



Feasibility of Reintroduction of Anadromous Fish Above or Within the Hells Canyon Complex

James A. Chandler
Editor

**Technical Report
Appendix E.3.1-2**

Hells Canyon Complex
FERC No. 1971

December 2001

Copyright © 2003 by Idaho Power Company



Conceptual Design of Passage Facilities for the Hells Canyon Complex

Glenn Aurdahl
Sverdrup Corporation

John Etulain
Sverdrup Corporation

Marinus Voskuilen
Sverdrup Corporation

Sharon E. Parkinson
Principal Engineer

Technical Report
Appendix E.3.1-2
Feasibility of Reintroduction of
Anadromous Fish above or
within the Hells Canyon
Complex

Chapter 9

Hells Canyon Complex
FERC No. 1971

December 2001

Copyright © 2003 by Idaho Power Company

TABLE OF CONTENTS

Table of Contents	i
List of Tables	vi
List of Figures	vi
1. Introduction.....	1
2. Basic Dam Characteristics	1
2.1. Hells Canyon Dam	1
2.2. Oxbow Dam	2
2.3. Brownlee Dam	2
3. Review of Fish Passage Concepts.....	2
3.1. Downstream Passage	3
3.1.1. Forebay Collection and Bypass—Fish Attraction Barges (Gulpers).....	3
3.1.2. Eicher Screens.....	5
3.1.3. Modular Inclined Screens	7
3.1.4. Intake Diversion Screens	8
3.1.5. Surface Collection.....	10
3.1.6. Spillway Release.....	12
3.1.7. Behavioral Guidance Structure	13
3.1.8. Turbine Passage	14
3.1.9. Upper Reservoir Collection—Portable Floating Traps.....	15
3.1.10. Upper Reservoir Collection—Fixed-Location In-River Trap.....	18
3.1.11. Tributary Collection—Fixed-Location In-River Traps (Wolfe Traps).....	19
3.1.12. Tributary Collection—Portable Screw Traps	21
3.1.13. Tributary Collection—Louver System	22

3.1.14. Upper Reservoir and Tributary Collection—Transport Options	23
3.2. Upstream Passage	26
3.2.1. Fish Ladders.....	26
3.2.2. Fish Locks.....	28
3.2.3. Fish Elevators.....	29
3.2.4. Trap and Haul	30
3.2.5. Entrance Conditions for Upstream Passage.....	31
4. Evaluation of Downstream Passage Concepts.....	32
4.1. Brownlee Dam	32
4.1.1. Forebay Collection and Bypass—Fish Attraction Barges (Gulpers).....	32
4.1.2. Eicher Screens.....	33
4.1.3. Modular Inclined Screens	33
4.1.4. Intake Diversion Screens	34
4.1.5. Surface Collection.....	34
4.1.6. Behavioral Guidance Structure Combined with Spillway Release.....	34
4.1.7. Turbine Passage	35
4.1.8. Upper Reservoir Collection—Portable Floating Traps.....	35
4.1.9. Upper Reservoir Collection—Fixed-Location In-River Traps	35
4.1.10. Tributary Collection—Fixed-Location In-River Traps (Wolfe Traps).....	35
4.1.11. Upper Reservoir and Tributary Collection—Transport Options	35
4.1.12. Other Issues.....	36
4.1.13. Recommended Alternatives	36
4.2. Oxbow Dam	37
4.2.1. Forebay Collection and Bypass—Fish Attraction Barges (Gulpers).....	37
4.2.2. Eicher Screens.....	37

4.2.3. Modular Inclined Screens	38
4.2.4. Intake Diversion Screens	38
4.2.5. Surface Collection.....	39
4.2.6. Behavioral Guidance Structure and Spillway Releases.....	39
4.2.7. Turbine Passage	39
4.2.8. Upper Reservoir Collection—Portable Floating Traps.....	39
4.2.9. Upper Reservoir Collection—Fixed-Location In-River Traps	39
4.2.10. Tributary Collection—Fixed-Location In-River Traps (Wolfe Traps).....	40
4.2.11. Other Issues.....	40
4.2.12. Recommended Alternatives	40
4.3. Hells Canyon Dam.....	40
4.3.1. Forebay Collection and Bypass—Fish Attraction Barges (Gulpers).....	40
4.3.2. Eicher Screens.....	40
4.3.3. Modular Inclined Screens	41
4.3.4. Intake Diversion Screens	41
4.3.5. Surface Collection.....	41
4.3.6. Behavioral Guidance Structure and Spillway Releases.....	41
4.3.7. Turbine Passage	41
4.3.8. Upper Reservoir Collection—Portable Floating Traps.....	42
4.3.9. Upper Reservoir Collection—Fixed-Location In-River Traps	42
4.3.10. Recommended Alternatives	42
5. Evaluation of Upstream Fish Passage Concepts.....	42
5.1. Hells Canyon Dam.....	42
5.1.1. Fish Ladder	42
5.1.2. Fish Lock	43

5.1.3. Fish Lift.....	43
5.1.4. Trap and Haul	44
5.1.5. Recommended Alternatives.....	44
5.2. Oxbow Dam.....	44
5.2.1. Fish Ladder	44
5.2.2. Fish Lock	45
5.2.3. Fish Lift.....	45
5.2.4. Trap and Haul	45
5.2.5. Recommended Alternatives.....	45
5.3. Brownlee Dam	45
5.3.1. Fish Ladder	45
5.3.2. Fish Lock	46
5.3.3. Fish Lift.....	46
5.3.4. Trap and Haul	46
5.3.5. Recommended Alternatives.....	46
6. Cost Estimates Based on Conceptual Designs.....	46
6.1. Construction Cost Estimates.....	46
6.2. Operation and Maintenance Costs	47
6.3. Estimate Summaries—Downstream Passage	47
6.3.1. Brownlee Dam	47
6.3.2. Oxbow Dam.....	48
6.3.3. Hells Canyon Dam.....	49
6.4. Estimate Summaries—Upstream Passage	49
6.4.1. Hells Canyon Dam.....	49
6.4.2. Oxbow Dam.....	50

6.4.3. Brownlee Dam50

7. Literature Cited51

LIST OF TABLES

Table 1.	Summary of conceptual cost estimates of recommended downstream passage options for HCC reservoirs and dams.	55
Table 2.	Summary of conceptual cost estimates of recommended upstream passage options for HCC reservoirs and dams.	56

LIST OF FIGURES

Figure 1.	Plan and section views of a fish attraction barge (gulper).	57
Figure 2.	Typical sections of fish attraction barge (gulper).	58
Figure 3.	Top and section views of an Eicher screen.	59
Figure 4.	Section and plan views of a modular inclined screen (MIS).	60
Figure 5.	Multiple unit concept of a modular inclined screen (MIS).	61
Figure 6.	Diagram of an intake diversion screen.	62
Figure 7.	Diagram of a notched spill gate.	63
Figure 8.	Diagram of a top-spill overflow weir.	64
Figure 9.	Illustration of a removable spillway weir (RSW).	65
Figure 10.	Diagram of a behavioral guidance structure (BGS).	66
Figure 11.	Illustrations of Francis and Kaplan runners.	67
Figure 12.	Illustration of an ARL/NREC fish-friendly hydroturbine.	68
Figure 13.	Schematic of a floating trap design.	69
Figure 14.	Plan view of a Wolfe trap.	70
Figure 15.	Sectional view of a Wolfe trap.	71
Figure 16.	Diagram of a louver system.	72
Figure 17.	Schematic of a flexible in-reservoir salmon passage (FISP) system.	73

Figure 18.	Cross section of a flexible in-reservoir salmon passage (FISP) conduit.	74
Figure 19.	Diagram of a sequential gravity flow system.	75
Figure 20.	Diagram of a fish ladder.	76
Figure 21.	Diagram of a Borland lock.....	77
Figure 22.	Diagram of a fish lock.....	78
Figure 23.	Diagram of a fish lift.....	79
Figure 24.	Diagram of an alternate fish lift.....	80
Figure 25.	Diagram of a trap-and-haul facility.....	81
Figure 26.	Potential locations of upper reservoir collection locations in Brownlee Reservoir.....	82
Figure 27.	Proposed location of forebay collection at Brownlee Dam.	83
Figure 28.	Proposed location of guide wall and spillway release in Brownlee Reservoir.....	84
Figure 29.	Schematic of proposed intake diversion screen at Oxbow Dam.....	85
Figure 30.	Proposed location of trap-and-haul facility at Hells Canyon Dam.	86
Figure 31.	Proposed location of fish ladder at Hells Canyon Dam.....	87
Figure 32.	Proposed location of fish trap and fish ladder at Oxbow Dam.....	88
Figure 33.	Proposed location of fish ladder at Oxbow Dam.....	89
Figure 34.	Proposed location of trap-and-haul facility at Brownlee Dam.	90
Figure 35.	Proposed location of fish ladder at Brownlee Dam.	91

This page left blank intentionally.

1. INTRODUCTION

In this chapter, we review current concepts for fish passage and evaluate those concepts for their potential use at the Hells Canyon Complex (HCC). Our specific objectives are to provide 1) an overview of fish passage options that might be applicable to the HCC, 2) an order-of-magnitude cost estimate for each option, and 3) a qualitative assessment of each option's potential for success if implemented at the HCC.

Dam passage is only one of the many hazards anadromous fish face during their life cycle. Therefore, even if complete passage through the HCC is attainable, that measure alone may not guarantee the success of an anadromous fish reintroduction program. This chapter focuses exclusively on passage options and does not address other important factors such as habitat availability, water quality, and predation. However, we want to emphasize that any passage options implemented at the HCC must be developed in conjunction with the overall requirements of the species' life cycle.

Because the HCC includes three projects (Brownlee, Oxbow, and Hells Canyon dams and reservoirs), we explored possible downstream and upstream fish passage routes through the entire complex. For the purposes of this study, we defined the downstream passage route as beginning at the backwater effects of Brownlee Reservoir (approximately 58 mile [mi] upstream of Brownlee Dam) and ending downstream of Hells Canyon Dam (approximately 38 mi downstream of Brownlee Dam). We defined the upstream passage route as beginning downstream of Hells Canyon Dam and ending at some point in Brownlee Reservoir.

The challenges of providing such a passage system are significant. No successful model exists for upstream passage within the height and distance ranges that this study addresses. Juvenile downstream migration through Brownlee Reservoir is perhaps the most significant challenge of the project. Although smaller projects have demonstrated that fish runs can be established above natural river obstructions or smaller dams with shorter reservoirs, no successful prototypes exist for high dams with long, slow reservoirs like Brownlee.

2. BASIC DAM CHARACTERISTICS

2.1. Hells Canyon Dam

Completed in 1967, Hells Canyon Dam (located at river mile [RM] 247.6) was the last of the three HCC dams to be built. It has a maximum height of 330 feet (ft) and is approximately 910 ft long. The dam's spillway is located on the east (Idaho) bank of the river. The powerhouse stands on the west (Oregon) bank of the river. Its three generating units are fitted with Francis runner turbines and have a total nameplate capacity of 391.5 megawatts (MW).

A fish trapping facility is located just downstream of the powerhouse on the west bank (Oregon side). This facility is comprised of a pumped attraction flow system and a fish ladder leading to a trapping pool. A hopper is used to load fish from the trapping pool onto trucks for transport.

2.2. Oxbow Dam

Oxbow Dam is the next dam upstream of Hells Canyon Dam. It takes its name from the unique U-shaped bend of the river at its location. This unique geological formation influenced the unusual design of the project. The rock-filled dam is located at RM 272.5. It is approximately 960 ft long and 209 ft high. The spillway is located on the north edge of the dam. The power intake is located approximately 0.5 mi upstream, on the north side of the channel. From this point, two horseshoe-shaped, power tunnels run through the hillside to the north. Each tunnel is 36 ft in diameter, approximately 170 ft long, and connected to separate 130-ft diameter surge tanks. From this point, each power tunnel divides into two 23-ft diameter penstocks (4 total), each approximately 70 ft long; these deliver the flows to the powerhouse. The powerhouse is comprised of four generating units fitted with Francis runner turbines, with a total nameplate capacity of 190 MW. The powerhouse is located at a portion of the bend approximately 3 river miles downstream of the dam and spillway.

2.3. Brownlee Dam

Brownlee Dam was the first and the largest of the three HCC dams to be constructed. It was completed in 1959 and is located at RM 284.6. It is a rock-filled structure approximately 1,380 ft long and 395 ft high. The spillway facilities are located on the west bank of the river, and the intake channel and power generating facilities are located on the east bank. Four 24-ft diameter steel penstocks, 512 ft long each, deliver flows from the power intake to the four generating units fitted with Francis runner turbines in the powerhouse. A fifth turbine is serviced by an additional 28-ft diameter penstock that is 660 ft long. This turbine is located above the original diversion tunnel used in the construction of the dam. It discharges into the diversion outlet channel. The total nameplate capacity of Brownlee Dam's generation units is 585.4 MW.

3. REVIEW OF FISH PASSAGE CONCEPTS

Protecting fishery resources in the vicinity of electric generating facilities has been a subject of interest and intense study for many years. The focus of these studies has changed along with advancements in electricity-generating technologies. Initial issues in the early part of this century were related to the construction of hydroelectric facilities that blocked upstream migration of anadromous fish. Intense study on providing upstream passage began in the 1950s and continues today. Additional issues relative to the protection of fish resources became evident with the large-scale development of steam and nuclear electric stations during the 1960s and 1970s. The need for large volumes of cooling water at these facilities raised concerns about the potential impacts on fish resources due to entrainment and impingement. In recent years, the focus of fish protection studies has also included the protection of downstream migrants at hydroelectric,

water diversion, and water-intake facilities. A general decline in both anadromous and resident fish populations in river systems throughout the United States prompted efforts to quantify losses of downstream migrants and to develop protection techniques. The relicensing process mandated by the Federal Energy Regulatory Commission (FERC) has led to many research projects on the development of protection and passage techniques that may prove effective at hydroelectric stations.

As we reviewed the various concepts discussed in this report, most of our information came from sources in North America. However, we also reviewed information and ideas from sources in Japan, Russia, Australia, and northern Europe. In general, the concepts found in the literature did not differ appreciably from those presented here.

3.1. Downstream Passage

3.1.1. Forebay Collection and Bypass—Fish Attraction Barges (Gulpers)

Description

The fish attraction barge concept was initially developed for installation at the Baker River Project, located on the Baker River east of Bellingham, Washington. The project comprises two dams: Lower Baker and Upper Baker. Completed in 1927, Lower Baker Dam is a concrete semi-gravity arch dam with a maximum height of 285 ft. Upper Baker Dam, completed in 1959, is a concrete gravity dam 312 ft high.

Lower Baker Dam initially operated without any dedicated downstream fish passage facilities. The only passage routes were through the Francis turbine runners or over the spillways. As a result, fish runs declined significantly, and studies identified high fish mortality with both turbine and spillway passage. The dam was retrofitted with a surface ski-jump spillway that created very favorable results for fish passage. However, the loss of 500 to 600 cubic feet per second (cfs) from power production, combined with limitations imposed on reservoir operating levels, made this method of downstream fish passage undesirable. This situation led to development of the fish attraction barge concept (Wayne 1981).

The Washington State Department of Fisheries experimented with a full-size fish attraction barge in the reservoir of Mud Mountain Dam. The purposes of the experiment were to determine whether fish could be collected and to establish basic design criteria for a prototype barge to be operated in the forebay of Lower Baker Dam. The prototype fish attraction barge was placed in service at the Lower Baker facility in April 1958. From the experience gained during the first two fishing seasons, researchers concluded that a greater quantity of water should be pumped through the barge entrance to increase the attraction water velocities. This change required the installation of larger attraction water pumps on a production version of the barge.

A completely new design was developed for the fish attraction barge at Upper Baker Dam based on the operating experience with the prototype at Lower Baker Dam. The new barge went into operation in the forebay at Upper Baker Dam in April 1960 and remains in operation today. The

initial deployment of the fish attraction barge did not include the use of a barrier net, so a means had to be developed to prevent downstream migrating fish from entering the power intakes when the reservoir was drawn down by up to 50 ft. A rigid, floating fish baffle was developed that extended 100 ft below the water surface and was deployed as a semicircular rigid structure in front of the two power intakes. The bottom of the baffle was open to allow flow to the intakes.

The baffle was not entirely effective, so an exclusionary net was placed across the reservoir. It extends from the surface to the bottom of the reservoir and is suspended from a 4-inch-diameter inflated hose along the float line and periodically placed 48-in ball buoys.

The fish attraction barge, measuring 36 ft wide and 70 ft long, is positioned at the apex of the exclusionary net, approximately 100 ft upstream of the dam's intake trash rack. Two large turbine pumps, each rated at 34,000 gallons per minutes (gpm) (75 cfs), and a secondary pump, rated at 5,400 gpm (12 cfs), are used to create attraction flow through the barge entrance. The shore-based power supply minimizes the sounds and vibration generated on the barge. The main waterway, or fish passage, is 12 ft wide and 9 ft deep. A sloping timber louver is installed across the inside of this waterway to guide the fish to a 3-ft-wide flume and into a hopper. See Figures 1 and 2 for the general arrangement and details of the barge.

The remaining water and fish pass vertically through a hopper and into a 10-in-diameter flexible pipe that is used to transport the fingerlings between the collection barge and fish trap. The flow in the pipe is controlled by gravity and is governed by differential water levels between the fish attraction barge and the fish trap. A submersible pump brings water from the downstream fish trap to create the differential head. The flow to the trap is 1,800 gpm with a minimum velocity of 7 feet per second (ft/s).

The water and fish are conveyed to the fish trap for holding and sampling. The fish trap consists of three sections: 1) an entrance, 2) a fish holding area, and 3) a fish loading area. The fish are held in four holding compartments, and a hopper is used to lift the fish to a truck for transport and to release the fish below Lower Baker Dam.

Biological Effectiveness

Fish attraction barges are a flexible alternative for collecting juvenile fish to transport below a dam or series of dams. However, several installations of fish attraction barges have been unsuccessful.

For example, in the late 1950s, a fish attraction barge system was installed at the HCC to collect downstream migrants. Brownlee Dam was closed May 9, 1958, to begin the installation of a partial barrier net and three fish attraction barges in the dam's forebay. This installation was unsuccessful, and fish collection was discontinued in 1964. It is believed that this system failed to achieve the prescribed anadromous fish collection goals for the following reasons:

- Predator species reduced the numbers of anadromous fish.
- Some fish failed to find their way down the reservoir.
- Some fish avoided the system by swimming under the barrier net and subsequently exited the reservoir either in spill or by passing through the turbines.

This last problem also occurred at Lower Baker Dam. The fish attraction barges located there initially operated by attracting fish with pumped flow. The fish were partially dewatered, entered a fish transportation pipe for passage through the dam, and were discharged to the tailrace downstream of the dam. The system operated in this mode until the late 1970s, when the average return of 3,000 sockeye salmon inexplicably began to decline. By 1985, the Baker River sockeye salmon return dropped to an all-time low of 99 adults.

Research determined that the young sockeye were avoiding the fish attraction barge and were either remaining in the reservoir or swimming under the power intake baffle to pass downstream through the turbine runners. To correct this problem, a complete barrier net was installed, with the only outlet from the net being the fish attraction barge. The barrier net is reported to be 76% effective in directing fish to the fish attraction barge. Also, fish are no longer routed by pipeline through the dam. Instead, they are routed to the dam structure, where they are held in a fish trap barge (floating raceway). The fish are then loaded onto a fish transportation truck for release into the Baker River below Lower Baker Dam.

With these modifications, the fish attraction barge system at Lower Baker Dam has proven to be very successful. In 1994 and 1998, the numbers of sockeye salmon returning to the Baker River to spawn totaled 16,000 and 13,000 fish, respectively. In recent years, the Baker River sockeye run has averaged between 7,000 and 8,000 fish. Some of this success is probably related to the hydrology and quality of the river basin and the moderate length of the reservoir. Because the river is largely fed by glacial melt from Mt. Baker and Mt. Shuksan during the spring and summer months, the water is very cold. Therefore, the river does not support warmwater predators. The average yearly flow of the Baker River is 2,520 cfs, and the Upper Baker Reservoir is 13 mi long.

Costs

We estimate that constructing a fish attraction barge system similar to the one used on the Baker River would cost approximately \$7 million (Sverdrup Corporation, pers. comm.).

3.1.2. Eicher Screens

Description

The Eicher screen is the invention of George Eicher, formerly a biologist for Portland General Electric (PGE). The device consists of an elliptical wedgewire screen that diverts fish within closed penstock systems and keeps them from entering hydroelectric turbines. The screen inclines upward to guide fish into a bypass located at the top of the penstock (Figure 3). The design has been modified often, with the porosity (spacing) of the wedgewire screen as the primary variable. The effectiveness of the screen has been increased by modifying the porosity and by using different screen spacings at the top and bottom of the ellipse. The screen is mounted on a pivot to allow for easy cleaning through backflushing.

The Eicher screen was originally developed in 1980 for use at the T.W. Sullivan Hydroelectric Project on the Willamette River in Oregon. Variations on this original design were installed at the Elwha Hydroelectric Project in Washington (1990) and the Puntledge Hydroelectric Project

in British Columbia (1993). These three installations were designed to divert juvenile salmonid species. They are the only instances of installed Eicher screens, although Eicher screens have been proposed for installation at irrigation intakes (non-penstock) and other hydroelectric facilities. An inclined screen was installed at the Winchester Dam on the North Umpqua River in Oregon in 1984, but it was permanently shut down due to problems with fry impingement.

Generally, the Eicher screen is more cost effective to install during the construction of a new hydroelectric facility as opposed to retrofitting an existing installation. Overall, however, Eicher screens are less expensive than most conventional screening systems, primarily because the higher velocities that are allowed tend to reduce the overall system size.

Biological Effectiveness

The Eicher screen has proved to be effective in diverting intended fish species away from project intakes. The high velocities (6–8 ft/s) minimize any delay in the system and exposure time to the screen. Tests at the three current installations have shown high diversion rates (> 94%) and long-term survival rates (> 99%) (Stone & Webster Engineering 1994). Data from tests performed at Elwah Dam (1990 and 1991) for the specific species addressed in this report are as follows:

Species	Average Length (mm)	Net Passage Survival (%)
Steelhead smolts	174	99.4
Steelhead fry	52	97.1
Chinook smolts	99	98.8
Chinook juveniles	73	99.9

Eicher screens offer protection from turbine entrainment and passage for all juvenile species traveling through the penstock. Therefore, even though some of the penstocks at the HCC dams have difficult access, we selected this technology for further investigation because it has proven to be extremely effective at several installations.

Costs

Two major factors affect the cost of an Eicher screen installation. One is the overall size of the penstock (and thus the screen). The other is access to the penstocks. Sites where the penstocks are exposed will have lower costs.

Some example costs include an estimated \$3.04 million for screening of 2,000 cfs at Elwah Dam in Washington. The actual cost of installing two screens for 1,000 cfs at Puntledge Dam in British Columbia was \$4.75 million (Canadian, or approximately \$4.0 million U.S.). Stone & Webster Engineering Corporation (1994) indicates that installing Eicher screen facilities may run from \$1,000 to \$4,000 per cfs capacity.

3.1.3. Modular Inclined Screens

Description

The modular inclined screen (MIS) is similar to the Eicher screen and is based on the same concept of high-velocity screening (Figure 4). MIS units can be installed together to provide fish protection at any flow rate (Figure 5). A module consists of an entrance with trash racks, dewatering stop log slots, an inclined wedge wire screen set at an angle of 10 to 20 degrees to the flow, and a bypass to direct diverted fish to a transport pipe. The screen is composed of 50% porosity profile bar with 0.08-inch spacing and, like the Eicher screen, the MIS is pivot mounted for backflushing. The module is completely enclosed and is designed to operate at water-approach velocities ranging from about 2 to 10 ft/s, depending on the species and life stages to be protected. When set at a shallow angle (15 degrees to the flow), the screen in a full-scale MIS may be approximately 31 ft long and 10 ft wide. The effective area of the screen would be about 250 ft². The entrance dimension to the MIS would be approximately 8 ft high and 10 ft wide, with a flow capacity of up to 800 cfs.

According to Stone & Webster Engineering (1994), the MIS concept can be installed in a forebay upstream of intakes, in a canal, or in a pressure conduit for all types of facilities including water supply, thermal power plants, irrigation, and hydroelectric projects. The first full-scale MIS prototype was tested in fall 1995 and fall 1996 at Niagara Mohawk Power Corporation's Green Island Hydroelectric Station in New York.

Biological Effectiveness

MIS units have shown promise in their first prototype testing at Green Island, with a high rate of biological effectiveness similar to that of Eicher screens (Taft et al. 1997). Survival rates have been between 96 and 100% for most species. Decreasing survival rates are attributed to increased velocities and debris collection on the screen. The following table shows results, by species, of laboratory tests performed between 1992 and 1993.

Species	Average Length (mm)	Net Passage Survival Rate (%)
Bluegill	47	97.9
Walleye	86	98.7
Rainbow trout fry	48	96.8
Rainbow trout juveniles	66	97.4
Chinook salmon	53	97.2
Atlantic salmon	169	100.0

The results of prototype testing performed at Green Island in 1995 and 1996 were similar to those obtained in the laboratory test (Odeh 1999a).

Costs

No full-scale MIS systems have been installed on any existing project. Therefore, no actual costs are available. In 1993, a cost estimate was prepared for an MIS alternative at the Glen-Colusa Irrigation Diversion on the Sacramento River. This shallow installation of an MIS was estimated at \$11.9 million, or approximately \$4,000 per cfs capacity.

The MIS appears to be more practical for stations with medium to smaller hydraulic capacities. The largest modular screen has a hydraulic capacity of only 800 cfs. Therefore, for an assumed maximum design flow of 20,000 cfs, over 25 MIS units would be needed.

3.1.4. Intake Diversion Screens

Description

Since the late 1970s, intake diversion screens have been the “standard” fish protection measure at high-discharge hydroelectric projects on the Snake and Columbia rivers. The systems consist of two screens—a main screen and a secondary, vertical barrier screen (VBS)—within the turbine intake gatewells. Together, the two screens divert juvenile migrants up into the gatewell and away from the turbine flow (Figure 6). The main diversion screen occupies the upper portion of the intake area, usually the upper third to half of the intake. It is sloped upward in the downstream direction from its nose to its top, where it meets the VBS. The slope on the main diversion screen is generally about 50 degrees from vertical.

There are two basic types of diversion screen systems. The first is a submerged traveling screen (STS). The fabric mesh screen face of this system rotates around the screen frame to provide for self-cleaning. The second type of diversion screen system is a fixed bar screen (FBS). The screen material in this case is fixed in place. The material is usually a prefabricated wedgewire-type stainless steel. FBS types require some form of periodic mechanical cleaning to keep the screen face clear of debris. In both cases, the screen face has clear openings between the bars of about 1/8 inch. The bars run in the downstream direction along the length of the screen and parallel to the flow. The VBS is a vertical screen installed in the gatewell to confine the diverted fish in the upstream half of the gatewell.

The basic premise of the intake diversion screen system is that if fish are oriented toward the upper part of the water column as they move downstream, they are likely to enter a deep turbine intake along the roof or upper portion of the intake. Therefore, the intake diversion screen is oriented in this upper region to divert fish up into the gatewell. The screen is sloped so that the flow passing through the screen has a greater directional component in the parallel sweeping direction than in the perpendicular direction that would tend to impinge the fish. A portion of the flow guides the diverted fish up the gatewell. The VBS allows all or most of this flow to pass through to the downstream half of the gatewell and back down into the turbine flow, while maintaining the fish in a confined space on the upstream half of the gatewell. The upstream face of the VBS is made from either wedgewire screen material or perforated plate. In the latter form, the diameter of the perforations is approximately 3/116 inch. The downstream side of the VBS consists of plates of various porosities to control the flow velocity through the screen over its length. Fish diverted into the gatewells either exit through an orifice/gallery facility, which leads

to a tailrace exit, or are manually extracted from the gatewell and transported to the river downstream of the project.

Biological Effectiveness

Intake diversion screen facilities were first installed at McNary Dam on the lower Columbia River in the late 1970s. This facility has been shown to divert over 78% of the spring yearling chinook salmon with about a 1% mortality rate. However, diversion rates for later summer run yearlings and subyearling chinook salmon drop to about 40%. Based on these encouraging results for spring chinook, intake diversion screen systems have been installed and/or experimented with at numerous other Columbia and Snake River projects. As with other juvenile bypass methods, the results of these tests have shown that the migrants' reactions to the diversion screen systems appear to be more site-specific than originally assumed. At Lower Monumental Dam on the Snake River, diversion rates for the screen installation were similar to those found at McNary Dam. However, most other installations resulted in lower diversion rates. For example, the initial prototype diversion screen structure tested at Rocky Reach Dam yielded diversion rates of less than 10%. Further development and testing of the screens at Rocky Reach Dam has improved performance, but only to 25%. The system at Rocky Reach Dam remains in operation, but it is used in conjunction with other bypass options (Odeh 1999a).

Incorrectly designed systems can pose unnecessary dangers to migrating juveniles. Varying flow velocities and debris collecting on screens can force fish against the screens or injure them in other portions of the diversion system. A study conducted at Powerhouse No. 2 at Bonneville Dam indicated that subyearling chinook salmon passing the intake diversion screen system had a higher mortality than fish that passed through either the turbines or the spillways. As a result of this study, the diversion screens were removed at this project during the summer when subyearling chinook pass the site.

Costs

Diversion screens can be expensive and time-consuming both to develop and to install. Hydraulic modeling is required to ensure a system design that is not likely to impinge or injure fish. Installation can require removing significant portions of concrete from the gatewells to increase the slot size to a dimension that accommodates the vertical barrier screen while still allowing for installation of the emergency gates without interference. Screen-cleaning equipment, or expensive machinery associated with the self-cleaning STS design, must be included. Seasonal installation and removal require a crane and access in which the crane can operate. As part of a study conducted at Wanapum Dam in 1993, three diversion screens were installed in Unit 4. The screens were 20 ft wide and 25 ft long, with 30 ft of VBSs. The center screen had an orifice collection system installed, and the two outside screens used gatewell dip nets to collect juveniles. The system was constructed in stages, with a total cost of approximately \$4 million. In 1992, 19 STS units with VBSs were installed at Lower Monumental Dam at an approximate cost of \$18.4 million (Francfort et al. 1994). Because the dams in the HCC do not possess the intake and gatewell configuration typical of the dams on the lower Snake and Columbia rivers, all of these features (or their equivalent) would need to be constructed within or in front of the existing project intakes.

3.1.5. Surface Collection

Description

In recent years, surface collection systems have received increased attention as a more effective, lower-cost alternative to physical screening. These systems are based on the understanding that many anadromous species tend to occupy the upper portions of the water column as they move downstream (USACE 1990). If these migrants are offered an alternative that does not require them to sound significant depths to find turbine entrances, they are likely to find and use the alternative. However, this tendency to be at shallow depths varies among different species—and even within a single species—in response to different environmental conditions. For example, warm surface water causes salmon to seek deeper, cooler water. Therefore, any bypass system installed to target a variety of species throughout a large portion of the year will undoubtedly vary in efficiency rates for the different species and will vary in efficiency throughout the year. Because this method is evolving rapidly, there is little published literature to reference on this approach. Therefore, we prepared the following discussion to provide the background necessary to make an informed decision concerning this approach to turbine bypass.

