Reservoir Drawdown: Case Study in Flow Changes to Potentially Improve Fisheries

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Abstract: Salmon populations in the Columbia River Basin have declined, and several species are now protected under the Endangered Species Act. Many factors have contributed to the decline, including overharvest, loss of habitat, degradation of water quality, and construction of dams. Many measures have been implemented to reduce the impact of the dams, but additional measures are being considered. Lowering water-surface elevations behind four lower Snake River dams has been proposed as a measure to improve juvenile salmonid survival. The Corps of Engineers has determined preliminary costs, schedules, and required modifications for several drawdown alternatives. Initial estimates of the ability of this type of operation to improve salmonid survival are controversial.

INTRODUCTION

Substantially lowering water-surface elevations behind some Columbia River Basin dams has been proposed as a means to improve salmon survival. This paper presents background on the salmon populations of the Columbia River Basin, the theory behind the drawdown concept, and a brief history of other measures that have been implemented to increase salmon survival. An initial physical test of the drawdown concept was performed at two Snake River Dams in 1992. Results of this test are presented here, along with a discussion of further evaluations that are ongoing.

BACKGROUND

Salmon Populations

The following species of anadromous salmonids inhabit the Columbia River Basin: spring, summer, and fall chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), and steelhead trout (*O. mykiss*). Anadromous fish are born in freshwater rivers and streams, migrate downstream to the ocean as juveniles, grow to maturity in saltwater, and return again to freshwater to spawn. As the juvenile salmonids migrate downstream they undergo a physiological process known as smoltification, which allows them to adapt to seawater.

Total numbers of adult salmon returning to the Columbia River Basin prior to development were an estimated 8,000,000–16,000,000 (Northwest 1987). Current estimates are that only about 2,000,000–2,500,000 return to the Columbia River, and of those, only about 20% are wild fish. The remainder are born and raised in hatcheries, prior to their release for downstream migration.

Wild salmon populations of the Snake River, a major tributary of the Columbia, have declined to the point where they are now protected under the Endangered Species Act (ESA) of 1973. Coho salmon are extinct. Sockeye are listed as endangered, and spring, summer, and fall chinook are listed

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Note. Discussion open until January 1, 1996. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on April 20, 1995. This paper is part of the ***Journal of Energy Engineering***, Vol. 121, No. 2, August, 1995. ©ASCE, ISSN 0733-9402/95/0002-0089–0096/$2.00 + $.25 per page. Paper No. 10565.

as threatened. The National Marine Fisheries Service (NMFS) is the federal agency responsible for administration of the ESA for anadromous fish species.

The salmon runs in the Pacific Northwest have been affected by many different factors. Overharvest in the late 19th century reduced the runs by an estimated 95%. As development of the region progressed, further damage was done by loss of spawning habitat, degradation of water quality from such practices as farming and logging, introduction of hatchery salmonids and nonnative predatory resident fish, and the construction of dams.

Effects of Dams on Salmon

Some dams in the region, such as Grand Coulee, on the upper Columbia River, the Dworshak, on the Clearwater River, and the Brownlee, on the middle Snake River, were constructed without adult-fish-passage facilities. Dams such as this eliminated the fish populations that had spawned upstream of them.

Dams on the lower Columbia and Snake Rivers constructed by the Corps of Engineers were built with adult-fish-passage facilities. However, the need for juvenile fish passage facilities was not widely recognized until the 1960s following completion of several dams. Fish passing through the turbines suffered an estimated 15% mortality at each dam. Only the Lower Granite Dam, the uppermost on the lower Snake River, was initially constructed with means to protect juvenile fish. The Little Goose, Lower Monumental, and John Day Dams had rudimentary systems, which proved to be inadequate. These have subsequently been replaced with state-of-the-art facilities.

Research on fish passage has been ongoing since the construction of the first Corps dam (Bonneville) in the late 1930s. Initial efforts focused attention on adult fish: improving ladder design, attraction to channels leading to ladders, etc. As noted, juvenile-fish-passage research intensified in the 1960s, and focused on migration rates and survival through the reservoirs and past the dams.

