STRUCTURAL AND OPERATIONAL CHANGES AT FCRPS DAMS TO IMPROVE FISH SURVIVAL

JUNE 19, 2007

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BONNEVILLE POWER ADMINISTRATION

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In reference to actions taken for fish protection at the FCRPS projects, Judge Marsh declared in 1994 "the situation literally cries out for a major overhaul." Since then, the Action Agencies made significant changes, including a number of improvements and additions to fish passage facilities, operational changes in flow, spill and the juvenile transportation program, and aggressive predator management.

Primarily through the Corps's Columbia River Fish Mitigation Project (CRFM), structural improvements at the dams have been added to improve fish passage resulting in significant survival improvements. Over $1 billion has been invested from the mid-1990's through 2006 in baseline research, development and testing of prototype improvements, and construction of new facilities and upgrades. The improvements in the physical facilities, along with improvements in the flow and spill programs, have delivered substantial improvements in both juvenile survival numbers and adult returns.

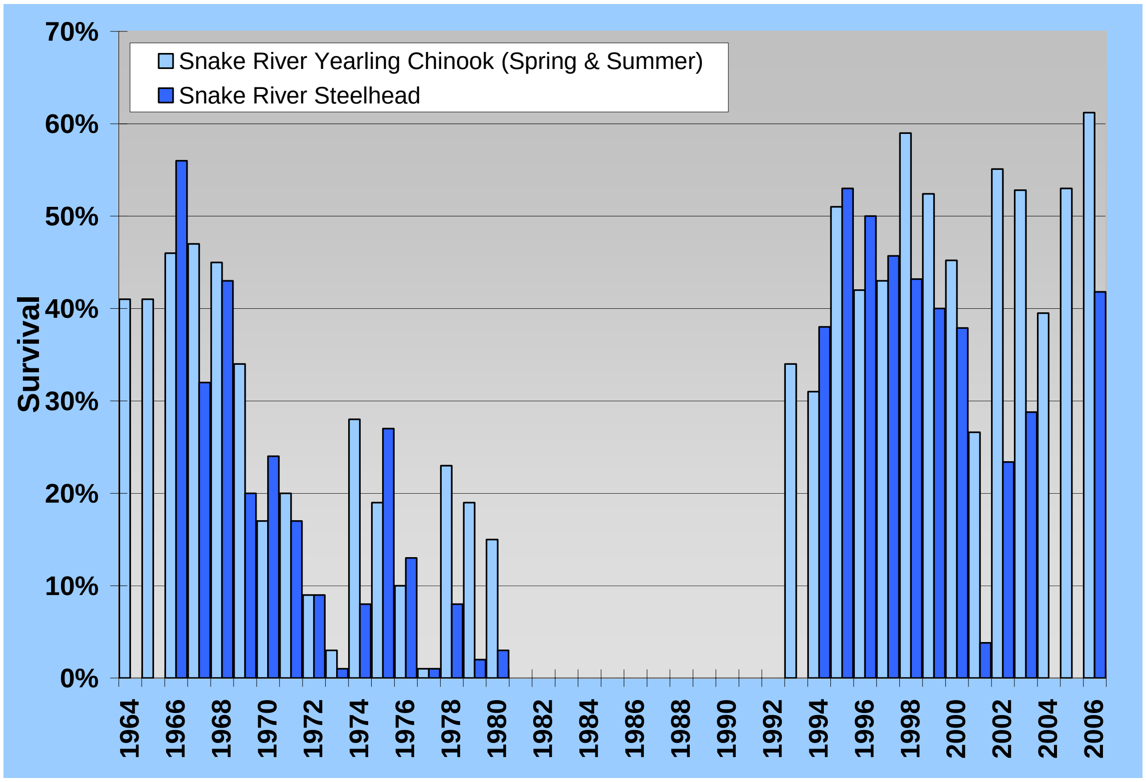

Figure A-1. Estimates of In-River Survival of Snake River Chinook Salmon and Steelhead from 1964 to 2006.[1]

[1] Data was not collected in some years for both species. Returns from 1964-1980 were obtained using a different methodology from the PIT tag based returns in 1993-2006. Trends within the two groups of data are accurate, but caution should be exercised when making direct comparisons between groups.

For instance, Figure A-1 above illustrates the changes in Snake River juvenile spring and summer Chinook salmon and steelhead in-river survivals during this period. Increases in juvenile survival will likely improve adult returns over the long term. Recent adult returns are shown below in Figure A-2.

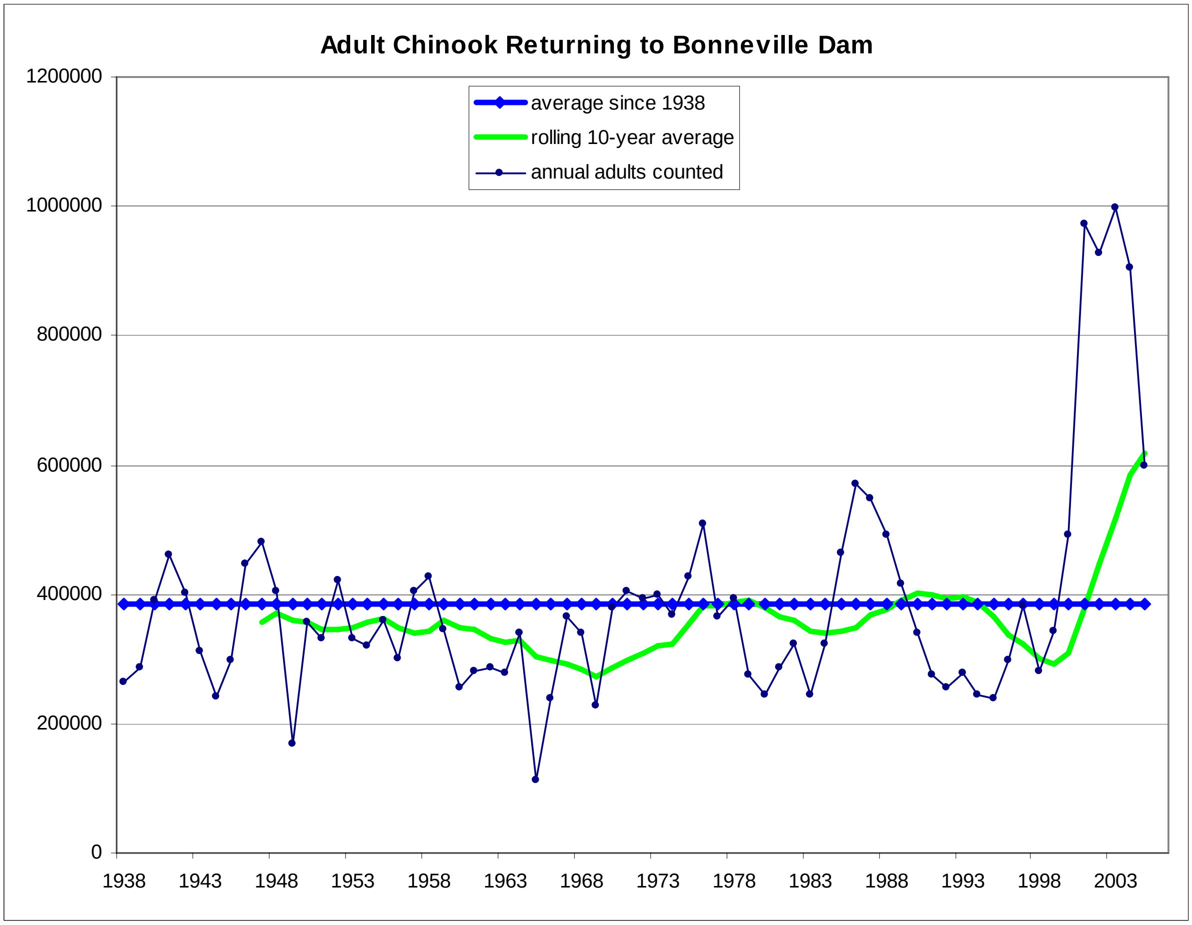

Figure A-2. Numbers of Adult Chinook Salmon Returning to Bonneville Dam, 1938 to 2005.

A. STRUCTURAL AND OPERATIONAL CHANGES FOR FISH PASSAGE AT MAINSTEM DAMS

Major modifications to dams and fish facilities for improving juvenile and adult salmon passage include:

- Addition of surface collectors or surface bypass systems, exemplified by the highly effective bypass collectors (Corner Collector) and flumes at Bonneville Dam, and the Removable Spillway Weirs (RSWs) at Lower Granite, and Ice Harbor dams

- Improvements to the existing juvenile fish guidance screens, bypass facilities and outfalls, transport collection and handling facilities, and state-of-the-art monitoring systems
- Installation of spillway flow deflectors on most spillbays at all projects, except The Dalles Dam[2], to reduce the harmful affects of total dissolved gas and increase spill passage of juvenile fish
- Improved adult fish ladders, auxiliary water supplies as well as more effective passive integrated transponder (PIT)-tag monitoring systems for both adults and juveniles, including the state-of-the-art facilities at Little Goose and Bonneville dams
- Developing and testing behavioral guidance structures (BGS) to influence the horizontal travel of juvenile fish toward bypass facilities at the dams
- Tailrace egress improvements such as the new “spill wall,” in year two of testing at The Dalles Dam
- Powerhouse turbine unit operational priorities to enhance juvenile egress and adult passage.