During the 1970s and 1980s, the U.S. Army Corps of Engineers (USACE) studied the effectiveness of the surface collector concept by using existing ice and trash sluiceways at hydroelectric facilities on the Columbia and Snake rivers. Studies at Ice Harbor and The Dalles dams revealed that up to 50% of the juvenile salmon approaching the powerhouse could be attracted into the sluiceways using as little as 3.7% of the powerhouse flow (Johnson et al. 1984, Steig and Johnson 1986). A study at Powerhouse No. 2 at Bonneville Dam indicated that during daylight hours, as many as 80% of the fish approaching the powerhouse could be attracted into the ice and trash sluiceway (Magne 1987). All three of these powerhouses have sluiceway entrances, which are shallow, adjustable overflow weirs located directly above the deeply submerged turbine entrances. The species being diverted at these projects included chinook, sockeye, and steelhead smolts.

The Wells Dam Hydroelectric Project, located on the middle Columbia River, is the most upstream Columbia River dam that has fish passage facilities. The design of the project was unique for North America at the time it was built because the powerhouse is located directly below the spillways. This type of project layout is called a *hydrocombine*. In the early 1980s, projects on the Columbia and Snake rivers were being directed to install intake diversion screens to divert fish from passing through turbines (see Section 3.1.4). Because Wells Dam is a hydrocombine, the project has no defined gatewells. Therefore, diversion screens could not be installed. Based on the reasonably good results from the USACE studies mentioned earlier, it was believed that attracting a significant number of fish into the spillway bays above the turbine intakes might be possible, with a relatively small portion of the river flow, if a strong perceptible velocity into these bays was introduced into the upper portion of the forebay. After a number of years of study and modification, a production surface bypass system was installed at Wells Dam that has proven to be the most effective juvenile salmon bypass system of any type on the Columbia River. Documentation shows that the Wells Dam system bypasses approximately 90% of the downstream migrating fish around the turbines using the spillway flow. The system uses five bypass entrances evenly spaced across the dam and located over the entrances for the

station's ten turbine units. Each bypass entrance is associated with two turbine units and is sized to pass approximately 10% of a single turbine flow at an average velocity of 2 ft/s.

Installation of surface collection bypass systems at conventional powerhouses, such as Hells Canyon, where the powerhouse is remote from the spillway and no sluiceway entrances are located directly above the turbine entrances, requires the installation of collection structures attached to the powerhouse intake. Experiments with this type of add-on surface collection bypass system have been conducted at two projects on the middle Columbia River downstream of Wells Dam. Prototype test facilities at Rocky Reach and Wanapum dams were both designed with entrance dimensions and flow rates similar to those used at Wells Dam. Although these projects are located on the same section of river, and they pass many of the same fish that are passed at Wells Dam, these tests have shown inconsistent passage efficiencies that appear to be the result of differing forebay conditions at each of the projects.

The Rocky Reach powerhouse extends along one side of a dead-end power canal. As the fish move into and along this canal, they tend to remain somewhat surface oriented and above the relatively deep turbine intakes. Historically, this situation has resulted in a large percentage of the fish accumulating near the most downstream units and ultimately passing through those units. Therefore, a test surface collection entrance was installed at the end of the canal above Unit 1, the most downstream unit. Studies have been performed on this facility since 1995, and modifications were made each year in an attempt to compensate for apparent shortcomings of the facility. Preliminary results from the 1999 studies have been positive, and plans are underway to expand the facility to include multiple entrances extending over more of the powerhouse.

On the other hand, the prototype surface collection channel at Wanapum Dam has failed to achieve anticipated passage rates. The channel extends down into the forebay to a depth of 55 ft (half the forebay depth at the powerhouse), but the majority of the fish passing the project at the powerhouse continue to pass under the channel and through the turbines. An unexpected result from the installation of the surface collection channel has been a change in the usual migratory patterns of the juveniles. The presence of the channel seems to divert more fish towards the spillway area, increasing the passage efficiency over the spillways.

At Lower Granite Dam on the Snake River, a surface bypass collector (SBC) was placed onto the face of the dam above three of the six power units. It was comprised of a floating box structure that was 18 meters (m) high and 6 m wide. Its length is 100 m, and it extends to the first spillway. The SBC has three entrances with multiple sliding doors that were used to vary the entrance configurations. The testing in 1996 showed that although only 7 to 11% of radio-tagged fish used the system, between 37 and 51% (depending on the species) of radio-tagged fish that came within 10 m of the entrance used the SBC. It was also noted that the depth at which the fish approached the SBC influenced passing numbers. The highest percentage using the system approached at depths of 10 m or less. Fish approaching at greater depths were more likely to pass under the SBC (Odeh 1999a).

Biological Effectiveness

As previously described, the biological effectiveness of surface collection systems varies depending on site-specific conditions. It would be difficult, if not impossible, to duplicate

adequately the conditions that exist at Wells Dam. Consequently, the possibility of installing surface collection systems at the HCC carries with it the risk of poor performance.

Costs

The cost for the prototype surface collection system installed at Wanapum Dam was approximately \$10 million. The cost for the SBC system at Lower Granite Dam was approximately \$8.4 million.

3.1.6. Spillway Release

Description

As is the case with surface collection, spillway release has received much attention in the past few years as a safe and effective way of passing fish. Various designs have included modifications to gates, additions of bulkheads in front of the gate to act as overflow weirs, and the installation of flow deflectors on the spillways to decrease the total dissolved gas (TDG). Spill studies at Rock Island Dam on the middle Columbia River confirmed previous studies that shallow or surface spill is more effective than deep spill in passing juvenile salmon through the spillways (Odeh 1999b).

Two designs for surface spill gates were tested at Rock Island Dam in 1996. One of the designs was for a gate with a notch 3.4 m wide by 4.3 m deep (Figure 7). The other design was for a 9.1-m-wide, 2.1-m-high overflow gate. Hydroacoustic estimates indicated that the notched gates passed significantly more fish per flow than did the overflow gates. Based on the results of these tests, additional notched spillway gates were installed at Rock Island Dam.

Wanapum Dam on the Columbia River has 12 spillways fitted with 12 bottom-opening Tainter gates that are 65 ft high and 50 ft wide. A top-opening ice/trash sluiceway is located adjacent to the spillways. This sluiceway is 20 ft wide and normally spills about 10 ft of surface water. The 2,000-cfs flow from the sluiceway plunges approximately 79 ft directly into the tailrace. Priest Rapids Dam is downstream of Wanapum Dam, and the Priest Rapids spillways and sluiceway are of similar design. Hydroacoustic estimates of spillway and sluiceway efficiency (the percentage of fish passed in spill divided by the percentage of flow passed as spill) were made over a number of years at both Wanapum and Priest Rapids dams (Normandeau Associates 1996a,b). For Priest Rapids Dam, the sluiceway was six times more efficient than the spillways in passing the spring migration and twice as effective for passing the summer migration. At Wanapum Dam, the sluiceway was found to be over three times more efficient than the spillways in passing both the spring and summer fish.

The effectiveness of the sluiceways in passing fish with surface spill led to a design that incorporates a top spill gate into the Tainter gates. A prototype of this top spill was developed to test the concept. One of the spillways was fitted with an upstream weir (or bulkhead) to create a top spill attraction flow. The weir was positioned upstream of the Tainter gate (Figure 8). The lower 40 ft of the spillbay was blocked, and only surface flow passed the bulkheads through up to four openings (6 ft x 20 ft deep) positioned near the surface. The number of openings and the Tainter gate setting combine to regulate the flow volume.

The Walla Walla District of the USACE is constructing a removable spillway weir (RSW) for installation at Lower Granite lock and dam on the lower Snake River (Sverdrup et al. 2000). The primary goal for the RSW is to create a flow pattern in the forebay of the dam that will attract juvenile salmonids and pass them safely over the dam (Figure 9). To create the desired flow pattern, the RSW will obstruct a spillway and cause water to flow over it. The RSW will be supplemented with a behavioral guidance structure that is planned to direct the juveniles away from the powerhouse on the south side of the river and toward the RSW.

Biological Effectiveness

In 1996, fish survival studies (1-hour and 48-hour) were conducted for the Wanapum Dam overflow weir with hatchery-reared chinook salmon. Three routes were compared; none had a 100% survival rate. The 48-hour fish survival rate for an unmodified spillway was estimated at 99.6%, compared with 92.0% for a spillway fitted with an overflow weir and having a spill rate of 2,000 cfs. Survival estimates for the overflow weir improved to 96.9% when the spill flow was increased to 4,000 cfs. The estimated survival for the sluiceway fish at 2,000 cfs was 97.4%.

Costs

The spillway bulkhead (Figure 8) was fabricated and installed at a cost of approximately \$2 million. The cost for the RSW being constructed for Lower Granite Dam (Figure 9) is about \$10 million for a minimum flow rate of about 6,000 cfs.

3.1.7. Behavioral Guidance Structure

Description

A behavioral guidance structure (BGS) only directs migrating fish to a specific area and is used to supplement one of the other passage systems. It can be constructed of steel or other materials and placed either along the dam face or in the river channel to direct fish to bypass systems. At Lower Granite lock and dam on the Snake River, juvenile fish have tended to be guided along a relatively shallow trash shear boom. Based on its experience with the trash boom, the USACE constructed and is testing a BGS at Lower Granite Dam.

The USACE commissioned a conceptual design report to study surface bypass collector (SBC) options for Lower Granite lock and dam (Sverdrup et al. 2000). The study options included constructing a BGS in the forebay that would passively direct fish approaching the dam. The goal of the BGS is to preclude fish from passing under it, while developing effective guidance velocities along the face of the BGS to divert fish away from the powerhouse and to an SBC or spillway for passage downstream.

Bjorset Dam in central Norway is a 3-m-high diversion dam on the Orkla River located just downstream of the intake tunnel to the Svorkmo Hydroelectric Power Station. A concrete wall was constructed in front of the intake to allow water from the lower depths of the river to enter the intake. This wall acts as a BGS and directs the migrating juveniles downstream where they pass over the spillway of the dam (Grande 1995).

Other examples of behavioral guidance include the use of light, sound, electrical stimuli, and air bubble curtains to discourage fish from entering turbine intakes.

Biological Effectiveness

We do not have any information on the biological effectiveness of the BGS systems installed at Lower Granite Dam.

Although it was unintentional, the surface collection channel at Wanapum Dam has acted as a BGS by directing fish to the spillway and by increasing the efficiency of the turbine intake screen system. At Lower Granite Dam, the performance of the turbine intake screens has improved with the addition of the surface collector and other associated structures.

Costs

The BGS studied for Option 3 at Lower Granite Dam was an articulated rigid-steel curtain suspended in the forebay by pontoons. The BGS would have a total length of 1,400 ft and vary in depth from 80 to 50 ft (Figure 10). The construction cost estimate for this BGS was \$15 million in 1997 dollars.

3.1.8. Turbine Passage

Description

Considerable research is being conducted in the Pacific Northwest to design a more “fish-friendly” Kaplan (adjustable propeller) turbine. The factors within the turbine design that tend to contribute to direct mortality are being modified to minimize their effects. These improvements should be especially pronounced when the turbines are operating outside their peak efficiency ranges. One modification being studied involves a spherical hub and discharge ring to eliminate gaps at the edges of the blades over the full range of blade angles. Another modification to the blade design should minimize or eliminate cavitation.

Tests are ongoing on a minimum gap runner installed on Units 4 and 6 at Powerhouse No. 1 at Bonneville Dam. Research is also proceeding with further modifications to a Kaplan runner that has blunt blade edges, a modified cone, and minimized gaps between the blade tips and the distributor ring. Future studies are also planned for the stay vanes and wicket gates that guide and control water flow to the runner (Sverdrup Corporation, pers. comm.).

Kaplan runners are most often used for low heads of up to 100 ft, while Francis runners are used for heads between 100 and 1,000 ft. Figure 11 shows the two types of runners. There are Kaplan runner installations for heads up to 200 ft, but they are smaller machines. For the machines at the HCC, Kaplan runners may be feasible up to heads of 120 ft; however, at that head Kaplan runners can experience more cavitation than Francis runners. Probably the greatest difficulty associated with changing to Kaplan runners would be the difference in operating speeds between the Kaplan and Francis runners. The different speeds might require that the generators also be changed.

Research in the Pacific Northwest has focused on Kaplan runners because they are the turbine runner type used at lower Snake River and Columbia River powerhouses. However, fish-friendly Francis runners with fewer blades are also in use (Sverdrup Corporation, pers. comm.).

In addition, a new fish-friendly turbine concept was recently developed. Alden Research Laboratory and Northern Research and Engineering Corporation developed a new turbine runner based on the design of a pump used to transfer fish and vegetables (Figure 12). It uses a screw-type impeller and may prove to be an effective alternative to Kaplan turbines at heads of 100 ft or less.

Biological Effectiveness

The traditional approach to downstream passage and protection at hydroelectric projects has been to minimize by any means available the percentage of fish passing through the turbines. This approach is now being questioned because of problems associated with high TDG levels from excessive spill flows, mortality rates for some species and age classes passing through bypass systems, and the high costs associated with installation and operation of bypass systems. Historically, mortality rates resulting from turbine passage have been based on assumption and speculation. Recent advances in passive integrated transponder (PIT) tag technology and the HI-Z Turb'N tag (or balloon tag) have allowed a closer investigation of turbine mortality issues. The indirect mortality components associated with turbine passage include predation downstream because of disorientation and delayed mortality resulting from stress. These components are difficult to define and remain somewhat speculative.

Recent studies performed at nine hydroelectric projects on the Columbia and Snake rivers revealed an average direct mortality rate of about 8% for smolt passage through large vertical Kaplan turbines. Individual results from these tests vary between 0 and 16% (Voith Hydro 1997).

Preliminary test results from the turbine tests at Bonneville Dam indicate fewer injuries and a higher rate of survival through the experimental minimum gap runner than through a conventional Kaplan unit. The experimental runner also proved to be more efficient and produced about 6% more power than a traditional runner (Cada and Rinehart 2000; Sverdrup Corporation, pers. comm.).

Costs

The feasibility and costs of changing turbines or runners for safe fish passage require complete information on the existing turbines and powerhouses and detailed study by a turbine manufacturer.

3.1.9. Upper Reservoir Collection—Portable Floating Traps

Description

The main reason for an upper reservoir collection option is to collect juveniles before or as they enter a reservoir. Such collection eliminates the need for the juveniles to travel through the reservoir and so eliminates the dangers associated with this portion of the migration. Collection

can be done with the use of fish attraction barges (gulpers) or other floating traps. Floating traps present a flexible, moderately priced method for collecting juveniles for transport below a hydroelectric project. The following is a discussion of floating trap options.

Studies of fish behavior in Lake Billy Chinook following the initial filling of the reservoir indicated that juvenile coho were located in the upper portion of the water column, generally in water less than 45 ft deep. Chinook and steelhead juveniles caught in gill nets in Pelton Reservoir in 1962–1963 were generally found near the surface of the reservoir in water less than 45 ft. Studies in other locations have confirmed that salmon juveniles are generally located in the upper portion of the water column and have noted that these juveniles are often near shore rather than in the open area of the reservoirs (Lake Merwin, North Fork Reservoir, Mayfield Reservoir, and Brownlee Reservoir). These fish, having just come out of a fluvial environment, would not be expected to sound immediately to depths that are outside of their experience range. This orientation to shallow water makes the fish more vulnerable to capture by floating trap than if they were moving in deeper water.

Several types of floating traps have been used successfully to capture migrant salmon and steelhead juveniles from reservoirs in the Pacific Northwest. A typical floating trap is shown in Figure 13. Two common types of floating traps are the Lake Oneida and the Lake Merwin traps. These devices have been used to collect juveniles for research purposes, to move fish past dams, and to evaluate the movement of fish in and through hydroelectric facility reservoirs. These traps are similar in design and share common features, but they differ in the way they are used and in the physical features of their most effective fishing locations.

Lake Oneida Floating Traps

Commercial fishermen of lake trout on Lake Oneida, New York, developed these traps. They are designed to fish on the bottom with a net lead, which directs the fish toward an opening and through a tunnel into a pot or spiller from which the fish are removed when the trap is raised to the surface. The pot or spiller is an enclosed cube. Fish enter by means of a mesh tunnel, which allows easy access but is very difficult to exit. The size of the mesh used depends on the size of the targeted fish. For example, the mesh is quite large for lake trout.

Modified versions of Lake Oneida traps have been used in several locations in the Pacific Northwest to collect migrating salmon and steelhead juveniles for research purposes. These locations include the North Fork Reservoir on the Clackamas River, the Round Butte and Pelton reservoirs on the Deschutes River, and the Wells Reservoir on the Columbia River. Modifications have included provisions for fishing on the surface and changes in mesh size to allow for the capture of small fish such as chinook and coho smolts.

Typically, Lake Oneida traps are fished perpendicular to the shoreline in areas where there is a sloping or relatively flat bottom. The trap generally has bars or rods on the corners to help maintain its shape when it is deployed.

Lake Merwin Floating Traps

The Lake Merwin floating traps were patterned after traps used successfully in Alaska for commercial salmon fishing. The trap, as modified for use in Lake Merwin, is generally fished

perpendicular to the shoreline over a gently sloping bottom. Like the Lake Oneida trap, the Merwin trap uses a lead net that guides fish to a heart section. However, in this case, the heart has a floor that slopes up from the bottom of the lead toward the pot. The heart wings direct fish, which attempt to move away from the trap, back toward the tunnel leading to the pot. Fish enter the pot through the pot tunnel, and from the pot they pass through the spiller tunnel to enter the spiller. The tunnels allow easy access for the fish from the heart to the pot, and from the pot to the spiller, but they are difficult to use in the opposite direction. The lead and heart sections of the trap are supported by floats along the top of the net, and they have weighted lines along the bottom. In general, the pot and spiller sections of the trap are supported by a floating framework that maintains the shape of these sections and provides a work platform for handling fish.

Both the Lake Oneida and Lake Merwin traps operate on the principle that fish traveling from one area to another generally orient to shoreline or to structure. When the fish encounter a lead net, they follow that net to continue their movement in the direction of travel. These traps take advantage of that movement by guiding fish toward the interior of the trap. For the traps to operate effectively, the netting must be as clean as possible to provide the best guidance. The lead net and the floor of the heart section must be in contact with the reservoir bottom to prevent fish from escaping under the net. As fish enter the heart section, they are guided upward to the tunnel leading into the pot, and then into the spiller through the spiller tunnel.

Attempts to use these traps as “scoops” by facing them into a current have been generally unsuccessful. Not only is it difficult to maintain the trap components in the right orientation, but keeping the trap free of debris is very difficult. Such use of a small-scale Lake Merwin trap at Mayfield Reservoir on the Cowlitz River and a larger-scale Merwin trap at Rocky Reach Dam on the Columbia River were unsuccessful in capturing salmon and steelhead smolts.

There is reason to believe that the site chosen for fishing traps should be selected carefully to provide the best chance for success. Very steep bottom contours are less conducive to successful trap operation than are gently sloping bottoms (1:2.5 to 1:5 slope). Such slopes allow the front of the heart section, 20 to 30 ft deep, to be in contact with the bottom using 50 to 150 ft of lead net. Lead nets longer than 150 ft should be avoided because they appear to be less effective in guiding fish into the trap. If information on fish distribution in a particular location is available, this information can be used in siting the trap to take advantage of the distribution and to increase the potential for success.

Biological Effectiveness

The Fish Commission of Oregon, now the Oregon Department of Fish and Wildlife (ODFW), operated three modified Lake Oneida traps in the Metolius arm of Round Butte Reservoir (Lake Billy Chinook) in spring 1964. These traps were successful in capturing chinook, coho, and steelhead smolts in the upper portion of the Metolius arm. From June 4 through July 1, 1964, the three traps captured 739 chinook, 3,796 coho, and 1,879 steelhead juveniles. One small-scale Merwin trap operating in the upper portion of the Mayfield Reservoir between April 7 and August 12, 1965, captured 43,000 chinook, 6,900 coho, and 1,100 assorted trout (Sverdrup 1996).

Costs

In 1996, cost estimates were prepared for placing six prototype floating traps in the three arms of Lake Billy Chinook, the reservoir formed by Round Butte Dam. The construction of the six prototype traps was estimated at \$300,000, and the annual operation and maintenance (O&M) cost at \$60,000 (Sverdrup Corporation, unpublished data).

3.1.10. Upper Reservoir Collection—Fixed-Location In-River Trap

Description

Another option for upper reservoir collection is an in-river structure that screens the entire width of the channel. The thought behind this option is to screen the juveniles in an area of the river where velocities and depths are conducive to such action. A low dam or screen structure could be built to collect juveniles before they enter the reservoir. The structure would have to account for debris in the river and possible boat traffic.

During early spring and summer 1964, the distribution of chinook and coho and the types of debris were sampled in the Snake River above Brownlee Reservoir (Monan et al. 1969). Salmon and debris were found to be present simultaneously and were distributed throughout the cross section of the river. The study concluded that to collect most of the downstream migrants effectively, the entire water mass would need to be screened for possibly large quantities of debris.

The USACE produced a report entitled *Columbia River Salmon Mitigation Analysis System Configuration Study—Phase I* from a study that examined the possibility of placing such a structure on the Snake River at Silcott Island near Lewiston, Idaho (USACE 1994). Some of the options considered by the agency used low-velocity barriers, submerged traveling screens, and MISs. This structure would collect all migrating salmon for transport to a release point downstream of Bonneville Dam.

Biological Effectiveness

No large-scale installations of fixed, in-river screens exist. Therefore, no data are available on their biological effectiveness. Also, the type of screen used (i.e., MIS, STS, etc.) would influence the biological effectiveness of the system.

Costs

The USACE study included some very preliminary construction costs. The high-velocity concepts were estimated to cost between \$873 million and \$982 million, depending on whether they used standard screens or MIS units.

3.1.11. Tributary Collection—Fixed-Location In-River Traps (Wolfe Traps)

Description

Wolfe traps, invented and developed by Eric Wolfe in Sweden, involve the construction of a low, screened weir in a free-flowing section of the river. Water is directed over the weir and through a sloped, porous screening medium. Juveniles are carried over the screen and into a collection trough, which empties into a trap area. Debris and larger fish are excluded from the collection trough by a sloped, self-cleaning debris rack. Figure 14 shows a plan view of a Wolfe trap conceptualized for use at tributaries; Figure 15 shows a section view of the structure.

The original models of these traps were built of wood with the downsloping portion of parallel wooden slats about 3/8 inches wide and spaced about 1/4 to 3/8 inches apart. The water flow was adjusted by a number of different means so that the water fell through the slats most of the way downstream, close to the edge of the screen array. One method of adjusting the flow was to change the slope. A steep slope allowed more of the water to approach the edge. Another method was to place boards over the slats near the upstream edge to reduce the area where water could fall through. A third method was to hang a sheet of plywood on a section of boards fastened together to form a sheet under the array of slats. This sheet was hinged at the upstream edge. Raising or lowering the downstream edge throttled the water flowing through the array and caused more of it to proceed farther downstream before falling through. Fish in the water followed it downstream and came clear of the water at the point where the last flow went through the slats. The fish then slid or flipped the remaining distance over the far edge of the screen array and into a trough hung at a right angle to the flow. This trough carried the fish to one side of the structure and into a holding box. The current of water through the trough was provided by a flow over a board a few inches wide lying flat on the bottom against the side wall opposite the holding box. The water falling through the slats continued downstream.

Many versions of the Wolfe trap were made in the United States and Canada starting in the 1940s. Often heavy mesh wire was substituted for the wood slats, but the mesh did not provide a good sliding surface. Another version used perforated steel or aluminum plate, which was more satisfactory. In the 1960s, wedgewire screen came into use, and it is probably the most preferred material today. Wedgewire steel screen was developed about 110 years ago for use with submerged well points that could not be cleaned. Small particles going through the openings between shoulders of the wedgewire tended to pass through readily. Most wedgewire in use for fish screening is made of stainless steel, which makes it fairly expensive but very durable.

An example of a Wolfe trap-type installation is at PGE's North Fork (Clackamas River) fish facilities where the fish, rather than entering a trap at the end of the collection trough, are diverted to a lower volume conduit. The screening medium at this installation consists of perforated aluminum plate (Sverdrup Corporation, pers. comm.).

Using Wolfe traps would involve the construction of a permanent concrete overflow weir and trapping facility on the free-flowing section of a stream. All the juveniles would be screened and retained in an adjacent trapping chamber.

Access to the trap for both construction and maintenance should be considered during site selection. Because the Wolfe trap establishes its own gradient, regardless of that present in the stream above the site, gradient would not be a location parameter.

Because the trap would effectively span the entire river, a fishway would be incorporated into the trap design to allow upstream passage by adult fish. A small pool and chute, or a vertical-slot fishway probably would meet upstream passage objectives over the low weir at the trap. Such a fishway would be self-adjusting and require minimum maintenance.

Rubber Dam

There is an alternative to constructing the Wolfe trap within the existing stream channel. This alternative method involves placing a rubber dam in the existing channel and constructing an adjacent off-stream channel in which to install the Wolfe trap. During the fish outmigration season, the rubber dam would be inflated to divert the stream over the Wolfe trap. During the rest of the year, the rubber dam would be deflated and the stream would flow in its original channel, bypassing the Wolfe trap.

There are numerous rubber dam installations used for diverting streamflow. The controls for the dam can be automated so they can quickly respond to changing streamflow conditions. The dams have proven to be relatively maintenance free and resistant to vandalism. When deflated, the rubber dam lies flat in the streambed. At low streamflows the deflated dam may be a velocity barrier to upstream migrating fish. Therefore, consideration must be given either to placing a fishway through the concrete foundation of the dam to allow fish passage or to placing “removable roughness” on the dam to break up the velocity barrier.

Non-target species of juveniles might be required to pass downstream of the trap and into the reservoir without holding. This passage is easily accommodated by fitting the trap holding box with slots that permit smaller fish to escape rapidly back into the stream. Adults would be excluded from the trap by the debris deflector over the collection trough.

The basic design concept for the Wolfe trap has been proven through over 50 years of application in various locations around the world. Thus, prototyping is not deemed to be crucial in the development of this type of trapping facility. Conventional designs would be employed for all aspects of the installations that do not require solutions specific to site or situation.

However, it may be desirable to conduct limited prototyping of unique aspects of the trap. Such testing might include prototyping of the slots in the holding box to allow for the escape of non-target species. Prototyping of alternate screening material may also have value.

Biological Effectiveness

Wolfe traps are used to collect downstream migrant fish from tributaries so they can be transported downstream. The Wolfe trap has been used in the original form, as well as in many derivations, in Europe, the United States, and Canada. It is the basis for the downward-sloping, inclined screen trap and diversions used at other projects.

The Wolfe trap offers many advantages. It can be installed in such a way that it captures virtually 100% of the fish passing a given point, as long as streamflows are relatively constant. However, if flows vary greatly, some high-flow events may effectively inundate the trap. Wolfe traps can be designed to cause little, if any, injury to fish. They are easily maintained, and their capital costs are relatively attractive. Maintenance costs are affected by debris amount and bed load in the stream. Although the Wolfe trap was designed primarily for downstream migrant salmonids, it has been useful for other species migrating downstream.

Costs

Cost estimates were prepared in 1996 for the placement of a prototype Wolfe trap in the Metolius River tributary to Lake Billy Chinook, the reservoir formed by Round Butte Dam. The construction cost of the Wolfe Trap was estimated at \$800,000, with annual O&M costs of \$30,000 (Sverdrup 1996).

3.1.12. Tributary Collection—Portable Screw Traps

Description

Rotary screw traps are portable devices used to capture, evaluate, and tag outmigrant salmonids. The rotary section of the trap is an Archimedes screw with the shaft oriented parallel to the flow. Fish entering the trap are directed to a live box at the downstream end of the device. The live box includes a rotating, self-cleaning screen at its downstream end. The torque from the current turning the screw is transferred with gears and drive belts to power the rotating screen so that, to a certain extent, the device is self-cleaning. However, large debris can easily put the trap out of operation. Also, the rotating screw makes the traps hazardous to animals and humans.

The patent for the screw mechanism is held by two ODFW biologists, and the device is manufactured by EG Solutions in Corvallis, Oregon. Users of the traps often purchase the screw mechanism and fit it to flotation devices that are suitable for the location where the trap will be fished.

The traps are not very efficient for catching fish, and their efficiency depends on a number of variables, including run timing, flow, and fish size. The successful locations for the traps are very site specific. The best fishing locations are in areas of concentrated fast current because the operating trap is noisy and the fish try to avoid it. Current is also required to power the self-cleaning screen, so the device would not operate in a slow-moving reservoir.

Biological Effectiveness

Users consider the fish-catching effectiveness of the traps to be relatively low. A trap presently fishing in a medium-sized river is estimated to catch 5 to 10% of the fish. A trap fishing in a creek is estimated to catch 30% of chinook fry and 20% of coho (Sverdrup Corporation, pers. comm.).

The Turlock Irrigation District reports a catch of 100,000 chinook fry in one day on the Toulumne River in California. The catch the previous day was 10,000 fry (Sverdrup Corporation, pers. comm.).

Users of rotary screw traps do not think that it would be feasible to use the traps in a production mode for the downstream collection of migrating salmonids. The fish try to avoid the traps, and there are few suitable fishing locations. If the goal is to trap and transport all the migrants from a stream, it is probably not feasible to achieve that goal using rotary screw traps.

Costs

In 1994, the cost of a small rotary screw trap was about \$15,000. A larger unit built by the owner cost about \$25,000 (Sverdrup Corporation, pers. comm.).

3.1.13. Tributary Collection—Louver System

Description

A louver system consists of an array of evenly spaced vertical slats aligned across a stream or water passage at a specified angle and leading to a fish bypass (Figure 16). Louver systems take advantage of the tendency of fish to orient themselves facing into a current, even if they are moving with the current. Louver screen systems work on a guidance velocity principle. A guided fish is carried along the face of the louver array by the flow. The fish is generally pointed upstream, but not parallel with the flow, and stays free of the louver face. The swimming speed of the fish must be sufficient to keep it from passing through the louver slats, but not strong enough to overcome the transport velocity. A louver system can be either a stationary system or a component of a portable trap.

The disadvantage of a louver system is that it collects debris and can present operational difficulties in providing a continuing combination of ideal hydraulic conditions. The performance of the louver systems is also highly dependent on the size and swimming ability of the fish. The louver systems tend to select for larger fish.

Biological Effectiveness

The only known operating stationary louver system in the Pacific Northwest is located at Tacoma Power's Mayfield Dam on the Cowlitz River in western Washington. At the time this system was designed and constructed, the concept was relatively new, with success reported at installations in California, Oregon, and Canada. During the 1964 and 1965 fish bypass season, experiments and modifications were made to the system. However, the modified louver system still did not adequately guide juvenile salmonids from the water leading to the turbines. The performance of the louver system was further improved by placing screens over the louvers. The existing louver bypass system at the Mayfield Project is still operating with a fish guidance efficiency of 60 to 80%, and the owner of the project is studying options to increase overall fish passage efficiency (Sverdrup Corporation, pers. comm.).

From 1962 to 1965, a stationary louver system was installed in the Eagle Creek tributary to Brownlee Reservoir. Researchers used the system to evaluate the reservoir's effect on the migrations of anadromous fish (Durkin et al. 1968). When the Eagle Creek louver system was installed in 1962, the average efficiency was 10.2%, and the system was selective for larger fish. The structure was altered in 1963, increasing the efficiency to 57.5% and eliminating fish size selectivity. In 1964, the creek channel upstream of the louvers was straightened to provide a more uniform approach velocity. Efficiency increased to 91.3%. During spring 1965, the louver system efficiency dropped to 85.2% as a result of ice and high flows that disrupted the velocity and direction of flow across the louver faces.

Costs

We could not find any cost information for stationary louver systems.

3.1.14. Upper Reservoir and Tributary Collection—Transport Options

Description

Upper reservoir collection options require a transport system to carry juveniles from the collection facility to a point downstream of the dam to be bypassed. The following are various options available for the transport of these fish.

