Chapter VII. Post Construction Evaluation and Operation and Maintenance Plans

> "Experience is not what happens to you; it's what you do with what happens to you."
>
> *– Aldous Huxley*

Once construction is completed, a new screen may be required to undergo a series of hydraulic and biological tests. These tests will validate facility construction and operating capability, guide refinement of hydraulic operations, and document facility effectiveness. Hydraulic tests will include velocity measurements (magnitude and direction) along the screen face, bypass entrance velocities, and bypass flow performance. Once the fish screen facility is operating as designed, biological tests can be conducted.

The Central Valley Project Improvement Act's Anadromous Fish Screen Program Technical Team proposed Guidelines for Developing Post-Construction Evaluation and Assessment Plans, and Operations and Maintenance Plans (Service, 1999). The team included the following:

- U.S. Fish and Wildlife Service
- Bureau of Reclamation
- NOAA Fisheries
- Natural Resources Conservation Service
- California Departments of Fish and Game and Water Resources

A. Post Construction Evaluation

Each site will have its own unique physical characteristics. However, all essential components of a fish screen structure should be tested to ensure their functionality. The following is a generalized list of evaluation criteria from USFWS, 1999:

a. Mechanical and Electrical equipment – Testing of mechanical and electrical systems should be performed before initiating operations, whenever possible. The Project Manager should be given adequate notice when testing will be performed. Tests should include alarm systems including audible alarms, pagers and other warning systems, automated data recording equipment, emergency shut-off systems, cleaning systems, actuators and solenoids, and other mechanical and electrical systems.

b. Automatic cleaning systems evaluations – Cleaning systems and their components should be tested in the dry, when possible, and again when screen facilities are operable prior to initiating normal operations. Using operations and maintenance documentation provided by the designer and/or fabricator of the cleaning systems, all cleaning systems shall be tested and calibrated by applying the design force to each panel. In cases where testing in situ can cause damage to the screen panel, the trip mechanism should be tested under controlled conditions prior to installation in the facility.

c. Fish entrainment evaluations – Fish entrainment evaluations may be required by the Project Manager, or the fishery regulatory agencies represented on the Program's Technical Team, on a case-by-case basis. If required, tests will be performed by qualified personnel using well established methodologies. Fish entrainment study plans should include equipment and methodologies to be used, duration of testing expected, and frequency of monitoring required.

d. Juvenile fish bypass systems evaluations – Biological and hydraulic testing of juvenile fish bypass systems may be required, where applicable, to ensure the safe return of juvenile fish to the main river channel. When required, the Project Manager, or the above mentioned fishery regulatory representative, will outline an acceptable evaluation process for the specific site. The Guarantee will then use the guidelines provided to prepare a study plan for inclusion in the Evaluation and Assessment Plan. Qualified personnel will use well established methodologies to carry out these evaluations. Expertise from the Program may be available to Grantees for preparing study plans and/or carrying out juvenile fish bypass evaluations.

Study plans may include measuring water velocity profiles at bypass entrances and exits at design bypass flow rates. The study plan should be designed to determine if juvenile fish traveling with the predominant water currents will be guided efficiently into the juvenile bypass system. National Marine Fisheries Service (NMFS) now referred to National Ocean and Atmospheric Administration Department of Fisheries (NOAA Fisheries) fish screen criteria call for bypass entrance velocities to "equal or exceed the maximum velocity vector resultant along the screen, upstream from the entrance."

Study plans may also include biological tests to evaluate the degree of safety provided to juvenile fish depending on the complexity of the bypass system and the size and number of juvenile fish likely to be present during the diversion season. Such biological evaluation would follow the hydraulic testing. The main points of interest in the biological evaluation are (1. fish passing by the screen and (2. fish passing through the bypass structure. Before any biological testing is performed, a study plan should be developed in cooperation with fishery resource agency staff.

e. Fish screen hydraulic evaluations – Hydraulic evaluations involve measuring water velocity values perpendicular (approach velocity) and parallel (sweeping velocity) to the screen face. The velocity measurements are usually performed some 3-inches off the face of the screen which corresponds to established criteria. Deviations from the 3-inch requirement may be necessary for screen designs where the total screen surface is not readily accessible, such as drum screens. Not all fish screens require hydraulic evaluations. Cylindrical screens with the central axis oriented perpendicular to river flows, and some other designs for small diversions, do not require hydraulic evaluations. This is in particular the case for commercially available, prefabricated screens, where design of the hydraulic and velocity distribution control was developed through generalized studies and laboratory investigations. Screens with flow balancing louvers (baffles) must employ hydraulic testing to properly adjust baffle systems to achieve uniform approach velocities across the screen face. Baffle systems must be properly adjusted prior to initiating normal diversion operations.

f. Post-construction retrofit – In the event the Post-Construction Evaluation determines that structural modifications must be made for the screen facility to operate as designed, a list of possible solutions to rectify these problems shall be submitted to the Project Manager along with a schedule for carrying out the preferred method."

In appendix A of the Guidelines for Developing Post-Construction Evaluation and Assessment Plans, and Operations and Maintenance Plans (Service, 1999), a guideline for Developing a Study Plan for Hydraulic Evaluations presents a rather complete template for development of a hydraulic evaluation plan.

A long term operations and maintenance plan needs to be developed as part of any fish screen facility design and construction project. The operations and maintenance plan should serve as an owner's manual for the fish screen facility.

B. Operations and Maintenance Plan

The operations plan should be clearly posted in a highly visible site at any water diversion site where fish screening protection is provided. The list should include instructions for:

- Specific operating procedures to achieve uniform approach flow velocities on the screen face for various diversion rates
- Emergency shut down procedures
- Specific pump use criteria (pumped diversions) and gate use criteria (gravity diversions) needed to achieve uniform approach flow velocities across the screen surface
- Operating instructions for pressure relief valves, auxiliary equipment, and emergency shut down procedures
- Operation guidelines for bypass control to ensure acceptable bypass entrance velocities are maintained when there are variations in downstream canal water surface elevations

Maintenance plans should include the following:

- Recommendations by designers, contractors, and suppliers of equipment used in the fish exclusion facility
- Intervals at which various procedures should be performed
- Documentation provided by suppliers for their products, including specifications and maintenance requirements

C. Periodic Inspections

Guidelines for conducting periodic inspections are given below.

1. Audit Maintenance Records

- Review the operations and maintenance log book for recurring problems
- Compare the logged records with the O&M plan for compliance and troubleshooting

2. Underwater Inspection or Unwatered Inspection, if Possible

- Check for gaps at joints, seals, and seams that could compromise screen efficiency.
- Note accumulation of debris.
- Inspect screen material for damage and material integrity.
- Check screens and structure for corrosion, wear, or other deterioration.
- Check the sacrificial anodes and replace if necessary.
- Check the screen hold-down plates and other protrusions from the screen face for damage and debris accumulation.
- View the cleaning system operation. Intentionally foul the screen with locally available materials, if possible, to view cleaning efficiency.
- Check spray orifices for fouling (water and air spray systems).
- Check screen face for undulations in the screen material that may reduce cleaning efficiency (travel brush systems).
- Check brushes for wear and deterioration (traveling brush systems), readjust or replace as needed.
- Check seals for wear and deterioration.
- Assess the overall efficiency of cleaning system - suggest solutions in inspection report.
- Inspect the moving parts below water surface for corrosion and damage.
- Inspect the channel morphology in the immediate vicinity of the screen for debris, erosion, and sedimentation that may damage screens and their supporting structures or adversely affect the screen operation.

3. Velocity Measurement (if problems warrant)

- Measure approach and sweeping flow velocities along the screen face using approved methods.

- Calculate the diversion rates from measured approach velocity values and compare with the measured diversion rates.

4. Test Backup and Alarm Systems

- Test the pump shutoff.
- Test the blow-out relief panels.
- Test the mechanical brush shutoff system. .
- Test the screen cleaning system operating and failure alarms.
- Test the water level (differential) readouts and alarms.

5. Reporting

- Document the results of periodic inspections in a report submitted to the Project Manager within 30 days of their completion.

- Suggest additions and eliminations to the operation and maintenance plan based on inspection results.

- Recommend corrective actions for ensuring that the diversion will function as designed and as required to satisfy fish screen standards. Corrective actions include repairs to facilities, changes in operation procedures, and changes in setting of baffles and automatic equipment.

Chapter VIII. Exclusion Barriers for Upstream Migrating Fish

> "Adapt or perish, now as ever, is nature's inexorable imperative."
>
> *– H.G. Wells (1866–1946)*

Exclusion barriers are designed to block upstream movement of fish. These barriers are used for a variety of purposes. *Instream* barriers are constructed across a river to block upstream movement of invasive species or guide migratory fish to fishways, count stations, or hatcheries. *Return flow* barriers are designed to exclude fish from man made conveyance channels that return flow to the stream. Return flow barriers are often used to prevent fish entry to tailraces of off channel hydropower facilities, water treatment plant outfalls, or irrigation wasteways.

Most barriers to upstream movement of fish are *velocity barriers* or *physical barriers*. Behavioral barriers (chapter V) including acoustic, light, electric and mixed flow systems have been used experimentally but have not proven to be effective in most cases (EPRI, 1999). A barrier must be designed to function over the expected design range of flow conditions for the site. In the case of anadromous fish, their presence may be seasonal and therefore, the barrier may not be required to function when the target species are not present in the river.

A. Velocity Barriers

Velocity barriers create a combination of flow conditions that restrict a fish's ability to swim and leap into oncoming flow. The advantages and disadvantages of velocity barriers are:

Advantages

- Low maintenance
- Debris passes with the flow
- All species and life stages that are weaker swimmers than the target species are excluded

Disadvantages

- Barriers require significant head

- Performance is dependent on maintaining a minimum head differential across the barrier

- The upstream barrier pool may increase sediment deposits and reduce channel flood flow capacity

The basic requirements of a velocity barrier are:

- the combination of barrier height and length in the flow direction must be sufficient that the target fish can not leap from the downstream face over the barrier

- the flow depth and velocity passing down the barrier (non-vertical barriers) exceeds the fish's ability to swim over the barrier and prevent opportunities for sequential leaps

1. Fish Swimming and Leaping Performance

The swimming speed, endurance, and leaping ability of many migratory fish are well documented. The magnitude of these parameters is influenced by many factors, including: size, age, gender, spawning condition, and water temperature. Therefore, a wide range of swimming and leaping ability is encountered between individual fish and as a result of environmental conditions. Velocity barriers designed to exclude 100 percent of the fish are based on the strongest fish swimming under ideal conditions. If less than 100 percent exclusion is acceptable, barrier design parameters may include coefficients applied to the swimming performance that account for fish conditions typically observed in the field.

The swimming performance of fish is described by three ranges; cruising speed, sustained swimming speed and darting or burst speed. Fish can swim at cruising speeds for long periods, maintain sustained swimming speed for several minutes and dart for several seconds. Bell (1991) presents values for these ranges for a number of fish species. For example, the maximum swimming speed in each range for adult Chinook salmon are given as 4 ft/s (cruising speed), 12 ft/s (sustained speed) and 22 ft/s (burst speed) respectively.

Powers (1985) describes the leap trajectory (height and distance) a fish can achieve by applying the theory of particle trajectory under the influence of gravity. The trajectory of a fish leap is a function of the initial velocity (speed and direction) of the fish as it leaves the water at the initiation of the leap. To estimate the leap trajectory of the strongest fish, the maximum burst speed is used as the initial velocity. Since the main propulsion is created by a fish's tail, the calculated trajectory can be thought of as following the path of the fish's tail with the body of the fish reaching above the estimated trajectory path. The relationship for particle trajectory can be expressed as:

$$y = x \tan\theta - \frac{gx^2}{2V^2 \cos^2 \theta}$$

At its maximum trajectory:

$$y = \frac{V^2 \sin^2 \theta}{2g}$$

where: y = vertical distance
x = horizontal distance
θ = angle of initial trajectory measured from horizontal
g = acceleration of gravity
V = initial velocity

Flow depth significantly affects the swimming and leaping performance of fish. Swimming performance is reduced if the flow depth is less than the depth of the fish. The movement of a fish's body and tail lying above the water can not produce propulsion. Leaping performance is restricted if the pool depth the fish leaves does not allow it to reach maximum burst speed or achieve the necessary leap trajectory. As a rule of thumb, pool depth should be less than the length of the fish to retard its ability to leap.

