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FISH PASSAGE DEVICES

Prepared by Steve Thomas (NMFS) and Jonathan Mann (CDFW)

For consideration of fish passage options for PG&E's Potter Valley Project.

The selection and design for a fish passage facility is typically through an interactive and collaborative process involving technical specialists and based on a synthesis of site and biological information. Determination of appropriate fish passage devices that may make up elements or components of a fish passage facility or fish passage project alternative is obtained through this process and may evolve during development and design, especially if new information becomes available. This list of fish passage devices is not meant to be all-inclusive or all encompassing. There may be other methods, devices, and technologies for fish passage that are not included here, inadvertently, or possibly intentionally if it is not considered relative to the project being considered.

Fish passage devices are typically designed specifically for upstream or downstream passage, not both. Some of the upstream passage devices may also afford downstream migrants an opportunity to move downstream, but they are less efficient than devices designed specifically for downstream passage. That said, there may be new ways to integrate upstream and downstream passage devises, especially when only small volumes of water are available to release past a barrier.

Upstream Passage

The following fish passage devices are generally intended to provide upstream passage for adult (and less commonly juvenile) anadromous salmonids and some other fish species. Upstream fish passage for juvenile salmonids or other fish with lower capability than adult salmonids may be accommodated through application of specific hydraulic design criteria but requirements for upstream passage of juvenile fish and other species should be determined on a site-specific basis. For example, design criteria for lamprey may need to be included as features for different devices or may not work at all for certain devices. Guidelines for design of such features and devices are available for lamprey.

Upstream fish passage devices are organized below into three groups: fish ladders, other fishways using natural materials, and mechanical systems to allow upstream passage.

Fish Ladders

Note that the term "fishway" is a general term referring to any waterway design or operated specifically to provide fish passage. Fish ladders are types of fishways with steps, like rungs of a ladder, although sometimes fishways without discrete steps are also referred to as fish ladders. "Fish ladders" may also be referred to as "conventional" meaning a traditional way of providing fish passage. Nomenclature on this point is somewhat fuzzy and unimportant. Fishways are designed for fish movement, fish ladders are fishways that allow fish to ascend to waters at a higher elevation. Fish ladders can be used to have fish swim into a collection facility, such as a hatchery or a trap for subsequent transport, as well so they are not limited to providing passage around barriers.

For fish ladders, the entrances and exits are defined based on the direction of fish movement. A fish ladder entrance is the location that fish enter the fishway and the exit is the location that the fish leave the fishway. For upstream passage of adult anadromous salmonids the fish ladder entrance is the downstream end of the fishway or hydraulic outlet and the fish ladder exit is the upstream end of the fishway or hydraulic inlet.

Pool-and-weir fish ladders use a series of weirs within a sloping channel to create a series of step pools which fish can use to ascend over a barrier. Fish must be able to leap or swim over each weir so the fish ladder must be designed for specific fish species and life stages that conservatively match their swimming capabilities. Pool-and-weir fish ladders can only be used successfully when the water surface elevation upstream of the barrier does not fluctuate widely and maintains flow connectivity; for salmonids, pool fluctuation is limited to about one foot unless the ladder has multiple exits and regulating gates so as the water surface level changes the best exit can be used.

Pool-and-orifice fish ladders are similar to a pool-and-weir fish ladder but instead of having water spill over a weir, there are holes (orifices) in the weirs to allow fish to swim between pools rather than leap or swim over a weir. Lamprey and other non-salmonids may more easily use this type of fishway if the orifices are located along the floor of the fish ladder.

Ice Harbor style fish ladders use both weirs and orifices to provide flow through the fishway. The weirs and orifices are specially designed to create hydraulic conditions favorable for fish passage. They can function well for a variety of species and have the added benefit of two passage routes (over the weirs and through the orifices) so if one route gets clogged with debris the other is still available for passage. Fish can also choose the route that best matches their swimming mode and capability. Weir flow requires a relatively stable upstream water surface elevation without the addition of a regulating structure and gates.