The juvenile-fish-passage facilities developed at the dams include large screens that divert fish that have entered the turbine intakes from actually going through the turbines. The diverted fish (an estimated 35–95% of the total entering the turbine intake, depending on species, stage of smoltification, and dam design) are routed through a channel in the dam and then downstream of the dam via a pipe or flume. The fish are then released to the river, or transported, via truck or barge, for release below the most downstream dam.

In addition to the physical injury the dams can cause the fish, the reservoirs created behind the dams have reduced the average water velocity and provide excellent habitat for salmonid predators, both native and introduced. Research in the 1970s indicated that the length of time it took juvenile fish to reach the ocean from their native streams had substantially increased as a result of dam construction. In the early 1980s, a plan was developed by the Northwest Power Planning Council (NPPC) to reduce the amount of time it takes juvenile salmon to travel through the reservoirs, reducing the exposure to predators, warmer water temperatures, and disease. The plan called for an increase in flow from upstream storage projects during the downstream migration period (primarily April through June). This plan, called the "water budget" (Northwest 1982), was first implemented in 1983, but a series of low flow years, as well as some institutional difficulties, has limited the total amount of water available. In addition, the water budget has had limited evaluation, and the benefit of increased flow has become very controversial (U.S. Army 1992).

The water budget and the juvenile-fish-transportation program have been the primary means of improving juvenile survival through the Snake and Columbia River system for the last decade. However, the populations have not responded as hoped for, and additional measures are being evaluated for their potential to increase survival. These measures include additional substantial improvements to existing adult and juvenile-fish-passage facilities, and the juvenile-fish-transportation program; construction of a facility at the head of the most upstream reservoir to collect juvenile fish for transportation; a canal or pipeline to transport the fish; and reservoir drawdown. Each of these measures is being evaluated by the Corps of Engineers (Corps) in their Columbia River Salmon Mitigation Analysis System Configuration Study (SCS). The objective of the SCS is to evaluate structural measures that have a potential of improving salmonid survival through the eight lower Snake and lower Columbia River dams. A parallel study on Columbia River Basin system operation, called the System Operation Review (SOR), is being conducted by the Corps, the Bonneville Power Administration (BPA), and the Bureau of Reclamation. The SOR is evaluating the operation of the 14 federal dams in the Columbia River system in light of all system requirements, including anadromous and resident fish, wildlife, recreation, power generation, and flood control. Reservoir drawdown is being evaluated in both the SCS and the SOR and is the focus of this paper.

RESERVOIR DRAWDOWN

1992 Lower Granite–Little Goose Dams Reservoir Drawdown Test

The concept of drawdown has been proposed as a means to reduce the cross-sectional area of the reservoirs and thereby increasing the average velocity. Implementation of reservoir drawdown on an annual basis would potentially reduce the amount of water required from upstream storage reservoirs, replacing increased average velocities for increased flow.

The Corps was first requested to complete a test of the reservoir drawdown concept in 1991. Preliminary analysis revealed the potential for substantial environmental and socioeconomic impacts, necessitating completion of National Environmental Policy Act requirements. An Environmental Impact Statement (EIS) was completed during 1991 for a test in 1992.

The test was designed by a group that consisted of representatives from the Corps, the NMFS, other state and federal fish and wildlife agencies, regional Native American tribes, various environmental organizations, public utility districts, Bonneville Power Administration (BPA), and business groups that would be affected by reservoir lowering, such as farmers and the navigation industry.

The objective of reservoir drawdown is to reduce the amount of time it takes juvenile fish to travel through the reservoirs. However, it was quickly determined that without safe fish-passage facilities, the test could not be conducted during the time in which adult and juvenile fish migrations would be occurring. Since existing fish-passage facilities do not work below the normal minimum operating pool levels, test alternatives designed to evaluate the effect of reservoir drawdown on fish migration and survival were evaluated, but not chosen for implementation.

