FISH PROTECTION SCREEN GUIDELINES FOR WASHINGTON STATE

April 25, 2000
Washington Department of Fish and Wildlife

TABLE OF CONTENTS

GUIDELINES FOR SALMONID HABITAT PROTECTION AND RESTORATION

As part of Washington State's salmon recovery strategy, the Washington State Departments of Fish and Wildlife, Ecology, and Transportation, are currently developing guidelines for salmon habitat protection and restoration. The standards and guidelines 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 will make up the guidelines. Additional subjects for which guidelines have been (as of April, 2000) or will be developed are:

- Bank protection – *Integrated Streambank Protection Guidelines* is currently being developed.
- Fish passage at road culverts – *Fish Passage at Road Culverts* is available.
- Fishways guidelines are currently being developed.
- Sand and gravel removal guidelines.
- Estuary restoration guidelines.
- Shoreline salmonids habitat restoration guidelines.
- Freshwater habitat restoration guidelines.
- Channel design guidelines.

The guidelines will be published on the web when complete. Parts of the guidelines will also 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 under technical assistance at http://www.wa.gov/wdfw/habitat.htm.

ACKNOWLEDGEMENTS

Funded by WDFW, SRFB, and WSDOT as part of a project developing Guidelines for Salmonid Habitat Protection and Restoration.

Authors Bryan Nordlund, Ken Bates

Edited by Tony Whiley

INTRODUCTION

Fish protection screens are devices installed at surface water diversions to physically preclude passage of fish into the intake and injury of fish at the intake. This document presents criteria and practical considerations for the design of fish protection screens including applications for hydroelectric facilities, irrigation, municipal, and industrial water withdrawal projects. The major objective of the Fish Screen Guidelines is to highlight important design elements that should be considered in the design of fish screens at water diversion projects to provide the safe downstream passage of migrating juvenile salmonids.

This document is a guideline only. It is intended to describe how to comply with specific design criteria or other fish protection requirements. Design criteria generally accepted by Washington Department of Fish and Wildlife (WDFW) and Northwest Region of National Marine Fisheries Service (NMFS) are included as a guide. Design criteria and requirements for a specific site or facility should be verified directly with those agencies. Contacts are provided in Appendix X *Fish Screen Contacts in Washington State.* These guidelines cover common situations where fish screens are required; different or additional requirements may be stipulated for specific installations.

This document refers to specific NMFS requirements. This document is not a NMFS document and therefore is not intended to be a comprehensive or necessarily current reflection of policies or guidelines of that agency. Detailed NMFS and WDFW fish screening criteria should be applied. They are available on the web at http://www.wa.gov/wdfw/hab/engineer/fishscrn.htm and http://www.nwr.noaa.gov/1hydrop/nmfscrit1.htm respectively. NMFS has additional specific pump screen criteria at http://www.nwr.noaa.gov/1hydrop/pumpcrit1.htm.

There are many types of fish screens, designed for varying water withdrawal situations. However, they all share common design objectives; to allow the passage of water and the safe and relatively unimpeded movement of fish. Both of these objectives can be met through careful design considerations. The National Marine Fisheries Service (NMFS) and the Washington State Department of Fish and Wildlife (DFW) have set specific fish screen design criteria to protect juvenile salmonids. These criteria span the design process from screen materials, to hydraulic and biological considerations.

FISH SCREEN CONCEPTS, COMPONENTS AND NOMENCLATURE

The following definitions should help the reader understand the following technical detail sections.

This section not yet written.

Exclusion
Entrainment
Guidance
Screen
Approach velocity, sweep velocity
Bypass

Fish Screen Guiding Principles

We are using the concept of guiding principles in the guidelines for salmonid habitat protection and restoration. Guiding principles are general statements that define the objectives from which the specific guidelines are developed. The guiding principles that are the basis of these fish protection screen guidelines are:

- Assume worst conditions of size of fish present (steelhead swim-up fry) and water temperature;
- Use positive exclusion screening to approach 100% effectiveness.
- Use voluntary guidance for migratory fish.
- Use exclusion for non-migrating fish; must be able to voluntarily return upstream.
- Return fish to channel.

These guiding principles are further described and developed throughout this guideline.

Fish Screens: Types and Applications

The first step in the design process is identifying the type of screen and material appropriate to a particular application. This section will discuss the most common types of fish screens used in Washington and their typical applications and limitations. The following screen types are described in this guideline:

- Rotary Drum Screens
- Vertical Fixed Plate Screen
- Vertical Traveling Screen (panel and belt types)
- Non-vertical Fixed Plate Screens
- Pump Screens
- End-of-Pipe Screens
- Infiltration Galleries
- Portable Screens

Fish protection screen applications vary from complex to simple. This guideline does not include all possible styles and details of screens. Most detail is provided for common and complex situations such as mechanically cleaned screens in diversion canals. Less detail is provided for simple screens such as end-of-pipe screens. The reader must decide which details are applicable to the specific facility and situation being considered. For example, details on screen bypasses are not relevant to an end-of-pipe screen submerged in a reservoir. This guideline does not at this time include details of experimental devices such as Eicher or MIS screens or behavioral devices intended to protect fish.