Vertical slot fish ladders are similar to pool-and-weir ladders, but instead of weirs it uses wall baffles to constrict flow to create a series of pools. The baffles have nearly full-depth slots that are shaped and located precisely to create a current in each pool that dissipates energy without creating excessive turbulence. This allows fish to swim upstream without leaping or swimming over a weir. Vertical-slot fish passages are self-adjusting, within limits, to maintain a relatively consistent drop in water surface between each pool over a range of water surface elevations above and below the barrier. Vertical slot ladders are sometimes used on the upstream end of an Ice Harbor style fish ladder to compensate for fluctuations in reservoir water surface elevations without the use of regulating gates.

Baffled fishways use a series of symmetrical, close-spaced baffles in a sloping channel to redirect the flow of water, allowing fish to swim around the barrier. Baffle fishways are typically not longer than 30 feet in length and can be installed on slopes of up to 30%. To provide passage over higher obstacles, several lengths of baffled fishways may be joined with flat resting pools between each length. Because they have lots of structure within the channels they tend to clog easily and when clogged they do not allow for fish passage. There are three basic types of baffled fishways: Denil, Alaska steeppass, and Larinier.

Denil fishways have thin U-shaped baffles installed on a slant within a rectangular channel constructed of concrete or metal. The channels are typically installed in lengths of 30 feet on slopes of about 17%, although they've been used successfully on slopes up to 25%. For ascending greater heights two or more lengths may be used with flat resting areas or turning pools between runs. When many lengths or channel segments are used in combination the overall structure slope ends up being less than the individual channel segment because of the intermediate resting pools. Denil fishways are typically used to provide temporary fish passage as they can be quickly installed, but because they clog easily they are not ideal for remote locations or other places with debris laden water or where they cannot be serviced regularly. Although there is evidence that lamprey have successfully ascended Denil fishways, because of the sharp angles of the thin baffles Denil fishways are generally not considered acceptable for passing lamprey.

Alaska Steeppass fishways are similar to Denil fishways but with a minor change to the baffle design and are typically smaller and constructed in all metal as an integral unit. They have been used to provide fish passage in remote areas (like Alaska) where other types of fishways are difficult to construct; an Alaska steeppass may be flown in with a helicopter and attached to abutments fabricated in place. They are also used in hatcheries to allow fish to allow fish to swim into holding pools.

Larinier fishways, also called **super active-baffle fishways**, are a type of baffled fishway that have steel baffles in a chevron shape secured to the floor of a sloping channel. There are no baffles on the sidewalls. The baffles create secondary helical currents which dissipate energy and create a boundary of slower moving water near the floor in a pattern that allows fish to move upstream. They are typically installed at slopes of 10-15% for relatively short distances. Although they are not used widely in the United States, they are common in Europe.

Lamprey ramps are a relatively recent invention that takes advantage of the way lamprey use their mouths to hold on to smooth, wet, inclined or nearly vertical surfaces to ascend barriers. Lamprey ramps are typically open or closed flumes made of metal on slopes of up to about 70%. In some cases, vertical sections of metal plate or walls of relatively short distances are being used for lamprey passage in combination with other devices and routes. They have no baffles or other means to disrupt flow, requiring a continuous stream of laminar flow. Lamprey ramps have been added to the entrance pools and intermediate pools of fish ladders to provide lamprey with an alternate means to ascend a barrier. Experiments are taking place for other types of devices for lamprey passage including pipes and conduits.

Methods Using Natural Materials

Nature-like fishways are an alternative to conventional fishways like those described above, to provide a fish passage route around a barrier. They are channels constructed mainly of natural materials (rocks, gravel, logs, etc.) to mimic a natural waterway. Because they are designed to simulate a natural channel they provide fish passage for a variety of fish species.