2. Velocity Barrier Design

The simplest velocity barrier is a weir that creates a vertical free jet. A barrier relying solely on vertical drop requires sufficient differential head across the barrier for all flow and downstream channel conditions for the barrier to function successfully. Fish will often leap in an attempt to pass barriers created by free falling flow. This behavior has been observed in many fish species including species not considered prone to leaping. An example of the leaping capability of healthy Chinook salmon follows. Applying the previous equation and assuming a burst speed of 22 ft/s and a leap trajectory of 80 degrees, a salmon could leap over 7 ft high [$(22)^2 \sin^2 80°/2g = 7.3$ ft]). To exclude fish during high tailwater conditions requires a weir crest elevation about 8 ft above the design high tailwater elevation. To reduce the dependency of barrier height on tailwater elevation, a weir with a shallow sloping downstream apron can be used. The apron is elevated above the high tailwater elevation and therefore maintains a length of shallow high velocity flow immediately downstream from the weir. The apron is designed to require a fish to use its burst speed while shallow flow impedes swimming ability and prevents the fish from leaping from the apron to pass over the weir wall (figure 125). Draft design guidelines and criteria for velocity barriers for anadromous salmonids have been adopted by the United States NOAA Fisheries, attachment A.

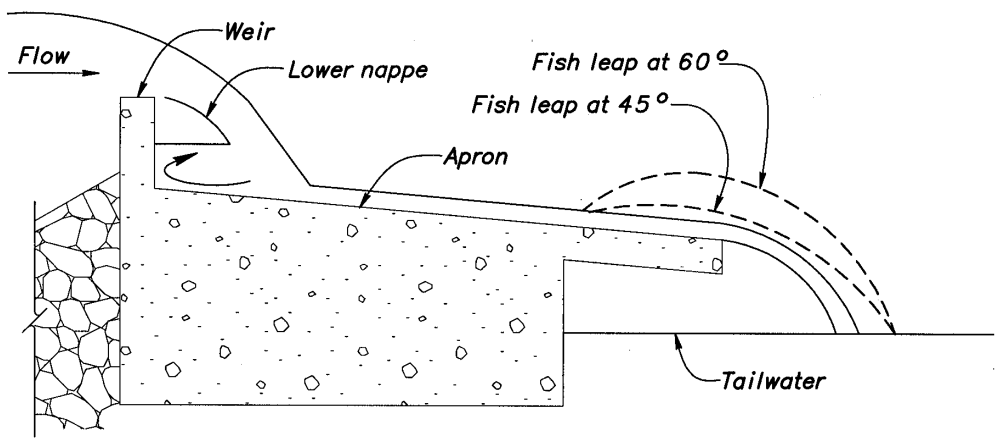

Figure 125.—Schematic of velocity barrier weir.

Consistent with the terminology used throughout the draft 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. Guidelines are not required, but deviation from a guideline require a written explanation by the project designer. NOAA Fisheries suggests that deviation from a guideline be discussed with them prior to final design.

A summary of the major design criteria follows:

- The minimum weir height relative to the maximum apron height shall be 3.5 feet
- The minimum apron length shall be 16 feet
- The minimum downstream apron slope shall be 16:1 (horizontal: vertical)

- The maximum head over the weir shall be 2 feet

- Flow over the weir crest must be fully vented

- The elevation of the downstream apron shall be above the high design flow water surface

If these guidelines and criteria are varied, physical modeling is recommended to ensure the performance of the barrier.

3. Hydraulic Design

Hydraulic design of the weir includes estimating the flow versus depth on the apron, the nappe profile, the impingement zone flow and the nappe aeration requirements.

a. Nappe Profile

The nappe profile for flow over a sharp crested weir was studied by Reclamation for the design of ogee spillways (1987). The lower nappe profile shown on figure 125 can be approximately defined by the equation:

$$\frac{y}{H_0} = -K\left[\frac{x}{H_0}\right]^n$$

where: K and n are constants whose values depend on the slope of the upstream face of the weir and velocity of approach flow,
x and *y* are nappe distances measured relative to the nappe trajectory apex
H_0 = total head on the weir measured relative to the nappe trajectory apex.

For the simplest case of a vertical weir of height greater than 0.5 times the head on the weir, K = 0.5, n = 1.87 and the apex of the nappe lies 0.284 H_0 downstream and 0.127 H_0 above the weir crest. Coefficients for short weirs or inclined weirs can be found in *Reclamation Design of Small Dams* (1987). Other methods to estimate nappe profiles are available. Chow (1959) presents a quadratic form of a sharp crested weir nappe formula based on particle trajectory developed by Blaisdell (1954). Rouse (1950) presents graphical descriptions of nappe profiles for sharp crested weirs, sills, and free overfalls.

b. Nappe Impingment Zone

Downstream from the weir, the nappe impinges on a shallow sloping apron redirecting the flow along the apron. Flow conditions at the impingement zone can be approximated utilizing study results by Moore (1941), White (1942) and Rand (1955) on free overfalls. In figure 126, White (1942) shows a portion of the jet is redirected both upstream and downstream from the impingement. The upstream flow results in an elevated water depth, d_f, between the lower flow nappe and the downstream weir face. Prior to impingement, the jet is shown thickening and slowing as it entrains water passing in front of the backflow pool. The water entrained is equal to the upstream flow dispersed by the impingement. By continuity, the downstream flow must be equal to the flow passing over the upstream weir. Flow moving downstream on the apron transitions toward normal depth based on the apron slope and roughness. White shows the velocity of the downstream jet is given by the equation:

$$V_d = \frac{V}{2}(1 + \cos\theta)$$

where: V_d = velocity of downstream flow
V = velocity of flow prior to impingement
θ = upstream angle between the nappe centerline and the apron surface

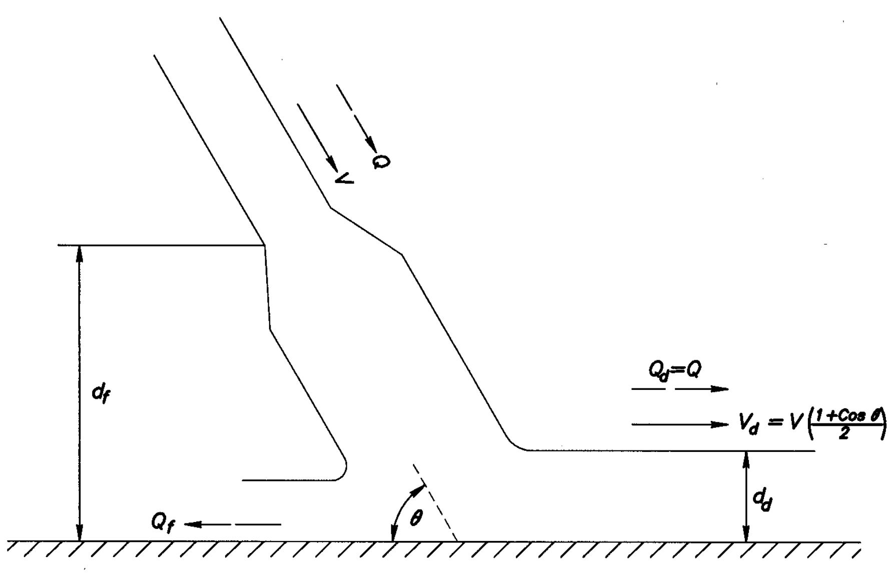

Figure 126.—Inclined jet impinging on a horizontal surface (White, 1942).

The flow velocity prior to impingement is estimated using the total upstream energy as:

$$V = \sqrt{2g\left(h + h_f\right)}$$

where: g = acceleration of gravity
h = head on the weir
h_f = distance from the weir crest to the apron

The depth of flow downstream from the impingement zone (d_d) is determined by the unit discharge divided by the downstream velocity $(q/V_{d.})$.

The depth of the backwater pool on an apron of shallow slope behind an aerated jet is estimated using the drop number developed by Rand (1955) for a free jet impinging on a horizontal surface. The drop number (D) is a dimensionless number defined as:

$$D = \frac{q^2}{g h_f^{\,3}}$$

The backwater pool depth (d_f) is approximately:

$$d_f = h_f D^{0.22}$$

c. Nappe Aeration

The lower flow nappe downstream from a barrier weir must spring free of the weir crest forming an air cavity between the lower nappe and the downstream weir wall. Stability of the air cavity depends on a continuous supply of air from above the flow to beneath the nappe at a rate equal to the air entrained and transmitted downstream by the flow. If insufficient air is available to the cavity, pressure below the nappe will decrease and suppress the flow nappe toward the weir wall. A sufficiently suppressed nappe increases the opportunity for fish passage over the weir through a reduction in the size of the air cavity and an increase in the strength of the backflow. Boss (1990) presents a relationship for estimating the air demand beneath the nappe per unit length of weir as:

$$\frac{q_{air}}{q_w} = \frac{0.1}{\left(d_f / h\right)^{1.5}}$$

where: q_{air} = unit discharge of air, $ft^3/s/ft$
q_w = unit discharge of water over the weir, $ft^3/s/ft$

Air may be drawn beneath the flow nappe by several paths. Thin flow nappes often breakup quickly as the water falls allowing air to pass through the nappe. Flow nappes that remain coherent over the length of the drop require access points where air is drawn into the air cavity under the flow nappe. Contracted weirs or weirs with the end walls that form a sudden expansion downstream from the weir can provide direct venting from the ends. Access for air across the length of the nappe can be attained downstream from crest piers that extend above the water surface and cause the flow to separate. If the structure geometry does not provide sufficient access for air to reach the lower nappe, venting can be achieved by installing air vent pipes. Vent pipes are commonly run through the structure endwalls and then daylight above the ground surface. Ideally, vent pipes should be sized sufficiently large to provide a fully aerated nappe. A fully aerated nappe was found by Hickox (1944) to occur when the ratio of pressure beneath the nappe (*p, ft of water*) to head on the weir (*p/h)* is less than about 0.01. This can result in large air vents for many barrier designs. Until data is available to identify allowable nappe suppression for barriers, it is suggested air vent designs use a *p/h* ratio of 0.05 to 0.1. The air vent can then be sized following standard hydraulic methods as:

$$p = \frac{1}{830}\left[\sum Losses\right]\frac{V_a^2}{2g}$$

where: p = pressure beneath the nappe, ft of water
Losses = loss coefficients for vent geometry and friction
V_a = Vent air velocity, ft/s
g = acceleration of gravity, ft/s^2
(1/830 = ratio of density of air to density of water)

4. Examples of Velocity Barriers

a. Coleman National Fish Hatchery Barrier

A photograph of the Coleman National Fish Hatchery Barrier located near Redding, California is shown in figure 127. The barrier constructed in 1992 by the U.S. Fish and Wildlife Service blocks salmon from moving upstream and guides them to a bypass where fish are taken for hatchery spawning. The barrier has a 2 ft high weir with a 15:1 downstream sloping apron, 14 ft in length.

Figure 127.—Fish barrier weir at Coleman National Fish Hatchery, Battle Creek, California.

Monitoring of the barrier has revealed approximately 5 to 10 percent of the Chinook salmon that reach the barrier are able to pass when the weir flow depth is between 1 to 1.5 feet. The 5 to 10 percent barrier passage is likely due to intermittent nappe suppression caused by insufficient venting of the flow nappe. Video records clearly show fish using the suppressed nappe condition to pass the barrier weir. The barrier weir is being modified to improve performance by improving air venting and mounting a 2-ft-wide-horizontal plate on the weir crest to form a cantilevered lip extending downstream over the apron **(**figure 128).

b. Walterville Tailrace Barrier

The Waterville tailrace barrier was designed by MWH Engineering for Eugene Water and Electric Board, Eugene, Oregon (2005). The barrier is located about 1,300 ft off the McKenzie River in the Waterville tailrace channel near river mile 21. The velocity barrier replaced an existing rack barrier. A section through the barrier is shown in figure 129. The velocity barrier was first operated in 2003. The barrier has a 3.5 ft high weir with an adjustable crest and a 16-ft-long apron sloping at 16:1. The weir is 250 ft long and is set at a 30 degree angle to the tailrace channel. At the upstream terminus of the barrier a bypass channel leads

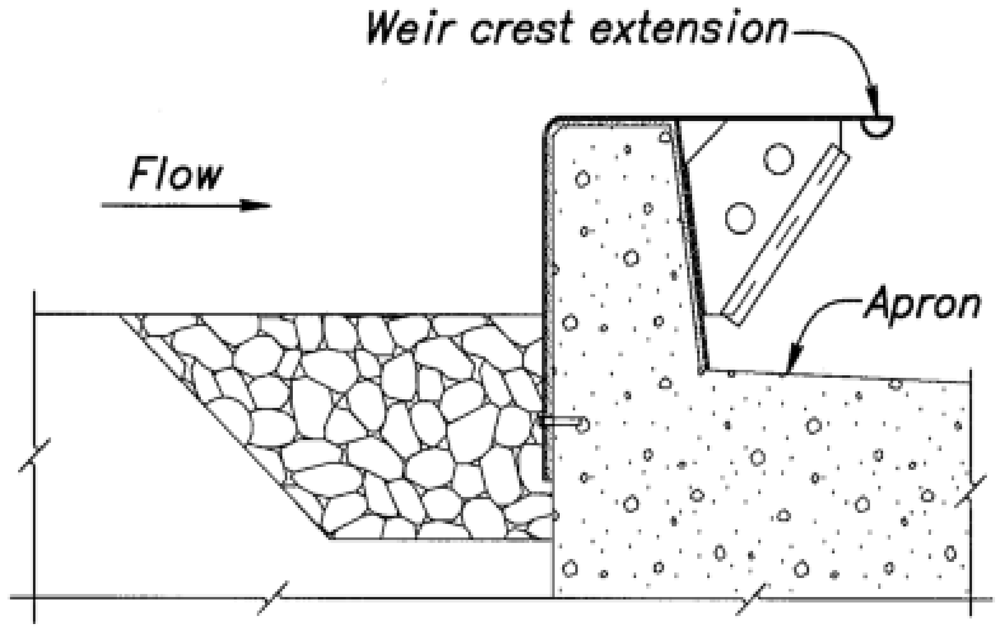

Figure 128.—Weir crest extension applied to the Coleman National Fish Hatchery barrier weir.