Truck Transport

After the juveniles have been collected at the tributaries and upper reach of the reservoir, they could be placed in tanker trucks and driven to a downstream release point. For its lower Snake River facilities, the USACE uses tanker trucks at the beginning of the migration season. Juveniles are collected at Lower Granite, Little Goose, and Lower Monumental dams and transported downstream to a release facility on Bradford Island at Bonneville Dam. The current fish agency criteria states that fish cannot be held for more than 48 hours after collection. The trip from Lower Granite Dam to Bonneville Dam takes approximately 8 hours to complete. The trucks have a maximum capacity of approximately 17,500 fish, and they are equipped with aeration systems to maintain oxygen levels during transport.

Barge Transport

Barges can be equipped with holding tanks to transport juveniles downstream. An advantage to barge transport is that it allows for a constant supply of fresh water to be pumped to the fish holding tanks, thereby continuing the imprinting of the water source. The USACE begins their fish barging operation when migration numbers rise above 20,000 fish per day. The agency collects fish at Lower Granite Dam and barges them downstream, picking up additional fish at Little Goose and Lower Monumental dams. The fish are released downstream of Bonneville Dam. The trip takes between 30 and 40 hours to complete. The USACE operates eight barges with an average capacity of approximately 55,000 pounds of fish.

Migratory Canal

The USACE's report, *Columbia River Salmon Mitigation Analysis System Configuration Study—Phase I*, discusses various options for transporting juvenile fish. These options include the previously mentioned truck and barge options. An additional option is the use of a migratory canal. This concept uses a concrete and rock-lined trapezoidal channel designed to carry 200 cfs at 3 to 6 ft/s. The canal would begin at the collection structure on Silcott Island and run to a discharge point downstream of Bonneville Dam. Juveniles collected at the existing dam would be placed in the migratory channel.

Resting ponds would be provided at 10-mi intervals, and 25% of the flows entering the ponds would be replaced with fresh, aerated water pumped from the adjacent river. An access road would be constructed along the side of the canal, and the canal would be fenced and covered with wire to protect the juveniles from predators. Portions of the canal may be elevated flumes or tunnel through rock, depending on the geographic area in which the canal is located.

Pressure Pipeline Conveyance System

The same report addressed a second concept—a pressure pipeline conveyance system—that uses a pipe buried along the shoreline to transport juveniles. This pipe would be 6 to 12 ft in diameter and constructed of steel or concrete. Resting facilities would be incorporated in the design. The pipeline would run from Silcott Island to the release point downstream of Bonneville Dam.

Flexible In-Reservoir Salmon Passage (FISP)

In the early 1990s, the Idaho National Engineering Laboratory (INEL), now the Idaho National Engineering and Environmental Laboratory, developed a report entitled *Proposal for a Flexible In-Reservoir Salmon Passage* (Dearien et al. 1993). In this study, INEL developed conceptual designs to transport juveniles through a flexible conduit. These designs could be used to transport fish from the beginning of their migration, around existing dams, and all the way to the estuaries. They provide a migration speed similar to the rate that occurred prior to the construction of dams (3–5 ft/s). The study addressed concerns including stress to smolts, migration requirements (such as homing, imprinting, and light/dark cycles), water velocities, feeding and resting, potential injury, exclusion of predators, oxygen and temperature requirements, and gas supersaturation.

The main components of the developed system were a flexible conduit (submerged or surface), a head tank, pumping stations, junction structures, and feeding and resting areas (Figures 17 and 18). This concept provided 1,000-ft segments of conduit 8 ft in diameter that began at a head tank where collected smolts would enter the system and be transported through the conduit to the following junction structure. Food, resting areas, and additional oxygen were added where needed. In-line axial pumps drove the system. These pumps could be powered by either electrical or hydraulic drives. Passage through the dams would occur at the existing bypass systems or through a conduit bored through the dam abutments. The conduit would be fabricated from a translucent, flexible material. Potential pipe types listed in the report included polyethylene, Kevlar (Dupont), and Spectra (Allied Chemical). A mat with a leafy, plant-like material would be laid in the bottom of the conduit to provide a resting area for the migrating smolts.

A gravity flow alternative was also developed (Figure 19). It moved fish sequentially by raising and lowering the water levels within a series of head tanks spaced at 1-mi intervals. These tanks would be connected with a flexible conduit 8 ft in diameter. Water would be pumped into the first head tanks, producing a head differential. This head would produce a flow in the pipe that would drive the fish into the second head tank. When fish collected in the second tank, the outlet to the third tank would be opened. Water pumped into the second head tank would move the smolts down the system. The sequence and frequency of this operation would require additional testing.

These INEL concepts used pumps to drive the systems. Another possible option would use the head difference between the reservoir elevation and the tailrace to drive the systems. High-density polyethylene plastic (HDPE) could be placed in the entire length of the reservoir and run through the dam to a point in the tailrace. A fish collection structure could be placed in the beginning of the pipe, and the head difference between the inlet and outlet located at the tailrace could drive the system. HDPE is available in a 60-inch-diameter size with large sizes (up to 120 inches in diameter) provided in a raised-profile outer wall. Because the ends of HDPE can be fused together (butt-fused), a strong, watertight connection can be provided.

Floating Flume

There has been discussion concerning the feasibility of placing a floating flume in the reservoir itself. This flume would act as a channel within a channel. The advantage to this idea is that the velocities of this interior channel could be controlled to increase the likelihood of the juveniles reaching the dam. One concept analyzed uses a series of 2-mi segments of floating flume with a bottom slope of 0.00095 ft/ft. The drop within each segment is 10 ft. At the end of the segment, the fish and flows are pumped up 10 ft to the adjoining segment, and the fish continue down the reservoir at a velocity of 4.9 ft/s and a flow of 103 cfs. This flow produces a normal depth in the flume of 2.1 ft. A disadvantage of the floating flume is that it produces a barrier to boats and other objects that travel on the surface of the reservoir.

Biological Effectiveness

It has been shown that transport by truck or barge has no significant effect either to homing or to fish survival. The majority of studies show that transportation returns more adult fish than in-river passage. Transportation typically increases the downstream migration time and decreases exposure to predators. It is also essential during low-flow years.

Little data exists on the effectiveness of any open-canal or closed-conduit alternatives to transport. These alternatives require additional studies and provide an engineering challenge to supply all of the juveniles' biological needs. In the conclusion of its *Columbia River Salmon Mitigation Analysis System Configuration Study—Phase I* report, USACE authors stated that the canal and pipeline proposals should be eliminated from further consideration because of biological concerns and uncertainties.

Costs

The *Columbia River Salmon Migration Analysis System Configuration Study—Phase I* report provides some very preliminary cost estimates. These costs include the collection structure

located at Silcott Island and a transportation system to Bonneville Dam (approximately 220 mi). The project costs are as follows:

Item	Cost
Migratory canal option	\$4.3 billion
Buried pipeline	\$4.0 billion
Barge transport	\$57–362 million
Floating pipeline	\$789–856 million

Maskell-Robins provided a quote of \$19 million for 30 mi of 54-inch diameter HDPE pipe. The quote included only purchase of the pipe and delivery to the site.

3.2. Upstream Passage

3.2.1. Fish Ladders

Description

Fish ladder installations date back to the early 1900s. They are the most traditional method of upstream passage. Basically, a ladder presents the upstream targeted fish with hydraulic conditions that are compatible with its swimming and behavioral characteristics. Ladders consist of an open-channel trough with various types of internal baffle schemes, each type having been found suitable for various types of fish. There are three basic types of fish ladders: the Denil, the vertical slot, and various types of pool and orifice-weir. The Denil and vertical-slot fishways have been used successfully by a wide variety of anadromous and freshwater fish, such as alewives and blue-back herring. The orifice-weir fishways have been used successfully by anadromous salmonids. Both the vertical-slot and Denil fishways allow fish to swim at their preferred depth. The Denil provides the most direct route of ascent, while the vertical slot requires fish to use a “burst-rest” pattern to move between pools. Typical installations place the pool and weir or vertical-slot fishways at slopes of between 8 to 1 and 10 to 1. A Denil fishway can be installed between slopes of 3 to 1 and 5 to 1. Fish move faster through Denil fishways than through vertical-slot or weir fishways. A variation of the Denil fishway is called an Alaskan Steep Pass. These fishways were developed for installation at remote sites in Alaska. They are prefabricated Denil-type fishways that can be flown in and easily installed on site.

In Norway and most other Nordic countries, the pool and weir, vertical-slot, and Denil ladders are commonly used to bypass both natural and manmade obstructions. There is one unique application at the Hellandsfossen waterfall on the Modalselva River in western Norway. A fish ladder was constructed there by placing baffles, spaced at 4-m intervals, within a pipe 2 m in diameter. Made of polyethylene, this pipe is translucent and allows light to enter. It has openings spaced along its top, and it is placed on a concrete foundation. The total rise of this ladder is 34.5 m (Grande 1995).

Biological Effectiveness

The dams of the Columbia and lower Snake rivers use pool and weir-type ladders (Figure 20) that have proven to be effective for the passage of adult salmon. This type of system lets fish use either the weirs at the surface or the orifice opening for upstream passage.

Although fish ladders are generally used at dams 125 ft high or lower, there are some fish ladders installed at high-head dams. The results of these installations vary. PGE has two high-head fish ladders. The first is at Pelton Dam on the Deschutes River. This ladder rises 200 ft and is approximately 3 mi long. The reason for the long length is that the ladder was designed to pass two separate developments. It became operational in 1958, but PGE stopped using it in 1968 after passage above the Round Butte development was discontinued. They have since converted it to a rearing facility. While in operation, the fish ladder experienced problems associated with water temperature. The transport flows were taken from the surface of the reservoir. During the hot summer months, the water temperature at the upper end of the ladder approached 18 °C. Once the transport water was in the ladder, the temperature increased further because of air temperature and solar heating. When the water discharged into the tailrace, it was too warm and was rejected by many of the migrating adults. Adults that entered the ladder experienced difficulties when attempting to climb the ladder in this warm water (up to 25 °C).

However, another of PGE's high fish ladders has proven to be an effective means of passage for adult salmon. The North Fork Dam fish ladder, located on the Clackamas River in Oregon, is 196 ft high and 1.7 mi long. It begins at the Faraday Diversion Dam and continues up to the North Fork Dam. It has been in operation since 1958 and has provided generally good passage. A fish trap located at the base of the ladder is used for evaluation and monitoring purposes. Because the transport water is taken from the reservoir surface, this facility also has experienced some problems with attraction because of the warming of the transport water. Because the chinook is now a listed species, all fish are now trapped at this project and selectively released.

Costs

For lower head applications, less than 100 ft, fish ladders frequently present the most economical approach. They usually have lower operational costs than fish locks and elevators. A disadvantage of the ladder at high-head sites is that it may become quite long because fish ladders generally cannot be built steeper than a 1-ft vertical rise in every 10 ft of horizontal run. Also, periodic, horizontal resting pools are needed. Some fish species may not be physically able to absorb the stresses imposed during the ascent of a very long ladder.

In 1983, a 42-step, vertical-slot fish ladder was constructed at Brunswick Dam on the Androscoggin River in Maine. This ladder was 500 ft long and was constructed for a total cost of \$4.3 million (Francfort et al. 1994). A fish passage study underway for the Cowlitz River Hydroelectric Project proposes two high-head fish ladders. The first ladder at Mayfield Dam is a half Ice Harbor-style ladder with an 8-ft width and a 10-to-1 slope. There are a number of resting pools, and the exit structure accommodates a 10-ft fluctuation in forebay elevation. The ladder also has a bridged river crossing. The capital cost estimated for this ladder is \$9.9 million, with an estimated annual O&M cost of \$297,000. The second ladder is located at the Mossy Rock Dam. It too is a half Ice Harbor-style ladder. The vertical rise for this ladder is 216 ft. The exit structure is designed for a forebay elevation variance of 48 ft, but it is also designed to

withstand a total head of 143 ft during peak flow. During high flows when the forebay elevation rises 48 ft above the minimum elevation, the ladder is shut down. Capital costs for this ladder were estimated at \$22.4 million, with an O&M cost of \$672,000 (Harza Northwest 1999).

3.2.2. Fish Locks

Description

Although experimental fish locks and elevators were tried as early as the 1920s, they were not developed into a practical method until the late 1940s. The first of these modern locks, constructed in Ireland and designed by J. H. T. Borland, became known as Borland locks. Figure 21 shows a typical Borland lock. The lock consists of a top and bottom chamber connected with a sloping chamber. A certain amount of flow is released through the top gate and flows down the sloping chamber into the bottom chamber. This flow empties into the tailrace, providing attraction to upstream migrating fish. At a predetermined cycle time, or when sufficient fish have entered the bottom chamber, the downstream gate is closed, the upstream gate is opened, and the lock fills with water. The fish then swim up the shaft and into the forebay. The gates are adjusted, the lock is drained, and the process is repeated. Borland locks have been designed for dams as high as 200 ft (Orrin Dam in Scotland). Most of the operating fish locks are in Europe, although a few have been built in the United States. The primary functional disadvantages of Borland locks are their inability to clear all fish from the vertical shaft in a timely manner and their much smaller capacity than ladders and lifts (Clay 1995).

Most of the Borland locks are constructed for salmon passage on smaller rivers in Europe. In Russia, fish locks have been designed to pass species other than salmon and have features not included in earlier Borland locks. The Tzymlyanskij fish lock on the Don River was designed with a vertical shaft to provide auxiliary water attraction, a fish crowder to direct the fish into the lock, and a vertical crowder or lifting basket to ensure that the fish ascend the lock into the forebay. See Figure 22 for an illustration of this fish lock. The Volzhskaya Dam on the Volga River is similar in design, but it has two locks side by side, so one lock is always attracting fish as the other lock is passing fish over the dam.

Biological Effectiveness

Fish locks have been used with success, mainly on the East Coast. An example is the fish lock with lifting brail located at the St. Stevens Dam on the Cooper River in South Carolina. On the Columbia River, the Bonneville, The Dalles, and McNary dams were all constructed with fish locks. However, because of high operating costs and the efficiency of the fish ladders, these locks are no longer in operation.

Costs

No cost figures are available for the construction of the fish locks described here.

3.2.3. Fish Elevators

Description

Fish elevators are similar to fish locks, except that the fish are transported vertically in a mechanically driven hopper. Figure 23 is a schematic cross section of a representative fish lift. The fish enter the lift from the tailrace, led by the attraction water flowing out of the lower entrance. When sufficient fish have entered the bottom entrance channel, the crowder closes and travels toward the elevator shaft to force the collected fish into the hopper. After the crowder has moved to the full closed position, the hopper is lifted up the vertical shaft by an electric or hydraulic hoist. When the hopper reaches the full up position, a hopper door opens and the fish are passed into the upper reservoir.

Biological Effectiveness

Fish lifts or elevators have been effective in passing adults. The main factors determining their effectiveness are location and ability to attract migrating fish. These factors are dam and site specific. The primary advantage of elevators over ladders is that they are more physically compact. They are also generally more economical to build at higher head sites. The hopper arrangement eliminates the lock's problem with fish collecting in the vertical shaft. Because the elevator's hoppers are mechanically driven, they have short cycle periods that result in high transporting capacities. Another advantage when compared with ladders is that an elevator's hydraulic design is not as specifically oriented to a particular species' swimming characteristics. Therefore, elevators are more readily amenable to passing a wider variety and size of targeted species. In addition to passing the fish directly into the forebay, a fish elevator is also readily adaptable to the addition of a fish-sorting facility with or without the option of a truck loading. Therefore, elevators can be readily adapted to a trap-and-haul option on either a permanent, temporary, or seasonal basis, as well as to direct passage to the forebay.

Fish elevators are more labor intensive to operate and more expensive to maintain than ladders. Winter operation also presents operational problems; we are not aware of any fish elevators to date that operate during winter.

The fish lift at Holyoke Dam on the Connecticut River is one of the most successful lifts located on the East Coast. In 1992, it passed 490 salmon, 720,000 shad, 310,000 herring, and 28,000 lamprey.

Costs

As previously mentioned, one advantage of a fish lift is that it is more economical to construct on high dams. One such example is at Round Butte Development on the Deschutes River in central Oregon. Although no longer in operation, the Round Butte fish lift used an aerial tram system to lift fish over the dam into the forebay 365 ft above the tailrace. Figure 24 shows a schematic sketch of an aerial tram system. Another option would use an inclined rail to lift the fish up and over the dam. This alternative is also illustrated in Figure 24. Both designs could be advantageous at projects where forebay elevations fluctuate.

In 1990, a second fish lift was constructed at the Conowingo Dam on the Susquehanna River in Maryland. This 40-ft lift places the fish into a sorting tank where they are then trucked upriver or released to the forebay. The construction cost for this lift was just under \$12 million, with an estimated annual O&M cost of \$400,000 (Francfort et al. 1994).

3.2.4. Trap and Haul

Description

The purpose of a trap-and-haul facility is to collect migrating adults below a dam, place them in tanker trucks, and release them in the forebay or any other predetermined location upstream of the dam. A trap-and-haul facility can be designed as a separate structure or as part of the previously described fish lift or elevator (Figure 25). For example, at many elevator facilities, the fish, either before or after a sorting section, can be passed directly into the forebay, into holding tanks for future movement, or directly into trucks for immediate transportation.

Trap-and-transport systems have been used extensively to transport fish around both manmade and natural obstructions. A successful example is the trap-and-haul facility at Sunset Falls located on the South Fork of the Skykomish River in western Washington and operated by the Washington Department of Fish and Wildlife (WDFW). This trap-and-haul facility began operations in 1958 and is used to pass migrating salmon past three natural falls. It was constructed to mitigate lost habitat in the lower Puget Sound system, and it opened up 90 mi of spawning and rearing area that had not previously been available to salmon. It currently is used to transport up to 24,000 wild-run fish to the new natural spawning areas. WDFW considered building fish ladders around the three falls, but they have found that the trap-and-haul system is an efficient and cost effective method of fish transport (Sverdrup Corporation, pers. comm.).

Biological Effectiveness

Trap-and-haul operations have proven effective in passing upstream migrating fish with little effect on their continuing migration. Transport vehicles must be designed to minimize injury that could occur during loading and unloading.

Costs

The primary potential advantage of a facility dedicated exclusively for trap and haul, as compared with a structure with direct forebay passage and a trap-and-haul option, is that the much shorter vertical height and smaller hopper size decrease the capital cost. An exclusive trap-and-haul facility also has great flexibility in location within the tailrace (as long as truck access is provided). Conversely, a dedicated trap-and-haul facility potentially offers higher operating and transportation costs than do ladders or elevators with only direct forebay passage.

The estimated cost of operating the trap-and-haul facility at Sunset Falls is approximately \$70,000 per year. The facility employs two people and uses a 1,000-gallon tanker truck to transport an average of 24,000 fish per year. The truck can transport up to 25 loads per day, carrying between 100 and 150 coho salmon per load, or fewer fish if they are chinook salmon. A new trap-and-haul facility is proposed for Mossyrock Dam with an estimated cost of

\$4.5 million. This cost includes the installation of an electric barrier. The project O&M costs are estimated at \$135,000 (Harza Northwest 1999). The cost of a tanker truck used in a trap-and-haul operation would be approximately \$100,000 to \$200,000.

3.2.5. Entrance Conditions for Upstream Passage

3.2.5.1. Entrance Location

The most important element in a successful upstream fishway is the entrance. The hydraulic conditions must suit the behavior of fish in how they respond to water velocity and depth. The entrance must also be located where the upstream migrating fish will find it. If there are no other overriding stimuli, classical fishway design assumes that the physiological processes guiding anadromous fish back to their home waters are a combination of odor response and the behavioral response of swimming upstream against the flow. Unless site-specific testing shows otherwise, it is also assumed that the proportion of upstream migrating fish at any location in the river will be the same as the relative proportion of total river flow. Migrating fish will follow flow as far upstream as possible until a barrier stops them. This barrier might be an obstruction too high to jump or water flowing too fast to swim against (i.e., discharge from a turbine runner).

3.2.5.2. Attraction Flow

The amount and source of the attraction flow are other important design considerations for an upstream fishway. Average rules of thumb are that the attraction flow should be 2 to 10% of the competing tailrace discharge. Because this attraction flow is a larger flow than is needed to transport fish through the fishway, it is common to provide attraction flow either by piping additional water from the forebay to the entrance or by pumping additional water into the entrance from the tailrace. In some installations, a turbine is added to recover most of the energy from the additional attraction water required for fish ladder or lock entrances.

Other biological clues should be used, if possible, to attract fish to the entrances. The temperature of the water can affect attraction. If temperature stratification is occurring in the upper reservoir, the depth from which the attraction flows are taken could be changed to control the temperature.

3.2.5.3. Exit Conditions

The fluctuation in headwater elevation must be considered in the design of any fish passage system, especially fish ladders. The exit structures of many fish ladders have multiple openings at varying elevations to account for the water-level fluctuations in the forebay. In Japan, some ladders are designed to rise and lower with the forebay elevation. The upper portion of these ladders consists of a steel channel that pivots and moves with the changing forebay elevation (Kamula and Laine 1998). An additional alternative would be to construct a pressure chamber at the exit structure to account for changes in forebay elevation. In Norway, a pressure chamber was constructed at the end of a fish ladder on the Nidelva River and began operating in 1992. The fish ladder rises 17 m to the base of the Rygene Dam where it connects to a pressure chamber that takes the migrating salmon through the 6-m-high dam (Kamula and Laine 1998).

4. EVALUATION OF DOWNSTREAM PASSAGE CONCEPTS

In this section we evaluate the downstream fish passage options we discussed in Section 3 for possible application at each of the three HCC dams. We emphasize that this evaluation is only a conceptual analysis. Further studies are required to determine actual migration patterns and other factors that would determine the effectiveness of each passage option.

4.1. Brownlee Dam

In our analysis of downstream passage options at Brownlee Dam, we assumed that the reservoir would be drawn down fully. For a full reservoir, we believe upper reservoir and/or tributary collection to be the only feasible alternatives. Raleigh and Ebel (1968) found that passage through Brownlee Reservoir was possible. Two factors dictated passage success: 1) reservoir elevation, and 2) time of migrations. Raleigh and Ebel found that the highest passage survival occurred when the reservoir was drawn down the greatest. They compared survival at a 21-ft draft in 1963 and an 89-ft draft in 1964. Larger drafts decreased reservoir length and increased downstream currents. They also found that species beginning migration earlier in the season had the best survival rate and entered the reservoir in the best environmental conditions.

Brownlee Dam has unique characteristics that affect the viability of the downstream fish passage concepts. For example, the upstream river channel is approximately 1,000 ft wide at the dam. Power generation flows are diverted into an intake channel, located on the right bank of the river. This intake channel is approximately 150 ft wide. Spillway flows travel through the spillway approach channel, which is approximately 200 ft wide. Fluctuations in forebay elevation can be as much as 101 ft.

4.1.1. Forebay Collection and Bypass—Fish Attraction Barges (Gulpers)

A Fish attraction barge could be developed for Brownlee Dam. This system could be similar to the one used at the Baker River Project (see Section 3.1). Such a barge might be located anywhere within the reservoir, but we focused on forebay locations. Possible forebay locations include the main channel itself, the intake channel, and the spillway approach channel. After reviewing the layout of Brownlee Dam, we determined that the preferred location for an attraction barge would be the intake channel. The majority of the flow enters this channel and would provide attraction. After entering the channel, the fish could be collected in the barge and routed to a holding sump. From there they would be lifted to shore and transferred downstream by truck or other methods. It might be possible to enhance the performance of the attraction barge by elevating the bottom of the intake channel in the area of the barge. This would help to concentrate the juveniles in the upper portions of the channel.

The major advantages of a floating attraction system are that it can readily adjust to the large fluctuation in forebay elevations at Brownlee Dam and that it is relatively low in cost. A

disadvantage of the system is that no existing examples of fish gulpers in the Pacific Northwest are as large in scale as what would be required for the Snake River flows.

4.1.2. Eicher Screens

An Eicher screen is a possible downstream fish passage option for Brownlee Dam and could be placed in the penstocks. The design of such a system would involve some difficulties, including construction access, bypass system routing, and head fluctuations.

The existing penstocks are tunneled into rock, so gaining access to install the Eicher screens would be difficult. Installation options include either tunneling to the penstocks or taking segments of the screen down through the intake to assemble them in the penstock. This last option requires the removal of intake trash racks and possible modifications to the intake, as well as the development of dewatering schemes for construction access.

After the Eicher screen is in place, a bypass must be constructed to carry diverted fish from the penstock to a downstream outlet. There is an existing access tunnel at an elevation of 1,960 ft. This tunnel could also serve as a portion of the fish bypass channel. The bypass must be designed to maintain appropriate velocities and to be fish friendly. It must accomplish these necessities while accounting for the large fluctuation in forebay elevation. The Eicher screen installation could include a telescoping riser to control the bypass flows.

Typically, Eicher screens are designed for velocities of up to 10 ft/s, with increased scale damage to fish occurring at higher velocities. A velocity of 6 ft/s is more typical. Assuming that the four turbines with the 24-ft diameter penstocks were in operation at a total flow of 20,000 cfs (and the fifth turbine was unable to operate because of low forebay elevation), the average velocity through the penstocks would be approximately 11 ft/s. This velocity is above the upper range of most survivability tests performed with Eicher screens. If Eicher screens were used at Brownlee Dam, tests would have to be performed to determine the maximum allowable flow through the turbines. The remaining flows would have to be released through the spillway. A 28-ft diameter Eicher screen would be installed in the fifth penstock and would be in operation when the forebay elevation was 2,000 ft or greater.

An advantage to the Eicher screen is a generally high survival rate. A disadvantage is the fact that no Eicher screens have been constructed for such a large penstock diameter (24 ft). The screen required at Brownlee Dam would be approximately 90 ft long. Access to the penstock would be very difficult and would increase construction costs dramatically. There is also the risk that increasing the size of the screen to several times that of proven systems might reduce the survival rates from those anticipated.

4.1.3. Modular Inclined Screens

An MIS system could be used at Brownlee Dam. The existing trash racks would be removed, and a series of MIS units would be installed in front of the power intake. The size and number of MIS units could be arranged to provide the needed surface area and to ensure that the approach velocities never exceed 10 ft/s. A typical MIS has an entrance area 8 ft high and 10 ft wide, with

an approximate length of 30 ft. A possible configuration for each unit might consist of three rows of three MIS units stacked on each other for a total of nine units. This configuration provides an approach velocity of just under 7 ft/s, assuming 5,000 cfs per unit. The bypass would have to be routed up to the surface so fish could be collected for transport downstream.

Advantages of the MIS are the high survival rate and the fact that the units could be constructed off site, which decreases construction costs. The disadvantages include the fact that no existing installations are on rivers of comparable flows. Also, the project requirements would call for multiple units stacked on top of each other, which would introduce additional complications, such as the limited space available in front of power intakes for installation. The routing and configuration for the fish bypass flows would also pose a challenge.

4.1.4. Intake Diversion Screens

Intake diversion screens have been used extensively at most of the dams on the Columbia and lower Snake rivers. A system similar to these existing intake diversion screens could be placed at the Brownlee Dam. However, the complications of installing a system at this dam would include issues with deploying the screen from the top of the dam and the distance it would have to travel to get to the intake. The existing trash rack would have to be modified to prevent it from interfering with the diversion screen. The transporting of juvenile fish to a bypass up to the surface once they have been screened may be difficult due to the large fluctuations in forebay elevations. Because of these complications, we do not consider an intake diversion screen to be feasible for Brownlee Dam.

4.1.5. Surface Collection

It would be difficult to implement a surface collection system at Brownlee Dam because of the great fluctuations in reservoir levels required for operations there. For this reason, we eliminated surface collection from consideration at Brownlee Dam.

4.1.6. Behavioral Guidance Structure Combined with Spillway Release

A guide wall and spillway-release system could be placed at Brownlee Dam. Such a system would require a guide wall approximately 1,400 ft long to span the forebay. This guide wall could begin just upstream of the power intake channel and run diagonally to the spillway channel. The spillway structure is comprised of four large Tainter gates at an elevation of 2,027 ft and three smaller Tainter gates at an elevation of 1,938 ft. Water could be released through either an upper or lower Tainter gate, depending on reservoir elevation.

An advantage to this system would be the lower initial cost. However, Idaho Power Company (IPC) would need to conduct spillway survival studies before this option could be pursued any further. There are two primary disadvantages to installing this type of system at Brownlee Dam. First, it may be difficult to attract fish away from the large flows entering the intake channel. Second, the spillway release may increase dissolved gas levels in the tailrace to unsafe levels.

4.1.7. Turbine Passage

Because Brownlee Dam has such a high head, we do not consider turbine passage to be a feasible option.

4.1.8. Upper Reservoir Collection—Portable Floating Traps

Two types of portable floating traps could be used on Brownlee Reservoir. They are the floating trap with the same features described for the floating attraction barge (gulper) and the Merwin or Lake Oneida traps. The traps would be located in the upper reach of the reservoir. One advantage to an upper reservoir collection facility is that migrating salmon could avoid some of the hazards associated with the reservoir, such as predation, poor water quality, and low water velocities.

Disadvantages include difficulties in attracting a high enough percentage of the fish in the reservoir because they may be distributed throughout a wide section of the river. Another disadvantage is the need for a transportation facility with its increased operating costs.

4.1.9. Upper Reservoir Collection—Fixed-Location In-River Traps

An in-river trap in the Snake River itself may be feasible, but we do not consider it to be a viable option because of cost. Such a system would require building a new structure across the width of the Snake River.

4.1.10. Tributary Collection—Fixed-Location In-River Traps (Wolfe Traps)

We assume that tributary collection would be done in conjunction with other upper reservoir collection options. For Brownlee Reservoir, a tributary collection facility would be required at Eagle Creek. We assume that fish entering the Snake River from all other tributaries, such as the Payette and Weiser rivers, would be collected in the upper reservoir collection system.

An advantage of a tributary collection facility is that the juveniles avoid traveling through Brownlee Reservoir. The disadvantages to this alternative are that it requires a transportation facility and entails higher O&M costs.

4.1.11. Upper Reservoir and Tributary Collection—Transport Options

There are various options to provide transport of juveniles from the collection points in the upper reservoir and tributaries. They include truck transport and floating barges. A truck transport operation would need to accommodate the various collection facilities. Assuming the uppermost collection facility is located 40 mi upstream of the dam, we estimate that it could take 3 to 4 hours to load the juveniles at the various loading stations and release them at a point downstream of Brownlee Dam. A second option would be to use a transport barge similar to the one used by the USACE at its lower Snake River dams. There are no navigational locks on Brownlee Dam, so a barge would only be able to transport the fish from the upper reach of the

reservoir to the forebay of the dam. From there, the fish might be released through whatever bypass system is proposed at the dam, or through a separate discharge designated only for the barge system. Estimated travel time for a barge system is 8 hours.

Another option for transporting juveniles is to use submerged HDPE pipe placed in the reservoir. This concept involves placing the juveniles into a 56-inch diameter pipe in the upper reach. The pipe would then be submerged and travel approximately 40 mi through the reservoir to Brownlee Dam. There, the pipe would pass through a retrofitted Tainter gate and down the spillway to discharge into the tailrace. We reviewed both the maximum forebay elevation and drafted reservoir scenarios for this concept. The following assumptions were used to calculate some of the factors that would determine feasibility of this plan:

- Inlet elevations = 1,976 ft and 2,077 ft
- Outlet elevation (tailrace) = 1,805 ft
- Pipe diameter = 4.5 ft
- Pipe length = 40 mi
- Pipe type = HPDE
- Hazen-Williams friction coefficient = 155

From these two scenarios the velocity and flow of the water in the pipe were calculated along with an estimate of travel time. These values are as follows:

Forebay Elevation (ft)	Flow (cfs)	Velocity (ft/s)	Travel Time (hours)
1,976	60.9	4.5	13.1
2,077	78.2	5.8	10.2

4.1.12. Other Issues

One item to consider, especially with upper reservoir collection options, is the possible collection of non-target fish, including predators such as smallmouth bass (*Micropterus dolomeui*) that live in the reservoir. The location of the collection point must be chosen carefully to minimize this possibility. Also, once these non-target species are collected, it may be difficult to separate them from the target species. Other factors requiring attention are oxygen depletion in any transport and air entrainment in any pressurized system.

