Appendix I: Upstream Juvenile Fish Passage

I.1 Introduction

Juvenile passage requires special and separate provisions from those designed to optimize adult passage. For a specific fish passage facility, when juvenile passage is prioritized over adult passage requirements, the juvenile considerations can negatively affect adult passage conditions. In general, deviations to adult attraction flow and fishway entrance hydraulics (to accommodate juvenile passage) become less adverse as the percent of streamflow diverted through the fishway increases. For example, in small tributaries and creeks, hydrology may limit the ability of a project to maintain typical adult passage requirements (e.g., hydraulic drop at a fishway entrance), whereas at large-scale projects (e.g., hydroelectric dams), designing adult fish passage facilities to also meet juvenile fish passage requirements can have a catastrophic effect on adult passage.

NMFS gives priority to adult fish passage as Endangered Species Act (ESA) recovery efforts at passage barriers rely primarily on providing adult access to upstream habitats to spawn.

I.1.1 Fishway Entrance Hydraulic Drop

The fishway entrance should operate under adult requirements for hydraulic drop when both adult and juvenile salmonids are present, and in cases where hydrology does not limit that criterion.

In cases where hydrology limits the application of typical entrance designs to maintain adult hydraulic drop criteria, hydraulic drop at the entrance is optimized to the extent possible when adults are present.

A potential condition where hydrology limits adult criteria being met occurs when insufficient fishway and auxiliary water system (AWS) discharge is available to maintain both; 1) a 1-foot drop at a fishway entrance and 2) a minimum slot width of 12 inches. Another potential situation is where a proposed fishway routes the entire streamflow through the fishway (channel spanning weirs) and at lowest flow operates under less than 1 foot of depth over the fishway weirs. This situation presents variances to criteria. It is suggested that these situations are presented to NMFS engineers early in the design process to allow for collaborative decision making.
I.1.2 Fishway Design

Fishways intended for upstream juvenile passage should be designed as pool and chute or roughened channel.

Pool and chute designs have been found to facilitate the implementation of juvenile criteria at a reduced cost and footprint over many other fishway types and approaches. This is due in large part to their ability to facilitate juvenile passage through hydraulic diversity, low velocity, and low energy dissipation factor (EDF) areas over a wide range of fishway discharges. Additionally, pool and chute designs benefit adult and juvenile passage through increased attraction hydraulics over many other types of smaller stream, tributary-scale fishway designs. This attribute is increasingly important when attraction facilities cannot be designed to adult passage criteria.

I.1.3 Hydraulic Drop at Fishway Entrance and Exit

Hydraulic drops recommended at a fishway entrance or exit for various size ranges of juvenile fish are as follows (Table I-1):

- 45 to 65 millimeters (mm): 0.13 foot
- 80 to 100 mm: 0.33 foot
- Greater than 100 mm: 0.5 foot

Table I-1. Juvenile upstream fish passage guidelines.

<table>
<thead>
<tr>
<th>Fish Size (millimeters)</th>
<th>Maximum Hydraulic Drop over Fishway Weir (foot)</th>
<th>Maximum Hydraulic Drop at Fishway Entrance and Exit (foot)</th>
<th>Velocity for Swimming Distances less than 1 foot (feet per second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 to 65</td>
<td>0.7</td>
<td>0.13</td>
<td>1.5 to 2.5</td>
</tr>
<tr>
<td>80 to 100</td>
<td>1</td>
<td>0.33</td>
<td>3 to 4.5</td>
</tr>
</tbody>
</table>

I.1.4 Fishway Entrance Configuration

When simultaneous passage of juveniles and adults is required, it may be necessary to install multiple fishway entrances at the facility. Each entrance should operate independently and meet the hydraulic drop criterion for each age class of fish. For example, one entrance would operate to attract adult fish and convey the appropriate volume, velocity, and shape of attraction jet at the entrance for adult passage, while another entrance would operate at the juvenile hydraulic drop differential and convey flow over a weir.

The lower hydraulic drop requirement between pools for juveniles is not an obstacle to adult fish provided that the facility satisfies the entrance design requirements of Section 5.2 of the NOAA Fisheries West Coast Region Anadromous Salmonid Passage Design (Manual). When juvenile fish passage is required, the fishway should meet the parameters listed in Table I-
1. However, the fishway entrance should operate per the guidelines and criteria listed in Section 5.2 of the Manual when adult salmonids are present.

