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FISH PROTECTION SCREEN GUIDELINES FOR WASHINGTON STATE

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE
http://wdfw.wa.gov

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AQUATIC HABITAT GUIDELINES

As part of Washington State's salmon recovery strategy, the Washington Departments of Fish and Wildlife, Ecology, and Transportation, have developed guidelines for salmon habitat protection and restoration. These are a series of manuals, workshops, and other tools addressing various activities of salmon habitat protection and restoration and are intended to ensure compliance with requirements of the federal Endangered Species Act and state salmon restoration policies.

This document is one of a series of documents that make up the guidelines. Additional subjects for which guidelines have been prepared as of October 2009 or will be developed are:

- Bank protection – *Integrated Streambank Protection Guidelines* is available
- Fish passage at road culverts – *Fish Passage at Road Culverts* is available
- Nearshore habitat protection in Puget Sound – *Protecting Nearshore Habitat and Functions in Puget Sound, An Interim Guide* is available
- Stream habitat restoration – *Stream Habitat Restoration Guidelines* is available
- Land Use - *Land Use Planning for Salmon, Steelhead and Trout* is available
- Fishway design guidelines – Draft document from 2000 is available
- Freshwater sand and gravel removal
- Freshwater on- and over-water structures
- Lakeshore protection
- Marine nearshore and estuary restoration
- Marine dredging
- Marine on- and over-water structures
- Marine shoreline modifications
- Water crossings (bridges, conduits, and culverts)
- Use of treated wood

The Aquatic Habitat Guidelines will be published on the web when complete. Parts of the guidelines will be available on the web as "works in progress" while they are still draft. Workshop opportunities will also be posted on the web. These resources are located on Washington Department of Fish and Wildlife's Habitat web page at http://wdfw.wa.gov/hab/ahg/.

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INTRODUCTION

Much of the nomenclature used in this document is unique to **fish screen**s and the reader should refer to the glossary (Appendix A) for definitions of words and terms used. Words and terms included in the glossary appear in **bold type** in the text of this document**.**

Fish protection screens are devices installed at **surface water diversions** that allow the withdrawal of water while providing for the safety and relatively unimpeded movement of **anadromous** and resident fish. There are many types of **fish screens**, designed for varying water withdrawal situations, but they share common design objectives; allowing the withdrawal of water, and the protection of fish health. Both of these objectives can be met through careful design considerations. The National Oceanic and Atmospheric Administration Fisheries Service (NOAA Fisheries), the Washington Department of Fish and Wildlife (WDFW), and other northwest states have set specific **fish screen** design criteria and guidelines to protect fish (see Section II). These criteria span the design process from screen materials to hydraulic and biological considerations.

This document describes those criteria along with practical considerations for the design of fish protection screens. The major objective of this document is to highlight important elements that should be considered in the design of **fish screen**s at water diversions. Relevant applications of these criteria and guidelines include irrigation, municipal and industrial water withdrawals. There are unique screen installations that are outside the scope of these guidelines (e.g., turbine and gatewell screens at hydroelectric dams).

The U.S. Fish and Wildlife Service (USFWS) do not currently have a separate set of screening criteria for the protection of bull trout. Screening to meet NOAA Fisheries criteria is considered adequate protection for bull trout, although it is unclear whether the criteria are protective of Pacific lamprey ammocoetes (lamprey larvae). More study is warranted and anticipated.

NOAA Fisheries and WDFW have established **fish screen** design criteria to protect fish in proximity to screened water withdrawals from injury, migration delay, or mortality. These criteria are based on providing protection to the weakest swimming species present, at their most vulnerable life stage, under adverse environmental conditions. It is recognized that there may be locations, or times of the year, that design based on these conditions may not be warranted. However, unless conclusive data from studies acceptable to WDFW indicate otherwise, it is assumed that these extreme conditions exist at some times of the year at all sites within the state.

Technical assistance for all aspects of **fish screen** design, installation, operation, and maintenance is available from WDFW. WDFW technical assistance contacts are provided in Appendix B.

I. FISH SCREEN CONCEPTS

A. Fish Screen Guiding Principles

Protection of the most vulnerable fish, under the most severe environmental conditions.

Fish survival at diversions and screens is affected by flow, weather, and other environmental conditions. Therefore, facility design is based on worst- case conditions; salmonids present at the screen at the most vulnerable life history stage and under the most severe environmental conditions (e.g., salmonid **fry** in cold water at high flows).

B. Fish Screening Approaches

Transportation of fish through diversion facilities without injury, stress, or delay

The first step in the design process is to identify the type of screen appropriate for a particular application. Site-specific conditions will determine the appropriate style of screen to select. Some of these conditions include stream flow characteristics (e.g., flooding and low flow), sediment -supply, canal and stream slopes, and water control structures. The various screen types described below differ in their applicability to the range of possible locations. Screen facilities can be located in either the streambank or in the diversion canal, although not all screen types are appropriate for streambank applications. Appropriate applications will be described in the following discussion of screen types.

This guideline primarily addresses screen types commonly used in the Pacific Northwest, discussing their typical applications and limitations.   These screens, described below, are well tested, reliable and practical, and are generally accepted by state and federal regulators. Usually they will provide at least one good option for any particular application.   In Section I. B. 6. – Experimental Fish Protection Approaches, a number of screening approaches that are currently considered to be non-conventional due to the potential for high risk of failure is briefly discussed. These may be applicable to certain narrow site conditions but will be subject to greater scrutiny in the permitting process, will require frequent inspection, and potentially higher levels of maintenance than conventional screening approaches.

1. Rotary Drum Screens

Figure 1 – Rotary Drum Screen

This style of screen is appropriate only for off-channel applications. The screen comprises the surface of a cylindrical drum that is oriented on a horizontal axis. Water passes through the slowly rotating drum. Screen material used for drums is usually stainless steel perforated plate or woven wire. When functioning properly, a rotary drum screen is self-cleaning. Debris collecting on its face is carried over the top by rotation of the drum and is subsequently washed off on the downstream side by water passing through the screen. Screen rotation is powered by an electric motor, paddlewheel, solar drive, or hydraulic motor. At larger diversions where multiple drum screens are installed, an advantage is that each drum is independent, providing operational flexibility.

A major design consideration for the drum screen is its submergence relative to the total drum diameter. Submergence level is important for both fish protection and debris management. A submergence level between 65 percent and 85 percent of the screen diameter is required for proper operation. Below 65 percent submergence, debris is less effectively carried over the drum. Plugging of the screen with accumulated debris not only reduces the amount of flow diverted, it also increases the velocity of flow through the unplugged portions of the screen, heightening the risk that juvenile fish will be impinged on the screen. Submergence greater than 85 percent poses the risk that the screen will be overtopped, conveying fish into the diversion, or fish may become impinged on the screen and carried over the drum.

The narrow range of the water surface elevation (WSE) that drum screens require to operate effectively represents the major disadvantage to this screen style. For example, to maintain appropriate submergence for a four-foot diameter screen, the upstream water surface can vary no more than 0.8 feet (20 percent of four feet, or the difference between 65 percent and 85 percent submergence). Another consideration in the use of this style of screen is maintenance of the seals around the sides and base of the drum. Inevitable wearing of the seals, caused by rotation of the drum, can result in leakage and screening failure, with small fish able to enter the canal behind the screen (**entrainment**). For this reason, site conditions that accelerate the wearing of the seals, such as high concentrations of sand or silt in the diverted water, should be considered when choosing this screen style.

2. Vertical & Inclined Traveling Belt Screens

Figure 2 – Vertical Traveling Screen

These styles of screens are applicable for both in-bank and off-channel applications. Belt screens are stretched around an upper and a lower shaft. Similar to rotary drum screens, the inclined screen is rotated to remove debris collected on the screen face, depositing the debris on the delivery side. Two types of traveling screens have been commonly used; panel-type screens, with individual hinged panels, and belt-type vertical traveling screens with a continuous belt cloth. Generally, improvements in belt screen technology have made belts superior in functionality; so hinged panels are no longer commonly installed.

Traveling screens are usually driven by electric motors through a drive shaft at the top and rotate around a parallel idler shaft at the bottom. This style of screen can be built to any length within the structural capacity of the frame, drive, and shafts. The limitation on the length of traveling belt screens is the weight of the belt material on the top roller and drive mechanism. Historically stainless steel mesh was the most common material used. More recently, engineered polymer (plastic) belt cloth has been developed for use in **fish screen**s applications and is now an acceptable and commonly used material.

The primary advantages of belt screens are they can be installed in deep water and can also be designed to accommodate large fluctuations in the water surface. Other advantages of the vertical traveling screen are that they can be installed on a riverbank, thus requiring no bypass to return fish to the river, civil works are relatively compact, and they are self-cleaned by rotation of the belt. Jet spray or brushes, if needed, can provide additional cleaning. Another advantage is that belt screens can be inclined to facilitate debris removal where passing it down the diversion canal is not an option.

A disadvantage of traveling screens is the wear introduced to seals and plastic mesh by high concentrations of sand or silt. Where streams carry high concentrations of suspended sediment, this can create the need for frequent maintenance. Also, the plastic mesh is susceptible to photo-degradation by sunlight.

3. Vertical & Inclined Fixed Plate Screens

Figure 3 – Vertical Fixed Plate Screen Graphic

Vertical plate screens are applicable for both in-bank and off-channel applications. In general, inclined plate screens are only appropriate for in-bank application. Under rare circumstances they can be utilized for off-channel applications, but this is not advised due to difficulties in meeting hydraulic criteria and constructability. Plate screen systems are a combination of fixed, rigid panels of screen material attached to a structure and an active cleaning system. Screen material used in a vertical fixed plate screen is usually stainless steel perforated plate or profile bar. Commonly used cleaning systems include traveling brush and hydraulic and/or pneumatic back-spray systems. The operation of the cleaning system is usually triggered by either a timing mechanism, a system for detecting head loss across the screen, or a combination of both. Medium and larger-sized plate screens generally require a baffle system installed behind the screen to achieve uniform flow through the screen.