Rotary Drum Screens

The rotary drum screen is a common type of fish screen in the Pacific Northwest (**figure 1**). Water passes through screen mesh that covers a rotating cylinder. The greatest advantage of the drum screen is that, through its rotation, it continuously removes debris. Debris is carried over the screen as it rotates and is washed off the screen on the downstream side. Screen rotation is achieved by an electric motor, paddlewheel, solar drive, or hydraulic motor. It's most current application is in open channel flow situations, such as irrigation ditches. Using a single drum or multiples, rotary drum screens can be used for a wide range of diversions and have been used in Washington at diversions from as low as severalcfs and up to 3,000 cubic feet per second (cfs) or more. Drum screens are generally used in gravity diversion canals but can also be used to deliver water to pumping plants.
The drum screen is very effective in protecting juvenile fish. Studies have found that greater than 98% of juvenile fish encountering a drum screen, designed by current criteria, survive (). A major design parameter for this screen type is its relative submergence. A submergence level between 65% and 85% of the screen diameter is appropriate. A greater submergence increases the potential for fish impingement and entrainment on the screen. At lower submergences, debris is not picked up on the face of the screen.

A disadvantage of the drum screen is, because of its movement, the wear of seals situated on the screen's side and bottom. The failure (or leakage) of the seals can result in fish impingement. For this reason, these screens must be closely monitored and require greater maintenance in comparison to other screen types. A second major disadvantage is the narrow range of submergence described above. 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% of four feet or the difference between 65% and 85% submergence).

Vertical Fixed Plate Screen

The vertical fixed plate screen is also widely used in the Pacific Northwest (**figure 2**). It is simply a vertical flat plate mesh. Fixed plate screens are commonly used for industrial, domestic water supply, and irrigation intakes both at pump and gravity diversions.

Advantages of the vertical fixed plate screen are that they are easy to seal, mechanically simple because there are no moving parts, and require a smaller civil works. For small diversions, these screens can be installed on the bank of a river and, therefore, require no bypass. Fixed plate screens are relatively simple to tightly seal since the mesh is fixed to the structural frame and there are no moving parts or wear surfaces between the screen mesh and the structural frame. However, the removal of debris is an important design consideration for this type of screen and may be more difficult than with a rotary drum screen depending on the type of debris.

Vertical fixed plate screens require a mechanical cleaning system for debris removal. Commonly used cleaning systems include traveling brush cleaners and hydraulic back-spray systems; refer to the section on cleaning systems. The operation of the cleaning system operation is usually triggered by either a timing mechanism that operates the cleaner on a specific time interval or by head loss detection across the screen mesh, or a combination of both.

The flat plate screen can be built in a canal with much less blockage of the canal cross section and flow compared to a rotary drum since screen support piers can be narrow columns instead of having to accommodate the drum diameter as in drum screen structures.

Vertical Traveling Screen (panel and belt types)

Similar to the rotary drum screens, the mesh of vertical traveling screen rotates to remove debris collected on the screen face, depositing it on the downstream side (**figure 3**). Two types of vertical traveling screens are commonly used; panel-type screens, which have individual mesh panels, and belt-type vertical traveling screens which have a continuous belt mesh. In common, both screens are driven by electric motors through a drive shaft at the top and rotate around a parallel idler shaft at the bottom. Vertical traveling screens are generally used for pump diversions.

The primary advantage of the belt screens is they can be installed in deep water. The screen can be built to any length within the structural capacity of the frame, drive, and shafts. Because the screen lifts vertically, there is no limitation on minimum or maximum screen submergence to be effective.

Other advantages of the vertical traveling screen include that they can be installed on a river bank, therefore, requiring no bypass; civil works are relatively compact; they are self-cleaned by rotation of the mesh, they can also be cleaned by jet spray cleaners or brushes for additional cleaning action; and they are commercially available as a standard manufactured product.

Vertical traveling screens have historically been built with horizontal troughs or ledges built onto the face of the screen. The purpose of the troughs is to lift debris and fish up as the screen rotates. A high pressure spray bar near the drive shaft washes the debris into a stationary trough on the deck of the structure. The debris can be collected there for removal. The troughs are problematic for fish protection in that they preclude sealing between the face of the screen and the front of the screen frame at the bottom of the structure.

Panel-type Vertical Traveling Screens

Many of the panel-type vertical traveling screens **(Figure 4)** are not specifically manufactured for purposes of fish protection. For this reason, adapting them for fish protection can be difficult. Many old installations of these screens do not exclude fish because of seal problems inherent in the design. The mesh seal problems are due to the design of the mesh panels that have hinges between them and must articulate when they rotate around the idler shaft at the bottom of the screen. Seals often do not adequately close the gap between the outer frame of the screen and the articulating rigid panels. This situation is hard to identify since the screen is often located in a sump.
An advantage of the panel screens is that individual screen panels can be replaced as necessary instead of replacing the entire screen mesh. A variety of screen mesh types and materials can be used.

Belt-Type Vertical Traveling Screens

As described above, the belt screen **(Figure 5)** has a continuous flexible chain mesh belt that rotates around the drive and idler shafts. Stainless steel mesh is commonly used and there have been successful application of plastic mesh. Disadvantages of the Belt-Type Vertical Traveling Screen are that the screen mesh can be deformed by flow if it is made too wide and not adequately supported from the backside, and as with the panel-type traveling screen, there can be seal problems.

Plastic belt mesh has been installed experimentally on vertical traveling screens recently and appears to be a viable option to steel mesh.

Non-vertical Fixed Plate Screens

Other possible alignments of fixed plate screens include placing them horizontal or sloping; either upward or downward in the direction of the flow.

The advantage of these types of screens is that there are no moving parts and no additional in-river diversion structures are required. Disadvantages include the method of debris removal may not be reliable. In addition, during low flow, fish are passed over shallow depth (or no depth) on the downstream end of the screen potentially causing injury or impingement and therefore, the water surface must be raised to provide successful passage.

