1-31-04 external review draft

ANADROMOUS SALMONID PASSAGE FACILITY GUIDELINES AND CRITERIA

Developed by
National Marine Fisheries Service
Northwest Region
Portland, Oregon

FOREWORD

The task involved in successfully passing fish upstream or downstream of an in-river impediment is a dynamic integration of fish behavior, physiology and bio-mechanics with hydraulic analysis, hydrologic study and engineering. Installing a fish passage structure does not constitute providing satisfactory fish passage, unless all of the above components are adequately factored into the design. The following document provides criteria, rationale, guidelines and definitions for the purpose of designing proper fish passage facilities for the safe, timely and efficient upstream and downstream passage of anadromous salmonids at impediments created by man-made structures, natural barriers (where provision of fish passage is consistent with management objectives), or altered in-stream hydraulic conditions. This document provides regional guidance for the National Marine Fisheries Service (NOAA Fisheries) fishway policies and guidelines, and is to be used for actions pertaining to the various authorities and jurisdictions of NOAA Fisheries (including Section 18 of the Federal Power Act), and for consultation under the Endangered Species Act and the Magnuson-Stevens Act. Section 12 (Juvenile Fish Screen and Bypass Criteria) supercedes previous criteria published by NOAA Fisheries, including Juvenile Fish Screen Criteria (February 16, 1995) and Juvenile Fish Screen Criteria for Pump Intakes (May 9, 1996). If passage facilities are designed and constructed in a manner consistent with these criteria, adverse impacts to migration will be minimized.

Instances will occur where a fish passage facility may not be a viable solution for correcting a passage impediment, due to biologic, sociologic, or economic constraints. In these situations, removal of the impediment or altering operations may be a suitable surrogate for a constructed fish passage facility. In other situations, accomplishing fish passage may not be an objective of NOAA Fisheries because of factors such as limited habitat, or lack of naturally occurring runs of anadromous fish upstream of the site. To determine whether NOAA Fisheries will use its various authorities to promote or to prescribe fish passage, NOAA Fisheries will rely on a collaborative approach, considering the views of other fisheries resource agencies, Native American Tribes, non-government organizations, and citizen groups, and will strive to accomplish the objectives in sub-basin plans for fisheries restoration and enhancement.

In general, NOAA Fisheries requires volitional passage, as opposed to trap and haul, for all passage facilities. This is primarily due to the risks associated with the handling and transport of migrant salmonids, in combination with the long term uncertainty of funding, maintenance and operation of the trap and haul program. However, there are instances in which trap and haul may be the only viable option for upstream and/or downstream fish passage at a particular site.

The fish passage facilities described in this document include various *fish ladders*[1], *exclusion barriers*, trap and haul facilities, fish handling and sorting facilities, in-stream structures and road crossing~~s~~ structures such as culverts or bridges, juvenile fish screens, tide gates, infiltration gallery, upstream juvenile passage facilities, and specialized criteria for mainstem Columbia and Snake River passage facilities. Passage facilities for projects under NOAA Fisheries jurisdiction should be consistent with the details described in this document, with the facility design developed in close coordination with NOAA Fisheries fish passage specialists.

This document does not address any aspect of design other than those that provide for safe and timely fish passage. Structural integrity, public safety and other aspects of facility design are the responsibility of the principal design engineer, who should ensure that the final facility design meets all other requirements in addition to the fish passage criteria and guidelines contained in this document.

Proponents of new, unproven fish passage designs (i.e. not meeting the criteria and guidelines contained in this document) shall provide to NOAA Fisheries: 1) development of a biological basis for the concept; 2) demonstration of favorable fish behavioral response in a laboratory setting; 3) an acceptable plan for evaluating the prototype installation; and 4) an acceptable alternate plan developed concurrently for a fish passage design satisfying these criteria, should the prototype not adequately protect fish. Additional information on the NOAA Fisheries approval process for unproven fish passage devices can be found in Section 17.

Since these criteria are general in nature, there may be cases where site constraints or extenuating biological circumstances dictate that certain criteria be waived or modified without delaying or otherwise adversely impacting anadromous fishes. It is the responsibility of the applicant to provide compelling evidence in support of any proposed waiver. Conversely, where NOAA Fisheries deems there is a need to provide additional protection for fish, more restrictive site-specific criteria may be added. These circumstances will be considered by NOAA Fisheries on a project-by-project basis. In addition, there may be instances where NOAA Fisheries provides written approval for use of alternative passage criteria, if NOAA Fisheries determines that the alternative criteria provides equal or superior protection as compared to the criteria listed herein,
for a particular site or for a set of passage projects within the Northwest Region.

Criteria are design, maintenance or operational standards that can not be changed without a written waiver from NOAA Fisheries. For the purposes of this document, a criterion is described by the word "shall". A guideline is a recommended design, maintenance or operational feature that will generally result in safe and efficient *fishway* facility design, and for the purposes of this document are described by the word "should". A waiver from NOAA Fisheries is not required

[1] Words printed in *italics* are defined in Section 2.

to deviate from a guideline. However, if the designer is unable to follow a guideline, the designer shall describe for the NOAA Fisheries administrative record the site specific circumstances that led to the chosen alternative. Where new or updated information suggests a different standard (criterion or guideline) provides better fishway passage, operation or maintenance this document will be periodically updated.

Existing facilities may not adhere to the criteria and guidelines listed in this document. However, that does not mean these facilities must be modified specifically for compliance with this document. The intention of these criteria and guidelines is to assure future compliance in the context of fish passage facilities major upgrades and new designs.

The following document is hereby designated as NOAA Fisheries Northwest Regional guidance for fish passage design responsibilities under the ESA, FPA and Magnusen-Stevens Act, for the purpose of providing project proponents with NOAA Fisheries' perspective on properly designed fish passage facilities. This document was developed by Hydro Division Fish Passage Engineers, in a collaborative process with many interested regional parties. This guidance is considered to be a working document, thus as new knowledge in fish passage is gained, these guidelines and criteria will be updated as necessary. Suggested changes, additions or questions should be directed to Bryan Nordlund of NOAA Fisheries at (360) 534-9338, for consideration in updating this document. Assistance from NOAA Fisheries fish passage specialists can be obtained by contacting the Hydro Division at (503) 230-5414.

Adopted,

Regional Administrator

TABLE OF CONTENTS

Section 1. Upstream Passage Impediments

1.1 An **upstream passage impediment is defined** as any manmade structural feature or project operation that causes adult or juvenile fish to be injured, killed, blocked or delayed on their upstream migration, to a greater degree than in a natural river setting. Manmade impediments require a design to utilize conservative criteria, because the natural complexity that usually provides fish passage has been substantially altered.

This definition is provided for the purpose of describing situations in which NOAA Fisheries will use these criteria in reviewing mitigative measures aimed at improving fish passage at an impediment. Any upstream passage impediment requires approved structural and/or operational measures to mitigate for adverse impacts to *upstream fish passage*. In addition, this criteria is applicable where passage over a natural barrier is desired, consistent with sub-basin or recovery plans.

1.2 It is important to note that not every *upstream passage facility* can fully compensate for an unimpeded natural channel. As such, additional mitigation measures could be required and will be established on a case-by-case basis.

1.3 Examples of upstream passage impediments include, but are not limited to:

1.3.1 Permanent or intermittent dams where either adult or juvenile upstream migrants are present, if fish cannot readily pass at any streamflow.

1.3.2 *Static head* over a manmade instream structure in excess of 1.5 feet.

1.3.3 *Weir*s, *aprons*, hydraulic jumps or other hydraulic features that produce shallow depth (less than 10 inches), high flow velocity (greater than 12 ft/s) for over 90% of the stream channel cross section, or exceed the hydraulic criteria specified for culvert length specified in Section 8.5.6.

1.3.4 Diffused or braided flow that impedes the approach to the impediment.

1.3.5 Road crossing culverts not achieving the criteria specified in Section 8.

1.3.6 Project operations that lead upstream migrants to impassable routes or cause excess migration delays.

1.3.7 Improperly designed fish passage (see Section 5) or fish collection facilities (see Sections 6 and 7).

1.3.8 Headcut control or improperly designed bank stabilization measures.

1.3.9 Insufficient *bypass reach* flows to induce upstream migrants to move upstream into the *bypass reach* adjacent to a powerhouse or *wasteway* return.

1.3.10 Degraded *bypass reach* discharge water quality, relative to that downstream of the confluence of *bypass reach* and return discharges.

1.3.11 Instream or *bypass reach* ramping rates that delay or strand fish.

1.3.12 Return discharges to the stream that may be detected and ascended by fish, with no certain means of continuing their upstream migration

1.3.13 Return discharges to the stream that are attractive to upstream migrating fish (eg. turbine draft tubes, shallow *aprons* and flow discharges) that have the potential to cause

injury.
1.3.14 Water diversions.

Section 2. Definition of Key Terms

Terms defined in this section are identified in *italics* throughout the document**.**

Active screens - juvenile fish screens equipped with a cleaning system with proven cleaning capability, and which are automatically cleaned as frequently as necessary to keep the screens free of any debris that will restrict flow area. An active screen is the required design in most instances.

Approach velocity - the vector component of *true velocity* that is perpendicular to and in front of the screen face, calculated by dividing the maximum diverted flow amount by the *effective screen area*.

Apron - a flat, usually slightly inclined slab below a flow control structure that provides for erosion protection and produces hydraulic characteristics suitable for energy dissipation or in some cases fish exclusion.

Attraction flow - the flow that emanates from a *fishway entrance* in sufficient quantity and location to attract upstream migrants into the *fishway*. Attraction flow consists of gravity flow from the fish ladder, plus auxiliary water system flow added in the lower ladder.

Auxiliary water system - a hydraulic system that augments *fish ladder* flow at various points in the *upstream passage facility*. Typically, large amounts of auxiliary water flow are added in the *fishway entrance pool* in order to increase the attraction of the *fishway entrance*.

Backwash - Providing debris removal by pressurized wash, opposite the normal flow direction.

Bankfull - The minimum elevation of a point on a streambank at which overflow into the *floodplain* begins. The *floodplain* is a relatively flat area adjacent to the channel constructed by the stream and overflowed by the stream at a recurrence interval of about one to two years. If the *floodplain* is absent or poorly defined, other indicators may identify bankfull. These include the height of depositional features, a change in vegetation, slope or topographic breaks along the bank, a change in the particle size of bank material, undercuts in the bank, and stain lines (the lower extent of lichens and moss on boulders). Field determination of bankfull should be calibrated to known stream flows or to regional relationships between bankfull flow and watershed drainage area.

Baffles - physical structures placed in the flow path designed to dissipate energy, or to re-direct flow for the purpose of achieving more uniform flow conditions.

Bedload - Sand, silt, gravel, or soil and rock debris transported by moving water. The particles of this material have a density or grain size that prevents movement far above or for a long distance out of contact with the streambed under natural flow conditions.

Bifurcation (*Trifurcation*) pools - pools where two or three sections of *fish ladder*s join.

Brail - a device that moves upward (vertically) through the water column, crowding fish into an area for collection.

Bypass reach - the portion of the river between the point of flow diversion and the point of flow return to the river.

Bypass System - the component of a downstream passage facility that transports fish from the diverted water back into the body of water from which they originated, usually consisting of a bypass entrance, a bypass conduit and a bypass outfall.

Coarse trash rack - a rack of vertical bars designed to catch large debris and preclude it from entering the *fishway*, while providing sufficient opening to allow the passage of fish.

Conceptual design - an initial design concept, based on the site conditions and biological needs of the species intended for passage.

Crowder - a combination of static and/or movable picketed and/or solid leads installed in a *fishway* for the purpose of moving fish into a specific area for sampling, counting, broodstock collection, or other purposes.

Diffuser - typically, a set of horizontal or vertical bars designed to introduce flow into a *fishway* in a nearly uniform fashion, but could also be of different geometry.

Distribution flume - a channel used to route fish to various points in a fish trapping system.

Effective screen area - the total submerged screen area (excluding major structural members). For rotating drum screens, this is the area that projects onto a vertical plane.

End-of-pipe screens - juvenile fish screening devices attached directly to the intake of a diversion pipe.

Exclusion barriers - upstream passage facilities that prevent upstream migrants from entering areas with no upstream egress, or areas that could lead to fish injury.

Exit control section - the upper portion of an *upstream passage facility* that serves to provide suitable passage conditions to accommodate varying *forebay* water surfaces, through means of pool geometry, *weir* design and the capability to add or remove flow at specific locations.

False weir - a device that adds pressurized flow to the top of a denil or steeppass ladder, normally used in conjunction with a *distribution flume* that routes fish to a specific area for management or other purposes.

Fish ladder - the structural component of an *upstream passage facility* that dissipates the potential energy into discrete pools or uniformly dissipates energy in a baffled chute to provide passage for upstream migrants.

Fish lift - a mechanical component of an upstream passage system that provides fish passage by lifting fish in a water-filled *hopper* or other lifting device into a conveyance structure that delivers upstream migrants past the passage impediment.

Fish lock - a mechanical and hydraulic component of an upstream passage system that provides fish passage by attracting or crowding fish into the lock chamber, activating a closure device to prevent fish from escaping, introducing flow into the enclosed lock, and raising the water surface to *forebay* level, and then opening a gate to allow the fish to exit.

Fish weir (or *picket weir*) - a device with closely spaced pickets to allow passage of flow, but not targeted adult fish. This device is commonly used in conjunction with an adult fish trap, for the purpose of broodstock collection. It is also used for the sorting of both wild and hatchery adult fish in the trap. This is not a *weir* in the hydraulic sense.

Fishway - the set of facilities, structures, devices, measures, and project operations that together constitute, and are critical to the success of, any upstream or downstream fish passage system.

Fishway entrance - the component of an *upstream passage facility* that discharges *attraction flow* into the *tailrace*, where upstream migrant fish enter (and flow exits) the *fishway*.

Fishway exit - the component of an *upstream passage facility* where flow from the *forebay* enters the *fishway*, and where fish exit into the *forebay* upstream of the passage impediment.

Fishway entrance pool - the pool immediately upstream of the *fishway entrance*(s).

Fishway entrance weir - a term frequently used to describe the partition between adjacent pools in a *fishway*.

Flood frequency - the frequency with which a flood of a given discharge has the probability of recurring. For example, a "100-year" frequency flood refers to a flood discharge of a magnitude likely to occur on the average of once every 100 years, or, more properly, has a one-percent chance of being exceeded in any year. Although calculation of possible recurrence is often based on historical records, there is no guarantee that a "100-year" flood will occur at all within the 100- year period or that it will not recur several times.

Floodplain - the area adjacent to the stream that is inundated during periods of high flow. The *floodplain* area is constructed by the river.

Flow duration curve - a statistical summary of river flow information over a period of time that describes cumulative percent of time for which flow exceeds specific levels (exceedance flows), exhibited by a cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded. *Flow duration curve*s are usually based on daily streamflow and describe the flow characteristics of a stream throughout a range of discharges without regard to the sequence of occurrence. If years of data are plotted, the annual exceedance flows can be determined.

Flow egress weir - a *weir* used to route excess flow (without fish) from a fish facility.

Forebay - the water body impounded immediately above a dam.

Freeboard - the height of a wall or other structure that extends above the maximum water surface elevation.

Hatchery supplementation - a hatchery propagation approach utilizing the progeny of local wild broodstock. Typically, the progeny are released into acclimation ponds at underused habitat locations.

Headloss - the loss of energy through a hydraulic structure.

Hopper - a device used to lift fish (in water) from a collection or holding area, for release upstream of the impediment.

Hydraulic drop - the energy difference between an upstream and downstream water surface, considering potential (elevation) and kinetic energy (*velocity head*). Also referred to as the "total energy head differential" as defined by Bernoulli's equation.

Off-ladder trap - A trap that is adjacent to a *fish ladder*, located in a sample loop which is separate from the normal *fish ladder* route - allows fish to either pass the ladder, or be routed into the trap

Ordinary high water mark - The mark along the bank or shore up to which the presence and action of the water are common and usual, and so long continued in ordinary years as to leave a natural line impressed on the bank or shore and indicated by erosion, shelving, changes in soil characteristics, destruction of terrestrial vegetation, or other distinctive physical characteristics.

Passive screens - juvenile fish screens with no automated cleaning system.

Picket leads - a set of vertically inclined flat bar or circular slender columns (pickets), designed to lead fish to a specific point of passage.

PIT tag detector - a device that passively scans a fish for the presence of a passive integrated transponder (PIT) tag.

Plunging flow - flow over a *weir* that falls into the receiving pool with a water surface elevation below the *weir* crest elevation. Generally, flow at the receiving pool water surface is in the upstream direction.

Porosity - the percent flow-through open area of a mesh, screen or rack relative to the entire gross area.

Rating curve - the graphed data depicting the relationship between water surface elevation and flow amount.

Redd - deposition of fish eggs in gravel.

Screen media - the screen face material that provides a physical exclusion barrier to reduce the probability of entraining fish.

Section 10 and 404 Regulatory Programs - The principal Federal regulatory programs, carried out by the U.S. Army Corps of Engineers, affecting structures and other work below mean high water. The Corps, under Section 10 of the River and Harbor Act of 1899, regulates structures in, or affecting, navigable waters of the U.S. as well as excavation or deposition of materials (e.g., dredging or filling) in navigable waters. Under Section 404 of the Federal Water Pollution Control Act Amendments (Clean Water Act of 1977), the Corps is also responsible for evaluating application for Department of the Army permits for any activities that involve the placement of dredged or fill material into waters of the United States, including adjacent wetlands.

Static head - the upstream-to-downstream difference in water surface elevation over a hydraulic control structure (also referred to sometimes as *hydraulic drop*).

Streaming flow - flow over a *weir* which falls into a receiving pool with water surface elevation above the *weir* crest elevation. Generally, flow at the receiving pool water surface is in the downstream direction.

Sweeping velocity - the vector component of *true velocity* that is parallel and adjacent to the screen face.

Tailrace - the river immediately downstream of an instream structure.

Total project head - the difference in water surface elevation from upstream to downstream of an impediment such as a dam. Normally, *total project head* encompasses a range based on river flows and/or the operation of flow control devices.

Thalweg - the line connecting the deepest parts of a stream channel

Tide Gate - a gate used in coastal areas to regulate tidal intrusion into protected areas.

Transport Channel - a hydraulic conveyance designed to pass fish between different sections of a fish passage facility.

True velocity - the velocity of flow in a water diversion, usually parallel to the bankline.

Turbine intake screens - partially screened turbine intakes on the mainstem Columbia and Snake River dams, which guide fish up a gatewell and into a collection and transport or bypass system.

Upstream fish passage - fish passage relating to upstream migration of adult and/or juvenile fish.

Upstream passage facility - a *fishway* system designed to pass fish upstream of a passage impediment, either by volitional passage or non-volitional passage.

Velocity head - the energy of flow contained by the water velocity.

Vertical barrier screens - screens that dewater flow from *turbine intake screens*, thereby concentrating fish for passage into a bypass system.

Wasteway - a channel (or other conveyance) which returns water originally diverted from an upstream location back to the diverted stream, whether for agricultural, power, or other uses.

Weir - a hydraulic term for an obstruction over which water flows (see also *fish weir* and *fishway entrance weir*).