The primary advantage of in-bank plate screens (vertical or inclined to match the existing bank line) is elimination of the need for a fish bypass, check structure, and headgate. The primary disadvantage of this screening approach is the extreme difficulty in dewatering the facilities for maintenance, repair, or alteration. The risk of damage from flooding, large woody debris, or coarse bedload should be carefully assessed prior to selecting an in-bank screening approach.

A primary limitation in the selection of vertical plate screens in off channel applications is the availability of adequate flow for bypass operation. Because debris is not carried into the delivery water, it must be removed through the **bypass system** or it will continue to accumulate in front of the screen. This may result in overwhelming the cleaning system and plugging the screen.

The advantages of plate screens include their relative simplicity and lower materials cost than comparably sized drum screens. They are easily sealed because the screen does not move and can accommodate variations in flow and WSE's and still operate properly. This is especially useful at diversions that have a variable diversion rate due to water rights restrictions or seasonally declining stream flows. Plate screens typically exclude trash from the diverted water, which can be an important advantage in pumping applications behind the screen.

The primary disadvantage of plate screens is the dependence on a single cleaning system for an entire bank of screens. Compared to banks of drum or belt screens, where each individual screen is self-cleaning, multiple plate screens can be disabled by the failure of the cleaning system. Another disadvantage of plate screens is the need for total dewatering of the screening facility to perform repairs. By contrast, facilities with multiple drum or belt screens allow for individual screen removal.

4. Modular Drum & Plate Screens

Figure 4 – Modular Screen Graphic

Developed in the early 1990s by the WDFW Yakima Screen Shop, various forms of modular screens are in wide use throughout the Pacific Northwest. The modular rotating drum and modular fixed plate systems are the most common forms. Originally designed for remote sites where conventional concrete construction was not feasible. The major advantage of modular screens is their lower cost and ability to be assembled on site and installed in one to three days. These systems are typically employed in off-channel settings and use a piped bypass system to return fish to the stream. They have proven to be an effective and inexpensive means for addressing numerous small diversions. The disadvantage of these screens is their lesser useful life compared to conventional concrete structures.

The modular drum screen is designed for diversions in the 2 to 6 cubic feet per second range. They are paddle wheel driven and can be fabricated to provide an **angled orientation** to flow. Modular plate screens were developed for diversions in the 0.5 to 3 cubic feet per second range and are used in off-channel settings. This design employs rotating brushes driven by a paddle wheel to clear debris from the screen.

A chart of gravity screen types and applications can be found on the WDFW web site at http://wdfw.wa.gov/hab/tapps/erta_screen.htm

5. End of Pipe Screens (including pump intakes)

Figure 5 – Pump Screen Graphic

This screen style is essentially a chamber with screen walls. They are usually cylindrical or 'Tee'd and range in size from single 3-inch diameter cylinders screening a fraction of 1 cubic feet per second, to large manifolded screen installations exceeding 50 cubic feet per second. Manifolded screens are generally needed for diversion rates greater than 3 cubic feet per second (1,346 gallons per minute).

Active cleaning systems are needed for most end-of-pipe applications. The most commonly used in small diversions (i.e., less than 3 cubic feet per second) is the internal water jet that cleans by spraying the screen face from the inside. An alternative cleaning approach is the airburst system, commonly used in larger diversions and lake withdrawals where sweeping flow is not present to carry debris away.

Diversions of 3 cubic feet per second or less may use **passive screens** (i.e., screens lacking an active cleaning system). **Approach velocity** criteria for **passive screen**s is 0.2 feet per second, half that of actively cleaned screens. Internal baffling in recently developed screens improves performance of **passive screen**s by maintaining uniform flow conditions across the entire screen face. With low approach and through-screen velocities, these are much less prone to plugging than non-baffled screens. For small applications where sweeping flow is available, these screens function very effectively.

The advantages and disadvantages of end-of-pipe screening relative to the gravity screening approaches described above largely relate to the pros and cons of pump versus gravity diversions. This screening approach represents significant savings, compared to gravity diversion screening facilities in both construction and maintenance, and eliminates the need for instream grade controls, bank armoring, and headgates. Another significant advantage of pumping at small diversions is

the portability of the pump intake, eliminating any need to control the water surface in the stream. Power costs associated with pumping are a consideration when evaluating screening approaches, although, when added to an already pressurized system, additional power costs are usually proportionally small. A disadvantage associated with pump diversions is that they are susceptible to flood damage if not removed during high flow periods.
Note: Screening for Mineral Prospecting and Placer Mining is not addressed in this document. Requirements (W220-110-201(6) (i) can be found in the Gold & Fish pamphlet that is available on-line at http://wdfw.wa.gov/habitat/goldfish/ or by requesting one from a WDFW office.

6. Experimental Fish Protection Approaches

The conventional screening approaches already described do not encompass all possible devices that will potentially provide acceptable protection to fish. Fish protection approaches other than those described above are considered experimental by both the NMFS and WDFW, and are subject to WDFW Policy POL – M5001, Appendix F *New Fish Protection Technology Development* (Appendix C). Examples of experimental approaches that have been tested and have so far proven ineffective include various systems intended to exclude fish through behavioral response to electricity, light, and sound. Below are brief discussions of several experimental screen types that are in use but are still considered experimental. These are being evaluated for safety and effectiveness.

a. Screening from Below

Various screen configurations described below have been developed that withdraw water from the bottom of the water column. These include horizontal, downward sloping, Coanda, and upward sloping plate screens. These approaches share a number of advantages and disadvantages. The primary advantages are that they are passively cleaned by hydraulic action, and there are no moving parts. The primary disadvantage is that **bypass flows** needed to provide safe fish passage over these screens are much greater than for other screen styles. Screening from below poses the threat of dewatering channels (either stream or canal) when low flows approach screen capacity. Prior to total dewatering occurring, shallow flows across the screen face can injure or **impinge** fish. The system functions effectively only if sufficient flow depth exists across the entire screen to assure continuous movement of fish and debris over the screen. Plugging can also be a problem. Because these screens withdraw water from the bottom of the water column, where suspended sediment concentrations are highest, fine sediment intrusion can be a significant problem.

1) Horizontal Fixed Plate Screens

Figure 6 – Horizontal Fixed Plate Screen Graphic

Fixed plate screens are placed approximately parallel to the channel bed. Historically, this screening approach was used in-stream, where it used the stream-flow to clean debris from the screen surface. In-stream application is not now commonly used because of the difficulty in meeting current fish protection criteria and the environmental impacts of in-stream structures.
Recent technological improvements of this design in off channel application has shown promise of being able to protect fish and provide reliable cleaning but because it is a relatively new technology it is still considered experimental.

2) Downward Sloping Fixed Plate Screens

(Figure 7 – ***Downward Sloping Fixed Plate Screen Graphic)***

Screens that slope downward in the direction of flow can either be flat plate or a contoured plate such as the Coanda screen. These screens function similarly to horizontal plate screens, effectively screening from below, however flow velocities are higher and pressures are lower.

Flow distribution through the flat plate downward sloping screen is seldom uniform because the water depth over the upstream end of the screen is greater than over the downstream end. To facilitate a more evenly distributed flow across the screen, baffle systems have been used. Reliable and easily operated baffling systems, able to accommodate a wide range of flow levels, however, have not been developed.

3) Coanda Screens

Figure 8 – Coanda Screen Graphic

Photo courtesy of Norris Screen and Manufacturing Inc.

The Coanda design improves on through-screen flow distribution. The Coanda shape is designed to follow the **nappe** of water, as if it were free spilling. This allows the head driving flow through the screen to be more uniform. The Coanda screen can be optimized for one flow, though the shape of the **nappe** will change with varying flow levels.

A minimum depth of flow over the crest is necessary to keep the lower section of the screen from becoming de-watered. To maintain the flow, it may be necessary to operate screens in parallel segments so, as the flow level changes; more or fewer segments are utilized.

4) Upward Sloping Fixed Plate Screens

(Figure 9 – ***Upward Sloping Fixed Plate Screen Graphic***)

Upward sloping screens are the reverse of downward sloping screens; their profile rises in the direction of the water flow. The primary advantage of this configuration is that there is a more uniform flow distribution through the screen because the head differential is uniform throughout its area. The screen is relatively simple except for the required automatic cleaning devices.

The structure associated with this style of screen functions as a check dam that will capture sediment on the upstream side. In streams with a high sediment load, this could cause plugging and create significant maintenance problems. Furthermore, in systems with high debris loads, **bypass flow**s inadequate to transport debris past the screen will also lead to plugging.

In general, screening from below is not a widely applicable approach, due to the shortcomings and constraints described above. However, it has been successfully applied in certain off-channel situations that include abundant, reliable **bypass flow** and adequate available head.

b. Infiltration Galleries

As with the 'screening from below' systems discussed above, infiltration galleries are considered experimental and are subject to similar restrictions and limitations. The successful application of this approach is extremely sensitive to site conditions. The appropriate conditions are highly specific and relatively uncommon, involving relatively high gradient, coarse-bedded streams with low fine sediment loads, and limited bed armoring. Failure, due to plugging of the system with fine sediment is likely when appropriate site conditions do not exist.

The primary advantage of infiltration galleries is that when sited in appropriate locations, the withdrawals function passively and further manipulation of the stream channel is not required. The primary disadvantage of their application is the rarity of favorable locations and the virtual certainty of failure through clogging where the appropriate site conditions do not exist. Another significant disadvantage is that installation represents a severe disturbance to the stream channel. If the gallery functions effectively, this disturbance may be offset by the absence of further manipulation of the stream. If an infiltration gallery fails, reinstallations are not justified due to the high likelihood of repeated failure. An additional consideration is that functional infiltration galleries located in small streams may have the potential to dewater the channels, possibly lowering the water table to a degree that adversely affects the entire aquatic food web.

Once plugged, infiltration galleries are not easily restored. Air and water burst backwash systems have been used to clean the bed over infiltration galleries, though with limited success. In order to clear fine sediment from the gravel matrix, the cleaning system has to mobilize the entire bed over the gallery. Mobilizing fine sediment into flowing water during low flows may be unacceptable due to the adverse effect on aquatic life.