The focus of the 1992 reservoir-drawdown test became the answering of questions about the physical feasibility of such an operation on an annual basis. The lower Snake reservoirs are approximately 100 ft deep, and the normal operating range is the top 3–5 ft. Below this elevation, the navigation locks and fish passage facilities (both adult and juvenile) will not function. The main areas of concern were the feasibility of turbine operation, effects on powerhouse structures, including the spillway stilling basin, and effects on reservoir structures and facilities, such as engineered embankments, ports and marinas, etc. Another key question was the effect of lowering reservoir elevations on dissolved gas supersaturation levels resulting from spill operations.

The test was conducted in March 1992, when very few adult or juvenile fish were migrating through the system. The following paragraphs summarize the results found in the report entitled *1992 Reservoir Drawdown Test, Lower Granite and Little Goose Dams* (Wik et al. 1993).

Lower Granite and Little Goose reservoirs were lowered a total of 36.5 and 12 ft, respectively, to simulate at Lower Granite the condition that would be created if all four pools were lowered. Data on turbine operation, structural impacts, and water quality were obtained. In addition, as much information as possible regarding biological impacts was gathered, including entrainment of resident fish, loss of bottom-dwelling organisms, and impacts on wildlife.

The test confirmed that the turbines would likely function with a substantially lowered pool, although their efficiency was lowered considerably, potentially affecting survival of fish that pass through. The reservoirs were lowered at a rate of 2 ft per day, which appeared to be acceptable for minimizing embankment sloughing, although highway and railroad embankments will need substantial additional riprap protection against wind, precipitation, and wave action if this operation is implemented on an annual basis.

Water velocities were measured throughout the Lower Granite reservoir during normal and lowered pool elevations. In addition, dye was released at the upstream end of the reservoir during the drawdown and travel time measured. Both the water velocity and dye-travel times were used to validate existing mathematical models used to calculate water-travel time through the reservoir. Velocities were increased substantially at the upstream end of the reservoir, where it was returned to a free-flowing river. Closer to the dam, velocities remained very slow.

Dissolved-gas supersaturation, which is harmful to aquatic organisms, including salmonids, was increased as a result of spill. It had been suggested that lowered forebay elevations would ameliorate this increase, but this was not evident. In addition, under higher spill levels, the lowered tailwater appeared to increase dissolved-gas supersaturation relative to normal pool operations.

Sediments deposited at the head of the reservoir were resuspended as velocities increased and redeposited downstream several miles. Turbidity was increased, although not as much as possible because the weather during the month of March was very mild and dry.

Substantial losses of resident fish and bottom-dwelling (benthic) organisms were observed. Resident fish were lost in pools behind reservoir embankments and in shallow-water embayments that dried up during the test. Rescue efforts were made, but were hampered by liquefied mud, which prevented workers from safely retrieving fish. Based on comparative population studies conducted following refill of the reservoir, the losses did not appear to affect the overall populations of resident fish. However, the long-term effects on benthic populations are not known.

Potential for Improvement of Fisheries

Since the 1992 test was conducted during a period with minimal downstream juvenile migration, the question of whether this operation will reduce juvenile salmon travel time has not been answered. The Corps and the NMFS are currently in the process of preparing an EIS for a potential test of reservoir drawdown during the salmon-migration time. This is being done in conjunction with the SCS evaluations of the concept. Both processes are discussed in the following paragraphs.

Study of Configuration of System

The original drawdown proposals considered lowering reservoirs up to as much as 50 ft—the level of the existing crest of the spillway. Since then, an additional alternative has been added: lowering the pools up to 115 ft to return the system to as near a natural river state as possible. Both the "near spillway crest" and "near natural river" alternatives are being considered for two time frames: approximately 2 months (mid-April through mid-June) to potentially provide benefits primarily for spring chinook, and 4.5 months (mid-April through the end of August) to potentially provide benefits for all stocks, including fall chinook, which currently have the lowest population size of the chinook stocks. When drafting and refill periods are added to the duration of the drawdown, the amount of time the river could be affected each year is as much as 10 months (natural river option under low flow refill conditions).