Downward Sloping Fixed Plate Screens

The downward sloping screens can either be flat plate **(Figure 6)** or a contoured plate such as the Coanda screen (**Figure 7**). With this design, only a portion of the total flow traveling across the screen passes through it. Flow passing through falls into a canal situated below the screen. Fish are passed over the screen with the remainder of the flow. For this reason, the Coanda screens function effectively, in terms of fish passage, only if sufficient flow depth exists at the downstream end of the screen ensuring continuous movement of fish and debris over the screen. A minimum depth of water should be provided over the entire screen face. That minimum should be based on expectations of size and type of debris, size and condition of fish passing, and potential changes in flow that could reduce the depth to below the desired minimum. To satisfy these minimums, a substantial amount of bypass flow might be required and they must be carefully operated to ensure that the depth conditions are continuously satisfied. Downward sloping screens require at least several feet of head loss to operateThese two constraints limit the application of this type of screen. It is generally used for gravity diversions.

Flow distribution through the flat plate downward sloping screen is often not uniform since the water depth over the upstream end of the screen is greater than over the downstream end. This occurs obviously because water is removed from the column as it passes over the screen. The extra depth at the upstream end provides additional head that drives more water through that portion of the screen. The extra depth and associated flow concentration is often made worse by the hydraulics of the transition onto the screen.

Baffling systems have been placed behind the screen to distribute flow. Reliable and easily operated baffling systems with a wide range of flow have not been developed. Downward sloping screens have been built in segments so, as the flow changes, more or fewer screen segments are operated. Gates upstream of each individual segments controls water over that segment. Each segment is separated from adjacent segments by a short divider wall.

The Coanda feature helps correct the non-uniformity of flow distribution. The Coanda shape is designed to follow more or less the nappe of water as if it were free spilling. By following that contour, the head driving flow through the screen can be more uniform. A Coanda shape can be optimized for one flow; the shape of the nappe will change as the flow changes.

Upward Sloping Fixed Plate Screens

Upward sloping screens **(Figure 8)** are the reverse of downward sloping screens; their profile rises in the direction of the water flow. Water does not drop through the screen; the screen is backwatered from below. Water drops over the downstream end of the screen creating the fish and debris bypass. The downstream end of the screen might narrow gradually to reduce the bypass dimension and therefore the bypass flow. This style of screen is generally used for gravity diversions.

The primary advantage of this configuration is that there is more or less a uniform flow distribution through the screen because the head differential is uniform throughout its area. The screen is relatively simple except for automatic cleaning devices.

A primary disadvantage is that debris is not automatically swept off the screen. It must be scraped off the screen into the bypass. Fish may reject the screen and the bypass. The rejection is often due to the low depth at the upstream and of the screen as it drops into the bypass. Typically a depth of at least a foot is needed to keep fish from rejecting the bypass. Fish may also reject the bypass if the acceleration into it is too great. See the section on bypasses.

The width should be at least eighteen inches and/or sufficient to pass debris likely to be present. There is little if any flexibility in upstream water surface elevation. If the water level drops below the design water surface, the minimum bypass depth criteria is not satisfied; if the water level rises, the excess water is put into the bypass system.

Upward sloping screens might be cleaned with mechanical brushes or air or water burst systems. There is a risk of structural failure if the cleaning mechanism fails and the weight of the water overcomes the structural strength of the screen support frame.

Pump Screens, End-of-Pipe, Fixed Drum, Tee Screens

This is a group of screen styles built as a chamber attached to an end of a pipe. They might be box-shape or cylindrical. The walls are screen mesh and a suction pipe is attached to one wall. They range in size from one-cfs screens attached to small irrigation pumps to large tee-screen installations for fifty cfs or more. The advantages associated with the fixed drum screen are that they provide a good option for deep intakes, they are submersible, and can be equipped with air-burst or water jet cleaning systems. The fixed drum screen is commonly used on the end of a pump intake in a pressurized system **(Figure 9)**. An ideal use of the small pump intake screen, are small irrigation diversions. Many different screen configurations are commercially available. In addition, models are available commercially that meet juvenile salmonid criteria. Some models for small screens (up to 5 cfs) have very efficient water jet cleaning systems.

The disadvantages of this type of screen primarily concern the clearing of debris. The fixed drum screen requires sufficient ambient water velocities to carry debris away from screen site, air burst cleaning systems, another cleaning system used with these screens, may not adequately remove debris accumulations especially from the bottom of the screen.

Infiltration Galleries

Infiltration galleries **(Figure 10)** are perforated pipe manifolds or single pipes buried in a streambed or bank. Water is drawn through the streambed or bank and into the pipe. They are installed in a steep section of a channel such as a riffle, which is maintained free of fine sediment by the hydraulic action of the stream. It is necessary to be in a location where the bed is regularly scoured and thereby cleaned rather in a depositional area such as an artificial pool. Infiltration galleries are generally used for pump diversions but can be use for gravity diversions in steep channels. The screen area is the area of the streambed or bank through which the water flows rather than the area of the intake pipe. The streambed or bank is also the feature that acts as the fish exclusion device.

The primary advantage of infiltration galleries is, when successful, that the stream hydraulics rather than mechanical cleaning devices manages debris and sediment. The primary disadvantage is the risk of being plugged with sediment and/or debris. They are unsuccessful if the appropriate size distribution of sediment is not present, if excess sediment is moving at lower flows, or if constructed in a depositional or unstable stream reach. Once plugged, they are not easily maintained since they are generally buried in the streambed or bank. The failure rate of infiltration galleries is high; likely about 50%. The failures are generally due to a poor understanding of technical design requirements.

Infiltration galleries are usually associated with pump diversions though can be used at gravity diversions where there is adequate head to drive the flow.

