Appendix D: Surface Collection

D.1 Introduction and Background

The basic assumption in traditional fish bypass designs is that all project flow will be screened all of the time, and juvenile fish that are collected will pass volitionally downstream of the barrier (Chapter 8 of the NOAA Fisheries West Coast Region Anadromous Salmonid Passage Design Manual [Manual]). However, more complex issues related to high-head dams and reservoirs can affect feasibility and require development of a surface collector.

Appendix D describes recommended approaches for developing surface-oriented systems for collecting juvenile salmonids in reservoirs and bypassing them around high-head impoundments (i.e., surface collection). The National Marine Fisheries Service (NMFS) will consider surface collection as a viable fish bypass option to traditional fish bypass designs on a case-by-case basis. Design and development of surface flow outlets (SFOs) based on spill or a structural system to collect juvenile fish are usually measured against site specific performance criteria. Surface collection is an evolving approach to improving the passage of juvenile and adult fish moving downstream past water storage projects. Each site and application is unique: a concept that works well at a given site may not directly transfer to another site.

Appendix D addresses the following surface collection concepts:

- In-reservoir floating surface collector (FSC) using pumped attraction flow with a volitional bypass or with a trap and haul bypass
- FSC located at a dam using pumped or plumbed attraction flow with volitional bypass
- FSC at a dam using pumped or plumbed attraction flow with trap and haul bypass
- Fixed surface collector at a dam using pumped or plumbed attraction flow with volitional bypass
- Flow releases through a spillway or sluiceway to provide an egress route out of the reservoir
- Other operational passage concepts
- Collection of fish at a head-of-reservoir location

In recent years, the development of surface-oriented passage routes has focused on what are generally referred to as surface collectors. An expanded description of the history of surface collector designs can be found in ENSR Corporation (ENSR 2007).

Appendix D provides descriptions of the following:

- Surface collector development history
- Definitions
• Types of SFOs
• Components of SFOs
• Design development, guidelines, and criteria
• Case studies of current surface collector technologies
• Performance standards
• Biological monitoring requirements

D.1.1 Glossary of Terms

**Direct survival** – juvenile salmonid survival through the main components of the SFO (entrance, conveyance, and outfall; ENSR 2007).

**Discovery efficiency** – the proportion of smolts passing the dam that arrives near the entrance to the SFO (ENSR 2007).

**Discovery zone (also termed ‘Zone of Influence’)** – the area where juvenile salmonids first encounter a surface collector flow net in the forebay (ENSR 2007).

**Entrance efficiency** – the proportion of fish near the SFO entrance that enter and pass through the SFO route to the tailrace (ENSR 2007).

**Fish collection effectiveness** – the ratio of FCE to the proportion of total project discharge through the SFO during a given FCE study. This metric reflects the fish:flow ratio that is useful to compare to other fish passage routes such as spill (ENSR 2007).

**Fish collection efficiency (FCE)** – the proportion of smolts passing the dam via the SFO. FCE was the most prevalent performance index reported across investigations (ENSR 2007).

**Floating surface collector (FSC)** – a surface collector that is not attached to a dam but is floating in the forebay, and where collected fish are typically loaded onto tanker trucks and transported to a release location in the tailrace or river below the dam.

**Guidance net** – a net system extending from a surface collector entrance into the forebay—typically from each side of the entrance and angled toward the shoreline—to concentrate fish in the vicinity of the surface collector entrance and increase FCE.

**Surface flow outlet (SFO)** – a facility comprising an entrance structure, conveyance system, and outfall that presents juvenile salmonids with hydraulic conditions of the right shape, location, velocity, and acceleration such that fish are attracted into the entrance and pass around a dam via the conveyance structure and are released back to the river in the tailrace below the dam.

**Total survival** – juvenile salmonid survival through the SFO and some portion of the tailrace (ENSR 2007).
D.2 Development History: High-Flow Bypass Systems

Development of SFOs for downstream fish passage in the Pacific Northwest expanded greatly starting in the 1990s. This occurred when it became apparent that high velocity turbine intake screens and their associated bypass facilities at Columbia River and Snake River hydroelectric projects (Appendix G) would not achieve the suite of juvenile salmonid survival and passage goals established by state, federal, and tribal fish resource agencies.

Research has shown that downstream-migrating juvenile salmonids are oriented in the upper portion of the water column (ISG 2000). Most juvenile salmon (*Oncorhynchus* spp.) and steelhead (*O. mykiss*) in mainstem Columbia and Snake river reservoirs reside in the upper 10 to 20 feet of the water column as they migrate downstream (Ogden et al. 2007). Fisheries biologists working at these mainstem dams noticed that juvenile salmon and steelhead converged at shallow depths near overflow weirs (i.e., debris sluiceways) installed at Ice Harbor, The Dalles, and Bonneville dams. Juvenile salmonids were also observed near the water surface in powerhouse gatewells (Appendix G). Additionally, hydroacoustic studies at dams on the upper Columbia River indicated that fish-like targets were moving within the upper third of the water column (Whitney et al. 1997). This behavior has since been observed at other dams in the Pacific Northwest (e.g., Karchesky et al. 2002; Biosonics 2004; Karchesky et al. 2004a; and Karchesky et al. 2004b), except when environmental conditions, such as when a reservoir stratifies, force fish deeper into the water column.

Beginning in the late 1960s, sampling from turbine intake gatewells and smolt monitoring facilities at Columbia River dams showed a consistent pattern where the majority of juvenile salmon and steelhead smolts passed the powerhouses at night (Long 1968; Brege et al. 1996). Juveniles arriving at these mainstem dams during daytime tended to not pass through powerhouse passage routes upon arrival to the forebay, but readily passed through surface-oriented outlets and daytime spill if these routes were available (Ferguson et al. 2005). This delay exposed juvenile salmonids to predators in the forebay (Ferguson et al. 2005). More recently, after surface outlets were installed at mainstem Columbia River dams, the median forebay passage times for yearling Chinook salmon were typically less than 2 hours (Skalski et al. 2012, 2013).

Figure D-1 compares the relative depths fish must sound to pass various passage routes at mainstem dams on the Columbia River.
Wells Dam is unique among mainstem Columbia River dams because the spillbay intakes are situated directly above the intakes for ten turbine units (Figure D-2), which is termed a ‘hydrocombine’ design. As part of the Federal Energy Regulatory Commission (FERC) relicensing process, the owner of Wells Dam (Douglas County Public Utility District [PUD]) modified 5 of its 11 spillbays to enhance downstream fish passage to meet fish passage efficiency goals established by FERC. Each spillbay has three intake openings. The bays—designated as fish passage bays—are blocked by three baffles, one in each bay’s intake opening. The center baffle in each bay includes a slot that is 16 feet wide and 70 feet deep. The resulting surface-oriented flow through the vertical spillway slots of up to 11,000 cubic feet per second (ft³/s), along with the turbine unit flow, results in flow velocities in front of the baffles of approximately 2 feet per second (ft/s; ENSR 2007).
According to ENSR (2007), the success of Wells Dam (for fish passage) is likely attributed to the following factors:

- There are five entrance slots spaced across the width of the powerhouse. This increases the probability that fish will encounter an entrance.
- River flow is concentrated horizontally. The placement of the spillbays directly above the turbine intakes concentrates the entire river to a flow path that is only 1,000 feet wide and concentrates downstream migrants near 1 of the 5 collector entrance slots.
- Hydroacoustic data indicate that 63 to 94% of Chinook and sockeye salmon smolts migrate at an elevation that is above the floor of the spillbays. This implies that most of the fish would move into the zone of increased localized velocity in front of the spillbay baffle slots.

The U.S. Army Corps of Engineers (USACE) continued the development of SFOs and developed a Removable Spillway Weir (RSW) concept that was tested at Lower Granite Dam in 2001. The RSW was attached to the face of the dam immediately upstream of Spillbay 1. The structure was termed ‘removable’ because it was hinged and could be rotated and submerged in the forebay in the event of unusually high flood flows (which allows the full hydraulic capacity of the spillbay to be used). Ice Harbor Dam and Lower Monumental Dam received RSWs in 2005 and 2009, respectively. Figure D-3 shows a cross section of a dam with an RSW.
USACE also developed a portable, top spill weir—called a Temporary Spillway Weir (TSW)—that could be readily moved to any spillbay using a gantry crane. TSWs are used to find the best bays in which to install an overflow weir system based on fish performance testing. TSWs were installed at McNary Dam in 2007 and 2008, at John Day Dam in 2008, and at Little Goose Dam in 2009 (Figure D-4).

Figure D-3. Schematic of a Removable Spillway Weir (RSW) in normal (a) and lowered (b) positions.

Figure D-4. Years in which surface flow outlets were installed at Columbia and Snake river dams and percentages of overall project survival for juvenile Chinook salmon migrating during springtime based on testing conducted between 2010 and 2012 (Source: adapted from Columbia River Federal Caucus 2013).
Grant County PUD owns and operates the Wanapum and Priest Rapids dams located on the Columbia River in central Washington. Grant County PUD began investigating SFOs in the early 1990s, and studies of full-scale prototypes revealed that discharging high flow volumes through wide, vertical slots in bulkheads installed in spillbays could meet FERC’s fish passage efficiency goals for Wanapum Dam. A permanent high-flow fish passage facility called the Future Units Fish Bypass (FUFB) was installed in the spring of 2008 at Wanapum Dam (Figure D-5(a)). At Priest Rapids Dam, the three spillbays closest to the powerhouse were modified in 2014 by raising the elevation of the ogee crests to allow free-surface discharge and the invert of the spillway aprons to reduce gas supersaturation. The Priest Rapids Fish Bypass (PRFB) is shown in Figure D-5 (b).

Figure D-5. High-flow surface flow outlet bypass discharges at (a) Wanapum Dam and (b) Priest Rapids Dam on the Columbia River in central Washington (Courtesy of Grant County Public Utility District).

Rock Island and Rocky Reach dams, located on the Columbia River in central Washington, are owned and operated by Chelan County PUD. Years of research and prototype development at Rock Island Dam led to a juvenile passage strategy involving a mix of top spill gates and over and under spill gates (ENSR 2007). A juvenile passage system at Rocky Reach Dam was installed in 2003 that diverts 6,000 ft³/s of flow from the forebay through conventional fish screens, allows collected fish to be evaluated, and bypasses collected fish back to the Columbia River downstream of the dam (Section D.3.2).

D.2.1 Development History: Surface Flow Outlets Using Screen Technology (Surface Collectors)

In the Pacific Northwest, multiple projects scheduled for FERC relicensing in the early 2000s generated interest in developing alternative fish passage approaches for projects where applying conventional screens (Chapter 8 of the Manual) was difficult. The types of collectors developed during this period are discussed in more detail in Sections D.2, D.3, and D.6.

The first surface collection system was located at Upper Baker Dam on the Baker River in northern Washington; it was built in 1959 when the dam was constructed. It incorporated a surface collector to collect fish in the reservoir near the dam and trap and haul as the means to
bypass fish around the dam (referred to as a “gulper” style of collector). It used 132 ft³/s of pumped flow to attract fish using two fish attraction barges. Testing continued over time, and guide nets were added to the system in the late 1980s. In 2004, the dam owner began designing a new and improved FSC that was first tested in 2008.

The new collector uses either 500 ft³/s or 1,000 ft³/s (depending on fish run timing) of pumped attraction flow, a floating screen facility, a net transition structure (NTS), and guide nets. The attraction flow is then dewatered, and collected fish are loaded into tanks, transported via trucks to stress relief ponds below Lower Baker Dam, held for 2 days, then released. This is an example of an FSC. Each of the other eight collectors are unique to each project. SFCs were installed at eight Pacific Northwest dams from 2008 through 2015.