Section 3. Preliminary Design Development

3.1 In cases such as (but not limited to) applications for a FERC license, ESA consultation, ESA Section 9 Enforcement activity, or ESA permit, a preliminary design for an *fish passage facility* shall be developed in an interactive process with NOAA Fisheries Hydro Program staff. For all *fish passage facility* projects, the preliminary design should be developed on the basis of a synthesis of the required site and biological information listed below. In general, NOAA Fisheries will review fish facility designs in the context of how the required site and the biological information was integrated into the design. Submittal of all information discussed below may not be required in writing for NOAA Fisheries review. However, the applicant should be prepared to describe how the biological and site information listed below was included in the development of the preliminary design. NOAA Fisheries will be available to discuss these criteria in general or in the context of a specific site. The applicant is encouraged to initiate coordination with NOAA Fisheries fish passage specialists early in the development of the preliminary design to facilitate an iterative, interactive, and cooperative process.

3.2 Site Information: The following site information should be provided for the development of the preliminary design.

3.2.1 Functional requirements of the proposed fish passage facilities as related to all anticipated operations and river flows. Describe median, maximum, and minimum monthly diverted flow rates, plus any special operations (eg. use of flash boards) that modify *forebay* or *tailrace* water surface elevations.

3.2.2 Site plan drawing showing location and layout of the proposed *fishway* relative to existing project features facilities.

3.2.3 Topographic and bathymetric surveys, particularly where they might influence locating *fishway entrance*s and exits, and personnel access to the site.

3.2.4 Drawings showing elevations and a plan view of existing flow diversion structures, including details showing the intake configuration, location, and capacity of project hydraulic features.

3.2.5 Basin hydrology information, including daily and monthly streamflow data and flow duration exceedence curves at the proposed *fish passage facility* site based on the entire period of available record. Where stream gage data is unavailable, or if a short period of record exists, appropriate synthetic methods of generating flow records may be used.

3.2.6 Project operational information that may affect fish migration (e.g., powerhouse flow capacity, period of operation, etc.)

3.2.7 Project *forebay* and tailwater *rating curve*s encompassing the entire operational range.

3.2.8 River morphology trends - If the *fish passage facility* is proposed at a new or modified diversion, determine the potential for channel degradation, meander or channel migration that may alter tailwater geometry and compromise *fishway* performance. Prepare to address potential adverse effects of stream channel gradient changes in this reach. Describe whether the river channel is stable or meandering, and how much recent meandering has occurred. Also, describe what effect the proposed *fish passage facility* may have on river alignment and the potential for future meandering.

3.2.9 Special sediment and/or debris problems - Describe conditions that may influence design of the *fish passage facility*, or present potential for significant problems.

3.3 Biological Information: The following biological information should be provided for the development of the preliminary design.

3.3.1 Type, life stage and run size of anadromous species present.

3.3.2 Run size, period of migration, spawning location, spawning timing and run duration for each life stage and species present at the site.

3.3.3 Identify other species present at the proposed fish passage site (including life stage), that may impact the facility design, particularly if state or Federally listed species are present.

3.3.4 High and low design passage flow for periods of *upstream fish passage* (see Section 4).

3.3.5 Identify any known fish behavioral aspects that affect salmonid passage. For example, most salmonid species pass readily through orifices, but other species unable to pass through orifices may impede salmonid passage.

3.3.6 Identify what is known and what needs to be researched about fish migration routes approaching the site.

3.3.7 Document, or estimate, minimum streamflow required to allow migration around the impediment during low water periods (based on past site experience).

3.3.8 Predation/poaching - describe the degree of human activity in immediate area and the need for security measures.

3.3.9 Identify water quality factors that may affect fish passage at the site. Fish may not migrate if water temperature and quality are marginal, instead seeking holding zones until water quality conditions improve.

3.4 Design Development Phases: A description of steps in the design process is presented here to clarify the *preliminary design* as it contrasts with often-used and related terms in the design development process. The following are commonly used terms (especially in the context of larger facilities) by many public and private design entities. NOAA Fisheries engineering staff may be consulted for all phases of design; required reviews are described in 3.4.5.

3.4.1 A reconnaissance study is typically an early investigation of one or more sites for suitability of design and construction of some type of facility.

3.4.2 A conceptual alternatives study lists types of facilities that may be appropriate for accomplishing objectives at a specific site, and does not entail much on-site investigation. It results in a narrowed list of alternatives that merit additional assessment.

3.4.3 A feasibility study includes an incrementally greater amount of development of each design concept (including a rough cost estimate), which enables selection of a most-preferred alternative.

3.4.4 The preliminary design includes additional and more comprehensive investigations and design development of the preferred alternative, and results in a facilities layout (including some section drawings), with identification of primary feature sizes and discharges. Cost estimates are also considered to be more accurate. Completion of the preliminary design commonly results in a preliminary design document that may be used for budgetary and planning purposes, and as a basis for soliciting (and subsequent collating) design review comments by other reviewing entities. The preliminary design is commonly considered to be at the 20% to 30% completion stage of the design process.

3.4.5 The detailed design phase uses the preliminary design as a springboard for preparation of the final design and specifications, in preparation for the bid solicitation (or negotiation) process. Once the detailed design process commences, NOAA Fisheries shall have the opportunity to review and provide comments at the 50% and 90% completion stages. These comments usually entail refinements in the detailed design that will lead to operations, maintenance, and fish safety benefits. Electronic drawings accompanied by eleven by seventeen inch are the preferred review medium.

Section 4. Design Flow Range

4.1 **Description, purpose and rationale:** The design streamflow range constitutes the operational bounds of the *fish passage facility*. Each *fish passage facility* shall be designed to pass migrants throughout a design streamflow range, bracketed by a designated high and low design passage flow. Within this range of streamflow, migrants should be able to pass safely and quickly. Outside of this flow range, fish shall either not be present or not be actively migrating, or shall be able to pass safely without need of a *fish passage facility*. Site-specific information is critical to determine the design time period and river flows for the passage facility - local hydrology may require that these design streamflows be modified for a particular site. In addition, the *fish passage facility* should be of sufficient structural integrity to withstand the maximum expected flow. It is beyond the scope of this document to specify structural criteria for this purpose.

Consistent with the terminology used throughout this document, criteria are specified by the word “shall” and guidelines are specified by the word “should”. Criteria are required design features, unless site specific conditions preclude their use and a site-specific written waiver is provided by NOAA Fisheries (also see Foreword). Guidelines are not required, but deviation from a guideline require a written explanation by the project designer. It is suggested that deviation from a guideline be discussed with NOAA Fisheries prior to final design. Since these guidelines and criteria are general in nature, there may be cases in which site constraints or extenuating circumstances dictate that certain criteria be waived or modified. Conversely, where there is a need to provide additional protection for fish, including species of fish not directly under NOAA Fisheries jurisdiction, site-specific criteria may be added. These circumstances will be considered by NOAA Fisheries on a project-by-project basis.

4.2 **Low Fish Passage Design Flow** is the mean daily average stream discharge that is exceeded 95% of the time during periods when migrating fish are normally (i.e. historically) present at the site, as determined by a flow-duration curve summarizing at least the previous 25 years of daily discharges, or by an appropriate artificial streamflow duration methodology if discharge records are not available. The low passage design flow is the lowest stream discharge for which migrants are expected to be present, migrating, and dependent on the proposed facility for safe passage. This could also be the minimum instream flow, as determined by state regulatory agencies, ~~or~~ by ESA consultations with NOAA Fisheries, or by an article in a FERC license.

4.3 **High Fish Passage Design Flow** is the mean daily average stream discharge that is exceeded 5% of the time during periods when migrating fish are normally (historically) present at the site, as determined by a flow-duration curve summarizing at least the previous 25 years of daily discharges, or by an appropriate artificial streamflow duration methodology if discharge records are not available. This is the highest stream discharge for which migrants are expected to be present, migrating, and dependent on the proposed facility for safe passage.

4.4 The *fishway* design should have sufficient river *freeboard* to minimize overtopping by 50 year flood flows. *Fishway* operations may include shutdown of the facility at very high flow or flood flow, in order to allow the facility to quickly return to proper operation when the river drops to within the range of passage design flows. Other mechanisms to protect *fishway* operations after floods will be considered on a case by case basis. In no case shall a *fishway* be inoperable for a period greater than 7 days during the migration period for any anadromous salmonid species.

4.5 The *fishway* design shall allow for safe, timely and efficient fish passage throughout the entire range of operations of the diversion structure causing the passage impediment. If the *fishway* can not be operated, the diversion structure should be shut down.

Section 5. Upstream Passage System Criteria

5.1 Types of *fish ladder*s

5.1.1 **Description, purpose and rationale:** The intent of this section is to identify potential pitfalls of a particular ladder type given specific site conditions, and to provide additional criteria for use with a specific type of *fish ladder*.

Consistent with the terminology used throughout this document, criteria are specified by the word "shall" and guidelines are specified by the word "should". Criteria are required design features, unless site specific conditions preclude their use and a site-specific written waiver is provided by NOAA Fisheries (also see Foreword). Guidelines are not required, but deviation from a guideline require a written explanation by the project designer. It is suggested that deviation from a guideline be discussed with NOAA Fisheries prior to final design. Since these guidelines and criteria are general in nature, there may be cases in which site constraints or extenuating circumstances dictate that certain criteria be waived or modified. Conversely, where there is a need to provide additional protection for fish, including species of fish not directly under NOAA Fisheries jurisdiction, site-specific criteria may be added. These circumstances will be considered by NOAA Fisheries on a project-by-project basis.

There are three basic categories of types of fish ladder. The most widely used is the pool-type ladder, characterized by a series of pools separated by fishway weirs that break the *total project head* into passable increments. Nearly all of the energy from upstream pools is dissipated in the downstream pool volume, resulting in a series of relatively quiescent pools that migrating fish can use to rest, stage and ascend upstream. Four examples of a pool-type ladder are a vertical slot (section 5.1.2), a pool and weir ladder (section 5.1.3), a weir and orifice ladder (section 5.1.4), and full width stream weirs (section 5.1.5). A second category of fish ladder is the roughened chute ladder, which consists of a hydraulically roughened channel with continuous energy dissipation throughout its length. Four examples of a roughened chute style of ladder are a steeppass, denil, a roughened stream channel and a pool-chute fish ladder (section 5.1.5).

In addition to describing the configuration and application of the particular styles of fish ladders, this section identifies general criteria and guidelines for use in completing the remainder of the upstream passage facility design.

5.1.2 **Vertical slot ladder -** The vertical slot configuration is a pool type of *fish ladder* widely used for the passage of salmon and steelhead. The passage corridor typically consists of 1 to 1.25 foot-wide vertical slots between *fishway* pools. However, narrower slots have been used in applications for other fish species and slots can be wider in designs (or two slots can be used per weir) where there is no *auxiliary water system* (see section 5.4). For anadromous salmonids, slots should never be less than one foot in width. This type of ladder is suitable for passage impediments which have *tailrace* and *forebay* water surface elevations that fluctuate at approximately the same rate. Maximum head differential (typically associated with lowest river flows) establishes the design water surface profile, which is on average, parallel to the fishway floor gradient. Vertical slot ladders require fairly intricate forming for concrete placement, so initial construction costs are somewhat higher than for other types of ladders.

Insert Drawing showing pool dimensions, slot orientation/dimensions and slot geometry

5.1.3 **Pool and weir ladder -** The pool and weir *fish ladder* passes the entire, nearly constant fishway flow through successive *fishway* pools separated by overflow *weir*s that break the *total project head* into passable increments. This design allows fish to ascend to a higher elevation by passing over a *weir,* and provides resting zones within each pool. Pools are sufficiently sized to allow for the flow energy to be nearly fully dissipated in the form of turbulence within each receiving pool. This type of *fish ladder* cannot accommodate much, if any, water surface elevation fluctuation in the forebay pool, since ladder flow and pool turbulence would excessively fluctuate. If forebay or tailwater fluctuates, this type of *fish ladder* is often designed with an auxiliary water supply and flow regulating section, as described in 5.4 and 5.8.

Insert Drawing

5.1.4 **Weir and orifice fish ladder** - The weir and orifice *fish ladder* passes the fishway flow from forebay through successive *fishway* pools connected by overflow weirs and orifices, that divide the *total project head* into passable increments. The Ice Harbor ladder is an example of a weir and orifice *fish ladder*. This ladder design was initially developed for use at Ice Harbor Dam (Lower Snake River) in the mid-1960's. The *weir* consists of two orifices, centered and directly below two *weir*s - one on each side of the longitudinal centerline of the ladder. Between the *two weir*s is a slightly higher non-overflow wall, with an upstream projecting flow baffle at each end. Half- Ice Harbor ladder designs consist of one *weir*, one orifice and a non-overflow wall between *fishway* pools. This type of ladder cannot accommodate much, if any, water surface elevation fluctuation in the forebay pool, since *fish ladder* flow and pool turbulence would fluctuate excessively. If forebay or tailwater fluctuates, this type of *fish ladder* is often designed with an auxiliary water supply and flow regulating section, as described in 5.4 and 5.8.

5.1.5 **Full Width Stream Weirs** - Full stream width weirs are *fishway*s are used in small stream systems to incrementally backwater an impassable barrier or impediment. These structures span the entire width of the stream channel and convey the entire stream flow, breaking the *hydraulic drop* into passable increments. This is accomplished by incrementally stepping down the water surface elevation from the barrier to intersect the natural stream gradient downstream.

Unlike many of the *fishway*s described herein, these structures are not designed with auxiliary water supply systems, trashracks, or a great deal of operational complexity. *Weir*s may be constructed from reinforced concrete, or in limited applications boulders or logs. Design of each *weir* shall concentrate flow into the center of the downstream pool, and/or direct flow toward the downstream thalweg. This concentration is accomplished by providing a slight *weir* crest elevation decrease from each bank to the center (flow notch). Typically, the flow notch will be designed to pass the minimum instream flow, while higher stream flows pass over the entire *weir* crest. Pool volumes should be designed per the pool volume criteria specified in section 5.6.7, but natural *bedload* movement will fill in pools providing a scour pool area below the flow notch, and shallower fringe areas.

Scour is a critical and often underestimated design issue. If sills and *weir*s are not anchored on bedrock, a means of preventing undermining is required. If a pool lining technique (riprap, concrete, etc) is selected to prevent undermining of the *fishway*, a minimum 4 feet of depth should be provided in each pool and in the *tailrace* below the *fishway*. This allows for a fish to stage or hold below each *weir* before proceeding upstream. In addition, the *tailrace* area should be protected from scour to prevent lowering of the streambed, and should be monitored after high flows occur to ensure the facility remains passable

Insert Ice Harbor Drawing

5.1.6 **Roughened Channels** - These types of ladders have excellent fish attraction characteristics while using relatively low *attraction flow* amounts, and are widely used in fish trap designs (steeppass) or closely monitored sites with low streamflow (denil). Baffled chute type *fish ladder*s entail a sloped channel that has a constant discharge for a given normal depth, chute gradient, and baffle configuration and spacing. Energy is dissipated gradually (based on channel roughness) and results in a constant velocity compatible with the swimming ability and behavior of targeted fish. The passage corridor consists of a high velocity chute flow between the *baffles*. There are no resting locations within a given length of chute. Once fish start to ascend a length of baffled chute, they must either pass or fall back which will likely cause injury. Intermediate resting pools are used between component lengths of chute to minimize fallback by weaker swimming fish. Denil and steeppass baffled chutes shall not be used in areas where downstream passage occurs, or where even minor amounts of debris are expected. Usually, these types of ladders are only used where they can be closely monitored because of debris concerns.

Denil and steeppass *fishway*s are examples of baffled chute ladders, and are of similar design. The denil *fishway* generally is designed with slopes up to 20%, and has higher flow capacity and less roughness than a steeppass *fishway*. Steeppass *fishway*s can be used at slopes up to 28%. For either *fishway*, the average chute design velocity should be less than 5 ft/s. For a *upstream passage facility* utilizing a denil or a steeppass ladder, the horizontal distance between resting pools should be less than 25 feet. Resting pool volumes shall adhere to volume requirements specified in section 5.6.7. The minimum flow depth shall be 2 feet, and shall be consistent throughout the length of the ladder for all ladder flows. Designs shall be developed to minimize fallback of fish to limit injury potential.

Insert Drawing

Rock channels are often proposed as a passage alternative. Design of this type of facility varies widely. Criteria for this type of ladder design are still evolving, and proposals for this type of ladder will be assessed on a site-specific basis.

Pool and Chute - Pool and chute type *fish ladder*s may a more desirable alternative to the previous options when migrating fish must pass through a greater range of streamflow. During low streamflow, the ladder can operate in the pool ladder mode. When streamflow is greater, improved attraction to the ladder can be attained by routing a proportionately higher discharge through the ladder, which acts as a cross between pool and baffled chute ladders. However, this typically requires manual adjustment of stoplogs, an operation that is cumbersome and could be dangerous. Criteria for this type ladder design are still evolving, and proposals for this type ladder will be assessed on a site-specific basis.

5.2 ***Fishway entrance*** **design criteria**

5.2.1 Description, purpose and rationale: The *fishway entrance* is composed of an entrance gate or slot, through which *fishway attraction flow* is discharged and through which fish enter the *upstream passage facility*; it is possibly the most critical component in the design of an upstream passage system. Placing a *fishway entrance* in the correct location(s) will allow a passage facility to provide a good route of passage throughout the design range of passage flows; optimal *fishway entrance* hydraulic characteristics and geometry are key design parameters. The most important aspects of a *fishway entrance* design are the 1) location of the entrance, 2) shape and amount of flow emanating from the entrance, 3) approach channel immediately downstream of the entrance, and 4) flexibility in operating the entrance flow to accommodate variations in *tailrace* elevation, stream flow conditions, and project operations.

5.2.2 The *fishway entrance* gate configuration and operation will vary based on site specific project operations and streamflow characteristics. Entrance gates are usually operated in either a fully open or fully closed position, with the operating entrance dependent on *tailrace* flow characteristics. Sites with limited tailwater fluctuation may not require an entrance gate to regulate the entrance head. Adjustable *weir* gates that rise and fall with tailwater elevation may also be used to regulate the *fishway entrance* head. Other sites may accommodate maintaining proper entrance head by regulating auxiliary water flow through a fixed geometry entrance gate.

5.2.3 *Fishway entrances* shall be located at points where fish can easily locate the *attraction flow* and enter the *fishway*. When choosing an entrance location, high velocity and turbulent zones in a powerhouse or spillway *tailrace* should be avoided, in favor of relatively tranquil zones adjacent to theses areas. At locations where the *tailrace* is wide, shallow and turbulent, excavation to create a deeper, less turbulent holding zone adjacent to the *fishway entrance*(s) may be required.

5.2.4 *Attraction flow* from the *fishway entrance* should be between 5% and 10% of high design passage flows for streams with mean annual discharges exceeding 1000 cfs. For smaller streams, where feasible use larger percentages (up to 100%) of streamflow. Generally speaking, the higher percentage of total river flow used for attraction into the *fishway*, the more effective the facility will be in providing upstream passage.

5.2.5 The *fishway entrance* head (*hydraulic drop*) shall be maintained between 1 to 1.5 feet, and designed to operate from 0.5 to 2.0 feet of *hydraulic drop*.

5.2.6 The minimum *fishway entrance* width should be four feet, and the entrance depth should be at least six feet, although the shape of the entrance is dependent on *attraction flow* requirements. Also, see requirements for mainstem Columbia and Snake rivers in section 10.

5.2.7 If the site has multiple zones where fish accumulate, each *tailrace* accumulation location will require a minimum of one entrance. For long powerhouses, additional entrances are required. Since *tailrace* hydraulic conditions usually change with project operations and hydrologic events, it is often necessary to provide two or more *fishway entrance*s.

5.2.8 Closure gates shall be provided to provide flow to the appropriate entrance gate, and shall not conflict with any potential path of fish migration. *Fishway entrance*s shall be closed by downward-closing slide gates, unless otherwise approved by NOAA Fisheries.