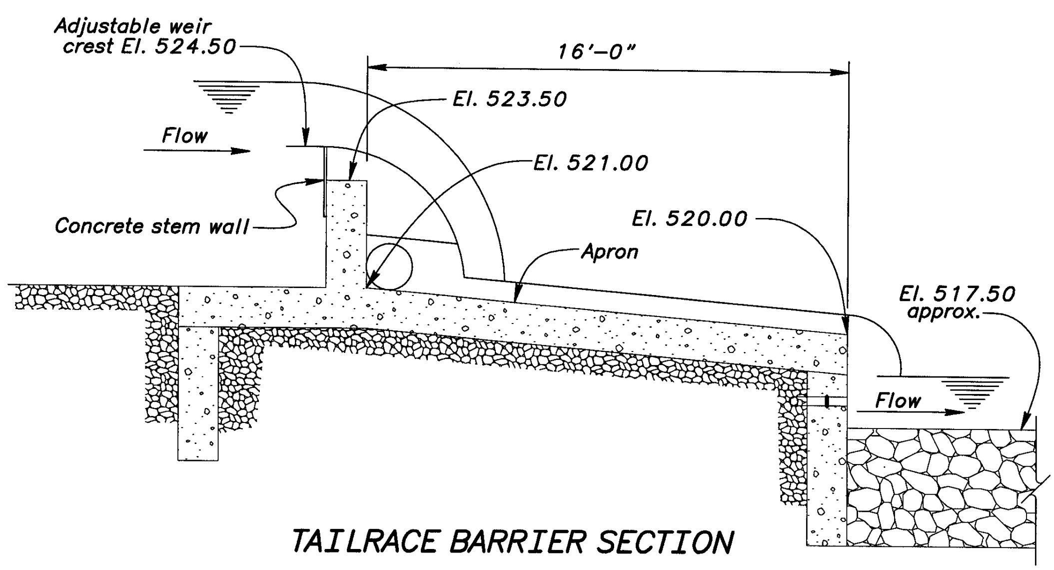

Figure 129.—Walterville tailrace velocity barrier weir, McKenzie River, Oregon. (Eugene Water and Electric Board).

fish back to the river. Some Chinook salmon were observed passing the barrier during the first year of operation. It was determined the weir was not sufficiently vented. Modifications were made to the weir vent system which has improved fish exclusion to nearly 100 percent.

B. Physical Barriers

Physical barriers (picket barriers) to upstream passage are typically flow-through structures designed to exclude fish using closely spaced bars also referred to as pickets. Physical barriers may be permanent structures with cleaning devices, seasonal structures with or without cleaning devices or temporary structures. Where no cleaning device is provided, periodic hand raking and cleaning is typically performed. Temporary physical barriers are used for guiding fish to traps or counting stations and to control fish movement during in-river construction. The advantages and disadvantages of physical barriers are:

Advantages

- Low head loss under clean and partially plugged conditions.
- Functions over a wide range of river stage.
- Barriers can be designed to be installed and removed seasonally, if not required.

Disadvantages

- Physical barriers only exclude fish larger than the bar spacing.
- Bar racks require periodic cleaning and are subject to rapid plugging if exposed to high flow events that transport large debris.

1. Physical Barrier Design

Physical barrier bar racks designed to exclude upstream migrating fish are similar in concept to intake trashracks. The main differences are:

- The bar spacing is designed to prevent adult fish passage.
- Fish are swimming into the flow downstream from the bar rack.
- If the barrier is to provide fish guidance, the entire structure is typically aligned at an angle to the main channel flow.

Draft design guidelines and criteria for bar rack barriers for adult anadromous salmonids have been adopted by the United States NOAA Fisheries, attachment A. A summary of the major design criteria follows:

- The maximum clear opening between the bars (pickets) is 1 inch.
- Bars shall be flat bars aligned with flow or round tubes aligned in the vertical direction.
- The rack shall have a minimum of 40 percent open area.
- The average design velocity passing the rack should not exceed 1 ft/s for all design flows with a maximum local velocity of 1.25 ft/s or half the velocity of the adjacent river flow which ever is less. Velocity is based on the gross submerged area of the bar rack.
- Bar racks shall be designed to lead fish to a safe passage route by angling the barrier to the safe passage route and providing sufficient attraction flows from the safe passage as to minimize false attraction to the bar rack flow.
- The maximum headloss across the bar rack should be 0.3 ft during operation. The rack should be cleaned if higher headlosses occur.
- The rack shall extend at least 2 ft above the maximum design water elevation.
- A minimum depth of 2 ft shall be maintained at the barrier for at least 10 percent of the river cross section at the barrier.
- A uniform concrete sill should be provided.
- Bar racks shall be structurally designed to withstand high stream flows.

For fish species other than adult anadromous salmonids, consideration of fish size and behavior should be reviewed before applying the NOAA criteria for bar rack design.

2. Examples of Bar Racks

a. Nimbus Dam

A removable bar rack has been used for many years on the American River, near Sacramento, California to prevent Chinook salmon from reaching Nimbus Dam (figure 130). The bar rack spans the river and guides upstream migrating salmon to the Nimbus Fish Hatchery. The rack has been an effective fish barrier but is now scheduled for replacement due to continued problems with debris accumulation on the rack during high flow events.

b. Leaburg Tailrace

The Leaburg tailrace barrier located on the McKenzie River at river mile 33 is an example of an off-river bar rack style tailrace barrier (figure 131). The barrier was designed by MWH Engineering for Eugene Water and Electric Board, Eugene, Oregon (2003). The barrier is designed for 2,500 ft^3/s flow from the power station. The structure is 250 ft long and sets at the confluence of the river and the tailrace. The barrier is aligned approximately parallel to the river to provide a strong guidance current along the rack. The rack has 50 panels that can be lowered during the non-migration period.

Figure 130.—Nimbus Dam bar rack barrier, American River, near Sacramento, California. (Nimbus Fish Hatchery).

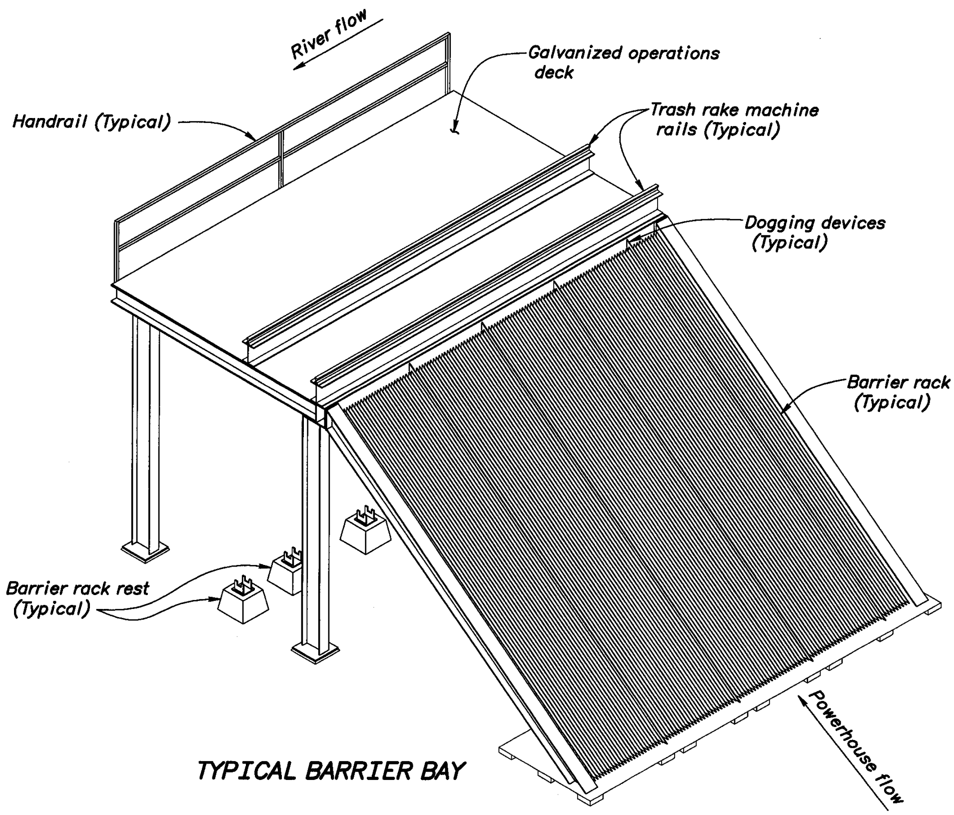

Figure 131.—Leaburg bar rack tailrace barrier McKenzie River Oregon. (Eugene Water and Electric Board).

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Glossary

Active Screens – Juvenile fish screens equipped with a cleaning system with proven capability 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.

Affect and effect – To affect (a verb) is to bring about a change (“The proposed action is likely to adversely affect piping plovers nesting on the shoreline”). The effect (usually a noun) is the result (“The proposed highway is likely to have the following effects on the Florida scrub jay”). “Affect” appears throughout the Environmental Species Act, Section 7 regulations and documents in the phrases “may affect” and “likely to adversely affect.” “Effect” appears throughout Section 7 regulations and documents in the phrases “adverse effects,” “beneficial effects,” “effects of the action,” and “no effect.” From ESA Section 7 Consultation Handbook, March 1998

Approach Velocity – The flow velocity perpendicular to and approximately 3 inches in front of the screen face, V_a.

Anadromous Fish – Fish that are born in freshwater streams and lakes and migrate as juveniles to saltwater to grow and mature and return as adults to fresh water to spawn.

Behavioral Devices – Requires a decision, response, or reaction (volitional taxis) on the part of the fish to avoid entrainment.

Benthic Species – Orient themselves based on tactile mechanisms. They concentrate along stream margins or in other suitable velocity zones and exhibit high threshold velocities and low critical velocities.

Biological Assessment – Information prepared by, or under the direction of, a Federal agency to determine whether a proposed action is likely to: (1) adversely affect listed species or designated critical habitat, (2) jeopardize the continued existence of species that are proposed for listing, or (3) adversely modified proposed critical habitat. Biological assessments must be prepared for “major construction activities.” See 50 CFR Par402.02. The outcome of this biological assessment determines whether formal consultation or a conference is necessary. [CFR par 402.02, 50 CFR Par 402.12] from ESA Section 7 Consultation Handbook, March 1998.

Biological Opinion – A document that includes: (1) the opinion of the Fish and Wildlife Service or NOAA Fisheries as to whether or not a Federal action is likely to jeopardize the continued existence of listed species, or result in the destruction or adverse modification of designated critical habitat; (2) a summary of the information on which the opinion is based; and (3) a detailed discussion of the effects of the action on listed species or designated critical habitat. [50 CFR Par 402.02, 50 CFR Par 402.14(h)] from ESA Section 7 Consultation Handbook, March 1998.

Bypass Entrance Velocity, V_b – Flow velocity at the bypass entrance.

Bypass Flow , Q_b – The diverted flow required to effectively attract fish into the bypass entrance(s) and convey fish to the bypass outfall location or other destination.

Bypass Ratio, V_b / V_c – Ratio of the flow velocity at the bypass entrance to the channel velocity.

Candidate Species – Animal taxa considered for possible addition to the List of Endangered and Threatened species.