According to Johnson and Giorgi (2015), these systems work on the following key premises:

- Smolts follow bulk flow as they approach a dam.
- Smolt migration is active, not passive.
- Smolts are surface-oriented and typically are concentrated (horizontally) somewhere across the face of a dam.
- SFO entrances do not elicit an avoidance response.
- Once guided, smolts remain in the SFO system and are passed safely.
- Smolts re-enter the tailrace and quickly resume their downstream migration.

Across all types of SFOs, performance levels have been generally high after completion of prototype testing and system configuration adjustments. According to Johnson and Giorgi (2015), SFOs have the following benefits:

- SFOs have high smolt survival (e.g., yearling Chinook salmon survival was 98.2% through the Bonneville Dam Second Powerhouse Corner Collector in 2011).
- Smolt residence times in forebays are short when SFOs are operating (e.g., a mean of 1.22 hours for steelhead at The Dalles Dam in 2011).
- A high proportion of smolts pass the dam through a small proportion of water relative to other passage routes.
- SFOs provide safe routes of passage for downstream-migrating adult salmonids (e.g., steelhead kelt survival was 93.6% through the TSW at Little Goose Dam in 2013).

Based on evaluations of the collectors installed in the early 2000s, it is becoming evident that both smolted and non-smolted juvenile salmonids utilize these systems, and that once fish passage is restored, fish outmigration timing and distribution also change. Younger fish that have not smolted exhibit a passage seasonality that is separate from smolted fish. The surface collectors are allowing fish that are rearing to become more broadly distributed within a watershed.

Until 2013, these systems relied upon trap and transport of collected fish. Contemporary approaches to this issue have evolved to consider the option of providing a volitional bypass. Portland General Electric’s (PGE) Clackamas Hydroelectric Project had an early corner collector installed along the north bank of the North Fork Dam Reservoir. This facility passed collected fish down a fish ladder for approximately 2 miles and separated the fish from the ladder for
placement into a separate bypass pipe to convey fish further downstream for release below the lowest of three dams in the complex. At the time of relicensing, PGE shifted their approach to fish passage at the three dams toward installing large surface collectors at two dams. The bypass pipe was updated, lengthened, and connected to the uppermost dam (North Fork Dam). The new low-velocity, low-impact bypass pipe is approximately 7 miles long, and it successfully provides volitional passage at a high-head dam complex with a combined head differential of over 300 feet. This bypass moves fish from North Fork Dam downstream to below the River Mill (Dam), and it eliminates impacts to fish from the trapping, handling, holding, and transportation and release associated with the original bypass design. This is an ideal circumstance and application can be difficult in some instances (limited land available, increased cost, etc).
Table D-1. Listing of various surface flow outlets installed at mainstem Snake and Columbia river and tributary dams.

| River          | Dam             | SPO Type                  | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 |
|----------------|-----------------|---------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|               |                 |                           | X  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Mid-Columbia   | Wells           | Modified spillway         |    | X  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | Rocky Reach     | Pumped collector          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | Rock Island     | Modified spillway         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | Wanapum         | FUBF (1)                  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | Priest Rapids   | Spill bay weir            |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Lower          | McNary          | Spill bay weir            |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Columbia       | John Day        | Spill bay weir            |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | The Dalles      | Ice and trash sluice      |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | Bonneville 1st  | Ice and trash sluice      |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | Bonneville 2nd  | Ice and trash sluice (2)  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Lower          | Lower Granite   | RSW                       |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Snake          | Little Goose    | Spill bay weir            |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | Lower Monumental| RSW                       |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | Ice Harbor      | RSW                       |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Tributaries    | Round Butte     | Turbine flow collector    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | River Mill      | Turbine flow collector    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | Upper Baker     | FSC                       |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | Lower Baker     | FSC                       |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | North Fork      | FSC                       |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | Swift           | FSC                       |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | Cushman         | FSC (3)                   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|               | Cowlitz Falls   | Modified spillway (4)     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

Notes: (1) FUBF constructed between powerhouse and spillway.
(2) Modified ice and trash sluice and constructed corner collector.
(3) Floating collector attached to face of dam.
(4) Modified spillway configurations tested since 1998. Surface collector currently under construction.

Source: Adapted from Johnson and Giorgi (2015).
The most important factor for successfully applying the SFO concept is to understand the project characteristics (head and forebay shape and flow patterns) and fish behavior unique to the site. The following factors play a role in selecting what type of SFO is most appropriate for a site:

- Project total head (i.e., whether the project is high or low head)
- Usage (i.e., whether the project is used for hydropower production or for water storage and flood control)
- Fish management objectives (i.e., whether it is necessary to handle, evaluate, and transport collected fish)
- Reservoir issues (length, temperature, predatory fish, elevation fluctuation, etc)

Table D-2 shows the most commonly encountered combinations of forebay environments and the types of SFOs that are used with each environment. The physical components that comprise each type of SFO are discussed in Section D.4.
Table D-2. Surface flow outlet options based on project usage of surface water.

<table>
<thead>
<tr>
<th>Type of Dam</th>
<th>Minimally Variable Surface Elevation (Run of River project) Evaluate, bypass or transport fish</th>
<th>Minimally Variable Surface Elevation (run of river project) Bypass fish to tailrace; no evaluation, holding, or transport</th>
<th>Highly Variable Surface Elevation (storage or flood control project) Evaluate, bypass or transport fish</th>
<th>Highly Variable Surface Elevation (storage or flood control project) Bypass fish to tailrace; no evaluation, holding, or transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-head dam (Total head is too high to spill fish to tailrace safely)</td>
<td>Fixed or FSC with screening and dewatering. Handling, holding, and transport facilities or bypass pipe to tailrace.</td>
<td>Fixed or floating dewatering structure. Bypass fish in conduit to tailrace.</td>
<td>FSC with screening and dewatering. Handling, holding, and transport facilities or bypass pipe to tailrace.</td>
<td>FSC with screening and dewatering. Bypass pipe to tailrace.</td>
</tr>
<tr>
<td>Low-head dam (Fish can be safely spilled to tailrace)</td>
<td>Fixed or FSC with screening and dewatering. Handling, holding, and transport facilities or bypass pipe to tailrace.</td>
<td>1. Spill without dewatering, or 2. Fixed or floating dewatering. Bypass fish to tailrace.</td>
<td>FSC with screening and dewatering. Handling, holding, and transport facilities or bypass pipe to tailrace.</td>
<td>FSC with screening and dewatering. Bypass pipe to tailrace.</td>
</tr>
</tbody>
</table>
D.4 Components of Surface Flow Outlets

This section describes the major components of high-flow bypasses and collection-and-transport systems. Note that numerous structural, mechanical, electrical, and biological design criteria should be met for each component.

D.4.1 High-Flow Bypasses

A high-flow bypass (Figures D-1, D-2, and D-3) is a spillbay or flume that conveys water and fish from the forebay of a dam to the tailrace. In most applications, flow rate is not controlled by any type of gate; rather, flow rate is determined by the head of the forebay water surface above the crest of the bypass. Adjustable spill weirs have been installed in spillbays at Little Goose Dam that allow the crest elevation to be set at two positions to adjust discharge into the bypass.

Typically, the existing spillbay control gates (radial arm or leaf) are either fully closed onto the top of the crest or are raised completely out of the flow (Figure D-3). A flume, or spillway-type floor, can be used to convey flow from the crest of the high-flow bypass outlet to the spillway surface and then to the tailrace. Log booms and boat safety booms are used to prevent large debris and boats from entering the high-flow bypass channels. Panel (a) of Figure D-6 shows the approximate location of the approach, discovery, and decision zones, which are described in Section D.6. It is also possible in some situations to install dewatering screens and pump a portion of the attraction flow back to the forebay (Figure D-6 (b)).
D.4.2 Surface Collectors

Surface collectors (Figure D-7) can be rigidly affixed to a dam (e.g., River Mill Dam on the Clackamas River, Oregon), supported on the bottom of the reservoir (e.g., Rocky Reach Dam on the Columbia River, Washington), or be free-floating (e.g., Upper Baker and Lower Baker dams on the Baker River, a tributary to the Skagit River, Washington, and North Fork Dam on the Clackamas River). Surface collectors use relatively large flow volumes to attract fish out of...
the forebay and into the collector. Electrically driven pumps are used for generating attraction flow into the FSCs in reservoirs that operate with large fluctuations in water levels and for pumping dewatered attraction flow back to the forebay. Attraction flow can also be provided by connecting the facility to a turbine intake or to a spillbay (e.g., Round Butte Dam on the Deschutes River, Oregon, and River Mill Dam on the Clackamas River, Oregon). Conventional fish screens (Chapter 8 of the Manual) are used to reduce the total flow needed for attraction to an SFO entrance to a smaller volume more suitable for bypass (or collection and transport) of the fish.

The following is a general list of surface collector components, although site-specific conditions may warrant that additional or fewer components be incorporated into the design:

- A floating log boom or debris barrier upstream of the collector to keep large debris from entering the collection system (sometimes more than one)
- A forebay guidance structure—consisting of guide nets, forebay curtains, walls, or louvers—that helps guide fish to the zone of discovery in front of the collector entrance and into the collector and prevents fish from entering a turbine penstock or spillway.
- Exclusion of alternate passage routes using screens or nets.
- An net transition structure that provides a gradual physical and hydraulic transition from the reservoir into the collector
- A collector, which is a dewatering structure consisting of fish screens designed to criteria (Chapter 8 of the Manual)
- Fish holding and sampling facilities
- A means to bypass collected fish to the river below the dam either via trap and haul or volitionally, as appropriate for the situation
- Personnel facilities
- For FSCs, a mooring system to hold the collector in position under the full range of reservoir forebay elevations
- Electrical power supply from the shore
Figure D-7. A general example of an FSC layout and components in plan (a) and cross-sectional (b) views. This example is floating and features full depth guide nets, a net transition structure, and trap and haul.

D.5 Design Development, Guidelines, and Criteria

Successful surface collector design requires a thorough understanding of project operations, site conditions, and fish behavior (e.g., congregation areas, vertical and horizontal distribution, searching behavior, and migration timing). It is unlikely that application of similar
designs at two different facilities will perform equally due to differences in fish behavior and flow patterns.

The designer must understand the three-dimensional (3D) and seasonal movements of both fish and water, including the effects of project operations and how these movements change in the future when project operations change. This cannot be emphasized enough and skipping these analyses can lead to poor performance.

**D.5.1 General Design Considerations**

The following considerations should be accounted for during conceptual development of SFO facilities:

- Fish resource managers need to establish reservoir passage design goals or standards.
- Identify how the reservoir affects fish passage:
  - Determine reservoir currents from tributaries to the collector, including knowledge of possible thermal stratification and its effects on the movement of warmer and colder water; determine if operations affect the currents and whether a seiche (oscillation in the water level of a body of water) is present.
  - Determine the migration timing, location in the water column and forebay, and behavior of fish that move from the tributaries, through the reservoir, and to the collector.
  - Determine the effect of future climate change on fish behavior and collection efficiency. This includes, but is not limited to, climate changes affecting reservoir currents, stratification, operational changes, migration timing, water quality, water use, fish health, and predation.
  - Determine whether there are issues in the reservoir that affect the health and movement of fish during passage (e.g., parasites and predators).
- The collection, holding, evaluation, and transport facilities should be designed, operated, and tested in a manner that satisfies the overall biological objectives for the project.
- The purpose of surface collectors, what they do, and how they work must be understood: they attract and collect a high percentage of migrating fish using a limited amount of attraction flow.
- Developers should determine when to use SFO technologies (with volitional bypass or trap and haul) instead of turbine intake screens (Appendix G).