5.2.9 *Fishway entrance*s can be either adjustable submerged *weir*s, vertical slots, orifices, or other shapes provided that the hydraulic requirements specified in 5.2.3, 5.2.4 and 5.2.5 are achieved. It is noted that some non-salmonid species will avoid using orifices.

5.2.10 The desired entrance *weir* and/or slot discharge jet hydraulic condition is streaming, not plunging, for submerged *weir* discharges. *Plunging flow* induces jumping and can cause injuries, and it presents hydraulic condition some species may not pass.

5.2.11 In general, low flow entrances should be oriented more or less perpendicular to streamflow, and high flow entrances should be oriented more or less parallel to streamflow. Site-specific assessments are required.

5.2.12 The *fishway entrance* design shall include staff gages to allow for a simple determination of whether entrance head criterion (see 5.2.4) is being met. Staff gages shall be located in the entrance pool and in the tailwater just outside of the *fishway entrance*, in an area visible from an easy point of access. Care should be taken in the design when placing staff gages, being sure to avoid turbulent areas and areas where velocity is increasing in front of the *fishway entrance*. Gages should be readily accessible to facilitate in-season cleaning.

5.3 ***Fishway entrance pool*** **criteria**

5.3.1 Description, purpose and rationale: The *fishway entrance pool* is at the lowest elevation of the upstream passage system. It discharges flow into the *tailrace* through the entrance gates for the purpose of attracting upstream migrants. In many *fish ladder* systems, the entrance pool is the largest and most important pool, in terms of providing proper guidance of fish to the ladder section of the *upstream passage facility*. It combines ladder flow with *auxiliary water system* flow through *diffuser* gratings to form entrance *attraction flow* (see 5.4). The entrance pool shall be configured to readily guide fish toward ladder *weir*s or slots.

5.3.2 The minimum transport velocity (between entrance and first *fishway weir*, and over submerged *fishway weir*s) is 1.5 ft/s.

5.3.3 The *fishway entrance pool* shall be designed to optimize attraction to the lower *fishway weirs*. This can be accomplished by angling vertical AWS *diffuser*s toward and terminating near the lowest ladder *weir*.

5.4 ***Auxiliary Water System*** **(AWS) Criteria**

5.4.1 Description, purpose and rationale: AWS flow is usually routed from the *forebay* through a trash rack or intake screen, a back set flow control gate, an energy dissipation zone, energy *baffles*, and *diffuser*s, and into the *fishway*. An AWS provides flow to the entrance pool and/or area upstream of *weir*s that on occasion become back-watered, and usually provides the bulk of the *attraction flow* through *fishway entrance*s. In addition, the AWS is used to provide make-up flows to various transition pools in the ladder such as *bifurcation* or *trifurcation* pools, trap pools, *exit control section*s, or counting station pools.

5.4.2 *Vertical diffuser*s should consist of non-corrosive, vertically-oriented flat-bar grates, and shall have a maximum one-inch clear horizontal spacing.

5.4.3 The maximum AWS *diffuser* velocity shall be less than 1.0 ft/s for vertical *diffuser*s and 0.5 ft/s for horizontal *diffuser*s, based on total *diffuser* panel area.

5.4.4 The design shall provide access for debris removal from each *diffuser*.

5.4.5 All *diffuser* edges and surfaces exposed to fish shall be rounded during fabrication to reduce the potential for contact injury.

5.4.6 Vertical AWS *diffuser*s shall have a top elevation at or below the low design entrance pool water surface elevation.

5.4.7 A trash rack shall be provided at the AWS intake with clear space between the vertical flat bars of less than one inch, and maximum velocity of less than 1 ft/s. The support structure for the trash rack shall not interfere with cleaning requirements, and shall consider access, debris raking and debris removal. Where possible, the trash rack should be installed at a 1:5 (horizontal:vertical) slope (or flatter) for ease of cleaning. The trash rack design shall allow for easy maintenance, considering access for personnel, travel clearances for manual or automated raking, and removal of debris

5.4.8 In instances where the majority of the instream flow passes through the AWS during periods of juvenile out-migration, the AWS intake should be screened to NOAA Fisheries Juvenile Fish Screen Criteria (see Section 12). Trip gates or alternate intakes can be included in the design to ensure that AWS flow targets are achieved if the screen reliability is uncertain at higher flows. Debris and sediment issues may preclude the use of juvenile fish screen criteria for AWS intakes at certain sites.

5.4.9 AWS flow control can consist of a control gate, turbine intake flow control, or other flow control systems, located sufficiently far away from the AWS intake to ensure uniform flow distribution at the AWS trash rack at all AWS flows. AWS flow control is required to ensure that the correct quantity of AWS flow is discharged at the appropriate location during a full range of *forebay* water surface elevations.

5.4.10 Excess energy shall be dissipated from AWS flow prior to passage through add-in *diffuser*s (5.4.3). This is necessary to minimize surging and to induce relatively uniform velocity distribution (± 10%) at the *diffuser*s. Surging and non-uniform velocities may cause adult fish jumping and associated injuries or excess migration delay. Examples of methods to dissipate excess AWS flow energy include: 1) routing flow into the pool with adequate volume (see 5.4.11), then through a baffle system (*porosity* less than 40%) to reduce surging through entrance pool *diffuser*s, 2) passing AWS flow through a turbine, or 3) passing AWS flow through a pipeline with concentric rings or other hydraulic transitions designed to induce *headloss*.

5.4.11 An energy dissipation pool in an AWS should be a minimum volume established by the following formula:

$$V \geq \frac{\gamma Q H}{(16\ \text{ft-lb/s})/\text{ft}^3}$$

where: V = pool volume, in ft^3
γ = unit weight of water, 62.4 pounds (lb) per ft^3
Q = AWS flow, in ft^3/s
H= *Velocity head* of AWS flow, in feet

5.4.12 Staff gages shall be installed to indicate head differential across the AWS intake trash rack, and shall be located to facilitate observation and cleaning. Head differential across the AWS intake shall not exceed 0.3 feet.

5.4.13 AWS intake trash racks shall be of sufficient structural integrity to avoid the permanent deformation associated with maximum occlusion.

5.4.14 To facilitate cleaning, the AWS shall be valved or gated to provide for easy shut-off during maintenance activities, and subsequent easy re-set to proper operation.

5.4.15 At locations where *bedload* can cause accumulations at the AWS intake, sluice gates or other simple *bedload* removal devices are required.

5.5 ***Transport Channel*s**

5.5.1 Description, purpose and rationale: A *transport channel* conveys flows between different sectors of the *upstream passage facility*, providing a route for fish to pass.

5.5.2 The range of *transport channel* velocities shall be between 1.5 and 4 ft/s, including flows over or between *weir*s inundated by high tailwater.

5.5.3 The *transport channel*s should be a minimum of 5 feet deep.

5.5.4 The *transport channel*s should be a minimum of 4 feet wide.

5.5.5 The *transport channel*s shall be of open channel design.

5.5.6 Ambient natural lighting should be provided in all *transport channel*s, if possible. Otherwise acceptable artificial lighting is to be used, as described in 5.10.2.

5.5.7 Care shall be taken in design to avoid hydraulic transitions or lighting transitions, in order to reduce the possibility of excess migration delay.

5.6 ***Fish ladder*** **design criteria**

5.6.1 Description, Purpose and Rationale: A *fish ladder* converts the *total project head* at the passage impediment into passable increments, by providing suitable conditions for fish to hold, rest, and ultimately pass upstream. The criteria provided in this section have been developed to provide conditions to pass all anadromous salmonid species upstream with minimal delay and injury.

5.6.2 The maximum *hydraulic drop* per pool shall be 12 inches.

5.6.3 Ladder overflow *weir*s shall be designed to provide at least 12 inches of flow depth over the weir crest. The depth shall be indicated by locating a single staff gage (with the zero reading at the overflow *weir* crest elevation) in an observable, hydraulically stable location.

5.6.4 The pool dimensions should be a minimum of 8 feet long (upstream to downstream), 6 feet wide, and 5 feet deep. However, specific ladder designs will require specific pool dimensions that are greater than the minimums specified here.

5.6.5 Turning pools (i.e. where the *fishway* bends more than 90°) should be at least double the length of a standard *fishway* pool, as measured along the centerline of the fishway flowpath. Special consideration shall be given for the direction of the flow path from the upstream weir to assure that passage through the downstream weir is not compromised.

5.6.6 Additional guidance and criteria for application of specific ladder types is located in Section 5.1.

5.6.7 The *fishway* pool volume shall be a minimum of:

$$V \geq \frac{\gamma Q H}{(4\text{ft-lb/s})/\text{ft}^3}$$

where: V = pool volume, in ft^3
γ = unit weight of water, 62.4 pounds (lb) per ft^3
Q = *fish ladder* flow, in ft^3/s
H = energy head of pool-to-pool flow, in feet

under every expected design flow condition.

5.6.8 The dimensions of orifices should be at least 15 inches high by 12 inches wide, with the top and sides champhered 0.75 inches on the upstream side, and champhered 1.5 inches on the downstream side of the orifice.

5.6.9 The *freeboard* of the ladder pools shall be at least 3 feet at high design flow.

5.6.10 Ambient lighting is preferred throughout the *fishway*, and in all cases abrupt lighting changes shall be avoided.

5.6.11 At locations where the flow changes direction more than 60 degrees, 45 degree vertical miters or 2-foot vertical radius of curvature shall be included at the outside corners of *fishway* pools.

5.7 **Counting Window Stations**

5.7.1 Description, Purpose and Rationale: A counting station provides a location to observe and enumerate fish utilizing the fish passage facility. Although not always required, a counting station is often included in a *fishway* design to allow fishery managers to assess fish populations, make observations on fish health, or conduct scientific research. Other types of counting stations (such as submerged cameras, adult *PIT tag detector*s, or orifice counting tubes) may be acceptable, but they shall not interfere with the normal operation of the ladder or increase fish passage delay.

5.7.2 Counting stations shall be located in a hydraulically stable, low velocity (i.e. the lower end of velocity range specified in 5.5.2) accessible area of the *upstream passage facility*.

5.7.3 The counting window shall be designed for complete, convenient cleaning of sufficient frequency to ensure sustained visibility and accurate counts. The counting window material shall be of sufficient abrasion resistance to allow frequent cleaning.

5.7.4 Counting windows shall be vertically oriented.

5.7.5 The counting window sill should be positioned to allow full viewing of the passage slot.

5.7.6 The counting window shall include sufficient indirect artificial lighting for satisfactory fish identification at all hours, so as not to retard upstream passage due to excessive light intensity in the path of upstream migrants.

5.7.8 The minimum observable width (i.e. upstream to downstream dimension) of the counting window shall be 5 feet, and the minimum height (depth) should be full water depth (also see 5.7.11).

5.7.9 A *crowder* may be required in the design to move fish closer to the counting window to accommodate observation during turbid water conditions. If required, the minimum counting station slot width between the counting window and vertical counting window *crowder* surface should be 18 inches and shall be adjustable. The counting window slot width should be maximized as water clarity allows, and when not actively counting fish.

5.7.10 To guide fish onto the counting window slot, a downstream *picket lead* shall be included in the design, with orientation at a flow deflection angle of 45° relative to *fishway* flow direction. An 45° upstream *picket lead* shall also be provided. Picket orientation, picket clearance, and maximum allowable velocity shall conform to specifications for *diffuser*s specified in section 5.4. Flat picket bars shall be oriented parallel to flow. Circular pickets may also be used. Maximum head differential through each set of pickets shall be less than is 0.3 feet above the clean condition differential. Both upstream and downstream picket leads will be equipped with “witness marks” to verify correct position when picket leads are installed in the fishway. A one foot square opening in the upstream picket should be provided in the upstream picket to allow escape if fish pass through the downstream picket.

5.7.11 To minimize flow separations that may impede passage and induce fallback behavior at the counting window, transition ramps shall be included that provide gradual transitions between walls, floors and the count windows. As general guidance, these transitions should be more than 1:8 (i.e. one foot horizontally or vertically per eight feet in the direction of flow). The water surface over a counting window slot shall not be covered.

5.7.12 The pool downstream of the counting station shall extend at least two standard *fishway* pool lengths from the downstream end of the *picket lead*s. The pool upstream of the counting station shall extend at least one standard *fishway* pool length from the upstream end of the *picket lead*s. Both pools shall be straight and in line with the counting station.

5.8 ***Fishway exit*** **section**

5.8.1 Description, purpose and rationale: The *fishway exit* section provides a flow channel to provide fish with egress from the *fishway* and continue on their upstream migration. The exit section of *upstream fish passage* facilities can be composed of the following features: add-in auxiliary water valves and/or *diffuser*s, exit pools with varied flow, exit channels, coarse exit channel trash rack (for fish passage), and fine auxiliary water trash racks and control gates. One function of the exit section is to attenuate *forebay* water surface elevation fluctuations to ensure hydraulic conditions suitable for fish passage are maintained in ladder pools. Other functions should include minimizing the entrainment of debris and sediment into the *fish ladder*. Different types of ladder designs (see Section 6) require specific *fish ladder* exit design details.

5.8.2 The *exit control section hydraulic drop* per pool should range from 0.25 to 1.0 feet.

5.8.3 The length of the exit channel upstream of the *exit control section* should be a minimum of two standard ladder pools.

5.8.4 Exit section design shall utilize the requirements for auxiliary water *diffuser*s, channel geometry, and energy dissipation as specified in 5.4, 5.5 and 5.6.

5.8.5 The ladder exit should be located along a shoreline and in a low velocity zone (less than 4 ft/s), sufficiently far enough upstream of a spillway, sluiceway or powerhouse to minimize the risk of fish non-volitionally falling back through these routes. Distance depends on bathymetry near the dam spillway or crest, and associated longitudinal river velocities. Public access near the ladder exit should not be allowed.

5.9 ***Fishway Exit*** **Trash Rack and Debris Management**

5.9.1 Description, purpose and rationale: *Coarse trash rack*s should be included at the *fishway exit*, to minimize the entrainment of debris into the *fishway*. Floating debris can occlude passage corridors, potentially creating hazardous passage zones and/or blocking fish passage. Other types of debris, such as *bedload* transport into the *fishway*, can also adversely affect the operation of the facility.

5.9.2 The maximum allowable velocity through a clean trash rack is 1.5 ft/s.

5.9.3 The minimum submerged trash rack depth is 5 feet.

5.9.4 Where possible, the trash rack should be installed at 1:5 (horizontal:vertical) slope (or flatter) for ease of cleaning. The trash rack design shall allow for easy maintenance, considering access for personnel, travel clearances for manual or automated raking and removal of debris

5.9.5 Debris booms, curtain walls, or other provisions are required if coarse floating debris is expected.

5.9.6 If debris accumulation is expected to be high, the design should include an automated mechanical debris removal system. If debris accumulation potential is unknown, the design should include features to allow the simple retrofit of an automated mechanical debris removal system, should the need arise.

5.9.7 The *fishway exit* trash rack should have a minimum clear space between vertical flat bars of 10 inches if chinook are present, and 8 inches otherwise. Lateral support bar spacing shall be a minimum of 24 inches, and shall be sufficiently back set of the trash rack face to allow full trash rake tine penetration. Trash racks shall extend to the appropriate elevation to allow easy removal of raked debris.

5.9.8 The *fishway* trashrack shall be oriented at a deflection angle greater than 45° relative to the direction of river flow.

5.9.9 The *fishway exit* should be designed to minimize entrainment of sediment.

5.9.10 For AWS trashrack design information, see section 5.4

.

5.10 Miscellaneous considerations

5.10.1 *Fishways* should be secured to discourage vandalism and poaching and to provide public safety.

5.10.2 Ambient lighting shall be provided throughout the *fishway*. Where this is not possible (such as in tunnels), artificial lighting should be provided in the blue-green spectral range. Lighting shall be designed to operate under all environmental conditions at the installation.

5.10.3 Personnel access shall be provided to all areas of the *fishway*, to facilitate operational and maintenance requirements. Walkway grating should allow as much ambient lighting into the *fishway* as possible.

5.10.4 All metal edges in the flow path used for fish migration shall be ground smooth to minimize risk of lacerations. Concrete surfaces shall be finished to ensure smooth surfaces, with one-inch wide 45° corner chamfers.

5.10.5 Protrusions (such as valve stems, bolts, gate operators) shall not extend into the flow path of the *fishway*.

5.10.6 All control gates exposed to fish (such as at entrances in the fully-open position) shall have a shroud or be recessed to minimize or eliminate fish.

Section 6. *Exclusion Barriers*

6.1 **Description, purpose and rationale:** *Exclusion barriers* are designed to minimize the attraction and stop the migration of upstream migrating fish into an area where there is no upstream egress or suitable spawning area, and to guide fish to an area where upstream migration can continue. *Exclusion Barriers* can also be used to restrict movement of undesirable species into habitat. *Exclusion barriers* are designed to minimize the potential for injury of fish that are attracted to impassable routes.
Some examples of the use of *exclusion barriers* include:

- preventing fish from entering return flow from an irrigation ditch
- preventing fish from entering the *tailrace* of a power plant
- guiding fish to a trap facility for upstream transport, research or broodstock collection
- guiding fish to a counting facility
- preventing fish from entering a channel subject to sudden flow changes
- preventing fish from entering turbine draft tubes
- preventing fish from entering channels with poor spawning gravels, poor water quality or insufficient water quantity.

The two primary categories of *exclusion barriers* are picket barriers and velocity barriers. Another type of exclusion barrier is a vertical drop structure, which provides a jump height that exceeds the vertical leaping ability of fish. Other types of barriers, such as electric and acoustic fields, have very limited application because of inconsistent results most often attributed to varying water quality (turbidity, specific conductance).

Consistent with the terminology used throughout this document, criteria are specified by the word “shall” and guidelines are specified by the word “should”. Criteria are required design features, unless site specific conditions preclude their use and a site-specific written waiver is provided by NOAA Fisheries (also see Foreword). Guidelines are not required, but deviation from a guideline require a written explanation by the project designer. It is suggested that deviation from a guideline be discussed with NOAA Fisheries prior to final design. Since these guidelines and criteria are general in nature, there may be cases in which site constraints or extenuating circumstances dictate that certain criteria be waived or modified. Conversely, where there is a need to provide additional protection for fish, including species of fish not directly under NOAA Fisheries jurisdiction, site-specific criteria may be added. These circumstances will be considered by NOAA Fisheries on a project-by-project basis.

6.2 **Picket Barrier - Description**: Picket barriers diffuse nearly the entire streamflow through pickets extending the entire width of the impassable route, sufficiently spaced to provide a physical barrier to upstream migrant fish. This category of exclusion barrier includes a fixed bar rack and a variety of hinged floating *picket weir* designs. Picket barriers usually require removal for high flow events, increasing the potential to allow passage into undesirable areas.

In general, since the likelihood of impinging fish is very high, these types of barriers can not be used in waters containing species listed under the ESA, unless they are continually monitored by personnel on-site, and have a sufficient operational plan and facility design in place to allow for timely removal of impinged or stranded fish prior to the occurrence of injury. Since debris and downstream migrant fish must pass through the pickets, sites for these types of *exclusion barriers* must be carefully chosen. Picket barriers shall be continually monitored for debris accumulations, and debris shall be removed before it concentrates flow and violates the criteria established below. As debris accumulates, the potential for the impingement of downstream migrants (e.g., juvenile salmonids, kelts, adult salmon that have overshot their destination, or resident fish) increases to unacceptable levels. Debris accumulations will also concentrate flow through the remainder of the open picket area, increasing the attraction of upstream migrants to these areas and thereby increasing the potential for jumping injury or successful passage into areas without egress.