Prior to the development of a design, a hydrogeologist who is familiar with the application of infiltration galleries should be consulted to determine the feasibility and the potential capacity of a given site. A fisheries biologist should also be consulted to assess potential impacts to juvenile salmonids; juveniles have been observed moving considerable distances through channel substrate and may not be protected by infiltration galleries.

Various manufacturers and vendors of **fish screen**s and materials may be found in Appendix D.

II. NOAA FISERIES FISH SCREEN DESIGN CRITERIA AND GUIDELINES

Note: To maintain consistency between government agencies, this section is predominantly taken from the NOAA Fisheries 2008 Anadromous Salmonid Passage Facility Design document.

A. Introduction – Fish Screen and Bypass Facilities

This section provides criteria and guidelines that are supported by WDFW and were developed by NOAA Fisheries to be used in the development of designs of downstream migrant **fish screen** facilities for irrigation, hydroelectric, and other water withdrawal projects. Unless directly specified herein, this guidance is not intended to provide guidance on the application of the design for any particular site.

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

The NOAA Fisheries 2008 document is considered specific federal criteria. However, as this document is considered guidance and WDFW has not adopted formal administrative rules, the term "must" in the NOAA Fisheries document has been changed to "should" when it is referring to specific design criteria that are not already in WDFW rule. It is strongly recommended that individuals follow these guidelines, as they will likely be required by NOAA Fisheries. Applicants are encouraged to consult with WDFW and NOAA Fisheries staff early in project development to help ensure that their proposal will be permissible. Guidelines should be followed in the fish screen design until site-specific information indicates that a different value would provide better fish protection conditions or solve site-specific issues

B. Functional Screen Design

A functional screen design should be developed that defines type, location, size, hydraulic capacity, method of operation, and other pertinent juvenile **fish screen** facility characteristics. By law, the screen must be approved by WDFW (RCW 77.57.010). Functional design drawings should show all pertinent hydraulic information, including water surface elevations and flows through various areas of the structures. Functional design drawings should show general structural sizes, cross-sectional shapes, and elevations. Types of materials should be identified where they may directly affect fish.

C. Site Conditions

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

D. Existing Screens

1. Acceptance Criteria and Guidelines for Existing Screens

If a **fish screen** was constructed prior the establishment of these criteria, but constructed to NOAA Fisheries criteria established August 21, 1989, or later, it may be considered adequate provided that all six of the following conditions are met:

- The entire screen facility functions as designed;
- The entire screen facility has been maintained and is in good working condition;
- When the screen material wears out, it is replaced with screen material meeting the current criterion stated in this document. Structural modifications may be necessary to retrofit an existing facility with new screen material;
- No mortality, injury, entrainment, **impingement**, migration delay, or other harm to **anadromous** fish has been noted that is being caused by the facility;
- No emergent fry are likely to be located in the vicinity of the screen, as agreed to by biologists familiar with the site; and
- When biological uncertainty exists, WDFW staffs are consulted for verification of the above criteria.

E. Structure Placement

1. Specific Criteria and Guidelines – Structure Placement: Streams and Rivers

a. Instream Installation

Where physically practical and biologically desirable, the screen should be constructed at the point of diversion with the screen face generally parallel to river flow. However, physical factors may preclude screen construction at the diversion entrance. Among these factors are excess river gradient, potential for damage by large debris, access for maintenance, operation and repair, and potential for heavy sedimentation. For screens constructed at the bankline, the screen face should be aligned with the adjacent bankline and the bankline should be shaped to smoothly match the face of the screen structure to minimize turbulence and eddying in front, upstream, and downstream of the screen. Adverse alterations to riverine habitat must be minimized.

b. Canal Installation

Where installation of **fish screen**s at the diversion entrance is not desirable or impractical, the screens may be installed in the canal downstream of the entrance at a suitable location. All screens installed downstream from the diversion entrance must be provided with an effective **bypass system** designed to collect and transport fish safely back to the river with minimum delay. The screen location should be chosen to minimize the effects of the diversion on instream flows by placing the bypass outfall as close as biologically feasible (i.e., considering minimizing length and optimizing the hydraulics of the bypass pipe) and practically feasible to the point of diversion.

c. Functionality

All screen facilities must be designed to function properly through the full range of stream hydraulic conditions and in the diversion conveyance, and must account for debris and sedimentation conditions, which may occur.

2. Specific Criteria and Guidelines – Structure Placement: Lakes, Reservoirs, and Tidal Areas

a. Intake Locations

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

b. Surface Outlets

If a reservoir outlet is used to pass fish from a reservoir, the intake should be designed to withdraw water from the most appropriate elevation based on providing the best juvenile fish attraction and appropriate water temperature control downstream of the project. The entire range of forebay fluctuation should be accommodated in design. Since surface outlet designs need to consider a wide spectrum of site-specific hydraulic and fish behavioral conditions, WDFW engineers and biologists should be consulted to ensure development of an acceptable conceptual design for any surface outlet fish passage system before the design proceeds.

F. Screen Hydraulics – Rotating Drum Screens, Vertical Screens, and Inclined Screens

1. Specific Criteria and Guidelines – Screen Hydraulics

a. Approach Velocity

The **approach velocity** should not exceed 0.4 feet per second for **active screens**, or 0.2 feet per second for **passive screen**s. Using these approach velocities will minimize screen contact and/or **impingement** of juvenile fish. For screen design, **approach velocity** is calculated by dividing the maximum-screened flow amount by the vertical projection of the **effective screen area**. An exception may be made to this definition of **approach velocity** where a clear egress route minimizes the potential for **impingement**. In such cases, the **approach velocity** is calculated using the entire **effective screen area**, and not a vertical projection.

b. Effective Screen Area

The minimum **effective screen area** is calculated by dividing the maximum-screened flow by the allowable **approach velocity**.

c. Submergence

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

d. Flow Distribution

The screen design should provide for nearly uniform flow distribution over the screen surface, thereby minimizing **approach velocity** over the entire screen face. To maintain uniform flow, providing adjustable porosity control on the downstream side of screens, and/or flow training walls may be necessary. Large facilities may require hydraulic modeling to identify and correct areas of concern. Uniform flow distribution avoids localized areas of high velocity, which have the potential to impinge fish.

e. Screens Longer Than Six Feet

- Screens longer than 6 feet should be angled and have sweeping velocity greater than the **approach velocity**. This angle may be dictated by site-specific geometry, hydraulic, and sediment conditions. Optimally, sweeping velocity should be at least 0.8 feet per second and less than 3 feet per second.
- For screens longer than 6 feet, sweeping velocity should not decrease along the length of the screen.

f. Inclined Screen Face

An inclined screen face should be oriented less than 45 degrees vertically with the screen length (upstream to downstream) oriented parallel to flow, unless the inclined screen is placed in line with the riverbank and reasonably matching the slope of the riverbank.

g. Horizontal Screens

Horizontal screens have been evaluated as an experimental technology, and should only be considered if the majority of flow passes over the end of the screen at a minimum depth of 1 foot, and positive downstream sweeping velocity in excess of the **approach velocity** exists for the entire length of screen. Post construction monitoring of the facility should be conducted to evaluate effectiveness. WDFW should be consulted throughout the development and evaluation of the design.

G. Screen Material

1. Specific Criteria and Guidelines – Screen Material

a. Circular Screen Openings

Circular screen face openings should not exceed 3/32 inch (2.4 millimeters) in diameter. Perforated plate should be smooth to the touch with openings punched through in the direction of approaching flow.

b. Slotted Screen Openings

Slotted screen face openings should not exceed 0.07 inches (1.75 millimeters) in the narrow direction.

c. Square Screen Openings

Square screen face openings should not exceed 3/32 inch (2.4 millimeters) on the diagonal.

d. Material

The screen material should be corrosion resistant and sufficiently durable to maintain a smooth uniform surface with long-term use (e.g., stainless steel, aluminum, engineered polymer).

e. Other Components

Other components of the screen facility (e.g., bottom and side seals) should not include gaps greater than the maximum screen opening defined above.

f. Open Area

The percent open area for any screen material should be at least 27 percent.

H. Civil Works and Structural Features

1. Specific Criteria and Guidelines – Civil Works and Structural Features

a. Placement of Screen Surfaces

The face of all screen surfaces should 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.

b. Structural Features

Structural features should be provided to protect the integrity of the **fish screen**s from large debris, and to protect the facility from damage if overtopped by flood flows. A trash rack, log boom, sediment sluice, and other measures may be necessary.

c. Civil Works

The civil works should be designed in a manner that prevents undesirable hydraulic effects (e.g., eddies and stagnant flow zones) that may delay or injure fish or provide predator habitat or predator access.

