6. PASSAGE CONCEPTS

6.1 INTRODUCTION

This section is a reconnaissance-level assessment of the engineering requirements for concepts that could provide passage for anadromous salmonids and bull trout at the five Project storage dams. The dams reviewed are Keechelus, Kachess, Cle Elum, Bumping Lake, and Tieton. The report is prepared to collect and analyze the hydrologic data and information on the existing features of each of the dams and then to determine potential upstream and downstream fish passage options.

As a starting point for this assessment the team members reviewed the Reclamation report *Appraisal Design Study, Keechelus Dam Fish Passage* (2001a). Based on the review and comments received, several of the upstream and downstream passage concepts were included in this report. Several other concepts involving downstream passage were reviewed and considered but not pursued further. These will be discussed in Section 6.5.5 – Other Downstream Fish Passage Concepts.

In general, fish passage at each of these dams is complicated by the large fluctuation of reservoir water surface elevations. Typically, the reservoirs begin to fill at the start of the water year (October), reach maximum water surface elevation in the spring (at the start of the irrigation season), and are drawn down through the remainder of the year. Depending on the reservoir, the annual difference in elevation can be as much as 120 feet. Under these conditions, a traditional fish ladder would not function because of large water surface differential on the headwater to the ladder.

The passage concepts in this report describe means of providing fish passage that is exacerbated by the problem of high water surface elevation fluctuations. Some concepts would provide fish passage over the entire range of elevations. Others are designed to operate over a specific and more limited range of elevations that would result in shorter time periods when passage could be provided.

6.2 FISH PASSAGE DESIGN CONSIDERATIONS

A number of physical, hydrological, and biological considerations are involved in the analysis of a fish passage concept. The biological considerations are related to the species targeted for passage, the periods when passage is required, and other issues that are presented elsewhere in this assessment report.

Considerations for upstream passage of adult fish involve providing passage facilities that would minimize delays and would aid in their upstream migration. This would be accomplished by providing adequate attraction flow to the fish passage system, maintaining proper hydraulic conditions in the system, and locating and designing the passage exit to aid fish egress.

Considerations for downstream passage of juvenile fish involve attracting and capturing them within the reservoir and then transporting them to the river. The method of transportation to the river should minimize delay and injury to fish. For design purposes, the attraction flow for upstream passage was assumed to be 10 percent of the release flow from the reservoir. During the irrigation season, this amount of water would not constitute an additional impact on storage.

The attraction flow necessary to attract downstream migrants is a function of site-specific variables such as reservoir orientation, surface currents, depth of existing outlet works, reservoir water surface elevation, and spill from the existing spillway. The features described in this report for downstream passage are designed with the assumption of an attraction flow that is 20 percent of the reservoir release flow. However, an attraction flow that is a higher percentage of the release flow could be used in the design but would likely increase the capital cost of construction.

The percentage of the reservoir releases used as attraction flow for either upstream or downstream passage design methods is assumed to be a percentage of the normal operational releases from the reservoir. The fish passage systems do not require additional releases from storage.

In developing new fish passage operations and structures at Project storage reservoirs, the winter hydrology and/or conditions under which these facilities would need to operate must be carefully considered. All of the storage reservoirs have frozen-over solid some times in the past. In many years, this layer of ice will support light vehicle traffic and in most years the snowpack. Generally, the snowpack in the Keechelus reservoir area ranges from 15 inches (early December) to 105 inches (early April); in the Cle Elum reservoir area, it ranges from 8 inches (early December) to 42 inches (early March); and in the Bumping reservoir area, it ranges from 17 inches (early December) to 90 inches (early April). The cold, snowy conditions would not necessarily preclude the development of fish passage at the dams; however, when designing and installing fish passage features, the winter conditions and associated impacts on operations and maintenance (O&M) activities must be taken into account.

6.3 GENERAL INFORMATION

The five dams studied in this assessment were constructed in the early 1900s to provide irrigation water to the areas adjacent to the Yakima River. None of the dams have power generation facilities. Specific information relative to each dam was presented in Chapter 3.