4.1.13. Recommended Alternatives

Portable upper reservoir collection with a floating gulper appears to be the best option for Brownlee Dam. Advantages of this alternative include lower construction costs, lower reservoir

predation, and the ability to move the system with fluctuating reservoir elevations. Other feasible options include the forebay collection system that consists of a gulper placed in the intake channel, and the installation of a guide wall and spillway-release system. However, these alternatives are viable only if it can be demonstrated that juveniles can successfully reach the project.

Figure 26 shows a number of general locations that might be considered for upper reservoir collection. Specific sites have not been identified at this level of concept development. Figure 27 illustrates the suggested location for multiple floating gulpers in the Brownlee Dam forebay. Figure 28 illustrates the suggested location and orientation for a guide wall and spillway-release system in the Brownlee Dam forebay.

4.2. Oxbow Dam

Alternatives for Oxbow Dam must consider the development's layout. The power intake is located approximately 0.5 mi upstream of the dam on the west bank of the river. Flows enter the intake and travel through the rock bank to the powerhouse outlet at the other end of the oxbow. Under current operations, only a small portion of the total flow is released at the dam itself, so attraction to passage systems located at this point would likely be unsuccessful because fish tend to follow flow. Also, bypassing fish collected at the intake could prove to be difficult. Bypass systems located at conventional dams are usually mined a short distance through the dam to a release point downstream of the tailrace. In the case of Oxbow Dam, the bypass would have to be bored through approximately 1,000 ft of rock. Alternatively, the collected fish could be transported by truck to the powerhouse tailrace.

4.2.1. Forebay Collection and Bypass—Fish Attraction Barges (Gulpers)

A fish attraction barge could be used as a forebay collection system for Oxbow Dam. This barge could be located at either the power intake or downstream at the dam, with the location at the power intake providing the best attraction of juveniles. It would be similar in design to that proposed for Brownlee Dam. The advantage of the fish attraction barge would be that it is a low-cost alternative. A problem with the effectiveness of such a system at Oxbow Dam is the fact that the intake channel is not defined with sidewalls as at Brownlee Dam. Consequently, the fish likely would be scattered throughout the forebay and enter at various approaches to the intake, making it difficult to attract a high percentage of fish through the system.

4.2.2. Eicher Screens

Flows from the power intake enter into one of two 36-ft-diameter horseshoe-shaped power tunnels and then into a 130-ft-diameter surge tank. From there, the flows enter into one of four 23-ft-diameter penstocks. Installation of an Eicher screen would be best suited to the penstocks. Gaining access to the penstocks would be difficult, but it could be accomplished either by tunneling into the rock or going through the surge tanks. Similar to Brownlee Dam, Oxbow Dam

has a drainage tunnel above the penstocks at an elevation of 1,772 ft, which could be used as part of the bypass system.

The total cross-sectional area for the four penstocks is approximately 1,660 ft². The amount of flow used for power generation during migration periods may be controlled by the maximum allowable velocity through the Eicher screen. Assuming a maximum velocity of 10 ft/s, the maximum flow through the generating units would be 16,600 cfs. The remaining flows would have to be released over the spillway.

As at Brownlee Dam, the advantage to the Eicher screen is the high survival rate that could be expected. Disadvantages are that no Eicher screens have been constructed for such a large penstock diameter and gaining access to the penstock would be difficult, increasing construction costs dramatically. There is also the risk that the necessary increase in the size of the Eicher screen to several times that of proven systems might reduce the anticipated survival rates.

4.2.3. Modular Inclined Screens

At Oxbow Dam, there are two areas where MIS units could be installed. The first is at the intake to the two 36-ft-diameter horseshoe-shaped power tunnels. The existing trash racks could be removed and a series of MIS units could be placed in front of these two tunnels. Since these intakes are larger than those at Brownlee or Hells Canyon dams, they may require a higher number of MIS units to match the entrance flow distribution adequately.

A second installation option would be in the transition between the power tunnel and the penstocks. Each power tunnel transitions into two separate 23-ft-diameter penstocks in the area under the 130-ft-diameter surge tanks. MIS units might be installed in this area, depending on the available space. Locating the MIS units in this area would be more advantageous for routing of the screened fish and bypass flow.

The advantages of the MIS option are that it provides a high survival rate and the units can be constructed off site, decreasing construction costs. The disadvantages include the fact that there are no existing installations on conduits of comparable size. The MIS option would also require multiple units, with the exact configuration depending on the installation location.

4.2.4. Intake Diversion Screens

An intake diversion screen could be placed either at the power intake or in the surge tanks. Velocities are likely to be lower at the power intake, and the existing trash rack and stop log guides are conducive to the installation of an intake diversion screen. A collection flume could be located in the gatewell for eventual transfer of the juveniles into trucks for transport.

The intake diversion screen is a mature technology installed at many dams on the Snake and Columbia rivers. However, most installations are on dams with multiple intakes that are smaller than those at Oxbow Dam. Therefore, the diversion screen required at Oxbow Dam might be larger than what is typically constructed. Also, this system requires that juveniles be transported to the tailrace.

4.2.5. Surface Collection

A surface collection system similar to those used at other dams on the Snake and Columbia rivers could be placed in front of the power intake. This system could consist of a large, floating channel-like structure with vertical slots running the width of the intake. Attraction flows would empty into a fish collection area and then be discharged back into the forebay. The juveniles would be taken out of the collection area and loaded into trucks for transport downstream.

The advantage to such a system is that it is constructible and would be located above the majority of the flow, a location that should be beneficial in attracting juveniles. The disadvantage learned from other installations is that it is difficult to determine the biological effectiveness of a surface collection system before it is constructed.

4.2.6. Behavioral Guidance Structure and Spillway Releases

Because of the length of guide wall required (from power intake to spillway), we did not consider using a spillway-release system as the sole method for downstream passage at Oxbow Dam.

4.2.7. Turbine Passage

Because the maximum operating head of 123 ft at Oxbow Dam is within the range of a Kaplan turbine, this dam is the likeliest choice for turbine passage. Additional factors such as existing turbine dimensions, speed, and flow rates would have to be studied to determine the feasibility of modifying or replacing the turbines.

4.2.8. Upper Reservoir Collection—Portable Floating Traps

Because velocities in reservoirs are conducive to migrating juveniles, and collection of fish would occur at the upstream project, an upper reservoir collection system is not recommended.

4.2.9. Upper Reservoir Collection—Fixed-Location In-River Traps

Oxbow Reservoir is relatively narrow compared with Brownlee Reservoir. Therefore, a fixed-location in-river trap is possible but still unlikely. This option requires the construction of a low-level dam across the river. Such a structure would be extremely expensive to build. Moreover, it would be very difficult to gain approval for placing a new, permanent structure on the Snake River. We anticipate that any such effort would face much opposition. Because other options are available, we do not recommend a fixed-location in-river trap.

4.2.10. Tributary Collection—Fixed-Location In-River Traps (Wolfe Traps)

The Wildhorse River is the only tributary entering Oxbow Reservoir considered to be suitable for anadromous fish production. Other possible sources of juveniles would be those that would be passed or released from Brownlee Dam. A Wolfe trap installation on the Wildhorse River could be part of an overall plan that would include transporting juveniles collected from Brownlee Reservoir past Oxbow Dam rather than releasing them into the Brownlee Dam tailrace.

4.2.11. Other Issues

Fish collection at the power intake requires either a large amount of tunneling to construct a discharge flume or the use of trucks to transport juveniles downstream. Passage systems placed in the penstock or in the vicinity of the surge tank provide a better opportunity for direct discharge of juveniles downstream of the powerhouse.

4.2.12. Recommended Alternatives

Of all the alternatives we studied, intake diversion screens appear to be the most feasible option for Oxbow Dam. A schematic layout for an intake diversion screen system is shown in Figure 29. However, the feasibility of the other alternatives, including turbine passage, is similar to that for intake diversion screens. We recommend that all of the alternatives be considered and studied further.

4.3. Hells Canyon Dam

Unlike the other two dams in the HCC, the Hells Canyon Dam resembles the other conventional dams located on the Snake and Columbia rivers. Flows that pass through both the powerhouse and spillway pass through the center of the river channel.

4.3.1. Forebay Collection and Bypass—Fish Attraction Barges (Gulpers)

A forebay collection system similar to that on the Baker River would be feasible at Hells Canyon Dam. The dam is approximately 1,000 ft wide and would require a barrier net across the full channel. Factors to consider with this option include maintaining the barrier net and both collecting and removing debris. It should be noted that average flows of the Baker River are approximately 10% of those of the Snake River at Hells Canyon.

4.3.2. Eicher Screens

Eicher screens could be placed in the penstocks, but they would be difficult to install. Also, it would be necessary to remove concrete to gain access to the penstocks. Any such removal must

be evaluated in terms of the overall structural integrity of the dam. The length of the Eicher screen would be approximately 90 ft, a length difficult to design and very expensive to construct.

4.3.3. Modular Inclined Screens

Using MIS units at Hells Canyon Dam is feasible, but their use would be challenging because the power intakes are 30 to 150 ft above the channel bottom. IPC would need to build a structural support for the MIS. That construction effort would be both difficult and costly.

4.3.4. Intake Diversion Screens

A typical intake diversion screen could be placed at the three power intakes on Hells Canyon Dam. The dam has both wheel gate and bulkhead gate slots, which might be used to install and deploy the intake diversion screens. The juveniles would be collected in a gallery, and a passage could be mined through the dam to a discharge flume.

Intake diversion screens have proven to be successful at other dams on the Columbia and Snake rivers. The feasibility of using such a system at Hells Canyon Dam would depend mainly on the existing intake geometry and on gate slot locations and configuration.

4.3.5. Surface Collection

Because of its layout, Hells Canyon Dam may be the best-suited project in the complex for a surface collection bypass system. The spillways are adjacent to the power intakes, so surface collection may provide the best attraction flow field at this location. The surface collection system could be mounted to the vertical walls of the dam, and the discharge could be passed through the dam, the future capped penstock (fourth penstock), or a modified spillway gate.

As previously mentioned, the effectiveness of a surface collection system is difficult to predict without extensive fish migration studies and would not be fully known until after construction.

4.3.6. Behavioral Guidance Structure and Spillway Releases

Hells Canyon Dam is equipped with three Tainter gates 43 ft wide and 50 ft high. These gates are located at a crest elevation of 1,638 ft. Two lower, radial gates are located at an elevation of 1,549 ft. With the fluctuation in forebay elevation ranging between 1,678 and 1,688 ft, the three upper Tainter gates could be equipped with top-spill structures, vertical notched gates, or a removable spillway weir for spillway release. A BGS could be placed in front of the power intakes to discourage fish from entering the turbines. However, because the spillways are located in the center of the channel, the BGS may not be needed. This system could be very efficient and cost effective. However, further spillway studies would be required.

4.3.7. Turbine Passage

Due to the high head associated with Hells Canyon Dam, turbine passage is not a feasible option.

4.3.8. Upper Reservoir Collection—Portable Floating Traps

Because most spawning areas are in the upper reaches of the reservoir (e.g., Indian Creek, Pine Creek, and the oxbow), an upper reservoir collection facility could be feasible for Hells Canyon Reservoir. This system could be located in the reservoir downstream of Pine Creek, depending on predation and the migratory travel patterns of the outmigrants.

4.3.9. Upper Reservoir Collection—Fixed-Location In-River Traps

Again, because most spawning areas are in the upper reaches of the reservoir, an upper reservoir collection facility could be installed for Hells Canyon Reservoir. We did not consider this option, however, because of the high cost and the relatively high confidence that juveniles can successfully pass Hells Canyon Reservoir.

4.3.10. Recommended Alternatives

Of the alternatives we reviewed, we consider spillway release, intake diversion screens, and MIS units to be the most feasible options for Hells Canyon Dam. We believe that these three options merit further consideration. Additional tests would be required to determine the survivability of releasing fish over a 220-ft-high spillway and the impacts of high levels of TDG. Schematic layouts for an intake diversion screen system and MIS alternatives are shown in Figures 5 and 6.

5. EVALUATION OF UPSTREAM FISH PASSAGE CONCEPTS

In this section, we apply the upstream passage concepts described in Section 3.2 to the three dams of the HCC. The dam type, location, height, and surrounding topography dictate which fish passage concepts are most feasible at each site.

5.1. Hells Canyon Dam

Hells Canyon Dam is located in a narrow section of the canyon with steep rock walls on both sides. The existing fish trapping facility is located approximately 500 ft downstream of the dam on the Oregon side of the river.

5.1.1. Fish Ladder

The construction of a fish ladder is a feasible option, but such construction would be difficult because of the heights and the extensive amount of rock excavation required. Most ladders on the Columbia and lower Snake rivers rise no more than 100 ft. If a ladder were constructed at Hells Canyon Dam, it would be the tallest one in North America, with an elevation gain of 221 ft.

For a fish ladder of this size to succeed, it is critical that the water temperature in the ladder and at the ladder entrance be maintained at an appropriate level because salmonids are sensitive to water temperature. Therefore, to avoid the problems encountered at PGE's high ladders (see Section 3.2.1 for details), careful attention must be given both to the selection of the water source for ladder operations and to heat transfer as water flows through the ladder. The water temperature at the ladder entrance must not be higher than that of the water flowing from the powerhouse.

We recommend a pool and weir-type ladder for Hells Canyon Dam because such ladders are widely used on the Snake and Columbia rivers and because of their ability to account for fluctuating forebay elevations. Denil ladders are limited in size and, unlike a pool and weir or a vertical-slot fishway, they cannot readily be scaled up in size to accommodate larger flows. If a Denil fishway were to be used, a series of parallel fishways would have to be installed to accommodate a large number of fish. Additional resting pools would also be required, increasing construction costs.

Before construction of Hells Canyon Dam, a fish ladder study was conducted, and a preliminary design called for a ladder on the east bank of the river. This design used a bottom slope of 16 to 1 and routed the ladder from the base of the dam, downstream into the Deep Creek ravine, and then back upstream to the top of the dam. Another option would be to use the standard 10-to-1 slope but provide intermittent resting pools. This configuration could use a fish ladder with three segments, rising approximately 74 ft each, with 100-ft-long resting pools between the segments. The estimated total length would be approximately 2,420 ft. The actual length might be longer to account for specific site conditions.

A fish ladder on the west bank may also be feasible, but it would be more difficult and expensive to construct because of existing site feature limitations.

5.1.2. Fish Lock

The most suitable location for a fish lock at Hells Canyon Dam is adjacent to the spillway on the Idaho side of the dam. The powerhouse and power transmission lines located on the Oregon side would need to be rerouted, or they would interfere with a fish lock placed on that side of the dam. An entrance to a fish lock could be placed at the bottom and to the right of the spillway, but this placement would require excavation and widening of the channel.

The height of the dam could complicate the installation of a fish ladder. The high head pressure (13,800 pounds/ft²) that the facility would have to withstand may make this alternative difficult to design and costly to construct. Also, a fish lock at Hells Canyon Dam would operate slowly because of the time required to fill and empty the lock column.

5.1.3. Fish Lift

A fish lift could be constructed on Hells Canyon Dam at the same location described for the fish lock alternative. A pipeline delivering water from the forebay would supply attraction flow. The

fish would be collected in the entrance area and guided to a hopper. This hopper would then be lifted up through a vertical tower to a flume, which would discharge into the forebay.

An additional option would be to construct a cable tram system to transport fish from the collection area to the forebay of the dam.

5.1.4. Trap and Haul

Using the existing trapping facility may prove to be the optimum alternative in the short term. This facility could be enlarged to increase capacity, and the entrance could be modified to attract other targeted species if a reintroduction program were established.

5.1.5. Recommended Alternatives

Of the four alternatives discussed, the trap and haul scored highest and appears to be the best-suited and most cost-effective option for Hells Canyon Dam. The existing structure has proven to be effective in the past and could be expanded to handle larger numbers of fish. A fish ladder or fish lift could be considered as a potential option that may be feasible and provide a more passive passage system (i.e. require less handling of the fish).

Figure 30 shows the approximate location of the existing trap-and-haul facility at Hells Canyon Dam. Figure 31 shows a possible ladder routing concept at Hells Canyon.

5.2. Oxbow Dam

5.2.1. Fish Ladder

Of the three dams in the HCC, Oxbow Dam is the most conducive to the use of a fish ladder. The dam has a tailrace-to-forebay elevation difference of 123 ft. This difference in elevation requires a ladder at least 1,230 ft long. Ideally, the ladder entrance would be located where there is sufficient flow in the river, (i.e., downstream of the powerhouse discharge). However, this placement would be challenging because a ladder located in this area would need to reach the forebay on the other side of the oxbow. The most direct route for the ladder would be a tunnel mined through the hill. The more feasible option would be to place a fish ladder at the dam itself. The ladder would begin near the abandoned fish trapping facility at the base of the dam and traverse back and forth across the face of the dam to an exit adjacent to the Oregon spillway gates. Sufficient water would have to be spilled or released to ensure that the fish would travel up the stretch of river between the powerhouse tailrace and the base of the dam. A small powerhouse could be constructed at this location to generate power and dissipate the energy required for the attraction flow and the existing 100 cfs bypass flow.

5.2.2. Fish Lock

A Borland-type fish lock could be placed at Oxbow Dam. A small powerhouse could be incorporated into the design to generate power and dissipate the energy required for the attraction flow, plus the existing 100 cfs bypass flow. The system would be automated, and cycle times would depend on the number of fish passing.

5.2.3. Fish Lift

A fish lift could be placed at the powerhouse. However, we did not pursue this option because of the complications with transporting fish over the neck of the oxbow and the required manpower. A fish lift could also be placed at the base of the dam, but because a fish ladder is more feasible, we did not pursue this option.

5.2.4. Trap and Haul

A trap-and-haul station could be placed either at the dam or just downstream of the powerhouse tailrace. An anadromous fish trap was built during construction of the dam and powerhouse. The design for the trap-and-haul station could be similar to the existing fish trap below Hells Canyon Dam.

5.2.5. Recommended Alternatives

Of the three alternatives discussed in our analysis, the trap and haul and the fish ladder were equally effective. These two alternatives should be considered for future passage options.

Figure 32 illustrates a possible location for a trap-and-haul facility near the powerhouse and its position relative to the dam. Figure 33 shows a possible ladder route at the dam.

5.3. Brownlee Dam

5.3.1. Fish Ladder

Because of the large difference in elevation between the top of the dam and the tailrace (290 ft at normal operating levels) and the large range in forebay fluctuation (101 ft), it would be difficult to design and construct a traditional fish ladder at Brownlee Dam. A possible option would be to construct a fish ladder from the tailrace to the top of the dam with a pumped water supply. This option would require a ladder length of approximately 3,000 ft and the incorporation of at least two resting pools. A control structure would be located at the end of this ladder to direct migrating adults into a discharge flume running to the forebay. The water supply would have to be pumped up to this control structure, which would supply both the ladder and the forebay side discharge flume.

5.3.2. Fish Lock

Because of complications with the dam's height and the large fluctuations in forebay elevations, we do not consider a fish lock to be a feasible option for Brownlee Dam.

5.3.3. Fish Lift

A fish lift could be used at Brownlee Dam. In fact, because of the large fluctuations in forebay elevations, a fish lift may be better suited to the site, in conjunction with a trapping facility. Fish could be trapped and placed either into a cable tram type system or onto an inclined lift on rails traveling up the dam.

5.3.4. Trap and Haul

A trap-and-haul system could be constructed at Brownlee Dam, similar to the facility in place at Hells Canyon Dam. The trapping facility could be placed in the area at the base of the dam near the powerhouse tailrace. Further studies are necessary to determine migration patterns so the trapping facility can be placed in the optimum location. Hauling could be done either by truck or by using one of the lift options described in this chapter.

5.3.5. Recommended Alternatives

Of the alternatives discussed, trap and haul appears to be the most suitable for Brownlee Dam. Figure 34 shows a possible location for a trap-and-haul facility. A fish lift facility might also originate at this location and proceed up the dam. Figure 35 shows a conceptual placement of a fish ladder and discharge plume.

6. COST ESTIMATES BASED ON CONCEPTUAL DESIGNS

6.1. Construction Cost Estimates

Our task in this chapter was to provide conceptual designs for fish passage at the HCC dams. Consequently, the designs lack the detail necessary to prepare precise estimates of construction costs. Items such as exact material quantities and labor expenses can be calculated only when necessary studies have been completed, options have been selected, and detailed construction plans have been developed. For the purposes of this chapter, we prepared broad construction cost estimates using estimated unit costs we derived from the actual construction costs of similar facilities. We supplemented that information with input from vendors about large components, with standard industry cost guides, and with engineering judgment.

Because fully developed production systems of the magnitude required for the HCC do not yet exist and because these concepts are not fully developed, we added a construction contingency of

50% to all cost estimates. We did not include other costs such as planning and engineering, project management, and value-engineering studies. The costs presented are current-year costs and would need to be adjusted to the anticipated time of construction.

Also, because some of the concepts presented in this chapter are, as yet, untested, we must emphasize that a significant amount of hydraulic modeling and prototyping would be required before any of the design options can be fully implemented.

6.2. Operation and Maintenance Costs

Developing annual O&M cost estimates is similarly constrained by the absence of detail, an absence that is typical at the concept design stage. For this reason, we estimated O&M costs based on percentages of construction costs (excluding planning, design, construction management, and the contractor's mobilization and overhead and profit [O&P] costs). Due to their relatively higher maintenance requirements, O&M costs for mechanical and electrical systems such as gates, screen cleaners, cranes, hoisting equipment, and controls were assigned an annual cost equal to 10% of their construction cost. These costs include the annualized cost of periodic replacement or rehabilitation of components.

For concepts that are largely structural elements, we assigned an annual O&M cost equal to 5% of their construction cost. The estimates typically reflect periodic inspection, refurbishing, and other maintenance activities.

6.3. Estimate Summaries—Downstream Passage

6.3.1. *Brownlee Dam*

We prepared estimates for the following three downstream passage options at Brownlee dam and reservoir (Table 1):

- Upstream reservoir collection system using floating gulpers
- Forebay collection using floating gulpers in the intake channel
- Spill release using a BGS or a guide wall

6.3.1.1. Upstream Reservoir Collection

The first option we estimated is the upper reservoir collection system using floating gulpers. We assumed two collection points, one on the upper reach of Brownlee Reservoir (using three different gulpers) and the other on the Powder River arm (using one gulper). Using information from the Baker Dam gulper system, we estimated the construction price of each gulper to be \$7 million. A delivery system to take juveniles from the gulpers to a holding facility that is accessible by truck could cost about \$2 million. A fleet of three trucks to transport the juveniles downstream would cost approximately \$600,000. Therefore, the total estimated cost for this alternative would be \$30.6 million. The O&M costs for this system would be high because of the

operation of barges, pumps, and the transportation system. Therefore, we assigned a cost factor of 10%.

6.3.1.2. Forebay Collection

The second alternative we estimated is the forebay collection system using floating gulpers in the intake channel. Because of the confined channel, we planned for two gulpers at a cost of \$14 million. A cost of \$2 million was set aside for a retrieval system, which might use a crane to deliver juveniles from the gulpers to a holding area located near the top of dam. Because this alternative has only one collection area, we assumed that two trucks would be sufficient for the operation. The total construction cost was assumed to be \$16.4 million with a 10% O&M cost. This collection facility option assumes a full draft of Brownlee Reservoir. Therefore, the lost revenue from power generation would be substantial. We did not include the amount of that lost revenue in our estimate of this option.

6.3.1.3. Spill Release

The third alternative we estimated was spill release with a BGS or guide wall. Using the cost of a similar guide wall estimated for Lower Granite Dam (1,400 ft at \$15 million), we estimated the 2,000-ft guide wall itself at \$22 million. We added \$4 million for a bulkhead structure and any modifications to the spillway (i.e., flip lip) for a total construction cost of \$26 million. O&M costs were assumed at a rate of 5%, which does not account for lost power generation revenue that would be associated with the release flows.

6.3.2. Oxbow Dam

We selected the following two downstream passage options for Oxbow Dam (Table 1):

- Diversion screens
- Turbine passage

6.3.2.1. Diversion Screens

The first option we focused on was the diversion screens. The attraction flow and juveniles would be routed through a pipe or flume to a collection facility located on the edge of the intake channel. Fish then would be loaded into trucks and released at either the tailrace or another downstream area.

For the cost opinion, we assumed that two diversion screens (35 ft x 40 ft) with vertical barrier screens would be needed. However, we did not develop a specific screening design for this report chapter. We based our estimates of screen size on the available structural opening sizes. We estimated screen costs at \$4.2 million each and added an allowance of \$2.0 million for structural modifications at the intake and \$1.0 million for loading and holding facilities. Approximately \$0.5 million was designated for release facilities, and \$0.4 million was assigned for two transport trucks. Therefore, the total cost estimate is \$12.3 million. Because the screens are so large, we assigned an O&M rate of 10% of the construction cost.

6.3.2.2. Turbine Passage

We did not prepare a cost estimate for turbine passage at Oxbow Dam. Further studies are necessary before we can prepare an accurate estimate.

6.3.3. Hells Canyon Dam

For Hells Canyon Dam we prepared estimates for the following two passage options (Table 1):

- Diversion screens
- Spillway release

6.3.3.1. Diversion Screens

The diversion screen option would use three inclined diversion screens (25 ft x 40 ft) with VBSs. We did not develop a specific screening design for this report. Screen size estimates are based on the available structural opening sizes. Existing trash racks would require modification or replacement. A collection gallery could be mined in the dam with a discharge pipe routed for release into the tailrace. We estimated screen costs for this alternative at \$3.0 million each (\$9 million total). We added an allowance of \$3.0 million for project structural modifications. The gallery and bypass piping costs were estimated to be \$6.0 million, for a total cost of \$18.0 million. We assumed the annual O&M cost for this option to be 10%.

6.3.3.2. Spillway Release

The spillway-release system would use a bulkhead structure or spillway gate modifications, as well as the installation of flip lips onto the spillway. One or all three of the upper spillways could be modified for spillway release, but we used only one spillway for this estimate. Assuming no BGS was used in this option, we assigned a cost of \$5.0 million for the conceptual estimate. We estimated O&M costs at 5%, but this estimate does not include the revenues lost from the added spill.

6.4. Estimate Summaries—Upstream Passage

6.4.1. Hells Canyon Dam

We estimated the following two upstream passage alternatives for Hells Canyon (Table 2):

- Trap-and-haul facility
- Fish ladder

6.4.1.1. Trap-and-Haul Facility

Because there is an existing trap-and-haul facility on site, we estimated the costs to upgrade it. Upgrades could include modifications to increase the attraction flow and the holding capacity for

returning adults. Similar upgrades were estimated at the barrier dam located just downstream of Mayfield Dam on the Cowlitz River. The preliminary costs of the upgrades for that site were estimated at \$2.8 million with an annual O&M cost of \$135,000. For comparative purposes, we used this same construction cost for our preliminary estimate, with a 10% O&M cost. Further study is required to determine which modifications would be warranted.

6.4.1.2. Fish Ladder

The second alternative estimated was construction of a fish ladder on the Idaho side of the river. After reviewing the costs of some smaller fish ladders that have been constructed in the area, we developed a unit cost range between \$50,000 and \$75,000 per foot of rise. This cost includes the entrance and exit facilities. However, because of the large amount of rock excavation required for the construction of the ladder, we used the upper range of \$75,000 per foot of rise in our estimate of the Hells Canyon ladder. The 221-ft ladder results in a cost of approximately \$16.6 million. This cost falls between the \$9.6 and \$22.4 million estimated for the two similar ladders proposed at Mayfield and Mossyrock dams (Harza Northwest 1999). The Mossyrock ladder had a much more complex exit structure, which accounts for its higher cost. We based O&M costs on an estimate of 5% of construction costs.

6.4.2. Oxbow Dam

As with the Hells Canyon Dam, we estimated two alternatives for upstream passage at Oxbow Dam (Table 2):

- Trap-and-haul facility
- Fish ladder

6.4.2.1. Trap-and-Haul Facility

The first option we estimated was a trap-and-haul facility. At one time, a trap-and-haul facility was operated adjacent to the dam's spillway. For this alternative, we assumed that a new facility would be constructed in the same location. If a trap-and-haul facility were similar to that proposed for Mossyrock Dam, the estimated construction cost for this alternative is \$4.5 million. We assumed a 10% rate for the O&M costs.

6.4.2.2. Fish Ladder

The second alternative we estimated was the construction of a 123-ft fish ladder at the dam itself. Using a unit cost of \$60,000 per foot of rise, we estimated a construction cost of \$7.4 million. We used a 5% rate for the O&M costs.

6.4.3. Brownlee Dam

We consider the following two options to be viable for upstream passage at Brownlee Dam:

- Trap-and-haul facility
- Fish ladder

6.4.3.1. Trap-and-Haul Facility

The option that shows the most promise at Brownlee Dam is a trap-and-haul facility (Table 2). This facility would be located at the toe of the dam at an approximate elevation of 1,850 ft. The location would require a 50-ft fish ladder to gain access from the normal tailwater elevation. For this reason, we increased the \$4.5 million estimated cost for the proposed trap-and-haul facility proposed at Oxbow Dam by an additional \$1.5 million to account for the larger fish ladder that would be required. This latter figure is based on 30 ft at a cost of \$50,000 per foot. We assumed a 10% rate for the O&M costs.

6.4.3.2. Fish Ladder

An alternative option is a fish ladder. This ladder would be unique in that it would rise 290 ft to a control structure at the top of the dam where the fish would be directed into a discharge flume routed to the forebay. To determine a conceptual cost estimate, we assumed a unit cost of \$75,000 per foot of rise and added an additional \$3.0 million for the discharge flume and exit control structure. We also added a cost of \$3.0 million for a pumping station to bring the total cost to \$27.8 million. Because of the complexity of the ladder and its water supply, we assumed a 10% O&M cost.

7. LITERATURE CITED

- Cada, B., and B. H. Rinehart. 2000. Hydropower R & D: recent advances in turbine passage technology. 36 p. DOE/ID-10753. Prepared for: U.S. Department of Energy, Idaho Operations Office, Idaho Falls, ID.
- Clay, C. H. 1995. Design of fishways and other fish facilities. 2nd edition. Lewis publishers (CRC Press), Boca Raton, FL. 248 p.
- Dearien, J. A., M. L. Howell, J. S. Irving, B. N. Rinehart, and G. C. Thurston. 1993. Proposal for a flexible in-reservoir salmon passage. Department of Energy, Idaho National Engineering Laboratory, Idaho Falls, ID. 43 p. Prepared for: U.S. Army Corps of Engineers.
- Durkin, J. T., D. L. Park, and R. F. Raleigh. 1968. Distribution and movement of juvenile salmon in Brownlee Reservoir 1962–65. Fishery Bulletin 68:219–243.
- Francfort, J. E., G. F. Cada, D. D. Dauble, R. T. Hunt, D. W. Jones, B. N. Rinehart, G. L. Sommers, and R. J. Costello. 1994. Environmental mitigation at hydroelectric projects. Volume II, Benefits and costs of fish passage and protection. Contract DE-AC07-76ID01570. Prepared for: U.S. Department of Energy, Idaho Operations Office, Idaho Falls, ID.
- Grande, R. 1995. Fishway solutions in connection with hydro-electric plants and regulated rivers in Norway. Proceedings of the International Symposium on Fishways, Gifu, Japan.