Channel Velocity, V_c – Flow velocity approaching a fish protection screen or louver. It is made up of the approach velocity vector, V_a, and sweeping velocity vector Vs, (figure 37).

Colorado Squawfish – Now called Colorado Pikeminnow, Ptychocheilw lucius.

Critical Habitat – For listed species consists of: (1) the specific areas within the geographical area occupied by the species, at the time it is listed in accordance with the provisions of Section 4 of the Endangered Species Act, on which are found those physical or biological features (constituent elements) (a) essential to the conservation of the species and (b) which may require special management considerations or protection; and (2) specific areas outside the geographical area occupied by the species at the time it is listed in accordance with the provision of Section 4 of the Act, upon a determination by the Secretary that such areas are essential for the conservation of the species. [ESA Par 3 (5)(A)] Designated critical habitats are described in 50 CFR Par 17 and 226. From ESA Section 7 Consultation Handbook, March 1998.

Cruising Speed – A swimming speed that fish can maintain for long periods of time (hours).

Darting/Burst Speed – A swimming speed that fish can achieve in a single effort but cannot maintain.

Delisted – Removing a fish species from being “listed” as “Threatened” or “Endangered”.

Diurnal – Active in the daytime

Diversion Losses – Includes power, irrigation, municipal, and other potential fish losses associated with the use of water by man.

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 screen.

Endangered Fish Species – Species determined by U.S. Fish and Wildlife Service or NOAA Fisheries, under the Endangered Species Act, to be in imminent danger of extinction throughout all or a significant portion of their range are listed as "endangered."

Energy Dissipation Factor (EDF) – The measurement of energy in a bypass downwell to assist in providing enough water volume in the downwell to dissipate the energy entering the downwell and to limit turbulence and circulation patterns that may trap debris and/or fish.

Entrainment – The unwanted passage of fish through a water diversion.

Environmental Assessment – Addresses impacts of development on listed fish species and species proposed for listing.

Exclusion Barriers – Velocity or physical barrier (picket barrier) built to minimize the attraction and stop the migration of upstream migrating fish.

Exotic fish – Any species not naturally occurring, either currently or historically, in an ecosystem.

Fish Habitat – A place where fish can find the physical, chemical, and biological features needed for life, including suitable water quality, passage routes, spawning grounds, feeding and resting sites, and shelter from predators.

Fingerling – Fish greater than 60 mm in length (approximately size of a human finger).

Formal Consultation – A process between the services (resource agencies) and a Federal agency or applicant that: (1) determines whether a proposed Federal action is likely to jeopardize the continued existence of a listed species or destroy or adversely modify designated critical habitat, (2) begins with a Federal agency's written request and submittal of a complete information package, and (3) concludes with the issuance of a biological opinion and incidental take statement by either of the Services. If a proposed Federal action may affect a listed species or designated critical habitat, formal consultation is required. From ESA Section 7 Consultation Handbook, March 1998.

Fry – Fish generally between 25 and 60 mm in length.

Head Differential – The water pressure difference across the surface of a screen, trashrack, or louver. Usually measured in inches of water.

Incidental Take – Take of listed fish or wildlife species identified under ESA that results from, but is not the purpose of, carrying out an otherwise lawful activity conducted by a Federal agency or applicant.

Informal Consultation – An optional process that includes all discussions and correspondence between the U.S. Fish and Wildlife Service (resource agency) and a Federal agency or designated non-Federal representative to determine whether a proposed Federal action may affect listed species or critical habitat. This process occurs before formal consultation and allows the Federal agency to use the U.S. Fish and Wildlife Services' expertise to evaluate the agency's assessment of potential effects or to suggest possible modifications to the proposed action which could avoid potential adverse effects. From ESA Section 7 Consultation Handbook, March 1998.

Impingement – Physical contact of fish with a structure occurs when the fish is not able to avoid contact with a screen surface, trashrack, or debris at the intake.

Jeopardize the Continued Existence of – To engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species. [50 CFR Par 402.02] From ESA Section 7 Consultation Handbook, March 1998.

Larval Stage – Fish less than 25 mm in length.

Listed Fish Species – The authority to list species as threatened or endangered is shared by NOAA Fisheries (formerly National Marine Fisheries Service (NMFS)), which is responsible for listing most marine species, and the U.S. Fish and Wildlife Service (Service), which administers the listing of all other plants and animals. There are two classifications under which a species may be listed: "threatened" or "endangered."

Native Fish Species – Any species that naturally occurred within a given body of water, as opposed to an introduced species.

Native Fish or Riverine Fish – Freshwater species that use rivers or lakes as residence for their entire life. They cannot tolerate long-term exposure to salt water.

Passive Screens – Juvenile fish screens with no automated cleaning system.

Pelagic Species – Visual mechanism is dominant in determining orientation. Distribute themselves fairly uniformly in the flow and locate themselves in the upper portion of the water column.

Picket Barrier – A flow barrier that diffuses the entire streamflow made up of flat bars or round columns placed such that the clear opening between pickets is not more than 1-inch to provide a physical barrier for upstream migrating fish.

Post Larval – Fish greater than 1.0 inch (25 mm) long.

Predation – Occurs when fish are preyed upon by aquatic or avian animals.

Screen Porosity – The ratio of open area to total area of the screen.

Screen Area – The open slots and perforations in the screen that provide for free flow of water through the screen.

Smolt – Young anadromous fish as their bodies change (physiological) from the fry/fingerling stage and prepare for life in sea water.

Species – Includes any subspecies of fish or wildlife or plants, and any distinct population segment of any species or vertebrate fish or wildlife that interbreeds when mature. [ESA Par 3(16)]

Sustained/Maximum – A fish swimming speed that fish can maintain for minutes.

Sweeping Velocity – The average flow velocity parallel to and adjacent to the screen face, V_s.

Take – The ESA prohibits the taking of any listed species of fish or wildlife by any person, "...to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt to engage in any such conduct"- [ESA Par 3(19)].

Through-slot Velocity, V_t – The flow velocity passing through the screen slot openings (suggested not to exceed 0.5 ft/s for submerged cylindrical screens).

Trapping Velocity – Also referred to as capture velocity. It is the velocity needed to "trap" or "capture" the specific fish species and prevent it from returning up a bypass pipe at a fish screen facility.

Threatened Fish Species – Species determined likely to become endangered in the foreseeable future are listed as "threatened."

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Attachment A – Fish Screen Criteria

The users of this manual should verify the criteria published herein with the latest fish resource agencies draft criteria before advancing into the predesign and final design phases of a fish protection project.

1. Screen Criteria For Juvenile Salmonids (NMFS – Northwest Region 1995)

Juvenile Salmonid Fish Screen Criteria – NMFS
February 16, 1995

NMFS Web site
<http://www.nwr.noaa.gov/1salmon/salmesa/pubs/nmfscrit.pdf>

A. Structure Placement

1. Streams and Rivers

a. Where physically practical and biologically desirable, the screen shall be constructed at the diversion entrance 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 from the screen. If trash racks are used, sufficient hydraulic gradient is required to route juvenile fish from between the trash rack and screens to safety.

b. Where installation of fish screens at the diversion entrance is not desirable or impractical, the screens may be installed in the canal downstream from the entrance at a suitable location. All screens installed downstream from the diversion entrance shall be provided with an effective bypass system approved by NMFS, designed to collect juvenile fish and safely transport them back to the river with minimum delay. The angle of the screen to flow should be adequate to effectively guide fish to the bypass (see Section F, Bypass Layout).

2. Lakes, Reservoirs and Tidal areas

a. Intakes shall be located offshore where feasible to minimize fish contact with the facility. Water velocity from any direction toward the screen shall not exceed allowable approach velocities (see Section B, Approach Velocity). When possible, intakes shall be located in areas with sufficient sweeping velocity to minimize sediment accumulation in or around the screen and to facilitate debris removal and fish movement away from the screen face (see Section C, Sweeping Velocity).

b. If a screened intake is used to route fish past a dam, 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 from the project. The entire range of forebay fluctuation shall be accommodated in design, unless otherwise approved by the NMFS.

B. Approach Velocity

Approach velocity is the water velocity component perpendicular to and approximately three inches in front of the screen face.

1. Salmonid fry [less than 2.36 inches {60.0 millimeters (mm)} in length]: The approach velocity shall not exceed 0.40 ft/s {0.12 m/s}.

2. Salmonid fingerling {2.36 inches (60.0 mm) and longer): The approach velocity shall not exceed 0.80 f/s (0.24 m/s).

3. The total submerged screen area required (excluding area affected by structural components) is calculated by dividing the maximum diverted flow by the allowable approach velocity (also see Section K, Modified Criteria for Small Screens).

4. The screen design must provide for uniform flow distribution over the screen surface, thereby minimizing approach velocity. This may be accomplished by providing adjustable porosity control on the downstream side of screens, unless it can be shown unequivocally (such as with a physical hydraulic model study) that localized areas of high velocity can be avoided at all flows.

C. Sweeping Velocity - Definition

Sweeping velocity is the water velocity component parallel and adjacent to the screen face Sweeping velocity shall be greater than the approach velocity. This is accomplished by angling the screen face at less than 45 degrees relative to flow (also see Section K, Modified Criteria for Small Screens). This angle may be dictated by site specific canal geometry, hydraulic, and sediment conditions.

D. Screen Material Characteristics

1. Fry criteria - If biological justification can not be provided to demonstrate the absence of fry-sized salmonids (less than 2.36 inches (60.0 mm)} in the vicinity of the diversion intake leading to the screen, fry will be assumed present and the following criteria apply for screen material:

    a. Perforated plate: Screen openings shall not exceed 3/32 or 0.0938 inches (2.38 mm).

    b. Profile bar screen: The narrowest dimension in the screen openings shall not exceed 0.0689 Inches (1.75 mm) in the narrow direction.

    c. Woven wire screen: Screen openings shall not exceed 3/32 or 0.0938 inches (2.38 mm) in the narrow direction (example: 6-14 mesh).

    d. Screen material shall provide a minimum of 27% open area.

2. Fingerling criteria - If biological justification can be provided to demonstrate the absence of fry-sized salmonids {less than 2.36 inches (60.0 mm)} in the vicinity of the diversion intake leading to the screen, the following criteria apply for screen material:

    a. Perforated plate: Screen openings shall not exceed 1/4 or 0.25 inches (6.35 mm).

    b. Profile bar screen: The narrowest dimension in the screen openings shall not exceed 1/4 or 0.25 inches (6.35 mm) in the narrow direction.

    c. Woven wire screen: Screen openings shall not exceed 1/4 or 0.25 inches (6.35 mm) in the narrow direction.

    d. Screen material shall provide a minimum of 40% open area.

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

E. Civil works and Structural Features

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.

2. Structural features shall be provided to protect the integrity of the fish screens from large debris. Provision of a trash rack, log boom, sediment sluice, and other measures may be needed. A reliable, ongoing preventative maintenance and repair program is necessary to assure facilities are kept free of debris and that screen mesh, seals, drive units, and other components are functioning correctly.

3. Screen surfaces shall be constructed at an angle to the approaching flow, with the downstream end of the screen terminating at the entrance to the bypass system.

4. The civil works shall be designed in a manner that eliminates undesirable hydraulic effects (such as eddies and stagnant flow zones) that may delay or injure fish or provide predator habitat or predator access. Upstream training wall(s), or some acceptable variation thereof, shall be utilized to control hydraulic conditions and define the angle of flow to the screen face. Large facilities may require hydraulic modeling to identify and correct areas of concern.

F. Bypass Layout

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 placed in diversions shall be constructed with the downstream end of the screen terminating at a bypass entrance. Multiple bypass entrances (intermediate bypasses) shall be employed if the sweeping velocity will not move fish to the bypass within 60 seconds, assuming fish are transported at this velocity.

2. 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.

3. 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 (see Section F, Bypass Layout, Part 1).

4. 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 allow for all but a reduced residual bypass flow to be routed back (by pump or gravity) for the primary diversion use. The residual bypass flow (not passing through the secondary screen) would then convey fish to the bypass outfall location or other destination.

5. Access is required at locations in the bypass system where debris accumulations may occur.

6. The screen civil works floor shall be designed to allow fish to be routed back to the river safely, if the canal is dewatered. This may entail a sumped drain with a small gate and drain pipe, or similar provisions.

G. Bypass Entrance

1. Each bypass entrance shall be provided with independent flow-control capability, acceptable to NMFS.

2. The minimum bypass entrance flow velocity must be greater than or equal to the maximum flow velocity vector resultant upstream from the screens. A gradual and efficient acceleration of flow into the bypass entrance is required to minimize delay by out-migrants.