6.3.1 Hydrologic Data — The assessment team obtained data for reservoir water surface elevations and reservoir releases from Reclamation's Hydromet Archive data base. We selected the period 1994-2001 for this Phase I assessment. Flip-Flop and Mini Flip-Flop operations of the Project began in 1994, and the period also contains representative high, low, and normal water years. These data are presented in Appendix D, Figures 1 through 5, with a pair of hydrographs for each dam.

The upper graph shows "actual reservoir water surface elevation versus time" for WY 1994-2001. This demonstrates how the reservoirs fluctuate seasonally and typical high and low water elevations. The horizontal lines at specific elevations show levels at which fish passage would be provided for various concepts (these concepts are discussed below). The "Time Period for Juvenile Passage" is also shown; this is the "window" when juvenile passage is required; these were previously established and are summarized in Table 4-5. The lower graph shows the actual outflows, or reservoir releases, for the same time period.

6.3.2 Attraction Flows — An adequate attraction flow is a critical design consideration for fish passage. As discussed in Section 6.2, the attraction flow for adult upstream passage is assumed to be 10 percent of the release flow from the reservoir and 20 percent of the release flow for juvenile downstream passage. The release flow or reservoir outflow can be expressed as a percent exceedance flow, or percentage of the time the flow is equaled or exceeded. Exceedance flow data are shown on Figure 6 (in Appendix D) for various reservoir water surface elevations at each dam. Some of the passage concepts provide passage at specific reservoir water surface elevation ranges. The data in Figure 6 are used to determine the reservoir outflows for the concepts at each dam.

6.4 UPSTREAM FISH PASSAGE CONCEPTS

The methods for providing upstream passage for anadromous salmonids examined in this report include trap-and-haul, fish ladder with pumped flow, and a traditional fish ladder. A general discussion of each concept is provided below. Site-specific information for applications at each dam is presented later in this report.

6.4.1 Trap-and-Haul — The trap-and-haul is a conventional but labor intensive method that has been used at other sites in the past. Fish swimming upstream are attracted into a collection facility where they can be captured and then transported over the dam, usually by trucks equipped with tanks and water-quality equipment.

As previously discussed, an attraction flow for upstream passage of a minimum of 10 percent of the flow would be provided. This concept also assumes the use of a barrier dam to provide the attraction flow and to prevent upstream migrants from swimming past the collection facility. The barrier dam would span the width of the river downstream from the storage dam and would be designed to produce approximately a 10-foot water-surface differential to function as a physical barrier to upstream migrating fish.

The entrance to the collection facility consists of a short section of fish ladder. Flow to the ladder is provided by the head differential created by the barrier dam. Fish swim up the ladder and into a fish collection facility; this might include holding ponds, sorting and tagging areas, crowder, hopper, and truck-loading area. After the fish are collected in a hopper, they would be loaded on a truck, transported, and released upstream from the dam. The fish could be released into the reservoir or tributary streams.

The cost of this concept includes the construction of a barrier dam, collection-and-trap facility, and haul roads, and the purchase of transportation trucks. The total estimated construction cost of this concept is about $7 million. (Site-specific conditions that might cause some cost variations among sites were beyond the scope of this Phase 1 assessment.)

The primary annual operation and maintenance (O&M) cost for the trap-and-haul concept is for personnel to operate the facility. This assumes two people working 8-hour days and 7-day weeks for 10 months, the time period when passage is required. Additional O&M costs include the operation of a haul truck, electric power at the trap facility, routine maintenance of facility and haul roads, and replacement costs for pumps (and other facility equipment), all assumed to have a 20-year operational life. The total estimated annual O&M cost is $250,000.

A trap-and-haul system offers several advantages. Upstream migrants can be released at a variety of locations in the reservoir or tributary streams, depending on fish management considerations. The facilities can also be used for monitoring, gathering biological data, and evaluating fisheries restoration objectives. A disadvantage of this type of system is that it requires personnel and their associated costs to operate the system and requires handling the fish.