Picket barrier design criteria include the following:

6.2.1 The maximum clear opening between pickets and between pickets and abutments is one inch.

6.2.2 Pickets shall be comprised of flat bars aligned with flow, or round columns of steel, aluminum or durable plastic.

6.2.3 The picket array shall have a minimum 40% open area.

6.2.4 Picket barriers should be sited where there is a relatively constant depth over the entire stream width.

6.2.5 The average design velocity through pickets should be less than 1.0 ft/s for all design flows, with maximum velocity less than 1.25 ft/s, or half the velocity of adjacent river flows whichever is lower. The average design velocity is calculated by dividing the flow by the total submerged picket area over the design range of stream flows. When river velocities exceed these criteria, the picket barrier shall be removed.

6.2.6 The maximum head differential across the pickets should be 0.3 feet. If this differential is exceeded, the pickets shall be cleaned as soon as possible.

6.2.7 A debris and sediment removal plan is required that anticipates the entire range of conditions expected at the site. Debris shall be removed before accumulations develop that violate the criteria specified in 6.2.5 and 6.2.6.

6.2.8 The minimum picket extension above the water surface at high fish passage design flow is two feet.

6.2.9 The minimum submerged depth at the picket barrier at low design discharge shall be two feet for at least 10% of the river cross section at the barrier.

6.2.10 Pickets barriers shall be designed to lead fish to a safe passage route. This can be achieved by angling the picket barrier toward a safe passage route, providing nearly uniform velocities through the entire length of pickets, and providing sufficient *attraction flow*s from a safe passage route that minimizes the potential for false attraction to the picket barrier flows.

6.2.11 A uniform concrete sill, or an alternative approved by NOAA Fisheries Hydro Program staff, should be provided to ensure that fish do not pass under the picket barrier.

6.2.12 Picket panels should be of sufficient structural integrity to withstand high streamflows.

6.3 **Velocity Barrier - Description:** A velocity barrier consists of a *weir* and concrete *apron* combination that prevents upstream passage by producing a shallow flow depth and high velocity on the *apron*, followed by an impassable vertical jump over the *weir*. A velocity barrier does not have the fore-mentioned problems of a *picketed weir* barrier, since flow passes freely over a *weir*, allowing the passage of debris and downstream migrant fish. However, since this type of barrier creates an upstream impoundment, the designer must consider backwater effects that may induce loss of power generation or property inundation.

Velocity barrier design criteria include the following:

6.3.1 The minimum *weir* height relative to the maximum *apron* elevation is 3.5 feet.

6.3.2 The minimum *apron* length (extending downstream from base of *weir*) is 16 feet.

6.3.3 The minimum *apron* downstream slope is 16:1 (horizontal:vertical).

6.3.4 The maximum head over the *weir* crest is two feet.

6.3.5 The elevation of the downstream end of the *apron* shall be greater than the *tailrace* water surface elevation corresponding to the high design flow.

6.3.6 Other combinations of *weir* height (6.3.1) and *weir* crest head (6.3.4) may be approved by NOAA Fisheries Hydro Program staff on a site-specific basis.

6.3.7 The flow over the weir must be fully and continuously vented along the entire length, to allow a fully aerated nappe to develop between the weir crest and the apron.

6.4 **Vertical Drop Structures** - Description: A vertical drop structure can function as an exclusion barrier by providing *total project head* in excess of the leaping ability of the target fish species. These can be a concrete monolith, rubber dam, or approved alternative.

Vertical drop structure criteria include the following:

6.4.1 The minimum height for vertical drop structure shall be 10 feet relative to the *tailrace* high design flow elevation.

6.4.2 To minimize the potential for leaping injuries, a minimum of two feet of cantilevered ledge shall be provided.

6.4.3 Provision shall be made to ensure that fish jumping at the drop structure flow will land in a minimum five foot deep pool, without contacting any solid surface.

6.5 **Bottom Hinged Leaf Gates** - Description: A bottom-hinged leaf gate is a device that can be elevated to provide an exclusion barrier by providing *total project head* in excess of the leaping ability of the target fish species. These can be mounted on a concrete base, where the leaf gate is raised into position by a hydraulic cylinder, pneumatic bladders, or other means.

Bottom-hinged leaf gate criteria include the following:

6.5.1 The minimum vertical head drop (*forebay* to tailwater) shall be 10 feet at high design flow.

6.5.2 Provision shall be made to ensure that fish jumping at flow over the structure will land in a minimum five foot deep pool, without contacting any solid surface.

6.6 **Horizontal Draft Tube *diffuser*s** - Description: A horizontal draft tube *diffuser* is a device used below a powerhouse at the turbine draft tube outlet to prevent fish from accessing the turbine runners, where injury is likely. Even if draft tube velocities are sufficiently high to prevent fish access during normal operations, ramping flow rates during turbine shut-down or start-up create velocities low enough to allow fish to swim up the draft tubes and impact turbine runners.

Horizontal Draft Tube *diffuser* criteria include the following:

6.6.1 Average velocity of flow exiting the *diffuser* grating shall be less than 1.25 ft/s, and distributed as uniformly as possible. Maximum velocity should not exceed 2 ft/s.

6.6.2 Clear spacing between *diffuser* bars and any other pathway from the *tailrace* to the turbine runner shall be less than one inch.

6.6.3 *Diffuser*s shall be submerged a minimum of two feet for all tailwater elevations.

Section 7. Adult Fish Trapping Systems

7.1 Description, purpose and rationale: In general, NOAA Fisheries requires volitional passage, as opposed to trap and haul, for upstream passage facilities. This is primarily due to the risks associated with the handling and transport of adult upstream migrants, in combination with the long term uncertainty of funding, maintenance and operation of the trap and haul program. However, there are instances where trap and haul may be the only viable option for a particular site. In particular, at high head dams where thermal stratification occurs in the reservoir, temperature differentials in the *fishway* (as opposed to water temperatures below the dam) may dissuade fish from utilizing volitional passage facilities.

This section addresses design aspects of adult fish trapping systems. The operations and design criteria and guidelines are dependent on each other, since the management objectives for trap operation define the facility functional design and must be stipulated before the trap design development can be proceed.

In many cases, NOAA Fisheries will not require retrofit of existing facilities to comply with criteria listed herein. It is emphasized that these criteria and guidelines are viewed as a starting point for design development of new, or upgraded, trapping facilities. This section does not directly apply to existing trapping programs/facilities, unless specifically required by NOAA Fisheries.

Consistent with the terminology used throughout this document, criteria are specified by the word “shall” and guidelines are specified by the word “should”. Criteria are required design features, unless site specific conditions preclude their use and a site-specific written waiver is provided by NOAA Fisheries (also see Foreword). Guidelines are not required, but deviation from a guideline require a written explanation by the project designer. It is suggested that deviation from a guideline be discussed with NOAA Fisheries prior to final design. Since these guidelines and criteria are general in nature, there may be cases in which site constraints or extenuating circumstances dictate that certain criteria be waived or modified. Conversely, where there is a need to provide additional protection for fish, including species of fish not directly under NOAA Fisheries jurisdiction, site-specific criteria may be added. These circumstances will be considered by NOAA Fisheries on a project-by-project basis.

Adult fish trapping systems can either be included in the initial design of a proposed *upstream passage facility*, or in some cases can be retro-fitted to an existing *fishway*. Traps should be designed to utilize known or observed fish behavior to benignly route fish into a trap holding pool that precludes volitional exit. From the trap holding pool, fish can be loaded for transport and/or examined for research and management purposes. Traps can be used as the terminus of volitional *upstream fish passage* followed by transport to specific sites, or as a parallel component of a *fish ladder* where fish can either be routed into an adjacent trapping loop or if the trap is closed allow to fish pass unimpeded through the *fishway*.

7.2 Trap Design Scoping
Trap new-construction or major upgrade proposals shall address and describe the consideration of (at least) the following issues:

- Objective of trapping - count, handle, collect, interrogate for tags, etc.
- Number of fish targeted and total number potentially present
- Target species
- Other species likely to be present at the trap
- Environmental conditions during trap operation such as water and air temperature, flow conditions (lows and peaks), debris load, etc.
- Operation location, duration and scale
- Fish routing and ultimate destination
- Maximum duration of delay or holding within the trapping system for target and non-target fish.
- Security mechanisms

Note: It is also permissible to attach a Hatchery and Genetic Management Plan (HGMP), 4(d) Limit 7 Scientific Research and Take Authorization application, or Section 10 (a) (1) (A) permit application if it contains some of this information**.**

7.3 Fish Handling Guidelines
7.3.1 The following general fish handling guidelines should be utilized for design of new or updated facilities.

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

7.3.3 Fish should be anesthetized before being handled.

7.3.4 New or upgraded trapping facilities shall be designed to enable non-target fish to bypass the anesthetic tank.

7.3.5 Fish shall be removed from traps at least daily - more often when either environmental (eg. water temperature extremes or high debris load) or biological conditions (eg. migration peaks) warrant.

7.3.6 Individuals handling fish shall be experienced or trained to assure fish are handled safely.

7.3.7 Fish ladders shall not be completely dewatered during trapping operations, and should not experience any reduction in fishway flow.

7.4 General Trap Design System Criteria

7.4.1 Primary trapping system components usually include:

- in-ladder removable *diffuser*s or gates to block passage within the ladder and guide fish into the trap
- an off-ladder holding pool including a transition channel or port and trapping mechanism (through which *attraction flow* is discharged via one of the devices described in 7.6)
- a gate to prevent fish from entering the trap area during crowding operations
- a holding pool fish *crowder* (for encouraging adult egress from the off-ladder holding pool to sorting/loading facilities)
- separate holding pool inflow and outflow facilities
- *distribution flume* (used with *false weir* or steeppass to enable fish entry to and/or egress from the holding pool)
- and a lock or lift for truck-loading fish.

Insert trap drawing

General trap design system criteria include:

7.4.2 *Fish ladder*s are the preferred means of upstream passage at impediments, unless site conditions preclude their use. This is due to the preference that fish be allowed to pass at their inclination, rather than that of a human operator. Factors to be considered include the adverse effects of holding trapped fish in a potentially high-density holding pool for an excessive period, the long-term uncertainty of maintaining funding and trained personnel, exposure to poaching or predation in the trap, injuries from jumping, facility failures (e.g., loss of water supply), and cumulative handling and holding stresses.

7.4.3 In general, *fish ladder*s should not be designed or retrofitted with either in-ladder traps or loading facilities. Rather, trap/holding and loading facilities should be in an adjacent, off-ladder location where fish targeted for trapping purposes can be routed. This allows operational flexibility to readily switch from passage to trapping operational modes.

7.4.4 A wetted *distribution flume* shall be used if, after trapping, fish are to be routed to anesthetic/recovery tanks, pre-transport holding tanks, *forebay* return, etc. The flume shall have smooth joints, sides and bottom, and no abrupt vertical or horizontal bends. Circular pipes with smooth joints can also be used. Provision of continuous wetted surfaces (to minimize abrasions) is required.

7.4.5 Holding pool water quality should not be less than the ambient waters from which the fish are trapped. For example, the water temperature, oxygen content and pH should not deviate substantially. Fish shall be provided with a safe, healthy environment.

7.4.6 Trap inflow shall be routed through an upstream *diffuser* conforming with Section 5.3 , with maximum 1.0 fps average velocity. Baffling should be used to assure against excessive turbulence and surging, which could induce adult jumping within the trap.

7.4.7 Anesthetized fish shall be routed to a recovery pool to allow monitoring of fish to ensure full recovery from anesthetic effects prior to release. Fish recovering from anesthesia shall not be routed directly back to the river where unobserved mortality can occur. Recovery pool inflow shall satisfy the specified water quality guidelines (see 7.4.5). Recovery tank hydraulic conditions shall not result in partially or fully anesthetized fish being carried onto an outflow screen/grating, or any other hazardous area. The recovery pool shall be designed so that fish, once fully recovered, can exit volitionally.

7.5 Trap Holding Pool Guidelines and Criteria
For single-pool traps, refer to Section 7.9.

For trap holding pools at multi-pool ladders:

7.5.1 For new or existing *fish ladder*s, fish shall not be trapped and held within the ladder for intermittent sampling or truck-loading. Rather, an *off-ladder trap* system is required. This type of system allows normal unimpeded ladder passage during non-trapping periods, and intermittent trapping of fish for target collection or sampling, as required. The intent is to minimize adverse impacts (such as delay and elevated jumping injury/mortality) of fish trapping by allowing rapid transition from one operational mode to the other.

7.5.2 Trap holding pools, for both *off-ladder trap*s and trap and haul facilities, shall be sized to hold a predetermined maximum number of fish (i.e. trap capacity, as specified by NOAA Fisheries biologists) with a minimum allowable volume of 0.25 ft^3 per pound of average fish size weight times the maximum number of fish.

7.5.3 *Off-ladder trap* holding pools shall be designed with a separate water supply and drain system. Trap holding pool design water supply capacity shall be at least 0.5 gallons per minute per pound of adult fish for the predetermined adult salmon trap holding capacity.

7.5.4 Trap holding pool designs shall include provisions to minimize adult jumping which can result in injury or mortality. Examples include (but are not limited to): high *freeboard* on holding pool walls; covering to keep fish in a darkened environment; providing netting over the pool strong enough to prevent adults from breaking through the mesh fabric; sprinkling the holding pool water surface to diffuse the ability of fish to see movement above the trap pool.

7.5.5 Off-ladder holding pools should include intake and exit *diffuser*s designed to prevent adult egress and to conform with Section 5.4, and with an adjustable exit overflow *weir* to control holding pool water surface elevation.

7.5.6 Removable *diffuser*s within the ladder (that are lowered/installed to block fish ascent within the ladder when fish are to be routed into an *off-ladder trap*ping pool) shall be angled toward the *off-ladder trap* entrance location, and shall comply with Sections 5.4.2, 5.4.3, 5.4.4, 5.4.5 and 5.4.6. *Diffuser*s shall be completely removed from the ladder when not actively trapping.

7.5.7 Off-ladder holding pool *crowder*s should have a maximum clear bar spacing of 7/8 inch. Side gap tolerances shall not exceed one inch, with side and bottom seals sufficient to allow *crowder* movement without binding and to prevent fish movement behind the *crowder* panel.

7.5.8 Where *false weir*s and steeppass ladders are used to route fish into or out of a trap holding pool, *distribution flume*s or pipes are used. The *distribution flume* invert shall be wetted to minimize friction between fish and flume invert surfaces. Where there are horizontal and vertical bends in the *distribution flume*, a continuous spray shall be used to minimize friction between fish and side walls. Horizontal and vertical bends shall be gradual to minimize risk of fish strike injuries.

7.5.9 The minimum inside width (or diameter) of the *distribution flume* shall be 15 inches.

7.5.10 The minimum sidewall height in the *distribution flume* shall be 24 inches.

7.6 Trapping Mechanism Criteria and Guidelines

The trap holding pool trapping mechanism (e.g., finger weir, vee-trap, *false weir*, steeppass ladder) allows fish to enter, but not volitionally exit, the holding pool. Fish will not volitionally stay within a confined area if they can find an exit. Design criteria and guidelines include:

7.6.1 All components exposed to fish shall have all welds and sharp edges ground smooth, with other features as required to minimize injuries.

7.6.2 Bars and spacings shall conform with Section 5.4. Circular bars should be used to improve fish safety.

7.6.3 Trapping mechanisms shall allow temporary closure to avoid spacial conflict with *brail* crowding and loading operations.

7.6.4 Trapping mechanisms should be designed to safeguard against fish entry into an unsafe area such as behind a *crowder* or under floor *brail*.

7.6.5 A gravity (i.e. not pumped) water supply should be used for false-weirs and steeppass ladders to avoid potential rejection of the trapping mechanism associated with the transmission of pump/motor sounds.

7.7 Lift/*Hopper* Guidelines
A lift in this context includes a full-sized *hopper* that is capable of collecting/lifting all fish trapped in a holding pool at one time, then either routing fish to the *forebay*, or loading onto a truck for transport.

Criteria and guidelines for the design of lift/*hopper* systems include the following:

7.7.1 Maximum *hopper* and transport truck loading density should be 0.15 ft^3 per pound of fish at a design maximum fish loading. The reason for this guideline is to avoid having so many fish in a *hopper* during lifting operations that there is in little remaining volume for water.

7.7.2 *Hopper freeboard* during lifting, from *hopper* water surface to top of *hopper* bucket, should be greater than the water depth within the *hopper*, to reduce risk of fish jumping out during lifting operations.

7.7.3 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 inch, thereby minimizing fish access below the *hopper*. Flexible side seals shall be used to assure that fish do not pass below the *hopper*.

7.7.4 Truck transport tanks shall be compatible with the *hopper* design to assure minimized handling stress. If an existing truck or fleet will be used, *hopper* shall be designed to be compatible with existing equipment. If transport tank's opening is larger than the tube or *hopper* opening, a cap or other device shall be designed to prevent fish from jumping at the opening.

7.7.5 Fail-safe measures shall be provided to prevent entry of fish into the holding pool area to be occupied by the *hopper* before the *hopper* is lowered into position.

7.7.6 Design should allow *hopper* water surface control to be transferred to the truck transport tank, so that water and fish do not plunge abruptly from the *hopper* into the fish transport tank during loading.

7.7.7 The fish egress opening from the *hopper* into the transport tank shall have a minimum horizontal cross-sectional area of 3 ft^2, and shall have a smooth transition that minimizes fish injury potential.

7.7.8 The *hopper* interior shall be smooth, and be designed to safeguard fish.

7.8 *Fish Lock*
7.8.1 Description: A *fish lock* allows trapped fish in the trapping system holding pool to be elevated without a *hopper* or *hopper* sump.

7.8.2 For clarification, the following steps are presented describing routing of fish from the lock to the *forebay* or transport vehicle:

- Fish are crowded into the lock.
- The closure gate is shut.
- In-flow into the lock is introduced through floor *diffuser*s below the floor *brail*.
- As the water level rises within the lock, it will ultimately reach a control *weir* equilibrium elevation. The floor *brail* should be raised only after lock water surface elevation is at equilibrium, and should not be used to lift fish out of the water.
- Overflow passes over a control *weir* and through a short, descending slope separator (screen), allowing excess flow to be drained off and adult fish to routed either directly into the anesthetic tank, or into a wetted chute for routing to separate sorting/holding pools, or loading into a transport vehicle.

7.8.3 The lock inflow chamber (below the lowest floor *brail* level) shall be of sufficient depth and volume (see Section 5.6.7) to limit turbulence into the fish holding zone, immediately before lock inflow is introduced. The inflow sump should be designed so that flow upwells uniformly through add-in floor *diffuser*s (see Sections 5.4.2, 5.4.3, 5.4.4, 5.4.5), thereby limiting unstable hydraulic conditions within the lock that may agitate fish.

7.8.3 Depth over the *egress weir* should be at least 6 inches, to facilitate fish egress from the lock for transport or anesthesia/handling.

7.8.4 Floor *brail* should be composed of sufficiently sized screen material (based on life stage and species present), to preclude injury or mortality of non-target species. Side gap openings shall not exceed one inch with seals included to cover all gaps. The floor *brail* panel should be kept in its lowest position until flow passes over the *flow egress weir*.

7.8.5 The floor *brail* hoist should be designed for manual operation to allow movement of the *brail* at 2 feet/minute (upward and downward) that will minimize stress of fish crowded between the floor *brail* and lock *flow egress weir*. Automated operation is allowed only when the water depth above the *brail* is 4 feet or more.