FISH SCREEN DESIGN

Fundamental design considerations surrounding the screen are primarily hydraulic; controlling velocities and flows to eliminate impingement or entrainment of juvenile salmon on the screen and to guide juveniles to the bypass system. Velocities surrounding the screen are controlled by, among other factors, the screen orientation and the approach channel configuration. Designing a screen facility based on the fish screen criteria doesn't guarantee that it will protect juvenile fish. In addition, and perhaps the most critical element of the fish screen design, is the implementation of an operations and maintenance program. An effective operations and maintenance program ensures that the flows and velocities the screen were designed for are maintained, that debris collecting on the screen face potentially leading to harmful velocities is cleared, and that seals are fish tight. Simply put, an effective operations and maintenance program ensures the screen operates as designed, allowing water to flow through while fish are excluded and moved safely downstream. These guidelines provide the framework to achieve both of these objectives. In this section pre-design considerations will be discussed. Screen design criteria, which serve as the basis of the fish screen design are presented then design considerations for the bypass system. For screens located away from the parent stream diversions, the bypass is route that delivers fish back to the stream. Then initial information needs and processes that must be confirmed prior to the advancement of the project are listed.

Screen Design Criteria

Washington State Department of Fish and Wildlife and the National Marine Fisheries Service have established fish screen design criteria to protect juvenile fish (salmonids) in proximity to screened water withdrawals from injury, migration delay, or mortality. Those criteria are included in Appendix X of this guideline. These criteria are conservative and are based on providing protection to the weakest swimming species present, in their most vulnerable life stage, under adverse environmental conditions. This is the first of the fish screen guiding principles listed earlier; If protection can be provided at that level, it is expected that nearly all fish that encounter a fish screen designed by these criteria will survive. It is recognized that there may be locations or times of the year for which design for these conditions may not be warranted. It is common for conditions of fish size and water temperature to both be most severe at the same time and likewise to both be less severe at other times. Unless conclusive data from studies acceptable to Washington Department of Fish and Wildlife indicate otherwise, it is assumed that these extreme conditions exist at some time of the year at all screen sites within the state.

The swimming ability of fish was the primary consideration in establishing the criteria. The screen hydraulics are designed to allow fish to voluntarily be guided and/or to escape the screen. This is based on the second guiding principle; use voluntary guidance for migratory fish. Voluntary guidance means a fish is under control and able to voluntarily be guided or move away from the screen. This minimizes the threat of impingement on or entrainment through the screen. Swimming ability, however, varies depending on multiple factors relating to fish physiology, biology, and the aquatic environment. These factors include: species, physiological development, duration of swimming time required, behavioral aspects, physical condition of the fish, water quality, and lighting conditions. Since conditions affecting swimming ability are variable and complex, screen criteria are expressed in general terms and the specifics of any screen design must address on-site conditions.

The primary design considerations of a diversion screen are all hydraulics; providing for the passage of a sufficient quantity of water, consistently, with a minimum of head loss. The fish protection criteria impose no significant restriction on these fundamentals. The criteria are based on the control of velocities surrounding the screen. Screen approach velocity, sweep velocity, bypass entrance velocity are the most critical hydraulic elements of fish protection at a screen. Their criteria will be discussed first followed by additional design considerations for the control of screen velocities.

Approach Velocity

Physical contact with a screen may result in some level of injury to fish and, at worst, death. For this reason, the primary objective in the design of fish screens is to match the swimming ability and behavior of fish to the hydraulic characteristics of the screen and civil works design to minimize the probability of contact with the screen. In other words, the screen is designed so it creates velocities low enough that fish can voluntarily keep themselves from being impinged on or entrained through the screen. Studies of fish biomechanics have led to hydraulic criteria used for approach velocity in fish screen design (Smith, 1988).

The true velocity of the water moving towards a screen can be broken down into two vector components **(Figure 11)**. The velocity component perpendicular to the screen face (rate of water moving through the screen) is known as the approach velocity. The other component, the sweep velocity, is parallel to the screen face. Criteria are provided for the approach velocity to avoid entrainment or impingement and the sweep velocity, to facilitate guidance to the bypass or, if the screen is located in-channel, movement past the screen.

The approach velocity is set at a level that is less than the sustained swimming speed of juvenile fish. Juvenile fish must be able to swim at a speed equal to the approach velocity for an extended length of time to avoid impingement on the screen. The must be able to swim at a speed greater than that to escape the screen and return to the channel upstream. The criteria are set based on juvenile salmonid size and diversion surface water type.

For screens in screens in streams, rivers, and canals with an ambient velocity (velocity of the water past the diversion structure) greater than 0.4 feet per second (fps), the approach velocity criterion is 0.4 fps. For lakes and reservoirs where the ambient velocity is less than 0.4 fps, the approach velocity criterion is 0.33 fps. The ambient velocity in still water can be increased to the 0.4 fps by guide walls or other means within the structure if there is an adequate bypass to return fish to the reservoir or pass them downstream. For the purposes of measurement and compliance, the approach velocity is considered to be the velocity present three inches in front of, and perpendicular to the screen face.

At these levels nearly 100% of fry are protected. The criteria are maximum approach velocities, levels that are not to be exceeded anywhere on the face of the screen. The intake structure and/or fish screen shall be designed to assure that the diverted flow is uniformly distributed through the screen so the maximum approach velocity is not exceeded.

The approach velocity at a screen is calculated based on the **effective screen area**. This takes into account the area covered by seals and other potential obstructions and any area that is not submerged. The effective area is the gross area of the screen, not the open area of the mesh. The approach velocity is therefore calculated by dividing the screened flow by the effective screen area.