3. Ambient lighting conditions are required at, and inside of, the bypass entrance and should extend downstream to the bypass flow control.

4. The bypass entrance must extend from the floor to the canal water surface.

H. Bypass Conduit Design

1. Bypass pipes shall have smooth surfaces and be designed to provide conditions that minimize turbulence. Bypass conduits shall have a smooth joint design to minimize turbulence and the potential for fish injury and shall be satisfactory to the NMFS.

2. Fish shall not be pumped within the bypass system.

3. Fish shall not be allowed to free-fall within a confined shaft in a bypass system.

4. Pressures in the bypass pipe shall be equal to or above atmospheric pressures.

5. Bends shall be avoided in the layout of bypass pipes due to the potential for debris clogging. Bypass pipe center-line radius of curvature (R/D) shall be greater than or equal to 5. Greater R/D may be required for super-critical velocities.

6. Bypass pipes or open channels shall be designed to minimize debris clogging and sediment deposition and to facilitate cleaning as necessary. Therefore, the required pipe diameter shall be greater than or equal to 24 inches {0.610 meters (m)}, and pipe velocity shall he greater than 2.0 fps (0.6 10 mps), unless otherwise approved by the NMFS, for the entire operational range (also see Section K, Modified Criteria for Small Screens, Part 4).

7. Closure valves of any type are not allowed within the bypass pipe, unless approved by NMFS.

8. The minimum depth of open-channel flow in a bypass conduit shall be greater than or equal to 0.75 ft (0.23 m), unless otherwise approved by the NMFS (also see Section K, Modified Criteria for Small Screens, Part 5).

9. Sampling facilities installed in the bypass conduit shall not impair normal operation of the facility.

10. The bypass pipe hydraulics should not produce a hydraulic jump within the pipe.

I. Bypass Outfall

1. Bypass outfalls should be located such that ambient river velocities are greater than 4.0 f/s (1.2 m/s).

2. Bypass outfalls shall be located to minimize avian and aquatic predation in areas free of eddies, reverse flow, or known predator habitat.

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.

4. Maximum bypass outfall impact velocity (including vertical and horizontal velocity components) shall be less than 25.0 fps (7.6 mps).

5. The bypass outfall discharge into tailrace shall be designed to avoid adult attraction or jumping injuries

J. Operations and Maintenance Requirements

1. Fish screens shall be automatically cleaned as frequently as necessary to prevent accumulation of debris. The cleaning system and protocol must be effective, reliable, and satisfactory to the NMFS. Proven cleaning technologies are preferred.

2. Open channel 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.

3. The head differential to trigger screen cleaning for intermittent type cleaning systems shall be a maximum of 0.1 ft (0.03 m) or as agreed to by the NMFS.

4. The completed screen and bypass facility shall be made available for inspection by NMFS, to verify compliance with the design and operational criteria.

5. Screen and bypass facilities shall be evaluated for biological effectiveness and to verify that hydraulic design objectives are achieved.

K. Modified Criteria for Small Screens (Diversion flow less than 25 CFS)

The following criteria vary from the criteria listed above and apply to smaller screens. Twenty-five CFS is an approximate cutoff; however, some smaller diversions may be required to apply more universal criteria listed above, while some larger diversions may be allowed to use the “small screen criteria. listed below. This will depend on site constraints.

1. The screen area required is shown in Section B, Approach Velocity, Parts 1,2 and 3. Note that “maximum” applies to the greatest flow diverted, not necessarily the water right

2. Screen orientation:

    a. For screen lengths less than or equal to 4 ft, screen orientation may be angled or perpendicular relative to flow.

b. For screen lengths greater than 4 ft, screen-to-flow angles must be less than or equal to 45 degrees (see Section C, Sweeping Velocity, Part 1).

c. For drum screens, the design submergence shall be 75% of drum diameter. Submergence shall not exceed 85%, nor be less than 65% of drum diameter.

3. The minimum bypass pipe diameter shall be 10 inches, unless otherwise approved by NMFS.

4. The minimum allowable pipe depth is 0.15 ft (1.8 inches or 4.6 cm) and is controlled by designing the pipe gradient for minimum bypass flow.

2. Juvenile Fish Screen Criteria For Pump Intakes (NMFS – Northwest Region – 1996)

Developed by
National Marine Fisheries Service
Environmental & Technical Services Division
Portland, Oregon
May 9, 1996

<http://www.nwr.noaa.gov/1hydrop/pumpcrit1.htm>

The following criteria serve as an addendum to current National Marine Fisheries Service gravity intake juvenile fish screen criteria. These criteria apply to new pump intake screens and existing inadequate pump intake screens, as determined by fisheries agencies with project jurisdiction.

Definitions Used in Pump Intake Screen Criteria

Pump intake screens are defined as screening devices attached directly to a pressurized diversion intake pipe. Effective screen area is calculated by subtracting screen area occluded by structural members from the total screen area. Screen mesh opening is the narrowest opening in screen mesh. Approach velocity is the calculated velocity component perpendicular to the screen face. Sweeping velocity is the flow velocity component parallel to the screen face with the pump turned off.

Active pump intake screens are equipped with a cleaning system with proven cleaning capability, and are cleaned as frequently as necessary to keep the screens clean. Passive pump intake screens have no cleaning system and should only be used when the debris load is expected to be low, and

(1) if a small screen (less than 1 CFS pump) is over-sized to eliminate debris impingement, and

(2) where sufficient sweeping velocity exists to eliminate debris build-up on the screen surface, and

(3) if the maximum diverted flow is less than .01% of the total minimum streamflow, or

(4) the intake is deep in a reservoir, away from the shoreline.

Pump Intake Screen Flow Criteria

The minimum effective screen area in square ft for an active pump intake screen is calculated by dividing the maximum flow rate in cubic ft per second (CFS) by an approach velocity of 0.4 ft per second (FPS). The minimum effective screen area in square ft for a passive pump intake screen is calculated by dividing the maximum flow rate in CFS by an approach velocity of 0.2 FPS. Certain site conditions may allow for a waiver of the 0.2 FPS approach velocity criteria and allow a passive screen to be installed using 0.4 FPS as design criteria. These cases will be considered on a site-by-site basis by the fisheries agencies.

If fry-sized salmonids (i.e. less than 60 millimeter fork length) are not ever present at the site and larger juvenile salmonids are present (as determined by agency biologists), approach velocity shall not exceed 0.8 FPS for active pump intake screens, or 0.4 FPS for passive pump intake screens. The allowable flow should be distributed to achieve uniform approach velocity (plus or minus 10%) over the entire screen area. Additional screen area or flow baffling may be required to account for designs with non-uniform approach velocity.

Pump Intake Screen Mesh Material

Screen mesh openings shall not exceed 3/32 inch (2.38 mm) for woven wire or perforated plate screens, or 0.0689 inch (1.75 mm) for profile wire screens, with a minimum 27% open area. If fry-sized salmonids are never present at the site (by determination of agency biologists) screen mesh openings shall not exceed 1/4 inch (6.35 mm) for woven wire, perforated plate screens, or profile wire screens, with a minimum of 40% open area.

Screen mesh material and support structure shall work in tandem to be sufficiently durable to withstand the rigors of the installation site. No gaps greater than 3/32 inch shall exist in any type screen mesh or at points of mesh attachment. Special mesh materials that inhibit aquatic growth may be required at some sites.

Pump Intake Screen Location

When possible, pump intake screens shall be placed in locations with sufficient sweeping velocity to sweep away debris removed from the screen face. Pump intake 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 adjacent natural or constructed features. 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 considered, placed in the channel or at the edge of the river. Intakes in reservoirs should be as deep as practical, to reduce the numbers of juvenile salmonids that approach the intake. Adverse alterations to riverine habitat shall be minimized.

Pump Intake Screen Protection

Pump intake screens shall be protected from heavy debris, icing and other conditions that may compromise screen integrity. Protection can be provided by using log booms, trash racks or mechanisms for removing the intake from the river during adverse conditions. An inspection and maintenance plan for the pump intake screen is required, to ensure that the screen is operating as designed per these criteria.

3. National Marine Fisheries Service Southwest Region Fish Screening Criteria (1997) for Anadromous Salmonids

January 1997
Southwest Region

<http://www.nwr.noaa.gov/1salmon/salmesa/pubs/swrscrng.pdf>

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Fish Screening Criteria for Anadromous Salmonids [1]
National Marine Fisheries Service

I. General Considerations

This document provides guidelines and criteria for functional designs of downstream migrant fish passage facilities at hydroelectric, irrigation, and other water withdrawal projects. It is promulgated by the National Marine Fisheries Service (NMFS), Southwest Region as a result of its authority and responsibility for prescribing fishways under the Endangered Species Act (ESA), the Federal Power Act, administered by the Federal Energy Regulatory Commission (FERC), and the Fish and Wildlife Coordination Act (FWCA), administered by the U.S. Fish & Wildlife Service.

The guidelines and criteria are general in nature. There may be cases where site constraints or extenuating circumstances dictate a waiver or modification of one or more of these criteria. Conversely, where there is an opportunity to protect fish, site-specific criteria may be added. Variances from established criteria will be considered on a project-by-project basis. The swimming ability of fish is a primary consideration in designing a fish screen facility. Research shows that swimming ability varies depending on multiple factors relating to fish physiology, biology, and the aquatic environment. These factors include: species, physiological development, duration of swimming time required, behavioral aspects, physical condition, water quality, temperature, lighting conditions, and many others. Since conditions affecting swimming ability are variable and complex, screen criteria must be expressed in general terms and the specifics of any screen design must address on-site conditions.

NMFS may require project sponsors to investigate site-specific variables critical to the fish screen system design. This investigation may include fish behavioral response to hydraulic conditions, weather conditions (ice, wind, flooding, etc.), river stage-discharge relationships, seasonal operations, sediment and debris problems, resident fish populations, potential for creating predation opportunity, and other pertinent information. The size of 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 over a number of years. NMFS will normally assume that fry-sized salmonids are present at all sites unless adequate biological investigation proves otherwise. The burden of proof is the responsibility of the owner of the screen facility.

[1] Adapted from NMFS, Northwest Region

New facilities which propose to utilize unproven fish protection technology frequently require:

(1) development of a biological basis for the concept;

(2) demonstration of favorable behavioral responses in a laboratory setting;

(3) an acceptable plan for evaluating the prototype installation;

(4) an acceptable alternate plan should the prototype not adequately protect fish.

Additional information can be found in Experimental Fish Guidance Devices, position statement of the National Marine Fisheries Service, Southwest Region, January 1994.

Striped Bass, Herring, Shad, Cyprinids, and other anadromous fish species may have eggs and/or very small fry which are moved with any water current (tides, streamflows, etc.). Installations where these species are present may require individual evaluation of the proposed project using more conservative screening requirements. In instances where state or local regulatory agencies require more stringent screen criteria to protect species other than salmonids, NMFS will generally defer to the more conservative criteria.

General screen criteria and procedural guidelines are provided below. Specific exceptions to these criteria occur in the design of small screen systems (less than 40 cubic ft per second) and certain small pump intakes. These exceptions are listed in Section K, Modified Criteria for Small Screens, and in the separate addendum entitled: Juvenile Fish Screen Criteria For Pump Intakes, National Marine Fisheries Service, Portland, Oregon, May 9, 1996.

II. General Procedural Guidelines

For projects where NMFS has jurisdiction, such as FERC license applications and ESA consultations, a functional design must be developed as part of the application or consultation. These designs must reflect NMFS design criteria and be acceptable to NMFS. Acceptable designs typically define type, location, method of operation, and other important characteristics of the fish screen facility. Design drawings should show structural dimensions in plan, elevation, and crosssectional views, along with important component details. Hydraulic information should include: hydraulic capacity, expected water surface elevations, and flows through various areas of the structures. Documentation of relevant hydrologic information is required. Types of materials must be identified where they will directly affect fish. A plan for operations and maintenance procedures should be included- i.e., preventive and corrective maintenance procedures, inspections and reporting requirements, maintenance logs, etc.- particularly with respect to debris, screen cleaning, and sedimentation issues. The final detailed design shall be based on the functional design, unless changes are agreed to by NMFS.

All juvenile passage facilities shall be designed to function properly through the full range of hydraulic conditions expected at a particular project site during fish migration periods, and shall account for debris and sedimentation conditions which may occur.