7.9 Single Holding Pool Trap Design Guidelines and Criteria

Single pool traps are often used in tandem with intermittent *exclusion barriers* (see Section 7) for brood-stock collection from small streams. These trapping systems are used to collect, sort, and load adult fish. The following are single holding pool trap design guidelines and criteria:

7.9.1 The trap holding pool volume shall be designed according to Section 5.6.7 to achieve relatively stable interior hydraulic conditions and minimize jumping of trapped fish.

7.9.2 Intakes shall conform with Sections 5.4.7 and 5.4.8.

7.9.3 Sidewall *freeboard* should be a minimum 4 feet above trap pool water surface at high design streamflow.

7.9.4 The trap holding pool interior surfaces shall be smooth to reduce the potential for fish injury.

7.9.5 A description of the proposed means of removing fish from the trapping pool and loading onto a transport truck shall be submitted to NOAA Fisheries for approval.

Section 8. Fish Passage Criteria and Guidelines for Culverts and other Road Crossings

8.1 **Description, Purpose and Rationale:** This section provides criteria and guidelines for the design of stream crossings to aid upstream and downstream movement of anadromous salmonids. Consistent with the terminology used throughout this document, criteria are specified by the word "shall" and guidelines are specified by the word "should". Criteria are required design features, unless site specific conditions preclude their use and a site-specific written waiver is provided by NOAA Fisheries (also see Foreword). Guidelines are not required, but deviation from a guideline require a written explanation by the project designer. It is suggested that deviation from a guideline be discussed with NOAA Fisheries prior to final design. Since these guidelines and criteria are general in nature, there may be cases in which site constraints or extenuating circumstances dictate that certain criteria be waived or modified. Conversely, where there is a need to provide additional protection for fish, including species of fish not directly under NOAA Fisheries jurisdiction, site-specific criteria may be added. These circumstances will be considered by NOAA Fisheries on a project-by-project basis.

For the purpose of fish passage, the distinction between bridge, culvert, and low water crossing is not as important as the effect the structure has on the form and function of the stream. To this end, these criteria conceptually apply to bridges and low water crossings, as well as culverts. In addition to providing fish passage, any road crossing design should include consideration of maintaining ecological function of the stream - passing woody debris, flood flows and sediment, and other species that may be present at the site. The objective of these criteria and guidelines is to provide the basis for road crossing fish passage designs for all life stages of anadromous salmonids present at the site and requiring passage. The design team should be in close contact with all biologists familiar with the site to assess potential impacts on spawning, life stages requiring passage and to assess bed stability.

8.2 **Preferred alternatives for new or replacement culverts** - All the alternatives listed below have the potential to pass fish, but some will perform better than others at a particular site. Based on the biological significance and ecological risk of a particular site, NOAA Fisheries may require a specific design alternative to be developed, if feasible, to allow normative physical processes within the stream-floodplain corridor by (1) promoting natural sediment transport patterns for the reach, (2) providing unaltered fluvial debris movement, (3) restoring or maintaining functional longitudinal continuity and connectivity of the stream-floodplain system.

The following alternatives and structure types are listed in general order of NOAA Fisheries preference:

8.2.1 Road abandonment or road realignment to avoid crossing the stream.

8.2.2 Bridge - spanning the stream to allow for long-term dynamic channel stability, retention of existing spawning areas, maintain food (benthic invertebrate) production and to minimize risk of failure.

8.2.3 Streambed simulation strategies - bottomless arch, embedded culvert design. Note: If a road crossing is proposed in a segment of stream channel that includes a salmonid spawning area, only full span bridges or streambed simulations are acceptable (see Sections 8.3 and 8.4).

8.2.4 Hydraulic design method, associated with more traditional culvert design approaches - limited to low stream gradients (0 to 1%) for fish passage (see Section 8.5).

8.2.5 Culvert designed with a external *fishway* (including roughened channels)- for steeper slopes (see Section 5).

8.2.6 Baffled culvert - to be used only when other alternatives are infeasible. Many baffle designs are untested for anadromous salmonid passage, and *baffles* always reduce the hydraulic capacity of culverts. NOAA Fisheries will only approve baffled culverts on a site by site basis if compelling evidence of successful passage is provided.

8.3 Active Channel Design Method: This provides is a simplified design methodology that is intended to provide a culvert of sufficient size and embedment to allow the natural movement of *bedload* and the formation of a stable bed inside the culvert. Determination of the high and low fish passage design flows, water velocity, and water depth is not required for this method, since the stream hydraulic characteristics within the culvert are intended to mimic the stream conditions upstream and downstream of the crossing. This design method is usually not suitable for stream channels that are greater than 1% in natural slope or for culvert lengths greater than 100 feet. Structures for this design method are typically round, oval, or squashed pipes made of metal or reinforced concrete.

8.3.1 Culvert Width - The minimum culvert bed width shall be equal to or greater than bankfull channel width, and of sufficient vertical clearance to allow ease of maintenance activities.

8.3.2 Culvert Slope - The culvert shall be placed level (0% slope).

8.3.3 Embedment - The bottom of the culvert should be buried into the streambed not less than 20% of the culvert height at the outlet and not more than 40% of the culvert height at the inlet. The slope of the bed shall replicate the natural upstream and downstream stream gradient in the vicinity of the road crossing.

8.3.4 Fill materials should be comprised of material of similar size and shape to natural *bedload* and shall be able to remain in place for all flows.

8.3.5 Water depth and velocity in the culvert shall replicate the natural stream depth and water velocity upstream and downstream of the road crossing.

8.4 Streambed Simulation Design Method: This method is a design process that is intended to mimic the natural upstream and downstream processes within a culvert or under a bridge. Fish passage, sediment transport, and flood and debris conveyance within the culvert are intended to function as they would in a natural channel. Determination of the high and low fish passage design flows, design water velocity, and design water depth is not required for this option since the stream hydraulic characteristics within the culvert or beneath the bridge are designed to mimic the stream conditions upstream and downstream of the road crossing. The structures for this design method are typically open-bottomed arches or boxes but could have buried floors in some cases, or a variety of bridges that span the stream channel. This method utilizes streambed materials that are similar to the adjacent stream channel. Streambed simulation requires a greater level of information on hydrology and geomorphology (topography of the stream channel) and a higher level of engineering expertise than the Active Channel Design method (see section 8.3). In general, streambed simulation should provide sufficient channel complexity to provide passage conditions similar to that which exists in the natural stream, including sufficient depth, velocity and resting areas.

8.4.1 Channel width - The minimum culvert width shall be greater than the *bankfull* channel width. There are many cases where greater widths will be required, based on the objective of providing a stable structure that will allow ecological function to continue.

8.4.2 Channel Vertical clearance - In no case should the minimum culvert vertical clearance be less than six feet.

8.4.3 Channel slope - The slope of the reconstructed streambed within the culvert should approximate the average slope of the adjacent stream from approximately 500 feet upstream and 500 feet downstream of the site in which it is being placed. The maximum slope should not exceed 6%.

8.4.4 Embedment - If a culvert is used, the bottom of the culvert should be buried into the streambed not less than 20% and not more than 50% of the culvert height. For bottomless culverts the footings or foundation shall be designed for the largest anticipated scour depth. Demonstration of ability to retain *bedload* in the design configuration is required.

8.4.5 Maximum length of road crossing - The maximum allowable length for streambed simulation is 125 feet.

8.4.6 Fill materials should be comprised of material of similar size and shape to natural *bedload* and shall be able to remain in place for all flows.

8.4.7 Water depths and velocities shall closely resemble those that exist in the adjacent stream, as described in 8.4.3, or those listed in 8.5.6. For streambed simulation gradients exceeding 3% in slope, a resting/holding pool should be provided near the midpoint of the length of the culvert. In addition, holding areas should be provided throughout the length of the streambed simulation, reasonably replicating those found in the adjacent stream.

8.5 Hydraulic design method: The Hydraulic design method is a design process that matches the performance of a culvert with the swimming abilities of a target species and age class of fish. This method targets distinct species of fish and therefore does not account for ecosystem requirements of non-target species. There are significant errors associated with estimation of hydrology and fish swimming speeds that are resolved by making conservative assumptions in the design process. Determination of the high and low fish passage design flows, water velocity, and water depth is required for this option. The Hydraulic design method requires hydrologic data analysis, open channel flow hydraulic calculations, and information on the swimming ability and behavior of the target group of fish. This design method can be applied to the design of new and replacement culverts and can be used to evaluate the effectiveness of retrofits of existing culverts.

8.5.1 Culvert Width and Vertical Clearance **-** The minimum culvert width and vertical clearance (i.e. from culvert invert to culvert ceiling) shall be six feet.

8.5.2 Culvert Slope **-** The culvert slope should not exceed the average slope of the stream from approximately 500 feet upstream to 500 feet downstream of the site in which it is being placed. If embedment of the culvert is not possible, the maximum slope should not exceed 0.5%.

8.5.3 Embedment - Where physically possible, the bottom of the culvert should be buried into the streambed a minimum of 20% of the height of the culvert below the elevation of the tailwater control point downstream of the culvert. The minimum embedment shall be at least 1 foot.

8.5.4 High Fish Passage Design Flow - The high design flow (see section 4.3) for adult fish passage is used to determine the maximum water velocity within the culvert.

8.5.5 Low Fish Passage Design Flow - The low design flow (see section 4.2) for fish passage is used to determine the minimum depth of water within a culvert.

8.5.6 The maximum average water velocity in the culvert refers to the calculated average of velocity within the barrel of the culvert at the fish passage design high flow. In most instances, upstream juvenile fish passage requirements should be used for design. Use table 8.5.6 to determine the maximum average water velocity allowed.

Table 8.5.6 - Maximum Allowable Average Culvert Velocity

Culvert Length (ft)	Maximum Average Velocity (ft/s)		
	chinook, steelhead, sockeye and coho adults	pink, chum adults	juvenile salmonids
<60	6.0	5.0	1.0
60-100	5.0	4.0	1.0
100-200	4.0	3.0	1.0
200-300	3.0	2.0	1.0
>300	2.0	2.0	1.0

8.5.7 Minimum water depth at the low fish passage design flow should be: twelve inches for adult steelhead, chinook, coho, and sockeye salmon; nine inches for pink and chum salmon; and six inches for all species of juvenile salmon.

8.5.8 Maximum *Hydraulic Drop* - *Hydraulic drop*s between the water surface in the culvert and the water surface in the adjacent channel should be avoided in all cases. This includes the culvert inlet and outlet. Where physical conditions preclude embedment and the streambed is stable (eg, culvert installation on bedrock) the *hydraulic drop* at the outlet of a culvert shall not exceed the limits specified in Table 11.1 if juvenile fish are present and require upstream passage, or 1 foot if juvenile fish are not present or do not require upstream passage.

8.6 Retrofitting Culverts: For future planning and budgeting at the state and local government levels, redesign and replacement of substandard stream crossings will contribute substantially to the recovery of salmon stocks throughout the state. Unfortunately, current practices do little to address the problem: road crossing corrections are usually made by some modest level of incremental, low cost "improvement" rather than re-design and replacement. These usually involve bank or structure stabilization work, but frequently fail to address fish passage. Furthermore, bank stabilization using hard point techniques frequently denigrates the habitat quality and natural features of a stream. Nevertheless, many existing stream crossings can be made better for fish passage by cost-effective means. The extent of the needed fish passage improvement work depends on the severity of fisheries impacts, the remaining life of the structure, and the status of salmonid stocks in a particular stream or watershed. For work at any stream crossing, site constraints need to be taken into consideration when selecting options.

Some typical site constraints are ease of structure maintenance, construction windows, site access, equipment, and material needs and availability. The decision to replace or improve a crossing should fully consider actions that will result in the greatest net benefit for fish passage. If a particular stream crossing causes substantial fish passage problems that hinder the conservation and recovery of salmon in a watershed, complete redesign and replacement is warranted. Consolidation and/or decommissioning of roads can sometimes be the most cost effective option. Consultations with NOAA Fisheries biologists can help in selecting priorities and alternatives.

Where existing culverts are being modified or retrofitted to improve fish passage, the hydraulic requirements specified in Section 8.5 should be the design objective for the improvements. However, it is acknowledged that the conditions that cause an existing culvert to impair fish passage may also limit the remedies for fish passage improvement. Therefore, short of culvert replacement, the Section 8.5 criteria and guidelines should be the goal for improvement but not necessarily the required design threshold. Fish passage through existing non-embedded culverts may be improved through the use of gradient control *weir*s upstream or downstream of the culvert, interior *baffles* or *weir*s, or, in some cases, *fish ladder*s. However, these measures are not a substitute for good fish passage design for new or replacement culverts. The following guidelines should be used:

8.6.1 Hydraulic Controls - Hydraulic controls in the channel upstream and/or downstream of a culvert can be used to provide a continuous low flow path through culvert and stream reach. They can be used to facilitate fish passage by establishing the following desirable conditions: Control depth and water velocity within culvert, concentrate low flows, provide resting pools upstream and downstream of the culvert, and prevent erosion of bed and banks.

8.6.2 An entrance pool should be provided that is at least 1.5 times the stream depth, or a minimum of two feet deep, whichever is deeper.

8.6.3 *Baffles* may provide incremental fish passage improvement in culverts (if the culvert has excess hydraulic capacity) that cannot be made passable by other means. However, *baffles* will increase the potential for clogging and debris accumulation within the culvert and require special design considerations specific to the baffle type. Culverts that are too long or too high in gradient require resting pools, or other forms of velocity refuge spaced at increments along the culvert length. Baffles will only be approved on a site specific basis, and generally only for interim use.

8.6.4 *Fishway*s (see Section 5 and Section 11) may be required for some situations where excessive drops occur at the culvert outlet. *Fishways* require specialized site-specific design for each installation and as such, a NOAA Fisheries fish passage specialist shall be consulted.

8.7 Miscellaneous Criteria and Guidelines for Fish Passage at all types of Road Crossings

8.7.1 Trash racks should not be used near the culvert inlet. Accumulated debris may lead to severely restricted fish passage and potential injuries to fish. Where trash racks cannot be avoided in culvert installations, they shall only be installed above the water surface indicated by bankfull flow. A minimum of 9 inches clear spacing should be provided between trashrack vertical members. If trash racks are used, a long term maintenance plan shall be provided along with the design, to allow for timely clearing of debris

8.7.2 Livestock fences should not be used near the culvert inlet. Accumulated debris may lead to severely restricted fish passage and potential injuries to fish. Where fencing cannot be avoided, it should be removed during adult salmon upstream migration periods. Otherwise, a minimum of 9 inches clear spacing should be provided between pickets, up to the high flow water surface. If fencing is used, a long term maintenance plan shall be provided along with the design, to allow for timely clearing of debris. Cattle fences that rise with increasing flow are highly recommended.

8.7.3 Natural or artificial supplemental lighting should be considered in new or replacement culverts that are over 150 feet in length. Where supplemental lighting is required, the spacing between light sources should not exceed 75 feet.

8.7.4 NOAA Fisheries and State Fish & Wildlife Officials commonly set in-stream work windows in each watershed. Work in the active stream channel shall not be performed outside of the in-stream work windows.

8.7.5 Temporary crossings, placed in salmonid streams for water diversion during construction activities, shall meet all of the guidelines in this document. However, if it can be shown that the location of a temporary crossing in the stream network is not a fish passage concern at the time of the project, then the construction activity only needs to minimize erosion, sediment delivery, and impact to surrounding riparian vegetation.

8.7.6 Culverts shall be installed only in a de-watered site, with a sediment control and flow routing plan acceptable to NOAA Fisheries.

8.7.7 The work area shall be fully restored upon completion of construction with a mix of native, locally adapted, riparian vegetation. Use of species that grow extensive root networks quickly should be emphasized. Sterile, non-native hybrids may be used for erosion control in the short term if planted in conjunction with native species.

8.7.8 Construction disturbance to the riparian area shall be minimized and the activity shall not adversely impact fish migration or spawning.

8.7.9 If salmon are likely to be present, fish clearing or salvage operations shall be conducted by qualified personnel prior to construction. If these fish are listed as threatened or endangered under the Federal or state Endangered Species Act, consult directly with NOAA Fisheries biologists to gain authorization for these activities. Care should be taken to ensure fish are not chased under banks or logs that will be removed or dislocated by construction. Any stranded fish are to be returned to a suitable location in a nearby live stream by a method that does not require handling of the fish.

8.7.10 If pumps are used to temporarily divert a stream (to facilitate construction), an acceptable fish screen (see Section 12) shall be used to prevent entrainment or impingement of small fish. At no time shall construction or construction staging activity disrupt continuous streamflow downstream of the construction site.

8.7.11 Unacceptable wastewater associated with project activities shall be disposed of off-site in a location that will not drain directly into any stream channel.

8.7.12 Structural Design and Flood Capacity: All culvert stream crossings, regardless of the design option used, shall be designed to withstand the 100-year peak flood flow without structural damage to the crossing. The analysis of the structural integrity of the crossing shall take into consideration the debris loading likely to be encountered during flooding. Stream crossings or culverts located in areas where there is significant risk of inlet plugging by flood-borne debris should be designed to pass the 100-year peak flood without exceeding the top of the culvert inlet (headwater-to-diameter ratio is less than one). This is to ensure a low risk of channel degradation, stream diversion, and failure over the life span of the crossing. Hydraulic capacity shall compensate for expected deposition in the culvert bottom.

8.7.13 Other Hydraulic Considerations: Besides the upper and lower flow limit, other hydraulic effects need to be considered, particularly when installing a culvert. Water surface elevations in the stream reach shall exhibit gradual flow transitions, both upstream and downstream of the road crossing.

Within the culvert, abrupt changes in water surface and velocity, hydraulic jumps, turbulence and drawdown at the upstream flow entrance shall be avoided in design. A continuous low flow channel shall be maintained at all time throughout the entire stream reach affected by the road crossing construction. In addition, especially in retrofits, hydraulic controls may be necessary to provide resting pools, concentrate low flows, prevent erosion of stream bed or banks, and allow passage of *bedload* material. Hydraulic control devices shall be installed downstream of the culvert to avoid headcutting. Culverts and other structures should be aligned with the stream, with no abrupt changes in flow direction upstream or downstream of the crossing. This can often be accommodated by changes in road alignment or slight elongation of the culvert. Where elongation would be excessive, this must be weighed against better crossing alignment and/or modified transition sections upstream and downstream of the crossing. In crossings that are unusually long compared to streambed width, natural sinuosity of the stream will be lost and sediment transport problems may occur even if the slopes remain constant. Such problems should be anticipated and mitigated in the project design.

Section 9. Tide Gates

9.1 Description, Purpose, and Rationale

This section provides guidelines and criteria to be utilized in the design of *tide gates* for the purpose of providing passage for juvenile and adult salmonids. This material is applicable for projects that are undergoing consultation with NOAA Fisheries, pursuant to Section 7, Section 10 or 4(d) rule responsibilities for protecting fish under the Endangered Species Act (ESA).

Consistent with the terminology used throughout this document, criteria are specified by the word "shall" and guidelines are specified by the word "should". Criteria are required design features, unless site specific conditions preclude their use and a site-specific written waiver is provided by NOAA Fisheries (also see Foreword). Guidelines are not required, but deviation from a guideline require a written explanation by the project designer. It is suggested that deviation from a guideline be discussed with NOAA Fisheries prior to final design. Since these guidelines and criteria are general in nature, there may be cases in which site constraints or extenuating circumstances dictate that certain criteria be waived or modified. Conversely, where there is a need to provide additional protection for fish, including species of fish not directly under NOAA Fisheries jurisdiction, site-specific criteria may be added. These circumstances will be considered by NOAA Fisheries on a project-by-project basis.