A.1 Surface Collectors or Surface Bypass Systems

Observation of fish behavior led to the concept of providing surface routes to attract or “skim” the fish from the forebay of the dam into a “surface bypass” structure to improve passage efficiency and reduce forebay passage delays. With conventional passage systems, juvenile fish must dive or “sound” as deep as 50 feet to enter turbine intakes or conventional spillway openings. The Corps has designed and installed different surface collector systems at several dams.

One such surface bypass structure is the Corner Collector installed at Bonneville Dam in 2003 (Figure A-3). Other successful surface bypass systems, called Removable Spillway Weirs (RSWs), have been installed at Lower Granite and Ice Harbor dams in the lower Snake River.

[2] Flow deflectors have not been installed at The Dalles due to the shallow stilling basin.

Figure A-3. Fish Bypass Corner Collector at Bonneville Dam

A.1.1 Bonneville Dam Corner Collector

The Corner Collector at the Bonneville Dam second powerhouse (PH2) on the north shore of the river has proved to be very effective in attracting and safely moving juvenile fish past the project. It consists of an overflow weir adjacent to the powerhouse with a half mile open flume providing downstream reentry well below the second powerhouse tailrace. Thirteen percent of the juvenile fish approaching the dam pass through the Corner Collector, exiting into higher velocity water, which reduces predation by other fish downstream of the dam. A large antenna detects PIT-tagged fish as they pass by, transferring data to computers that record the origin of the fish and other data needed for scientific analysis. Corner Collector survival is virtually 100 percent.

The following discussion about modifications made at Bonneville Dam is presented to illustrate the significance of the juvenile survival improvements associated with these changes. Figure A-4 describes the survival of juvenile salmonids by route of passage in years 1995 to 1999, prior to installation of the Corner Collector and other major improvements.

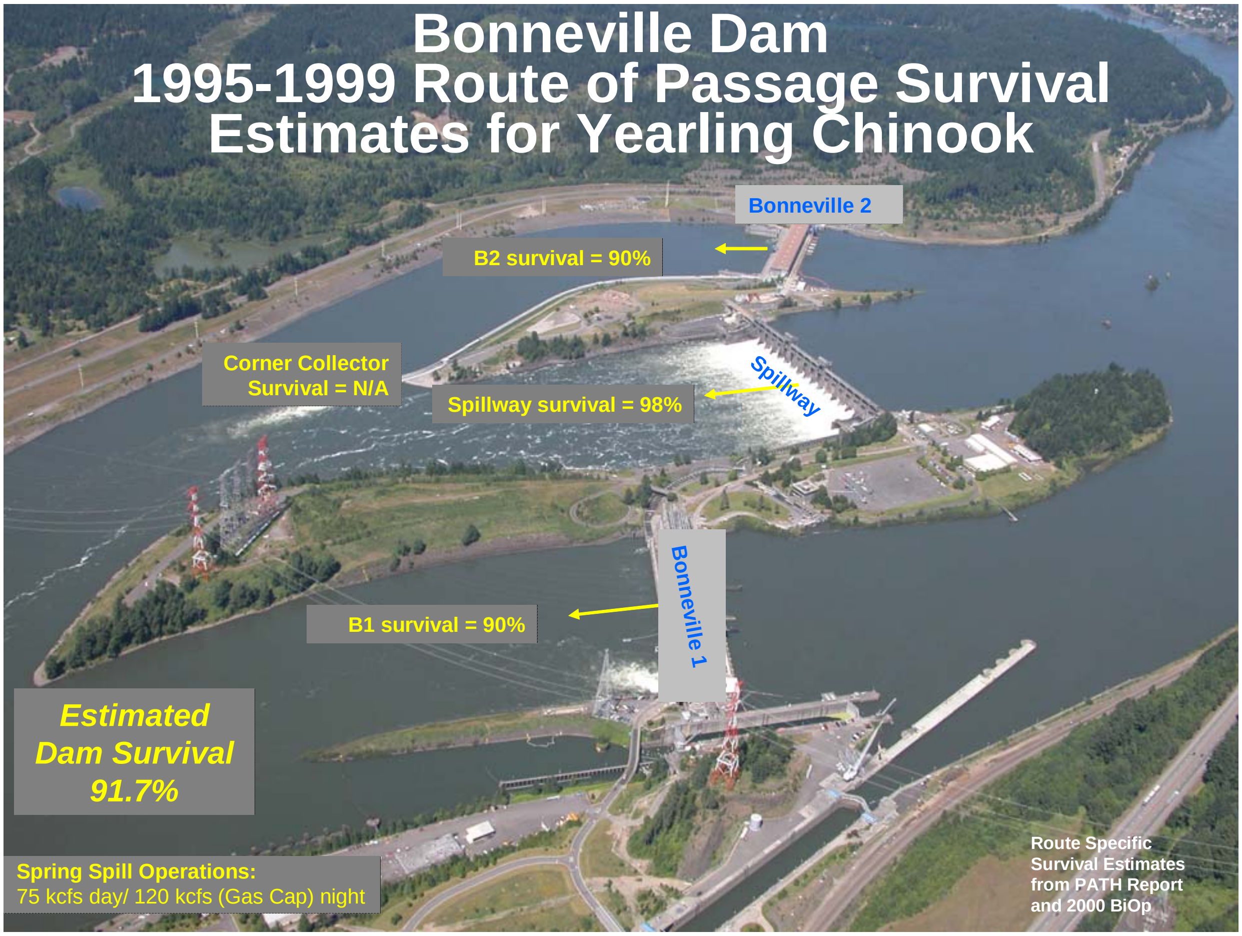

Figure A-4. Estimated dam survival rate at Bonneville Dam for yearling Chinook from 1995-1999. (Survival numbers depicted do not include improvements from the Corner Collector, which was not installed until 2004.)