Nature-like channels require a much larger footprint and length due to their low slope. Conventional fish ladders have slopes of about 10%, but nature-like channels have slopes of 2-4%, so they need to be much longer than a fish ladder, as much as five times longer! Nature-like fishways often need a flow control structure at the upstream end of the channel to regulate the amount of water entering the channel. In a storage reservoir situation like that at Scott Dam, to accommodate the fluctuations in reservoir level a fish ladder would be required at the upstream end of the channel to allow passage over a range of reservoir water surface elevations.

Rock ramps are another type of nature-like fishway that can be installed within the extents of an existing stream channel. They are essentially a matrix of rock in varying sizes placed in layers on the downstream side of a dam or other large drop to create a relatively steep stream channel that allows fish to swim over the barrier. Rock ramps are typically constructed on grades of 2-4% and up to 6% in limited cases of short distances so they are more practical on low head dams or barriers with only a few feet of drop. Rock ramps can also be used in a fishway system as shorter intermediate channel segments with resting areas in-between to accommodate an overall drop for a barrier.

Mechanical Upstream Passage Devices

Fish elevators, or **fish lifts**, concentrate fish into a hopper that may be lifted to transport fish short distances, like for loading onto a transport truck. The elevator or lift system includes multiple components: a fish ladder, holding pool, a trap, and a hopper. It may also require a fish barrier weir or dam to guide fish toward the fish ladder entrance. Fish volitionally ascend a fish ladder to access a holding pool. Once in the holding pool a finger weir or fyke keeps the fish from swimming back down the fish ladder to the river. When the facility operator wants to move the fish a false floor (brail) in the holding pool rises or a crowder moves horizontally to force fish to enter the trap. Inside the trap is a hopper, a fancy bucket that can be raised to collect the fish. The hopper concentrates the fish into a small amount of water which can then be lifted like an elevator to a location where the contents may be drained into a transport truck or other vessel.

Fish elevators require a steady and appropriate quantity of flow to attract fish into the holding pool. The size of the holding pool, trap if applicable, and the size of the hopper depends on the maximum number of fish expected to be moved at one time. An elevator may be operated as often as every hour but often only once per day depending on the seasonality of the fish migration and number of fish that are in the holding pool. Since fish cannot pass a barrier until the elevator is operated, fish elevators are not considered a volitional passage alternative.

Fish lock systems are very similar to fish elevator systems. They use a fish ladder to attract fish to a holding pool and fish are then moved into a trap, but in this case the trap is in a tower. Similar to the elevator concept, a crowder or brail is used to move fish from the holding pool into the tower. Once fish are in the tower the entrance gate is closed and the water is added to the tower so the water surface rises. A brail, or false floor, rises with the water surface to ensure fish move to the higher elevation. Once the tower is full of water an upper gate is opened and fish can swim out of the lock into a reservoir or a fish handling facility.

Fish locks have similar flow requirements and are operated on similar schedules as fish elevators. They differ from elevators in that fish are not confined to a hopper so they may not as easily be transferred to a transport truck or tank as with an elevator or lift system.

Pneumatically driven tubes. Whooshh Innovations, a company based in Seattle, Washington, developed a system whereby adult sized fish can be transported within a flexible tube using air pressure. Testing thus far shows fish can be moved over distances of 1,000 feet or more without significant injury, although more testing is needed. The company is working on a means to allow fish to enter a tube on their own volition, but so far fish must be loaded into a tube by hand, one-by-one and both of these techniques still require a way to collect fish such as a short section of fish ladder leading to a holding pool and trap. The tubes are manufactured in different sized to accommodate a range of fish sizes. The consequences of putting a too-small fish into a tube results in that fish not moving through the tube until another fish comes up from behind to push it the rest of the way through. The Whooshh fish transport tube system appears to be a useful tool for moving fish in small numbers for relatively short distances, like to load a fish transport truck, but the technology is not ready for providing volitional fish passage at a dam.