6.4.2 Fish Ladder with Pumped Flow — This concept uses a traditional fish ladder to the top of the dam and a flume (slide) that slopes down to the reservoir. Ladder flow would be pumped from the river to the top of the dam.

The concept has the same requirements of attracting fish to the entrance of the ladder as described above for the trap-and-haul concept. A barrier dam would also be used for this concept to attract fish to the ladder entrance. The ladder could be a pool-and-weir, vertical slot, or orifice type.

A typical ladder for this concept would begin at the barrier dam in the river and extend to the crest of the dam at either abutment. A "false weir" would be at the top of the ladder on the crest of the dam. Pumped flow would enter the ladder at the weir with the majority of the water flowing down the ladder. A portion of the water would flow over the reservoir side of the weir. When fish jump over the weir, they enter a chute that extends into the reservoir. The lower end of the chute is at the reservoir minimum pool elevation. Fish exit the chute at the current reservoir water surface elevation.

For purposes of this assessment, the pumping structure would be located in the river downstream from the dam. The intake to the pump would be screened to meet juvenile fish screen criteria. The large fluctuation in the reservoir water surface elevation would make the placement of pumps on the upstream side of the dam difficult (but not impossible). The pipe from the pump structure to the false weir would be located next to the ladder.

The cost to construct this concept would include the cost to construct the fish ladder, pump with pump structure, fish screen on the pump intake, pipeline, and chute. The total estimated cost of this concept is approximately $8.5 million with some possible variations from site to site that are beyond the scope of this Phase 1 assessment.

Most of the O&M cost for the fish ladder with pumped flow is the cost of electricity to pump water for the ladder flow from the river to the top of the dam. It was assumed that the pumps would run continuously for a 10-month operating season and costs would vary depending on the height of the dam. Additional costs for this concept include inspection and minor work, assuming 1 staff-hour every other day for the 10-month operating season; routine maintenance of the system; and replacement costs for the pumps and motors with a 20-year operational life. Depending on the site, the total estimated annual O&M costs range from $210,000 to $380,000.

The advantage of this concept is that it does not require on-site, full-time personnel to operate the system for passage to function. Fish are provided volitional upstream passage opportunities. The system would also have minimal debris problems since all ladder flow would be pumped. Disadvantages include high O&M costs due to the need to provide pump flow to the top of the ladder continuously. If the pumps were to fail or if there were a power failure, fish ascending the ladder could become stranded. The length of the ladders and number of pools might be a concern for passage of some species of fish.

6.4.3 Fish Ladder — A traditional gravity flow fish ladder using a series of stepped pools with orifices may be feasible at Bumping Lake Dam. The reservoir's annual water surface fluctuation is approximately 34 feet. At the other dams, water surface differentials range between 60 and 120 feet. A description of the ladder is presented in Option 7.4.2. "Bumping Lake Dam Upstream Fish Passage – Fish Ladder."

The cost involved with this concept would primarily be the cost of the construction of the fish ladder which is estimated to be $11 million.

The O&M cost for the traditional fish ladder would be much less than the fish ladder with pumped flow because there are no pumping costs or pumps to maintain and replace. The associated costs include inspection every other day for one person for one hour for the 10-month operating season, routine maintenance, debris removal, minor repairs, and replacement costs for gates and valves assuming a 20-year life. The total estimated annual O&M cost for this concept is $15,000.

The advantage of this concept is that it would not require staff to operate the system. It would only require periodic cleaning of trashracks, minor maintenance, and adjustments to gates and valves to account for changes in the reservoir elevation. The gate and valve adjustment could be automated.

6.5 DOWNSTREAM FISH PASSAGE CONCEPTS

The methods for providing downstream fish passage examined in this Phase 1 assessment include surface spill with modification to the existing spillway, construction of new spillways, use of a fish collection barge, and construction of new outlet works. A general discussion of each concept is presented below. Site-specific information and the application of concepts at each dam are presented later in this report.