Sizing the Screen - Total Submerged Area

The screen area is determined based on meeting the approach velocity criteria. To calculate the required screen area (square feet) for or a screen in a canal with a required approach velocity of 0.4 fps, divide the design flow (cubic feet per second) by the maximum approach velocity, 0.4 fps. The major assumptions of this design approach are that the flow through the screen is uniform and that the screen is completely submerged. In other words, a minimum of 2.5 square feet of screen area is required for every cubic feet per second of flow diverted through it.

A = Design Flow/Approach Velocity

A = Screen Area
Design Flow = Quantity of Water Diverted
Approach Velocity = 0.4 ft/s

The area calculated is the **effective screen area**. The design should provide for an appropriate area of submerged screen surface throughout the entire range of diverted flows. It may be necessary to elevate the water surface at the screen face in a canal to ensure that sufficient area is submerged. The water surface might be elevated by stop logs or control gates downstream of the screen The minimum required screen area must be submerged during lowest stream flows and may not include any area that is blocked by screen guides or structural members.

For rotating drum screens, the vertical projection of the screen area (the effective drum length times the water depth at the face of the screen) is used to calculate the approach velocity, as opposed to the circumferential screen area.

Approach Flow Considerations and Adjustment

The flow approaching a screen can be controlled in some situations such as within a canal. There are four primary components that should be considered; velocity, turbulence, flow distribution, and depth. There may also be specific constraints such as canal geometry.

The velocity of the flow approaching the screen can affect sediment passage, successful operation of the bypass, and flow distribution through the screen.

Consider the sediment load that will be carried to the screen. How will flow patterns and velocities created by the screen structure affect the transport or deposition of the material? What will be the effective geometry of the screen structure and flow patterns within it after that material is deposited? The geometry of the screen should be designed to minimize unnecessary collection of sediment. Areas that will create still water or eddies should be eliminated. For screens within canals, the water velocity approaching the screen should be maintained at a level to keep as much sediment suspended as possible within the additional velocity limitations described here.

An assumption of the approach velocity criteria is that the flow coming to the screen structure is laminar with parallel streamlines and uniform velocity. However, obstructions in the flow path upstream of the screen or abrupt transitions in the geometry of a canal or screen structure or bends in a canal can result in turbulence or non-uniformity in the true water velocity upstream of the screen and therefore variations in the screen approach velocity and even flow reversals in extreme cases.

To promote uniform flow, the channel above a screen in a canal should be relatively straight for at least a length equal to four times the width of the canal. If the true water velocity is greater than 2.0 fps, the straight section should be longer. The canal cross-section should be fairly uniform for a similar distance upstream.
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 22 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 is to minimize head loss and turbulence associated with the expansion and to eliminate the potential for adverse hydraulic conditions at the screen face.

One method to alleviate areas of high concentrated flow and high velocity on the screen ("hot spots") is to include an adjustable baffle system just downstream of the screen mesh. A baffle system is an array of bars, usually oriented vertically, that generally control where flow passes through the face of the screen by adjusting the open spacing between them. Baffles may be required for the entire length of the screen if the flow distribution approaching the screen is not uniform. Baffles are commonly needed on the downstream two thirds of a screen face of large screen facilities (longer than about thirty feet) if the approaching flow is uniform to start with. If a screen layout is unique for a particular site, a baffle system should be considered in the design or, at least, provisions for later installation if necessary.

If there is a large skew in flow across the channel, baffles will not be adequate to create the appropriate distribution at the screen. 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.

The velocity of the flow approaching the screen can also affect velocity distribution through the screen. In an enclosed screen bay, flow with a high velocity has momentum that can cause it to literally “pile up” as it is forced to slow at the downstream end of a screen. The “piled up” super-elevated flow creates additional head at that portion of the screen and therefore causes excess flow through that area. True water velocities approaching screens in large installations should not exceed about 2.0 fps unless careful consideration of the flow distribution and possibly a physical model is used.

Debris accumulation on the face of a screen results in the loss of the screen’s effective area and therefore an increase in approach velocity. If allowances are not made in the design for debris accumulation (e.g.: sizing the screen conservatively using a safety factor) the approach velocity could exceed the criteria when debris accumulates. For this reason, effective screen cleaning systems and the implementation of operations and maintenance plans are what ultimately lead to the long-term safe passage of fish. These components, as well as management of sediment and debris, are discussed in following sections of this guideline.

Juvenile salmonids can sense rapid changes in velocity and tend to avoid moving from lower to higher velocity and vice versa (Bell, 1984). Delays in fish migration can be avoided by maintaining the sweep velocity at a uniform level from the face of the screen to the bypass. This is accomplished by the removal of all hydraulic obstructions along this flow path.

Depth considerations relate to screen submergence and are discussed above in the section *Total Submerged Area.*

Screen Mesh Materials and Minimum Openings

Mesh size criteria have been established for several screen face materials (**table x**) to prevent **entrainment** of fish. These criteria are based on the type of mesh material and the size of juvenile salmonid expected to encounter the screen. (Juvenile salmon are considered “fry” if their fork length is less than 60 millimeters (mm), 2.4 inches and “fingerlings” if greater than 60 mm.) The mesh openings in **Table X** represent the minimum screen opening dimension in the narrowest direction.

Screen openings may be round, square, rectangular, or any combination of these forms, provided structural integrity and cleaning operations are not impaired. The following are the maximum screen openings allowable for emergent salmonid fry. The maximum opening applies to features throughout the entire screen structure including the screen mesh, guides, and seals.

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

Table x. Criteria for screen face material based on juvenile fish size.

