drafts and only two years when the reservoir was more than a foot below full pool at the end of June. After the first ESA-listings, water was released from the reservoir in August to supplement flows for juveniles and to cool river temperatures for adults.

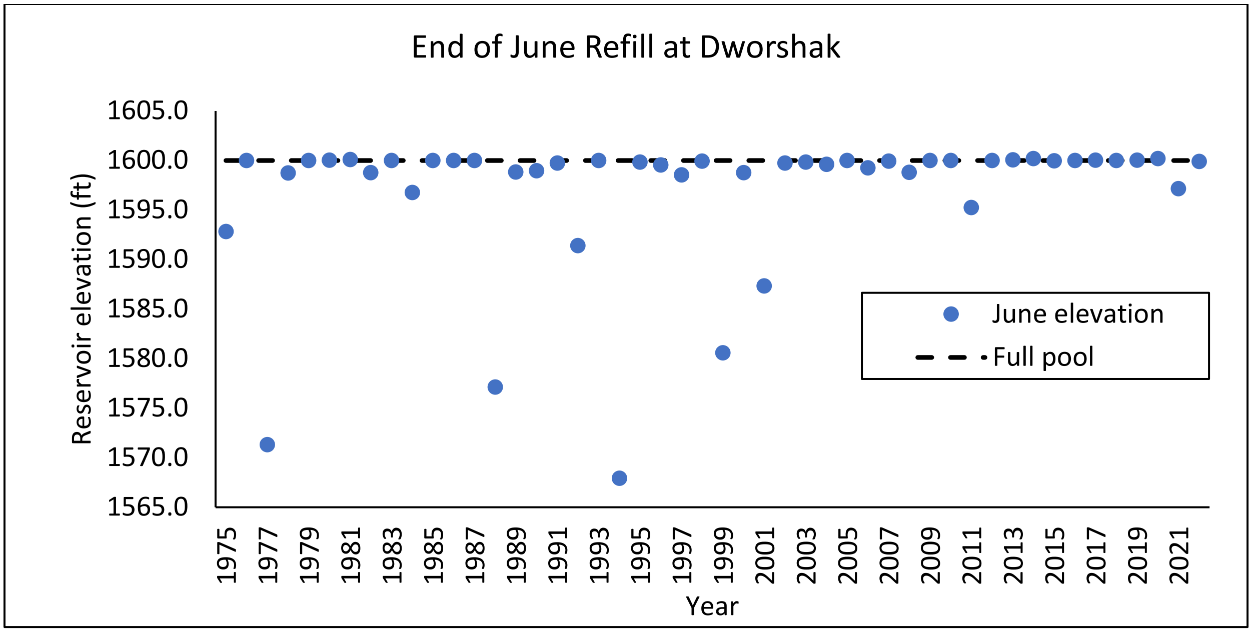


Figure A4. Maximum reservoir elevation (ft; blue dots) in June at Dworshak Dam, 1975 – 2022, relative to full pool (black dash). Beginning in 2003, refill by the end of June was described as a high priority.