6.5.1 Spillway Modifications — Several concepts at each dam would involve downstream passage through the use of "overshot gates," which operate by spill over the top. At Cle Elum Dam, fish were not attracted to the spill from submerged radial gates (NMFS 2000). This concept would provide surface releases that would attract fish and then encourage them to pass out of the reservoir. No additional water would be required since the surface spill would be taken from normal operational releases. Operational releases from the reservoir would be maximized at the surface spill system and any additional flow beyond the design capacity of the overshot gate would be released from the existing outlet works. Releases from the outlet works are in deep water and would not likely cause a false attraction for juvenile fish away from the overshot gate. If there is a temperature problem in the river downstream from the dam caused by flow from the surface spill only, releases from the outlet works would be used for part of the total release. It is assumed that during periods of the year with ice on the reservoir, the Spillway Modifications concept would not operate and reservoir releases would be made only from the outlet works.

An existing spillway would be modified by the installation of gates or by the addition of gates for those dams with uncontrolled spillways. At least four manufacturers market adjustable-crest overshot-type gates that could be used for these installations. These gates include Langemann (adjustable horizontal bi-fold gates that spill over the top), Obermeyer (weir gates, a steel panel adjusted by an air-inflated, reinforced rubber bladder), Rodney Hunt (crest gates, a steel panel operated by hydraulic cylinders from above), and Waterman (downward operating slide gates or roller gates).

Surface spill concepts would involve the construction of gates at a lower elevation on the spillways than the existing gates; this would allow a surface release of water to lower elevations. Many of these concepts require the excavation of entrance channels upstream from the spillways. Further geologic investigations as to the implications of these excavations on the embankments would be required. The Spillway Modifications concept and the other downstream passage concepts are assumed to require the installation of trashracks to remove debris.

The estimated construction costs for this concept vary by dam and by the type of system used. These are summarized in Table 7-1 and listed in the subsection in Chapter 7 describing each option. The estimated costs range from \$1.7 million (Bumping Lake Dam) to \$5.0 million (Kachess Dam).

The O&M costs for this concept are relatively minor. The costs are assumed to include inspection and debris removal every other day by one person for the 10-month operating season, routine maintenance and repairs, and replacement costs of the gates assuming a 20-year life. The total estimated annual O&M cost for this concept is \$20,000.

These downstream passage concepts have three main advantages — they would be relatively simple to construct, less expensive than other concepts, and easier to operate and maintain. Their biggest disadvantage is that they do not permit passage over the entire range of reservoir water surface elevations, and therefore limit the overall time during which passage would be provided. This will be discussed in more detail for each specific concept at each dam.

6.5.2 New Fish Spillway — The New Fish Spillway operates under the same principle as the Spillway Modifications. The idea of this concept is to provide surface-spill releases at lower reservoir elevations than could be obtained by modifications to the existing spillways. NMFS (2000) noted:

> "…safe exit routes from the reservoir through reconfiguration of the radial gates at Cle Elum Dam and through installation of floating surface weirs were unsuccessful … an adequate smolt bypass system will probably need to be configured at elevations of at least 10+ m below the current spilldeck elevation."

For this concept, a new fish spillway would be located adjacent to existing spillways. The existing spillways would remain in place and operational, and no additional water would be required for the new fish spillway. It is assumed that normal operational reservoir releases would be made by maximizing flow through the fish spillway. Any additional required water would be released through the outlet works. Depending on the proportion of flow between the new fish spillway and the outlet works, the deep-level release through the outlet works would likely not be a false attraction flow for juvenile fish away from the fish spillway.

The New Fish Spillway concepts typically contain a series of gates at various elevations. The gate at the current water surface reservoir elevation would be opened to provide a surface spill into the spillway. The New Fish Spillway concept allows a release of water at lower elevations than the modified spillway concepts. This requires excavations into the abutments and deeper channel excavations upstream into the reservoirs. Further geologic investigations as to the implications of these excavations on the embankments are required.

The estimated construction costs for this concept vary by dam. They are summarized in Table 7-1 and listed in the subsection in Chapter 7 describing each option. The estimated costs range from $4.6 million (Bumping Lake Dam) to $42 million (Tieton Dam).