I. Bypass Facilities

1. Specific Criteria and Guidelines – Bypass Layout

a. Bypass Location

- The screen and bypass need to work in tandem to move out-migrating salmonids (including downstream migrant adult salmonids such as steelhead kelts, if present) to the bypass outfall with a minimum of injury or delay;
- The bypass entrance should be located so that it may easily be located by out-migrants;
- The bypass entrance and all components of the **bypass system** should be of sufficient size and hydraulic capacity to minimize the potential for debris blockage;
- Screens greater than 6 feet in length should be constructed with the downstream end of the screen terminating at a bypass entrance. Screens less than or equal to 6 feet in length may be constructed perpendicular to flow with a bypass entrance at either or both ends of the screen, or may be constructed at an angle to flow, with the downstream end terminating at the bypass entrance; and
- Some screen systems do not require a **bypass system**. For example, an end of pipe screen located in a river, lake, or reservoir does not require a **bypass system** because fish are not removed from their habitat. A second example is a riverbank screen with sufficient hydraulic conditions to move fish past the screen face.

b. Multiple Entrances

Multiple bypass entrances should be used if the sweeping velocity may not move fish to the bypass within 60 seconds, assuming fish are transported along the length of the screen face at a rate equaling sweeping velocity.

c. Training Wall

A training wall should be located at an angle to the screen face, with the bypass entrance at the apex and downstream-most point. For many facilities, the wall of the civil works opposite to the screen face may serve as a training wall. For single or multiple Vee screen configurations, training walls are not required, unless an intermediate bypass is used.

d. Secondary Screen

In cases where there is insufficient flow available to satisfy hydraulic requirements at the bypass entrance for the primary screens, a secondary screen may be needed within the primary bypass. The secondary **bypass flow** conveys fish to the bypass outfall location or other destination, and returns secondary screened flow for water use.

e. Bypass Access

Access for inspection and debris removal should be provided at locations in the bypass system where debris accumulations may occur.

f. Trash Racks
If trash racks are used, sufficient hydraulic gradient should be provided to route juvenile fish from between the trash rack and screens to the bypass.

g. Canal Dewatering
The floor of the screen civil works should be designed to allow fish to be routed back to the river safely when the canal is dewatered. This may entail using a small gate and drainpipe, or similar provisions, to drain all flow and fish back to the river. If this cannot be accomplished, an acceptable fish salvage plan should be developed in consultation with WDFW and included in the operation and maintenance plan.

h. Bypass Channel Velocity
To ensure that fish move quickly through the bypass channel (i.e., conveyance from the terminus of the screen to the bypass pipe), the rate of increase in velocity between any two points in the bypass channel should not decrease and should not exceed 0.2 feet per second per foot of travel.

i. Natural Channels
Natural channels may be used as a bypass upon approval by WDFW. A consideration for utilizing natural channels as a bypass is the provision of off-stream habitat. Requirements for natural channels include adequate depth and velocity, sufficient flow volume, protection from predation, and good water quality.

2. Specific Criteria and Guidelines – Bypass Entrance

a. Flow Control
Each bypass entrance should be provided with independent flow-control capability.

b. Minimum Velocity
The minimum bypass entrance flow velocity should be greater than 110 percent of the maximum canal velocity upstream of the bypass entrance. At no point should flow decelerate along the screen face or in the bypass channel. **Bypass flow** amounts should be of sufficient quantity to ensure these hydraulic conditions are achieved for all operations throughout the smolt out-migration period.

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

d. Dimensions
For diversions greater than 3 cubic feet per second, the bypass entrance should extend from the floor to the canal water surface, and should be a minimum of 18 inches wide. For diversions of 3 feet per second or less, the bypass entrance should be a minimum of 12 inches wide. In any case, the bypass entrance should be sized to accommodate the entire range of

bypass flow, utilizing the criteria and guidelines listed throughout Section II.I.

e. Weirs

For diversions greater than 25 cubic feet per second, weirs used in **bypass system**s should maintain a weir depth of at least 1 foot throughout the smolt out-migration period.

3. Specific Criteria and Guidelines – Bypass Conduit and System Design

a. General

Bypass pipes and joints should have smooth surfaces to provide conditions that minimize turbulence, the risk of catching debris, and the potential for fish injury Every effort should be made to minimize the length of the bypass pipe, while maintaining hydraulic criteria listed below.

b. Bypass Flow Transitions

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

c. Flows and Pressure

In general, **bypass flow**s in any type of conveyance structure should be open channel. If a closed conveyance structure is needed due to site conditions, pressures in the bypass pipe should be equal to or above atmospheric pressures. Pressurized to non-pressurized (or vice-versa) transitions should be avoided within the pipe. Bypass pipes should be designed to allow trapped air to escape.

d. Bends

Bends should be avoided in the layout of bypass pipes due to the potential for debris clogging and turbulence. The ratio of bypass pipe centerline radius of curvature to pipe diameter (R/D) should be greater than or equal to 5. Greater R/D may be necessary for super-critical velocities (see Section II.I.3.h).

e. Access

Bypass pipes or open channels should be designed to minimize debris clogging and sediment deposition and to facilitate inspection and cleaning as necessary. Long bypass designs (e.g., greater than 150 feet) may include access ports provided at appropriate spacing to allow for detection and removal of debris. Alternate means of providing for bypass pipe inspection and debris removal may be acceptable as well.

f. Diameter/Geometry

The bypass pipe diameter or open channel bypass geometry should generally be a function of the **bypass flow** and slope, and should be chosen based on achieving the velocity and depth criteria in Sections II.I.3.h and II.I.3.i.

Table 1 provides examples for selecting the diameter of a bypass pipe based on diverted flow amount, assuming:

- bypass pipe slope of 1.3 percent;
- Manning's roughness of 0.009; and
- other bypass pipe criteria (Section II.I) are met.

Bypass pipe hydraulics should be calculated for a given design to determine a suitable pipe diameter if the design deviates from the assumptions used to calculate pipe diameters in Table 1.

Table 1 – Bypass Design Examples

Diverted Flow (cubic feet per second)	Bypass Flow (cubic feet per second)	Bypass Pipe Diameter (inches)	Bypass Flow Depth (inches)
< 6	5% of diverted flow	10	2 ½
6 - 25	5% of diverted flow	10	4
40	2.0	12	4 ¾
75	3.75	15	6
125	6.25	18	7 ¼
175	8.75	21	8 ½
250	12.5	24	9 ½
500	25.0	30	12
750	37.5	36	14
> 1000	Design with direct NOAA Fisheries engineering involvement		

g. Flow

Design bypass flow should be about 5 percent of the total diverted flow amount, unless otherwise approved by WDFW. Regardless of the **bypass flow** amount, hydraulic guidelines and criteria in Sections II.I.3.h and II.I.3.i apply.

h. Velocity

The design bypass pipe velocity should be between 6 and 12 feet per second for the entire operational range. If higher velocities are approved, special attention to pipe and joint smoothness must be demonstrated by the design. To reduce silt and sand accumulation in the bypass pipe, pipe velocity must not be less than 2 feet per second.

i. Depth

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

j. Closure Valves

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

k. Sampling Facilities

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

l. Hydraulic Jump

There should not be a hydraulic jump within the pipe.

m. Spillways
Spillways upstream of the screen facility also act as a **bypass system**. These facilities should also be designed to provide a safe passage route back to the stream and follow the bypass design principles described throughout Section II.I.

4. Specific Criteria and Guidelines – Bypass Outfall

a. Location

- Bypass outfalls should be located to minimize predation by selecting an outfall location free of eddies, reverse flow, or known predator habitat. The point of impact for bypass outfalls should be located where ambient river velocities are greater than 4 feet per second during the smolt out-migration. Predator control systems may be necessary in areas with high avian predation potential. Bypass outfalls should be located to provide good egress conditions for downstream migrants; and
- Bypass outfalls should 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 flow**s. The **bypass flow** should not impact the river bottom or other physical features at any stage of river flow.

b. Impact Velocity
Maximum bypass outfall impact velocity (i.e., the velocity of **bypass flow** entering the river) including vertical and horizontal velocity components should be less than 25 feet per second.

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

J. Debris Management

1. Specific Criteria and Guidelines – Debris Management

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

b. Screen Cleaning (Active Screens)
Active screens must be automatically cleaned to prevent accumulation of debris. The screen cleaner design should allow for complete debris removal at least every 5 minutes, and operated as required to prevent accumulation of debris. The head differential to trigger screen cleaning for intermittent type cleaning systems should be a maximum of 0.1 feet over clean screen conditions or as agreed to by WDFW. A variable timing

interval trigger should also be used for intermittent type cleaning systems as the primary trigger for a cleaning cycle. The cleaning system and protocol must be effective and reliable.

c. Passive Screens

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

- The site is not suitable for an **active screen**, due to adverse site conditions;
- Uniform **approach velocity** conditions exist at the screen face, as demonstrated by laboratory analysis or field verification;
- The debris load is low;
- The combined rate of flow at the diversion site is less than 3 cubic feet per second;
- Sufficient ambient river velocity exists to carry debris away from the screen face;
- A maintenance program is approved by WDFW and implemented by the water user;
- The screen is frequently inspected with debris accumulations removed, as site conditions dictate;
- Sufficient stream depth exists at the screen site to provide for a water column of at least one screen radius around the screen face; and
- The screen must is designed to allow easy removal for maintenance, and to protect from flooding.

d. Intakes

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

e. Inspection

The completed screen and bypass facility must be made available for inspection by WDFW to verify that the screen is being operated consistent with the Hydraulic Project Approval.

k. Evaluation

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

g. Sediment

Steps should be taken to limit the build-up of sediment, where it may impact screen operations.

K. End of Pipe Screens (including pump intake screens)

1. Specific Criteria and Guidelines – End of Pipe Screens

a. Location

End of pipe screens should be placed in locations with sufficient ambient velocity to sweep away debris removed from the screen face, or designed in a manner to prevent debris re-**impingement** and provide for debris removal.

b. Submergence

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

c. Escape Route

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 (e.g., intake lagoon), a conventional open channel screen should be placed in the intake channel or at the edge of the river to prevent fish from entering a lagoon.

III. SCREEN DESIGN

A. Pre-design

Pre-design entails identifying the basic design parameters (i.e., quantity of diverted flow, season of use, stream hydrology, and types and life history of fish to be protected) and site reconnaissance [i.e., site survey, identification of bank full and, if possible, low flowWSE's, evaluation of channel stability, flood hazards, and sediment and debris loads].

1. Design Parameters

Screen size will be determined by the maximum diverted flow, so this information is fundamental to screen design. This will usually be determined by the existing water right. Additionally, **fish screen**s need to be designed to remain in criteria throughout the full range of flows that will be diverted, through all seasons of use. This information, too, must be well understood prior to beginning design.

Stream flow patterns throughout the period of diversion need to be identified, particularly low flow. If stream gage records are not available, a full season of periodic flow measurement should be conducted.

2. Site Reconnaissance

A topographic survey of the site is essential design information. Of particular importance are the stream channel and water surface profiles throughout the project area and along the diversion canal. Points where the water surface slope changes are important to include in the profile survey. These include the tailout of pools, where the water surface transitions from relatively flat to noticeably sloped, and at the bottom of riffles, where the transition is from steep to flat. Because channel geometry or diversion structures (i.e., dams, weirs) near the point of diversion controls the elevation of the water surface available for diversion, this is critical information. Channel and WSE's downstream of that point will be needed for design of the screen facility. More complete topographic data for the channel, particularly a series of cross-sections taken along the profile, will allow for hydraulic modeling. Surveying during low flow conditions is particularly useful because it provides the opportunity to directly measure low flow WSE's; these do not vary greatly with small changes in stream flow.