Trap-and-truck or trap and haul is a method used to move fish from one location to another. The method typically includes a fish elevator system (described above) to collect fish into a trap where they can then be loaded or transferred into tanks for transport via truck or barge. This type of fish passage system has also been referred to as CHTR: Collection, Handling, Transfer or Transport, and Release.

Trap-and-truck is used fairly frequently on rivers that have high head dams or multiple barriers, especially when the stream between barriers has little habitat value or where conventional fish ladders are not considered feasible or preferential. Trap-and-truck systems give river managers flexibility to optimally distribute (release) the fishery resource on the river reach. Trapping and then trucking adult migrants to move them upstream can be controversial for those who advocate for volitional fish passage, raise concerns about "handling" fish, or see the mechanism being "unnatural." The costs of a conventional fishway and the difficulty of providing the flow connectivity for volitional passage over a wide range of reservoir elevations are typical reasons for using this alternative means of fish passage. Some practitioners have concerns regarding the effect that handling and transport have on fish behavior and health. On the other hand, trap-and-truck operations have been successfully used in some cases to move adult salmonids upstream of long reservoirs, or around multiple dams; fish can then be released close to spawning grounds.

Downstream Passage

Methods for facilitating downstream passage around dams and other significant barriers are primarily aimed at passing juvenile salmonids and steelhead kelts. Other target species may have completely different needs to pass downstream so all target species and their passage needs must be identified and considered.

To provide downstream passage for out-migrating fish one must consider the cues that fish will follow to find their way downstream. For salmon and steelhead that is primarily water flow and water temperature. Salmonids moving downstream will naturally follow the path with the greatest flow so the greater amount of flow a fish passage route has will likely increase the success of the passage system. However, many projects cannot afford to allow a large amount of water to continually move fish downstream. In those cases pumps may be used to create a current that fish may follow and screens are used to funnel fish

Juvenile salmon and steelhead are surface oriented species so building the entrance of a downstream passage facility (hydraulic inlet in this case of downstream fish movement) near the water surface (the upper 5-10 feet) is important; however, in a storage reservoir situation the water surface in the reservoir varies greatly so the fish passage route needs to either float so it’s always near the water surface, or a fixed bypass system would need to have multiple entrances and be operated such that the best entrance is operated for the exiting conditions.

At dams with no facility specifically constructed for downstream fish passage, fish have only a few paths available to move past a dam: spillways, gates or valves, turbines, or fishways designed for upstream passage (if available). Turbines will not be discussed here because it is not applicable to Scott Dam since it does not contain power generation.

Fishways designed for upstream passage typically do not convey sufficient flow to attract many downstream migrants; therefore, they are not typically the most efficient means for downstream passage. If fish do find a fish ladder they may pass downstream safely but they may require considerable time to move down the fishway and they could be preyed upon within the facility.

Gates and valves are often used to regulate flow releases from a reservoir and **not** a preferred pathway for downstream passage because they typically include small openings that can cause physical injury to passing fish. Additionally, fish passing through gated conduits and pipes often are exposed to large and sudden changes in pressure that may result in physical injury.

Spillways can be an efficient means to move fish downstream but they must be designed specifically for fish passage and are not suitable for all locations. Many spillways allow water to spill onto the face of the dam or other hard surfaces that may injure fish. Also, many spillways use radial gates to regulate flow which do not draw water from the surface where juvenile salmonids are found. The opening for radial gates may be up to 30 feet below the water surface and fish may be reluctant to sound to such depths, causing delay. Additionally, often times the gates are open merely a few inches which can allow debris to become trapped and can injure larger fish that won't fit through the thin opening.

Spillway radial gates can be modified with a **fish passage weir** or **removable spillway weir** designed to provide downstream fish passage. These weirs draw water from near the surface where juvenile salmonids are often found so fish are more likely to find the passageway more quickly. The weirs must direct water and fish to a plunge pool, not onto hard surfaces, to minimize the chance of injury.