9.2 General Procedural Guidelines

In designing for fish passage at *tide gates*, the ability of the fish to swim past the open *tide gate* and through the connected culvert is an important consideration. Research has shown that swimming ability of fish varies and may depend upon a number of factors relating to the physiology of the fish, including species, size, duration of swimming time required, behavioral aspects, migrational stage, physical condition and others, in addition to water quality parameters such as dissolved oxygen concentrations, water temperature, lighting conditions, and others. For this reason, *tide gate* design criteria must be expressed in general terms.

A functional design should be developed that defines type, location, size, hydraulic capacity, method of operation, and other pertinent juvenile fish screen facility characteristics. In the case of applications and consultations under the ESA, a functional design for juvenile and adult fish passage facilities shall be developed and submitted as part of the application or of the Biological Assessment for the facility. It shall reflect NOAA Fisheries input and design criteria and be acceptable to NOAA Fisheries. Functional design drawings shall show all pertinent hydraulic information, including water surface elevations and flows through various areas of the structures, throughout the tidal cycle or river stage fluctuation. Functional design drawings shall show general structural sizes, cross-sectional shapes, and elevations. Types of materials shall be identified where they will directly affect fish. The final detailed design shall be based on the functional design, unless changes are agreed to by NOAA Fisheries.

To minimize risks to anadromous fish at some locations, NOAA Fisheries may require investigation (by the project sponsors) of important and poorly defined site-specific variables that are deemed critical to development of the screen and bypass design. This investigation may include factors such as fish behavioral response to hydraulic conditions, weather conditions (ice, wind, flooding, etc.), river stage-discharge relationships, seasonal operational variability, potential for sediment and debris problems, resident fish populations, potential for creating predation opportunity, and other information.

9.3 Applicability of Criteria
These criteria should be used only for the replacement or modification of existing *tide gates*. Installation of new *tide gates* at sites where none presently exist should only be done as part of an overall enhancement project or for restoration of baseline conditions. This section is intended to provide general criteria in which *tide gates* may be replaced or modified to improve fish passage and habitat functions. *Tide gate* projects that operate in conjunction with other water control methods, such as pumps or diversions, should also account for other NOAA Fisheries criteria (i.e. fish screens), as appropriate. NOAA Fisheries believes that site specific variability can dramatically alter the design and performance of *tide gates*, and that innovative designs can be utilized to meet the criteria outlined here.

Flood gates are mechanically similar to tide gates and are used where the water levels are not influenced by tides. These criteria are intended to include flood gates for the period of time when the water surface elevation in the regulated water body (upland of the flood gate) is higher than the water surface elevation in the receiving water body (seaward of the flood gate).

9.4 Habitat Functions that are Altered by Tide Gates
Tide gates can disrupt habitat function in the following ways:

- Impair or prevent fish passage for adult and juvenile migrating salmonids,
- Dramatic alteration of estuarine water quality,
- Change surface water hydrology and groundwater levels,
- Impede the movement of woody debris,
- Modify natural flooding processes landward of the *tide gate*,
- Create severe water temperature gradient across the *tide gate*,
- Create severe salinity gradient across the *tide gate*, and
- Modify sediment transport regimes upstream and downstream of the *tide gate*.

The biological and engineering design of modified or replacement *tide gates* shall take the above effects into account to minimize the adverse effects to the extent possible.

9. 5 Criteria
The tide gate-culvert system should be designed to meet the following criteria:

9.5.1 The tide gate-culvert system should provide fish passage during 90% of the fish passage season.

9.5.2 The permit application package shall document how the effects listed in Section 9.4 were addressed in the design.

9.5.2 The tide gate-culvert system shall have the following design properties:

a) Culvert Slope: The culvert slope shall not exceed the average slope of the stream from approximately 500 feet upstream and 500 feet downstream of the site

in which it is being placed.
b) Embedment - The bottom of the tide gate culvert will normally be placed at or above the elevation of the stream bed. The vertical distance from the stream bed to the bottom of the culvert shall be based on fish passage and habitat requirements at low tide levels.
c) Culvert Width - The minimum culvert width for non-embedded culverts shall be 6 feet.
d) Maximum water velocities - In order to achieve fish passage, the maximum average water velocity within the barrel of the culvert shall comply with section 8.5.6.

9.5.3 The designers shall establish the Design Tide Inundation Elevation. This elevation is the maximum design water surface elevation to be allowed upland of the *tide gate* during a rising tide. This value should be selected to create the maximum inundation levels that incorporate both drainage and habitat requirements, and that maximize the fish passage time window. The *tide gate* shall remain open whenever the water surface elevation seaward of the tide gate is lower than the Design Tide Inundation Elevation. The Design Tide Innundation Elevation should facilitate the equalization of water quality parameters, such as conductivity, salinity, pH, dissolved oxygen and temperature on the regulated water body (upstream of the tidegate) and the receiving body (downstream of the tidegate).

9.5.4 The hydraulic design should minimize the difference between the upstream and downstream water levels when the *tide gate* is open. The maximum localized water surface drop at the entrance and exit of the culvert and *tide gate* is 0.5 feet when the *tide gate* is open.

9.5.5 The bottom lip of a top-hinged flap gate shall be open at least 1.5 feet from the invert of the culvert when the *tide gate* is open. Side-hinged *tide gates* shall open a minimum of 70-degrees from the closed position when the *tide gate* is open.

9.6 Other Design Considerations
The following design features should also be included:

9.6.1 The design should provide sufficient sediment transport to minimize dredging requirements.

9.6.2 The flow in the culvert should have a free water surface for at least 90 % of the migration season.

9.6.3 It should be possible to adjust the elevation at which the gate closes if necessary to meet habitat and passage goals.

Section 10. Specialized Guidelines and Criteria for Main-Stem Columbia and Snake River Upstream and Downstream Fish Passage Facilities

10.1 Description, Purpose and Rationale

The following criteria and guidelines are specially adapted to certain Columbia and Snake River upstream and downstream fish passage facilities.

Consistent with the terminology used throughout this document, criteria are specified by the word "shall" and guidelines are specified by the word "should". Criteria are required design features, unless site specific conditions preclude their use and a site-specific written waiver is provided by NOAA Fisheries (also see Foreword). Guidelines are not required, but deviation from a guideline require a written explanation by the project designer. It is suggested that deviation from a guideline be discussed with NOAA Fisheries prior to final design. Since these guidelines and criteria are general in nature, there may be cases in which site constraints or extenuating circumstances dictate that certain criteria be waived or modified. Conversely, where there is a need to provide additional protection for fish, including species of fish not directly under NOAA Fisheries jurisdiction, site-specific criteria may be added. These circumstances will be considered by NOAA Fisheries on a project-by-project basis.

The guidelines and criteria in this section apply at main-stem hydroelectric projects. When not referenced in this section, criteria elsewhere in this document may apply. This section is intended as a starting point for future fish passage facilities designs, and is based on experience at Corps of Engineers (Corps) main-stem hydroelectric dams on the Lower Columbia and Snake Rivers. Where coordinated and scientifically-sound research indicates that one or more of these criteria can be waived without compromising fish protection, alternative criteria will be considered (see Foreword).

Note that this document is *not* for the purpose of including cumulative design criteria and guidelines for all past fish passage facilities designs at main-stem Corps hydro-projects. (That would be a more extensive document, which the Corps of Engineers is considering developing.) Rather, this section lists specific main-stem fish passage criteria and guidelines, for which NOAA Fisheries believes there is a benefit in adding to this document.

10.2 Main-Stem Upstream Passage Criteria and Guidelines

Each main-stem fish ladder system is designed with a specific number (and location) of primary entrances (typically at each shore, and at the powerhouse/spillway interface), a defined hydraulic capacity, and specific operations of auxiliary water, entrance, and exit facilities. For a number of reasons, ladder entrance operations may evolve - and not be consistent with that envisioned in the design phase. Ladder entrances are perhaps the most important feature of the adult fish ladder system. (If entrances are improperly located, and/or discharge is inadequate, excessive upstream fish passage delay may occur.) While this document primarily focuses on design criteria and guidelines, operations of fish passage facilities are a vital and overlapping link. The criteria and guidelines in this sub-section are intended to reinforce what NOAA Fisheries believes is an unfortunate compromise in ladder entrance operations at some locations, relative to original design criteria and intended operation.

Therefore, the following apply to main-stem ladder entrance design and operations.

10.2.1 Total ladder attraction discharge, combined with whether ladder entrances are at satisfactory locations, determine whether up-stream migrating adult fish are able to pass with minimum delay. Total attraction flow discharged from adult fishway entrances should be either a minimum of 3% of mean annual discharge, or the discharge approved in the original design memorandum phase prior to construction.

10.2.2 Unless specifically stated in the original design, all ladder entrances shall be designed to be opened continuously during fish passage months, and operated in accordance with ladder entrance attraction discharge criteria (see below).

10.2.3 Auxiliary water systems shall be designed with sufficient back-up hydraulic capacity to assure continued operation consistent with design criteria.

10.2.4 Unless approved by NOAA Fisheries on the basis of investigations confirming that closure of one or more entrance gates will not adversely influence upstream passage during passage periods, adult ladder total entrance attraction discharge (gravity ladder plus auxiliary water flow) shall not be reduced from original design levels.

10.2.5 Ladder Entrance Attraction Discharge Criteria: Adjustable weir gate crest elevations at primary entrances shall be submerged at a minimum depth of 8 feet (relative to tailwater water surface elevation), with a head differential of 1.0 to 2.0 feet. These two parameters have evolved to become the standard for determining whether main-stem hydro-project fish ladder entrances are discharging at, or above, the minimum satisfactory ladder attraction flow. However, if this criteria cannot be satisfied at one or more ladder entrances (as is the case at some main-stem hydro-projects), an hydraulic investigation should be initiated to determine whether some entrances are discharging excessive attraction flow, while others fail to satisfy minimum discharge criteria. In these cases, it should be determined whether different ladder entrance combinations of head differential and weir submergence can be implemented to provide the minimum equivalent discharge (e.g., provided by 8' weir submergence and 1' head) at each ladder entrance. For instance, if the weir depth at one entrance is reduced by 25%, but the differential is increased, and is still within criteria listed above, the equivalent discharge can still be provided. Analysis findings should be coordinated with all parties before implementation.

All other ladder design and operational features shall comply with Section 5 .

10.3 Main-stem Juvenile Screen and Bypass Criteria and Guidelines

General - *Turbine intake screens* and *vertical barrier screens* at main-stem Columbia and Snake River hydroelectric dams are an exception to design criteria for *conventional screens* referenced in Section 12. Turbine intake screens are considered *partial* screens, because they do not screen the entire turbine discharge. They are *high-velocity* screens, because approach velocities are much higher than allowed for all conventional screens (as described in Section 12). However, since screens were retrofitted to large Columbia and Snake River turbine intakes, it was necessary to protect fish to the extent possible. The following turbine intake screen and vertical barrier screen design criteria are the product of extensive research and development, which has resulted in systems that safely guide a large percentage of downstream migrating juvenile salmon into bypass systems, then route them safely around the dam. This research, in the context of high-volume turbine intake capacity, has demonstrated that high-velocity intake screen and bypass systems can prevent turbine entrainment, and route fish past main-stem dams with low injury/mortality rates. The extensive research confirming satisfactory performance is the primary basis for deviation from conventional screen criteria.

10.3.1 **Turbine Intake Screens** - Existing intake screens are either 20 ft, or 40 ft, long and are located in the bulkhead slot of each turbine. They are lowered into the intake, then rotated to the correct operating inclination.

The following are design criteria for turbine intake screens:

10.3.1.1 Maximum approach velocity (normal to the screen face) shall be 2.75 ft/s. This is supported by extensive research of high-velocity screens. Above this velocity threshold, injury rates increase more rapidly.

10.3.1.2 Intake screen porosity shall be determined on the basis of physical hydraulic modeling.

10.3.1.3 Stagnation point (point where the component of velocity along the screen face is zero ft/s) shall be at a location where the submerged screen intercepts between 40-43% of turbine intake discharge, and shall be within 5 ft of the leading edge of the screen.

10.3.1.4 Gatewell flow shall be approximately 10% of intercept flow (which is flow above the intake screen stagnation point), and approximately 4% of turbine discharge.

10.3.1.5 Intake screen face shall be stainless steel bar screen, with maximum clearance between bars equal to1.75 mm.

10.3.1.6 Intake screen shall have an approved and proven screen cleaning device, which can be adjusted for desired cleaning frequency.

10.3.2 **Vertical Barrier Screens (VBS)** - These screens pass nearly all flow entering the gatewell from the intake screen and intake ceiling apex zone. Fish pass upward along the VBS, then accumulate in the upper gatewell, near an orifice that is designed to pass them safely into the juvenile bypass system.

The following are criteria and guidelines for design of VBS's:

10.3.2.1 Hydraulic modeling shall be used to assure the greatest possible uniform velocity distribution across the entire VBS. Note that this criterion assumes that operating gate position has a significant influence over VBS velocity flow distribution, and is one of the design issues to be reconciled through use of the physical model.

10.3.2.2 Variable-porosity stacked panels shall be developed using a physical hydraulic model, in order to achieve uniform velocity distribution and minimize turbulence in the upper gatewell.

10.3.2.3 Where gatewell flow is increased by a flow vane at the gatewell entrance, VBS's should be constructed of stainless steel bar screens, with upstream surface bar strands oriented horizontally, and a maximum clearance between bars of 1.75 mm.

10.3.2.4 A screen cleaner and debris removal system shall be features of each VBS with a gatewell flow increaser vane.

10.3.2.5 Average VBS through-screen velocity shall be a maximum of 1.0 fps, unless field testing is conducted to prove sufficiently low fish descaling/injury rates at a specific site.

Section 11. Upstream Juvenile Fish Passage

11.1 **Description, Purpose and Rationale:** Upstream juvenile fish passage is necessary at some passage sites, where inadequate conditions exist downstream for rearing fish. In a ladder that uses only a portion of the river flow for *upstream fish passage*, juvenile passage may require special and separate provisions from those designed to optimize adult passage. However, adult passage should never be compromised to accommodate juvenile passage..

As discussed in Section 5.2 (Upstream Passage Systems, Entrance Design), it is recommended that a 12 to 18 inch *hydraulic drop* from entrance pool to tailwater is used for *fishway entrance* design. Attraction of adult salmonids to a *fishway entrance* is compromised with decreased *headloss* at a *fishway entrance*, unless all of the streamflow is passed through the entrance. *Fishway* attraction (i.e., fishes' ability to locate the *fishway entrance* downstream of the dam) is the critical design parameter for an upstream passage facility. Previously, of many *fishway*s on the Columbia River operated with six-inches of *headloss* (measured from the entrance pool water surface to tailwater surface). After extensive laboratory and field studies, it was conclusively determined that higher velocities, which directly relates to the amount of *headloss* through the entrance, provided better attraction of adult salmonids than did lower velocities. This resulted in making hydraulic adjustments to *fishway entrance*s so that they operated with 12 to 18 inches of *headloss*, instead of six inches. Subsequent radio telemetry studies verified that passage times decreased as a result. Thus, there is a clear basis for designing entrance pool to tailwater differentials between 12 and 18 inches for adult salmonid passage.

Within the Northwest Region of NOAA Fisheries (which includes the states of Washington, Oregon, and Idaho), there are varying requirements for juvenile passage. NOAA Fisheries will consider the appropriate design requirements as applicable. Lower required headloss between pools is not going to provide an obstacle to adult fish, provided that the facility satisfies entrance design requirements of Section 5.2.. Powers has researched juvenile fish passage and reports in <u>Structures for Passing Juvenile Salmon Into Off-Channel Habitat American Fisheries Society Annual Meeting in Portland in 1993</u>:

> Studies (Blake, 1983) have shown that fish are more energetically efficient at leaping as opposed to swimming, at certain speeds (usually greater than 9 fps). Also, entrained air which creates an upwelling current from the air bubbles returning to the surface often provides "standing wave" velocities which can propel fish upwards. Even with these considerations the leaping capabilities of juvenile coho salmon appear exceptional. To investigate this further fish passage tests were conducted. The objective was to determine the percent passage of juvenile coho salmon over a wide range of hydraulic drops (i.e. 6", 9", 12" etc.). The preliminary data for coho fry indicate that fish in the 60 to 70 mm size range can pass 12 inches (8 of 37 passed). But, since the percent passing for the 6" and 9" drop was similar, there are no conclusions on percent of passage at this time.
>
> Given the reported swimming speeds for juvenile coho salmon and the observed leaping capabilities, submerged ports or pipes should be avoided when designing passage facilities for juvenile fish, except for inlet and outlet conditions. Fishways should be designed as pool and weir or roughened channel, with drops not to exceed the criteria listed in Table 11.1. In addition to the hydraulic drop, calm water in the pools and a low velocity just upstream of the weir crest is important. Weirs should be designed as sharp crested, where the head over the weir is two times the breadth.

Table 11.1. Juvenile Upstream Fish Passage Criteria

Juvenile Fish Passage Criteria			
Fish Size (mm)	Hydraulic Drop (weir), ft	Hydraulic Drop (Entrance and exit), ft	Velocity (fps) distances <1 ft
45 to 65	0.7	0.13	1.5 to 2.5
80 to 100	1	0.33	3 to 4.5

Powers also indicated that pool volume criteria described in section 5.6. are critical to ensuring appropriate passage conditions. This pool volume, if exceeded, serves as a turbulent barrier to juvenile fish.

Hydraulic design for juvenile upstream passage should be based on representative flows in which juveniles typically migrate. Recent research (NOAA Fisheries, 2001, in progress) indicates that providing for juvenile salmon passage up to the 10% annual exceedance flow will cover the majority of flows in which juveniles have been observed moving upstream.

In some situations, it may be feasible to operate a ladder entrance with a decreased *headloss* at times when adult salmon are not present, and at 12 to18 inches during the adult salmon upstream migration. The feasibility of doing this often entails making a judgement call on the timing of adult passage when often little or no information is available, and if it is available, it can change from year to year. In other situations, it may be appropriate to provide multiple fishway entrances that operate independently, according to the desired *headloss*. One entrance may operate to attract adult fish and convey the appropriate volume shape of attraction jet and velocities and another entrance may operate at a lower differential and convey flow over a weir.

Section 12. Fish Screen and Bypass Facilities

12.0 **Description, Purpose and Rationale**: This section provides criteria and guidelines to be utilized in the development of designs of downstream migrant fish screen facilities for hydroelectric, irrigation, and other water withdrawal projects. Consistent with the terminology used throughout this document, criteria are specified by the word "shall" and guidelines are specified by the word "should". Criteria are required design features, unless site specific conditions preclude their use and a site-specific written waiver is provided by NOAA Fisheries (also see Foreword). Guidelines are not required, but deviation from a guideline require a written explanation by the project designer. It is suggested that deviation from a guideline be discussed with NOAA Fisheries prior to final design.

In designing an effective fish screen facility, the swimming ability of the fish is a primary consideration. Research has shown that swimming ability of fish varies and may depend upon a number of factors relating to the physiology of the fish, including species, size, duration of swimming time required, behavioral aspects, migrational stage, physical condition and others, in addition to water quality parameters such as dissolved oxygen concentrations, water temperature, lighting conditions, and others. For this reason, screen criteria must be expressed in general terms.

Since these criteria and guidelines are general in nature, there may be cases where site constraints or extenuating biological circumstances dictate that certain criteria or guidelines be waived or modified, without delaying or otherwise adversely impacting fish migration. It is the responsibility of the project sponsor provide compelling evidence in support of any proposed waiver. Particular fishway elements that can not be designed to meet these criteria and guidelines should be discussed with NOAA Fisheries engineering staff as early in the design process as possible to explore potential options. Conversely, where NOAA Fisheries deems there is a need to provide additional protection for fish, more restrictive site-specific criteria may be added. These circumstances will be considered by NOAA Fisheries on a project-by-project basis. To facilitate construction of any fish passage facility, rationale for criteria waivers shall accompany design documents sent to NOAA Fisheries staff for review.