**D.5.2 Hydraulic Design Process**

The following steps should be followed as part of the hydraulic design of SFO facilities and in coordination with biological studies conducted to obtain information on fish migration behavior:

1. Characterize the 3D hydraulic conditions and stratification in the forebay, using the following:
   - Submerged recording current meters and thermometers
- 3D computational fluid dynamic (CFD) modeling, including water temperature modeling
- Field data to calibrate the CFD model
- CFD modeling to simulate expected reservoir operating conditions and test effects of alternate outlet locations and reservoir operating strategies to maximize fish passage

2. When fish are present, perform 3D tracking of fish (both target and predator species) to ascertain their vertical and horizontal distribution as well as movement and holding patterns. Determine and look for search behavior and congregation areas within the range of expected project operations.

3. Design dewatering screens (based upon criteria presented in Chapter 8 of the Manual and modified as appropriate in this appendix).

4. Design collection, evaluation, transport, and release facilities (based upon the criteria and guidelines presented in Chapter 8 of the Manual and Appendix F) incorporated into the SFO.

5. Use the design process outlined in Chapter 3 of the Manual.

6. Conduct post-construction evaluations of SFO performance and adjust the configuration of the SFO facilities to improve fish attraction and collection efficiencies if needed.

**D.5.3 Floating Surface Collector Design Guidelines and Criteria**

Successful FSCs combine a good entrance location oriented to fish approach and milling behavior, attraction flow volume, and entrance hydraulic conditions. While the amount of flow required, location, and entrance orientation of surface collectors is different at every location, there are basic design components that are consistent among FSCs. Designers should work to anticipate how fish may change behavior upon installation of a new FSC (Will the fish mill in the same area? Do baseline active tag studies exhibit clear “search” behavior, shown by multiple trips back and forth? Should a mock-up version be installed to test fish reaction?).

The fish protection required for FSCs is the same as that provided in any screen facility. Chapter 8 of the Manual describes fish screen facility requirements and their importance. In addition, Appendix F provides information on juvenile fish collection and evaluation facility design requirements.
Fish Screen Components

1. Trash rack
2. Screen cleaning brush (in parked position)
3. Primary screen panels (typical)
4. Porosity control panels (typical)
5. Screen panel support structure (typical)
6. Secondary screen panels (if required)
7. Secondary screen floor ramp
8. Downwell
9. Adjustable bypass flow control gate and ramp
10. Fish bypass return-to-river pipe
11. Tailwater elevation control gates
12. Mud sill

Figure D-8. Components of a standard fish screen design.
D.5.3.1 General

D.5.3.1.1

All surface collector screen systems should have a trash rack at the entrance to minimize the amount of debris that will reach the fish screen structure. Trash racks should have openings not less than 10 inches wide for Chinook salmon passage, or 8 inches for all other salmonid species. For surface collectors, this trash rack should be automatically cleaned and trashed removed.

Fine debris can be the bane of a trap and haul facility, especially when fish and debris are diverted to raceways for holding, evaluation, and transport. Many dewatering screen designs only concentrate debris rather than removing it. Large amounts of fine debris in the holding raceways can plug screens and cause fish injury.

The use of fine mesh “debris skimmers” (which intercepts debris in the upper 2 to 3 feet of the water column) have been used outside of the mouth of the NTS (Upper and Lower Baker FSC). Also, traveling screens (which remove the debris from the water flow) have been used in place of primary or secondary screens (Cushman FSC and the North Shore Collector at Cowlitz Falls Dam).

D.5.3.1.2

NMFS staff experience maintains that design minimum attraction flow is in the range of 10% to 20% of the powerhouse discharge (or 500 ft³/s, whichever is greater), but can be as high as 100% of project outflow. Due to the individual nature of most sites, NMFS supports designing and testing the SFO or FSC at higher attraction flows. NMFS will carefully consider proposals and may identify reasons to increase attraction flow, based upon site-specific issues.

For project examples showing project outflow, please see the case studies presented in Section D-6.

D.5.3.1.3

Surface collectors should be designed for operation throughout the year. Actual operating timing will depend on site-specific information and juvenile outmigration timing.

D.5.3.2 Dewatering Screen Systems

D.5.3.2.1

The design approach velocity for dewatering screens within the surface collector screens should not exceed 0.4 ft/s for fish screens, and exposure time should be limited to less than 60 seconds.
D.5.3.2.2

Sweeping velocity is defined as the water velocity component parallel to the face of a fish screen. The design sweeping velocities should not be less than the design approach velocity and should not decrease along the length of the screen.

D.5.3.2.3

The screen design should provide for nearly uniform flow distribution over the screen surface, thereby minimizing approach velocity over the entire screen face. The designer should show how a uniform flow distribution will be achieved. The maximum deviation from the target design approach velocity is 10%.

D.5.3.2.4

To ensure uniform flow distribution, most screens should be equipped with some form of adjustable porosity controls placed immediately behind the screen. For tall screens, NMFS may require that the screen height be divided into multiple, independent tuning modules to ensure approach velocity uniformity. Screen porosity controls should be tuned to achieve the criteria approach velocity prior to a screen being placed in commission. The use of louver-style porosity control baffles are not applicable for use in surface collectors, because they have shown insufficiency in balancing inflow with a high sweep flow screen.

D.5.3.2.5

All FSC screens should incorporate an automated cleaning system.

D.5.3.2.6

Screen cleaners should be capable of removing debris from the entire screen surface at least once every 5 minutes and should be operated as required to prevent debris accumulation. Cleaning systems should be designed to operate continuously or on an adjustable timer.

D.5.3.2.7

Screen materials should be corrosion-resistant and sufficiently durable so as to maintain a smooth, uniform surface over the course of long-term use. Perforated plate surfaces should be smooth to the touch, with the openings punched through in the same direction as the water flow.

D.5.3.2.8

The maximum screen opening allowed is based on the shape of the opening. Circular screen face openings should not exceed 3/32 inch in diameter. Slotted screen face openings should not exceed 0.069 inch (1.75 mm) in the narrow direction. Square screen face openings should not exceed 3/32 inch as measured on a diagonal.
The circular screen face opening criterion is based on Neitzel et al. (1990a), the slotted screen face opening criterion is based on Mueller et al. (1995), and the square screen face opening criterion is based on Neitzel et al. (1990b).

D.5.3.2.9

The percent open area (porosity) for any screen material should be at least 27%.

D.5.3.2.10

Screens and associated civil works that are exposed to fish should be constructed such that there are no gaps greater than 0.069 inch (1.75 mm). For traveling belt screens or other screens with moving screen material, screen seals should be sufficient to prevent gaps larger than 0.069 inch (1.75 mm) from opening during screen operations.

D.5.3.3 Surface Collectors that Utilize Volitional Bypass

For surface collectors that volitionally bypass collected fish to a downstream release location, the following criteria apply.

D.5.3.3.1

Bypass systems should work in tandem with the fish screens to move all fish present (target and non-target species and all life stages) from the area in front of the screens and return them back to the stream or river (or to a holding pool, in the case of trap and haul facilities) with a minimum of injury and delay (Clay 1995).

D.5.3.3.2

The bypass entrance should be located at the downstream terminus of the fish screens and should be designed to allow downstream migrants to easily locate and enter the bypass (Clay 1995). The screen and any guidewalls should naturally funnel downstream migrants and flow to the bypass entrance. For screens that are less than 6 feet in length and are constructed perpendicular to canal flow, the bypass entrance(s) may be located at either end (or both ends) of the screen.

D.5.3.3.3

Each bypass entrance should be capable of controlling the flow rate through that entrance.

D.5.3.3.4

At no point should flow decelerate along the screen face (except in sections downstream of fish capture) or in the bypass channel.
D.5.3.3.5

Lighting conditions upstream of a bypass entrance should be ambient and extend downstream to the structure or device controlling bypass flow. In situations where transitions from light to dark conditions (or vice versa) cannot be avoided, they should be gradual or occur at a point in the bypass system where fish cannot escape the bypass and return to the canal (i.e., at a location where bypass flow velocity exceeds fish swimming ability).

D.5.3.3.6

The bypass entrance should be sized to accommodate the entire range of bypass flow, utilizing the criteria listed in Section 8.6 of the Manual.

D.5.3.3.7

The minimum water depth over the bypass weir is 1 foot; however, a depth of 1.5 feet over a weir is preferred. Similarly, weir width should be a minimum of 1.5 feet; greater widths are preferred.

D.5.3.3.8

All bypass entrances should be designed to gradually accelerate flow into the bypass entrance and between the entrance and the flow control device at a rate not to exceed 0.2 ft/s per linear foot and achieve capture velocity of 8 ft/s.

D.5.3.3.9

Secondary (and tertiary, etc.) dewatering screens should meet all design guidelines (e.g., approach velocity, sweeping velocity, cleaning, and screening material) of the primary screens.

D.5.3.3.10

Depending on the site-specific conditions, the bypass conduit can be either U-shaped flume or round pipe.

D.5.3.3.11

The interior surfaces and joints of bypass flumes or pipes should be smooth to the touch to provide conditions that minimize turbulence, the risk of catching debris, and the potential for fish injury.

D.5.3.3.12

The minimum bypass pipe diameter should be 10 inches.
D.5.3.3.13

The minimum design bypass flow should be 5% of the total diverted flow rate. In surface collectors, certain factors make it necessary to reduce flow even more, likely using a second (secondary) or third (tertiary) set of dewatering screens.

D.5.3.3.14

Water velocity in the bypass conduit should be between 6 and 12 ft/s for the entire operational range of bypass flow, and it should always be greater than 2 ft/s.

D.5.3.3.15

The design minimum depth of free surface flow in a bypass pipe should be at least 40% of the bypass pipe diameter.

D.5.3.3.16

Closure valves should not be used within the bypass system.

D.5.3.3.17

Fish should transition through bypass system components via gravity flow and should not be pumped.

D.5.3.3.18

Downwells should be sized based on an energy dissipation factor between 8 to 10 ft-lb/ft³/s. Fish should not free-fall within a bypass system pipe or enclosed conduit. Equation 8-1 in the Manual should be used to calculate downwell volume.

D.5.3.3.19

Flow in all types of fish conveyance structures should be open channel (i.e., not pressurized). Bypass systems should be vented or open to the atmosphere. If a pressurized bypass conveyance is required by site constraints, pressures in the bypass pipe should remain equal to or above atmospheric pressures. Transitions from pressurized to non-pressurized conditions within a bypass pipe, and vice versa, should be avoided.

D.5.3.3.20

For bends provided in the bypass—the ratio of bypass pipe center-line radius of curvature (R) to pipe diameter (D), or R/D—should be greater than or equal to 5.

D.5.3.3.21

Bypass pipes or open channels should be designed to minimize debris clogging, sediment deposition, and facilitate their inspection and cleaning as necessary.
D.5.3.3.22

Access for maintenance inspections and debris removal should be provided at locations in the bypass system where debris accumulation may occur. Bypass systems greater than 150 feet in length should include access ports at appropriate spacing to allow for the detection and removal of debris.

D.5.3.3.23

Bypass outfall locations should meet the following conditions:

- Bypass outfalls should be located to minimize predation by selecting an outfall location that is free of eddies and reverse flow and does not place bypassed fish into an area of known predator habitat (Bell 1991).
- The point of impact for bypass outfalls should be located where ambient river velocities are greater than 4 ft/s when in operation (Shively et al. 1996).
- Bypass outfall locations should provide good egress conditions for juvenile fish exiting the bypass and re-entering the stream channel (Bell 1991).
- The bypass flow should not impact the river bottom or other physical features at any stage of river flow. Bypass outfalls should be located where the receiving water is of sufficient depth to ensure that fish injuries are avoided at all river and bypass flows.
- The bypass outfall should not release fish into areas where conditions downstream from the bypass discharge point will pose a risk of injury, predation, or stranding (Bell 1991). For example, bypass outfalls should avoid discharging fish into areas from which they can enter reaches where flows run subsurface. In this situation, fish can become stranded in pools that are isolated from the main channel under low flow conditions. Also, bypass outfalls should not discharge in the vicinity of any unscreened water diversion or near eddies that may be habitat for predator fish.