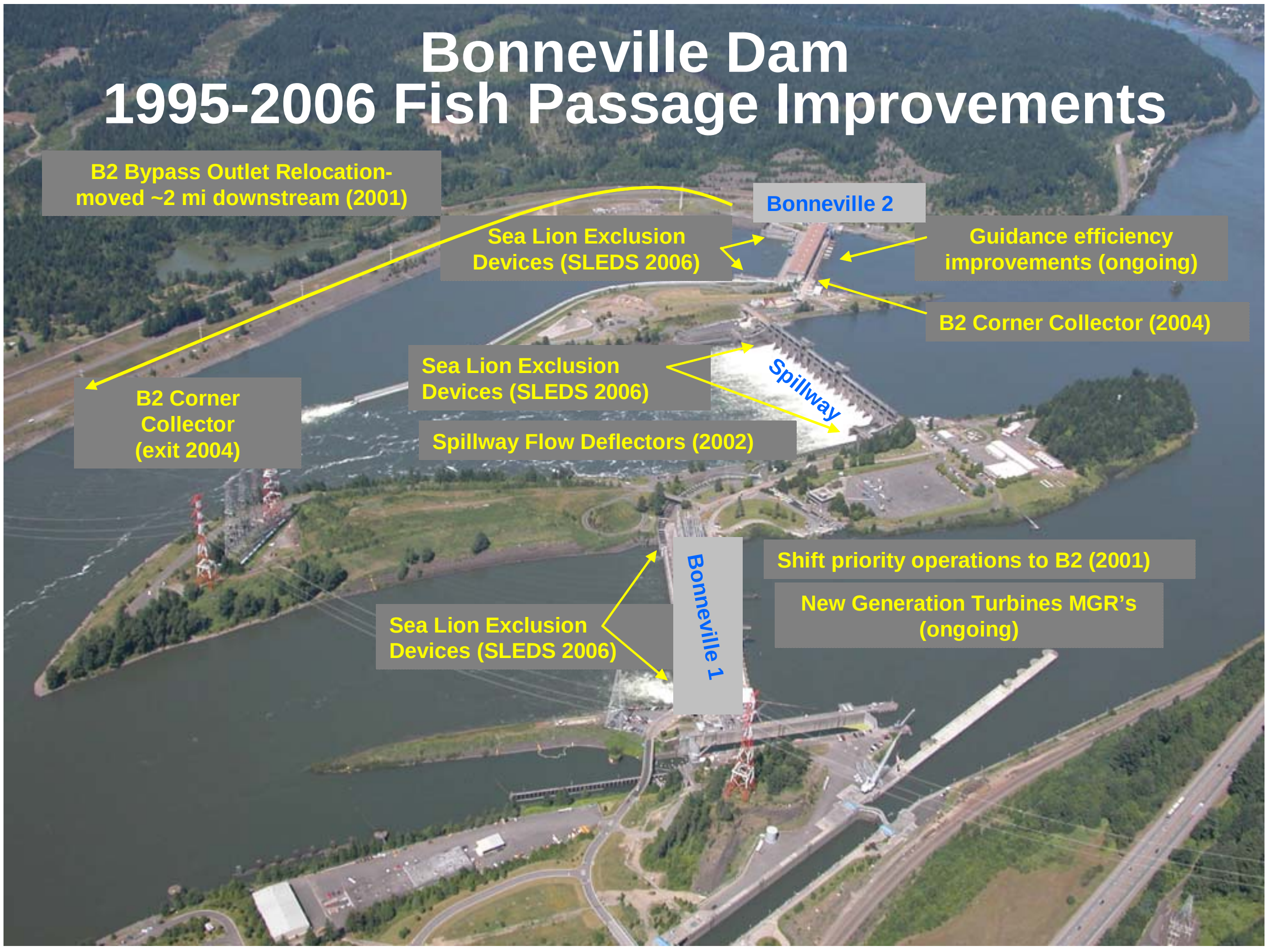

Figure A-5. Improvements at Bonneville Dam from 1995-2006.

The combined modifications identified in figure A-5 have improved survival of listed ESU's, as well as non-listed salmonid populations, passing Bonneville Dam. The primary actions that have contributed to these improvements include:

- Priority operation of Bonneville PH2. Increased juvenile survival as well as reduced adult fallback at the project
- Improvements to the Bonneville PH2 juvenile bypass system and outfall. The entire juvenile bypass system was rebuilt including modifications to the orifices, complete rebuild of the collection channel and dewatering facility, a two mile conveyance system, a new monitoring facility to ensure fish passage was safe, and a new outfall structure to release the fish below the dam in a high velocity area to minimize predation
- Addition of the Bonneville PH2 Corner Collector. Includes a surface collection system in the forebay, one half mile conveyance system, and an outfall. This structure was intended to provide a means for the fish to decrease forebay residence time, minimize stress through passage, and provide an outfall in a location to minimize predation
- Minimum Gap Runner installation at the Bonneville PH1. Complete replacement of the turbines to minimize gaps on the blades of main turbine units and redesign of the blades to decrease pressure across the blades. This reduced fish injury by 40% (from 2.5% to 1.4% of the fish being injured) and improved survival of turbine passed fish

- Remove fish screens and juvenile bypass system from Bonneville PH1
- Spillway structural and operational changes. With the addition of 5 flow deflectors, all spillbays have deflectors, with new spill patterns to move fish out of the basin. As illustrated by comparing Figures A-4 and A-6, this action may have decreased spillway survival. Evaluation of potential operational or structural modifications is underway to improve spillway survival
- Addition of sea lion excluder devices (SLEDS) at all entrances to the adult fishways. This action was taken to stop passage of sea lions into the adult fishways to reduce predation on salmonids and potential adult delay at the project

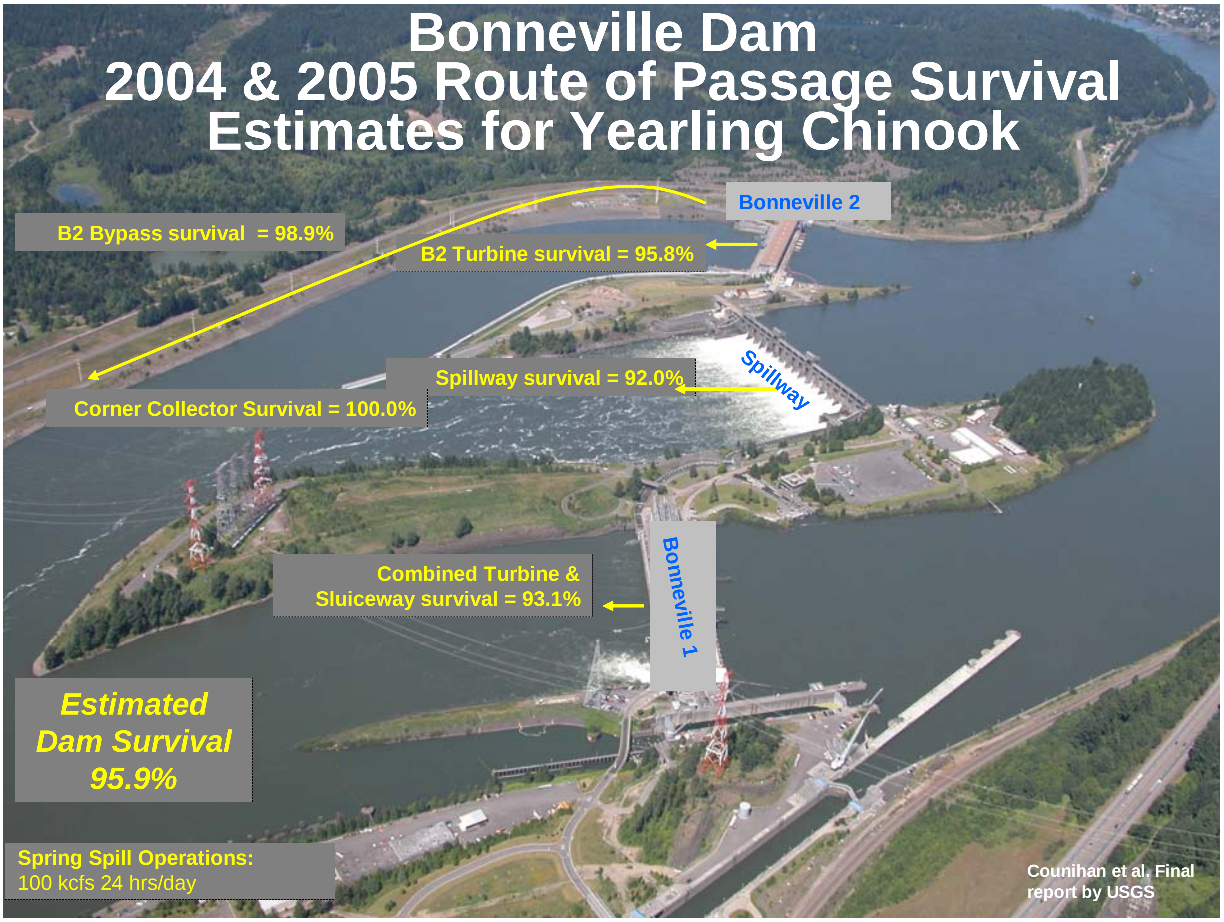

Figure A-6. Route specific dam survival estimates for yearling Chinook for 2004 and 2005.

Figure A-6 describes the changes in estimated dam survival from 91.7 to 95.9 percent for yearling Chinook as a result of modifications made at Bonneville Dam.

A.1.2 Removable Spillway Weirs (RSWs)

Another successful surface bypass system, called Removable Spillway Weirs (RSWs), installed at Lower Granite and Ice Harbor dams provide a surface passage route for juvenile fish (Figure A-7). RSW construction is underway for Lower Monumental Dam and under design for Little Goose Dam.

The massive, seven-story-high steel structures are bolted to the upstream faces of dams. Fish entering the device get a smoother, gentler ride over the spillway. Testing has shown that these “fish slides” decrease juvenile fish delay in the forebay and increase survival of juveniles as compared to other routes of passage.

Figure A-7. Removable Spillway Weir in operation at Lower Granite Dam during testing in 2001.

The Corps is currently testing smaller temporary spillway weirs (TSW), which are more economical to build and possibly equally effective. The first test is ongoing at McNary Dam for the 2007 fish passage season. If successful, the TSWs could become permanent fixtures on other dams. They work on the same principle as their larger counterparts, attracting fish at the surface to avoid the dive required to pass through a conventional spillway. Initial thinking is that these devices could be installed in multiple spillbays at McNary and John Day dams, and potentially at The Dalles Dam.

Testing of surface passage devices (RSW's) at Lower Granite and Ice Harbor dams on the Snake River have demonstrated that forebay delay can be decreased, dam survival is better than or equal to past operations, and good juvenile egress through the tailrace can be provided. For example in tests at Ice Harbor in 2003, forebay residence times decreased from 1.8 hours to 1.1 hours for yearling Chinook (despite a lower spill volume) and tailrace egress times were under 5 minutes. In addition dam survival (concrete to tailrace) at Lower Granite and Ice Harbor in 2006 was estimated at 97% and 100% respectively.

A.2 Project Specific Changes

The following identifies structural improvements and upgrades made at particular projects through 2006, including baseline research, development and testing of prototype improvements, and construction of new facilities.