Modifications required, an estimate of costs, and tentative schedules for implementation of these alternatives have been developed for the SCS. All this information is preliminary, or what the Corps calls "reconnaissance level" and if drawdown is continued to be considered, will need to be refined. Additional engineering and biological studies would be required.

All drawdown alternatives would require reconstruction of adult- and juvenile-fish-passage facilities. Turbines may or may not need to be replaced, depending upon impacts to juvenile salmonids and the effectiveness, under drawdown, of facilities used to guide fish away from them. Structures to maintain tailwater elevations below the spillway would be required to prevent erosion of the toe of the dam. It has been determined that the reservoirs can only be lowered 33 ft unless the spillway crest is lowered or a new spillway is built. The near natural river option requires construction of a new bypass structure on one side of the dam. This would include removal of existing earth-fill dam sections or surrounding bedrock, as well as dredging of a new river channel through this area rather than the existing powerhouse.

Estimates of time to construct these and other modifications at each of the four dams range from 14 to 17 years, once authority and funding have been received. These schedules assume two dams would be modified first, a minimum of testing, and then the other two. Costs for construction of modifications are estimated to be between \$1.3 and \$3 billion for the near spillway crest alternatives (depending on the depth of drawdown chosen) and \$5 billion for the near natural river option. These costs do not include mitigation, impacts to navigation and agriculture, or loss of power generation.

The proposed costs of reservoir drawdown are quite high, but are generally considered to be worth investing if this measure will result in bringing the Snake River salmon populations back up to sustainable and harvestable levels. However, whether or not this measure will work is very controversial. As noted previously, the existing data regarding the potential relationship between flow, travel time, and juvenile fish survival are interpreted in many different ways. Some argue that fish would have to survive better since they evolved with higher velocities. Others argue that while there might be a potential to reduce travel time and survival through the reservoir itself, the increased mortality through the dams as a result of changed turbine and bypass conditions would outweigh any gains in the reservoirs.

An additional element of the controversy surrounding reservoir drawdown is whether or not the river system can ever be made reasonably "safe" for juvenile-fish passage. Research on the existing juvenile-fish-transportation program, developed by the NMFS and implemented by the Corps, indicates that this method provides substantially higher survival than allowing the fish to travel in-river. However, due to consecutive low-flow years, this comparison has not been made in high flow years, just average to above average flow years. There are many regional interests who do not feel that removing the fish from the system is acceptable for a long-term solution and who want measures that will allow adequate in-river survival through the eight Corps dams and reservoirs.

Mathematical models have been employed to try to evaluate the potential of reservoir drawdown to improve the declining fish populations. Three different sets of fish models, each including a downstream passage and a life-cycle component, have been developed. The NPPC, the BPA, and the state and federal fish agencies and tribes represented by the Columbia Basin Fish and Wildlife Authority (CBFWA) each have a set. The models are based on existing data, but have varying interpretations of those data.

The group that designed the 1992 reservoir drawdown test, now known as the Columbia River Salmon Mitigation Analysis Technical Advisory Group (TAG), continued to meet following test completion. This group acts in an advisory capacity to the Corps for the SCS. TAG developed a range of assumptions regarding impacts of drawdown to various dam passage parameters. These assumption ranges were combined into a "best" and "worst" case scenario for the potential of reservoir drawdown and were incorporated into two of the model sets. (The CBFWA's model set was unavailable for use at the time these runs were made, so no results are available.)

Initial results from these models indicate little potential benefit for near spillway crest drawdown alternatives, and in most cases indicate a reduction in survival compared to base case. The models differ in their assumptions about the benefit of juvenile-fish transportation, which directly impacts the potential benefit of drawdown. However, both downstream passage models assume fairly conservative estimates of transport benefit. The only drawdown alternative that consistently shows potential benefit with these models is the natural river option. Even assuming that dam-passage conditions are substantially improved over existing conditions, which is highly unlikely, the potential gains in reservoir survival under the near spillway crest alternatives are outweighed by losses in the lower Columbia reservoirs, which are not proposed for drawdown. Only the natural river appears to improve lower Snake survival enough to compensate for increased mortality through the lower Columbia reach.