D.5.3.3.24

Maximum bypass outfall impact velocity (i.e., the velocity of the bypass flow as it enters the receiving water) should be less than 25 ft/s, including both the vertical and horizontal velocity components.

D.5.3.3.25

Predator control systems may be needed in areas with a high potential for avian predation.

D.5.3.3.26

Bypass outfall discharge into the receiving water should be designed to avoid attracting adult fish to the discharge. If the potential exists that adults may be attracted to bypass outfall discharge, the design of the bypass outfall should include a provision for adult fish to land safely in a zone or location after jumping.
D.5.3.4 Surface Collectors that Utilize Trap and Haul

For projects that are designed to collect, hold, transport, and release bypassed fish (i.e., trap and haul) to a downstream location, the following criteria apply.

D.5.3.4.1

*Personnel should be experienced and trained to ensure that fish are handled safely.*

D.5.3.4.2

*Use of nets to capture or move fish should be minimized or eliminated. If nets are used, they should be sanctuary-type nets with solid bottoms to allow minimal dewatering of fish. Fish should be handled with extreme care.*

D.5.3.4.3

*In most cases, fish should be anesthetized before being handled. The method of anesthetization for Endangered Species Act (ESA)-listed anadromous salmonids may be specified by the appropriate ESA permit, which should be received prior to any directed taking of listed species. In the design process and prior to permit submittal, the type of anesthetic can be selected with help from NMFS staff involved in the design of the collection facility.*

D.5.3.4.4

*Fish should be removed from traps at least daily. When either environmental (e.g., water temperature extremes, low dissolved oxygen, or high debris load) or biological conditions (e.g., migration peaks) warrant, fish should be removed more frequently to preclude crowding, injury, or adverse water quality.*

D.5.3.4.5

*As with other collection facilities (Chapter 7 of the Manual), juvenile fish collection and evaluation facilities should be located off line from the primary route of passage. The collection and evaluation facilities should not disrupt the normal operation of the bypass flow, which allows fish to proceed down the bypass and continue their outmigration when the facility is not being operated.*

D.5.3.4.6

*A diverter gate—or switch gate—should be used to divert fish and flow from the main bypass channel into the collection or evaluation facility, and it should be designed to not reduce water velocity in the flume or create areas where fish can hold and delay. Depending on the design and frequency of operation, it may be necessary to provide flushing water downstream of the gate to insure the fish remaining in the bypass channel are not stranded.*
D.5.3.4.7

The dewatering screen should meet the screening criteria (e.g., maximum approach velocity, sweeping velocity, screen type and material, and maximum screen opening) established in Chapter 8 of the Manual. Most dewatering screens use horizontal floor screens due to the very shallow nature of the flow.

D.5.3.4.8

The design of the dewatering screens should guarantee a minimum amount of water off the end of the downstream end of the screens to carry downstream migrants into the holding pool.

D.5.3.4.9

The separator bars (that will be used to separate sizes of fish) should be submerged by several inches of water so small fish are able to swim down between the bars into the holding tank underneath.

D.5.3.4.10

The separator bars should be smooth and are typically 1-inch diameter pipes with 1.5-inch clear openings between pipes. Depending on site conditions, it may be best to construct the separator bars such that the clear opening can be adjusted depending on the size of the target species.

D.5.3.4.11

The slope of the separator bars for wet separators is generally flat.

D.5.3.4.12

The separator bars are located above the water surface in the holding tank. Fish and flow from the dewatering screen transition onto the separator bars, and the water and small fish pass (fall) through the bars to the holding tank below.

D.5.3.4.13

A minimum slope for the separator should be 5%; however, this may need to be adjusted depending on the length of the separator and the speed at which fish enter the separator.

D.5.3.4.14

The length of the separator bars is usually 8 to 12 feet but depends on the speed of the fish entering the separator system and the slope of the bars.

D.5.3.4.15

The separator bars of a wetted system should be kept wet by either of the following:
• An overhead spray bar system: This consists of a series of water spray bars located a minimum of 18 inches above the separator bars.

• Pressurized separator bars: The separator bars can be used to create a pressurized manifold that delivers water into each bar. A series of 0.125-inch holes, approximately 6 inches on center, are drilled at the top of each separator bar. The holes create a series of small water jets (about 6 to 8 inches high) along the length of the separator bars.

D.5.3.4.16

To collect more than one size class of juvenile fish, separator bar systems can be located in a series one downstream of the other. The upstream separator bar system should have the smallest clear opening between bars, and the downstream system should have the largest.

D.5.3.4.17

Both the wet and wetted separator systems should be staffed with appropriately trained personal 24 hours per day while the system is collecting fish.

D.5.3.4.18

The holding area beneath the separator bars should include add-in flow and funnel fish and flow to a distribution flume that conveys fish to a raceway, holding tank, and/or transportation vehicle.

D.5.3.4.19

It is usually necessary to provide flushing flow to the upstream end of the holding tank to encourage fish to leave the holding tank and provide flow to the distribution flume.

D.5.3.4.20

Fish passing through the separator bars should land in water. The holding tank should provide enough volume to safely transition the fish to the distribution flume, but not so much volume that it allows fish to reside in the holding area.

D.5.3.4.21

A distribution flume (or pipe) should be used whenever fish are routed from one area to another.

D.5.3.4.22

At junctions where bypass flumes, distribution flumes, or pipes meet, the invert elevation of one conveyance structure should be above the water surface elevation of the receiving structure (flume or pipe). Water flow volume in the receiving conveyance structure should be constant, and differences in water velocity between the two conveyance flows should be less than or equal to 2 ft/s. The maximum angle between the centerline of the two flumes should be less than or equal to 45 degrees (aligned in the downstream direction).
D.5.3.4.23

Flat bottom or square distribution flumes for juvenile passage should be avoided. Round bottom (U-shaped) flumes are the preferred shape for distribution flumes; however, pipes are acceptable under limited circumstances provided adequate access is provided.

D.5.3.4.24

U-shaped flumes should be covered to provide a minimum of 40% shading (60% occluded).

D.5.3.4.25

The flume should have smooth joints, sides, and bottom with no abrupt vertical or horizontal bends.

D.5.3.4.26

The flume should have a continuously wetted surface throughout the flume (i.e., no dewatered areas).

D.5.3.4.27

Horizontal and vertical radii of curvature should be at least 5 times the width of the flume to minimize the risk of fish-strike injuries and trapping debris.

D.5.3.4.28

At locations where debris blockages are a concern, juvenile distribution flumes should include access ports (with removable covers) for inspection and debris removal.

In any distribution flume, it is important to have access for inspection and removal of accumulated debris. The access port cover can be designed to provide 40% shading (60% occluded).

D.5.3.4.29

The inside diameter of the distribution flumes and pipes should be less than or equal to 10 inches.

D.5.3.4.30

Water depth in the flume should be less than or equal to 2.5 inches. Water velocity in the flume should be between 6 and 12 ft/s.
D.5.3.4.31

Guidance for distribution flumes designed to transport larger fish (e.g., adults that fallback over the dam, kelts migrating downstream, and resident fish) after being separated from juvenile fish are outlined in Section 7.5.10 of the Manual.

D.5.3.4.32

If a passive integrated transponder (PIT)-tag detection system is installed, the manufacturer should be contacted to obtain the specific hydraulic conditions required for the selected detector to function properly.

D.5.3.4.33

The diverter gate should be designed to not reduce water velocity in the flume or create areas where fish can hold and delay. The gates should be designed so they are flush with the walls and floor of the flume without any projections or sharp edges where fish could become injured.

D.5.3.4.34

Flushing flow should be provided downstream of any diverter gate on all flumes to ensure that any fish downstream of a closed diverter gate can continue to move downstream and are not dewatered.

D.5.3.4.35

The holding density of holding pools or raceways should be 0.5 pounds (lb) of fish per gallon (3.74 lb/ft³; Appendix B in USACE 2018).

D.5.3.4.36

Water falling freely into a holding pool, tank, or raceway can cause juvenile fish to leap at the flow and should be minimized or eliminated. Consideration should be given to include an overhead spray system that delivers a fine mist of water on the surface of the raceway. This breaks up the water surface and provides the fish with cover, which can reduce stress on fish and decrease jumping behavior.

D.5.3.4.37

If the holding or sample tanks are outside, it may be necessary to provide shading and/or bird protection (netting) to reduce stress and insure fish safety.

D.5.3.4.38

Water quality in the holding tanks and raceways should be equal to or exceed that of the waters from which the fish were trapped. Water temperature, oxygen concentration, and pH levels should provide fish with a safe, healthy environment.
D.5.3.4.39

Water supply to holding tanks and raceways should be routed through a diffuser that conforms to the design criteria identified in Section 5.3.7 of the Manual and results in a maximum average water velocity of 0.5 ft/s through either vertical or horizontal diffusers. Diffuser openings should conform to juvenile screening requirements (Section 8.5.7.10 of the Manual).

The screen face opening criteria identified in Section 5.3.2.8 of the Manual apply to diffuser openings as well.

Horizontal diffusers should be used when supplying water directly to holding pools. Baffling or other structural means to dissipate water energy should be used to prevent excessive turbulence and surging associated with water supplied to holding tanks or raceways to support fish being held.

The inflow should be 5 gallons per minute per lb of fish (Appendix B in USACE 2018).

D.5.3.4.40

The approach velocity for holding pools and raceways should not exceed 0.2 ft/s and should be regularly cleaned. The screen opening should conform to the juvenile screen requirements (Section 8.5.7.10 of the Manual).¹

D.5.3.4.41

A freeboard of 2 feet should be provided on all holding facilities to reduce the chance of fish jumping out of the holding tank and being stressed and facility personnel walking past the tank.

Often, netting is needed to either cover the holding tank/raceway or raise the height of the tank walls to prevent fish from jumping out.

D.5.3.4.42

The minimum depth of the raceway or holding tank should be 30 to 36 inches (Piper et al. 1982) although deeper raceways are possible.

D.5.3.4.43

Unless a holding tank or raceway is drained to evacuate fish being held, crowders or a brail system will be required to remove fish from the tank or raceway. Key design aspects of crowder and brails systems are as follows.

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¹ This information is consistent with Section F.5.8.4.
D.5.3.4.44

Crowder and brail components that contact fish should be smooth and free of sharp edges or projections.

A brail should not be used to lift fish completely out of the water.

- The clear openings on screens used for crowders and brails should not exceed 1.75 millimeters and 3/32 inch for circular or square openings in perforated plate or woven mesh material.
- The crowder and brail should seal to the sides and floor of the tank or raceway, and also at the joint between the crowder and brail. Soft neoprene rubber gaskets or brush seals are all acceptable methods of sealing crowders and brail, although gaps in these methods should not exceed 1.75 millimeters.
- The speed of the crowder should not exceed 0.5 to 1 ft/s.
- Fish lifts and hoppers should be sized to hold 0.5 lb of fish per gallon of water.

D.5.3.4.45

The distance from the water surface of a hopper to the top of the hopper bucket should be greater than water depth in the hopper to reduce the risk of fish jumping out during lifting operations.

D.5.3.4.46

When a trap design includes a hopper sump (into which the hopper is lowered during trapping), side clearances between the hopper and sump sidewalls should not exceed 1.75 millimeters, thereby minimizing fish access below the hopper. Flexible side seals should be used to ensure that fish do not pass below the hopper.

D.5.3.4.47

Frequently, trucks or tanks used to transport adult fish are also used to transport juvenile fish. In these instances, the opening from the juvenile hopper should be the same as the adult hopper. The opening from the hopper into the transport tank through which fish pass should have a cross-sectional area of at least 3 square feet and a smooth transition that minimizes any potential for fish injury.