The minimum required WSE at the point of use should be identified and related to elevations at the point of diversion. Obviously, gravity diversions require a sloping water surface (i.e., head) from the point of diversion to the point of use. An efficient design will minimize the head required for operating the diversion and may eliminate the need for in-stream check structures. Identifying and eliminating impediments to efficient delivery of flow to the water user (e.g., high spots in the canal) or locations of wasted head (e.g., unnecessary drops in the canal upstream of the point of use) will aid in the development of an efficient and effective screening system.

Additionally, reconnaissance should include survey data on existing ground elevations, all man-made features (e.g., diversion head gate, flow measuring weir, operational spillway, power availability, etc.) and any significant natural features (e.g., large trees, outcropping bedrock, etc.) within the project area. If the project involves the replacement of an existing screen, survey data should include the screen location and bypass route.

Evaluating channel characteristics as part of site reconnaissance can aid in the selection of the appropriate screening approach. If in-bank screening is under consideration, it is critical to evaluate channel stability and the hazards posed by debris and coarse sediment transported during flood flows. In-bank screening is not appropriate in unstable stream channels. Channel stability is also important to off-channel screen design for selection of the bypass outfall location. Sediment and debris loads can become design considerations for off-channel screening. If the design engineer is not experienced in assessing channel characteristics, a fluvial geomorphologist or stream processes expert should be consulted.

Water users are usually a vital source of information for understanding the particular challenges associated with their diversion.

B. Preliminary Design

Preliminary design (typically 20% to 30% completion) entails selecting the best screen type for the application and site layout (identifying the locations, configurations and elevations of the screen and **bypass system**). Plan, profile, and section drawings will generally be needed to pursue funding and permitting for the proposed project. The preliminary design document may also be used for budgetary and planning purposes, and as a basis for soliciting design review comments by other reviewing entities.

1. Screen Selection

After identifying design parameters and performing site reconnaissance, as described above, the information provided in Section I.B. "**Fish Screen** Approaches" allows the designer to select the best screening approach. Technical assistance for the selection of the best screen type is available from WDFW (see Appendix B).

2. Site Layout

In-channel screens are located in the bankline at the head of the canal. If this location is not already established, it should ideally be located in a stable, straight channel section where there is continuous adequate flow depth and sweeping velocity without excessive energy concentration near the bank. Protection of the facility under high flow conditions is an important consideration.

Off-channel site layout for an off-channel system that safely returns fish to the stream is determined by a number of factors. Key among these is determining the appropriate location for the bypass outfall. The design objective is to develop a **bypass system** that discharges at a secure and stable location in the stream channel. Site conditions may make this challenging to a degree that bypass design will essentially drive the system layout. For instance, if little difference in slope exists between the stream channel and the canal, achieving an adequate slope on the bypass pipe and preventing reverse flow under conditions of high stream flow may require the screens to be located relatively far down the canal. Fish bypass design is treated in detail in Section IV. It is important for the designer to understand the information in that section when establishing the system layout.

The location of the screen structure along the canal (consistent with providing a good bypass) will determine the water surface and depth available for the screen to operate (i.e., the design water surface), thereby establishing the elevation of the screen. This available water depth must be consistent with the selected screen. Under conditions of limited water depth, it may be advantageous to sump (or recess) the screen below the invert (bottom) of the canal. This can create problems with sediment deposition that will cause increased maintenance costs. An alternative is to select a different style or size of screen.

Another key consideration is protection of the facility during high water. Depending on site conditions, protection may be provided by screen location, headgates, wasteways, the screen structure, piping, or a combination of these elements.

Within lakes, reservoirs, or tidal areas, the withdrawal point should be located off shore, at depth, where a low density of fish is expected. Salmonid fry generally inhabit shallow, near-shore areas. If possible, screen intakes should be located where sufficient sweeping velocity exists to minimize sediment accumulation in and around the screen, facilitate debris removal, and encourage fish movement away from the screen face.

C. Final Design

1. Configuration of Intake Structure and Screen

Off-channel screens greater than 6 feet in length must be oriented at an angle to the direction of the approaching flow. This orientation affects the magnitude of the sweeping velocity along the face of the screen. The magnitude of the sweeping velocity is important because it ultimately guides juvenile fish to the bypass. To guide fish quickly and effectively past the screen, the sweeping velocity must be greater than the **approach velocity**. Optimal sweeping velocity ranges from 0.8 to 3 feet per second. Experience has shown that screen angles between 18 and 22 degrees work well to provide adequate sweeping and through-screen velocities. It is difficult to maintain good sweeping velocities at screen angles greater than 45 degrees.

In-channel screens should be installed with the screen face parallel to the stream flow and designed to match the existing bankline. Smooth upstream and downstream transitions between the bank and the installation should be provided to minimize turbulence and maintain uniform through-screen velocities.

As stated in Section II.H, the face of all screen surfaces should 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. Approach Canal

The intake structure and **fish screen** should be designed to assure that the diverted flow is uniformly distributed through the screen so the maximum **approach velocity** is not exceeded. An assumption of the **approach velocity** criteria is that the flow coming to the screen structure has parallel streamlines and uniform velocity. Obstructions in the flow path approaching the screen, including abrupt transitions in canal geometry and bends in the canal, can result in turbulence or non-uniformity in the screen **approach velocity**.

If flow in the canal is significantly skewed, flow distribution should be corrected before it reaches the screen. Poor flow distribution cannot be corrected at the screen. The approach canal should be relatively straight, with a uniform cross-section, for at least a length equal to four times the width of the canal. If the average water velocity entering the structure is greater than 2 feet per second, a longer straight approach is recommended.

(Figure 10 – ***Canal Approach Characteristics***).

When canal expansions are required to transition into the screen civil works, the transition should be designed at an expansion rate of 1:8. For example, if the average canal width is 20 feet and the civil works provide a 24-foot wide approach canal, then the expansion should begin at least 16 feet upstream of the civil works allowing for a two foot expansion on each side of the ditch. This transition minimizes head loss and turbulence associated with the expansion and eliminates the potential for adverse hydraulic conditions at the screen face. In addition, to promote uniform flow conditions through the screen, lateral offsets in the sidewalls of the structure should be avoided.

Characteristics of approaching flow can affect the screen's velocity distribution. In an enclosed screen bay, flow with a high velocity can have sufficient momentum to cause it to "pile up" as it is forced to slow at the downstream end of a screen. The super-elevated flow creates additional head at that portion of the screen resulting in excess flow (and elevated velocities) through those areas. For this reason, **true water velocities** approaching screens in large installations should not exceed about 2 feet per second unless careful consideration of the flow distribution, and possibly a physical model, are used to anticipate flow conditions at the screen.

3. Guide Walls

Guide walls can be used in canals to align and distribute flow, and also for riverbank and reservoir screens to create appropriate approach and sweeping velocities. Keep in mind that diversions and guide walls can change river hydraulics, potentially altering the streamline and sweeping flow.

4. Baffles

Baffles located immediately behind (downstream of) the screen mesh can be used to control and balance flow through the screen. Adjustment of the baffles can correct the hydraulics in areas of concentrated flow and high velocity (i.e., hot spots). Baffles are often an array of plates that can be adjusted to alter the open space between them. Generally, a baffle system is needed in off-channel medium or larger plate screen facilities, where "piling up" of flow at the downstream end of the screen would otherwise create uneven flow distribution.

Baffles will not correct an uneven distribution of flow across the approach channel. In these situations, flow deflectors in the canal upstream, or a realignment of the approach channel, might be necessary to correct approach flow problems at a screen face.

5. Porosity Boards

Porosity boards are commonly used to control deposition of fine sediment in front of drum screens, thereby protecting the screen seals. These locally increase flow velocity, keeping fine sediment in suspension. Guide slots should be included in the design of the screen bays to allow deployment of the boards if they are found to be necessary during screen operations.

D. Structural Features

1. Trash Rack

Trash racks collect coarse debris that might damage the screen or create a blockage in the **bypass system**. A typical design includes a pipe or bar rack with a vertical angle of approximately 45 degrees. The bar spacing is determined by site factors, including the type of debris encountered at the site, and local biological considerations. Contact the local WDFW Area Habitat Biologist for these considerations (Appendix B). Typically, between-bar spacing ranges from four to eight inches.

For ease of cleaning, intermediate support bars should be located at least 18 inches above or below the normal operational water surface, where debris accumulates. Locating support bars on the downstream side of the rack also allows easier cleaning.

For large facilities, trash racks that cannot be cleaned manually at least daily should be equipped with an automatic rack-cleaning device. Both a timer and a head loss controller should actuate trash rack cleaners. For manual cleaning, an access walkway with appropriate safety rails and consideration for off-site trash removal (e.g., security fence gates and vehicle access) should be provided.

2. Head Gate

Head gates can be an important feature for off channel screening facilities. They provide protection against flooding and sediment intrusion, the ability to control flows and WSE, and de-watering the facility for maintenance. Designs that include down-opening capabilities can provide greater protection against sediment intrusion than the more common up-opening gate. Headgates should be designed to avoid damage to migrating fish. Potential injury can result from operating the gate as a sluice with a narrow opening and high velocities through the slot. Another condition to avoid is passing fish over a gate with a large vertical drop onto a shallow concrete or rock apron.

IV. FISH BYPASS SYSTEM

Off-channel screen systems include bypasses that return fish to the stream channel. As discussed in Section II.I, the screen and bypass must work in tandem to move out-migrating salmonids with a minimum of injury or delay.

Occasionally there will be biological reasons for providing upstream fish passage through the **bypass system**s. In these cases, the trash rack and head gate structures must also be designed for upstream passage. Adult fish passage criteria apply to each of these facilities in addition to the screening criteria described in this guideline.

A. Bypass Entrance Geometry

The entrance to the bypass is one of the most critical elements of the screen design. The typical geometry of a bypass is a vertical slot at the downstream end of the screen. The screen and bypass should be oriented so the screen terminates at the bypass entrance and the flow approaching the screen is not forced to turn as it enters the bypass.