Several categories of screen designs are in use but are still considered as experimental technology by NOAA Fisheries. These include Eicher screens, modular inclined screens, coanda screens, and horizontal screens. Criteria for experimental screens can be developed through discussions with NOAA Fisheries engineers, on a case-by-case basis. The process to evaluate experimental technology is described in Section 17.

12.1 A functional screen design should be developed that defines type, location, size, hydraulic capacity, method of operation, and other pertinent juvenile fish screen facility characteristics. In the case of applications to be submitted to the FERC and for consultations under the ESA, a functional design for juvenile (and adult) fish passage facilities shall be developed and submitted as part of the FERC License Application or of the Biological Assessment for the facility. It shall reflect NOAA Fisheries input and design criteria and be acceptable to NOAA Fisheries.

Functional design drawings shall show all pertinent hydraulic information, including water surface elevations and flows through various areas of the structures. Functional design drawings shall show general structural sizes, cross-sectional shapes, and elevations. Types of materials shall be identified where they will directly affect fish. The final detailed design shall be based on the functional design, unless changes are agreed to by NOAA Fisheries.

12.2 To minimize risks to anadromous fish at some locations, NOAA Fisheries may require investigation (by the project sponsors) of important and poorly defined site-specific variables that are deemed critical to development of the screen and bypass design. This investigation may include factors such as fish behavioral response to hydraulic conditions, weather conditions (ice, wind, flooding, etc.), river stage-discharge relationships, seasonal operational variability, potential for sediment and debris problems, resident fish populations, potential for creating predation opportunity, and other information. The life stage and size of juvenile salmonids present at a potential screen site usually is not known, and can change from year to year based on flow and temperature conditions. Thus, adequate data to describe the size-time relationship requires substantial sampling efforts over a number of years. For the purpose of designing juvenile fish screens, NOAA Fisheries will assume that fry-sized salmonids and low water temperatures are present at all sites and apply the appropriate criteria listed below, unless adequate biological investigation proves otherwise. The burden-of-proof is the responsibility of the owner of the diversion facility.

12.3 Acceptance criteria for existing screens: If a fish screen was constructed prior the establishment of these criteria, but constructed to NOAA Fisheries criteria established August 21, 1989, or later, approval of these screens will be considered providing that all of the following conditions are met:

1) the entire screen facility is still functioning as designed.
2) the entire screen facility has been maintained and is in good working condition.
3) when the *screen media* wears out, it shall be replaced with *screen media* meeting the current criterion stated in this document. Structural constraints may limit this activity in some instances, and these should be discussed with NOAA Fisheries engineering staff prior to replacing *screen media*.
4) no mortality, injury, entrainment, impingement, migrational delay or other harm to anadromous fish has been noted that is being caused by the facility;
5) no emergent fry are likely to be located in the vicinity of the screen, as agreed to by NOAA Fisheries biologists familiar with the site; and
6) when biological uncertainty exists, access to the diversion site by NOAA Fisheries is permitted by the diverter for verification of numbers 1 through 5.

12.4 **Structure Placement - Streams and Rivers:**

12.4.1 Where physically practical and biologically desirable, the screen shall be constructed at the point of diversion with the screen face generally parallel to river flow. Physical factors that may preclude screen construction at the diversion entrance include excess river gradient, potential for damage by large debris, and potential for heavy sedimentation. For screens constructed at the bankline, the screen face shall be aligned with the adjacent bankline and the bankline shall be shaped to smoothly match the face of the screen structure to prevent eddies in front, upstream, and downstream of the screen. Adverse alterations to riverine habitat shall be minimized.

12.4.2 Where installation of fish screens at the diversion entrance is not desirable or impractical, the screens may be installed in the canal downstream of the entrance at a suitable location. All screens installed downstream from the diversion entrance shall be provided with an effective bypass system approved by NOAA Fisheries, designed to collect and transport fish safely back to the river with minimum delay. The screen location shall be chosen to minimize the effects of the diversion on in-stream flows by placing the bypass outfall as close as biologically and practically feasible to the point of diversion.

12.4.3 All passage facilities shall be designed to function properly through the full range of hydraulic conditions in the river (see Section 4) and in the diversion conveyance, and shall account for debris and sedimentation conditions which may occur.

12.5 Structure Placement - Lakes, Reservoirs and Tidal areas:

12.5.1 Intakes shall be located offshore where feasible to minimize fish contact with the facility. When possible, intakes shall be located in areas with sufficient ambient velocity to minimize sediment accumulation in or around the screen and to facilitate debris removal and fish movement away from the screen face. Intakes in reservoirs should be as deep as practical, to reduce the numbers of juvenile salmonids that encounter the intake.

12.5.2 If a reservoir outlet is used to pass fish from a reservoir, the intake shall be designed to withdraw water from the most appropriate elevation based on providing the best juvenile fish attraction and appropriate water temperature control downstream of the project. The entire range of forebay fluctuation shall be accommodated in design.

12.6 Screen Hydraulics - Rotating Drum Screens, Vertical Screens and Inclined Screens

12.6.1 The *approach velocity* shall not exceed 0.40 feet per second (ft/s) for *active screens*, or 0.20 ft/s for *passive screens*. For screen design, *approach velocity* is calculated by dividing the vertical projection of the effective screen area into the diverted flow amount. This approach velocity will minimize screen contact and/or impingement of juvenile fish.

12.6.2 The *effective screen area* required is calculated by dividing the maximum diverted flow by the allowable *approach velocity*.

12.6.3 For rotating drum screens, the design submergence shall not exceed 85%, nor be less than 65% of drum diameter. Submergence over 85% of the screen diameter increases the possibility of entrainment over the top of the screen (if entirely submerged), and increases the chance for impingement with subsequent entrainment if fish are caught in the narrow wedge of water above the 85% submergence mark. Submerging rotating drum screens less than 65% will reduce the self-cleaning capability of the screen. In many cases, stop logs can be installed downstream of the screens to achieve proper submergence. If stoplogs are used, they should be located at least two drum diameters downstream of the back of the drum.

12.6.4 The screen design shall provide for nearly uniform flow distribution (see section 16) over the screen surface, thereby minimizing approach velocity over the entire screen face. The screen designer shall show how uniform flow distribution is to be achieved. Providing adjustable porosity control on the downstream side of screens, and/or flow training walls may be required. Large facilities may require hydraulic modeling to identify and correct areas of concern. Uniform flow distribution avoids localized areas of high velocity, which have the potential to impinge fish.

12.6.5 Screens longer than six feet shall be angled and shall have sweeping velocity greater than the approach velocity. This angle may be dictated by site specific geometry, hydraulic, and sediment conditions. Optimally, sweeping velocity should be at least 0.8 ft/s and less than 3 ft/s.

12.6.6 Sweeping velocity shall not decrease along the length of the screen.

12.6.7 The plane of an inclined screen shall be oriented at 45° or more relative to the downstream water surface. Horizontally inclined screens are currently under evaluation, and considered as experimental technology (see Section 17).

12.7 *Screen Media*

12.7.1 Circular screen face openings shall not exceed 3/32 inch in diameter. Perforated plate openings shall be punched through in the direction of flow

12.7.2 Slotted screen face openings shall not exceed 1.75 mm (approximately 1/16 inch) in the narrow direction.

12.7.3 Square screen face openings shall not exceed 3/32 inch on a side.

12.7.4 The *screen media* shall be corrosion resistant and sufficiently durable to maintain a smooth uniform surface with long term use.

12.7.5 Other components of the screen facility (such as seals) shall not include gaps greater than the maximum screen opening defined above.

12.8 Civil Works and Structural Features

12.8.1 The face of all screen surfaces shall be placed flush (to the extent possible) with any adjacent screen bay, pier noses, and walls to allow fish unimpeded movement parallel to the screen face and ready access to bypass routes.

12.8.2 Structural features shall be provided to protect the integrity of the fish screens from large debris, and to protect the facility from damage if overtopped by flood flows. A trash rack, log boom, sediment sluice, and other measures may be required.

12.8.3 The civil works shall be designed in a manner that prevents undesirable hydraulic effects (such as eddies and stagnant flow zones) that may delay or injure fish or provide predator habitat or predator access.

12.9 Bypass System

12.9.1 Bypass layout

12.9.1.1 The screen and bypass shall work in tandem to move out-migrating salmonids (including adults) to the bypass outfall with a minimum of injury or delay. The bypass entrance shall be located so that it can easily be located by out-migrants. Screens greater than or equal to six feet in length shall be constructed with the downstream end of the screen terminating at a bypass entrance. Screens less than or equal to six feet long may be constructed perpendicular to flow with a bypass entrance at either or both ends of the screen, or else could be constructed at an angle to flow, with the downstream end terminating at the bypass entrance. Some screen systems do not require a bypass system. For example, an end of pipe screen located in a river, lake or reservoir does not require a bypass system because fish are not removed from their habitat. A second example is a river bank screen with sufficient hydraulic conditions to move fish past the screen face.

12.9.1.2 Multiple bypass entrances may be required if the sweeping velocity will not move fish to the bypass within 60 seconds, assuming fish are transported along the length of the screen face at this velocity.

12.9.1.3 The bypass entrance and all components of the bypass system shall be of sufficient size and hydraulic capacity to minimize the potential for debris blockage.

12.9.1.4 In order to improve bypass collection efficiency for a single bank of vertically-oriented screens, a bypass training wall shall be located at an angle to the screens, with the bypass entrance at the apex and downstream-most point. This will aid fish movement into the bypass by creating hydraulic conditions that conform to observed fish behavior. For single or multiple vee screen configurations, training walls are not required, unless a intermediate bypass is used.

12.9.1.5 In cases where there is insufficient flow available to satisfy hydraulic requirements at the bypass entrance (entrances) for the main screens, a secondary screen may be required. This is a screen located in the main screen bypass which allows the prescribed bypass flow to be used to effectively attract fish into the bypass entrance(s) and then allows for all but a reduced residual bypass flow to be routed back (by pump or gravity) to the diversion canal for the primary use. The residual bypass flow (not passing through the secondary screen) would then convey fish to the bypass outfall location or other destination.

12.9.1.6 Access for inspection and debris removal is required at locations in the bypass system where debris accumulations may occur. If trash racks are used, sufficient hydraulic gradient is required to route juvenile fish from between the trash rack and screens to the bypass.

12.9.1.7 The screen civil works floor shall be designed to allow fish to be routed back to the river safely when the canal is dewatered. This may entail a sumped drain with a small gate and drain pipe, or similar provisions. If this can not be accomplished, an acceptable fish salvage plan shall be developed in consultation with NOAA Fisheries and included in the operation and maintenance plan.

12.9.1.8 To assure that fish move quickly into the bypass system, the rate increase in velocity between any two points in the screen/bypass system should not decrease and should not exceed 0.2 ft/s per foot of travel.

12.9.2 Bypass Entrance

12.9.2.1. Each bypass entrance shall be provided with independent flow-control capability.

12.9.2.2. The minimum bypass entrance flow velocity should be greater than 110% of the maximum true velocity upstream of the bypass entrance. At no point shall flow decelerate along the screen face or in the bypass channel. Bypass flow amounts should be of sufficient quantity to ensure these hydraulic conditions are achieved over the entire range of operations throughout the smolt out migration period.

12.9.2.3 Ambient lighting conditions are required upstream of the bypass entrance and should extend to the bypass flow control device. Where lighting transitions can not be avoided, they should be gradual, or should occur at a point in the bypass system where fish can not escape the bypass and return to the canal (i.e. when bypass velocity exceeds swimming ability).

12.9.2.4 For diversions greater than 3 cfs, the bypass entrance shall extend from the floor to the canal water surface, and be a minimum of 18 inches wide. For diversions of 3 cfs or less, the bypass entrance shall be a minimum of 12 inches wide.

12.9.2.5 For weirs used in bypass systems, depth over the weir shall be a minimum of one foot throughout the smolt out-migration period.

12.9.3 Bypass Conduit and System Design

12.9.3.1 Bypass pipes and joints shall have smooth surfaces to provide conditions that minimize turbulence, risk of catching debris and the potential for fish injury. Pipe joints may be subject to inspection and approval by NOAA Fisheries prior to implementation of the bypass. Every effort should be made to minimize the length of the bypass pipe.

12.9.3.2 Fish should not be pumped within the bypass system.

12.9.3.3 Fish shall not be allowed to free-fall within a pipe or other enclosed conduit in a bypass system. Downwells shall be designed with a free water surface, and designed for safe and timely fish passage by proper consideration of turbulence, geometry and alignment.

12.9.3.4 In general, bypass flows in any type of conveyance structure should be open channel. If required by site conditions, pressures in the bypass pipe shall be equal to or above atmospheric pressures. Pressurized to non-pressurized (or vice-versa) transitions should be avoided within the pipe. Bypass pipes shall be designed to allow trapped air to escape.

12.9.3.5 Bends should be avoided in the layout of bypass pipes due to the potential for debris clogging and turbulence. The ratio of bypass pipe center-line radius of curvature to pipe diameter (R/D) shall be greater than or equal to 5. Greater R/D may be required for super-critical velocities (see section 12.9.3.9).

12.9.3.6 Bypass pipes or open channels shall be designed to minimize debris clogging and sediment deposition and to facilitate inspection and cleaning as necessary. For bypass pipes longer than 150 feet, access ports should be provided at spacing of less than 100 feet to allow for detection and removal of debris.

12.9.3.7 The bypass pipe diameter or open channel bypass geometry should generally be a function of the bypass flow and slope but shall also comply with velocity and depth criteria in 12.9.3.9 and 12.9.3.10. Generally, a bypass pipe less than 18 inches in diameter is not acceptable. However, if other hydraulic criteria cannot be reasonably satisfied with that size of pipe, the diameter can be reduced with special consideration given to management of debris. In no case can a pipe diameter of less than 10 inches be used. For bypass flows greater than 20 cfs, a 30 inch diameter bypass pipe is recommended. Bypass flows greater than 50 cfs are special cases that need specific consultation with NOAA Fisheries engineers.

12.9.3.8 Design bypass flow should be at least 5% of the total diverted flow amount, unless otherwise approved by NOAA Fisheries.

12.9.3.9 The design bypass pipe velocity should be between 6 and 12 ft/s for the entire operational range. If higher velocities are approved, special attention to pipe and joint smoothness is required. In no instance shall pipe velocity be less than 2 ft/s.

12.9.3.10 The design minimum depth of free surface flow in a bypass pipe should be at least 40% of the bypass pipe diameter, unless otherwise approved by NOAA Fisheries.

12.9.3.11 Closure valves of any type should not be used within the bypass pipe unless specifically approved based on demonstrated fish safety.

12.9.3.12 Sampling facilities installed in the bypass conduit shall not in any way impair operation of the facility during non-sampling operations.

12.9.3.13 There should not be a hydraulic jump within the pipe, unless a weak jump is specifically approved by NOAA Fisheries engineers.

12.9.3.14 Spillways upstream of the screen facility also act as a bypass system. These facilities should also be designed to provide a safe passage route back to the stream, adhering to the bypass design principles described in sections 12.9 and 12.10.

12.10 Bypass Outfall

12.10.1 Bypass outfalls should be located where ambient river velocities are greater than 4.0 ft/s.

12.10.2 Bypass outfalls shall be located to minimize predation by selecting an outfall location free of eddies, reverse flow, or known predator habitat. Predator control systems may be required in areas with high avian predation potential. Bypass outfalls should be located to provide good egress conditions for downstream migrants.

12.10.3 Bypass outfalls shall be located where the receiving water is of sufficient depth (depending on the impact velocity and quantity of bypass flow) to ensure that fish injuries are avoided at all river and bypass flows. The bypass flow shall not impact the river bottom or other physical features at any stage of river flow.

12.10.4 Maximum bypass outfall impact velocity (i.e. the velocity of bypass flow entering the river) including vertical and horizontal velocity components shall be less than 25.0 ft/s.

12.10.5 The bypass outfall discharge into the receiving water shall be designed to avoid attraction of adult fish thereby reducing the potential for jumping injuries and false attraction. The bypass outfall design shall allow for the potential attraction of adult fish, by provision of a safe landing zone if attraction to the outfall flow can potentially occur.

12.11 Debris Management

12.11.1 A reliable, ongoing inspection, preventative maintenance and repair program is necessary to assure facilities are kept free of debris and that *screen media*, seals, drive units, and other components are functioning correctly during the out migration period. A written plan should be completed and submitted for approval with the screen design.

12.11.2 *Active screens* shall be automatically cleaned as frequently as necessary to prevent accumulation of debris. The cleaning system and protocol shall be effective, reliable, and satisfactory to NOAA Fisheries.

12.11.3 A *passive screen* can only be used when all of the following criteria are met:

12.11.3.1 The site is not suitable for an active screen.
12.11.3.2 Uniform flow characteristics can be demonstrated.
12.11.3.3 The debris load is expected to be low.
12.11.3.4 The rate of diversion is less than 3 CFS.
12.11.3.5 Sufficient ambient river velocity exists to carry debris away from the screen face.
12.11.3.6 A maintenance program is approved by NOAA Fisheries and implemented by the water user.
12.11.3.7 The screen is inspected at least daily and debris accumulations are removed, with more frequent inspections as site conditions dictate.
12.11.3.8 Sufficient stream depth exists at the screen site to provide for distance of at least 1 screen radius around the screen.
12.11.3.9 The screen can be easily removed for maintenance, and to protect from flooding.

12.11.4 Intakes shall include a trash rack in the screen facility design which shall be kept free of debris. In certain cases, a satisfactory profile bar screen design can substitute for a trash rack. Based on biological requirements at the screen site, trash rack spacing may be specified that reduces the probability of entraining adult fish.

12.11.5 The head differential to trigger screen cleaning for intermittent type cleaning systems shall be a maximum of 0.1 feet or as agreed to by NOAA Fisheries. A variable timing interval trigger shall also be used for intermittent type cleaning systems as the primary trigger for a cleaning cycle.

12.11.6 The completed screen and bypass facility shall be made available for inspection by NOAA Fisheries, to verify that the screen is being operated consistent with the design criteria.

12.11.7 At some sites, screen and bypass facilities mayl be evaluated for biological effectiveness and to verify that hydraulic design objectives are achieved. At the discretion of NOAA Fisheries, this could entail a complete biological evaluation especially if waivers to screen and bypass criteria are granted, or merely a visual inspection of the operation if screen and bypass criteria is met in total.

12.11.8 Provision shall be made to limit the build-up of sediment, where it could impact screen operations.

12.12 Additional criteria for end of pipe screens (including pump intake screens)

12.12.1 End of Pipe Screen Location: When possible, end of pipe screens shall be placed in locations with sufficient ambient velocity to sweep away debris removed from the screen face.

12.12.2 End of pipe screens shall be submerged to a depth of at least one screen radius below the minimum water surface, with a minimum of one screen radius clearance between screen surfaces and natural or constructed features. For approach velocity calculations, the entire submerged effective area can be used.

12.12.3 A clear escape route should exist for fish that approach the intake volitionally or otherwise. For example, if a pump intake is located off of the river (such as in an intake lagoon), a conventional open channel screen should be placed in the intake channel or at the edge of the river to prevent fish from entering a lagoon.