D.5.3.4.48

Measures should be provided to exclude fish from entering the holding pool area that is to be occupied by the hopper when the hopper is lowered into position for loading. The measures should be fail-safe. Also, the interior of the hopper should be smooth and designed to not injure fish by eliminating rough surfaces and sharp corners.
D.5.3.5 Fish Evaluation Facilities

The sampling facility is a location where individual fish can be sorted, counted, and examined for marks, tags, or injury. The sampled fish can also be identified as to their species, run, or origin (wild or hatchery). Additional tagging or tissue samples can also be collected on individual fish in the sampling facility.

D.5.3.5.1

Personnel should be experienced or trained to ensure that fish are handled safely.

D.5.3.5.2

Fish should be anesthetized prior to handling using protocols identified in the permitting process. After examination, the anesthetized fish can be placed in a 4-inch-diameter wetted flume for delivery to a recovery tank. A source of water should be supplied to the upstream end of the 4-inch flume to convey fish in the flume to the tank.

D.5.3.5.3

Anesthetized fish should be routed to a recovery pool to allow for monitoring to ensure the fish have fully recovered from the anesthetic prior to release. Fish recovering from anesthesia should not be routed directly back to the river or bypass flow where unobserved mortality may occur. Water volume inflow to a recovery pool or tank should satisfy the water quality guidelines specified in Section F.5.8.3. Hydraulic conditions in the pool or tank should not result in partially or fully anesthetized fish being impinged on an outflow grating or any other hazardous area.

D.5.3.5.4

After the fish are recovered, they are often released back to the bypass system or river by draining the pool or tank. To accommodate this procedure, the design of the pool or tank should allow it to be safely drawn down to a certain water level before the release gate located at the bottom of the tank is opened to release the remaining fish and flow. The bottom of the tank should also be shaped, and the floor sloped, to guide fish into the release flume; flushing added to the pool or tank while it is being evacuated will ensure that fish readily exit the tank.

D.5.3.6 Transporting Fish from Surface Collectors

D.5.3.6.1

Maximum loading density is 5 lb of fish per 1 gallon per minute inflow for flow through barges, which is similar to those used to transport juvenile fish from Columbia River dams (Appendix B in USACE 2018).
D.5.3.6.2

There should be 0.5 lb of fish per 1 gallon of water (3.74 lb/ft³) for transport trucks or tanks on trucks (Appendix B in USACE 2018).

Transportation operations should be implemented in a manner that is consistent with the permit issued for the activity, including the use of oxygen and avoiding the transportation of fish under elevated water temperatures.

D.5.3.6.3

The hopper used to load truck transport tanks should be compatible with the truck tank and designed to minimize fish-handling stress.

D.5.3.6.4

The transport tank should provide for the safe transport and release of the juvenile fish. All edges that fish may come into contact with should be rounded and smooth.

D.5.3.6.5

The fish egress opening from the transport tank should have a minimum cross-sectional area of 1 square foot for a square opening and a 12-inch diameter for a circular opening.

D.5.3.6.6

The bottom of the transport tank should be sloped (front to back and side to side) toward the release opening and should have a smooth transition that minimizes the potential for fish injury.

D.5.3.6.7

After downstream transport, fish should be released into a stress relief pond where they can recover and acclimate to ambient water quality conditions before resuming their downstream migration.

D.5.3.6.8

The maximum holding density of the stress relief pond should be 0.5 lb of fish per gallon of water (3.74 lb/ft³).

D.5.3.6.9

Fish should be held in the pond for a minimum of 24 hours, then allowed to volitionally leave the pond. After 48 hours, the pond should be drained (or the fish should be crowded to the outlet) to the release point on the river.
D.5.3.6.10

If the acclimation pond is to be drained to release the fish, the bottom of the pond should be shaped such that fish and flow funnel into the release flume. The pond should be drawn down to a safe release level and flushing flow added to ensure fish exit the pond before the pond is completely drained.

D.5.3.6.11

The release flumes for the stress relief ponds should follow the guidance for the bypass conduit and outfall guidelines described in Sections 8.6.4 and 8.6.5 of the Manual.

D.5.3.6.12

If the fish are not released to a stress relief pond after transportation, then the fish should be released back to the river in a safe location with good water quality. Releases should be implemented in a manner that is consistent with the permit issued for the activity.

D.5.3.6.13

The release site should provide direct and simple egress for fish into the river for continued upstream migration.

D.5.3.6.14

Water quality (e.g., temperature and dissolved oxygen) at the release site should be representative of the general water conditions in the river at the release site, and water tempering techniques should be used before ESA-listed fish are released.

D.5.3.6.15

Fish should not be subjected to rapid temperature changes. Temperature differentials between the transport tank and release location should be no more than 2°C. If tempering is required to meet this criterion, changes in temperature should not exceed 1°C every 2 minutes or 5°C per hour. Tempering may take longer when temperatures are further away from the fishes’ optimal temperature.

D.5.3.7 Surface Collector Nets and Net Transition Structures

D.5.3.7.1

FSC designs usually includes a guidance net system.

There are many variations of FSCs and some examples where larger collectors are successful without guidance net systems. Designing guidance net systems requires the purpose of the net to be determined (e.g., whether the purpose of the system is to keep fish away from a passage route that injures fish or guide fish to the FSC entrance). An example of a guidance net system is shown in Figure D-9. A debris boom that extends from the right to left shoreline of the
reservoir can be seen in the foreground of the photo. The net guidance system in the background is comprised of barrier nets that extend from the FSC to each shoreline to keep fish from going behind the FSC and a lead net directly in front of the FSC to guide fish from the reservoir into the FSC entrance. An example of a net guidance system designed to keep fish away from a passage route is shown in Figure D-10.

The design, anchoring scheme and operation of guide nets is not a simple matter and should not be taken lightly. A subject expert should be employed during this design process. Other information to be taken into consideration is the following:

- Do not locate the net in areas where it can hang up.
- Do not use anchoring equipment that the nets can hang up on.
- Nets should incorporate reinforced or rip-stop seams so that if a net tears, the entire net is not damaged or lost.
- The net may need to incorporate some type of “gate” or access to allow boat traffic while preventing fish from getting through.
Figure D-10. North Fork Dam on the Clackamas River, Oregon. A net was installed to prevent fish from passing through a highly injurious spillway. The net also helped guide fish laterally in the forebay to a FSC that was installed near the penstock intakes after the photo was taken (Courtesy of Portland General Electric).

D.5.3.7.2

The net should span the open channel or cross section of the reservoir, be full depth, work to guide fish toward the entrance of the surface collector from upstream at the bank of the river/reservoir, and provide a clean transition from upstream to downstream at the collector entrance (commonly referred to the shape of the overall system as a V-shape). The net function and placement may vary based on site-specific project operations and stream flow characteristics.

D.5.3.7.3

The mesh opening for the net should be as close as possible to the requirements for fish screens. For example, Baker FSCs use a 3/2 mesh for the upper 30 feet of the guide net, with all guide net deeper being larger one inch mesh opening.
D.5.3.7.4

Most net structures benefit from having a solid section of material at the top of the net; this helps with debris.

D.5.3.7.5

The net design and operation should provide for some form of flood protection; most are lowered during flood flows to preserve the integrity of the net.

D.5.3.7.6

A net cleaning system should be included in the design. An inspection method (e.g., divers, remotely operated vehicle) and schedule should be included in the design.

D.5.3.7.7

An NTS is generally recommended with a surface collector. The purpose of the NTS is to guide fish and accelerate flow from the reservoir to the entrance of the FSC. The NTS should provide a slow and gradual acceleration, with the intent to increase fish acceptance of passage into the structure.

The NTS should accelerate flow such that the maximum acceleration does not exceed 0.2 ft/s per foot distance.

Figures D-11 through D-13 provide examples of various NTSs and their relationship to a FSC.
Figure D-11. A net transition structure for an FSC located at Cushman Dam No. 1 located on the North Fork Skokomish River, Hoodsport, Washington. The structure as shown is floating upside down on the surface of the lake during deployment (photo courtesy of Thompson Metal Fab. Inc.).

Figure D-12. NTS for the Lower Baker Dam FSC, Baker River, Washington (Courtesy of Puget Sound Energy).
The NTS generally serves as the anchor point for the downstream end of the guide nets. The Baker FSCs mouth of the NTS (Figure D-12) is 50 feet deep and 50 feet wide to develop a design target of 0.2 ft/s at the low design attraction flow of 500 ft³/s. The NTS itself consists of a floating, self-supporting frame structure, the inside of which is covered with relatively thin sheets of high-density polyethylene to create a smooth impermeable surface. The NTS accelerates (not to exceed 0.2 ft/s/ft) and guides flow and fish into the entrance to the FSC.

**D.6 Case Studies**

In 2007, ENSR conducted a thorough assessment of the performance of 16 types of SFOs at 10 dams located on the Columbia and Snake rivers (ENSR 2007). The types of surface outlets reviewed included traditional powerhouse sluiceways, surface spill, forebay collectors, and
retrofitted spillbays located above powerhouse turbine intakes. For fish migrating during spring, the review assessed the performance of these systems for yearling Chinook, Coho, and sockeye salmon; steelhead; run-at-large spring migrants not identified to species or run; and a spring biological index. For fish migrating during summer, the review assessed subyearling Chinook salmon, run-at-large summer migrants, and a summer biological index (ENSR 2007).

Since 2007, several large-scale surface collectors at high-head dams have been designed, installed, and tested. Each floating or fixed at-dam collector design incorporated site-specific information and the latest performance data and lessons learned from collectors at other dams. Because of this iterative process, the unique aspects of each design, and the evolving nature of the approaches and information, NMFS decided that presenting a series of case studies was the most effective means of describing surface collection systems and key design elements to consider during the design process.

In 2016, the Northwest Power and Conservation Council (Council) developed a paper “to identify and evaluate the current methods and effectiveness of fish passage systems used at high-head dams or emerging technologies that could be applied to dams of similar or greater size and capacity, such as Grand Coulee and Chief Joseph dams” (NPCC 2016). These two high-head dams are located on the upper Columbia River, lack fish passage facilities and blocked access to upper Columbia River habitats, and extirpated multiple anadromous fish stocks. Discussions are underway in the Columbia River basin regarding providing fish passage at the two dams, and the paper developed by the Council is an up-to-date synthesis of technologies that provide fish passage at high-head dams.

The Council granted NMFS permission to use the information in NPPC (2016) for Appendix D to the Manual. Three case studies described below were taken directly from the Council’s report (NPPC 2016): Baker River, Lewis River, and Pelton Round Butte Complex. The fourth case study on the Clackamas River Complex was developed by NMFS.
CASE STUDY 1: BAKER RIVER HYDROELECTRIC PROJECT

Project Location: Baker River, Skagit River basin, northwestern Washington (Figure D-14)

Figure D-14. Map of the Baker River Hydroelectric Project Dams and reservoirs in northwestern Washington.

Species of Interest: Primarily sockeye and coho salmon; also of interest was the passage of Chinook salmon, steelhead, bull trout (Salvelinus confluentus), non-native char (lake trout [S. namaycush] and brook trout [S. fontinalis]), and sea-run cutthroat trout (O. clarkii clarkia)

Passage System: An FSC, NTS, and guide nets installed at Upper Baker and Lower Baker dams. The fish are trapped, transported, and released downstream.