Bypass width is determined by a number of factors, including the minimum flow (5% of diverted flow) and hydraulic criteria, and considerations of sediment and debris management. In any case, 12 inches is the minimum allowable bypass width.

Current bypass design often includes a flume section long enough to accommodate an adjustable up-sloping weir, followed by a downwell. This configuration has several advantages, including **bypass flow** control, continuously accelerating flow up the ramp that effectively guides fish, followed by a drop into the downwell that captures the fish and prevents them from moving back to the screen, and improved transport of debris through the system.

(Figure 11 – ***Bypass design drawing***)

Juvenile salmonids often avoid sudden changes in lighting conditions. Typically, bypass entrances are open to full daylight, transitioning to partial shade in the flume section, due to grating used for walkways. There has been no documented observation of fish avoiding bypasses with this configuration.

B. Bypass Entrance Velocity and Bypass Flow

Depending on site conditions, it may not be possible to provide optimal **bypass flow** conditions throughout the entire season of diversion. **Bypass system** functioning is most critical during smolt out migration, when delays can affect survival. It is important to identify the out migration period during pre-design and design for the best possible conditions during that period.

The key to creating optimal bypass conditions is the availability of adequate flow for operating the bypass. Optimally, flow velocity at the bypass entrance is at least 10 percent greater than the velocity approaching the entrance and velocity through the bypass channel continues to increase. To accomplish increasing velocity through the bypass channel, the channel cross-section must be continuously reduced. This is commonly achieved by the use of an adjustable up-sloping weir gate (Note: prints of up-sloping weir gates are available from WDFW – see Appendix B).

NOAA Fisheries criteria identify a minimum bypass entrance width of 12 inches for diversions of 3 cubic feet per second or less, and a minimum width of 18 inches for all larger diversions. The bypass entrance must extend from the floor to the canal water surface. Additionally, bypasses must be provided with independent flow control (e.g., adjustable up-sloping weir, or check boards).

Typically, **bypass flow** passes over a weir and into a downwell. If using an adjustable up-sloping weir, the maximum slope of the ramp should not exceed 2:1. This slope, along with the depth of the water at the entrance, will determine the length of the bypass channel. Ramps in water depths less than about two feet are not practical. As discussed in Section II.I, multiple bypass entrances should be used if the sweeping velocity will not move fish to the bypass within 60 seconds., During low flow periods this may require more flow than is available for bypass operation. Secondary screens can be used to reclaim part of the primary **bypass flow**.

C. Downwell

Bypass flow passing over the control structure in the bypass channel drops into a downwell prior to entering the conduit that will return it to the main channel. The spill over the weir should not strike the downwell walls or floor. The downwell width should be greater than the weir crest to ensure that the spill does not contact the sidewalls, and the downwell length sufficient to allow the spill to fall directly into the pool. . A minimum pool depth of 1 foot should be provided under low flow conditions.

Fish can be trapped or injured by excessive turbulence, particularly where debris is present. Turbulence increases with flow rate and height of drop, and decreases with the volume of the downwell pool. It is important to provide sufficient volume in the downwell pool to dissipate enough energy that fish can safely exit. The amount of energy dissipated in a given volume of water, **Energy Dissipation Factor** (EDF), is expressed as foot-pounds per second per cubic foot (ft-lbs/s/ft^3). EDF is calculated as follows:

$$EDF = \gamma\ Q\ H / V$$

where: γ = unit weight of water (62.4 pounds per cubic foot)
Q = flow in cubic feet per second
H = total head (including velocity head) of flow entering the downwell in feet
V = effective volume of the plunge pool in cubic feet

Unfortunately, an allowable degree of turbulence has not yet been quantified. Based on observations of existing downwells, the suggested EDF should not exceed the range of 30 to 50 ft-lbs/s/ft^3 during bypass operation.

D. Bypass Conduit

The bypass conduit is the component of the **bypass system** that carries fish and debris back to the main channel. It may include pipe, drop structures, channels, and flumes. Plastic pipe (such as PVC and HDPE) is the most common material used for bypass conduit. Specific guidelines for closed bypass conduit are included in section I of the NOAA Criteria/Guidelines above.

Other design considerations include the provision of cleanout ports in bypass pipes greater than 150 feet in length, and the need for vents to allow trapped air to escape. Air vents are commonly located close to the inlet of the bypass pipe.

Additional downwells are sometimes used in bypass systems to quickly reduce the WSE between the screen structure and the ultimate discharge location. Occasionally, site conditions create the opportunity to use **bypass flow** in open channels that function as side channel habitat. Usually, these involve utilizing an existing natural channel feature in the floodplain. If adequate **bypass flow** exists to use in an open channel, a fisheries biologist familiar with the stream system should be consulted before choosing this option.

E. Bypass Outfall

The last step of successful screening is returning healthy fish to the main channel. Design considerations include providing a safe return to fish spilled from the bypass, deterring predation at the outfall, limiting attraction of adult fish to the bypass outflow, and also selecting a stable location.

The bypass outfall should be located at the ordinary high water elevation. Consideration must be given to creating safe bypass outfall conditions throughout the range of flow occurring during the diversion period. In stream channels that undergo significant dewatering during low flow, it may be necessary to locate the outfall where the **thalweg** is adjacent to the bank to ensure safe return for the bypassed fish. To protect fish from injury, outfalls discharging above the water surface of the stream should be located where an appropriate pool depth exists throughout the operating period to buffer the fall. Depth of pools must consider the likelihood of filling with sediment and bedload.

In order to protect fish, the impact velocity of the outfall jet should not exceed 25 feet per second. This velocity limitation protects fish from damage due to shear between the spilling water and the water in the receiving pool.

The outfall area should be selected and/or designed so it deters predation. Fish should be released into areas with a strong downstream current, without eddies or reverse flow, limiting the potential for predator habitat. At the outfall, the natural river velocity, during smolt migration, should be at least 4 feet per second in open water to minimize the holding of predators. It is important that there be cover habitat available to fish exiting the bypass. Depending on the stream character at the outfall, it may be difficult to achieve in design both flow depth and the high velocity preferences. For instance, in high gradient streams, the flow depth at low flow is often most critical, though in large rivers avoidance of predator habitat may be of greater importance.

Adult fish may be attracted to the bypass outfalls where there is significant flow, high velocity and/or plunging flow. In these cases (typically at large diversions), outfall design should assume that fish will be attracted, and include provisions to protect their health.

Spillways upstream of the screen facility also act as a **bypass system** and should be designed to provide a safe route back to the stream. Typically, this would be an unobstructed channel feature discharging to the stream channel.

V. SCREEN CLEANING SYSTEMS

A. Trolley Brush Cleaning
The trolley and brush cleaning system is commonly used for vertical flat plate screens. With this type of installation, the trolley and brush are pulled along the face of the screen by a cable drive system. In a typical installation, the brush (brushes) hangs vertically from an arm that is attached to a trolley. The trolley hangs on a rail along the screen structure deck and is pulled the length of the screen being cleaned. A second pivot at the connection between the trolley arm and the brush arm allows the brush to freely swing against the screen face and to pivot to match the vertical alignment of the screen face. A counterweight on the outside face of the trolley forces the brush against the screen face. The brush extends the full height of the screen face. A roller is commonly mounted at the bottom of large brushes to roll along the face of the screen and support the brush away from the face. The technical portions of a typical cleaner system consist of a 220 volt motor, gearbox, and programmable logic controller (PLC) for controlling the cycle and speed of the cleaner.

The trolley brush can also be installed as a supplement to high-pressure water or air spray systems for additional cleaning during high debris loads. The trolley and brush mechanism must be protected from both the impact and accumulation of larger debris and, therefore, requires an effective trash rack.

(Figure 12 – ***Trolley Brush Cleaner – show sequence***)

B. Water Jet Cleaning
A water jet cleaning system typically consists of a pump and water delivery components. With the water jet cleaner the delivery components are located on the backside of the screen. Water jet cleaning systems have been successfully used on flat plate screens, pump intake screens, and vertical traveling belt screens. They have also been used as a supplemental cleaner on drum screens at sites with high debris loads, and have been used effectively in ice removal during winter operation.

(Figure 13 – ***Water Jet Cleaner***)

C. Airburst Cleaning
Airburst cleaning systems consist of a charging system, air storage, and air delivery components. They operate by storing large volumes of compressed air and then using that air to either create an airburst at the screens, or drive water out of a storage system to the screens. Automatic controls for these systems should include a momentary 'startle burst' of compressed air at the beginning of the cleaning cycle that will cause fish to move away from the screen. Airburst cleaning systems have been successfully used on flat plate screens, pump intake screens, and vertical traveling belt screens.

Design features include sizing the compressor and air pressure tanks to fit the rate and duration of air flow for cleaning. Sites with significant debris loading may require larger compressors and/or additional pressure tanks so the length of time between cleaning cycles can be minimized.

Air is dispensed through a pipe manifold behind the screen, which can be divided into separate screen bays and activated sequentially beginning at the upstream end. This prevents debris from one section clogging a downstream screen section that was just cleaned. Size and spacing of nozzles in the manifold are crucial design features to ensure cleaning the entire screen, rather than small local circles of clean screen.

(Figure 14 – ***Airburst Cleaner***)

D. Pump Screen Cleaning

Pump screen cleaning systems, whether using pressurized water or air, are typically available from commercial sources as off-the-shelf components. Systems that utilize water or a combination of water and air for the cleaning system require closer manifold lateral and hole spacing as well as more manifold supply connections and larger lateral piping, compared to utilizing just air. The supply for these systems includes both pumps and air compressors and is more complicated to design and control. An eductor (ejector) is used to entrain air into discharging water where combination operations are used. These systems are designed to be dual purpose and allow air only operations as a backup to the water or combination operations. Due to the possible variations in these systems, it is not possible to develop design standards that cover all options available.