A.2.1 Bonneville Dam 1st Power House (PH1)

Bonneville Dam's PH1 was the first Federal hydroelectric dam to be built on the Columbia River. It is the last dam that migrating juvenile fish pass on their downstream journey to the ocean. This project began operating in 1938 with an adult fish ladder and an adult fish attraction system, and fish locks that were later closed because they were ineffective.

In the 1960s and 1970s, juvenile fish bypass channels were enhanced by drilling orifices from the turbine intake bulkhead slots into the ice/trash sluiceway. This allowed juvenile fish to enter the slots, swim into the sluiceway, and pass around the powerhouse. In the last few years these facilities have been improved. More effective screens have been installed to guide juvenile fish away from turbines. Flow deflectors were added to reduce total dissolved gas, and sophisticated monitoring devices have been installed to monitor passage for both juveniles and adult salmon.

Fish passage improvements at Bonneville Dam are listed in (Table A-1). These improvements complement earlier facilities, substantially improving in-river passage for both juvenile and adult salmon.

Table A-1. Fish Passage Improvements at Bonneville Dam PH 1 since 1995

Juvenile Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. Spillway deflectors added to 5 bays.	1. Decreases gas entrainment, allows higher level of juvenile spillway passage
	2. Power distribution system modified for fish operations.	2. Allowed for B2 priority for powerhouse operations to improve juvenile survival (and reduce adult fallback)
	3. Installation of minimum gap turbine runners - 5 units completed by 2006. (2 additional units in 2007 and remaining 3 by 2009)	3. Reduce injury and mortality for fish passing through turbines

Adult Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. Gates were taken out of entrances 1, 2, 64, and 65 to provide 8 feet of opening.	1. Enhance collection system effectiveness and reliability.
	2. Floating gate/orifice operating system modified with new motors and control system.	2. Enhances collection system effectiveness and reliability
	3. Adult PIT-tag detector installed.	3. Provides for monitoring PIT-tags on adults.
	4. Sea Lion Exclusion Devices (SLED).	4. Gates installed to keep marine mammals out of fish ladders.

A.2.2 Bonneville Dam 2nd Powerhouse (PH2)

The 2nd Powerhouse (PH2) at Bonneville Dam was the last constructed at a FCRPS mainstem dam; therefore, designers had the benefit of lessons learned from the monitoring and evaluation of fish passage facilities at the other dams. The construction included an adult ladder and an adult powerhouse collection system, which proved to be effective and few modifications have been needed. The construction also included juvenile bypass facilities; however, follow-on studies identified several issues with the juvenile facilities including lower than desired guidance efficiency and survival. Improvements to juvenile bypass facilities have increased their efficiency putting more fish in the juvenile bypass facility and decreasing the number of fish passing through turbines (Table A-2). In 2001, a new non-pressurized flume was installed from the powerhouse to a reach of the river with swifter flow several miles below the project. New PIT-tag monitoring equipment, separation/sampling facilities, and an outfall structure were constructed at the site.

Table A-2. Fish Passage Improvements at Bonneville Dam PH2 since 1995

Juvenile Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. Juvenile bypass system upgraded, including outfall relocation and new collection channel and dewatering facility	1. Relocated bypass avoids predation at original outfall location. New collection channel and dewatering facility improved the potential for injury and stress. These features provided survival improvements.
	2. Surface bypass Corner Collector with ½ mile conveyance channel.	2. Further increases the percentage of fish that avoid turbine passage and provided outfall in location to improve survival.
	3. Improvements for fish guidance into juvenile bypass system (6 out of 10 units completed by 2006.	3. Improves percentage of fish guided away from turbines.
	4. Full flow PIT detection on bypass outfall flume.	4. Reduces need to subject juveniles to very low flow levels for PIT-tag detection, which will stress levels.
	5. PIT-tag antenna installed in the corner collector channel.	5. Capable of detecting tagged fish moving at high speeds down flume.
Adult Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. Adult PIT-tag detectors. 3. Sea lion exclusion gates (SLEDS).	1. Provides collection point for PIT-tag data on adults. 3. Keeps marine mammals out of fish ladders.

A.2.3 The Dalles Dam

The Dalles Dam was completed in 1957 and its adult passage design was based on Bonneville Dam's design. In the 1990s, a series of improvements were made to the adult passage system. Juvenile fish passage facilities were not included in the initial construction of The Dalles Dam. In 1971, the ice/trash sluiceway was opened to skim juveniles from the forebay, and it has proved to be effective at passing juvenile fish. Improvements to passage facilities are shown in Table A-3.

Table A-3. Fish Passage Improvements at The Dalles Dam since 1995

Year	Improvement	Purpose
Juvenile Passage Improvements		
1995 to 2006	1. Constructed spillway wall.	1. Allows increased flows and fish at the North end of spillway which improves collection efficiency and juvenile egress from the spillway.
	2. Sluiceway improvements including opening additional gates.	2. Provides increased sluiceway efficiency and reduced turbine entrainment.
Adult Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. Modifications to allow for adult entrance channel dewatering.	1. Allows for inspection and maintenance to ensure reliability of adult ladder system.

A.2.4 John Day Dam

John Day Dam was completed in 1968 and included a full adult passage system on each side of the project. A juvenile fish bypass system was retrofitted to the project in the 1980's and has subsequently been upgraded with a new monitoring facility. Recent improvements at John Day are shown in Table A-4.

Table A-4. Fish Passage Improvements at John Day Dam since 1995

Year	Improvement	Purpose
Juvenile Passage Improvements		
1995 to 2006	1 Juvenile fish monitoring facility,	1. Allows evaluation of juvenile condition and counting/sampling of PIT-tagged fish.
	2. Spill deflectors installed on 18 of 20 bays.	2. Reduces TDG levels during spill.
	3. Refurbished two north shore fish pumps.	3. Improves reliability.
	4. Full flow PIT-tag detection.	4. Improves detection and reduces stress on juvenile fish.
Adult Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. Rehabilitated auxiliary water pumps.	1. Provides reliable auxiliary water supply for attraction/passage of fish.
	2. South ladder exit control section reconfigured.	2. Reduces fish jumping and delays in the south ladder.

A.2.5 McNary Dam

McNary Dam, the second dam to be built on the lower Columbia River, was completed in 1953 with adult fish ladders on both shores of the project. Fish passage conditions at McNary are very important because this is the first of four dams that all juvenile fish migrating from the upper Columbia River and the lower Snake River pass as they swim towards the ocean. This project was retrofitted with a juvenile bypass facility in 1978, with a full compliment of submerged traveling screens (STSs) screens and vertical barrier screens (VBSs) added in 1981.

In 1996 to 1997, extended submerged traveling screens (ESBSs) and vertical barrier screens (VBSs) were added to the bypass system. The system now guides over 80 percent of spring and 60 percent of summer migrants from the turbine intake into the bypass.

The McNary fish passage system is considered to be state-of-the-art. As research, monitoring, and evaluation efforts form a feedback loop, additional enhancements will be made to McNary passage system to further benefit migrating fish. More recent improvements at McNary are shown in Table A-5.

Table A-5. Fish Passage Improvements at McNary Dam since 1995

Juvenile Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. ESBSs installed.	1. Guides more migrants away from the turbines into the bypass system.
	2. Spill deflectors place in remaining four bays. Others installed earlier.	2. Reduces TDG production during spill.
	3. Bypass system upgrades including full flow system.	3. Improves fish survival and health as they transit the bypass system.
	4. Rehabilitation of spillway gates and addition of hoists.	4. Allowed optimal spillway operation for fish passage.
Adult Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. Adult PIT-tag detection systems in both fish ladders. 2. Replaced powerhouse collection system stop logs with new stop logs.	1. Improves ability to detect PIT-tags. 2. Increases reliability of adult fish passage system.

A.2.6 Ice Harbor Dam

The Ice Harbor project was completed in 1961. Its original design included two adult fish ladders and a powerhouse adult fish attraction and collection system, all of which have been improved (Table A-6). The dam was constructed without dedicated juvenile salmon passage facilities because at that time it was assumed that juvenile survival would be adequate through the turbines and spill.

By the mid-1960s, studies of improvements with access to the ice/trash sluiceway were provided and in 1996, a powerhouse bypass system consisting of submerged traveling screens STSs, a dedicated channel in the old sluiceway, a flume to carry juveniles to the tailrace, and sampling facilities were installed. High TDG levels from spill proved to be especially problematic at Ice Harbor, so spillway deflectors were installed on all ten spillbays in 1999.