III. Screen Criteria for Juvenile Salmonids

A. Structure Placement

1. General:

The screened intake shall be designed to withdraw water from the most appropriate elevation, considering juvenile fish attraction, appropriate water temperature control downstream or a combination thereof. The design must accommodate the expected range of water surface elevations. For on-river screens, it is preferable to keep the fish in the main channel rather than put them through intermediate screen bypasses. NMFS decides whether to require intermediate bypasses for on-river, straight profile screens by considering the biological and hydraulic conditions existing at each individual project site.

2. Streams and Rivers:

Where physically practical, the screen shall be constructed at the diversion entrance. The screen face should be generally parallel to river flow and aligned with the adjacent bankline. A smooth transition between the bankline and the screen structure is important to minimize eddies and undesirable flow patterns in the vicinity of the screen. If trash racks are used, sufficient hydraulic gradient is required to route juvenile fish from between the trashrack and screens to safety. 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. Large stream-side installations may require intermediate bypasses along the screen face to prevent excessive exposure time. The need for intermediate bypasses shall be decided on a case-by-case basis.

3. Canals:

Where installation of fish screens at the diversion entrance is undesirable or impractical, the screens may be installed at a suitable location downstream from the canal entrance. All screens downstream from the diversion entrance shall provide an effective juvenile bypass system- designed to collect juvenile fish and safely transport them back to the river with minimum delay. The angle of the screen to flow should be adequate to effectively guide fish to the bypass. Juvenile bypass systems are part of the overall screen system and must be accepted by NMFS.

4. Lakes, Reservoirs, and Tidal Areas:

a. Where possible, intakes should be located off shore to minimize fish contact with the facility. Water velocity from any direction toward the screen shall not exceed the allowable approach velocity. Where possible, locate intakes where sufficient sweeping velocity exists. This minimizes sediment accumulation in and around the screen, facilitates debris removal, and encourages fish movement away from the screen face.

b. If a screened intake is used to route fish past a dam, the intake shall be designed to withdraw water from the most appropriate elevation in order to provide the best juvenile fish attraction to the bypass channel as well as to achieve appropriate water temperature control downstream. The entire range of forebay fluctuations shall be accommodated by the design, unless otherwise approved by NMFS.

B. Approach Velocity

Definition: *Approach Velocity* is the water velocity vector component perpendicular to the screen face. Approach velocity shall be measured approximately three inches in front of the screen surface.

1. Fry Criteria - less than 2.36 inches {60 millimeters (mm)} in length.

If a biological justification cannot demonstrate the absence of fry-sized salmonids in the vicinity of the screen, fry will be assumed present and the following criteria apply:

Design approach velocity shall not exceed-

Streams and Rivers: 0.33 ft per second
Canals: 0.40 ft per second
Lakes, Reservoirs, Tidal: 0.33 ft per second (salmonids) [2]

2. Fingerling Criteria - 2.36 inches {60 mm} and longer

If biological justification can demonstrate the absence of fry-sized salmonids in the vicinity of the screen, the following criteria apply:

Design approach velocity shall not exceed -

All locations: 0.8 ft per second

3. The *total submerged screen area required* (excluding area of structural components) is calculated by dividing the maximum diverted flow by the allowable approach velocity. (Also see Section K, Modified Criteria for Small Screens, part 1).

4. The screen design must provide for uniform flow distribution over the surface of the screen, thereby minimizing approach velocity. This may be accomplished by providing adjustable porosity control on the downstream side of the screens, unless it can be shown unequivocally (such as with a physical hydraulic model study) that localized areas of high velocity can be avoided at all flows.

C. Sweeping Velocity

Definition: *Sweeping Velocity* is the water velocity vector component parallel and adjacent to the screen face.

1. Sweeping Velocity shall be greater than approach velocity. For canal installations, this is accomplished by angling screen face less than 45 degrees relative to flow (see Section K, Modified Criteria for Small Screens). This angle may be dictated by specific canal geometry, or hydraulic and sediment conditions.

[2] Other species may require different approach velocity standards, e.g.- in California, the U.S. Fish & Wildlife Service requires 0.2 fps approach velocity where delta smelt are present in the tidal areas of the San Francisco Bay estuary.

D. Screen Face Material

1. Fry criteria

If a biological justification cannot demonstrate the absence of fry-sized salmonids in the vicinity of the screen, fry will be assumed present and the following criteria apply for screen material:

a. Perforated plate: screen openings shall not exceed 3/32 inches (2.38 mm), measured in diameter.

b. Profile bar: screen openings shall not exceed 0.0689 inches (1.75 mm) in width.

c. Woven wire: screen openings shall not exceed 3/32 inches (2.38 mm), measured diagonally. (e.g.: 6-14 mesh)

d. Screen material shall provide a minimum of 27% open area.

2. Fingerling Criteria

If biological justification can demonstrate the absence of fry-sized salmonids in the vicinity of the screen, the following criteria apply for screen material:

a. Perforated plate: Screen openings shall not exceed 1/4 inch (6.35 mm) in diameter.

b. Profile bar: screen openings shall not exceed 1/4 inch (6.35 mm) in width

c. Woven wire: Screen openings shall not exceed 1/4 inch (6.35 mm) in the narrow direction

d. Screen material shall provide a minimum of 40% open area.

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

E. Civil Works and Structural Features

1. The face of all screen surfaces shall be placed flush with any adjacent screen bay, pier noses, and walls, allowing fish unimpeded movement parallel to the screen face and ready access to bypass routes.

2. Structural features shall be provided to protect the integrity of the fish screens from large debris. Trash racks, log booms, sediment sluices, or other measures may be needed. A reliable on-going preventive maintenance and repair program is necessary to ensure facilities are kept free of debris and the screen mesh, seals, drive units, and other components are functioning correctly.

3. Screens located in canals - surfaces shall be constructed at an angle to the approaching flow, with the downstream end terminating at the bypass system entrance.

4. The civil works design shall attempt to eliminate undesirable hydraulic effects (e.g.- eddies, stagnant flow zones) that may delay or injure fish, or provide predator opportunities. Upstream training wall(s), or some acceptable variation thereof, shall be utilized to control hydraulic conditions and define the angle of flow to the screen face. Large facilities may require hydraulic monitoring to identify and correct areas of concern.

F. Juvenile Bypass System Layout

Juvenile bypass systems are water channels which transport juvenile fish from the face of a screen to a relatively safe location in the main migratory route of the river or stream. Juvenile bypass systems are necessary for screens located in canals because anadromous fish must be routed back to their main migratory route. For other screen locations and configurations, NMFS accepts the option which, in its judgement, provides the highest degree of fish protection given existing site and project constraints.

1. The screen and bypass shall work in tandem to move out-migrating salmonids (including adults) to the bypass outfall with minimum injury or delay. Bypass entrance(s) shall be designed such that out-migrants can easily locate and enter them. Screens installed in canal diversions shall be constructed with the downstream end of the screen terminating at a bypass entrance. Multiple bypass entrances (intermediate bypasses) shall be employed if the sweeping velocity will not move fish to the bypass within 60 seconds [3] assuming the fish are transported at this velocity. Exceptions will be made for sites without satisfactory hydraulic conditions, or for screens built on river banks with satisfactory river conditions.

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[3] In California, 60 second exposure time applies to screens in canals, using a 0.4 fps approach velocity. Where more conservative approach velocities are used, longer exposure times may be approved on a case-by-case basis, and exceptions to established criteria shall be treated as variances.

2. All components of the bypass system, from entrance to outfall, shall be of sufficient hydraulic capacity to minimize the potential for debris blockage.

3. To improve bypass collection efficiency for a single bank of vertically oriented screens, a bypass training wall may be located at an angle to the screens.

4. In cases where insufficient flow is available to satisfy hydraulic requirements at the main bypass entrance(s), a secondary screen may be required. Located in the main screen's bypass channel, a secondary screen allows the prescribed bypass flow to be used to effectively attract fish into the bypass entrance(s) while allowing all but a reduced residual bypass flow to be routed back (by pump or gravity) for the primary diversion use. The residual bypass flow (not passing through the secondary screen) then conveys fish to the bypass outfall location or other destination.

5. Access is required at locations in the bypass system where debris accumulation may occur.

6. The screen civil works floor shall allow fish to be routed to the river safely in the event the canal is dewatered. This may entail a sumped drain with a small gate and drain pipe, or similar provisions.

G. Bypass Entrance

1. Each bypass entrance shall be provided with independent flow control, acceptable to NMFS.

2. Bypass entrance velocity must equal or exceed the maximum velocity vector resultant along the screen, upstream from the entrance. A gradual and efficient acceleration into the bypass is required to minimize delay of out-migrants.

3. Ambient lighting conditions are required from the bypass entrance to the bypass flow control.

4. The bypass entrance must extend from floor to water surface.

H. Bypass Conduit Design

1. Smooth interior pipe surfaces and conduit joints shall be required to minimize turbulence, debris accumulation, and the risk of injury to juvenile fish. Surface smoothness must be acceptable to the NMFS.

2. Fish shall not free-fall within a confined shaft in a bypass system.

3. Fish shall not be pumped within the bypass system.

4. Pressure in the bypass pipe shall be equal to or above atmospheric pressure.

5. Extreme bends shall be avoided in the pipe layout to avoid excessive physical contact between small fish and hard surfaces and to minimize debris clogging . Bypass pipe centerline radius of curvature (R/D) shall be 5 or greater. Greater R/D may be required for super-critical velocities.

6. Bypass pipes or open channels shall be designed to minimize debris clogging and sediment deposition and to facilitate cleaning. Pipe diameter shall be 24 inches (0.610 m) or greater and pipe velocity shall be 2.0 fps (0.610 mps) or greater, unless otherwise approved by NMFS. (See Modified Criteria for Small Screens) for the entire operational range.

7. No closure valves are allowed within bypass pipes.

8. Depth of flow in a bypass conduit shall be 0.75 ft. (0.23 m) or greater, unless otherwise authorized by NMFS (See *Modified Criteria for Small Screens*).

9. Bypass system sampling stations shall not impair normal operation of the screen facility.

10. No hydraulic jumps should exist within the bypass system.

I. Bypass Outfall

1. Ambient river velocities at bypass outfalls should be greater than 4.0 fps (1.2 mps), or as close as obtainable.

2. Bypass outfalls shall be located and designed to minimize avian and aquatic predation in areas free of eddies, reverse flow, or known predator habitat.

3. Bypass outfalls shall be located where there is sufficient depth (depending on the impact velocity and quantity of bypass flow) to avoid fish injuries at all river and bypass flows.

4. Impact velocity (including vertical and horizontal components) shall not exceed 25.0 fps (7.6 mps).

5. Bypass outfall discharges shall be designed to avoid adult attraction or jumping injuries.

J. Operations and Maintenance

1. Fish Screens shall be automatically cleaned as frequently as necessary to prevent accumulation of debris. The cleaning system and protocol must be effective, reliable, and satisfactory to NMFS. Proven cleaning technologies are preferred.

2. Open channel 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.

3. The head differential to trigger screen cleaning for intermittent type systems shall be a maximum of 0.1 ft (.03 m), unless otherwise agreed to by NMFS.

4. The completed screen and bypass facility shall be made available for inspection by NMFS, to verify compliance with design and operational criteria.

5. Screen and bypass facilities shall be evaluated for biological effectiveness and to verify that hydraulic design objectives are achieved.

K. Modified Criteria for Small Screens (Diversion Flow less than 40 cfs)

The following criteria vary from the standard screen criteria listed above. These criteria specifically apply to lower flow, surface-oriented screens (e.g.- small rotating drum screens). Forty cfs is the approximate cut off; however, some smaller diversions may be required to apply the general criteria listed above, while some larger diversions may be allowed to use the “small screen” criteria below. NMFS will decide on a case-by-case basis depending on site constraints.

1. The required screen area is a function of the approach velocity listed in Section B, Approach Velocity, Parts 1, 2, and 3 above. Note that “maximum” refers to the greatest flow diverted, not necessarily the water right.

2. Screen Orientation:

   a. For screen lengths six ft or less, screen orientation may be angled perpendicular to the flow.

b. For screen lengths greater than six ft, screen-to-flow angle must be less than 45 degrees. (See Section C Sweeping Velocity, part 1).

c. For drum screens, design submergence shall be 75% of drum diameter. Submergence shall not exceed 85%, nor be less than 65% of drum diameter.

d. Minimum bypass pipe diameter shall be 10 in (25.4 cm), unless otherwise approved by NMFS.

e. Minimum pipe depth is 1.8 in (4.6 cm) and is controlled by designing the pipe gradient for minimum bypass flow.