The O&M costs for this concept are expected to be about the same as stated previously for the Spillway Modifications concept. The same assumptions and cost items apply. The total estimated annual O&M cost is approximately $20,000.

The advantages of the New Fish Spillway Passage concept would be similar to the Spillway Modification concept — relatively simple to construct, less expensive than some other concepts, and easier to operate and maintain.

The disadvantages are also similarly — it would not permit passage over the entire range of reservoir water surface elevations and it is limited in the overall time during which passage would be provided. However, this concept would offer a greater range of passage than the Spillway Modification concepts. Specific elevation ranges will be discussed in more detail for each specific concept at each dam.

6.5.3 Fish Collection Barge — This system consists of a barrier net (to guide fish), a collection (or "gulper") barge with pumps, an underwater bypass pipe, and a holding barge. The concept was modeled after existing facilities at Upper Baker Dam (on the Baker River in western Washington and owned by Puget Sound Energy). Drawing 11 shows a detail of the system as envisioned at Keechelus Dam.

A small-mesh guide-net would extend across the reservoir and direct fish toward a collection barge positioned to use outlet works flow for additional attraction. A log boom on the upstream side of the net would help protect it from floating debris. The net at the Upper Baker Dam has been used without major debris problems; however, it was reported that the orientation of the reservoir is such that debris does not drift toward the dam. This is not the case at all Project dams. Guide nets would be difficult if not impossible to manage at some sites due to debris and ice (Ken Bates, WDFW, pers. comm.). Significant debris drifts onto the dam at Keechelus Reservoir.

The collection barge would be similar in function to a fish screen. The barge's main pumps would be located at its downstream end and would draw an attraction flow into the upstream end (front) of the barge and through a sloping screen. The main pumps would be sized to draw 20 percent of the 10-percent exceedance flow release from the reservoir (figure 6 in appendix D). The sloping screen would meet current screen criteria for juvenile fry-sized fish. The portion of the attraction flow containing the fish would be diverted over the screen into a flume. Smaller pumps would then draw the flow through a second screen, further reducing the flow containing the fish. The fish would then be diverted into a collection hopper. A bypass pipe at the base of the hopper would convey the fish to a holding barge, equipped with a crowder and hopper.

The holding barge would be located in the low-reservoir channel in front of the outlet works. A bridge to the barge would be required from the crest of the dam to a point near the outlet works. A jib crane at the end of this bridge would be used to lift the fish hopper to a truck on the bridge. The truck would then transport fish for release in the river downstream from the dam. This would be a water-to-water transfer.

The primary cost for this concept is the cost of the fish collection barge and holding barge. Additional costs include the bridge on the dam embankment and trap and haul system. The total estimated cost for this concept is $11 million (for each of the five storage dams).

In calculating the O&M costs for the Fish Collection Barge concept, it was assumed that the barge would be operated 8 hours per day for a 10-month operating season. Two people would be required to operate the facility. Other O&M costs include annual maintenance on the barge, electric power to operate the attraction flow pumps, and replacement cost of the barge assuming a 20-year life. The total annual estimated O&M cost for this concept is $340,000.

The advantage of the Fish Collection Barge concept is that it can provide downstream passage for the full range of water surface elevations in the reservoir. This would allow passage over the entire downstream passage window, except for extreme winter conditions.

There are several disadvantages. One is that during the time of the year when the reservoir may be iced over, the barge would have to be removed or winterized. Another disadvantage is that it requires personnel to operate the barge and trap-and-haul system during the entire time that passage is required. Also, reservoir debris conditions simply may preclude this concept at some sites.

6.5.4 New Outlet Works — This concept is a stationary collection structure that provides an attraction flow to draw downstream migrants to the structure. Fish are separated from the attraction flow by a screen and are then transferred with a bypass flow that moves them into a collection chamber. From there, they are moved below the dam by one of two methods; either through a pipe or a trap-and-haul system.