Spillways only provide downstream passage when water in the reservoir is high enough to spill; therefore, they may work reasonably well for run-of-the-river dams, but in storage reservoirs the water surface may drop below the spillway elevation when fish need to move downstream.

Relying on spillways for downstream fish passage has inherent risks. As noted above, passage under a gate can result in abrasion, impingement on trapped debris, and rapid pressure changes; spillway flow may impact the dam face or other hard surfaces; water downstream of the dam may be supersaturated with dissolved gases which can lead to gas bubble disease; and fish may be disoriented and therefore more susceptible to predation.

Juvenile Bypass Systems are a special system that safely allows downstream-migrating fish to move around dams in a pipe or open channel. On hydroelectric dams with gatewells upstream of the draft tubes (tubes that lead to the turbines), screens are sometimes used to divert fish into the gatewell and a system of pipes to move fish downstream. This is not applicable at Scott or Van Arsdale dams. Other types of juvenile bypass systems use turbine flow or spillway flow to attract fish to a system of pipes and flumes that move fish downstream. The fish are concentrated into a smaller flow with a fish screen and the fish are routed to a release point downstream. These bypass systems may be used on dams that have relatively stable reservoir water surface elevations like run-of-the-river dams. Although these systems are often described as juvenile bypass systems, they may work well for steelhead kelts as well.

Floating surface collectors (FSC) are similar to some types of juvenile bypass systems but float on the reservoir so they always collect fish near the water surface. Because they float, and FSC may operate over a wide range of reservoir water surface elevations. FSCs usually have guide nets in the shape of a Vee that guide fish into the collector. For salmonids, a water current is also required to attract and guide fish towards the collector. The current may be generated by flow that is routed through the dam, such as turbine flow or spillway flow, but often the current must be generated with low-head pumps such as axial pumps onboard the FSC. Once "collected" fish are typically routed through transition areas with gradually accelerating flow until they pass a "capture" velocity and either enter a trap or a bypass system. If fish are trapped onboard the FSC they are then typically transferred via a hopper or other vessel to a truck for transport to a designated release point downstream of the dam.

FSCs have usually been installed in the reservoir near the dam but also may be installed in the arms of a reservoir (head of reservoir collectors). For an FSC to function well near a dam the reservoir should have a current to guide fish downstream. Also, the water temperature must be compatible for the fish. Warm surface waters and the risk of predation are the two biggest hurdles for locating a FSC near a dam. Because FSCs are always below the crest elevation of the dam there must be a penetration through the dam through which pipes carry the fish downstream. It is possible to use a “fish-friendly” pump to lift fish to a higher elevation for routing, but there is always a risk of fish getting injured in such pumps despite their friendly name. The risk of fish injury must be weighed in comparison with other transfer techniques.

Locating an FSC in an arm of the reservoir has significant challenges too. In reservoirs that rise and fall more than about 20 feet, the FSC would need to be relocated to places with optimal water depth as the water surface elevation changes. Because the upper reaches of reservoirs are often in rural locations, electrical power is not available to operate electrical equipment including pumps that may be needed to generate flows through the FSC. In addition, there are concerns with debris management head of reservoir collectors, especially during high inflows when juvenile fish collection may be more critical.

FSCs must have sufficient flow moving through them to attract fish to the collector. That flow is either water that needs to be passed downstream or it is generated using pumps onboard the FSC. The pumps generate a current in the dam forebay to draw fish into the collector and discharges most of the water back to the reservoir. Relatively large volumes of water are required to draw fish into an FSC which leads to increased energy costs for pumping water and creates challenges of discharging that water back to the reservoir without creating hydraulic patterns that may interfere with fish finding the collector.

FSCs are becoming the most commonly used method for collecting downstream-migrating salmonids for passage around an existing dam. While they have been successfully operated at some locations, they are still considered a developing technology and each location requires a custom design for the unique circumstances for the project.