Table A-6. Fish Passage Improvements at Ice Harbor Dam since 1995

Juvenile Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. Submerged traveling screens (STSs) and VBSs put into each turbine intake, 12-inch orifices drilled from gatewell to bypass channel in old sluiceway, evaluation/marking facilities at bottom of bypass flume.	1. Increases the percentage of fish bypassed from the turbines.
	2. Spill deflectors installed on all spillbays.	2. Reduces TDG levels.
	3. PIT detection on main bypass flume	3. Allows PIT monitoring with lower potential for stress.
	4. RSW installed in 2005.	4. Allows more efficient spillway passage, reduces delay in the forebay.
Adult Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. North shore auxiliary water supply system modified, new fish pumps installed.	1. Makes auxiliary water system effective and reliable.
	2. Adult PIT-tag detection systems.	2. Assesses adult fish passage and survival through the project.

A.2.7 Lower Monumental Dam

Lower Monumental Dam was completed in 1969 with adult fish ladders on both shores of the project. It also had a rudimentary powerhouse collection system with orifice entrances along the face of the powerhouse and a pipe that ran along the face of the dam. Recent improvements are substantial; including an RSW, spill deflectors, screen overhaul, and improved transportation facilities (Table A-7).

Table A-7. Fish Passage Improvements at Lower Monumental Dam since 1995

Juvenile Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. STS overhaul.	1. Ensures STS efficacy and reliability.
	2. Spill deflectors installed on bays one and eight.	2. Reduces TDG levels.
	3. Barge loading and improved dewatering facilities.	3. Improves juvenile transportation system.
	4. Addition of parapet wall	4. Reduces TDG levels and allows full use of end bays at the spillway
	5. PIT-tag detector in main transport flume	5. Allows for better counting and analysis of migration patterns and survival.
Adult Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. All three auxiliary water supply pumps rehabilitated.	1. Ensures fish ladder auxiliary water system efficacy and reliability.

A.2.8 Little Goose Dam

Little Goose Dam went into service in 1970 with a single south shore ladder for adult fish passage, a powerhouse collection channel, and two north spillway entrances with a channel leading to the powerhouse collection channel. A turbine pump provided auxiliary water from the tailrace for the powerhouse collection system. In 1991, picketed leads to reduce adult fish fallout from the ladder entrances were placed at the north end of the powerhouse collection channel and were enhanced in 1994.

Little Goose was constructed with the same elemental juvenile fish bypass design as Lower Monumental and John Day dams. It featured 6-inch orifices to each gatewell leading to an embedded pipe that carried fish around the powerhouse and discharged them into the tailrace. The bypass-transport facilities that had been built in 1980 were replaced in 1990. The new facilities featured a modified collection channel, a new dewatering structure, a corrugated flume, a new "wet" separator, a new evaluation facility, holding ponds, and a loading/outfall structure. In the mid-1990's the STSs were replaced with newly designed VBSs and extended length bar screens (ESBSs). The PIT-tag diversion and detection system has also been rebuilt and is now state of the art. Turbine intake emergency gates were also raised to increase fish guidance efficiency (FGE). More recent improvements at Little Goose are shown in Table A-8.

Table A-8. Fish Passage Improvements at Little Goose Dam since 1995

Juvenile Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. ESBS's and improved VBSs.	1. Increases FGE and reduced turbine entrainment on juveniles.
	2. Upgraded PIT-tag sort by code, routing, bypass outfall.	2. Reduces fish delay, stress, and predation. .
	3. Trash shear boom	3. Reduces amount of debris entering gatewells, thereby reducing fish injury and mortality.

Adult Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. Picketed leads in collection system channel.	1. Fewer fish fall out of the channel into the tailrace.
	2. Auxiliary water supply improvement.	2. Improves fish ladder system reliability.

A.2.9 Lower Granite Dam

Lower Granite Dam was constructed in 1975 with an adult fish collection and passage system consisting of a single south shore adult fish ladder, a powerhouse collection channel with main entrances at the end of the powerhouse, and two north shore entrances with a transportation channel under the spillway leading to the powerhouse collection channel.

The adult passage system proved to be effective and was not modified until the early 1990s when the fishway controls were upgraded. In 1993, permanent picketed leads were installed to reduce fallout of adults from the ladder entrances. The adult fish trap was rebuilt in 1998 and adult PIT-tag detectors were added.

Lower Granite Dam was the first mainstem project to have a full juvenile STS bypass-transport system included in its original design. The bypass included VBSs, 8-inch orifices that led to dewatering structures, and a pressurized pipe at the south end of the powerhouse. The pipe led down the tailrace into a fish/water separator, holding ponds, an evaluation/monitoring facility, a transport loading dock, and an outfall.

In the early 1980s, the juvenile bypass and transportation systems were overhauled. New generation STSs were installed, the gatewell orifices were increased to 10 inches, the dry separator was replaced by a wet separator, and new raceways were installed. In the early 1990s, emergency gates were removed from their gate slots in a successful effort to improve FGE. In 1996, the STSs were replaced with new VBSs and extended-length bar screens. To provide a surface passage route for juvenile fish a RSW was installed in 2001 at Lower Granite, which yields roughly 98 percent passing survival for juvenile fish. More recent improvements at Lower Granite are shown in Table A-9.

Table A-9. Fish Passage Improvements at Lower Granite Dam since 1995

Juvenile Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. New ESBSs and VBSs installed.	1. Fish stress and injury reduced in bypass system
	2. PIT-tag sort by code improvements.	2. Decrease stress.
	3. Spill deflectors.	3. Reduces TDG levels.
	4. RSW installed and tested.	4. Allows more efficient spillway passage and decreased forebay delay.
Adult Passage Improvements		
Year	**Improvement**	**Purpose**
1995 to 2006	1. PIT-tag detectors added.	1. Allows for monitoring of returning adult fish.
	2. Fish trap modified and expanded	2. Provide better adult fish handling conditions.
	3. modified diffuser and transition pools	3. Improve adult passage by eliminating fishway fallout
	4. Auxiliary water supply improvements.	4. Increased reliability of ladder operation.

B. REGULATING FLOW TO ASSIST JUVENILE FISH MIGRATION

Managing water in the Columbia River system for its many purposes is particularly challenging given the relatively small portion of the annual runoff volume that can actually be stored in reservoirs. The runoff produces an annual average of about 200 million acre-feet of water, but only about 20 percent of it can be impounded for useful purposes. By contrast, the Colorado River system can store about three times as much runoff as it normally receives in a given year. The Missouri River system has about two times more useable storage than average annual runoff.

The notably larger storage capacities of the Colorado and Missouri River systems present much different management considerations than the Columbia River system. These systems have the capacity to store water for subsequent years' use, whereas the Columbia River system, with its large annual volume to usable storage ratio, has to evacuate on a yearly basis to accommodate water supply conditions in the Columbia Basin. This means that operators cannot use stored water to transform a dry year's water supply into an average flow year. Operators of the hydropower system must deal with the variability in annual rain and snowpack relying on professional judgment.

Flows for fish are an important component of water management in the Columbia River Basin. Fish operations draw on 8 million acre-feet of stored water annually—about one-quarter of the 30-million acre-feet of storage in U.S. reservoirs and Treaty storage in Canada. Because much of the available storage is in Treaty projects in Canada, its use downstream is governed by the Columbia River Treaty. Use of Treaty storage for fishery purposes depends on development of mutually beneficial agreements between the United States and Canada. Use of space in Canadian reservoirs not included in the Treaty, referred to as non-Treaty storage, requires negotiation of additional agreements.

In recent Treaty agreements, Canada has allowed storage of flow augmentation water (1 million acre-feet) for U.S. fishery benefits in exchange for flow shaping for meeting fishery objectives in Canada. The 1 million acre-feet is released within the May through July period to assist juvenile migration in the United States. If this flow augmentation water is released across one month, it equates to an additional flow of 16,000 thousand cubic feet per second (kcfs) for that month, equal to about 6 percent of spring flow objective, or about 8 percent of the summer flow objective of 200 kcfs at McNary Dam.

The 1995 biological opinion "substantially alters the operation of the reservoirs in the FCRPS compared to the 1993 and 1994 biological opinions" (1995 BiOp, p. 96). The Action Agencies were to henceforth operate the FCRPS during fall and winter months at high confidence levels that refill would be accomplished by April 20. Flow targets were to be met in the spring while ensuring sufficient storage of water to be available by June 30 to meet summer flow targets.

The objective of fish operations today is to provide flows in a natural pattern, to the extent that the design of the system for multiple purposes will allow. Figure A-8 illustrates how flows are shaped to more closely approximate a natural, unregulated river to assist fish migration. It compares the regulated flow in October 2005- September 2006 (the 2006 water year) to what would have been a natural flow in that year. In this year, precipitation was measured at about 100 percent of the 71-year average.