Project Information:

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<th>Lower Baker</th>
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</thead>
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<td>Power Production Capacity</td>
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### Dam Facts

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<th>Lower Baker</th>
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</thead>
<tbody>
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<td>Reservoir Length</td>
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<td>7</td>
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<td>Hydraulic Head</td>
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<td>Forebay Fluctuation Range</td>
<td>feet 50</td>
<td>68</td>
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<tr>
<td>Attraction Flow into Collector</td>
<td>ft³/s 500</td>
<td>500</td>
</tr>
</tbody>
</table>

Note:
MW: megawatt

Discussion: The 2006 relicensing settlement agreement and subsequent FERC license of 2008 for the Baker Project called for improved upstream and downstream fish passage facilities. The gulpers were decommissioned and, in their place, FSCs were installed in the forebays of both Upper and Lower Baker dams in 2008 and 2013, respectively. The FSC was the first of its kind and received national recognition once in operation. The FSC is the central feature of a multifaceted juvenile fish passage facility comprised of the following components (listed in a downstream direction) and the purpose and design of each:

- **Log boom**
  - Used for exclusion of floating debris and to prevent public access to the forebay facilities
  - Floats at the surface upstream of the guide nets

- **Guide nets**
  - Prevents juveniles from entering powerhouse turbines and assists in guiding fish to the NTS and FSC
  - Spans 5 acres of surface area, stretching shore to shore and surface to lakebed (up to 300 feet deep)
  - Anchored on each shore and connected to the NTS
  - Constructed of Dyneema mesh, which is a high-strength synthetic fiber
  - Mesh opening is 3/32 inch at the surface and 1/4 inch from 30 feet deep to the lakebed
  - Floats (pneumatic hose and high-density polyethylene booms) installed at the surface to allow the net to adjust with reservoir fluctuations of up to 70 feet

- **NTS**
  - Attached to both the downstream end of the guide nets and the upstream end of the FSC
  - Acts as a large funnel, with a narrowing channel and an inclined base, to direct the fish into the collector and provide a gentle acceleration for fish as they pass into the collector
  - Opening of the NTS is 50 feet deep and 50 feet wide to capture fish efficiently at migration depths of most migrating fish
  - Helps control water acceleration and velocity leading up the FSC
  - Detachable; it is removed from the FSC in the off season to allow FSC deballasting
- No dewatering occurs in the NTS

- FSC
  - Measures 130 feet long by 60 feet wide
  - Provides 500 ft³/s of attraction flow produced by low-head electric pumps that flows through a channel created by conventional vee-screens (Chapter 8 of the Manual). Dewatered attraction flow is pumped back (recirculated) into the forebay.
  - Installed pumps and capacity allow attraction flow to be increased to 1,000 ft³/s to permit testing of whether the increase affected fish collection performance
  - Flotation tanks allow for buoyancy control of the FSC, which is especially useful in the off season when the facility is raised and exposed to allow for maintenance
  - A fish trap allows for sampling, handling, and transporting of fish
  - After sampling, fish are diverted to a water-filled transport tank
  - The tank is then transferred to a truck for transport and eventual release into the Baker River downstream of the Lower Baker Dam

- Transport and access facilities
  - Pier, mooring docks for transport barges, and crane at Lower Baker Dam
  - Cantilevered deck, stairway tower, and floating walkway at Upper Baker Dam

This design information was synthesized from PSE (2011, 2014) and NPPC (2016).

Performance standards for fish passage at the Baker River Project:

- Collection efficiency: 95%
- Survival within the collection facilities: 98%
- Reservoir passage survival: 80%
- Overall survival through each dam and reservoir: 75%

An aerial photo of the Upper Baker Dam log boom, guide nets, and FSC is shown in Figure D-9.

Effectiveness of Downstream Fish Passage: Upgrading the facilities from the gulpers to the FSCs and using the improved guide nets resulted in juvenile outmigrations increasing more than two orders of magnitude compared to numbers observed in the late 1980s when only 8,838 juvenile salmonids were counted in 1987. A record number of salmon smolt outmigrants were collected and transported in the Lower Baker FSC’s second year of operation in 2014, with more than 1 million fish collected between the two FSCs (419,518 from the Lower Baker FSC and 617,483 from the Upper Baker FSC). The FCE goal set by PSE is 95%; FCE has ranged from 80 to 95% among the years tested.

Summary: Since installing the two FSCs, Puget Sound Energy (PSE) has successfully captured and transported record numbers of juvenile sockeye and coho salmon and has seen above average smolt-to-adult return rates. PSE biologists for the Baker Project measure success of the project by the percent of fish recovered and the increase in juvenile and adult fish numbers. It is important to note that the population of juvenile salmonids entering the Upper Baker Dam FSC comprise wild fish and hatchery releases from the Baker Project’s sockeye salmon hatchery and production from the hatchery’s spawning beds.
The Baker Project has become well known around the world as a successful case study for fish passage at a high-head dam. While a precise number of adult returns was not established (or provided publicly) as a goal, PSE views the results as being successful given the substantial increase in adult returns since the FSCs began operation. Since completion of the FSCs, PSE has won awards for its work restoring anadromous fish runs in the Baker River. The National Hydropower Association awarded the utility with the Top Environmental Award in 2008 and 2009 and the Recreational, Environmental, and Historical Enhancement award in 2011.
CASE STUDY 2: LEWIS RIVER HYDROELECTRIC PROJECT

Project Location: Lewis River, southwest Washington (Figure D-15)

Figure D-15. Map of the Lewis River Hydroelectric Project Dams and Reservoirs in southwest Washington.

Species of Interest: Spring Chinook salmon, early-run coho salmon, and winter steelhead

Passage System: An FSC, NTS, and guide nets were installed at Swift Dam No. 1. Fish collected in the FSC are transported and released downstream of Merwin Dam

Project Information:

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<td>mile</td>
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<td>12</td>
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<tr>
<td>Hydraulic Head</td>
<td>feet</td>
<td>188</td>
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<tr>
<td>Attraction Flow into Collector</td>
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<td>750</td>
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Discussion: The anadromous salmonid reintroduction program required fish passage and is a centerpiece of the 2004 relicensing settlement agreement. FERC incorporated the settlement agreement into the 2008 licenses for Merwin (FERC No. 935; Owner: PacifiCorp), Yale (FERC No. 2071; Owner: PacifiCorp), Swift No. 1 (FERC No. 2111; Owner: PacifiCorp), and Swift No. 2 (FERC No. 2213; Owner: Cowlitz PUD). The overarching goal of the comprehensive reintroduction program is to achieve genetically viable, self-sustaining, naturally reproducing, harvestable populations of the species above Merwin Dam at greater than minimum viable populations.

The Swift Reservoir FSC began daily operations on December 26, 2012. The facility is located at the south end of Swift Dam near the turbine intake (Figure D-16 and Figure D-17) and consists of five primary structures:

- Fish collection barge
- Truck access trestle
- Mooring tower
- Barrier and lead (guide) nets
- NTS

The Swift FSC is a floating barge that measures 170 feet long, 60 feet wide, and 53 feet tall. The FSC provides attraction flow at the surface of the reservoir where juvenile salmonids are migrating and attracts juvenile fish into the FSC where they are captured. Fish enter the FSC via the NTS, which funnels water and fish into an artificial channel created by electric pumps. The channel entrains and guides fish into a collection facility that automatically sorts fish by life stage (i.e., fry, smolt, and adult) and routes the fish to holding tanks for biological sampling and transport downstream.2 The artificial channel is maintained at a capture velocity of approximately 7 ft/s with 600 ft³/s attraction flow during normal operations, which is 80% of the pumping capacity.

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2 Following transport downstream, smolts are transferred into release ponds located near Woodland, Washington.
Figure D-16. Aerial photo of the Swift FSC (Courtesy of PacifiCorp).
Figure D-17. Aerial photo of the Swift FSC (Courtesy of PacifiCorp).
The 660-foot access trestle provides fish transport trucks access to the 280-foot-tall mooring tower. The mooring tower doubles as a hopper-to-truck fish transfer structure, allowing operators to move fish from the FSC to the truck across a broad range of reservoir surface elevations.

The barrier nets on either side of the FSC (Figure D-16) consist of three distinct vertical panel materials. The upper section of the net (0 to 15 feet deep) consists of a solid material. The middle net section (15 to 30 feet) consists of a fine net material (Dyneema) with 1/8-inch mesh opening. The lower-most section (30 feet and beyond) is also constructed of Dyneema with 3/8-inch mesh opening. In addition to the forward-facing barrier nets, two side nets extend from anchor points in the forebay on either side of the FSC and extend to shore. These are constructed of nylon material; the upper portion (0 to 15 feet) of the net has a mesh opening of 1/8 inch and the lower portion (15 feet and beyond) has a mesh opening of 3/8 inch.

In March 2016, a guidance net was installed at the entrance of the FSC (Figures D-16 and D-17). The guidance net orients juvenile salmonids towards the entrance of the collector to improve collection efficiency. The net is 650 feet long; the uppermost 30 feet is constructed from Dyneema with a 3/32-inch mesh gap, and the lower 30 feet is constructed from polyester with a 1/4-inch mesh gap, for a total net depth of 60 feet. The net extends approximately 30 feet inside the entrance of the NTS to prevent fish from easily swimming back out the opposite side of the FSC.

The following performance standards were established for the Swift FSC:

- Safe, timely, and effective passage of all salmonids being transported
- Construct, operate, and maintain fish passage facilities that collect all life stages of salmonids that are present at the specific facility and function during all flows and during all seasons except when infeasible for the passage facility.  
  - Achieve an overall downstream survival (ODS) of equal to or greater than 80%, which is defined as the percentage of juvenile anadromous fish of each of the species that enters the reservoirs from natal streams and that survives to enter the Lewis River below Merwin Dam by collection, transport, and release via the juvenile fish passage system, passage via turbines, or some combination thereof.
- Downstream collection standards
  - Collection efficiency of equal to or greater than 95%
  - Collection survival of equal to or greater than 99.5% for smolts and 98% for fry and survival of equal to or greater than 99.5% for adult bull trout
  - Injury less than or equal to 2%

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3 Except during periods when it was necessary to shut the facility down due to power outages, facility modification, or scheduled maintenance
4 An ODS of greater than or equal to 80% is required until such time as the Yale Downstream Facility is built or the Yale In-lieu Fund becomes available, after which ODS shall be greater than or equal to 75%. The parties to the Settlement Agreement acknowledged that ODS rates of 80% or 75% are aggressive standards and will take some time to achieve (PacifiCorp 2016).
CASE STUDY 3: PELTON ROUND BUTTE COMPLEX

Project Location: Deschutes River, central Oregon (Figure D-18)

Figure D-18. Map of the Pelton Round Butte Hydroelectric Project in central Oregon.

Species of Interest: Spring-run Chinook salmon, summer-run steelhead, and sockeye salmon

Passage System: The fish passage system for downstream migrating fish comprises a 6,000-ft³/s FSC, paired for use with a selective water withdrawal tower (Figure D-19). The FSC located at Round Butte Dam is not equipped with guide nets or an NTS. Fish collected in this system are held in the FSC until they are loaded onto trucks and transported to a release point below Pelton Dam.
Project Information:

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<td>Attraction Flow into Collector</td>
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Discussion: Fish passage began at Round Butte Dam in 1964 with a downstream surface collector, fish ladder, and transport hopper system for upstream and downstream migrating Chinook salmon, steelhead, and sockeye salmon. It was soon determined that confounding surface currents and water temperatures in Lake Billy Chinook made it difficult for juvenile salmonids to find the original surface collector. In 1968, Portland General Electric (PGE)
abandoned the fish passage system and began funding a hatchery program for the Oregon Department of Fish and Wildlife to mitigate for the loss of anadromous fish in the upper Deschutes River. In the mid-1990s, PGE revisited fish passage and began to design a system to accommodate passage and water temperature issues in anticipation of the FERC relicensing process (Corson 2012).