- Harza Northwest, Inc. 1999. Cowlitz River Hydroelectric Project—FERC No. 2016, 90% draft fish passage study. Tacoma Power, Tacoma WA. 61 p.
- Johnson, L., C. Noyes, and R. McLure. 1984. Hydroacoustic evaluation of the efficiencies of the ice and trash sluiceway and spillway at Ice Harbor Dam for passing downstream migrating juvenile salmon and steelhead, 1983. BioSonics. February 3. Contract No. DACW68-82-C-0066. Sponsored by: U.S. Army Corps of Engineers, Walla Walla District.
- Kamula, R., and A. Laine, editors. 1998. Proceedings of the Nordic Conference on Fish Passage; Oslo, Norway. University of Oulu, Finland.
- Magne, R. A. 1987. Hydroacoustic monitoring of downstream migrant juvenile salmon at Bonneville Dam. U.S. Army Corps of Engineers, Walla Walla, WA.
- Monan, G. E., R. J. McConnell, J. R. Pugh, and J. R. Smith. 1969. Distribution of debris and downstream-migrating salmon in the Snake River above Brownlee Reservoir. Transactions of the American Fisheries Society 98:239–244.
- Normandeau Associates. 1996a. Fish survival in passage through the spillway and sluiceway at Wanapum Dam on the Columbia River, Washington. 42 p. Prepared for: Grant County Public Utility District No. 2, Euphrata, WA.
- Normandeau Associates. 1996b. Fish survival investigation relative to turbine rehabilitation at Wanapum Dam, Columbia River, Washington. 63 p. Prepared for: Grant County Public Utility District No. 2, Euphrata, WA.
- Odeh, M., editor. 1999a. Innovations in fish passage technology. American Fisheries Society, Bethesda, MD. 212 p.
- Odeh, M. 1999b. A summary of environmentally friendly turbine design concepts. Contract DE-AI07-99ID13741. U.S. Department of Energy, Idaho Operations Office, Idaho Falls, ID. 37 p. Prepared for: U.S. Department of Energy, Idaho Operations Office, Advanced Hydropower Turbine System Program.
- Pavlov, D. S. 1989. Structures assisting the migrations of non-salmonid fish: USSR. Food and Agriculture Organizations of the United Nations, Rome. FAO Fisheries Technical Paper No. 308. 97 p.
- Raleigh, R. F., and W. J. Ebel. 1968. Effects of Brownlee Reservoir on migrations of anadromous salmonids. In: Reservoir fishery resources symposium; Athens, GA. p. 415–443.
- Steig, T., and W. R. Johnson. 1986. Hydroacoustic assessment of downstream migrating salmonids at the Dalles Dam in spring and summer of 1985. Contract No. DE-AC79-85. Bonneville Power Administration, Portland, OR. Funded by: U.S. Department of Energy, Bonneville Power Administration, Fish and Wildlife Division.

- Stone & Webster Engineering Corporation. 1994. Fish protection/passage technologies evaluated by EPRI and guidelines for their application. Prepared for: Electric Power Research Institute (EPRI).
- Sverdrup Corporation. 1996. Proposal to provide environmental and engineering services, downstream fish passage at Round Butte Dam. Portland General Electric, Portland, OR.
- Sverdrup Corporation, ENSR, Lund Engineering Inc., and The Glostén Associates, Inc. 2000. Lower Granite lock and dam surface bypass and collection removable spillway weir pre-engineering report. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA. Contract No. DACW68-99-D-0003. 53 p.
- Taft, E. P., F. C. Winchell, S. V. Amaral, T. C. Cook, A. W. Plizga, E. M. Palolini, and C. W. Sullivan. 1997. Field evaluations of the new modular inclined fish diversion screen. Proceedings of the International Conference on Hydropower 1:665–671.
- USACE (U.S. Army Corps of Engineers). 1990. Fisheries handbook of engineering requirements and biological criteria, 1991. Northern Pacific Division, Portland, OR.
- USACE. 1994. Columbia River salmon mitigation analysis system configuration study—phase 1. Technical Appendix D, Upstream collection and conveyance Snake and Columbia Rivers. USACE, Walla Walla, WA. 328 p.
- Voith Hydro. 1997. Physical and hydraulic characteristics of all hydroelectric dams equipped with propeller/Kaplan type turbines for which survival data are available. Voith Hydro, Inc., York, PA.
- Wayne, W. W., Jr. 1981. Fish handling facilities for Baker River Project. Stone & Webster Engineering Corporation. Journal of the Power Division Proceedings of the American Society of Civil Engineers.

This page left blank intentionally.

Table 1. Summary of conceptual cost estimates of recommended downstream passage options for HCC reservoirs and dams.

Project and Passage Options	Cost Opinion (in Millions)	Contingencies (%)	Annual O&M (%)	Final Cost (in millions)	
				Capital	Annual O&M
<i>Brownlee Reservoir</i>					
Upper Reservoir Collection	\$30.6	50	10	\$45.9	\$4.6
Forebay Collection ^a	\$16.4	50	10	\$24.6	\$2.5
Spillway—BGS	\$26.0	50	5	\$39.0	\$2.0
<i>Oxbow Reservoir</i>					
Diversion Screens	\$12.3	50	10	\$18.5	\$1.8
“Fish-Friendly” Turbine Passage	No cost estimate			No cost estimate	
<i>Hells Canyon Reservoir</i>					
Diversion Screens	\$18	50	10	\$27	\$2.7
Spillway Release	\$5	50	5	\$7.5	\$0.4

^a Assumes full draft of Brownlee Reservoir; lost revenue from reduced power generation is not included in cost estimate.

Table 2. Summary of conceptual cost estimates of recommended upstream passage options for HCC reservoirs and dams.

Project and Passage Options	Cost Opinion (in millions)	Contingencies (%)	Annual O&M (%)	Final Cost (in millions)	
				Capital	Annual O&M
<i>Brownlee Reservoir</i>					
Trap and Transport	\$6	50	10	\$9	\$0.9
Fish Ladder	\$27.8	50	10	\$41.7	\$4.2
<i>Oxbow Reservoir</i>					
Trap and Transport	\$4.5	50	10	\$6.8	\$0.7
Fish Ladder	\$7.4	50	5	\$11.1	\$0.6
<i>Hells Canyon Reservoir</i>					
Trap and Transport	\$2.8	50	10	\$4.2	\$0.4
Fish Ladder	\$16.6	50	5	\$24.9	\$1.2

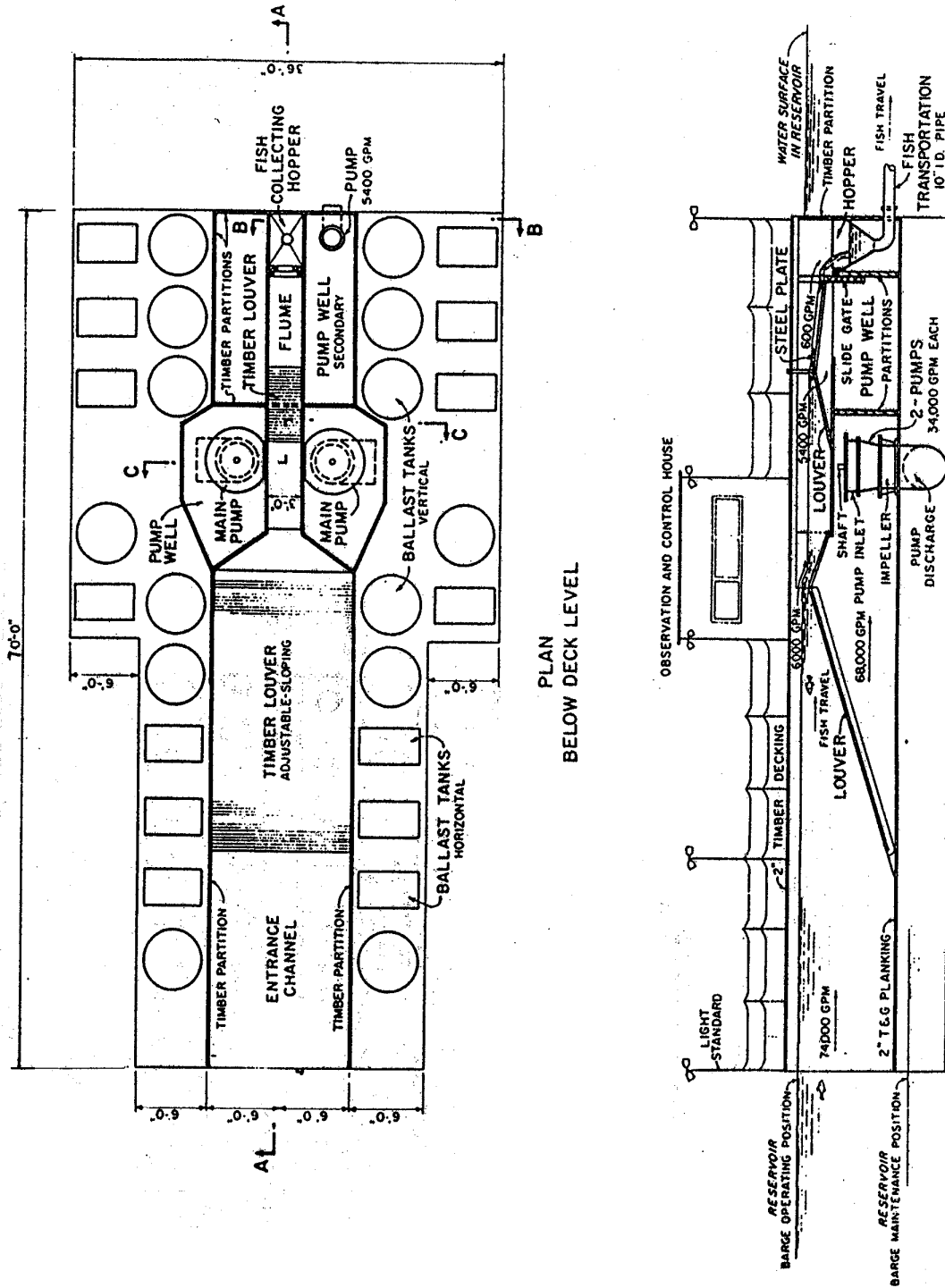


Figure 1. Plan and section views of a fish attraction barge (gulper).

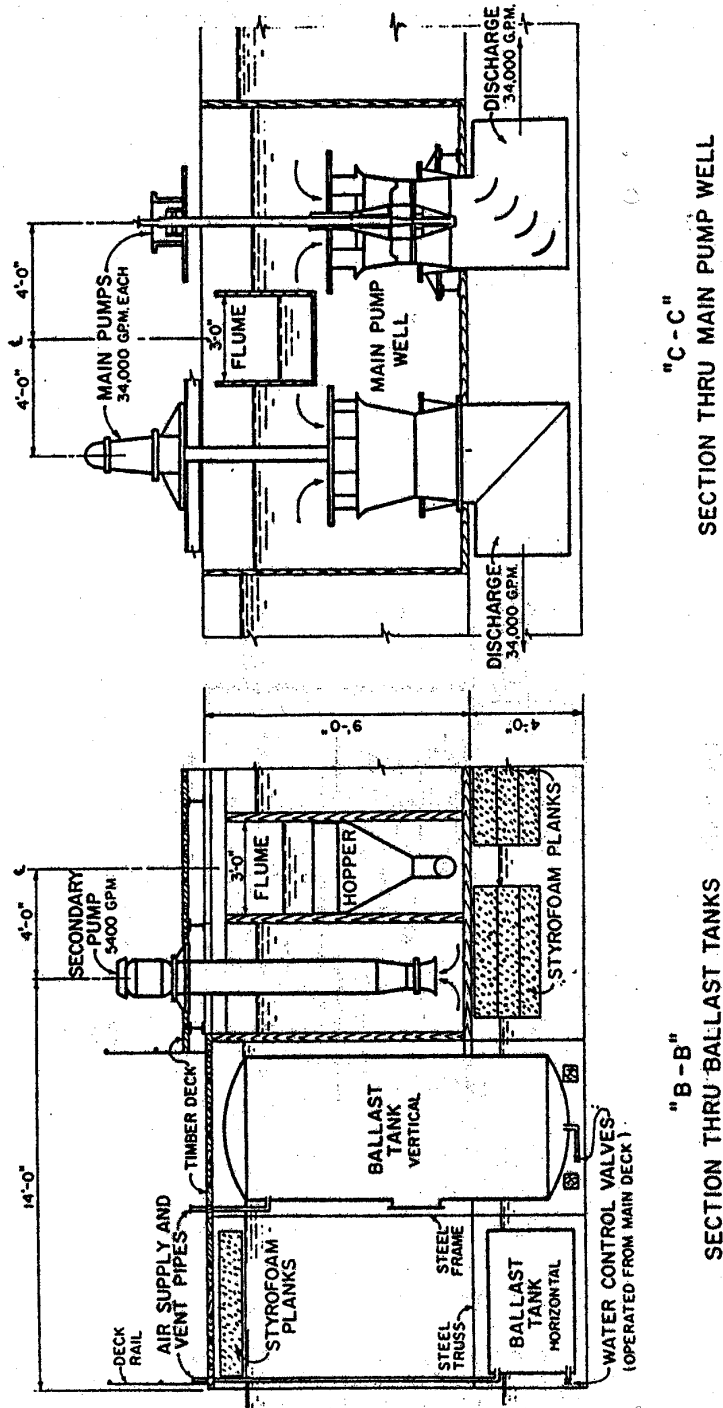


Figure 2. Typical sections of fish attraction barge (gulper).

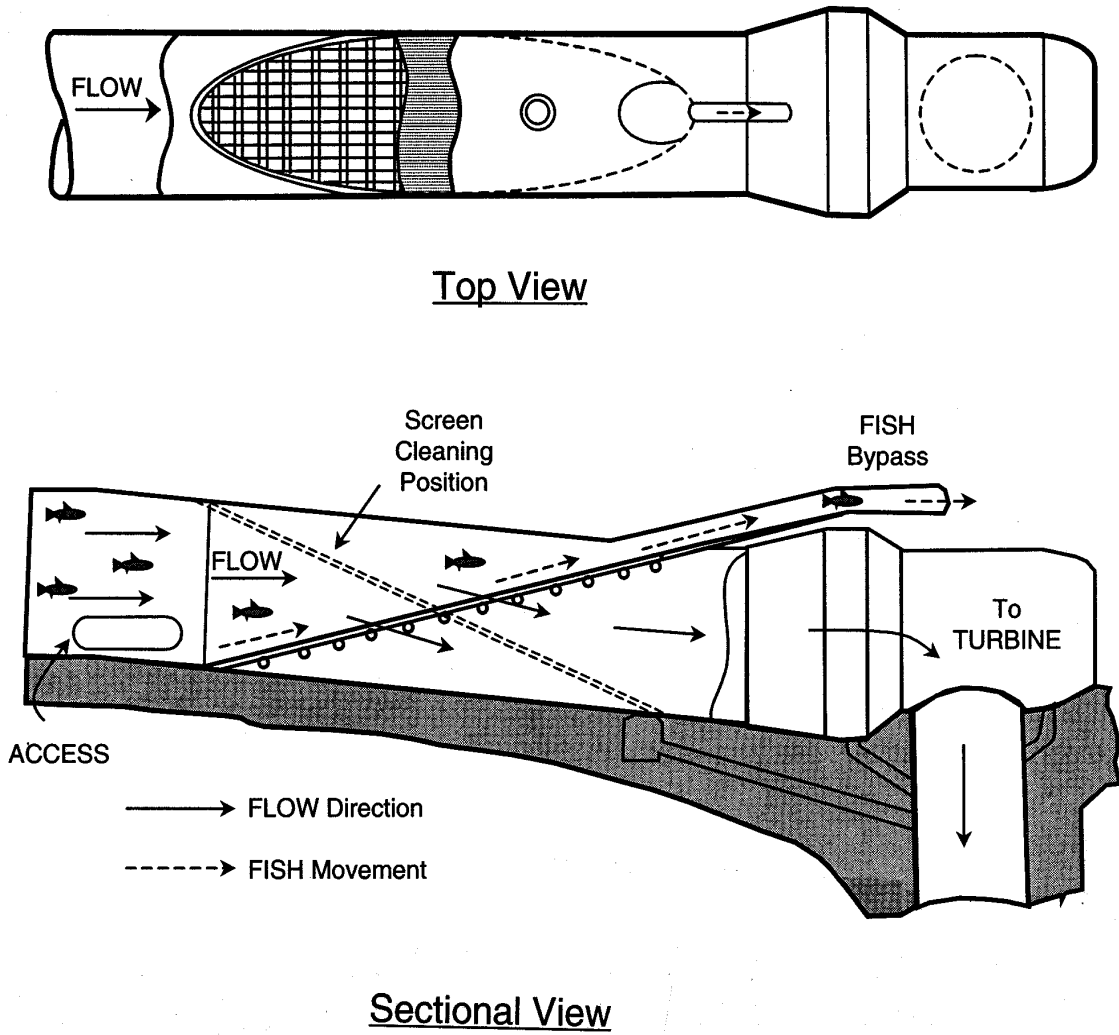


Figure 3. Top and section views of an Eicher screen.

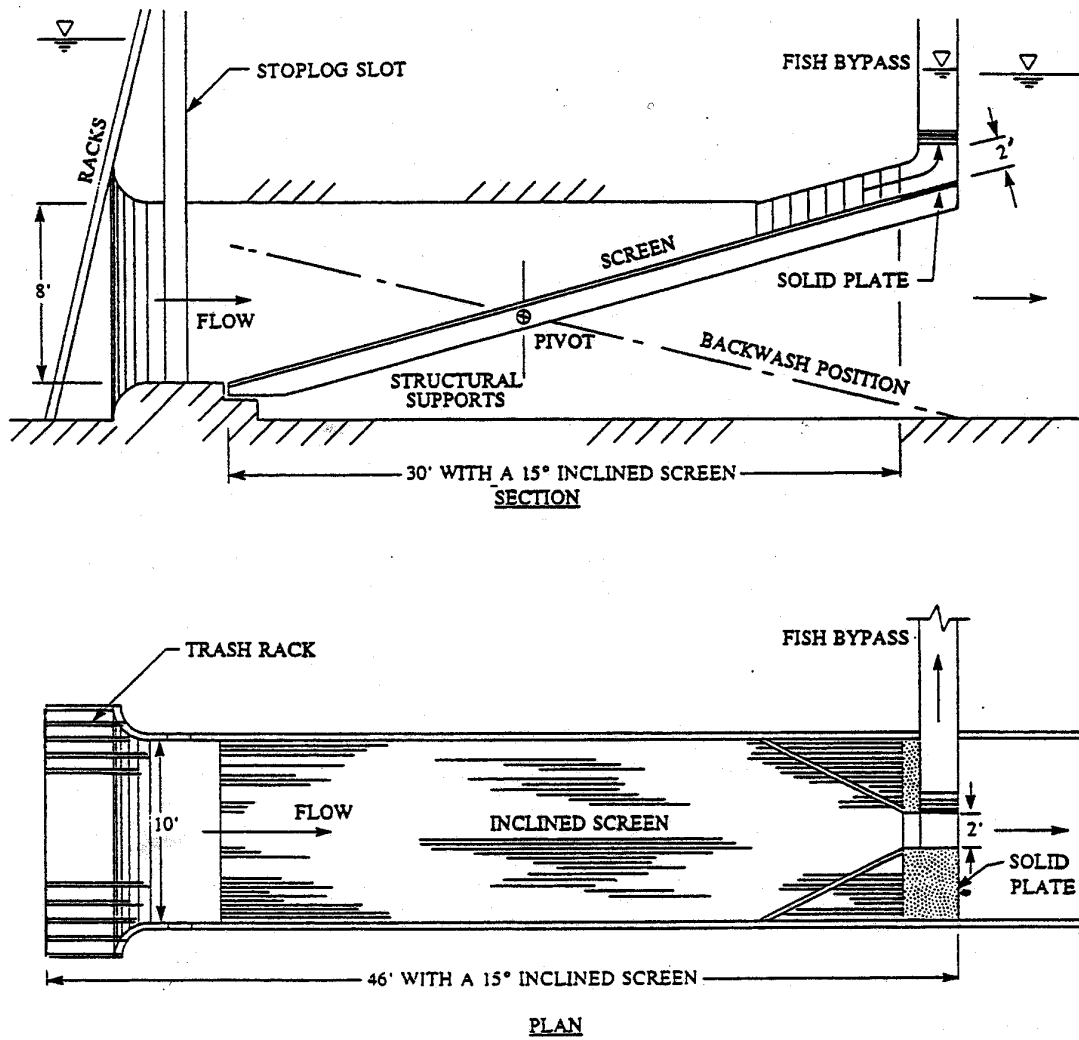


Figure 4. Section and plan views of a modular inclined screen (MIS).

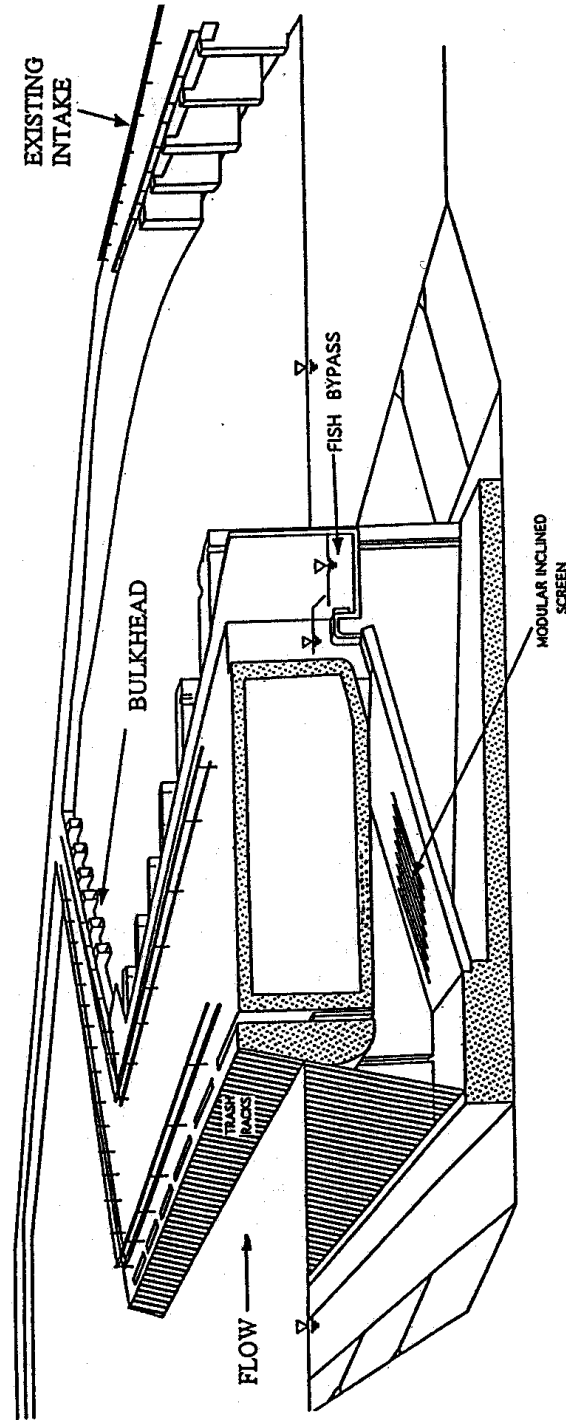


Figure 5. Multiple unit concept of a modular inclined screen (MIS).

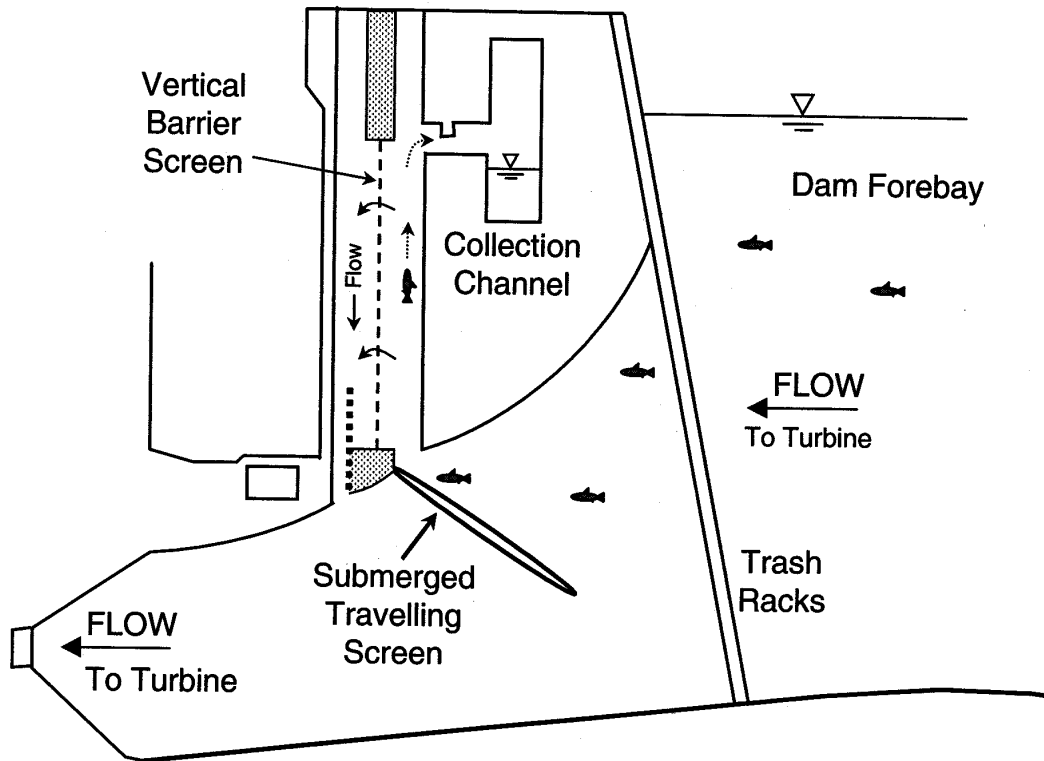


Figure 6. Diagram of an intake diversion screen.

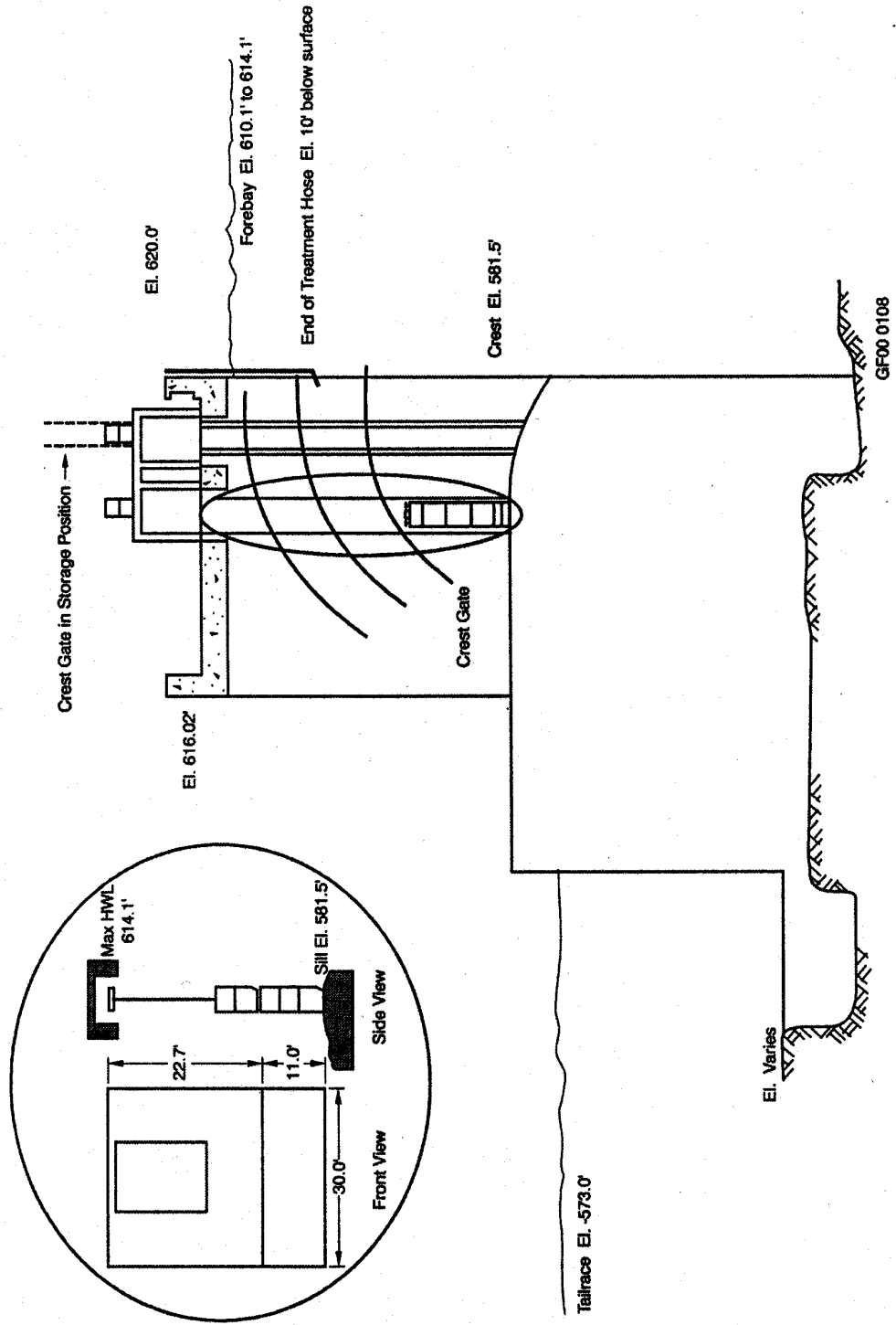


Figure 7. Diagram of a notched spill gate.