The model results are controversial because the estimates of downstream survival under existing conditions, which drives the results, have not been validated. The results from the model are not absolute numbers, but are merely tools to provide relative comparison between alternatives. The number of fish surviving through the system—either in-river or through transportation—is not known. The Corps monitors survival aboard the trucks and barges, and it is very high (95+ percent) to the point of release, but there are concerns about postrelease predation, stress-related death, etc. At this point, there is no method available to determine the overall survival of the juvenile fish, which makes it very difficult to determine the best method of improving survival. In addition to lack of validation, there are many factors that the models cannot or do not take into account, particularly effects of project operations on adult-fish passage.

The modifications to the dams and fish-passage facilities that are required to implement drawdown are known, but will require substantial additional studies prior to completion. Existing fish-passage facilities are still being evaluated and modified on essentially a constant basis. Fisheries biologists and engineers are always looking for ways to improve salmon survival through the dams. Many of the modifications are likely to increase adult-fish-passage delay, which may affect their ability to spawn successfully. Studies using large physical scale models (as much as 1:12) are proposed to assist in evaluation of modifications and impacts on fish passage.

Biological Testing of Reservoir Drawdown

As noted previously, the Corps and the NMFS are exploring the possibility of gaining additional information regarding the potential benefits of reservoir drawdown through a test during the fish-migration time. The Corps is designing a system to protect juvenile fish during lowered-pool operations, although the effectiveness of this system is uncertain.

The TAG is currently trying to develop a test plan. There are several theories about where the benefits to reservoir drawdown would occur. It may be that survival would increase in each reservoir that was lowered, or that survival would be improved in the lower Columbia reservoirs because fish would reach them sooner in the downstream migration, when water temperatures might be less and therefore predators would be less active. Earlier arrival to the estuary because of reduced travel time may be the primary potential benefit of reservoir drawdown.

The difficulty in developing a test plan is that these theories are difficult to evaluate. Data regarding existing survival through the reservoirs under normal operation do not exist. If travel time is used as a surrogate for survival measurements, then the test must not modify conditions such that travel time is changed at the dam, masking any change through the reservoir. Estuary survival is not known.

In addition to measuring the effect of drawdown on reservoir conditions for fish, a test should help evaluate changed dam-passage conditions. To do this, at least two reservoirs would have to be lowered. If only one pool is lowered, then the effects of drawdown on turbine and spillway juvenile-fish-passage conditions, as well as adult-fish-passage facilities, would not be measurable. A two reservoir drawdown test requires substantial modifications, some of which could be inadequate and would have to be totally rebuilt if the operation were chosen for long-term implementation.

SUMMARY AND CONCLUSIONS

The feasibility of conducting a reservoir drawdown test when fish are migrating is in the process of being evaluated. So far, methods to provide the critical information for deciding if reservoir drawdown will benefit salmon have not been developed. The potential of increasing juvenile salmon survival by lowering water-surface elevations of the four lower Snake reservoirs is unknown, but initial estimates indicate its potential may not be as great as originally thought. It may or may not be possible to gather information in a test that will adequately resolve the uncertainties regarding the potential of reservoir drawdown.

The Corps is finishing its initial evaluation of reservoir drawdown under the SCS, and plans to have a draft report to the public in the spring of 1994. This report will include a description of dam modifications necessary to implement drawdown, a discussion of studies required prior to a decision on reservoir drawdown, and a more detailed presentation of the mathematical model results.

The process of drawdown evaluation within the region has tended to be very political and highly emotional. The salmon are very important to the Pacific Northwest, and the regional desire is to maintain this magnificent resource. However, this is complicated by the fact that many of the players involved in evaluation of different methods to improve salmon conditions do not have a thorough understanding of the past research, and/or dam operations. In addition, there is distrust of representatives of agencies associated with the power system, who frequently have a better understanding of the potential positive and negative impacts of proposed measures. Because of these factors acting in the evaluation process, it is likely that a solution to improving salmon survival in the Columbia River basin will not be arrived at quickly or easily.

APPENDIX. REFERENCES

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