The Pelton Round Butte Hydroelectric Project is co-owned and operated by the Confederated Tribes of the Warm Springs (CTWS) and PGE and is a hydroelectric complex comprised of the following three facilities (from upstream to downstream): Round Butte, Pelton, and a re-regulating dam below Pelton Dam. As part of the 2005 FERC license, the co-owners produced a Fish Passage Plan with the following goals and objectives (Gauvin 2012):

- Establish self-sustaining, harvestable populations of steelhead, spring Chinook salmon, and sockeye salmon in the Deschutes River basin
- Provide access to habitat to support a self-sustaining fishery
- Support the contribution of salmon, steelhead, and other native species to a healthy ecosystem
- Provide access to and through project waters for Chinook salmon, rainbow trout, bull trout, and other native fish species
- Contribute to the recovery of steelhead listed under the ESA from the middle Columbia River

Pelton Round Butte’s juvenile collector is located at the top of a selective water withdrawal tower (SWT) that was designed to regulate water temperature below the dam similar to pre-project conditions, modify surface water currents to enhance fish collection, and provide power generation flow. After careful study by the co-managers, a blend of nutrient-rich surface water and cooler bottom water was achieved through use of the SWT that eliminated the influence of the project on downstream water temperatures. Prior to the SWT, the Pelton Round Butte Complex resulted in the lower Deschutes River being artificially cool in the spring and artificially warm in the late summer and fall. Modeling indicated this shift in water temperatures was not beneficial to native fall Chinook salmon and trout populations immediately downstream of the project.

The SWT is anchored directly in front of the powerhouse intake at Round Butte Dam. It is 273 feet tall, the width of the SWT ranges from 60 feet to 90 feet, and the surface collector is located at the top of the SWT. The collector opening is 40 feet deep. Fish are collected via two traditional dewatering screens (Chapter 8 of the Manual), as shown in Figures D-20 to D-23. Then, the fish are sorted by size where larger fish (bull trout and kokanee \(O.\ nerk\a\)) are returned to the lake, and smaller juvenile salmon and steelhead are routed to the floating fish transfer facility next to the collector. Salmon and kokanee are then loaded into a truck to be transported and released downstream of the re-regulating dam. All fish that enter the collector are handled and marked to indicate they originated upstream of the project.

The smolt transfer trucks have a capacity of 650 gallons and can carry 3,500 smolts per trip; the trucks maintain the proper temperature for the 10-mile, 35-minute drive to the release site below the complex (Corson 2012; Madden 2016).
Figure D-20. Graphic rendering of the Pelton Round Butte FSC and the selective water withdrawal tower at Round Butte Dam (Courtesy of Portland General Electric).
Figure D-21. Selective Water Withdrawal facility under construction in the forebay of Round Butte Dam; the bottom intake structure is in the foreground, and the dewatering screens are in the background (Courtesy of Portland General Electric).
Figure D-22. Pelton Round Butte FSC under construction; the view is looking into the FSC from the forebay. The two traditional dewatering screens (V-screens) with louver baffles form the sides of both FSC entrances (Courtesy of Portland General Electric).
A study was recently completed to evaluate flows near the FSC entrances to determine if the installation of guide nets could improve FCE. The co-owners are currently conducting studies to learn more about fish survival in the Deschutes River, including studies of migration timing, predation, and disease. PGE is currently conducting studies on juvenile fish migration that focus on determining the following:

- The number of smolts entering the reservoir from each tributary (specifically, the Metolius River, Whychus Creek, and Crooked River)
- The timing and number of salmon and steelhead emigrating from the reservoir
- The percentage of fish that enter the reservoir and successfully enter the SWT.

As part of this study, increased flow at night (between 8:00 p.m. and 5:00 a.m.) was provided for 18 days because biologists observed that salmonids were attracted to more flow and tended to pass during the evening and early morning period. One hundred juvenile Chinook salmon were released into the forebay each evening prior to the increase in flow; the highest Chinook salmon passage was observed under these conditions in 2016. PGE has continued nighttime generation to see if fish collection numbers continue to improve. Additionally, PGE is examining juvenile migration patterns downstream of the three-dam project as the fish migrate toward the Columbia River and the Pacific Ocean. For this study, biologists are using telemetry techniques to determine where delays in migration and mortality are occurring and estimate travel times to the mouth of the Deschutes River. Adult salmon and steelhead migration, spawning, and
competition and overall fish health are also being studied (Bennett 2016; Quesada 2016; Stocking 2016).

The CTWS and the Columbia River Inter-Tribal Fish Commission are conducting a sockeye salmon study to examine if a local and historical gene pool for anadromous sockeye salmon is present in the kokanee population in Lake Billy Chinook and its tributaries. Prior to the construction of Round Butte Dam, sockeye salmon populations existed in Suttle Lake, which drains into the Metolius River. Completion of Round Butte Dam blocked passage into the Metolius River, and the landlocked sockeye continued to exist in the basin as kokanee. Results of tissue sample analysis indicate the kokanee population of Lake Billy Chinook is more consistent with the genes of kokanee than with the genes of sockeye salmon, meaning that it is likely these kokanee will not pass through the fish passage system and return to their spawning grounds as a sockeye salmon population would (Matala et al. 2015).

Effectiveness of Downstream Fish Passage: The goal for Phase I of the project was to achieve a 50% reservoir passage efficiency. Since the SWT began operating in 2009, the proportion of smolts in the reservoir that entered the facility has ranged from 20 to 60%. The 50% goal was reached in 2011, at which time a goal of 75% reservoir passage efficiency was set; the co-owners are currently working to achieve that goal. The co-owners also set smolt survival criteria at 93% for the first 5 years of downstream passage operations, which then increased to 96% thereafter. This criterion applies to the collection, transport, and release of smolts below the re-regulating dam (i.e., it does not apply to passage through the reservoir). This criterion has been exceeded (greater than or equal to 98%) since passage operations began (ODFW 2008; Madden 2016).
CASE STUDY 4: CLACKAMAS RIVER COMPLEX – PASSAGE FROM ABOVE NORTH FORK DAM TO BELOW RIVER MILL DAM

Project Location: Clackamas River, Willamette River basin, northwestern Oregon (Figure D-24)

Figure D-24. Map of the Clackamas Hydroelectric Project in northwestern Oregon.

Species of Interest: Spring-run Chinook salmon, coho salmon, and steelhead

Passage System: At North Fork Dam (the uppermost dam in the Clackamas Hydroelectric Project), downstream passage is provided via two systems:

- FSC with a pumped attraction flow of 1,000 ft³/s
- Existing, smaller, fixed corner collector with its attraction flow of 240 ft³/s

Fish collected in both systems pass downstream through a pipe and are released below the lowest dam in the three-dam complex. An exclusion net across the spillway operates up to 4,000 ft³/s flow through the spillway. When spill volumes are greater than 4,000 ft³/s, the exclusion net is lowered to protect it from being damaged.
At Faraday Diversion Dam located downstream of North Fork Dam, protective measures at North Fork Dam were chosen during FERC relicensing that minimize passage of fish into the reach directly downstream of North Fork Dam.

At River Mill Dam (the lowermost dam in the complex), a surface collector was installed by attaching it to the dam. Attraction flow of 500 ft³/s is provided by passing inflow to a powerhouse turbine via gravity through the fixed collector. The collector has a design attraction flow of 500 ft³/s, but can be operated at slightly higher flow rates. Fish collected pass downstream to below the dam volitionally through a bypass pipe.

### Project Information:

<table>
<thead>
<tr>
<th>Dam Facts</th>
<th>Units</th>
<th>North Fork Dam</th>
<th>Faraday Diversion Dam</th>
<th>River Mill Dam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>feet</td>
<td>207</td>
<td>50</td>
<td>85</td>
</tr>
<tr>
<td>Length</td>
<td>feet</td>
<td>676</td>
<td>407</td>
<td>578</td>
</tr>
<tr>
<td>Power Production Capacity</td>
<td>MW</td>
<td>58</td>
<td>41.65</td>
<td>25</td>
</tr>
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<td>Reservoir Name</td>
<td>-</td>
<td>North Fork</td>
<td>Faraday Lake</td>
<td>Lake Estacada</td>
</tr>
<tr>
<td>Reservoir Length</td>
<td>Mile</td>
<td>2.8</td>
<td>NA</td>
<td>2.85</td>
</tr>
<tr>
<td>Hydraulic Head</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forebay Fluctuation Range</td>
<td>feet</td>
<td>+/- 2</td>
<td>NA</td>
<td>5.75</td>
</tr>
<tr>
<td>Attraction Flow into Collector</td>
<td>ft³/s</td>
<td>1,000 plus 240 ft³/s into the fixed collector on north bank</td>
<td>NA</td>
<td>500</td>
</tr>
</tbody>
</table>

Discussion: In 2006, a settlement agreement was reached whereby PGE agreed to a project survival standard of 97% for the passage of juvenile fish through all three dams and reservoirs. Since 2006, PGE has worked diligently to complete the suite of fish passage improvement measures in their project license.

**Juvenile Downstream Fish Passage – North Fork Dam:**

Downstream passage at North Fork Dam is provided via three components:

- Existing 240 ft³/s migrant collection channel on the north bank
- Partial depth exclusion net across the spillway
- 1,000-ft³/s FSC

Fish collected via the existing fish migrant collector and FSC pass volitionally via a bypass pipe to below River Mill Dam. During project relicensing, determining how fish and flow passed North Fork Dam was a key effort and goal. A computational fluid dynamics (CFD) model was developed (PNNL 2004). Figures D-25 and D-26 show the surface collector concept modeled using CFD and the grids used. Figure D-27 shows CFD model outputs in the form of flow streamlines and velocity for one of the SFC alternatives that were modeled. The data have proven invaluable in the decision process used to develop successful fish passage alternatives.
Figure D-25. A plan view of the CFD model grid developed for the North Fork Reservoir (Taken from PNNL 2004).

Figure D-26. CFD model grid showing the surface collector concept incorporated into the model runs (Taken from PNNL 2004).
Figure D-27. Flow streamlines and velocity for one North Fork Dam SFC alternative modeled using CFD (Taken from PNNL 2004).

Figure D-27 presents CFD results for a 500-ft³/s collector oriented perpendicular to the dam (a 1,500-ft³/s collector with a similar entrance orientation was also modeled). Flow conditions leading to the FSC entrance indicate the collector is in a favorable location in the reservoir.

Figure D-28. The depth distribution of targets during a hydroacoustics study (Biosonics 2004).
Multiple biological studies were also conducted using a variety of technologies to monitor fish behavior through the reservoir and how fish approached North Fork Dam, which provided a picture of fish behavior under existing (i.e., pre-relicensing) conditions (e.g., Karchesky et al. 2003; Biosonics 2004; and Karchesky et al. 2004b). This valuable information was used as the basis for developing the fish passage plan for the Clackamas River Hydroelectric Project.

During April and May 2001, acoustic tags were used to track Chinook salmon smolts in the forebay of North Fork Dam (Timko et al. 2004). Figure D-29 shows where the hydrophones for this study were located. The study provided information on how individually tagged fish approached and passed the dam. Figure D-28 presents results of a hydroacoustic study that indicated fish in the North Fork Dam forebay preferred to reside in the upper part of the water column. The hydroacoustic data corroborated other information, indicating fish primarily resided in the upper water column (Biosonics 2004 and Timko et al. 2004). The data shown in Figure D-30 aligned perfectly with CFD model results. The congruence of the physical and behavioral data provided verification that the preliminary location selected for the FSC had elements that suggested it would be a good location for fish passage.

Figure D-29. This shows the locations of the acoustic telemetry hydrophones (Timko et al. 2004).
As is shown in the Figure D-30, fish congregated over the turbines. What is not detailed in the acoustic telemetry report of Timko et al. (2004) was the large effort by a fish committee engaged in the development of the fish passage plan to look at individual tracks of acoustically tagged fish. Based on presentations by the researchers of detailed passage information to the committee, it was apparent that not only do the fish congregate over the turbines, but they exhibit multiple lateral (i.e., back and forth) movements along the face of the dam. Committee members discussed this and interpreted it as a searching behavior, which helped inform a decision to
realign the intake and orientation of the FSC to pull fish laterally toward the FSC as opposed to drawing the fish directly (perpendicular) from the forebay to the dam and FSC (Figure D-31).