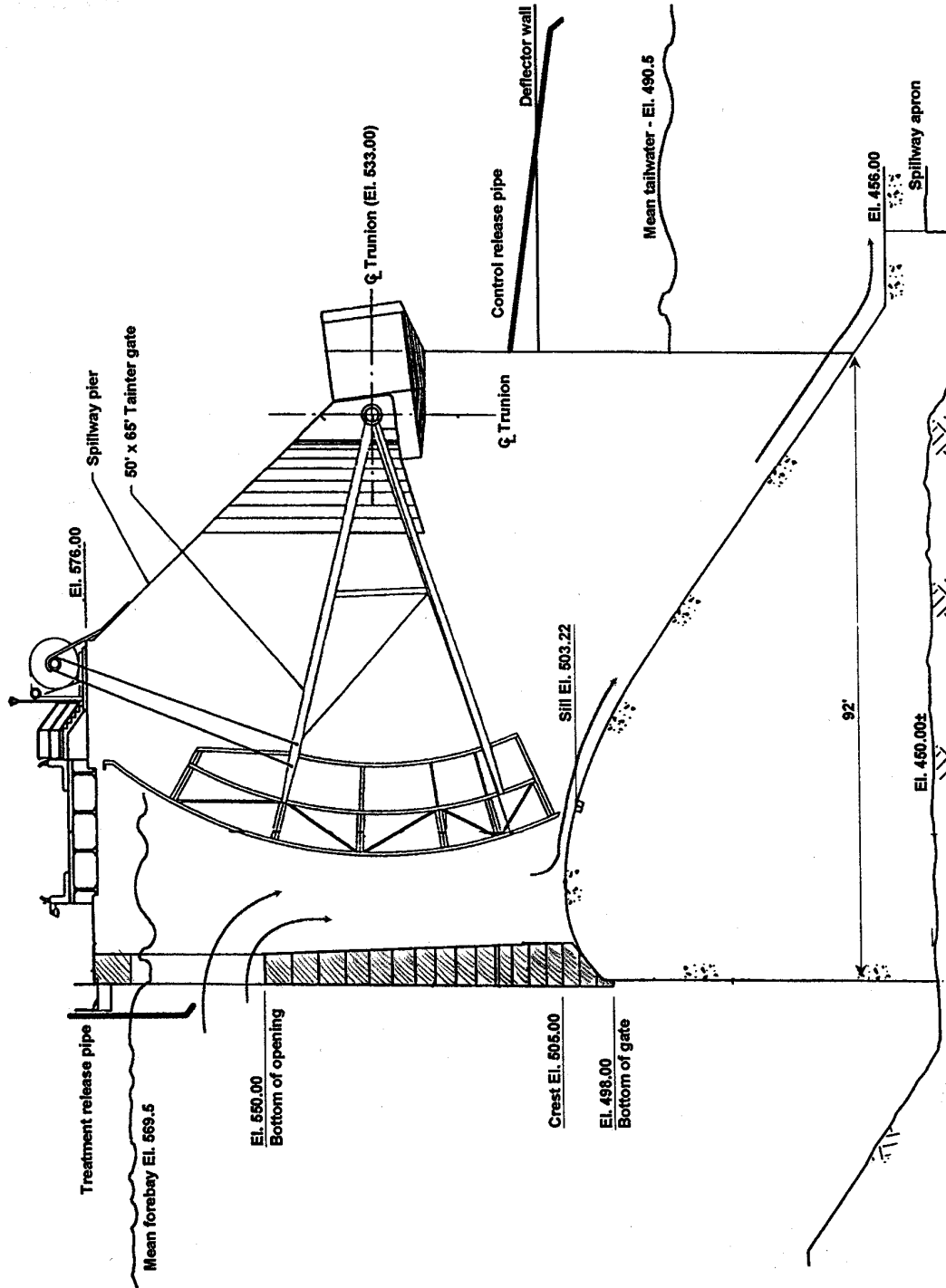


Figure 8. Diagram of a top-spill overflow weir.

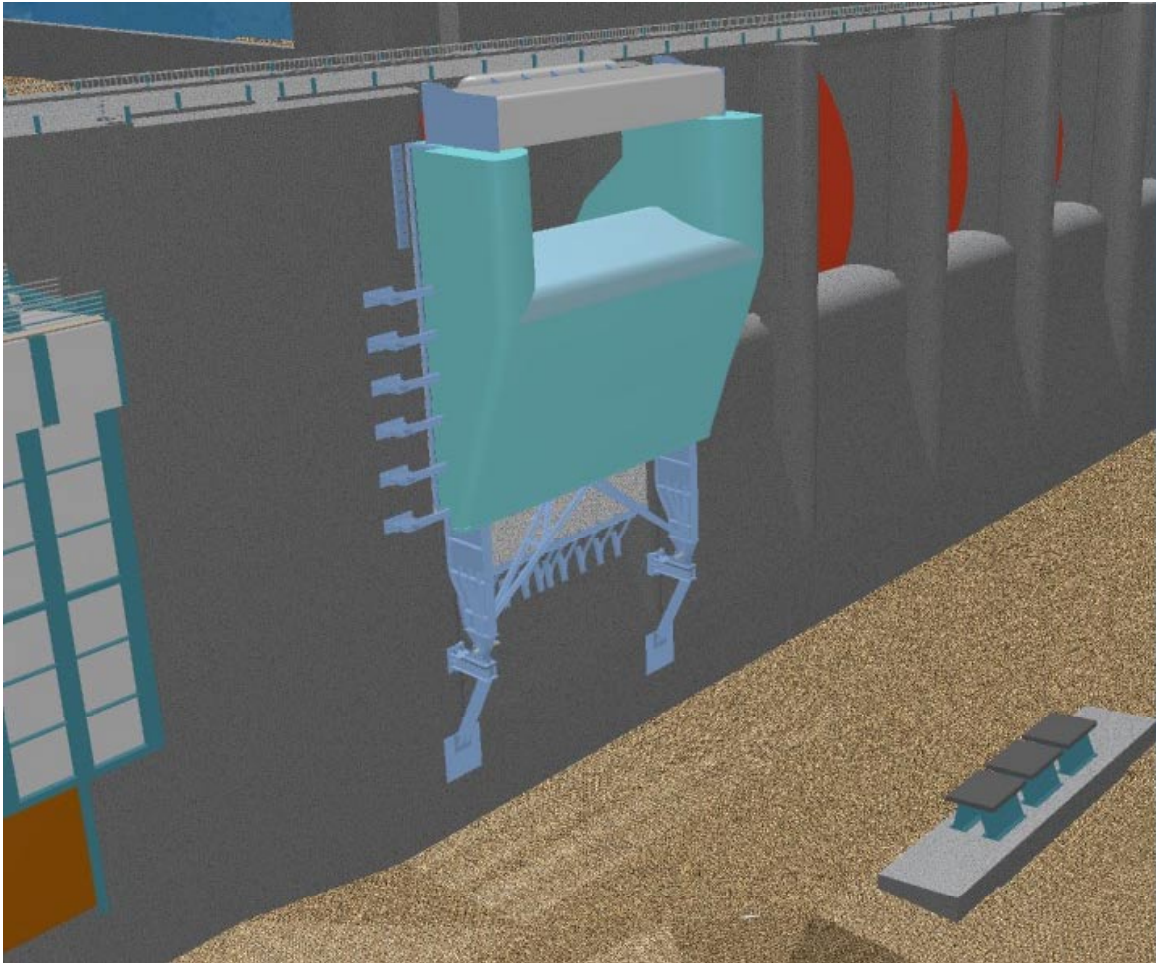


Figure 9. Illustration of a removable spillway weir (RSW).

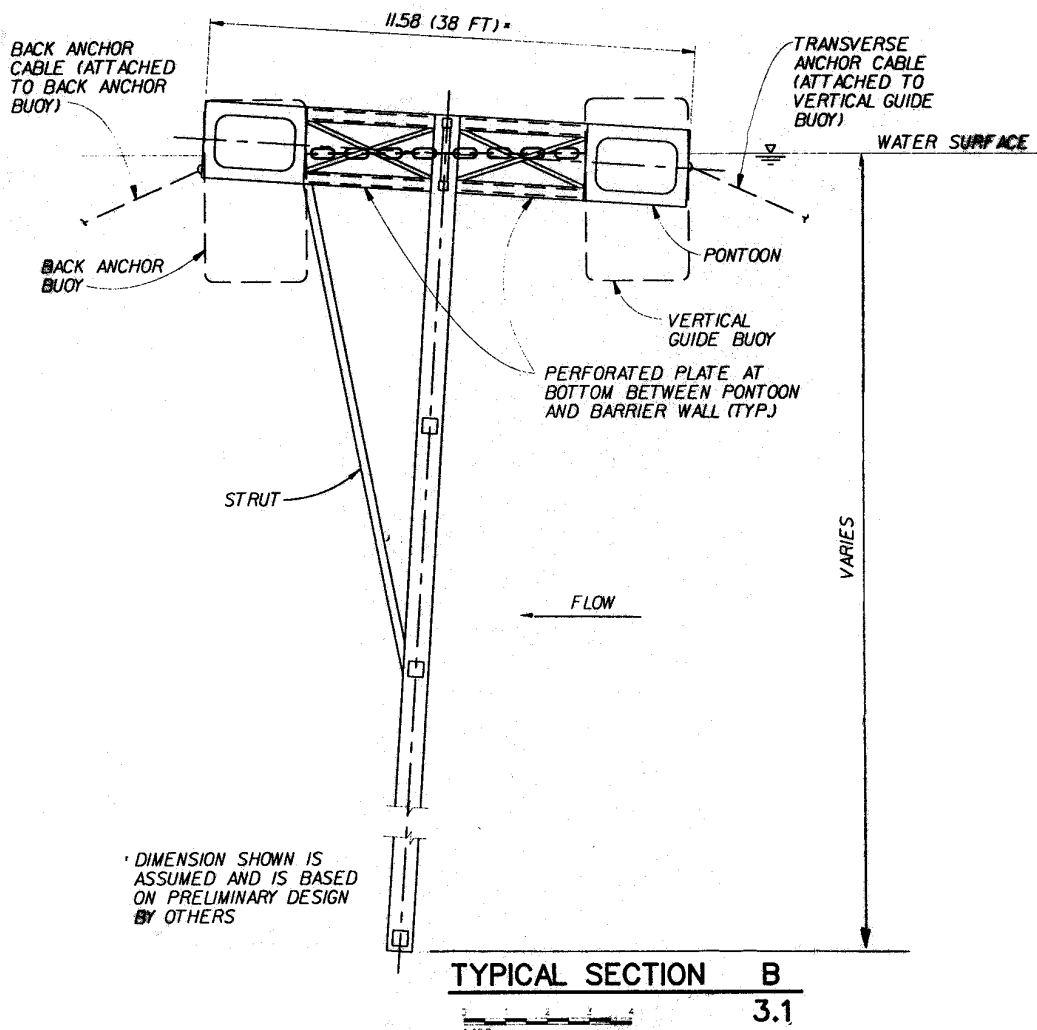


Figure 10. Diagram of a behavioral guidance structure (BGS).

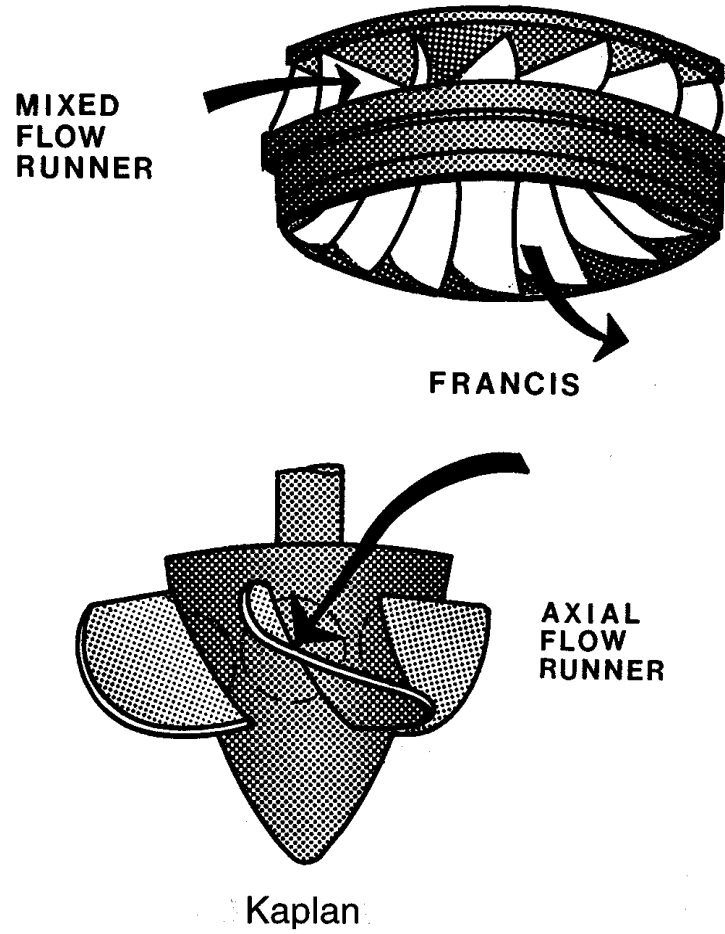


Figure 11. Illustrations of Francis and Kaplan runners.

ARL/NREC Fish Friendly Hydroturbine

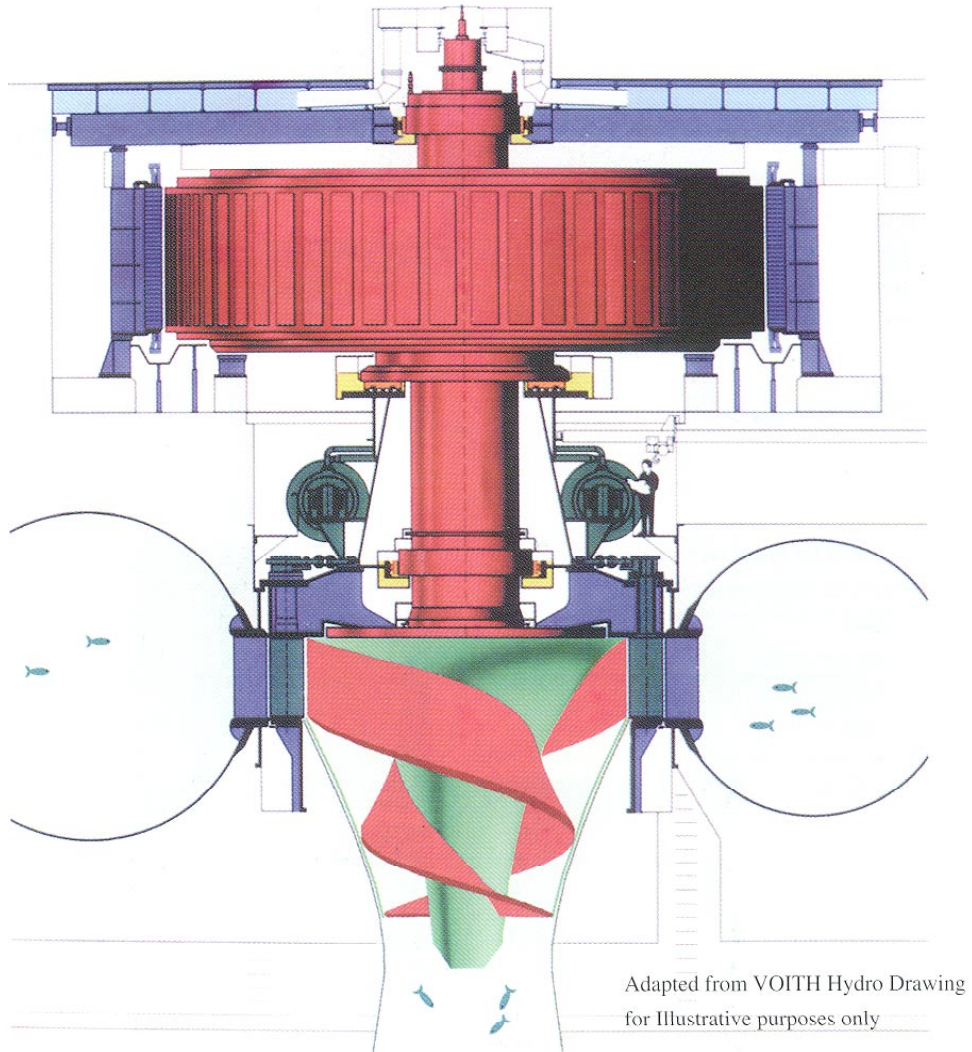


Figure 12. Illustration of an ARL/NREC fish-friendly hydroturbine.

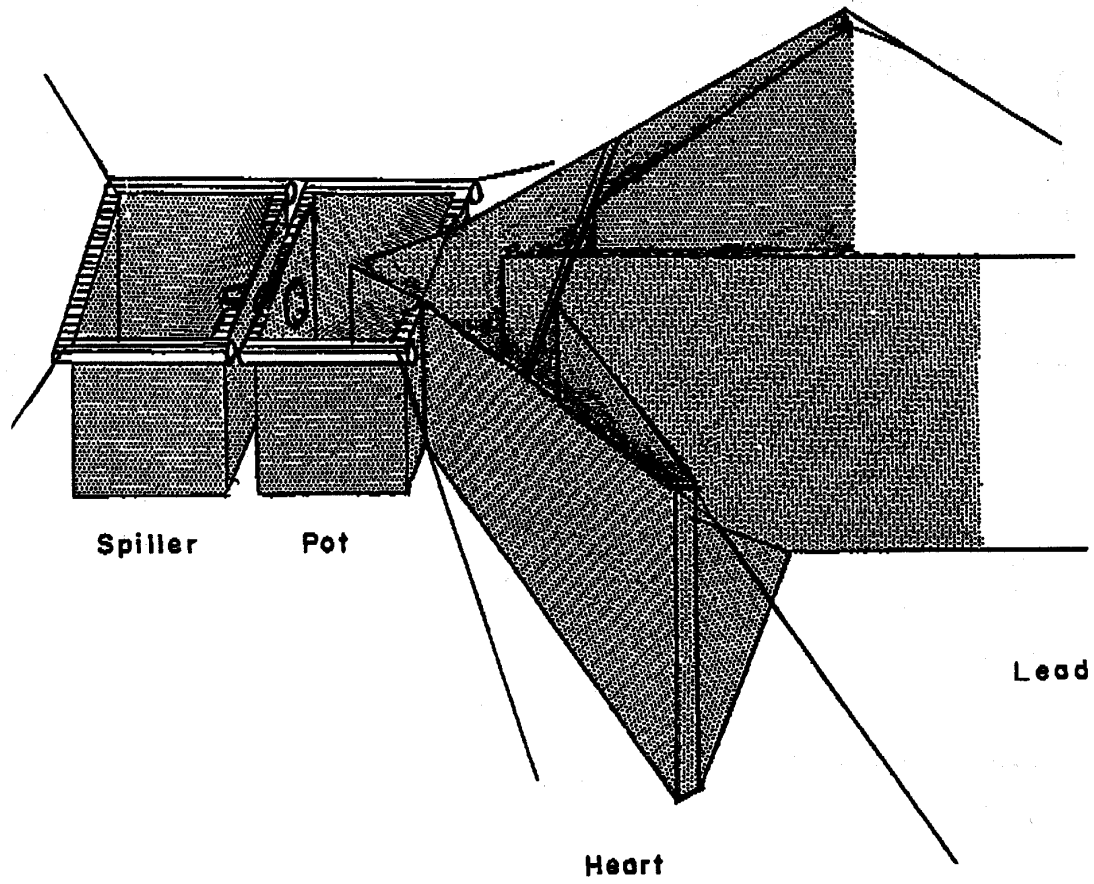


Figure 13. Schematic of a floating trap design.

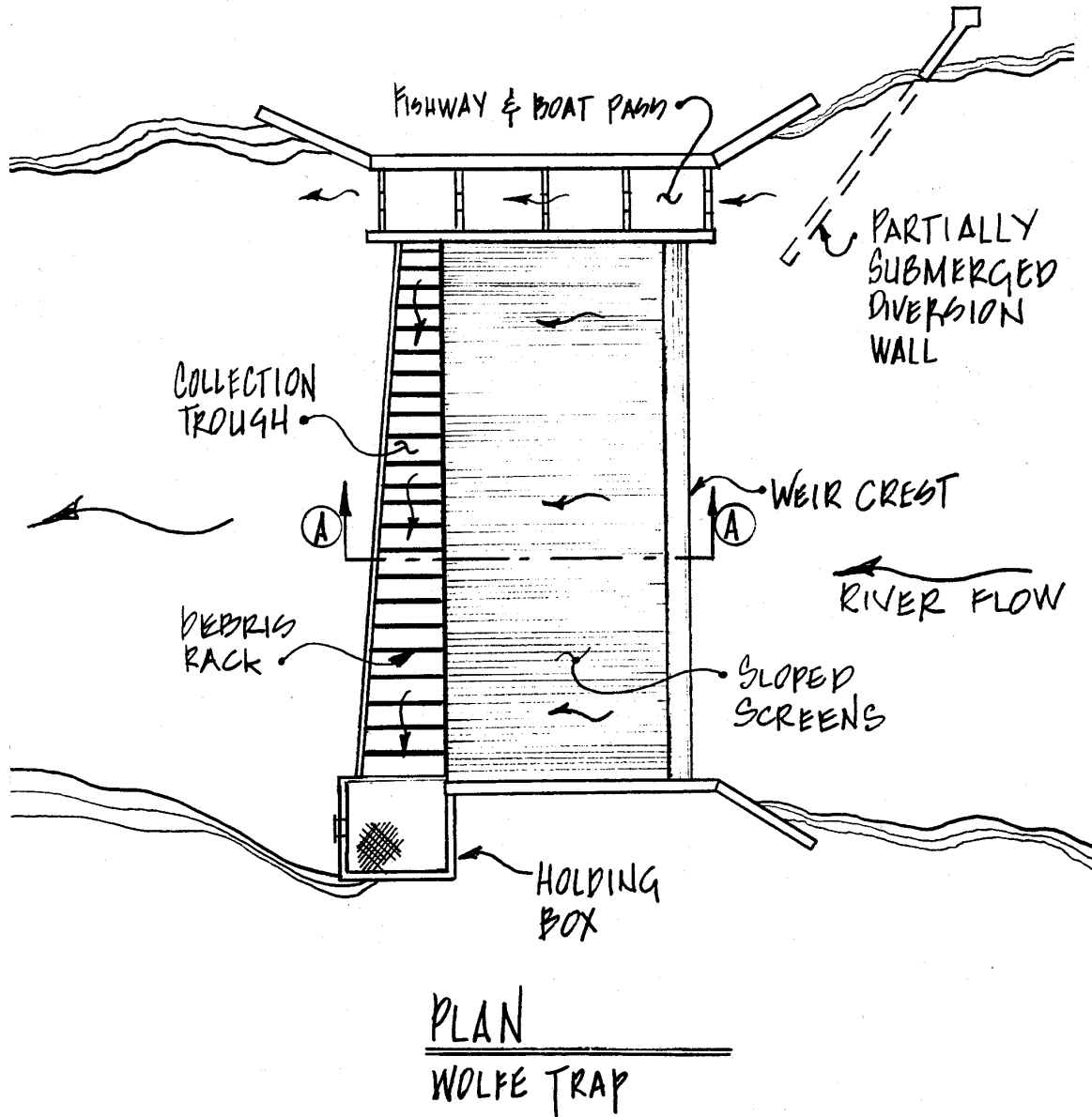


Figure 14. Plan view of a Wolfe trap.

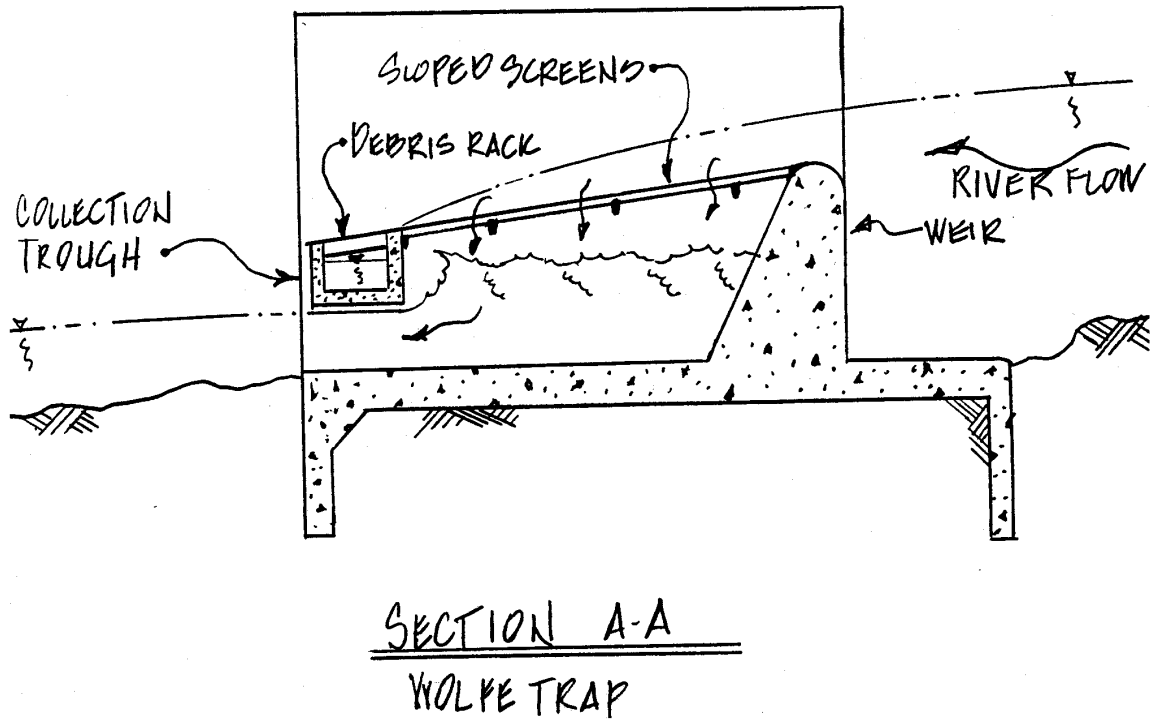


Figure 15. Sectional view of a Wolfe trap.

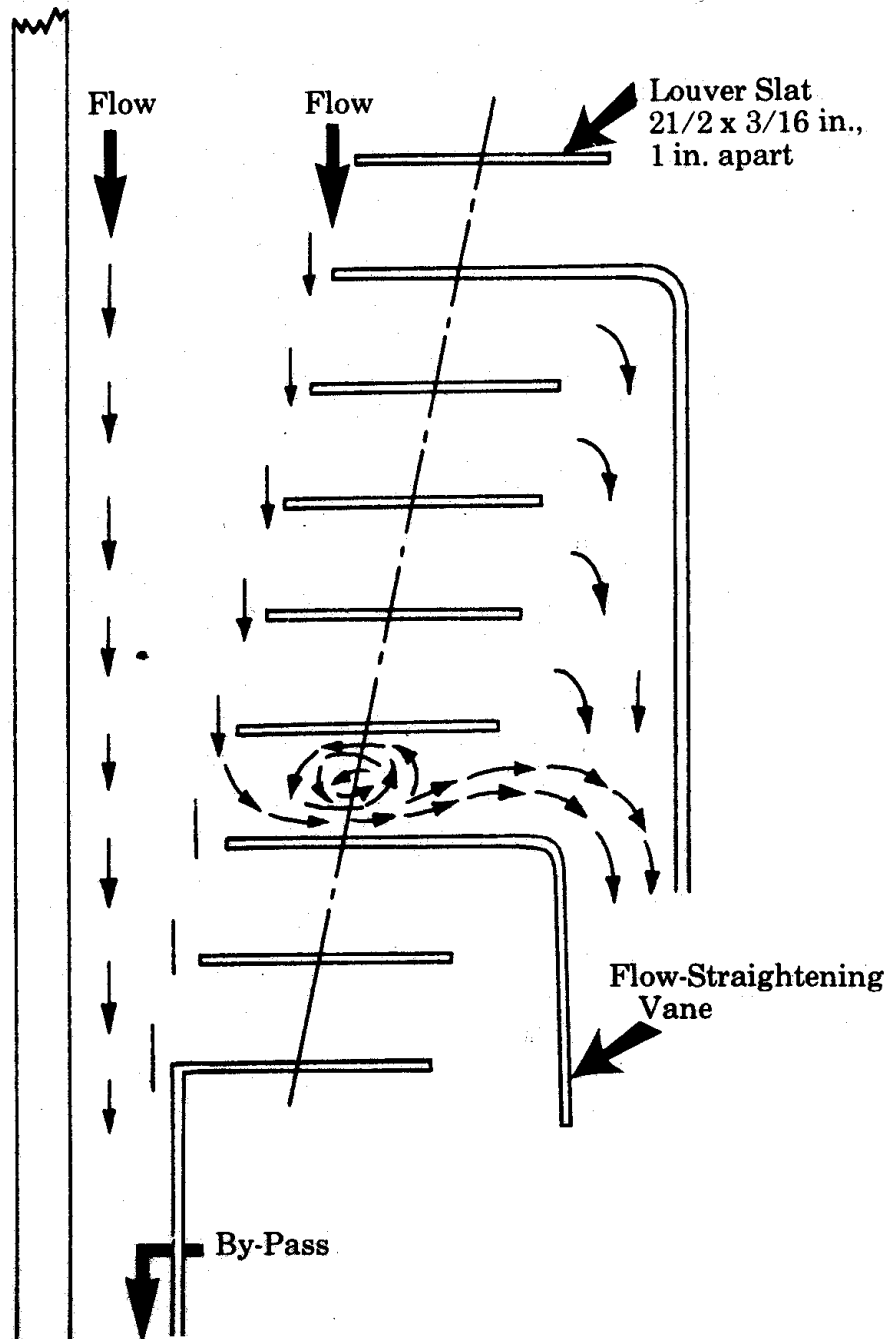


Figure 16. Diagram of a louver system.

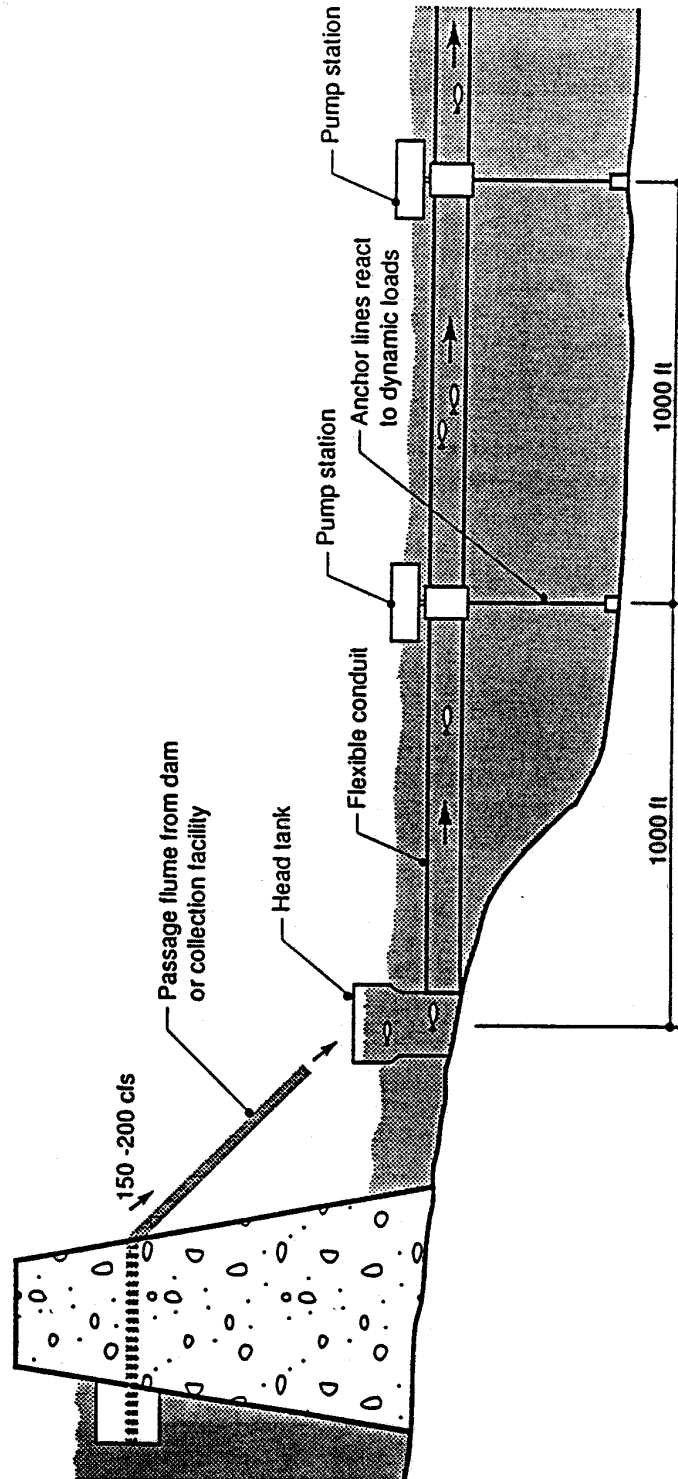


Figure 17. Schematic of a flexible in-reservoir salmon passage (FISP) system.