Section 13. Infiltration Galleries

13.1 **Description, Purpose and Rationale:** This section discusses the application and suitability for the installation *infiltration galleries*. In concept, *infiltration galleries* could provide suitable fish passage conditions at a diversion site. However, if improperly sited, failure can occur that can result in severe adverse habitat impacts and loss of habitat access in addition to the loss of the diversion. This section describes the guidelines and criteria that should be followed in the planning, design, operation, monitoring, and maintenance of *infiltration galleries*.

The intent of these criteria is to build and operate *infiltration galleries* that provide at least the same level of fish protection as conventional screen facilities that meet NOAA Fisheries screen criteria, as presented in Section 12. Accordingly, *infiltration galleries* share some of the design goals as conventional screens. These include: screen media dimensions, approach velocity, bypass, ability to monitor head loss, and the ability to be self-cleaning, maintainability, and owner agreements to maintain and operate the system within criteria. These aspects are discussed in more detail in the following sections.

Since these criteria and guidelines are general in nature, there may be cases where site constraints or extenuating biological circumstances dictate that certain criteria or guidelines be waived or modified, without delaying or otherwise adversely impacting fish migration. It is the responsibility of the project sponsor to provide compelling evidence in support of any proposed waiver. Particular *infiltration gallery* elements that cannot be designed to meet these criteria and guidelines should be discussed with NOAA Fisheries engineering staff as early in the design process as possible to explore potential options. Conversely, where NOAA Fisheries deems there is a need to provide additional protection for fish, more restrictive site-specific criteria may be added. These circumstances will be considered by NOAA Fisheries on a project-by-project basis. To facilitate construction of any fish passage facility, rationale for criteria waivers shall accompany design documents sent to NOAA Fisheries staff for review.

13.2 **Scope:** The term *infiltration gallery*, in this document, refers to a water collection system that is installed in the substrate of a stream, between the stream banks, for the purpose of conveying water to either a pumped or gravity-fed water distribution network. See Figure 13-1. The *infiltration gallery* is intended to be a substitute for a surface-based diversion system that is normally installed above the bed of the stream.

The *infiltration gallery* shall be designed to:

a) provide the same volume, rate, and timing of water supply that the diverter would be entitled to when using a surface-based diversion.

b) withdraw water primarily from the portion of the stream located directly above the *infiltration gallery*, and

c) provide at least the same level of fish protection as conventional screens.

13.3 **Selection of Appropriate Screen Technology:** Due to their location below the stream bed, *infiltration galleries* are prone to become ineffective due to plugging by sediments. Besides reducing the flow capacity of the facility, plugged galleries also increase risk to small fish due to the creation of velocity hot spots. Since very few existing *infiltration galleries* include effective installed self-cleaning systems, it is a common practice to repair plugged galleries by digging them up and re-building them. This process can create enormous disruption to the river habitat and to the diverters' ability to divert water. Therefore, the designer should select an *infiltration gallery* as the preferred diversion method only after a thorough review of the benefits and risks of using conventional screens indicates that an *infiltration gallery* will create less risk for fish and their habitat.

13.2 **Site Selection** - NOAA Fisheries intends to only permit *infiltration galleries* at stream sites that exhibit sufficient natural fluvial processes to minimize sediment deposition on top of the *infiltration gallery* to the maximum practical extent. The sealing of *infiltration galleries* with transported bedload sediments seems to be a common mode of failure. *Infiltration galleries* should not be installed at sites where natural sedimentation occurs that would plug a gallery.

13.3 **Minimum Depths and Velocities over Infiltration Galleries:**
Infiltration galleries should not be operated when the water depth above the river bed over any part of the *infiltration gallery* is less than 0.5 feet. Use of temporary impoundments such as push-up berms and other dams to raise the water level is not permitted. The minimum stream velocity at low flow should be 2 feet per second.

13.4 **Screen Mesh Opening:** *Infiltration galleries* installed with less than 24 inches of gravel cover should meet juvenile fish screen criteria, as described in Section 12.

13.5 **Flow direction:** *Infiltration galleries* should be designed to withdraw flow primarily from the zone directly above the intake screen.

13.6 **Imported Gravels**: Rock used to backfill over the *infiltration gallery* shall be as designed and approved by the design engineer. The backfill material selection shall also be approved by NOAA Fisheries.

13.7 Induced vertical approach velocity at the stream bed: The maximum vertical interstitial velocity at through the substrate, V_s , shall not exceed 0.05 fps when the substrate is new and after *backwashing* (see Figure 13-1).

V_s is defined according to the following calculations:

$$V_s = Q / [(A_{eff}) (\eta)]$$

Where V_s = Average vertical interstitial velocity through the substrate

Q = *Infiltration gallery* flow rate

$A_{effective} = (W_{effective})(L_{screen})$ = The area, in the plan view, of the stream surface through which the flow is assumed to pass

η = porosity of gravel substrate

13.8 **Determination of Plugged Gallery:** As with conventional screen technology, it is essential to be able to measure the head loss through the *screening media* (See Section 12.11.5). As a minimum, sufficient instrumentation shall be installed to measure the Hydraulic Grade Line (H) values, as shown schematically in Figure 13-1. The gallery *media* shall be backwashed when the head loss measurements indicate that V_s is greater than or equal to 0.10 fps. If *backwashing* does not reduce V_s below 0.10 fps then the gallery shall be shut down and repaired.

13.9 **Backwashing:** All *infiltration galleries* shall be designed to be capable of being backwashed. *Backwashing* may be accomplished using air or water or both. The backwash system shall be designed to thoroughly clean all of the *media* in the Effective Cleaning Section (see Figure 13-1). The Effective Cleaning Zone is the volume of filter medium that the designer has assumed contributes about 90% of the diverted flow rate.

Insert Figure 13-1

13.10 **Limitations/Cessation of Use**

13.10.1 *Infiltration galleries* should not be constructed in areas in where spawning may occur.

13.10.2 Should spawning occur within 10' of a portion of an *infiltration gallery*, then use of those portions of the *Infiltration galleries* within 10' of the redd should be discontinued for 90 days, or as directed by NOAA Fisheries.

13.10.3 Instream excavation to repair *infiltration galleries* is not included in the scope of permitted work beyond 90 days from the date of commencement of initial instream construction, or the end of the approved work period, whichever is earlier, unless performed when there is no flowing water in the creek. This restriction does not apply to repairs that do not disturb the river bed or banks.

13.11 **Qualifications of Infiltration Gallery Designers:** The design of *infiltration galleries* shall be performed by an appropriately qualified engineer or engineering geologist, and the drawings should be signed by the designer and/or stamped with his/her seal. The design of each *infiltration gallery* shall be reviewed and approved by NOAA Fisheries.

13.12 **Operations and Maintenance:** Infiltration galleries shall be operated and maintained in accordance with Section 15.

Section 14. Interim Passage during Construction and/or Modifications

Where construction and/or modifications to man-made impediments (e.g., dams) or upstream passage facilities are planned, upstream passage may be adversely impacted. If possible, these activities should be scheduled for periods when migrating fish are not present, as specified in the in-water work period allowable for construction of facilities in streams. However, this may not always be possible or advisable. In these cases, an interim fish passage plan shall be prepared and submitted to NOAA Fisheries for approval, in advance of work in the field. Criteria listed herein will apply to the interim upstream passage plan. Where this is not possible, project owners shall seek NOAA Fisheries approval of alternate interim fish passage design criteria, and a final interim passage plan.

Section 15. Operations and Maintenance Responsibilities

Passage facilities at impediments must be operated and maintained properly for optimum, or even marginal, success. The preceding criteria are intended for use in the design of passage facilities; however, failure to operate and maintain these facilities to optimize performance in accordance with design will result in compromised fish passage, and ultimate deterioration of the entire facility. Therefore, NOAA Fisheries requires project sponsors to acknowledge and accept long-term responsibility for operations, maintenance, and repair of fish facilities described herein, to ensure protection of fish on a sustained basis. This includes immediate restoration of the passage facility (including repair of damage and sediment/gravel removal) immediately after flooding. Where facilities are inadequately operated or maintained, and mortality of listed fish can be documented, the responsible party is liable to enforcement measures as described in Section 9 of the Endangered Species Act.

An operation and maintenance plan shall be drafted and submitted for approval by NOAA Fisheries. This plan shall include a brief summary of operating criteria posted at the passage facility or made available to the facility operator.

Staff gages shall be installed and maintained at critical areas throughout the facility in order to allow personnel to easily determine if the facility is being operated within the established design criteria.

Section 16. Post-construction evaluations

Post-construction evaluation is important to assure the intended results of the fishway design are accomplished, and to assist in ensuring that mistakes are not repeated elsewhere. There are three parts to this evaluation: 1)Verify the fish passage system is installed in accordance with proper design and construction procedures; 2) measure hydraulic conditions to assure that the facility meets these guidelines, and 3) perform biological assessment to confirm the hydraulic conditions are resulting in successful passage. NOAA Fisheries technical staff may assist in developing a hydraulic or biological evaluation plan to fit site-specific conditions and species, but in any case, evaluation plans are subject to approval by NOAA Fisheries. These evaluations are not intended to cause extensive retrofits of any given project unless the as-built installation does not reasonably conform to the design guidelines, or an obvious fish passage problem continues to exist. Over time, NOAA Fisheries anticipates that the second and third elements of these evaluations will be abbreviated as commonly used designs are evaluated and fine-tuned to assure optimal passage conditions.

Hydraulic evaluations of juvenile fish screens shall include confirmation of uniform approach velocity and the requisite sweeping velocity over the entire screen face. Confirmation of approach and sweeping velocities shall consist of a series of velocity measurements encompassing the entire screen face, divided into a grid with each grid section representing no more than 5% of the total flow through the screen. The approach and sweeping velocity (parallel and perpendicular to the screen face) should be measured at the center point of each grid section, approximately 3 inches from the face of the screen. Uniform approach velocity is achieved when no individual approach velocity measurement exceeds 0.44 ft/s. In addition, velocities at the entrance to the bypass, bypass flow amounts, and total flow should be measured and reported.

Depending on the site and its potential for adverse biological impacts, detailed biological evaluations and/or monitoring will likely be required and are the responsibility of the project sponsor. The need for and scale of biological evaluation will be identified by NOAA Fisheries early in the design process. If a passage facility will be encountered by the majority of the fish migration, and if waivers to the criteria are granted, biological evaluation will likely be required.

Section 17. Experimental Fish Guidance Devices

SUMMARY

NOAA Fisheries believes that conventional fish passage facilities constructed to the criteria and guidelines described above are most appropriate for utilization in the protection of salmon and steelhead at all impediments. However, the process described herein delineates an approach whereby experimental behavioral guidance devices can be evaluated and, if comparable performance is confirmed to the satisfaction of NOAA Fisheries, installed in lieu of conventional passage facilities.

INTRODUCTION

The injury and death of juvenile fish at water diversion intakes have long been identified as a major source of overall fish mortality [Spencer1928, Hatton 1939, Hallock and Woert 1959, Hallock 1987]. Fish diverted into power turbines incur up to 40 percent immediate mortality, while also experiencing injury, disorientation and delay of migration that may increase predation related losses [Bell, 1991]. Fish entrained into agricultural and municipal water diversions experience 100 percent mortality. Diversion mortality is the major cause of decline in some fish populations. For the purposes of this document, diversion losses include turbine, irrigation, municipal, and all other potential fish losses related to the use of water by man.

Positive-exclusion barrier screens that screen the entire diversion flow have long been used to prevent or reduce entrainment of juvenile fish for diversions of up to 6000 cfs. In recent decades, design improvements have been implemented to increase the biological effectiveness of positive-exclusion screen and *bypass system*s by taking advantage of known behavioral responses to hydraulic conditions. Recent evaluations have consistently demonstrated high success rates (typically greater than 98 percent) at moving juvenile salmonids past intakes with a minimum of delay, loss, or injury. (For diversion flows over 6000 cfs, such as at Columbia River main-stem turbine intakes, submerged traveling screens or bar screens are commonly used. These are not considered positive-exclusion screens in the context of this position statement.)

The past few decades have also seen considerable effort in developing "startle" systems to elicit a taxis (response) by fish, with an ultimate goal of reducing entrainment. This paper addresses research performed to avoid losses at intakes and presents a position statement for reviewing and implementing future fish protection measures.

JUVENILES AT INTAKES

Entrainment, impingement, and delay/predation are the primary contributors to the mortality of juvenile migrating salmonids. Entrainment occurs when fish are drawn into the diversion canal or turbine intake. Impingement occurs when a fish is not able to avoid contact with a screen surface, trashrack, or debris at the intake. This can cause bruising, descaling and other injuries.

Impingement, if prolonged, repeated or occurring at high velocities, also causes direct mortality. Predation (which is the leading cause of mortality at some diversion sites) occurs when fish are preyed upon by aquatic or avian animals. Delay at intakes increases predation by stressing or disorienting fish and/or by providing habitat for predators.

A. Positive-Exclusion Screen and *Bypass System*s (PESBS)

Design criteria for PESBS have been developed, tested, and proven to minimize adverse impacts to fish at diversion sites. Screens with small openings and fish-tight seals are positioned at a slight angle to flow. This orientation allows fish to be guided to safety at the downstream end of the screen, while they resist being impinged on the screen face. These screens are very effective at preventing entrainment [Pearce and Lee 1991]. Carefully designed *bypass system*s minimize fish exposure to screens and provide hydraulic conditions that safely return fish to the river, thereby preventing impingement [Rainey 1985]. The PESBS are designed to minimize entrainment, impingement, and delay/predation from the point of diversion through the facility to the bypass outfall.

PESBS have been installed and evaluated at numerous facilities [Abernathy et al 1989, 1990, Rainey, 1990, Johnson, 1988]. A variety of screen types (e.g., fixed-vertical, drum, fixed-inclined) and screen materials (e.g., woven cloth [mesh], perforated plate, profile wire) have proven effective, when used in the context of a satisfactory design for the specific site. Facilities designed to previously referenced criteria consistently resulted in a guidance efficiencies of over 98 percent [Hosey, 1990, Neitzel, 1985, 1986,1990 a,b,c,d, Neitzel, 1991].

The main detriment of PESBS is cost. At diversions of several hundred cubic feet per second and greater, the low velocity requirement and structure complexity can drive the cost of fish passage to over $1 million. At the headworks, the need to clean thescreen, remove trash, control sediment, and provide regular maintenance (e.g., seasonal installation, replacing seals, etc.) also increases costs.

B. Behavioral Devices

Due to the high costs of PESBS, there has been considerable effort since 1960 to develop less expensive behavioral devices as a substitute for positive fish protection [EPRI, 1986]. A behavioral device, as opposed to a conventional screen, requires a volitional taxis on the part of the fish to avoid entrainment. Some devices were investigated with the hope of attracting fish to a desired area while others were designed to repel fish. Most studies focused on soliciting a behavior response, usually noticeable agitation, from the fish.

Investigations of prototype startle-response devices document that fish guidance efficiencies are consistently much lower for these devices than for conventional screens. Experiments show that there may be a large behavioral variation between individual fish of the same size and species to startle responses. Therefore, it cannot be predicted that a fish will always move toward or away from that stimuli. Until shown conclusively in laboratory studies, it should not be assumed that fish can discern where a signal is coming from and what constitutes the clear path to safety.

If juvenile fish respond to a behavioral device, limited size and swimming ability may preclude small fish from avoiding entrainment (even if they have the understanding of where to go and have the desire to get there). Another concern is repeated exposure; fish may no longer react to a signal after an acclimation period. In addition to vagaries in the response of an individual fish, behavior variations due to species, life stage, and water quality conditions can be expected.

Another observation is that past field tests of behavioral devices have been deployed without consideration of how controlled ambient hydraulic conditions (i.e., the use of a training wall to create uniform flow conditions, while minimizing stagnant zones or eddies that can increase exposure to predation) can optimize fish guidance and safe passage away from the intake. Failure to consider that hydraulic conditions can play a big role in guiding fish away from the intake is either the result of the desire to minimize costs or the assumption that behavioral devices can overcome the tendency for poor guidance associated with marginal hydraulic conditions. The provision of satisfactory hydraulic conditions is a key element of PESBS designs.

The primary motivation for selection of behavioral devices relates to cost. However, much of the cost in PESBS is related to construction of physical structures to provide hydraulic conditions that are known to optimize fish guidance. Paradoxically, complementing the behavioral device with hydraulic control structures needed to optimize juvenile passage will compromise much of the cost advantage relative to PESBS.

Skepticism about behavioral devices at this stage of their development is illustrated by the fact that few are currently being used in the field and those that have been installed and evaluated seldom show consistent guidance efficiencies over 60 percent [Vogel, 1988, EPRI, 1986]. The louver system is an example of a behavioral device with a poor record. Entrainment rates were high, even with favorable hydraulic conditions, due to the presence of smaller fish [Vogel, 1988, Cramer, 1973, Bates, 1961]. Due to their poor performance, most of these systems were eventually replaced by PESBS.

EXPERIMENTATION PROCESS

However, there is potential for future development of new passage devices that will safely pass fish at a rate comparable with conventional technology. These new concepts are considered "experimental" until they have been through the process described herein and have been proven in a prototype evaluation validated by NOAA Fisheries. These prototype evaluations should occur over the foreseeable range of adverse hydraulic and water quality conditions (eg. temperature, dissolved oxygen). NOAA Fisheries will not discourage research and development on experimental fish protection devices, but the following elements should be addressed during the process of developing experimental juvenile passage protection concepts:

(1) Consider earlier research. A thorough review of similar methods used in the past should be

performed. Reasons for substandard performances should be clearly identified.

(2) Study plan. A study plan should be developed and presented to NOAA Fisheries for review and concurrence. It is essential that tests occur over a full range of possible hydraulic, biological, and ecological conditions that the device is expected to experience. Failure to receive study plan endorsement from NOAA Fisheries may result in disputable results and conclusions.

(3) Laboratory research. Laboratory experiments under controlled conditions should be developed using species, size, and life stages intended to be protected. For behavioral devices, special attention must be directed at providing favorable hydraulic conditions and demonstrating that the device clearly induces the planned behavioral response. Studies should be repeated with the same test fish to examine any acclimation to the guidance device.

(4) Prototype units. Once laboratory tests show high potential to equal or exceed success rates of conventional passage devices, it is appropriate to further examine the new device as a prototype under real field conditions. Field sites shall be appropriate to (a) demonstrate performance at all expected operational and natural variables, (b) evaluate the species, or an acceptable surrogate, that would be exposed to the device under full operation, and (c) avoid unacceptable risk to depressed or listed stocks at the prototype locations.

(5) Study results. Results of both laboratory tests and field prototype evaluations shall demonstrate a level of performance equal to or exceeding that of conventional fish passage devices before NOAA Fisheries will support permanent installations.

Conclusions

Proven fish passage and protection facilities that have demonstrated high guidance rates at other sites can provide successful passage at most fish passage impediments. Periodically, major initiatives have been advanced to examine the feasibility of experimental passage systems. Results were generally poor or inconclusive, with low guidance efficiencies attributable to the particular device used. Often results were based on a small sample size, or varied with operational conditions. In addition, unforeseen operational and maintenance problems (and safety hazards) were sometimes a byproduct. Nevertheless, some of these passage systems have shown potential for success. To further advance fish protection technology, NOAA Fisheries will not oppose tests that proceed in accordance with the tiered process outlined above. To ensure no further detriment to any fish resource, including delays in implementation of acceptable passage facilities, experimental field testing should occur simultaneous to design and development of conventional passage design for that site. This conventional system should be scheduled for installation in a reasonable time frame, independent of the experimental efforts. In this manner, if the experimental guidance system once again does not prove to be as effective as a PESBS, a proven passage design can be implemented without additional delay and detriment to the resource.

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