The fish passage plan for the Clackamas River Hydroelectric Project was developed through an iterative process during FERC relicensing negotiations that began in 2003 when NMFS required full powerhouse screening at North Fork Dam. The process resulted in a collaborative settlement agreement whereby PGE agreed to a project-wide survival standard of 97%. As part of this process, an FSC was designed and installed at North Fork Dam that incorporated 1,000 ft³/s of pumped attraction flow, no NTS, and collected fish being released below River Mill Dam through use of a volitional bypass system.

In addition to the two collection facilities, two net systems are used at North Fork Dam (Figures D-32 and D-33) to prevent fish from entering the spillway, connect the FSC to the dam, and prevent fish from traveling around and behind the collector. Unlike the other FSCs used in the Pacific Northwest, the FSC at North Fork Dam is not equipped with an NTS. Another key feature that makes this system unique is that fish are not collected and transported, but instead are allowed to volitionally pass downstream of the lowest dam in the system (River Mill Dam), approximately 7 miles downstream from North Fork Dam. This volitional bypass feature has helped minimize effects to collected fish from handling, crowding, and delaying associated with collection and transportation. In addition, the volitional bypass system moves fish around all three dams and eliminates the need to recollect bypassed fish at the two lower dams.
Juvenile Downstream Fish Passage – River Mill Dam:

In the early 2000s, a surface collector was designed and constructed for juvenile salmon and steelhead downstream passage at River Mill Dam (Figures D-34 and D-35). This prototype was known as the “fish horn” and was a rough approximation of what might happen if a surface collector was placed over Turbine Unit 5 (Unit 5). Unit 5 was chosen because it is a priority unit for operation. It provides attraction flow to adult facilities located downstream of the dam (historically, it was referred to as the “fish unit”). This first surface collector prototype was constructed using temporary materials that allows researchers to learn about passage at this location. Results of fish passage studies conducted from 2001 to 2004 indicated the facility could effectively pass fish (Karchesky and Brush 2003; Karchesky et al. 2004a).
Based on these results, a permanent surface collection facility was designed and installed and began operation in 2012. The design utilizes 500 ft³/s of flow from Unit 5 to attract fish into the collector. Fishes collected in the River Mill Dam surface collector travel volitionally through a bypass pipe that joins the bypass flow and system from North Fork Dam and places collected fish from both dams back into the Clackamas River below River Mill Dam.

![Figure D-34](image1.png)

**Figure D-34.** An isometric illustration of the River Mill Dam surface collector located above Turbine Unit 5 (Courtesy of Portland General Electric).

![Figure D-35](image2.png)

**Figure D-35.** A photograph of the permanent surface collector and how it is oriented at River Mill Dam (Courtesy of Portland General Electric).

An evaluation based on PIT-tagged fish found that fish collection efficiency into the surface collector at River Mill Dam was 98.3% for Chinook salmon, 99.8% for coho salmon, and 95.8%
for steelhead; overall survival through the system was 98.6% for Chinook salmon, 99% for coho salmon, and 95.2% for steelhead (Shibahara 2014). PGE concluded that facility performance for fish guidance and condition during the first year of operation was excellent; benefits from the increased performance were estimated to result in a 3 to 6% increase in adult returns to the Clackamas River (Shibahara 2014). The surface collection facility at River Mill Dam has proven to be a valuable addition to the overall downstream migrant collection system at the Clackamas River Hydroelectric Project, averaging more than 100,000 juveniles being bypassed annually since initial commissioning occurred in 2013, 70% of which have been juvenile Chinook salmon.

Current Status:

Many positive changes are occurring in the Clackamas River basin that coincide with the installation and use of the passage facilities at North Fork and River Mill dams. These include the following:

- The outmigration timing of juvenile fish is occurring over a longer period
- The life history strategies of collected fish are more diverse than in the past and range from fry to outmigrating smolts.
- The increased collection efficiency has resulted in more recruits produced per spawner.

Prior to the facility improvements that occurred from 2000 to 2012, on average, 12,015 juvenile Chinook salmon were bypassed each year. Following the improvements, an average of 101,608 juvenile Chinook salmon have been collected annually. The number of juvenile steelhead collected each year during this timeframe increased from an average of 18,184 fish to 46,045 fish. These increases represent an 88% and 61% increase in the number of juvenile Chinook salmon and steelhead, respectively, that have been safely passed downstream through the three-dam complex.

Historically, juvenile salmonids required approximately 2 weeks to migrate from North Fork Dam to River Mill Dam through the original bypass system (the adult fish ladder and migrant pipeline). After the new juvenile salmonid collection, sampling facilities and bypass pipe were installed at North Fork Dam, and flow in the pipe was increased to 7 ft³/s. Additionally, passage time through the bypass system from North Fork Dam to release below River Mill Dam was reduced to approximately 2 hours.

While the increase in the number of juvenile Chinook salmon collected to date is substantial, the increase in the diversity of life history strategies represented in the collection samples may be just as important. The historic bypass system was moderately successful at collecting Chinook salmon smolts, but pre-smolts and fry were not successfully collected. In 2017, more than half (125,000) of the 216,000 juvenile Chinook salmon passed downstream at all facilities within the Clackamas River Hydroelectric Complex were fry or pre-smolts.

Adult salmonid returns to the Clackamas River since the fish passage improvements were completed at North Fork and River Mill dams have been compared to return patterns observed in neighboring basins (Figures D-36 and D-37). The results indicate an apparent benefit to the Clackamas River fish runs from implementation of the fish passage projects. The return of 7,081 wild coho salmon to the Clackamas River in 2017 proved to be a regional anomaly; that return was 254% of the 18-year average. During this same period, regional returns in
neighboring basins averaged approximately 40% of their respective 18-year averages. Coincidentally, 2017 was the first adult return of coho salmon that outmigrated with the added collection benefit of the 1,000-ft³/s North Fork Dam FSC. It was also the second year within the past 4 years where adult coho salmon counts at North Fork Dam exceeded 7,000 fish, a feat that has not been observed in the past 59 years.

Figure D-36. Annual wild Chinook salmon returns to the Clackamas River based on counts at North Fork Dam and the McKenzie River based on counts at Leaburg Dam, relative to their mean for the 2004 to 2014 period. Note: 100% on the vertical axis represents the 2004 to 2014 mean. The boxed area represents adult return years for juveniles that outmigrated through the new infrastructure (Courtesy of Portland General Electric).
Figure 37. Annual wild winter steelhead returns to the Clackamas River based on counts at North Fork Dam and the Willamette River based on counts at Willamette Falls relative to their mean for the 2000 to 2012 period. The boxed area represents adult return years for juveniles that outmigrated through the new infrastructure (Courtesy of Portland General Electric).

D.7 Performance Standards

Surface collector systems are comprised of several components (Section D.3). Once fish enter an SFO entrance, NMFS expects that surface flow facilities will meet or exceed the performance standards that have been developed for conventional screen technologies, which are presented in Table D-5. In other words, NMFS expects the collector facility to safely convey, dewater, hold, and transport collected fish to release locations at levels similar to conventional fish screen systems (Chapter 8 of the Manual).

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5 This information is also available in Table C-1 of Appendix C.
Table D-5. Performance standards for conventional, positive-barrier fish screen systems designed and built to the guidelines and criteria in Chapter 8 of the Manual.

<table>
<thead>
<tr>
<th>Smolt Mortality</th>
<th>Smolt Injury</th>
<th>Fry Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design performance objective &lt;0.5%</td>
<td>Design performance objective &lt;2%</td>
<td>Design performance objective &lt;2%</td>
</tr>
<tr>
<td>Actual mortality &gt;0.5%, but &lt;2% requires additional work to lessen mortality</td>
<td>Actual injury &gt;2%, but &lt;4% requires additional work to lessen injuries</td>
<td>Actual mortality &gt;2%, but &lt;4% requires additional work to lessen mortality</td>
</tr>
<tr>
<td>Actual mortality &gt;2% requires major operational or structural changes</td>
<td>Actual injury &gt;4% requires major operational or structural changes</td>
<td>Actual mortality &gt;4% requires major operational or structural changes</td>
</tr>
</tbody>
</table>

In addition, several additional key criteria are used when establishing design goals and post-construction performance criteria for surface collectors. These address overall survival through the reservoir, FCE and effectiveness, and direct and total survival. Examples of performances standards are presented in Section D-6. These values are either established by the FERC license or are negotiated between the project proponent (applicant) and NMFS, often in consultation with state agencies and tribal organizations.

**D.8 Biological Monitoring**

Two general types of biological data need to be obtained with respect to SFOs. The first is baseline information on fish behavior, survival, location (vertically and horizontally), areas of concentration, and responses to tributary inflow. The second is information on the post-construction performance of an SFO.

Study plans for assessing pre- and post-construction conditions and performance should be reviewed by NMFS prior to implementation. NMFS staff may suggest ways to improve the study designs and the value of the data being collected.

Various methods are used to gather baseline fish behavior and post-construction performance information, and each method has its strengths and weaknesses. In general, passive (e.g., PIT) and active telemetry (e.g., acoustic and radio) tags and detectors are used to assess both pre- and post-construction conditions. Oftentimes, PIT and active telemetry methods are combined to achieve a more comprehensive assessment of fish behavior in response to prevailing physical and environmental conditions. PIT tags can provide robust estimates of survival and information on migration timing in situations where adequate detection probabilities can be developed at a test location. Active telemetry methods provide more detailed information on fish behavior (e.g., the number of approaches to a collector and time spent searching a forebay before entry) and horizontal and vertical distribution. Three-dimensional positioning is also available.
with active telemetry systems. The scientific literature is a good source of study design, tagging protocol, survival modeling, and data analysis techniques for estimating pre- and post-construction fish behavior and survival using passive and active telemetry techniques.

**D.8.1. Pre-Development Biological Information**

_A critical aspect of a successful SFO design is understanding the behavior of the fish in the reservoir._

As discussed in Section D.5, the design starts with a thorough understanding of fish behavior. Early SFO prototypes tested at some Columbia River dams failed to successfully collect fish because they were based on hydraulic information rather than a thorough understanding of how fish responded to hydraulic conditions in the forebay. Indeed, based on their review of multiple types and installation of surface-oriented systems, ENSR (2007) concluded the following:

- Location of the SFO entrance(s) relative to smolt pathways and concentration areas in the forebay is a primary consideration for maximizing FCE.
- In general, the best performing surface outlets tend to have more of the features that most contribute to high FCE. This suggests that design teams should consider the breadth of features when formulating SFO designs and placement of entrances.

Another key aspect to consider when designing baseline biological studies is whether accurate estimates of survival through the reservoir are needed prior to installing the surface collector. This information would be useful in establishing reservoir survival goals during project relicensing discussions and would allow natural mortality and mortality caused by the surface collector system to be partitioned.

**D.8.2 Post-Construction Biological Performance Testing**

_Evaluating SFO performance after construction is mandatory and may require several years of testing. Performance metrics that are typically evaluated include reservoir survival, discovery efficiency, entrance efficiency, retention efficiency, fish collection efficiency, and direct and total survival (Section D.2)._  

Study designs should consider the species, life history type (fry, subyearling, or yearling), rearing history (hatchery or wild), size, and race (e.g., spring, summer, fall-run, or winter-run) of test fish used to evaluate survival and efficiency performance metrics. Power analysis to estimate detectable differences among treatments and sample sizes is a necessary component of any study design.
D.9 References