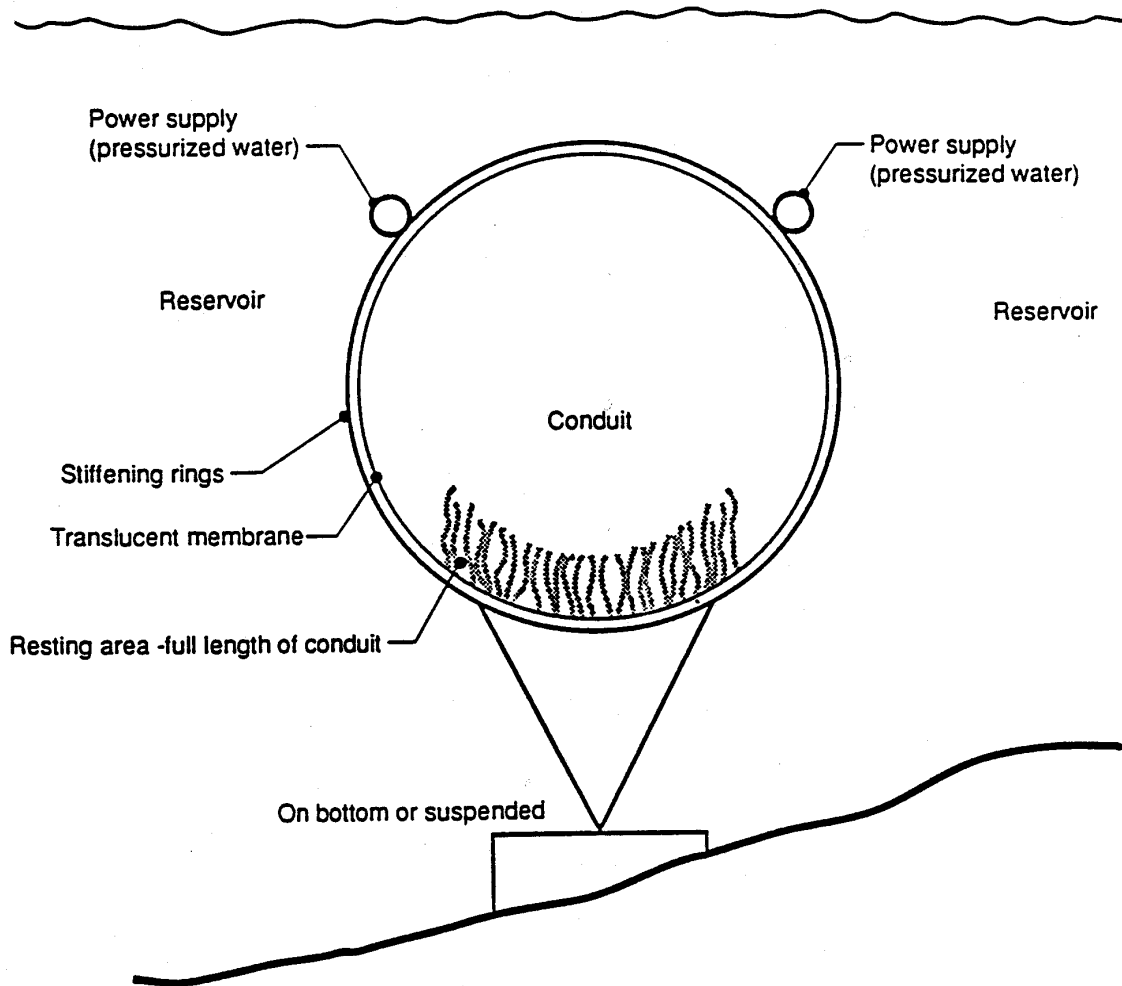


Figure 18. Cross section of a flexible in-reservoir salmon passage (FISP) conduit.

Sequential Gravity Flow System

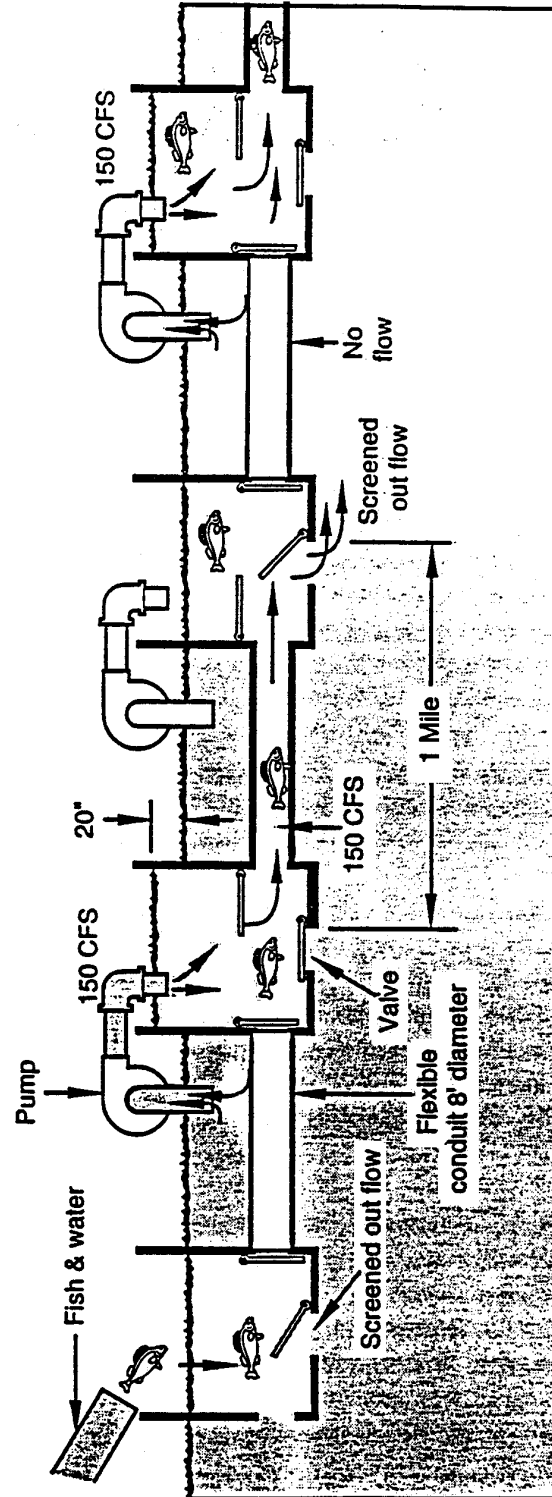


Figure 19. Diagram of a sequential gravity flow system.

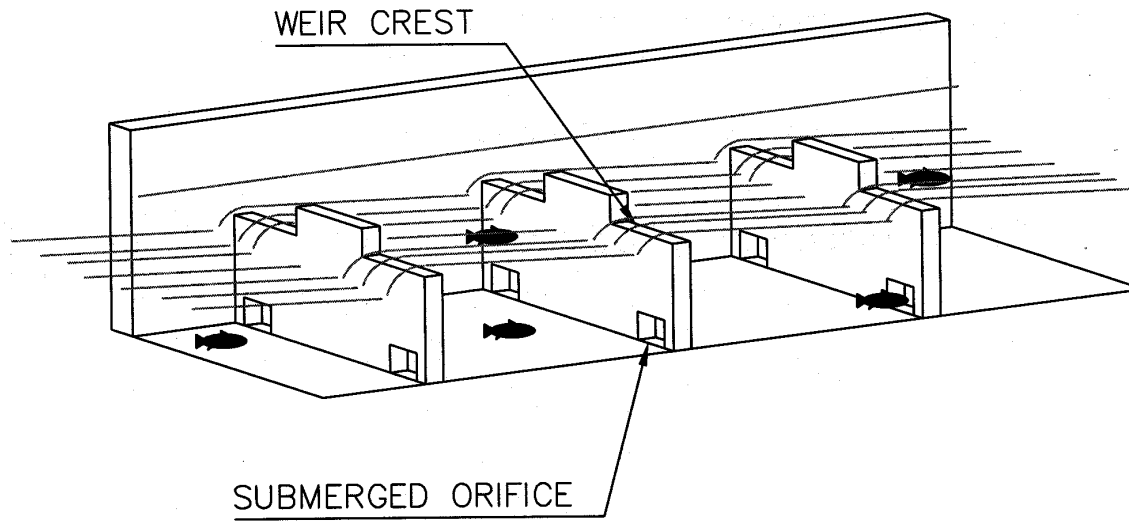


Figure 20. Diagram of a fish ladder.

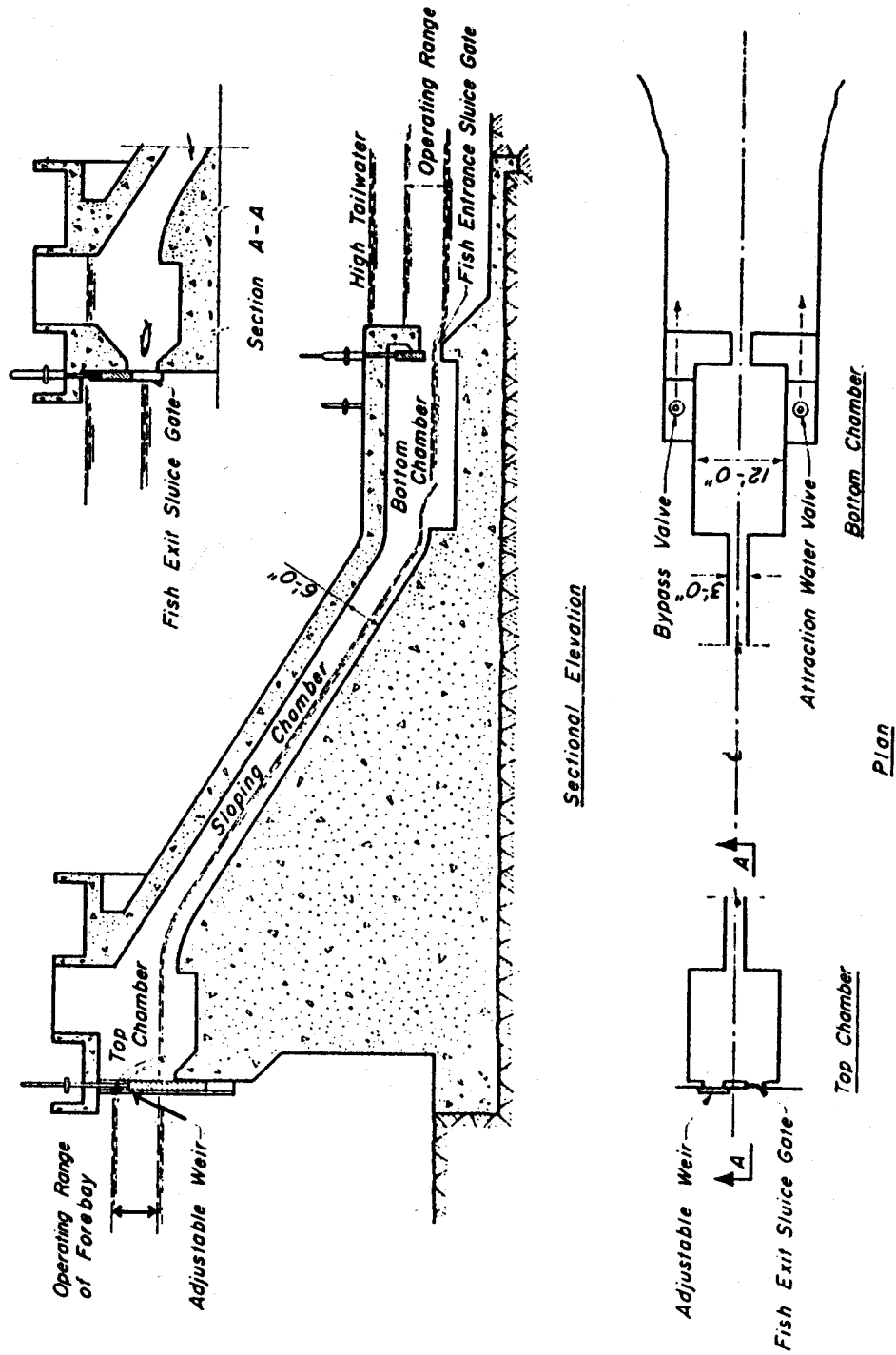
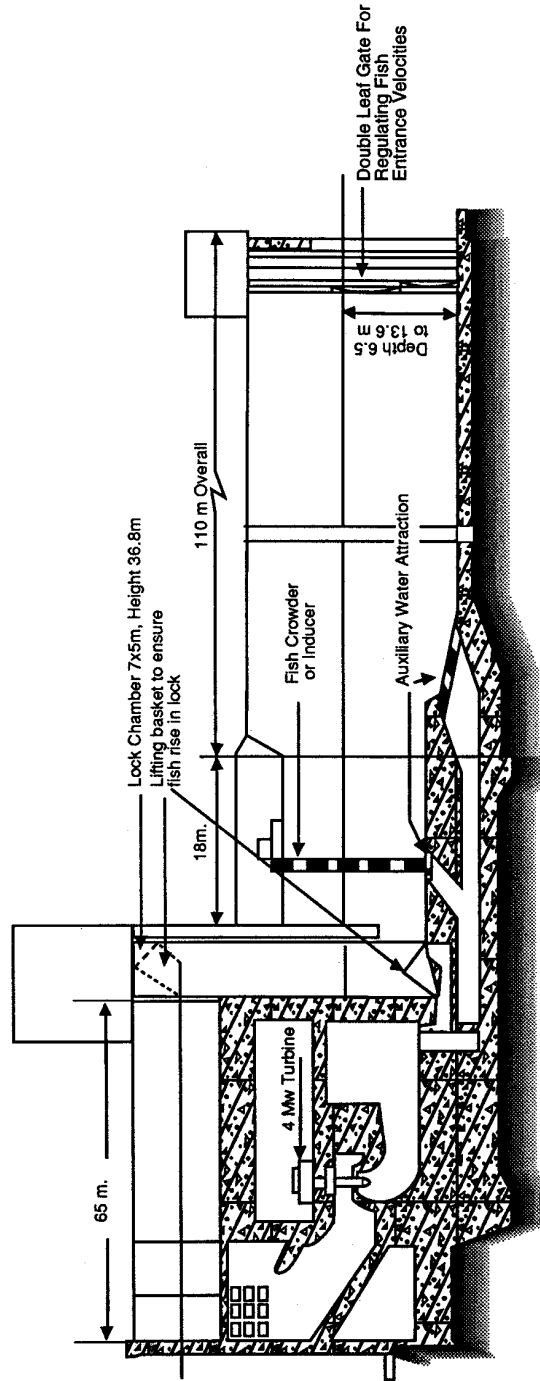


Figure 21. Diagram of a Borland lock.



The Tzymlyanskij Fish Lock on the Don River, former U.S.S.R., first built in 1955 and reconstructed in 1972. (After Pavlov, D.S., 1989.)

Figure 22. Diagram of a fish lock.

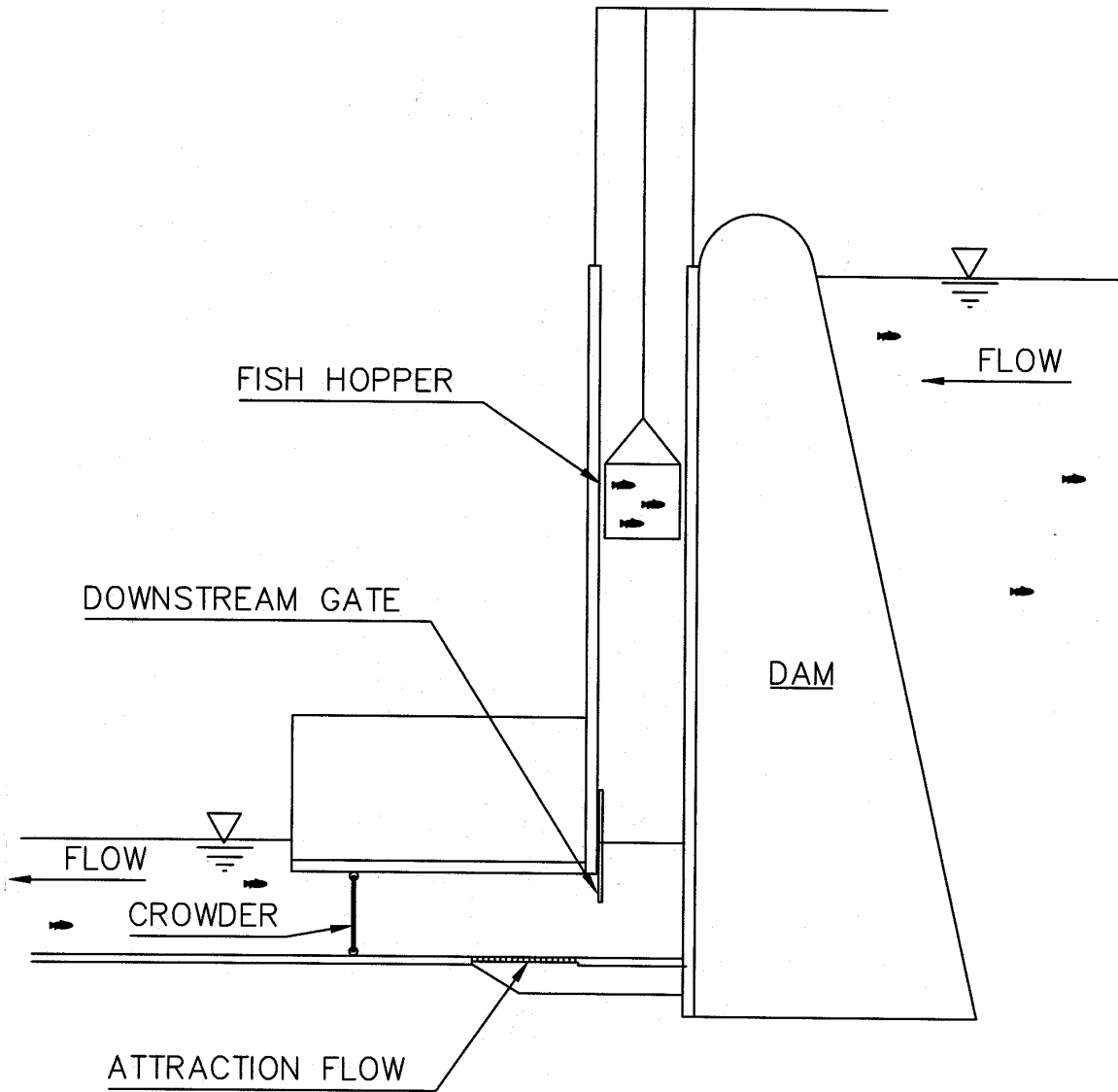


Figure 23. Diagram of a fish lift.

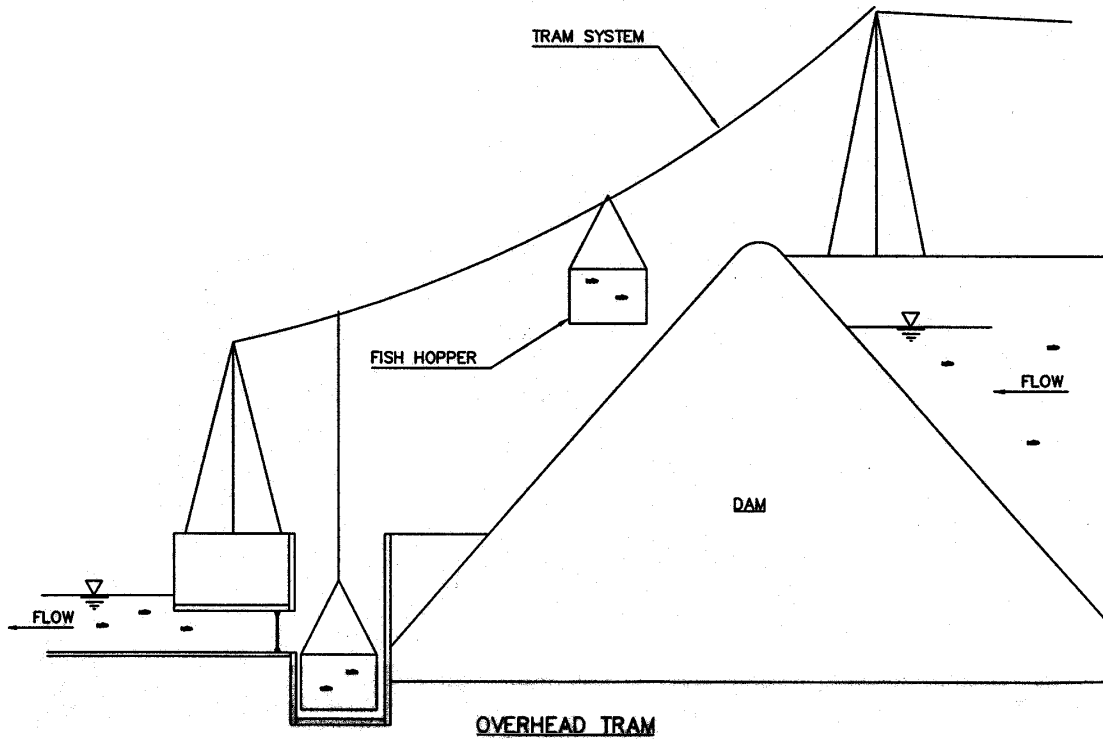
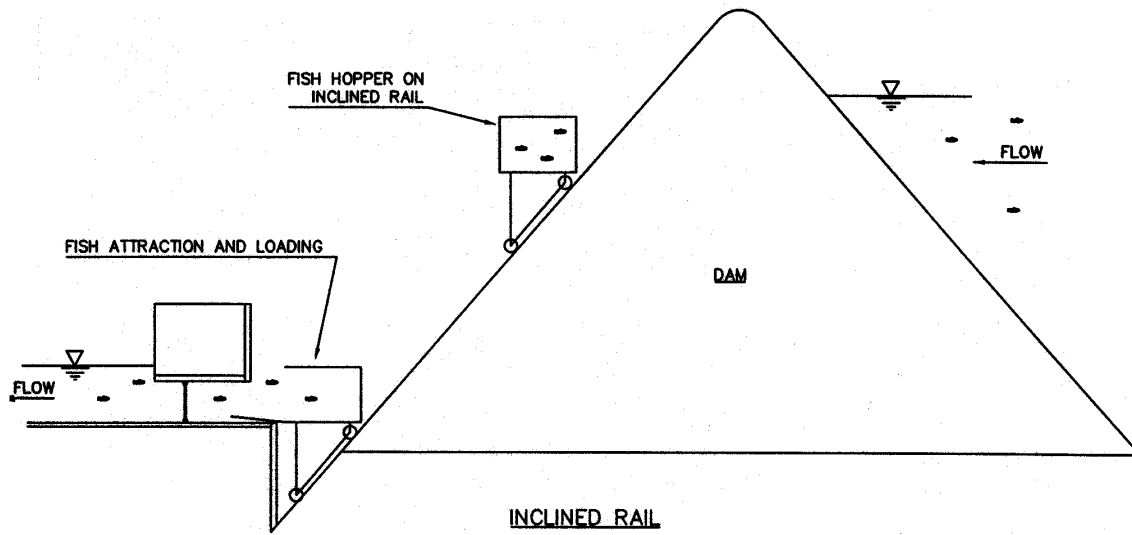


Figure 24. Diagram of an alternate fish lift.

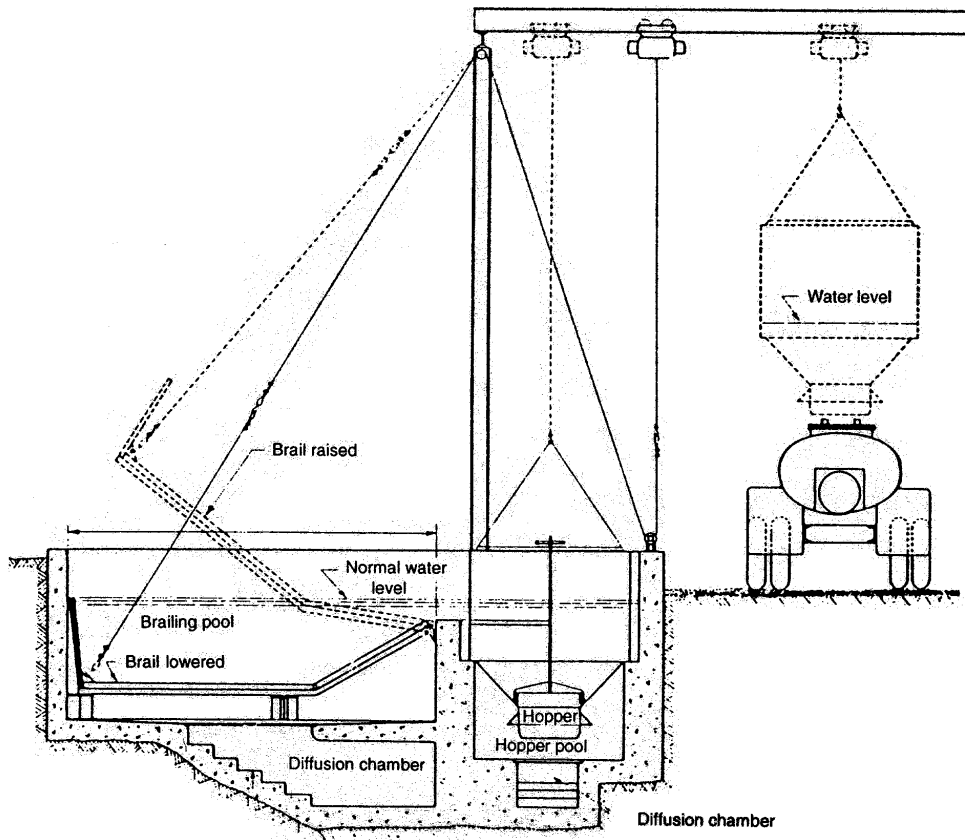


Figure 25. Diagram of a trap-and-haul facility.

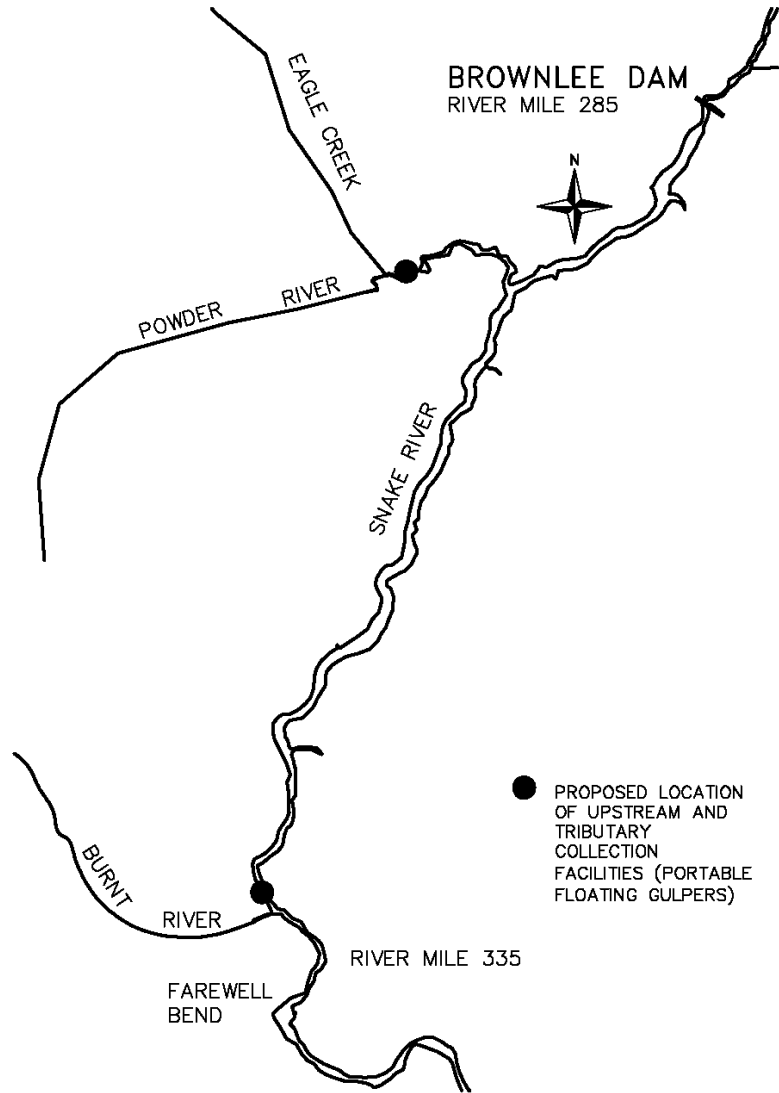


Figure 26. Potential locations of upper reservoir collection locations in Brownlee Reservoir.

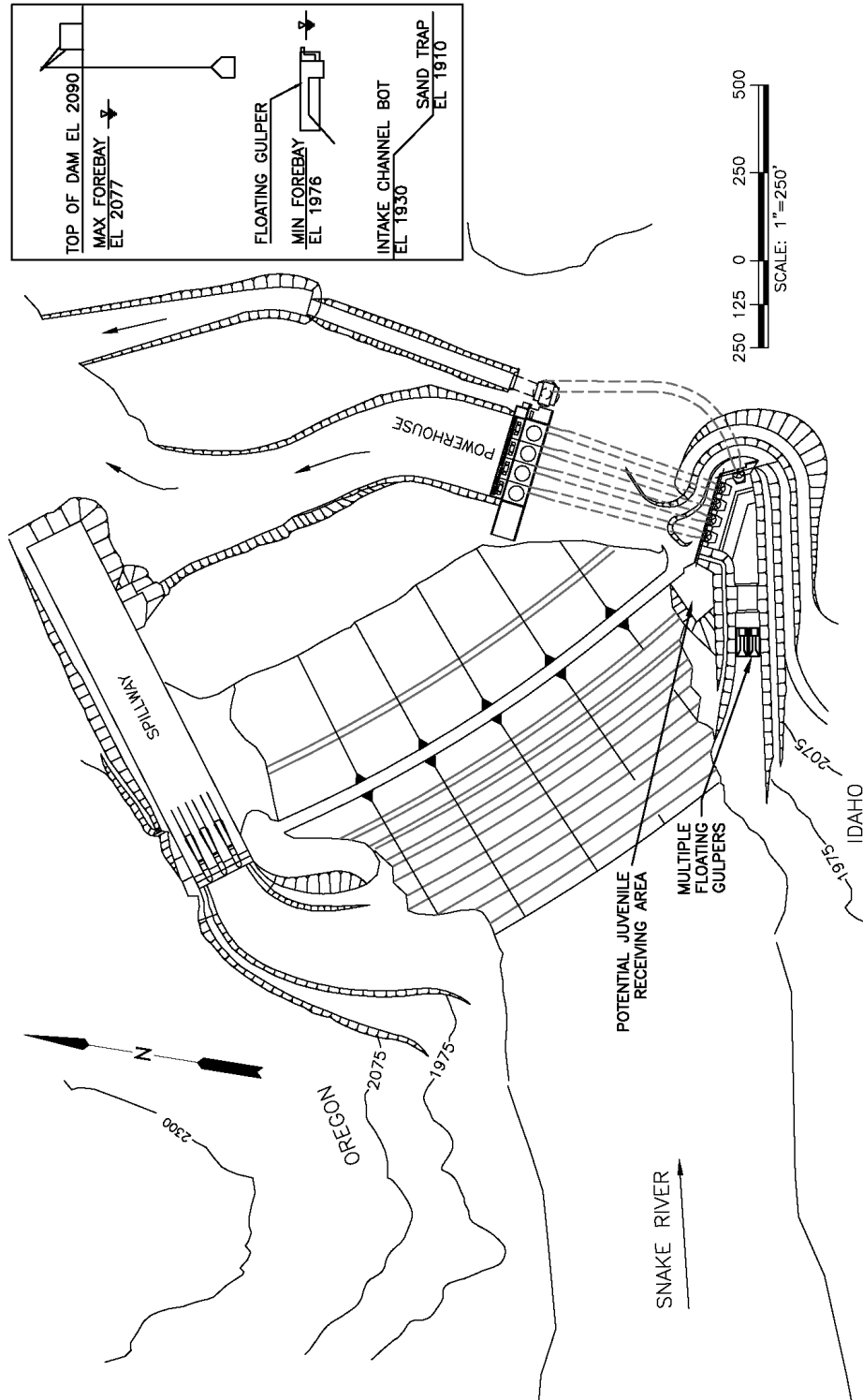


Figure 27. Proposed location of forebay collection at Brownlee Dam.