VI. DRIVE SYSTEMS

A. Electric
Electric drive systems are the type most commonly used to power new **fish screen** installations. Electric motors ranging from one-sixth to three-quarters horsepower are generally used. These motors are typically attached to a reduction gearbox, which in turn drives the drum or belt screen, or plate screen cleaning system. Motor gearbox drive systems are relatively inexpensive and very durable.

B. Paddlewheel
Paddlewheel powered screens were the standard on the first generation of **fish screen**s (1930s), and continued into the early 1960s when electric motor/gearbox systems became the standard. Paddlewheel design in recent years has been refined and is a viable source of power for driving screening devices where electricity is unavailable. Capital costs are somewhat higher than conventional electric powered sites, but there are obvious cost savings in long-term operation and maintenance. Paddlewheels transfer power to the screen by either mechanical or hydraulic drive systems. Paddlewheels can be relatively efficient, but still require hydraulic head that is not required with electric drive systems.

C. Hydraulic
Hydraulic systems consist of pump/motor combinations with a variety of components (filters, pressure relief valves, flow controls, and speed controls). Paddlewheel hydraulic systems have been used primarily on drum screen facilities, but also on plate screens with reciprocating gang brush cleaning systems. This type of system is relatively new (developed by the WDFW Yakima Screen Shop in the early 1990s) but has proven to be extremely reliable and is now being used by screening programs in adjoining states.

D. Solar
Solar is a viable source of power for smaller diversion screens. Because solar powered screens are not designed for continuous operation, they are typically used where debris loading is low. These systems are comprised of a solar collector, storage battery(s), programmable timer, and direct current gear-motor.

VII. OPERATION AND MAINTENANCE

Once built, all facilities should have an operation and maintenance plan to ensure proper flow through the screen and bypass and the clearing of debris. For a **fish screen** to adequately protect fish, attention to operation and maintenance detail is critical.

A. Operation and Maintenance Manual

An operation manual that guides the management of the **fish screen** facility should be developed. This manual should include:

- Designer operating criteria (DOC) – at a minimum the DOC should include the design flow, water surface elevations, and bypass weir rating chart, along with other pertinent operating criteria, such as **gantry crane** load ratings, electronic controls operation, etc. All operations should be based on staff gages, visible marks on the facility, or other easily identified parameters;
- Required operational procedures for start-up and shut-down;
- Contingency plan for emergency repair;
- Required maintenance – procedures (per manufacturers specifications) for the major components of the facility; and
- Annual inspections – inspection checklist for the facility.

When it is necessary to drain the canal for maintenance, at the end of the irrigation season or in the event of an emergency, fish in the canal must be directed back to the main channel. If a canal is sloped sufficiently and drains completely, fish can be routed out the bypass. This requires that the canal be drawn down gradually so that fish can volitionally exit. Depressions in the canal or structure where fish might become stranded should be inspected and fish may have to be carried or herded to the bypass. Prior to dewatering of the canal, the WDFW Area Habitat Biologist should be contacted. These procedures should be outlined in the operation manual.

An example operation manual for a drum screen facility is provided in Appendix E.

B. Routine Inspection and Maintenance

Inspection and maintenance must be provided on an as-needed basis to ensure proper functioning of the screen system. The timing and frequency of such visits will depend on site conditions, including sediment and debris loading throughout the diversion period. The operating water surfaces and the bypass pipe entrance and exit (outfall) should always be checked during each site visit. Headgate and bypass weir adjustments, debris cleaning, and sediment management may be needed. The screen surface should be checked for holes, dents, or cracks on a regular basis. Spare parts of critical mechanisms, or that are difficult to stock, should be kept in a readily accessible location or on site.

C. Corrosion Control

A corrosion control system for a **fish screen** can significantly increase the life of a facility depending on the water chemistry of a site. Providing isolation of dissimilar metals will prevent the electrolysis process that results in corrosion. Neoprene or HDPE washers and silicon bolt sleeves should be used when attaching screen mesh to the structural frame of the screen. Sacrificial anodes (e.g., magnesium alloy or zinc) should be used on all screening devices that are constructed of dissimilar metals or are routinely submerged in water. These anodes are welded directly to the screen structural frame and works by providing a more attractive location for electrolysis and corrosion to occur.

Metal paint coating (e.g., surface-tolerant epoxy, thermoplastic powder coating) is designed for corrosion control, if applied correctly. Screen structural frames with a 12-mil (1-mil = 0.001 inch) coating profile have not sustained significant corrosion after 12 to 15 years of operation compared to those with 8-mil coating or less. It should be noted that all metal paint coatings need to be examined on a yearly basis and repaired, if necessary, to protect metal integrity. Hot-dip galvanizing is also a common corrosion protection coating used on various screen facility components (e.g., **gantry crane**, handrail, walkway, safety ladder), but at a much thinner profile (2.3 oz/ft^2 minimum).

D. Winter Operation

In some locations, freezing conditions have to be considered for screen operation during winter months. **Frazil ice** can quickly clog screens, causing loss of flow to the diversion and leading to potentially damaging conditions. Screens may be located in heated enclosures for winter diversion in cold weather situations. Another technique that has been used successfully, in order to provide small quantities of winter stock-water, is to shut off screen or cleaning system and allow the canal to freeze at the full canal water surface. The frozen upper layer insulates the flow below. To prevent damage, the screen(s) should be shut down prior to freezing conditions.

For plate screens that will be operated during the winter, the metal portions of the screen and frame should be isolated below water (i.e., sumped) so the cold air temperatures are not transmitted through the metal. Some hatcheries that divert surface water in the winter inject warmer groundwater from wells into the canal just upstream of the screen to prevent **frazil ice** from forming and clogging the screen. Drum screens may require both heated enclosures and injected groundwater.

VIII. EFFECTIVENESS AND COMPLIANCE MONITORING

A. Hydraulics
Following the construction of a **fish screen** facility, water velocities should be measured at critical locations to evaluate whether it is operating as designed. Critical monitoring locations of flow and velocity are at the upstream end of the screen facility, along the entire screen face, and at the entrance to the bypass channel.

To examine the **approach velocity**, **true water velocity** measurements should be taken three inches in front of the screen face to avoid any hydraulic effects of the screen face itself. Where the velocity measurement is taken, the angle of the flow should be measured so the approach and sweeping velocity components can be calculated. To verify uniform **approach velocity**, a series of measurements should be taken along the screen at a depth of 0.6, the depth of submergence (measuring from the bottom).
If flow distribution baffles are included in the facility, they will need to be iteratively adjusted and **approach velocity** measured, until uniform flow distribution is achieved.

The canal should be initially operated throughout its diversion range to verify that the screen submergence and other hydraulic design criteria can be satisfied. Staff gage readings and flow control operations must be checked for consistency with the operation manual. The operation manual can then be revised as needed to reflect actual operating conditions.

IX Additional Screen Desgin Information

Bates, K. B. 1988. Screen Criteria for Juvenile Salmon. Washington Department of Fish and Wildlife Memo. June, 1988.

Bell, M.C. 1991. Fisheries Handbook of Engineering Requirements and Biological Criteria, Fish Passage Development and Evaluation Program. U.S. Army Corp of Engineers, North Pacific Division. Portland, OR.

Clay, C. H. 1995. Design of Fishways and other Fish Facilities. Lewis Publishers. 2nd Ed. 248pp.

Pearce, R.O., R.T. Lee. 1991. Some Design Considerations for Approach Velocities at Juvenile Salmonid Screening Facilities. American Fisheries Society Symposium 10: pp 237-248.

Smith, L.S., L.T. Carpenter. 1987. Salmonid **Fry** Swimming Stamina Data for Diversion Screen Criteria. Final Report to Washington State Departments of Fisheries and Wildlife. 217 pp.

APPENDIX A: GLOSSARY

Active Screen – An **active screen** is one with an automatic cleaning device. Juvenile **fish screen**s equipped with proven cleaning capability, and which are automatically cleaned as frequently as necessary to keep the screens free of any debris that will restrict flow area. An **active screen** is the required design in most instances.

Anadromous – Anadromous fish are those species that migrate from the sea to freshwater in order to reproduce.

Angled Orientation – **Angled orientation** is the acute angle of a **fish screen** relative to the axis of the approaching flow.

Approach Velocity – The **approach velocity** vector component of the **true water velocity** that is perpendicular (normal) to the face of the screen. It is a function of the diversion flow rate (expressed in cubic feet per second), and the **effective screen area** (square feet). The vector component of canal velocity that is perpendicular to and upstream of the vertical projection of the screen face is calculated by dividing the maximum-screened flow by the **effective screen area**. An exception to this definition is for end-of-pipe cylindrical screens, where the **approach velocity** is calculated using the entire **effective screen area**.

Bypass System – The fish **bypass system** is the device that collects fish from in front of the **fish screen** and safely transports them back to the stream. The fish bypass might consist of an entrance/flow control section and a fish conveyance channel or pipeline. For the case of a screen in a river, the bypass is the river itself.

Bypass Flow – The **bypass flow** is the flow required to operate the fish bypass for effective and safe fish passage. Fish **bypass flow** requires a positive hydraulic head differential between the water surface at the screen and the water surface at the bypass outfall.

Effective Screen Area – The **effective screen area** is the vertical projections of the gross submerged area of the screen that passes water, excluding areas not cleaned or blocked by major structural members. (This is not the **open screen area**.)

Energy Dissipation Factor – The **energy dissipation factor** is the amount of energy dissipated in a unit of water. Units are represented as foot-pounds per second per cubic foot ($ft\text{-}lbs/s/ft^3$).

Entrainment – **Entrainment** is the voluntary or involuntary movement of fish through, under, or around the **fish screen** and into the water supply that is supposed to be screened. Entrainment is a function of screen mesh opening size and gaps between the screen frame and canal structure walls.

Fish Screen – A **fish screen** (fish guard) is a device installed at a **surface water diversion** to prevent death or injury of fish. Effective **fish screen**s physically exclude fish from entering the diversion. **Fish screen**s are categorized by diversion type (gravity, pump, instream, and canal), and debris cleaning function (active, automatic, passive, manual cleaning).

Fork Length – **Fork length** is the straight-line distance measured from the tip of the nose to the fork of the tail of a fish.