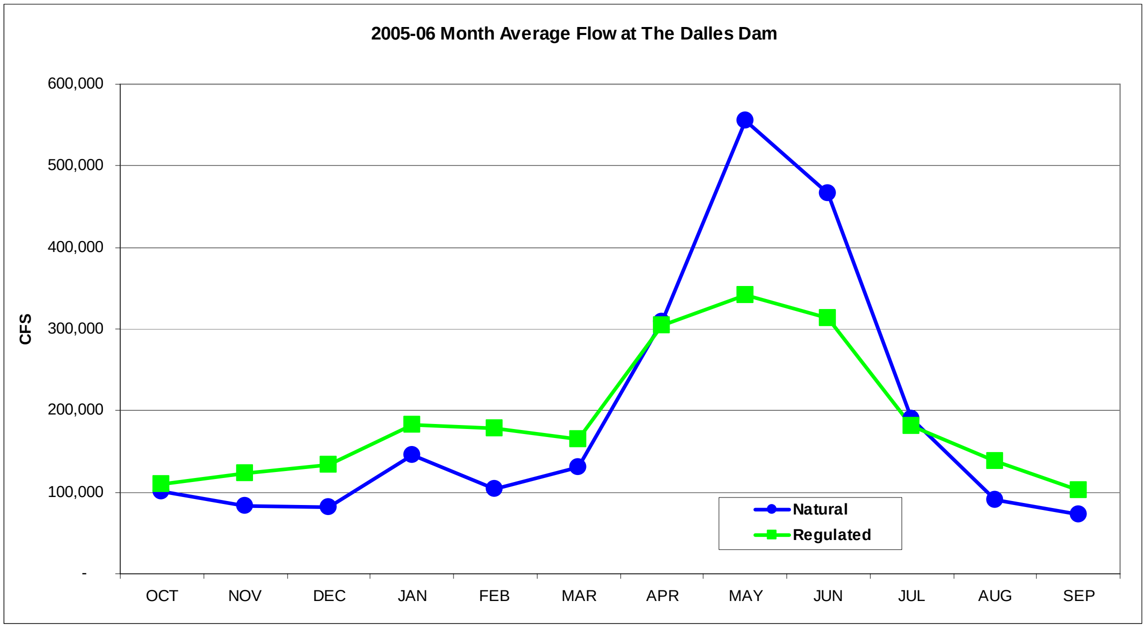

Figure A-8. Natural and Regulated Monthly Average Flow at The Dalles Dam for the 2006 water year.

Another way of looking at the changes in flow due to reservoir operations for fish is in millions of acre-feet of water passing The Dalles Dam. Figure A-9 shows the additional flow at The Dalles during the juvenile migration period (April through August) due to reservoir operations for fish (60-year average) under the 2004 BiOp. Fish operations would add 8.3 million acre-feet on average—4.6 to 13.2 million acre-feet, depending on annual precipitation.

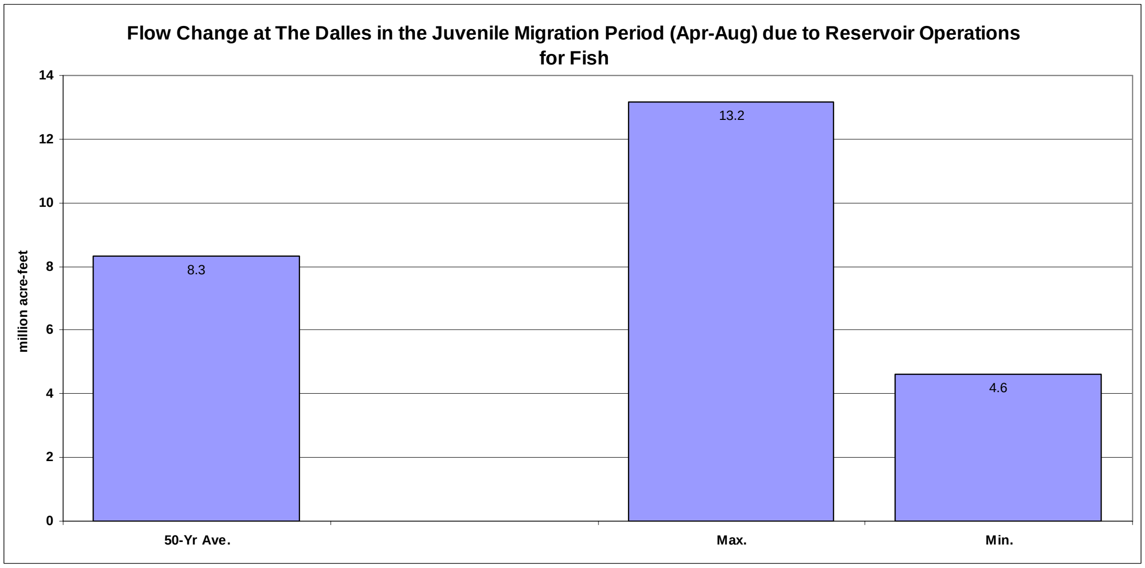

Figure A-9. Flow Change at The Dalles Dam during the Juvenile Migration Period (April through August) Due to Reservoir Operations for Fish (60-year average)

The volume of water in the river each year is as variable as the weather. Figure A-10 depicts a 60-year average regulated flow at The Dalles Dam, with and without fish operations. Given limited storage and other constraints, these operations are a substantial change, pressing the design capabilities of the system.

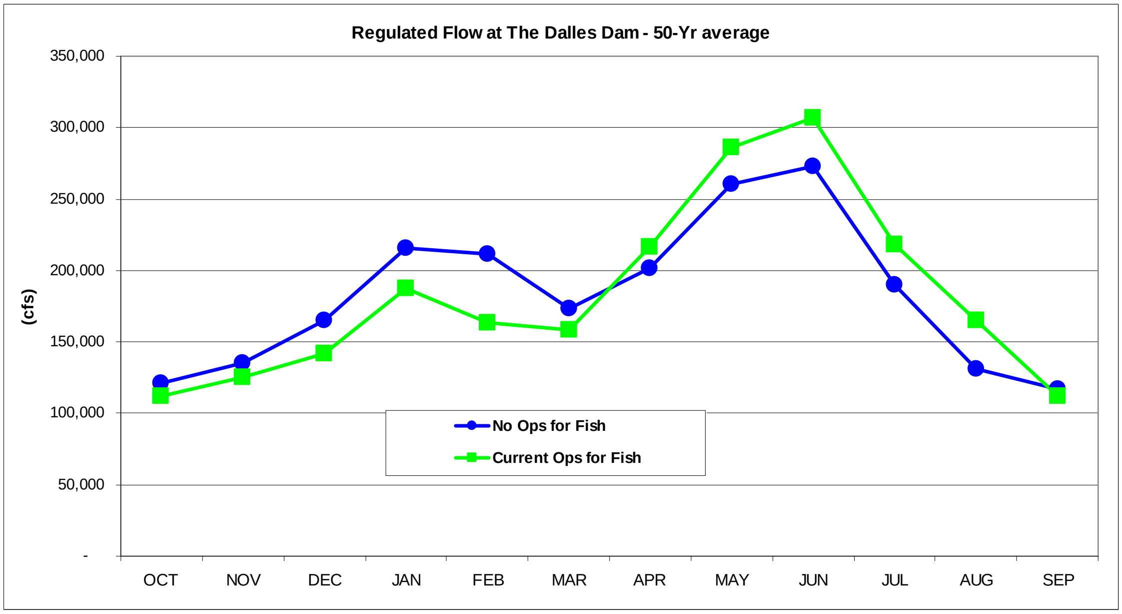

Figure A-10. Sixty-Year Average Regulated Flow at The Dalles Dam, With and Without Fish Operations

The eight federal dams on the lower Columbia and Snake Rivers are "run of the river" dams, that is, low head dams that have little or no storage capacity and essentially pass inflows[3]. Nevertheless, the impeded flow in these reservoirs affects the progress of juvenile salmon through the system in several ways: slower travel, increased water temperature, and increased exposure to predators among them. In 1995, the Corps began operating the lower Snake reservoirs within 1 foot of minimum operating pool (the level required to provide safe navigation, operate fish facilities within design criteria, and operate turbines). The 1995 biological opinion also called for John Day pool to be operated within one and one-half foot of minimum irrigation pool from April 20 through the summer. These drawdowns reduce the width or the cross-section of the reservoir, thereby increasing water velocity.

The summer flow management objective is to draft reservoirs within specific limits to meet flow targets and to manage water temperatures to benefit migrating juvenile salmon. Cooler water is also thought to assist adult migration.

Flood control procedures have been modified to the extent possible without unduly increasing risk. At storage reservoirs behind Libby and Hungry Horse dams, operators recently adopted a flexible release schedule called VARQ (i.e., VAR [variable] Q [flow]) to bolster flows for several ESA-listed fish. VARQ entails maintaining higher levels of water in certain reservoirs from January through April when the runoff is forecasted to be average or less. By this means, operators can provide flood control while ensuring that more water is available for adult Kootenai River white sturgeon and juvenile salmon and steelhead migration in spring and summer.

Finally, the operators strive to provide habitat for mainstem spawning chum and fall Chinook salmon. They maintain sufficient flow below Bonneville Dam to keep redds submerged until juvenile fish hatch in the spring.