### I.1.5 Attraction Flow

*Due to poor attraction conditions often associated with roughened channel designs, this type of fishway may require up to 100% of the 5% exceedance flow. When mean annual stream flow is less than 1,000 cubic feet per second (ft³/s), up to 100% of the stream flow during the migration window may be required for attraction. For projects with mean annual stream flow that is more than 1,000 ft³/s, the minimum attraction flow for fishways incorporating an AWS is 5% to 10% of the 5% exceedance flow. When auxiliary water is not available for attraction purposes, up to 20% of the 5% exceedance flow may be required through the fishway.*

For fishways without an AWS and attraction flow headworks, the fishway design flow is the attraction flow. When hydrology limits the ability to meet that criterion, hydraulic drop at the entrance is optimized to the extent possible when adults are present. An example of hydrology limiting adult criteria is when there is insufficient fishway or AWS discharge to maintain a 1-foot drop at the fishway entrance while simultaneously maintaining a minimum slot width of 12 inches.

When adult criteria for hydraulic drop at the fishway entrance cannot be achieved or maintained, the percentage of the high fish passage design flow required as fishway discharge should be increased. Fishway attraction (i.e., the ability of a fish to locate the fishway entrance downstream of the dam) is the critical design parameter for an upstream passage facility.

### I.1.6 Energy Dissipation Factor

*Pool volume is designed using an EDF of 2 ft-lb/ft³/s.*

### I.1.7 Minimum Pool Depth

*Minimum pool depth is 3 feet.*

Vertical slot ladders should maintain the minimum 3-foot pool depth at all required fishway discharges. Typically, depending on fishway slope, this requires a minimum operating flow of 20 to 30 ft³/s. Fishways that incorporate a single orifice into the design may require 5 to 10 ft³/s to maintain a pool depth of 3 feet; a dual-orifice fishway may require 15 to 20 ft³/s. When the required minimum fishway discharge is insufficient to maintain 3-foot pool depths, other fishway designs should be employed.

### I.1.8 Orifice and Weir Flow

*Fishways that incorporate orifices into the design should maintain both the through-orifice flow and over-weir flow criteria and requirements under all required fishway discharges. Minimum water depth over the weir is 3 inches. Orifice-style ladders cannot operate under strictly orifice flow during any of the required fishway discharges.*
A 3-inch depth over the weir ensures that a well-defined jet and appropriate plunging flow characteristics are available to allow juveniles to leap over the weir. When orifice and weir designs cannot maintain a minimum 3-inch depth of water over each fishway weir, other fishway designs should be employed.

**I.1.9 Hydraulic Drop Between Fishway Pools**

Projects should be designed using criteria that meet the jump requirements for the target species, age classes, and size of fish the facility should pass. The default hydraulic drop between pools is 0.5 foot.

The hydraulic drop between pools in weir-pool style ladders (e.g. Step-pool, Pool-and-Chute, Ice Harbor) which create jet plunging over a weir, may be designed to meet the specific leaping capabilities of a target juvenile size. When the target size of juvenile fish is unknown or undocumented the default hydraulic drop between pools should be no greater than 0.5 feet.

**I.1.10 Slot and Orifice Velocity**

Projects should be designed using criteria that meet the burst, prolonged, and sustained swim speeds for the target species, age classes, and size of fish the facility should pass. The default slot or orifice velocity is no more than 2.5 feet per second (ft/s). Slot and orifice velocity for various sizes of juvenile fish are as follows:

- 45-mm fish: 1.5 ft/s
- 60-mm fish: 2.5 ft/s
- 80-mm fish: 3 ft/s
- 100-mm fish: 4.5 ft/s

Vertical slot fish ladder designs for juvenile upstream passage are not designed using hydraulic drop criteria. Vertical slot fish ladders are designed for juvenile passage by ensuring the slot velocity and the target fish burst speed are compatible. Step-pool style ladders also employing orifice designs must ensure hydraulic drop criteria for the target juvenile size is simultaneously achieved. When the target size of juvenile fish is unknown or undocumented the default slot or orifice velocity is 2.5 ft/s.

**I.1.11 Weir Design**

Weirs should be designed such that they are sharp crested, and where the head over the weir is two times the breadth.

**I.1.12 Low Flow Connectivity**

Fishways are designed to pass fish over a range of flows bracketed by the designated fish passage design high and low flows. This range constitutes the bounds of the fish passage facility design where fish passage facilities should operate within the specified design criteria. Within this range of streamflow, the fishway design should allow for safe, timely, and effective fish passage. If juvenile fish are present, or actively migrating below the design range of streamflow,
juvenile fish should be able to pass upstream through the fishway or be able to pass safely without need of a fishway or other passage facility. For projects where the mean annual stream flow is less than 1,000 ft³/s, fishways are designed to pass juveniles during the lowest base flow conditions. For smaller stream and tributary-scale projects, this often requires the design of fishways that will pass juveniles at flows on the scale of 1 ft³/s.

**I.1.13 Fishway Slope**

Maximum slope for a pool and chute fishway should be 8%. The maximum slope for all other types of fishways should be 5%.