Frazil Ice – Ice crystals that form in super-cooled water.

Fry – Fry are salmonid juveniles less than 60 mm **fork length**.

Gantry Crane – A crane that lifts a **fish screen** with a hoist, which is fitted on a trolley and moves horizontally on a rail fitted under a beam.

Impingement – **Impingement** is the entrapment of fish onto an intake screen. **Impingement** occurs when a fish is held in contact with the intake screen by the pressure of the flowing water and is unable to free itself. It may be temporary or permanent.

Nappe – A sheet of water flowing over a dam or similar structure.

Open Screen Area – The sum of the area of all open slots, mesh, or perforations on the screen available for the free flow of water. The **open screen area** is used only to calculate the porosity of the screen, not the **approach velocity**.

Passive Screen – A **passive screen** is one without an automatic cleaning device (opposite of **Active Screen**)

Surface Water Diversion – An artificial structure or installation for diverting water from a stream, river, or other surface water body for any purpose (municipal, industrial, agricultural, hydroelectric generation, etc.). An infiltration intake with direct continuity to the surface water is considered as a **surface water diversion**. The substrate in this situation functions as the screen.

Sweep Velocity – The sweeping velocity is the vector component of the **true water velocity** that is parallel to the face of the screen. It is a function of the diversion flow rate (expressed in cubic feet per second), the **angled orientation** and the **effective screen area** (square feet).

Thalweg – A line drawn to join the lowest points along the entire length of a streambed in its downward slope, defining its deepest channel.

True Water Velocity – The **true water velocity** is the actual velocity. In the context of fish protection screens it is usually the actual velocity of the flow approaching the screen.

APPENDIX B: FISH SCREEN CONTACTS IN WASHINGTON STATE

Washington Department of Fish and Wildlife

WDFW **Fish Screen** Technical Assistance

Eric Egbers	Environmental Specialist	3705 W. Washington Ave. Yakima, WA 98903 (509) 575-2734
Pat Schille	Environmental Specialist	3705 W. Washington Ave. Yakima, WA 98903 (509) 575-2735
Bruce Heiner	Environmental Engineer	1300 NE Henley Ct., #5 Pullman, WA 99163 (509) 332-0892
Gina McCoy	Environmental Engineer	350 Bear Creek Rd. Winthrop, WA 98862 (509) 969-9557

Washington Department of Fish and Wildlife
WDFW Area Habitat Biologists

Region 1	Eastern	2315 N. Discovery Place Spokane, WA 99216 (509) 892-1001
Region 2	North Central	1550 Alder St. NW Ephrata, WA 98823 (509) 754-4624
Region 3	South Central	1701 S. 24th Ave. Yakima, WA 98902 (509) 575-2740
Region 4	North Puget Sound	16018 Mill Creek Blvd. Mill Creek, WA 98012 (425) 775-1311
Region 5	Southwest	2108 Grand Blvd. Vancouver, WA 98661 (360) 696-6211
Region 6	Coastal	48 Devonshire Rd. Montesano, WA 98563 (360) 249-4628

Washington Department of Ecology
Water Rights

Northwest Region	Bellevue	3190 160th Ave. SE Bellevue, WA 98008 (425) 649-7000
Southwest Region	Lacey	300 Desmond Drive P.O. Box 47775 Olympia, WA 98504

		(360) 407-6300
Central Region	Yakima	15 W. Yakima Ave. Ste. 200 Yakima, WA 98902 (509) 575-2490
Eastern Region	Spokane	N. 4601 Monroe, Ste. 202 Spokane, WA 99205 (509) 329-3400

APPENDIX E: SCREEN OPERATION MANUAL

These designer operating criteria (DOC) and operation and maintenance (O&M) manual are provided as an example. This example is for a drum screen facility with a diversion flow of 40 cubic feet per second. Elevations referred to should be posted at the site with staff gages. Additional operating procedures for a site such as this might also include **gantry crane** operation, backup generator test and operation, and headgate operation.

DESIGNER OPERATING CRITERIA

The Naches-Cowiche canal diverts from the Naches River at the Naches-Cowiche diversion dam, which is approximately 4 miles upstream from the confluence of the Naches River and the Yakima River, and approximately 1 mile west of Yakima, Washington.

The normal diversion period for the Naches-Cowiche canal is from March through October, and the design flow for the screens is 40 cubic feet per second (cfs). There are no winter (e.g., stock water) flow needs.

In addition to the screens and bypass, a wing wall was added to the right abutment of the dam to assist in blocking fish from passing upstream of the dam.

For drawings of the original structures and the current structures, and for information on materials, refer to specification number 8-SI-10-05460.

SCREEN AND STRUCTURE

Floor elevation
  Upstream of screens – Elev. 1161.1
  Downstream of screens – Elev. 1161.6

Top of wall elevation – Elev. 1169.0

Screen quantity/size – 2ea / 5′ diameter by 12′ long

Screen design flow – 40 cfs

Screen design velocity – 0.4 fps at 85% screen submergence

Design water surface elevation/screens submergence
  Low water – 0.65 x screen diameter – Elev. 1165.25 or 3.65′
  High water – 0.85 x screen diameter – Elev. 1166.25 or 4.65′

Screen design rotational speed – 3.0 ft/min screen surface speed

BYPASS STRUCTURE

Bypass maximum design flow – 10.4 cfs

Bypass slot design velocity – At the 1.5′ wide slot water depth is 5.15′ and therefore velocity is 1.35 fps. At the overflow gate the water width is 1.5′ and therefore the required depth for 10.4 cfs is 1.6′ using [q = clh (3/2), where c = 3.33].

The invert of the bypass pipe at the outlet end was set at elevation 1157.0, the top of the pipe at 1158.5, which corresponds to a river flow of about 200 cfs with an exceedence of 75 to 80 percent.

Bypass weir flow table:

Depth	0.25′	0.5′	0.75′	1.0′	1.25′	1.6′
Flow cfs	0.6	1.8	3.2	5.0	7.0	10.4

STRUCTURAL

Allowable flume invert floor loading
Uniform load – the floor was not designed for any specific loading

Design wall load
The flume retaining wall is 7.9′ high and was designed to withstand saturated compacted backfill (85 lbs/ft^3) to a height of 8′ on the outside face with a safety factor of 1.7.

The wing wall is 16′ high and was designed to withstand saturated compacted backfill to a height of 16′ on the inside face (the backfill side).

Floating limitations – the screen structure may be dewatered with the adjacent ground water up to elevation 1164.1 (4.9′ below the top of the walls) with a safety factor of 1.5, and to elevation 1165.6 (3.3′ below the top of the walls) with no safety factor.

Allowable screen walkway loadings
Grating walkway uniform load – 250 lbs/ft^2 live load

Allowable bypass walkway grating loadings
Load rating – H-20 (8,000 lbs)

WEIGHTS OF REMOVABLE ITEMS

Drum screen with frame – 3,300 lbs

Grating –	type	weight (lbs/ft^2)
	¾″ deep	7.0
	4″ deep	48.0

OVERHEAD SCREEN SUPPORT

Load rating – 4,400 lbs
Safety factor – 1.5 for the 4,400 lbs load, and 2 for 3,300 lbs screen and frame weight.
Design lifting setup – Double pick point on beam; double hoist.

OPERATION AND MAINTENANCE

OPERATION PROCEDURES

SPRING TURN-ON

1. With the down stream canal gates closed slowly open the head gate and allow the water surface elevation in the screen bay area to reach 75% submergence on the screens.
2. Slowly open the down stream canal gates and adjust the head gate to charge the canal while maintaining a minimum of 65% submergence on the screens. At this time the screens should be operational.
3. Open the bypass control gate to its full limits.
4. Readjust the head gate control and canal gate control to achieve the designed water surface elevation specified in the designer operating criteria, which are included.
5. Adjust the control gate in the fish bypass down-well entrance to the designed level specified in the bypass weir flow table, thereby providing fish passage back to the river.
6. Check the bypass outfall at the river to see that it is unobstructed and free flowing.
7. After setting fish **bypass flow** it may be necessary to readjust the head gate to achieve the desired canal flow and **fish screen** water surface elevation.

DAILY

1. Clean trash rack to prevent head loss and potential fish **impingement**.
2. Adjust head gate to maintain normal diversion flow.
3. Check facility for proper operation, vandalism, or mechanical failures. Replace or repair failed components as needed.
4. Adjust bypass control gate for proper flow (see chart above).

MAINTENANCE PROCEDURES

PRE-SEASON

1. Inspect screen, gantry, walkways, control gates, electrical system, safety handrail and fencing for wear, breakage or vandalism. Repair as needed.
2. Inspect the screen's side and bottom rubber seals for gaps, tears, or wear which allow openings greater than 3/32 inch; this is the maximum allowable opening, per NOAA Fisheries and WDFW criteria. Repair as needed.
3. Lube all bearings and universal joints (any multi-purpose grease). Check oil level in gearboxes; fill as needed with manufacturers recommended gear oil.
4. Lubricate the drive chain with an approved (environmentally friendly mineral oil) lubricant to ensure durability and long life.

DURING SEASON

1. Lube bearings and universal joints monthly.
2. Check gearboxes for leakage; repair leaking seals and refill as needed.
3. Add an environmentally friendly mineral oil to chain well as needed.
4. Perform scheduled maintenance per manufacturers' recommendations.

POST – SEASON

1. Raise hinged portion of inclined ramp and open bottom gate on the fish bypass gate to allow head-gate leakage to return to the river.
2. If there is no diversion head gate, install check boards in the slots provided in front of the screen structure to isolate the screen from the river to prevent flood damage.
3. Secure the site to protect it from other damage (e.g. falling trees, vandalism, etc.).

END OF SEASON SHUT DOWN

1. At the end of the irrigation season it will be necessary to ramp down your diversion flow to allow fish to voluntarily migrate back to the river through the fish bypass. The length of this procedure may take one to several days depending on the length of the screen facility from the point of diversion at the river.
2. Notify your local WDFW Area Habitat Biologist the date you intend to shut down so that they can assist if fish salvage is necessary.

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