	Fry Criteria (less than 60 mm fork length)	Fingerling Criteria (greater than 60 mm fork length)
Perforated Plate (maximum opening diameter or maximum slot width)	3/32 inch (2.38mm)	0.25 inch (6.35mm)
Profile Bar (maximum width opening)	0.069 inch (1.75mm)	0.25 inch (6.35mm)
Woven Wire (max. opening in the narrow direction)	0.087 inch (2.38mm) 6-14 mesh	0.25 inch (6.35mm)
Minimum Open Area (%)	27	40

Screen Face Material

The three most commonly used screen mesh types used in this region and for which criteria are established include: perforated plate, profile bar, and woven wire **(Figure 12)**.

Perforated Plate

Perforated plate is sheet metal stock punched with an array of holes in a variety of configurations **(Figure 12)**. Aluminum and stainless steel are generally used. It is available in a variety of widths but head loss should be considered if thick stock is used. Perforated plates are easy to work with, are relatively inexpensive, and handles floating debris well. The perforated plate mesh criteria for salmonid fry is 3/32 inch (2.38 mm) maximum opening and 27% open area.

Profile Bar

Profile bar is normally made from stainless steel bars welded parallel to each other on a structural backing and is available in a wide variety of openings and porosities **(Figure 12)**. It is a common commercial product with a variety of bar geometries, sizes and slot widths between the bars. It provides the most structural capacity of common screen face material. It is also the most expensive material used as a screen mesh though the cost of the structural components behind the profile bar can often be substantially reduce when compared to other screen face materials. Profile bar can be oriented either vertically or horizontally along the screen face depending on the operation of the screen cleaning mechanism and the type of debris expected at a site. If a brush type cleaning system is used for debris removal, it should track in the same direction as the orientation of the length of profile bars.

Profile bar is also available in cylindrical configuration for use as a pump intake screen. Profile bar porosity is calculated by dividing the bar opening by the sum of the bar opening plus the bar width. The regional criteria for salmonid fry (x< 60 mm) protection calls for 0.069 in (1.75mm) maximum opening.

Woven Wire Mesh

Woven wire mesh, widely used as a screen face material, is available in a wide range of wire gages (wire diameters), materials, and openings. Mesh opening and porosity for woven wire mesh is calculated by:

$$M = (1-(n*g))/(n)$$
$$P = ((n*M)^2) *100$$

Where M= Dimension of mesh opening inches
P = Percent open area
N = number of openings per inch
G = Wire diameter in inches.

For longevity and durability, minimum wire diameter for woven mesh should be 0.060 inch (18 gauge) on fixed panel screens, where they are not subjected to impact by debris. Minimum wire diameter for woven mesh is 0.80 inch (14 gauge) for rotary drum screens, traveling belt screens, and in areas where there is a potential for damage from floating debris or during repetitive cleaning operations such as wearing against seals, debris and/or sediment.

The regional criterion for salmonid fry (x<60mm) protection is 3/32 inch maximum opening and 27% minimum open area.

Head Loss Through Screen

Head loss through a screen is the difference in water levels upstream and downstream of a screen. A large head loss can diminish the flow diverted through the screen or the head available for power generation in the case of a hydroelectric diversion. The head loss through a screen is negligible when the approach velocities and porosities recommended here are used. Through a wire mesh screen with an approach velocity of 0.4 fps, the head loss is about a quarter of an inch.

Accumulation of debris or ice or corrosion will increase the head loss as the open area is decreased. When the head difference across a flat plate screen exceeds about two inches, debris becomes impinged more rapidly since the force of the head difference forces the debris onto the screen. The structural capacity of the screen and screen frame must be considered and designed for some high head loss. The structural design of the screen will partially depend on the risk of screen failure. The head loss used in the structural design might vary from a few feet to a situation of a fully plugged screen and no water passing through it.

Sweeping Velocity / Screen Orientation

The orientation of a screen relative to the direction of the approaching flow directly affects the magnitude of the **sweeping velocity** component. For a definition of sweeping velocity, see the section above on approach velocity. It is the sweeping velocity that ultimately guides juvenile fish to the bypass. One of the major objectives of a fish screen design is to provide for the safe and efficient return of fish back to the river. To accomplish this, fish must be guided to a bypass that will carry them to the river. To guide fish to a bypass the sweeping velocity component should be at least as great as the approach velocity. This provides for effective guidance and reduces exposure time along the face of the screen. The sweeping velocity is adjusted by altering the screen angle relative to the approach flow. For this reason, the screen should have a maximum angle of 45 degrees (relative to direction of the approaching) to meet criteria. At this angle, the approach velocity is equal to the sweep velocity. Smaller angles provide a greater component of sweep velocity to direct fish toward the bypass. Lower angles also increase the true water velocity approaching the screen. See the section on *Approach Flow; Considerations and Adjustments* for limitations.

The face of the screen should be smooth and uniform with no projections that would create turbulence or concentrations of flow through the screen. Special attention should be given to screen end walls and seals.

The natural flow of a river will not necessarily create a sweeping velocity component on a large screen installed on a riverbank. A large screen diversion will affect the flow direction of the river, especially at low flows. If a significant portion of the flow of the river is diverted. In this situation, the flow entering the diversion may flow directly into the screen rather than at the desired angle to create the sweeping component. To establish the sweeping component, a guide wall may have to be constructed to make a geometry similar to an angled screen in a canal.

Travel Time

The criterion for the maximum exposure time for juvenile salmonids along a screen face is 60 seconds. This criteria is set to limit potential impingement on the screen and is based on stamina studies that found over 98% of the salmon fry tested were able to swim for at least one minute at the approach velocity criteria. The sweep velocity should be of sufficient magnitude to pass the entire screen face under the 60-second criteria. If this is not possible, then the screen design should include intermediate bypass entrances.