Questions concerning this document can be directed to NMFS Hydraulic Engineering Staff at:

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4. National Marine Fisheries Service Southwest Region – Experimental Fish Guidance Devices

Experimental Fish Guidance Devices - 1994
Position Statement of
National Marine Fisheries Service
Southwest Region
January 1994

<http://swr.ucsd.edu/hcd/expert.htm>

NMFS Southwest Region Position Paper on Experimental Technology for Managing Downstream Salmonid Passage

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Introduction

Numerous stocks of salmon and steelhead trout in California streams are at low levels and many stocks continue to decline. The Sacramento River winter-run chinook salmon is listed as “endangered” under the Federal Endangered Species Act. Petitions for additional listings are pending. It is essential to provide maximum protection for juveniles to halt and reverse these declines.

The injury or death of juvenile fish at water diversion intakes have long been identified as a major source of fish mortality [Spencer 1928, Hatton 1939, Hallock and Woert 1959, Hallock 1987]. Fish diverted into power turbines experience up to 40 percent mortality as well as injury, disorientation, and delay of migration [Bell, 1991], while those entrained into agricultural and municipal water diversions experience 100 percent mortality. Diversion mortality is the major cause of decline in some fish populations.

Positive barrier screens have long been tested and used to prevent or reduce the loss of fish. Recent decades have seen an increase in the use and effectiveness of these screens and bypass systems; they take advantage of carefully designed hydraulic conditions and known fish behavior. These positive systems are successful at moving juvenile salmonids past intakes with a minimum of delay, loss or injury.

The past few decades have also seen much effort in developing “startle” systems to elicit a taxis (response) by the fish with an ultimate goal of reducing entrainment. This Position Statement addresses research designed to prevent fish losses at diversions and presents a tiered process for studying, reviewing, and implementing future fish protection measures.

Juveniles at Intakes

The three main causes of delay, injury, and loss of fish at water intakes are entrainment, impingement, and predation. Entrainment occurs when the fish is pulled into the diversion and passes into a canal or turbine. Impingement is where a fish comes in contact with a screen, a trashrack, or debris at the intake. This causes bruising, descaling, and other injuries. Impingement, if prolonged, repeated, or occurs at high velocities also causes direct mortality. Predation also occurs. Intakes increase predation by stressing or disorienting fish and/or by providing habitat for fish and bird predators.

A. Positive Barriers

Positive barrier screen systems and criteria for their design have been developed, tested, and proved to minimize harm caused at diversions. Positive barriers do not rely on active fish behavior; they prevent physical entrainment with a physical barrier. Screens with small openings and good seals are designed to work with hydraulic conditions at the site, providing low velocities normal to the screen face and sufficient sweeping velocities to move fish past the screen. These screens are very effective at preventing entrainment [Pearce and Lee 1991]. Carefully designed bypass systems minimize fish exposure to screens and provide hydraulic conditions that return fish to the river, preventing both entrainment and impingement [Rainey 1985]. The positive screen and fish bypass systems are designed to minimize predation, and to reduce mortality, stress, and delay from the point of diversion, through the bypass facility, and back the river.

Carefully designed positive barrier screen and bypass systems have been installed and evaluated at numerous facilities [Abernethy et al 1989, 1990, Rainey, 1990, Johnson, 1988]. A variety of screen types (e.g. flat plate, chevron, drum) and screen materials (e.g. woven cloth, perforated plate, profile wire), have proved effective, taking into consideration their appropriateness for each site. Well-designed facilities consistently result in a guidance efficiency of over 95 percent [Hosey, 1990, Neitzel, 1985, 1986, 1990 a,b,c,d, Neitzel, 1991].

The main drawback to positive barrier screens is cost. At diversions of several hundred cubic ft per second or greater, the low velocity requirement and structural complexity can drive the cost for fish protection and the associated civil works over a million dollars. At the headwork, the need to clean the screen, remove trash, and provide regular maintenance (e.g. seasonal installation, replacing seals, etc.) also increase costs.

B. Behavioral Devices

Due to higher costs of positive barrier screens, there has been much experimentation since 1960 to develop behavioral devices as a substitute for barrier screens [EPRI, 1986]. A behavioral device, as opposed to a positive (physical) barrier, requires a volitional taxis on the part of the fish to avoid entrainment. Early efforts were designed to either attract or repel fish. These studies focused on soliciting a behavioral response from the fish, usually noticeable agitation. Using these startle investigations to develop effective fish guidance systems has not been effective.

Experiments show that there is a large response variation between individual fish of the same size and species. Therefore, it cannot be predicted that a fish will always move toward or away from a certain stimulus. Even when such a movement is desired by a fish, it often cannot discern the source or direction of the signal and choose a safe escape route.

Many behavioral devices do not incorporate and use a controlled set of hydraulic conditions to assure fish guidance, as does the positive screen/bypass system. The devices can actually encourage fish movement that actually contrasts with the expected rheotactic response. Thus, the fish gets mixed signals about what direction to move. Another concern is repeated exposure; a fish may no longer react to a signal that initially was an attractant or repellant. In addition to the vagaries in the response of an individual fish, behavior variations are expected due to size, species, life stage, and water quality conditions.

In strong or accelerating water velocity fields, the swimming ability of a fish may prevent it from responding to a stimulus even if it attempts to do so. Other environmental cues (e.g., pursuing prey, avoiding predators, or attractive habitat) may cause a fish to ignore the signal.

A main motivation for opting to install behavioral devices is cost-savings. However, much of the cost in conventional systems is for the physical structure needed to provide proper hydraulic conditions. Paradoxically, complementing a behavioral device with its own structural requirements may lessen much of its cost advantage.

Present skepticism over behavioral devices is supported by the fact that few are currently being used in the field and those that have been installed and evaluated seldom exhibit consistent guidance efficiencies above 60 percent [Vogel, 1988, EPRI, 1986]. The louver system is an example of a behavioral device with a poor success record. In this case, even with the use of favorable hydraulics, performance is poor especially for smaller fish. Entrainment can be high, particularly when operated over a wide range of hydraulic conditions [Vogel, 1988, Cramer, 1982, Bates, 1961]. Due to their poor performance, some of these systems are already replaced by positive barriers.

Experimentation Process

However, there is potential for developing new positive screens as well as behavioral guidance devices for the future. Nonetheless, experimental technology must achieve, over the foreseeable range of adverse conditions, a consistent level of success that equals or exceeds that of best available technology. It should be a deliberate, logical process. NMFS will not discourage research and development on experimental fish protection devices if the following tiered study process is incorporated:

(1) Consider earlier research. A thorough review should be performed of past methods similar to that proposed. Reasons for substandard performances of these earlier methods should be clearly identified.

(2) Study plan. A study plan should be developed and presented to NMFS 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.

(3) Laboratory research. Controlled laboratory experiments should be developed using species, size, and life stages intended to be protected (or acceptable surrogate species). For behavioral devices, special attention must be directed at providing favorable hydraulic conditions and demonstrating that the device clearly causes the planned behavioral response. Studies should be repeated with the same test fish to examine any habituation to the stimulus.

(4) Prototype units. Once laboratory tests show high potential to equal or exceed success rates of state-of-the-art screening, it is appropriate to further examine the new device as a prototype under real field conditions. Field sites must be fully appropriate to (1) demonstrate all operational and natural variables expected to influence the device performance, (2) evaluate the species, or an acceptable surrogate, that would be exposed to the device under full operation, and (3) avoid unacceptable risk to resources at the prototype locations.

(5) Study results. Results of both laboratory tests and prototype devices examined in the field must demonstrate a level of performance equal to or exceeding that of conventional, established technology before NMFS will support further installations.

Conclusions

In the course of the past few decades, we have seen increased demand for water diversions. This trend is likely to continue. Accompanying this demand is a corresponding decline of fisheries. Therefore, prudence dictates that fish protection facilities be held to the highest practicable level of performance.

A major effort was made to examine experimental guidance systems over several decades by a variety of funding agencies. The 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, unforseen operational and maintenance problems, including safety hazards, sometimes developed.

Nevertheless, some of these experiments show potential. To further improve fish protection technology, NMFS will not oppose tests that proceed in the tiered process outlined above. Further, to ensure no further detriment to fish, experimental field testing should be done with the simultaneous design of a positive barrier and bypass system for that site. This conventional system should be scheduled for installation immediately, if the experimental guidance system, once again, does not prove to be as effective as a conventional system.

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5. State of Washington Screening Requirements For Water Diversions

<http://wdfw.wa.gov/hab/engineer/fishscrn.htm>

Washington State Laws (RCW 77.16.220; RCW 77.55.040 (formerly RCW 75.20.040), RCW (formerly RCW 75.20.061)) require all diversions from waters of the state to be screened to protect fish. These laws and the following design criteria are essential for the protection of fish at surface water diversions. Fish drawn into hydropower, irrigation, water supply, and other diversions are usually lost from the fish resources of the state of Washington.

The following criteria are based on the philosophy of physically excluding fish from being entrained in water diverted without becoming impinged on the diversion screen. The approach velocity and screen mesh opening criteria are based upon the swimming stamina of emergent size fry in low water temperature conditions. It is recognized that there may be locations at which design for these conditions may not be warranted. Unless conclusive data from studies acceptable to Washington Department of Fish and Wildlife indicate otherwise, it is assumed that these extreme conditions exist at some time of the year at all screen sites.

Additional criteria may be required for unique situations, large facilities or intakes within marine waters.

I. Screen Location and Orientation

a. Fish screens in rivers and streams shall be constructed within the flowing stream at the point of diversion and parallel to the streamflow. The screen face shall be continuous with the adjacent bankline. A smooth transition between the screen and bankline shall be provided to prevent eddies in front, upstream and downstream from the screen.

   Where it can be thoroughly demonstrated that flow characteristics or site conditions make construction or operation of fish screens at the diversion entrance impractical, the screens may be installed in the canal downstream from the diversion.

b. Diversion intakes in lakes and reservoirs shall be located offshore in deep water to minimize the exposure of juvenile fish to the screen. Salmon and trout fry generally inhabit shallow water areas near shore.

c. Screens constructed in canals and ditches shall be located as close as practical to the diversion. They shall be oriented so the angle between the face of the screen and the approaching flow is no more than 45 degrees. All screens constructed downstream from the diversion shall be provided with an efficient bypass system.

II. Approach Velocity

The approach velocity is defined as the component of the local water velocity vector perpendicular to the face of the screen. Juvenile fish must be able to swim at a speed equal or greater than the approach velocity for an extended length of time to avoid impingement on the screen. The following approach velocity criteria are <u>maximum</u> velocities that shall not be exceeded anywhere on the face of the screen. A maximum approach velocity of 0.4 ft per second is allowed.

The approach velocity is calculated based on the gross screen area not the net open area of the screen mesh.

The intake structure and/or fish screen shall be designed to assure that the diverted flow is uniformly distributed through the screen so the maximum approach velocity is not exceeded.

III. Minimum Screen Area

The minimum required screen area is determined by dividing the maximum diverted flow by the maximum allowable approach velocity. To find the screen area in square ft, divide the diverted flow in cubic ft per second (450 gpm = 1.0 cubic ft per second) by the approach velocity 0.4 ft per second):

$$\text{Minimum Screen Area} = \frac{\text{Diverted Flow (ft}^3\text{/s)}}{\text{Approach Velocity (ft/s)}}$$

The minimum required screen area must be submerged during lowest streamflows and may not include any area that is blocked by screen guides or structural members.

Diversions less than or equal to 180 gallons/minute (0.4 cfs) require a minimum submerged screen area of 1.0 square ft, which is the smallest practical screening device.

IV. Sweeping Velocity

The sweeping velocity is defined as the component of the water velocity vector parallel to and immediately upstream from the screen surface. The sweeping velocity shall equal or exceed the maximum allowable approach velocity. The sweeping velocity requirement is satisfied by a combination of proper orientation (angle of screen 45 degrees to the approaching flow) of the screen relative to the approaching flow and adequate bypass flow.

Screen bay piers or walls adjacent to the screen face shall be flush with screen surfaces so the sweeping velocity is not impeded.

V. Screen Mesh Size, Shape, and Type of Material

Screen openings may be round, square, rectangular, or any combination thereof, provided structural integrity and cleaning operations are not impaired.

Screen mesh criteria is based on the assumption that steelhead and/or resident trout fry are ubiquitous in the state of Washington and will be present at all diversion sites.

Following are the maximum screen openings allowable for emergent salmonid fry. The maximum opening applies to the entire screen structure including the screen mesh, guides, and seals. The profile bar criteria is applied to the narrow dimension of rectangular slots or mesh.