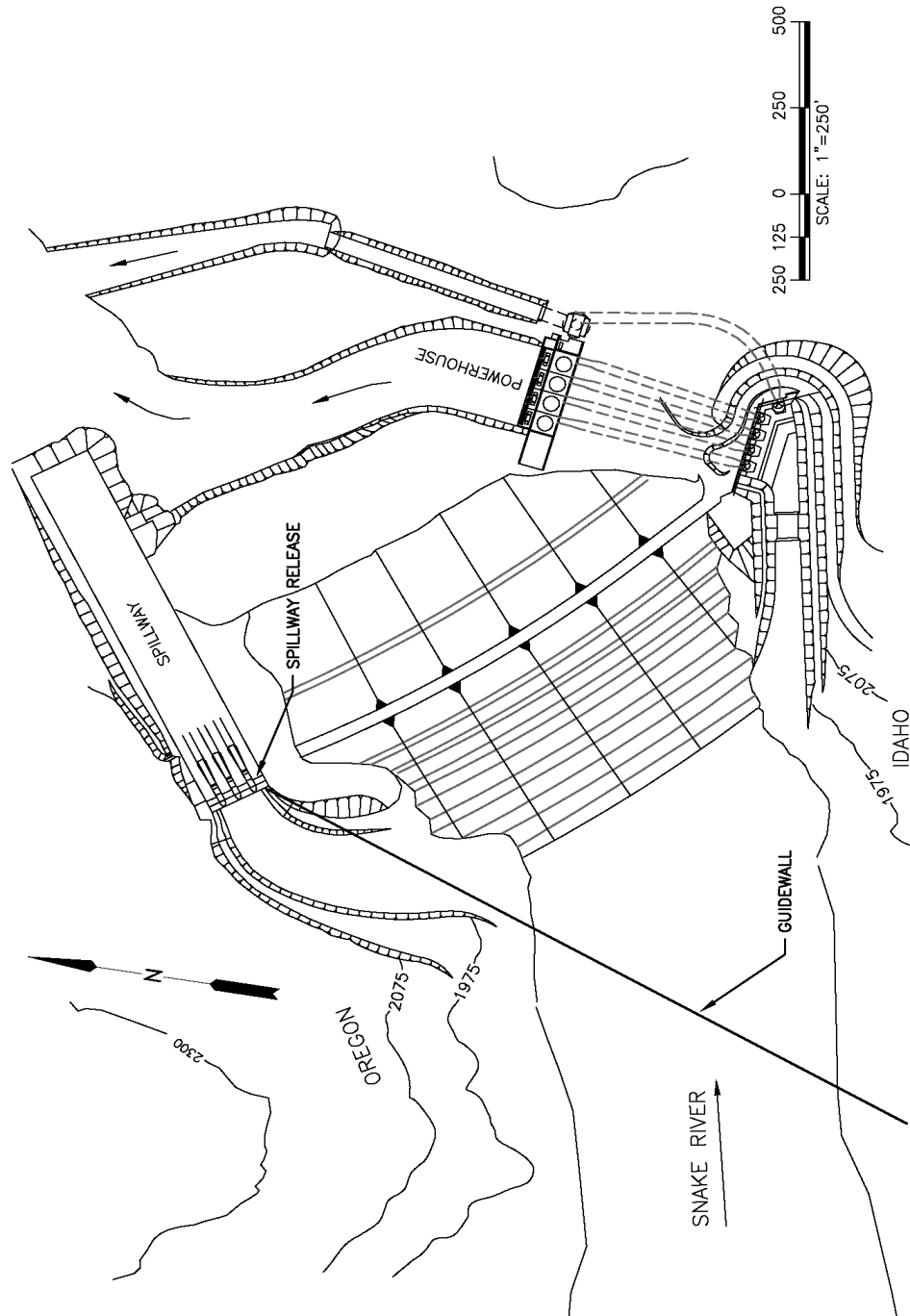


Figure 28. Proposed location of guide wall and spillway release in Brownlee Reservoir.

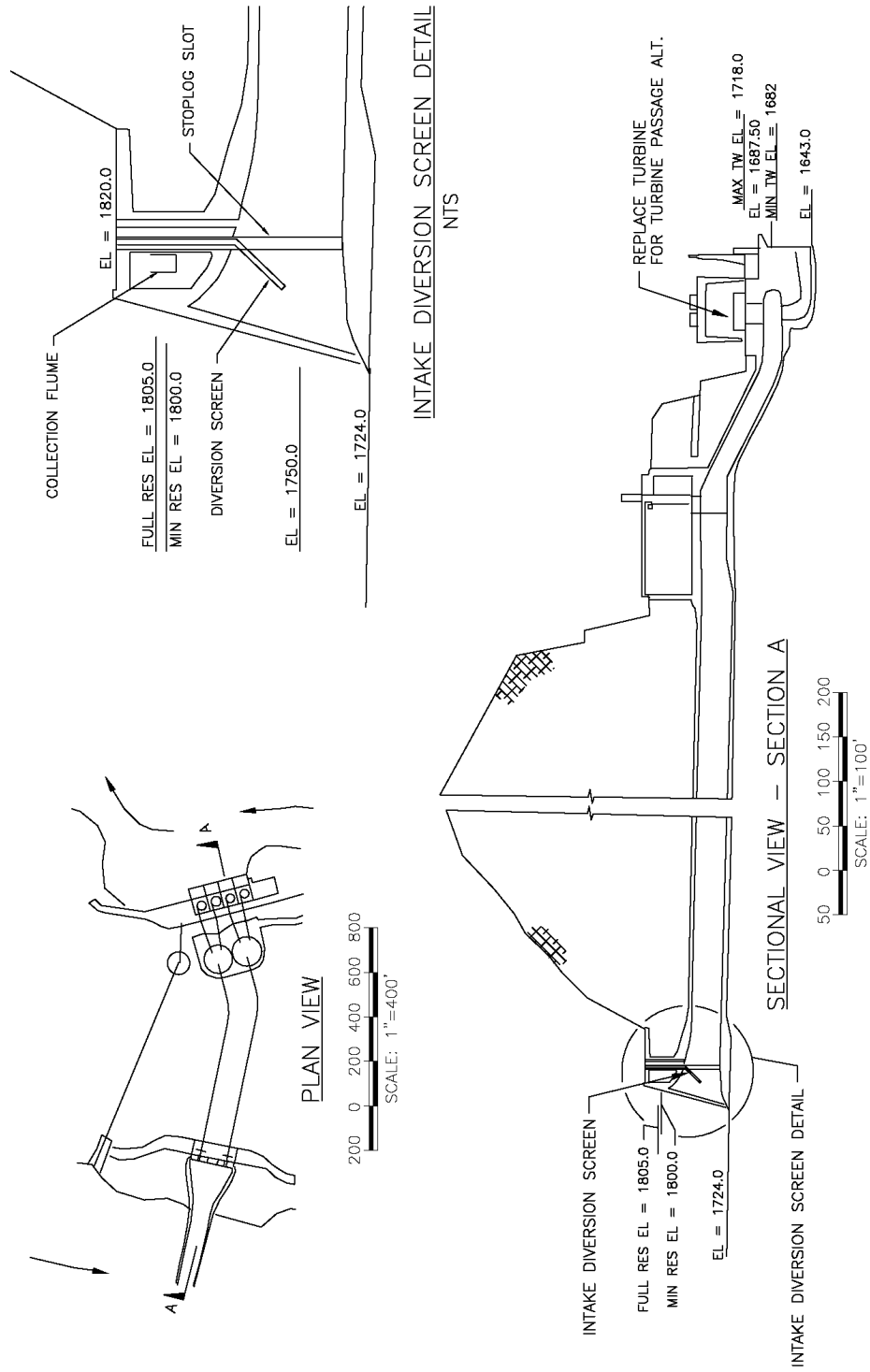


Figure 29. Schematic of proposed intake diversion screen at Oxbow Dam.

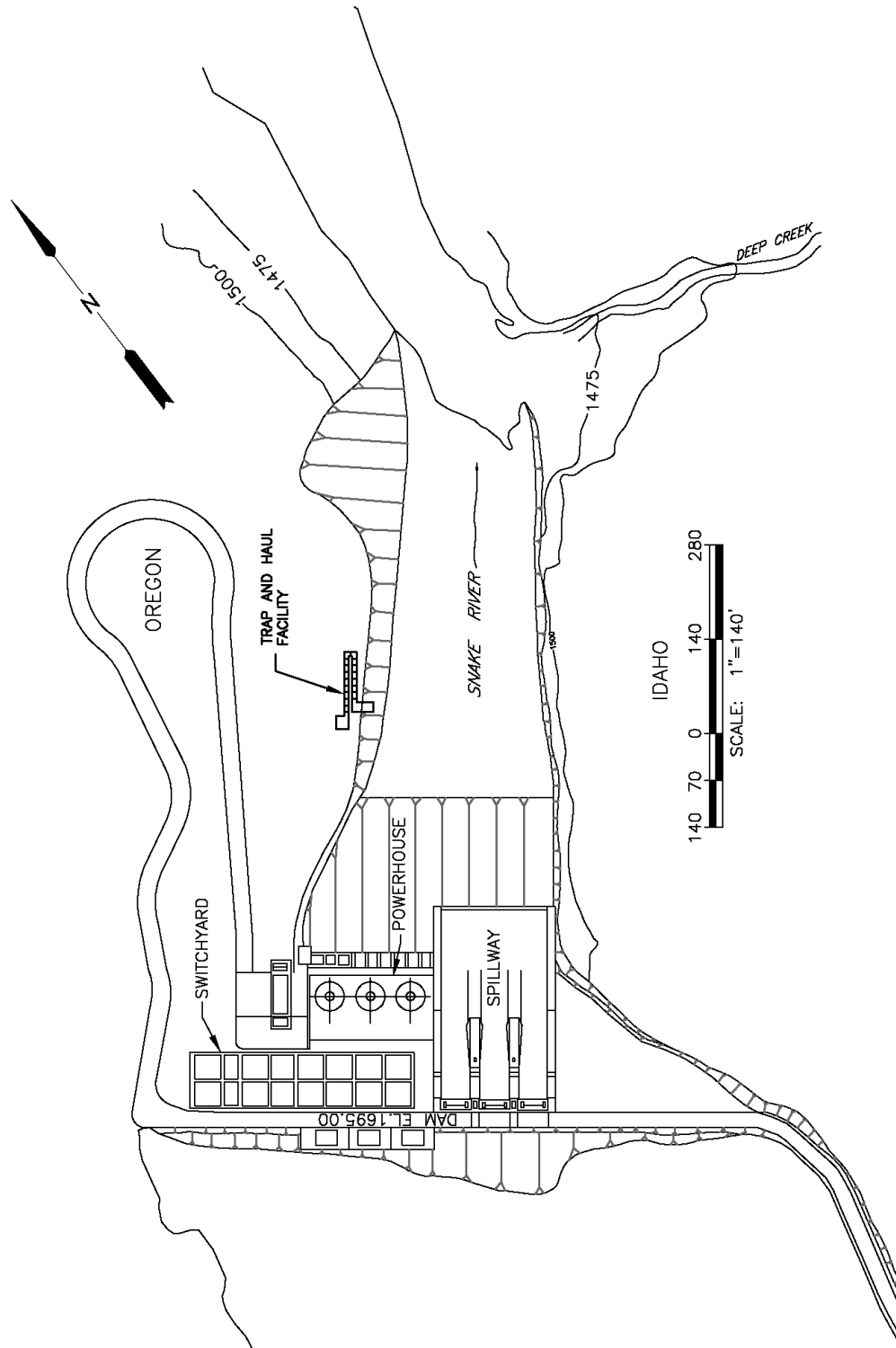


Figure 30. Proposed location of trap-and-haul facility at Hells Canyon Dam.

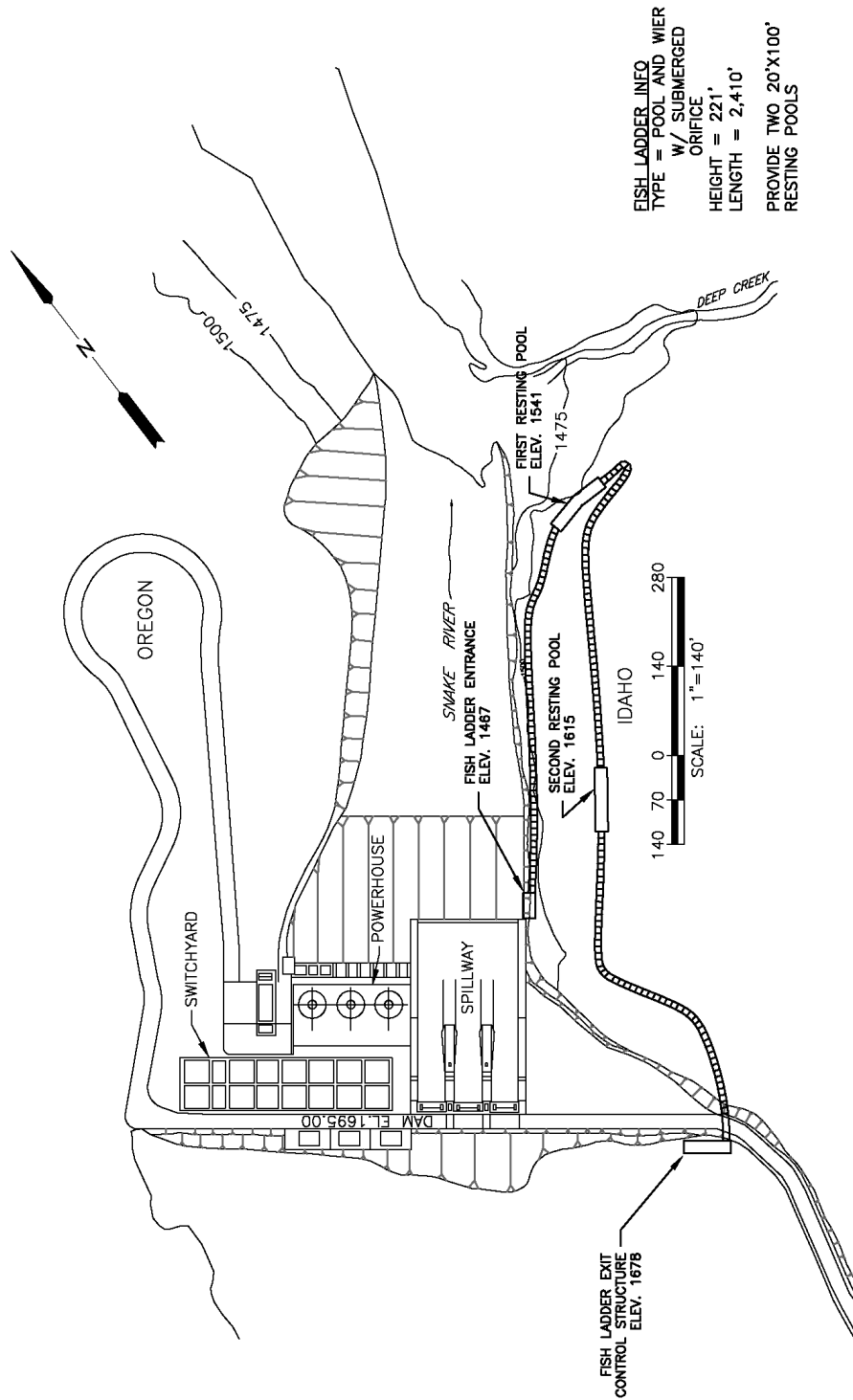


Figure 31. Proposed location of fish ladder at Hells Canyon Dam.

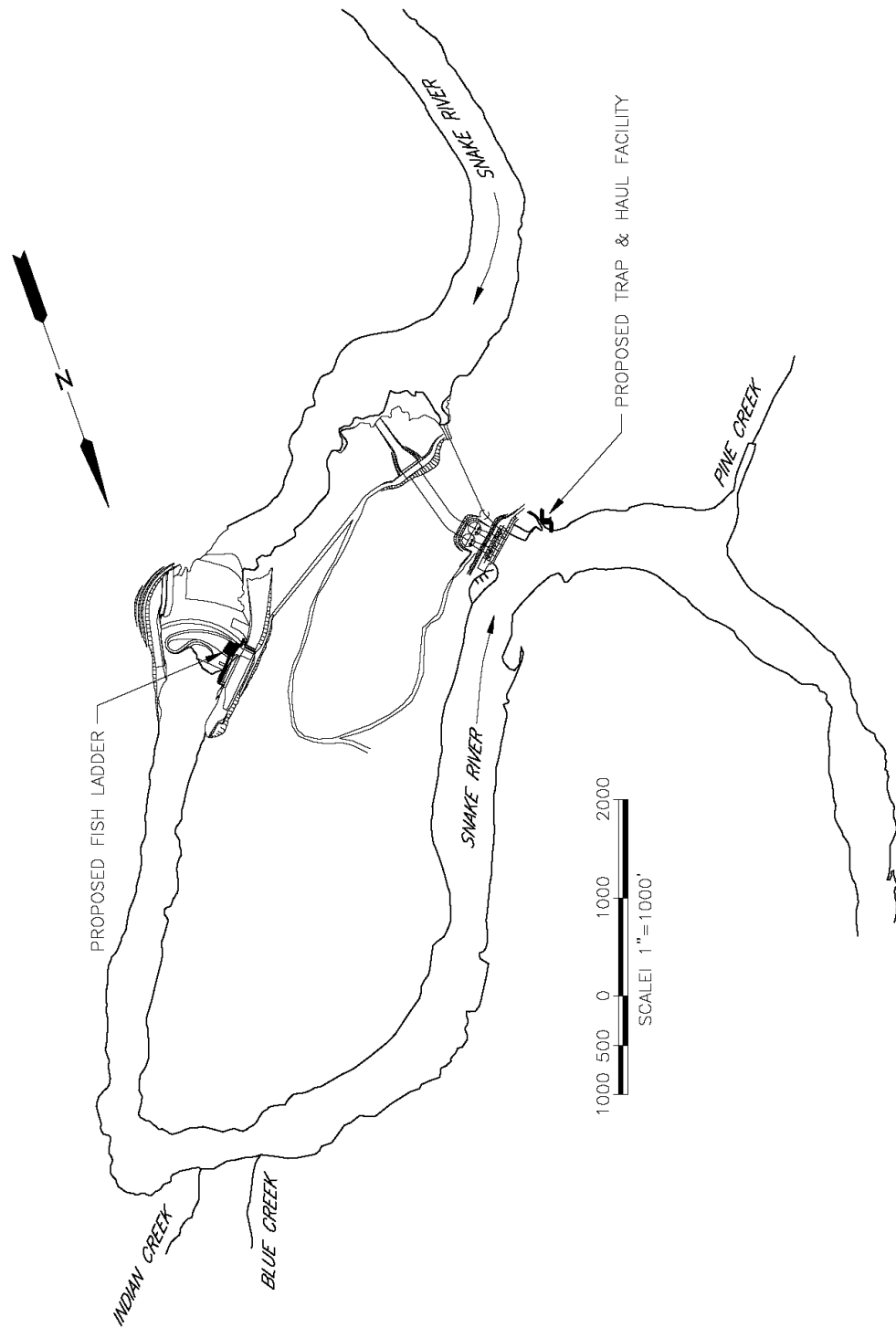


Figure 32. Proposed location of fish trap and fish ladder at Oxbow Dam.

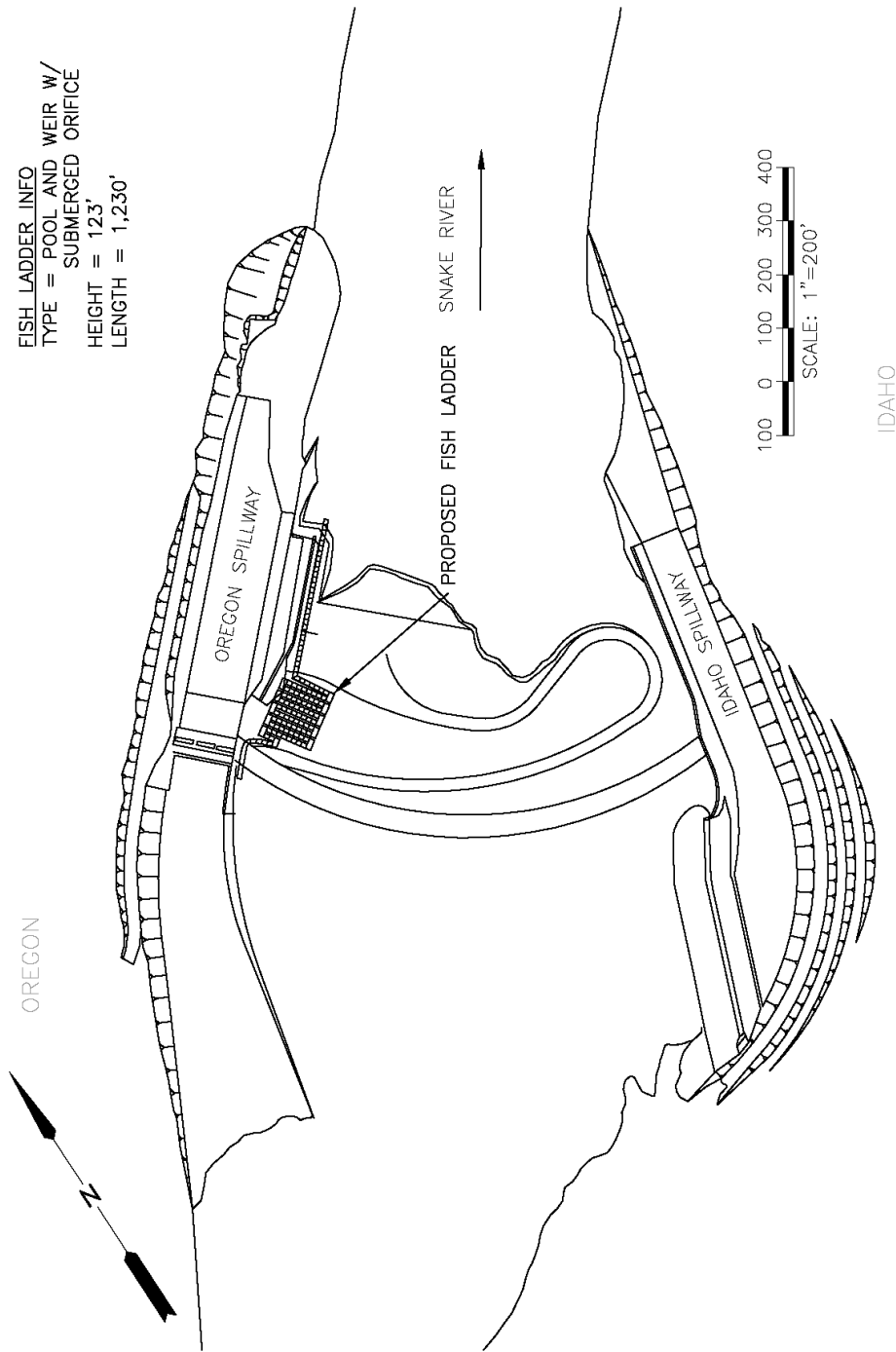


Figure 33. Proposed location of fish ladder at Oxbow Dam.

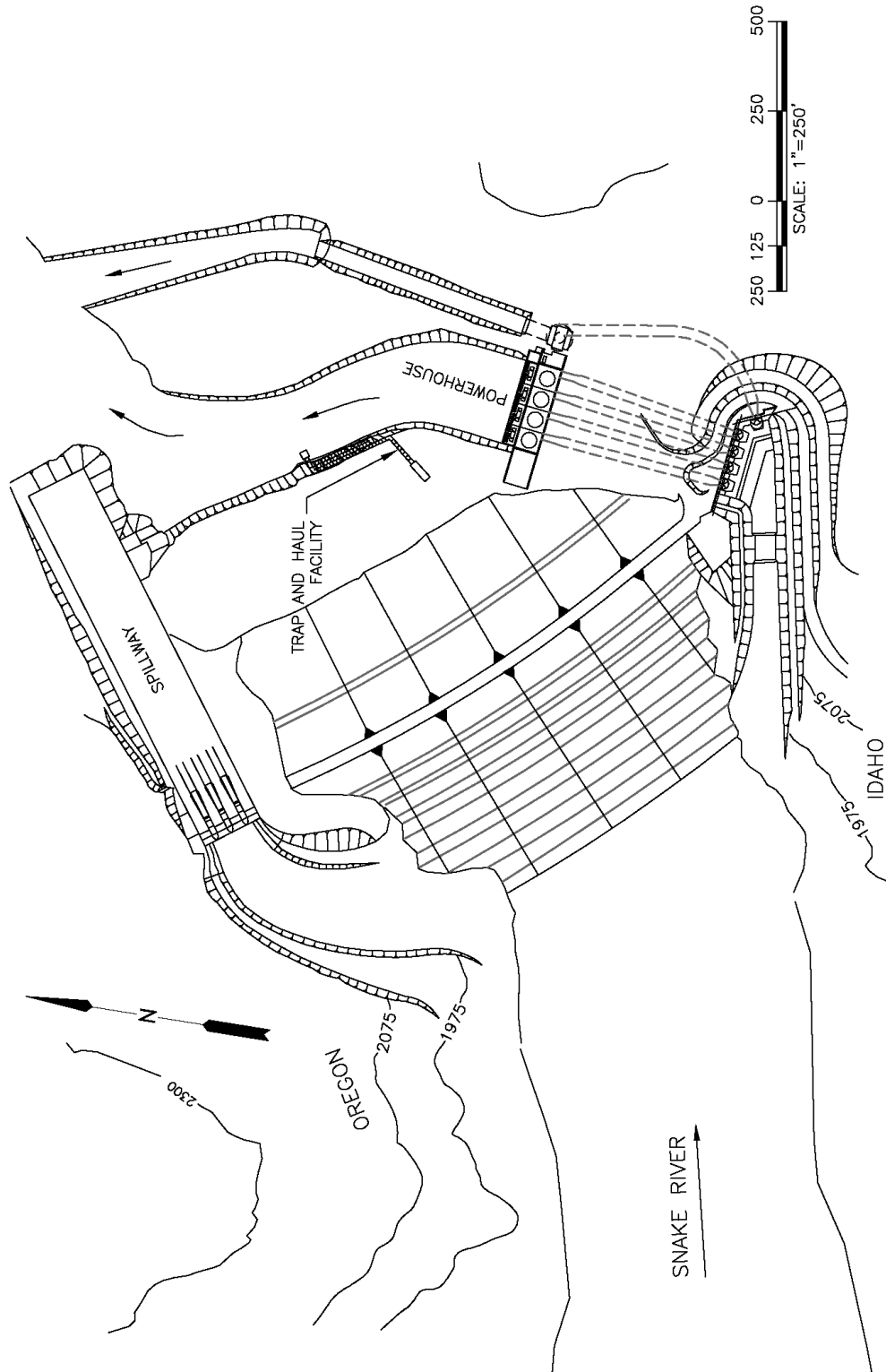


Figure 34. Proposed location of trap-and-haul facility at Brownlee Dam.

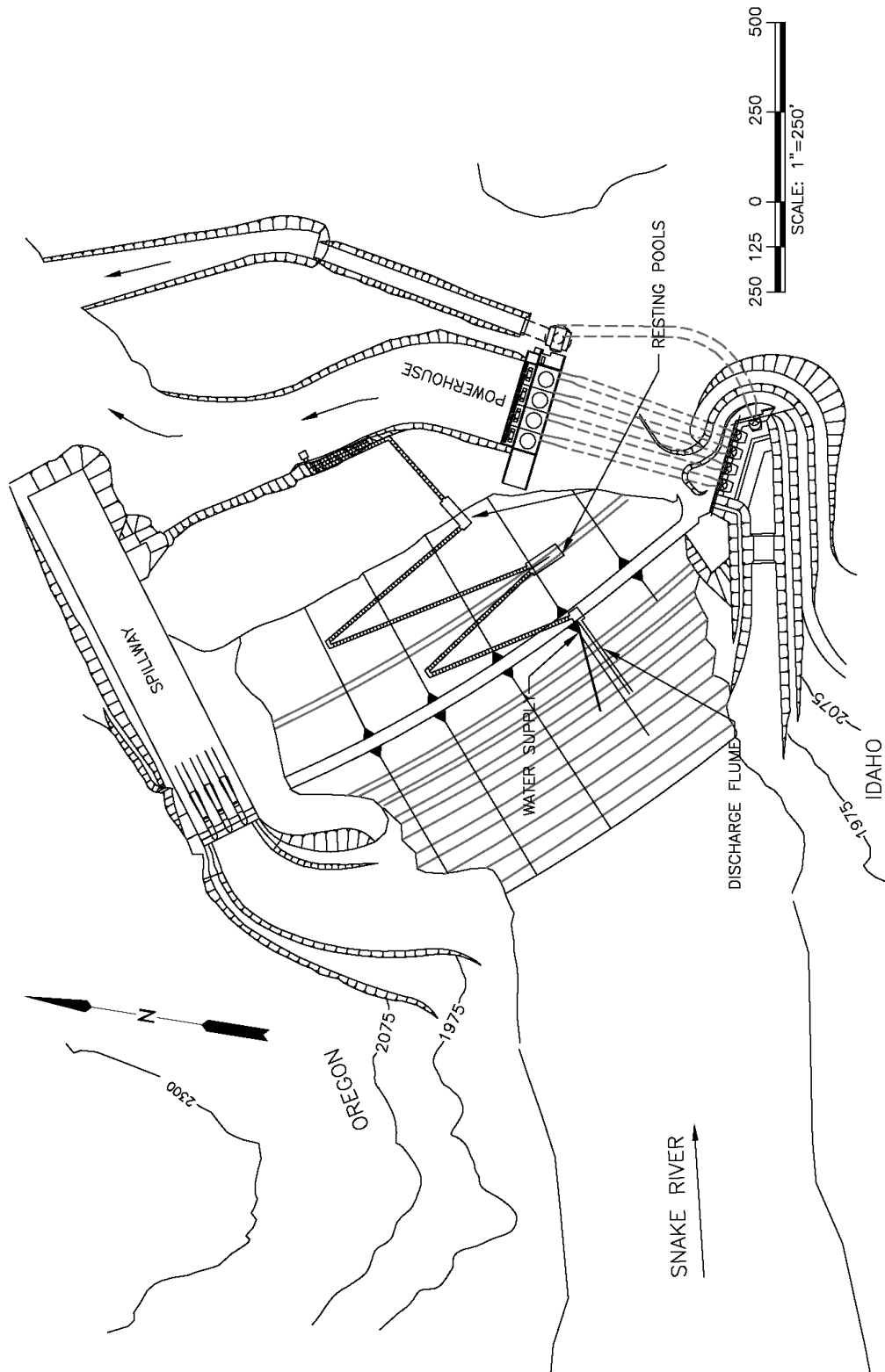


Figure 35. Proposed location of fish ladder at Brownlee Dam.

This page left blank intentionally.