[3] John Day Dam has approximately 500 thousand acre-feet of flood control storage.

C. SPILL OPERATIONS TO ASSIST JUVENILE FISH PASSAGE

Spill operations are a method of guiding juvenile salmon and steelhead through spillways rather than through turbines. The objective of the spill program is to achieve maximum survival, along with other passage routes, at each dam. Survival is measured by detecting the PIT-tagged fish as they pass from the forebay above the dam to the tailwater below the dam.

Prior to the 1995 BiOp, the operators' objective was to attain a fish passage efficiency[4] (FPE) of 70 percent for spring migrants and 50 percent for summer migrants. To accomplish this, spill was provided at three dams. The other dams met the goal without spill. In the longer term, the plan was to complete structural bypass systems at the four lower Snake River and four lower Columbia River dams to boost in-river survival.

In the 1995 BiOp, the objective was raised to achieve 80 percent FPE at all eight projects by spilling water through the spring months at each project. Timing and volume of spill at each project was designed to achieve biological benefits with a cap to avoid harmful levels of TDG. Given the fact that most juvenile fish have passed through the system by August, limited spill was to be provided in summer months, primarily at Ice Harbor and the three lower Columbia dams, where no fish are collected for transport.

Bypass facilities of various types have been added to dams with survival of juvenile fish increasing to 90 to 95 percent at each dam. As discussed earlier, surface passage modifications such as RSWs and the Bonneville Dam Corner Collector can achieve higher survival rates (97 percent or higher with RSWs, and 100 percent with the Corner Collector), while spilling less water.

The various routes of juvenile passage notwithstanding, most juvenile fish in the river find their way through spillways. Table A-10 illustrates how the use of spill has increased significantly in duration and volume since the 1995 biological opinion based on biological results. Notable are the significant increases in spring and summer spill in that year and again in 2000, along with the addition of biological criteria balancing gas saturation, tailrace conditions, and adult passage. The 2000 biological opinion based annual spill programs on "the best available monitoring and evaluation data concerning project passage, spill, and system survival research" (2000 BiOpp. 9-88). This principle was extended to the 2004 biological opinion, further increasing the reliance on biological performance to set spill levels at each project.

In 2004, emphasis turned to 24-hour surface spill through RSWs and the Corner Collector at Bonneville Dam. A Court Order in 2005 required summer spill at Lower Granite, Little Goose, and Lower Monumental dams on the Snake River, and at McNary Dam on the Columbia River, which was continued in 2006 and 2007. Monitoring in 2005 and 2006 showed nearly all of the Snake River fall Chinook salmon (both hatchery and wild) passed Little Goose and Lower Monumental dams by late July or early August.

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[4] Fish Passage Efficiency is a measure of percent of juvenile fish that are diverted away from turbine passage, either via spill or through the juvenile bypass facilities.

Table A-10. Historical, Spring, and Summer Spill Levels.

Historical Spill Levels

		1988 Spill MOA	1994 BiOp	1995 BiOp	1998 BiOp	2000 BiOp	2004 BiOp	2005 Court Order	2006 Court Order
	Starting ~1978 spill is provided informally based on fish presence at each dam	Spill is intended as an interim measure until bypass systems are installed to provide 70% spring and 50% summer FPE (non-turbine passage)	Still striving for 70% spring and 50% summer FPE and completion of bypass systems at all dams	Spill percentages primarily based on achieving 80% FPE (non-turbine passage), uncertainty about benefits of transportation is noted	Emphasis on increasing gas caps	Prioritized spill passage, also seeking balance between high gas cap spill, good tailrace conditions, and good adult passage	Emphasis on 24-hour surface spill, good tailrace conditions, and good adult passage	Addition of summer spill at transport projects	Continuing summer spill at transport projects

Spring Spill Levels

		1988 Spill MOA	1994 BiOp	1995 BiOp	1998 BiOp	2000 BiOp	2004 BiOp	2005 Court Order	2006 Court Order
Dates	No Formal Dates	Between 10 and 90% passage dates (4/15-5/31 @ IHR and LMN and 5/1-6/6 @ TDA)	4/15-5/31 @ IHR and 5/1-6/6 @ TDA	4/10-6/20 in Snake River, 4/20-6/30 in Columbia River	4/3-6/20 in Snake River, 4/10-6/30 in Columbia River	4/3-6/20 in Snake River, 4/10-6/30 in Columbia River	4/3-6/20 in Snake River, 4/10-6/30 in Columbia River	n/a (2004 BiOp operations implemented during the spring)	4/3-6/20 in Snake River, 4/10-6/30 in Columbia River
Hours	Generally at night, no specific times	12 hours @ LMN and IHR, 24 hours @ TDA	12 hours @ IHR, 8 hours @ TDA	24 hours @ IHR, TDA and BON, 12 hours @ all others	24 hours @ IHR, TDA and BON, 12 hours @ all others	24 hours @ LMN, IHR, TDA and BON, 12 hours @ all others	24 hours @ LMN, IHR, TDA and BON, 12 hours @ all others	n/a	12 hours @ JDA, 24 hours @ all others
Lower Granite		No spill	No spill	0 day and 80% night (40 kcfs gas cap)	0 day and 80% night (45 kcfs gas cap)	0 day and gas cap night (60 kcfs gas cap)	20 kcfs day and 20 kcfs night	n/a	20 kcfs day and night
Little Goose		No spill	No spill	0 day and 80% night (35 kcfs gas cap)	0 day and 80% night (60 kcfs gas cap)	0 day and gas cap night (45 kcfs gas cap)	0 day and gas cap night	n/a	30% of flow day and night
Lower Monumental		0 day and 70% night	No spill	0 day and 81% night (40 kcfs gas cap)	0 day and 81% night (40 kcfs gas cap)	Gas cap day and gas cap night (40 kcfs gas cap)	Gas cap day and night	n/a	Gas cap day and night

Table A-10. Historical, Spring, and Summer Spill Levels (continued)

		1988 Spill MOA	1994 BiOp	1995 BiOp	1998 BiOp	2000 BiOp	2004 BiOp	2005 Court Order	2006 Court Order
Spring Spill Levels (continued)									
Dates	No Formal Dates	Between 10 and 90% passage dates (6/1-7/22 @ IHR and LMN and 6/7-8/22 @ JDA and TDA)	6/1-8/23 @ IHR and 6/7-8/23 @ TDA and JDA	6/21-8/31 in Snake River, 7/1-8/31 in Columbia River	6/21-8/31 in Snake River, 7/1-8/31 in Columbia River	6/21-8/31 in Snake River, 7/1-8/31 in Columbia River	6/21-8/31 @ IHR, 7/1-8/31 @ JDA, TDA, and BON	2004 BiOp spill plus 7/1-8/31 @ LGR, LGS, LMN, MCN	6/21-8/31 @ Snake River Dams, 7/1-8/31 @ Columbia River Dams
Hours	Generally at night, no specific times	12 hours @ LMN and IHR, 24 hours @ TDA	12 hours @ IHR, 8 hours @ TDA	24 hours @ IHR, TDA and BON, 12 hours @ all others	24 hours @ IHR, TDA and BON, 12 hours @ all others	24 hours @ LMN, IHR, TDA and BON, 12 hours @ all others	24 hours @ LMN, IHR, TDA and BON, 12 hours @ all others	n/a	12 hours @ JDA, 24 hours @ all others
Ice Harbor		0 day and 25% night	0 day and 60% night up to 25 kcfs max	27% day and 27% night (25 kcfs gas cap)	45 kcfs day and gas cap night (75 kcfs gas cap)	45 kcfs day and gas cap night (100 kcfs gas cap)	20 kcfs day and night	n/a	45 kcfs day/Gas Cap Night 4/3-4/19, BiOp vs 30% ~4/20-6/20
McNary		No spill	No spill	0 day and 50% night (120 kcfs gas cap)	0 day and gas cap night (150 kcfs gas	0 day and gas cap night (120-150 kcfs gas cap)	0 day and gas cap night	n/a	0 day and Gas Cap night 4/10-4/19, 40% 4/20-6/20
John Day		No spill	No spill	0 day and 33% night (20-50 kcfs gas cap)	0 day and 60% night (180 kcfs gas cap)	0 day and 60% night (85-160 kcfs gas cap) (began testing 24-hr spill)	No spill day and 60% night	n/a	0 day, 60% night
The Dalles		0 day and 10% night	0 day and 10% night	64% day and 64% night (230 kcfs gas cap)	64% day and 64% night (230 kcfs gas cap)	40% day and 40% night (230 kcfs gas cap) (40% spill improved tailrace conditions)	40% day and 40% night	n/a	40% of flow day and night
Bonneville		No spill	Spill if necessary to provide 70% FPE (non-turbine passage	Not specified due to adult passage concerns, implemented 75 kcfs day and gas cap night (120 kcfs gas cap)	Not specified due to adult passage concerns, implemented 75 kcfs day and gas cap night (120 kcfs gas cap)	75 kcfs day and gas gap night (90-150 kcfs gas cap)	75 kcfs day and gas cap night	n/a	100 kcfs day and night