Woven Wire Mesh	Profile Bar	Perforated Plate
0.087 inch	1.75 mm (0.069 inch)	0.094 inch
(6-14 mesh)		(3/32 inch)

The allowable woven wire mesh openings is the greatest open space distance between mesh wires. An example allowable mesh specifications is provided; there are other standard allowable openings available. The mesh specification gives the number of mesh openings per lineal inch followed by the gauge of the wires. For example, 6-14 mesh has six mesh openings per inch of screen. It is constructed with 6, 14-gauge (0.080 inch diameter) wires per inch.

The profile bar openings are the maximum allowable space between bars. The allowable perforated plate openings are the diameter of circular perforations. Perforated slots are treated as profile bars.

Screens may be constructed of any durable material; woven, welded, or perforated. The screen material must be resistant to corrosion and ultraviolet damage.

For longevity and durability, minimum wire diameter for woven mesh shall be 0.060 inch (18 gauge) on fixed panel screens, where they are not subjected to impact of debris. Minimum wire diameter for woven mesh shall be 0.080 inch

(14 gauge) for rotary drum screens, traveling belt screens, and in areas where there is a potential for damage from floating debris or cleaning operations.

VI. Bypass

All screens constructed downstream from the diversion shall be provided with an efficient bypass system to rapidly collect juvenile fish and safely transport them back to the river. The downstream end of the screen shall terminate at the entrance to the bypass system. It is the water diversion owner's responsibility to obtain necessary water rights to operate the fish bypass; failure to do so may be considered failure to meet state screening law requirements.

VII. Cleaning

Fish screens shall be cleaned as frequently as necessary to prevent obstruction of flow and violation of the approach velocity criterion. Automatic cleaning devices will be required on large screen facilities.

Additional detailed information is available explaining the background and justification of these criteria and showing standard details of flow distributors, acceptable bypass designs, and screen areas required for various flows.

For further information contact:

Wash. Dept. of Fish and Wildlife
3705 W. Washington Ave.
Yakima, WA 98903-1137
(509) 575-2734 Fax: 454-4139

Wash. Dept. of Fish and Wildlife
600 Capitol Way North
Olympia, WA 98501-1091
(360) 902-2545 Fax: 902-2946

6. State of California Department of Fish and Game – Fish Screening Criteria – June 19, 2000

<http://www.dfg.ca.gov/nafwb/fishscreencriteria.html>

1. Structure Placement

A. Streams And Rivers (flowing water):

The screen face shall be parallel to the flow and adjacent bankline (water's edge), with the screen face at or streamward of a line defined by the annual low-flow water's edge.

The upstream and downstream transitions to the screen structure shall be designed and constructed to match the back-line, minimizing eddies upstream from, in front of and downstream from, the screen.

Where feasible, this “on-stream” fish screen structure placement is preferred by the California Department of Fish and Game.

B. In Canals (flowing water):

The screen structure shall be located as close to the river source as practical, in an effort to minimize the approach channel length and the fish return bypass length. This “in canal” fish screen location shall only be used where an “on-stream” screen design is not feasible. This situation is most common at existing diversion dams with headgate structures.

The National Marine Fisheries Service - Southwest Region “Fish Screening Criteria for Anadromous Salmonids, January 1997" for these types of installations shall be used.

C. Small Pumped Diversions:

Small pumped diversions (less than 40 cubic ft per second) which are screened using “manufactured, self-contained” screens shall conform to the National Marine Fisheries Service - Southwest Region “Fish Screening Criteria for Anadromous Salmonids, January 1997".

D. Non-Flowing Waters (tidal areas, lakes and reservoirs):

The preferred location for the diversion intake structure shall be offshore, in deep water, to minimize fish contact with the diversion. Other configurations will be considered as exceptions to the screening criteria as described in Section 5.F. below.

2. Approach Velocity (local velocity component perpendicular to the screen face)

A. Flow Uniformity:

The design of the screen shall distribute the approach velocity uniformly across the face of the screen. Provisions shall be made in the design of the screen to allow for adjustment of flow patterns. The intent is to ensure uniform flow distribution through the entire face of the screen as it is constructed and operated.

B. Self-Cleaning Screens: The design approach velocity shall not exceed:

1. Streams And Rivers (flowing waters) - Either:

   a. 0.33 ft per second, where exposure to the fish screen shall not exceed fifteen minutes, or

   b. 0.40 ft per second, for small (less than 40 cubic ft per second) pumped diversions using “manufactured, self-contained” screens.

2. In Canals (flowing waters) - 0.40 ft per second, with a bypass entrance located every one-minute of travel time along the screen face.

3. Non-Flowing Waters (tidal areas, lakes and reservoirs) - The specific screen approach velocity shall be determined for each installation, based on the species and life stage of fish being protected. Velocities which exceed those described above will require a variance to these criteria (see Section 5.F. below).

(Note: At this time, the U.S. Fish and Wildlife Service has selected a 0.2 ft per second approach velocity for use in waters where the Delta smelt is found. Thus, fish screens in the Sacramento-San Joaquin Estuary should use this criterion for design purposes.)

C. Screens Which are not Self-Cleaning:

The screens shall be designed with an approach velocity one-fourth that outlined in Section B. above. The screen shall be cleaned before the approach velocity exceeds the criteria described in Section B.

D. Frequency of Cleaning:

Fish screens shall be cleaned as frequently as necessary to prevent flow impedance and violation of the approach velocity criteria. A cleaning cycle once every 5 minutes is deemed to meet this standard.

E. Screen Area Calculation:

The required wetted screen area (square ft), excluding the area affected by structural components, is calculated by dividing the **maximum** diverted flow (cubic ft per second) by the allowable approach velocity (ft per second). Example:

1.0 cubic ft per second / 0.33 ft per second = 3.0 square ft
Unless otherwise specifically agreed to, this calculation shall be done at the minimum stream stage.

3. Sweeping Velocity (velocity component parallel to screen face)

A. In Streams And Rivers:

The sweeping velocity should be at least two times the allowable approach velocity.

B. In Canals:

The sweeping velocity shall exceed the allowable approach velocity. Experience has shown that sweeping velocities of 2.0 ft per second (or greater) are preferable.

C. Design Considerations:

Screen faces shall be designed flush with any adjacent screen bay piers or walls, to allow an unimpeded flow of water parallel to the screen face.

4. Screen Openings

A. Porosity:

The screen surface shall have a minimum open area of 27 percent. We recommend the maximum possible open area consistent with the availability of appropriate material, and structural design considerations.

The use of open areas less than 40 percent shall include consideration of increasing the screen surface area, to reduce slot velocities, assisting in both fish protection and screen cleaning.

B. Round Openings:

Round openings in the screening shall not exceed 3.96mm (5/32in). In waters where steelhead rainbow trout fry are present, this dimension shall not exceed 2.38mm (3/32in).

C. *Square Openings:*

Square openings in screening shall not exceed 3.96mm (5/32in) measured diagonally. In waters where steelhead rainbow trout fry are present, this dimension shall not exceed 2.38mm (3/32in) measured diagonally.

D. *Slotted Openings:*

Slotted openings shall not exceed 2.38mm (3/32in) in width. In waters where steelhead rainbow trout fry are present, this dimension shall not exceed 1.75mm (0.0689in).

5. Screen Construction

A. *Material Selection:*

Screens may be constructed of any rigid material, perforated, woven, or slotted that provides water passage while physically excluding fish. The largest possible screen open area which is consistent with other project requirements should be used. Reducing the screen slot velocity is desirable both to protect fish and to ease cleaning requirements. Care should be taken to avoid the use of materials with sharp edges or projections which could harm fish.

B. *Corrosion And Fouling Protection:*

Stainless steel or other corrosion-resistant material is the screen material recommended to reduce clogging due to corrosion. The use of both active and passive corrosion protection systems should be considered.

Consideration should be given to anti-fouling material choices, to reduce biological fouling problems. Care should be taken not to use materials deemed deleterious to fish and other wildlife.

C. *Project Review And Approval:*

Plans and design calculations, which show that all the applicable screening criteria have been met, shall be provided to the Department before written approval can be granted by the appropriate Regional Manager.

The approval shall be documented in writing to the project sponsor, with copies to both the Deputy Director, Habitat Conservation Division and the Deputy Director, Wildlife and Inland Fisheries Division. Such approval may include a requirement for post-construction evaluation, monitoring and reporting.

D. *Assurances:*

All fish screens constructed after the effective date of these criteria shall be designed and constructed to satisfy the current criteria. Owners of existing screens, approved by the Department prior to the effective date of these criteria, shall not be required to upgrade their facilities to satisfy the current criteria unless:

1. The controlling screen components deteriorate and require replacement (i.e., change the opening size or opening orientation when the screen panels or rotary drum screen coverings need replacing),

2. Relocation, modification or reconstruction (i.e., a change of screen alignment or an increase in the intake size to satisfy diversion requirements) of the intake facilities, or

3. The owner proposes to increase the rate of diversion which would result in violation of the criteria without additional modifications.

E. Supplemental Criteria:

Supplemental criteria may be issued by the Department for a project, to accommodate new fish screening technology or to address species-specific or site-specific circumstances.

F. Variances:

Written variances to these criteria may be granted with the approval of the appropriate Regional Manager and concurrence from both the Deputy Director, Habitat Conservation Division and the Deputy Director, Wildlife and Inland Fisheries Division. At a minimum, the rationale for the variance must be described and justified in the request.

Evaluation and monitoring may be required as a condition of any variance, to ensure that the requested variance does not result in a reduced level of protection for the aquatic resources.

It is the responsibility of the project sponsor to obtain the appropriate fish screen criteria as provided herein. Project sponsors should contact the Department of Fish and Game, the National Marine Fisheries Service (for projects in marine and anadromous waters) and the U.S. Fish and Wildlife Service (for projects in anadromous and fresh waters) for guidance.

Copies of the criteria are available from the Department of Fish and Game through the appropriate Regional office, which should be the first point of contact for any fish screening project.

Northern California and North Coast Region; 601 Locust Street, Redding, CA 96001 - (530) 225-2300.

Sacramento Valley and Central Sierra Region; 1701 Nimbus Drive, Rancho Cordova, CA 95670 - (916) 358-2900.

Central Coast Region; 7329 Silverado Trail/P.O. Box 46, Yountville, CA 94599 -(707) 944-5500.

San Joaquin Valley-Southern Sierra Region; 1234 E. Shaw Avenue, Fresno, CA 93710 - (209) 243-4005.

South Coast Region; 4649 View Crest Avenue, San Diego, CA 92123 - (619) 467-4201.

Eastern Sierra and Inland Deserts Region; 4775 Bird Farms Road, Chino Hills, CA 91709 - (909) 597-9823.

Marine Region; 20 Lower Ragsdale Drive, #100, Monterey, CA 93940 - (831) 649-2870.

Technical assistance can be obtained directly from the Habitat Conservation Division; 1416 Ninth Street, Sacramento, CA 95814 - (916) 653-1070.

The National Marine Fisheries Service - Southwest Region "Fish Screening Criteria for Anadromous Salmonids, January 1997" are also available from their Southwest Region; 777 Sonoma Avenue, Room 325, Santa Rosa, CA 95402 - (707) 575-6050.

7. Exclusion Barriers

Anadromous Salmonid Passage Facility Guidelines and Criteria
Developed by
National Marine Fisheries Service
Northwest Region
Portland, Oregon
1-31-04 external review draft
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<http://www.nwr.noaa.gov/1hydrop/hydroweb/docs/Passagecriteria.extrevdraft.pdf>

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.

Hydraulic Conversion Factors for Converting English to Metric Units

Multiply	By	To obtain
	Length	
Inches	25.4 (exactly)	Millimeters
Feet	30.48 (exactly)	Centimeters
Miles	1.609344 (exactly)	Kilometers
	Area	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	0.092903 (exactly)	Square meters
Acres	0.0040469	Square kilometers
Square miles	2.58999	Square kilometers
	Volume	
Cubic feet	0.0283168	Cubic meters
	28.3168	Liters
Gallons (U.S.)	3.78543	Liters
Cubic yards	0.7645	Cubic meters
	Mass	
Pounds	0.45359237 (exactly)	Kilograms
Tons	907.185	Kilograms
	Acceleration	
Feet/sec/sec	0.3048	Meters/sec/sec
	Force/unit area	
Pounds/in^2	0.070307	Kilograms/cm^2
	Mass/volume (density)	
Pounds/ft^3	16.0185	Kilograms/m^3
	Velocity	
Feet/second	30.48 (exactly)	Centimeters/second
	Flow	
Feet^3/second	0.028317	Meters^3/second
	28.317	Liters/second
	Power	
Horsepower	745.700	Watts
(English)	1.014	Horsepower (Metric)
	Viscosity	
Kinematic viscosity (feet^2/second)	0.0929	Meters^2/second