The Fish Bypass System

A fish bypass system is a flow route designed to transport both juvenile and adult fish from the face of a screen back to the river and is necessary if the screen is not located in the river itself. The bypass of in-river screens is the river itself if flow and fish are not carried into an enclosed structure. The major components of a bypass system are shown in **Figure 13**. The bypass route should facilitate fish passage back to the main channel to a safe location with minimum risk of injury or delay. To accomplish this, design aspects include guidance (moving the fish to the bypass and through the bypass channel), passage (transport through the system), and release to the main channel.

Screen bypasses often discharge into side channels through which swim adult fish. It may be necessary to provide passage for adult fish upstream through the bypass, trash rack, and head gate structures. Adult fish passage criteria apply to each of these facilities in addition to the screening criteria described in this guideline.

Bypass Entrance Geometry

The entrance to the bypass is one of the most critical elements of the entire screen design. It is the point with the highest concentration of fish in the entire facility. All of the fish that are protected by the screen must freely and volitionally enter the bypass without delay. Fish that reject the bypass will be further subjected to the diversion screen. Careful consideration should be given to the details of the bypass entrance to not create eddies, low velocity areas, rapid acceleration of the flow or other hydraulic disturbances that might delay fish passage.

The screen and bypass should be oriented so the screen terminates (at its most downstream end) at the bypass entrance and the flow approaching the screen is not forced to turn as it enters the bypass.
The width of the bypass entrance channel should be a minimum of 18 inches and it should extend from the floor to the water surface. This width allows schooling fish to enter the bypass without delay. The bypass on large screens (greater than 200 cfs) should be enlarged to several feet to minimize the likelihood of debris becoming lodged in the bypass opening and to allow light penetration further into the water column within the bypass.

Bypass Entrance Velocity and Bypass Flow

Juvenile fish often delay or avoid passing through areas where the velocity decreases or increases rapidly. The flow entering the bypass should accelerate slightly and gradually; it should not slow down. The bypass system should be operated such that the velocity at the entrance is 10% greater than the true water velocity approaching it. The optimum passage situation is where the bypass flow is controlled for various diversion rates so the velocity is always 10% greater than the approaching velocity regardless of the flow in the canal.

With the bypass entrance geometry and velocity provided as described, it is a simple calculation to determine the bypass flow. Due to common uncertainties in the flow distribution approaching a screen and in the hydraulic design of complicate bypass systems, the bypass system should be designed for a flow 15% greater than the optimum described here as a safety factor. In other words, the system should be designed with a bypass entrance velocity 25% greater (115% of 110%) than the approaching true water velocity.

The design bypass flow and bypass hydraulic capacity can then be calculated. For example, consider a four-foot diameter drum screen operating at 80% submergence, with a true water velocity of 1.0 fps approaching it and a bypass width of 18 inches. The design bypass flow would be 5.3 cfs (4.0 ft x .80 submergence x 1.5 ft bypass width 1.0 fps velocity x 1.1 acceleration).

The sensitivity of the bypass flow should be checked. Based on the expected true water velocity and the geometry of the bypass, what is the bypass entrance velocity when the canal water surface drops? A proper design accommodates all expected operating scenarios. If the result is a bypass entrance velocity less than the true water velocity approaching it, either the operating procedure or the designed geometry of the screen facility should be modified.

The bypass flow carrying juvenile salmon should flow over a weir into a down well (Figure 13) or into a chute. In addition to allowing for precise flow measurement and adjustment, the weir traps juvenile salmonids and keeps them from re-entering the bypass channel and forebay. Water spilling over a weir crest will create that trapping velocity. The capture velocity of steelhead smolts is about five feet per second. The weir should have at least six inches of water depth over it to facilitate downstream juvenile and adult fish passage and debris passage. The depth can either be provided naturally by the bypass flow or the weir can be notched. It is common for the bypass flow to provide adequate depth at the design operating point of the facility but the notch may have to be notched to provide the depth when the diversion rate and bypass flows are at their minimums.

A good option to an overflow weir is a weir with a chute attached to the downstream side. The chute would be in place of a plunge into a downwell. The chute would tie directly into the bypass pipe. Since the chute provides a very efficient transition from the weir crest to the bypass, risk of fish injury due to turbulence and/or debris blockages within the downwell and entrance to the bypass pipe are minimized.

Since fish will avoid rapid increases in velocity, the velocity should be gradually accelerated up to a trapping velocity high enough they cannot escape. To control the acceleration a ramp should be built up from the floor at the bypass entrance to the crest of the bypass weir. The slope of the ramp should not be greater than 2:1. This, 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 likely practical.

Fish bypass flow requires positive hydraulic head differential between the water surface at the screen and the water surface at the bypass outfall to the stream.

Bypass Conduit and Drop Structures

The bypass conduit is the facility that carries fish and debris back to the river. It may include pipes, drop structures, channels, and flumes. Criteria for the bypass conduit and structures are established to reduce the risk of injury to fish while being transported back to the river.. Smooth interior pipe surfaces and conduit joints are required to minimize turbulence, facilitate the passage of debris, and reduce the risk of injury. Additional criteria include:

- Maximum velocity in the pipe should not exceed 30 feet per second[k18].
- There should be no pumping of fish within a bypass system.
- Bypass hydraulics should be open channel flow; bypass pipes should not be pressurized.
- There should be no extreme bends in pipes.[k19] Bypass pipe centerline radius of curvature (R/D) shall be 5 or greater. (Greater R/D may be required for supercritical velocities.)
- Bypass pipes or open channels should be designed to minimize debris clogging and sediment deposition and to facilitate cleaning. The bypass pipe diameter should be 24-inches (0.610 m) or greater. For screens passing 40 cfs or less, the minimum bypass pipe diameter should be 10 inches (25.4 cm).
- Closure valves are not allowed in the bypass pipe.
- Depth of flow in a bypass conduit should be maintained at 0.75 ft (0.23m) or greater. For screens passing 40 cfs or less, the minimum water depth in the pipe is 1.8 inches (4.6 cm) and is controlled by designing the pipe gradient for minimum bypass flow[k20]. Nine inches of water depth should be provided where downstream kelt passage is expected.
- Bypass system sampling stations should not impair normal operation of the screen facility.
- There should be no hydraulic jumps within the bypass system.