Table A-10. Historical, Spring, and Summer Spill Levels (continued)

		1988 Spill MOA	1994 BiOp	1995 BiOp	1998 BiOp	2000 BiOp	2004 BiOp	2005 Court Order	2006 Court Order
Spring Spill Levels (continued)									
Dates	No Formal Dates	Between 10 and 90% passage dates (6/1-7/22 @ IHR and LMN and 6/7-8/22 @ JDA and TDA)	6/1-8/23 @ IHR and 6/7-8/23 @ TDA and JDA	6/21-8/31 in Snake River, 7/1-8/31 in Columbia River	6/21-8/31 in Snake River, 7/1-8/31 in Columbia River	6/21-8/31 in Snake River, 7/1-8/31 in Columbia River	6/21-8/31 @ IHR, 7/1-8/31 @ JDA, TDA and BON	2004 BiOp spill plus 7/1-8/31 @ LGR, LGS, LMN, MCN	6/21-8/31 @ Snake River Dams, 7/1-8/31 @ Columbia River Dams
Hours	Generally at night, no specific times	12 hours @ LMN and IHR, 10 hours @ JDA, 24 hours @ TDA	12 hours @ IHR, 10 hours @ JDA, 8 hours @ TDA	24 hours @ IHR, TDA and BON, 12 hours @ all others	24 hours @ IHR, TDA and BON, 12 hours @ all others	24 hours @ LMN, IHR, TDA and BON, 12 hours @ all others	24 hours @ LMN, IHR, TDA @ BON, 12 hours @ all others	24 hours at all projects	24 hours at all projects
Lower Granite		No spill	No spill	No spill	No spill	No spill	No spill	Operate one turbine, spill the rest	18 kcfs day and 18 kcfs night
Little Goose		No spill	No spill	No spill	No spill	No spill	No spill	Operate one turbine, spill the rest	30% day and 30% night
Lower Monumental		0 day and 70% night	No spill	No spill	No spill	No spill	No spill	Operate one turbine, spill the rest	17 kcfs day and 17 kcfs night
Ice Harbor		0 day and 25% night	0 day and 30% night up to 25 kcfs max	70% day and 70% night (25 kcfs gas cap)	45kcfs day and gas cap night (75 kcfs gas cap)	45kcfs day and gas cap night (100 kcfs gas cap)	45kcfs day and gas cap night (115 to 120 kcfs gas cap)	Operate one turbine, spill the rest	45 kcfs day and gas cap night
McNary		No spill	No spill	No spill	No spill	No spill	No spill	50 kcfs through powerhouse, spill the rest	Alternating 40% day and 40% night vs 60% day and 60% night
John Day		0 day and 20% night	0 day and 20% night	0 day and 86% night (20-50 kcfs gas cap)	0 day and 60% night (180 kcfs gas cap)	0 day and 60% night (85 to 160 kcfs gas cap) (began testing 24-hour spill)	30% day and 30% night	30% day and 30% night	30% day and 30% night
The Dalles		0 day and 5% night	0 day and 5% night	64% day and 64% night (230 kcfs gas cap)	64% day and 64% night (230 kcfs gas cap)	40% day and 40% night (230 kcfs gas cap) (40% spill improved tailrace conditions)	40% day and 40% night	40% day and 40% night	40% day and 40% night

Table A-10. Historical, Spring, and Summer Spill Levels (continued)

		1988 Spill MOA	1994 BiOp	1995 BiOp	1998 BiOp	2000 BiOp	2004 BiOp	2005 Court Order	2006 Court Order
Summer Spill Levels									
Dates	No Formal Dates	Between 10 and 90% passage dates (6/1-7/22 @ IHR and LMN and 6/7-8/22 @ JDA and TDA)	6/1-8/23 @ IHR and 6/7-8/23 @ TDA and JDA	6/21-8/31 in Snake River, 7/1-8/31 in Columbia River	6/21-8/31 in Snake River, 7/1-8/31 in Columbia River	6/21-8/31 in Snake River, 7/1-8/31 in Columbia River	6/21-8/31 @ IHR, 7/1-8/31 @ JDA, TDA and BON	2004 BiOp spill plus 7/1-8/31 @ LGR, LGS, LMN, MCN	6/21-8/31 @ Snake River Dams, 7/1-8/31 @ Columbia River Dams
Hours	Generally at night, no specific times	12 hours @ LMN and IHR, 10 hours @ JDA, 24 hours @ TDA	12 hours @ IHR, 10 hours @ JDA, 8 hours @ TDA	24 hours @ IHR, TDA and BON, 12 hours @ all others	24 hours @ IHR, TDA and BON, 12 hours @ all others	24 hours @ LMN, IHR, TDA and BON, 12 hours @ all others	24 hours @ LMN, IHR, TDA @ BON, 12 hours @ all others	24 hours at all projects	24 hours at all projects
Bonneville		No spill	Spill if necessary to provide 50% FPE (non-turbine passage)	Not specified due to adult passage concerns, implemented 75 kcfs day and gas cap night (120 kcfs gas cap)	Not specified due to adult passage concerns, implemented 75 kcfs day and gas cap night (120 kcfs gas cap)	75 kcfs day and gas cap night (90-150 kcfs gas cap)	75 kcfs day and gas cap night (115-120 kcfs gas cap)	75 kcfs day and gas cap night (115-120 kcfs gas cap)	75 kcfs day and 120 kcfs night

BON= Bonneville Dam, IHR= Ice Harbor Dam, JDA = John Day Dam, LGR = Lower Granite Dam, LGS = Little Goose Dam, LMN = Lower Monumental Dam, MCN = McNary Dam, MOA = memorandum of agreement

D. TRANSPORTATION OF JUVENILE FISH

Research on the most effective ways to transport juvenile fish began in 1968. Today, millions of juvenile fish are collected and transported each year from facilities located at Lower Granite, Little Goose, Lower Monumental, and McNary dams. Since 1995, two additional large transport barges went into service, bringing the total to eight.

Given uncertainties surrounding both in-river migration and transportation, the Action Agencies continue to use a risk management strategy for fish passage. Operations since 1995 dictate transport during summer flow and other low-flow periods, when juveniles face the highest risk if left in the river to migrate. Ninety-eight percent of transported fish survive to be released in the river below Bonneville Dam, however, the returns of adult fish are the key indicator for success of the program. In recent years, extensive research on transport has occurred to better manage the transport program. This research has focused on timing - when is it best to transport or leave fish in-river. The result of this work directs the recent transportation management strategy based on the type of water year (e.g. high or low runoff), water quality conditions (e.g. water temperature changes), and in-season changing flow conditions (e.g. changes from spring to summer like flow conditions). An example of this was water year 2000-2001, a very low water year when virtually all spring and summer migrants in the Snake River were transported. When those fish returned as adults to Ice Harbor Dam as adults in 2003 and 2004, their numbers were among the highest of record (University of Washington Data Access in Real Time [DART] Program). Transportation, along with other mitigating measures, helped ensure that a large number of juvenile fish entered the Pacific Ocean to benefit from favorable ocean conditions.

E. CONTROL OF PREDATORS

Many kinds of human activity in the river environment have had the unintended consequence of increasing predation on juvenile salmon by birds, fish, and marine mammals. In some cases, this predation can be severe. For example, Caspian terns residing on islands in the estuary consume large numbers of listed juvenile fish. A program to encourage the terns to move away from the estuary and closer to the ocean has proved effective, reducing the losses of young salmon from an estimated 14 million in 1999 to 3.6 million in 2005. Cormorants consumed an estimated 6.4 million juvenile salmon in 2005.

Sea lions have appeared at Bonneville Dam, 140 miles upstream from the Pacific Ocean. Adult salmon congregating below the dam are easy prey for the sea lions. NOAA Fisheries and the Corps, with the Oregon and Washington fish and wildlife agencies, and the CRITFC, have employed a variety of harassment techniques to drive the sea lions away. Large, removable steel gates (SLEDS) have been installed to keep the animals out of the fish ladders. The SLEDS have been effective in keeping most of the sea lions out of the fishways. One animal, “C404,” continues occasional excursions into the Washington shore fishway.

One of the largest and most successful predator control programs addresses the northern pikeminnow, a fish that consumes juvenile salmon. A sport-reward angling program, which began in the early 1990s, pays fishers for each pikeminnow they catch. Each year the program is upgraded to produce better results. This year, the fishers hooked nearly 200,000 pikeminnow and were paid $4 to $8 per fish at reception stations. Since its inception, the program has removed 2.7 million pikeminnow, saving about 3 million juvenile salmon.