Drawing 12 shows a detail of this concept as envisioned at Keechelus Dam. The concept was modeled after a fish passage facility being designed by the Army Corps of Engineers for Howard Hanson Dam on the Green River in western Washington. The system shown on Drawing 12 uses an adjustable “collection horn” that can be raised or lowered by a hoist to adjust to the level of the reservoir. (The Howard Hanson design has recently been revised to replace the adjustable collection horn with a series of smaller vertically aligned stationary screens.)

The existing outlet works would remain in place and operational. No additional water release would be required. Normal operational releases would provide the attraction flow used in the new outlet works.

The system is also designed to minimize detrimental impacts to fish. For example, the water surface elevation in the fish collection chamber can be controlled to minimize the free-fall distance the fish travel after being screened out to drop into the chamber. For the alternative of using a pipe to transport fish below the dam, an acceptable velocity of the flow in the pipe can be maintained by controlling the water level in the fish collection chamber when the fish are released.

The costs involved for this concept include the cost of the outlet works structure, the costs of collection and modular inclined screen, hoist system, numerous piping systems, valves, and controls.

The estimated costs for this concept vary by dam. These costs are summarized in Table 7-1 and listed in the subsection in Chapter 7 describing each option. The estimated constructions costs of this concept range from $20 million (Bumping Lake Dam) to $25 million Keechelus, Kachess, and Cle Elum dams).

As previously discussed, this concept provides for two methods to transport fish downstream from the dam. One is to move the fish in a bypass flow with a pipe that extends through the existing outlet works. This method would not require personnel to operate the system. The second method would be to collect the fish in a trap within the new outlet works and use a trap-and-haul method to move the fish downstream from the dam. This method assumes two people working 8 hours per day for a 10-month operating season. Other O&M costs that are common to both methods are routine maintenance of facility components; electric power for lights, controls, and other systems; and replacement cost of the major components, such as collection horn, rubber dam, and modular inclined screen. These items are assumed to have a life of 20 years. The estimated annual O&M costs for the bypass pipe option is $110,000; annual O&M for the trap-and-haul option is estimated to be $320,000.

Like the fish collection barge concept, the main advantage of this concept is that it could provide downstream passage over the full range of water surface elevations in the reservoir. This would allow downstream passage over the entire passage window. This concept would also be less susceptible to problems with winter icing conditions and with debris than the barge concept. The biggest disadvantage would be the construction cost of a large structure in the reservoir; that would likely require a low reservoir pool elevation combined with extensive cofferdams.

6.5.5 Other Downstream Passage Concepts — Several additional methods were considered in the *Appraisal Design Study, Keechelus Dam Fish Passage* (USBR 2001a) but were not pursued further in the Phase I assessment for various reasons. These include:

- ***Fish collection barge with a fish conveyance pipe*** — This concept would use the fish collection barge (as described above) with a conveyance pipe through the dam to transport the fish downstream to the river. The main objection to this method is the inability to maintain hydraulic conditions inside the pipe that are within juvenile bypass pipe criteria. Because of the fluctuating reservoir water surface elevation, the flow depths and velocities would vary widely.
- ***Multiple level intake gates with multiple bypass pipes*** — This concept would use a collection structure with juvenile fish intakes at multiple levels in the reservoir. The intakes connect to several bypass pipes at multiple levels that extend through the dam. The concept was dropped because the pipes through the dam are a dam-safety concern due to potential leakage or failure of the pipe, which could result in erosion of the embankment and catastrophic failure of the dam.
- ***Multiple-level intakes with bottom flow energy dissipation wells*** — This concept would use the same type of multiple-level collection structure as described above with a series of interconnected vertical shafts (or well-type structures) and a single pipe through the dam. The wells are connected at the base and would dissipate the hydraulic head from a high reservoir water surface elevation and then move fish in the pipe through the dam at a reasonable velocity. This concept was rejected because of the dam-safety issue with the pipe through the dam, debris problems in the wells, and turbulence in the system.
- ***Multiple level intakes with top flow energy dissipation wells*** — This is the same as the previously described concept, except that the wells are connected at the top. The same concerns apply.