Drop structures are often needed to get back down to the elevation of the river. A pipe designed with the smoothness, flow, and depth criteria provided above will be at a very low slope and therefore very long. Drop structures can be much more compact. They have additional risk however of causing injury due to turbulence or from debris that might accumulate. The weirs of drop structures should be design similar to the bypass weir described above. A typical range in drop heights is 2 to 4 feet. Some cushioning should be provided in the down well by countersinking the floor of the downwell at least several feet below the minimum water surface.

Turbulence the downwells should be limited by providing a specific volume of water based on the energy to be dissipated in the pool.

Delivery- The Outfall

The last step of successful screening is returning fish to the river channel. Considerations include safety of fish spilled from the bypass, deterring predation at the outfall, and attraction of adult fish to the bypass outflow.

To protect fish from direct injury, any outfall should be designed similar to downwells described above with appropriate volume for energy dissipation and buffer depth in the bottom of pools. Depth of pools must consider the likelihood of filling with river bed material. Also, to protect fish, the impact velocity of the outfall nappe or jet should not exceed 25 fps. The impact velocity is the velocity of the bypass water striking the water in the channel. The 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 strong downstream current and without eddies, reverse flow, or likely predator habitat. The outfall natural river velocity should be at least 4.0 fps to minimize holding of predators. It may be difficult to satisfy both the pool release and the high velocity design preferences. In natural high gradient streams, the pool discharge is often most critical. In large rivers, avoidance of predator habitat may be most critical.

Upstream migrating adult fish may be attracted to the bypass outfall especially if it has a significant flow relative to the stream and the outfall is high velocity and/or plunging flow. Expect that fish will be attracted to it. Consider where they might leap at the outfall and minimize risk of them being damaged or stranded on the bank. Bypasses often discharge into side channels through which swim adult fish. It may be necessary to provide passage for adult fish upstream through the bypass, trash rack, and head gate structures. Adult fish passage criteria apply to each of these facilities in addition to the screening criteria described in this guideline.

STRUCTURE PLACEMENT

The point of withdrawal is important for the hydraulic aspects of the screen as well as for the protection of juvenile fish. Considerations may include whether to screen water directly in the river channel or in a canal diverted from the river channel. Regardless, the screened intake should be designed to withdrawal water from the most appropriate elevation, accommodating the expected range of water surface elevations, considering juvenile fish attraction, and appropriate water temperature control downstream. For river screens, it is preferable to keep the fish in the main channel avoiding the necessity of a bypass at the screen.

Streams and Rivers

Optimally, and where physically practical, the screen should be constructed at the point of diversion with the screen face parallel to river flow, aligned with the adjacent bank line. A smooth transition between the bank line and the screen structure is important to minimize eddies and undesirable flow patterns in the vicinity of the screen, flow situations that can result in migration delays.

Physical factors that may limit screen construction at the diversion entrance include excess river gradient, the potential for damage by large debris, heavy sedimentation, or inappropriate flow conditions. Large streambank installations may require intermediate bypasses along the screen face to limit exposure to the screen. If it can be demonstrated that flow characteristics, or site conditions, make construction or operation of fish screens at the diversion entrance impractical, screens can be installed in off-channel diversion canals.

Canals

Screens constructed in canals and ditches should be located as close as practical to the diversion. Because flow is directed off the main channel, screens located in canals require an effective juvenile bypass system designed to collect and safely transport juvenile fish back to the river with minimal delay. This adds to the complexity of the screen facility and underscores that, if possible, to have a screened withdrawal at the diversion point. Design elements of the bypass system are discussed in the Bypass System section. The further away the screen is from the bypass, the more head differential there may be between the canal water surface and the river water surface and therefore the more complex the design and operation of the fish bypass.

Lakes, Reservoirs, and Tidal Areas

Within lakes, reservoirs, or tidal areas, the withdrawal point should be located off shore at depth where lower density of fish is expected. Salmon and trout fry generally inhabit shallow water areas near the shore. The 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.

If a screened intake is used to route fish past a dam, the intake should be designed to withdraw water from the most appropriate location and elevation in order to provide the best juvenile fish attraction to the bypass. Normally, the most attractive reservoir outlet is designed in combination with the normal reservoir outlet works. Such an outlet location may or may not comply with other objectives of achieving appropriate water temperature control for the downstream channel.

DEBRIS MANAGEMENT

Fish screens must have a reliable, fully functional, cleaning system capable of removing debris from the entire mesh surface. It is important both to the passage of fish and the passage of water that the cleaning system removes debris efficiently, completely, and ultimately away from the screen mesh.

The primary concern of inadequate screen cleaning is that debris may build on the screen face resulting in a loss of effective screen area. Greater flow then passes through the remaining clean screen area resulting in higher approach velocities. Because there is a relatively small tolerance for increases in approach velocity at most screens, debris accumulation can quickly result in impingement of juvenile fish. In some cases it has been found necessary to specify sufficient screen area to create an approach velocity as low as 0.1 ft/s to allow for some debris accumulation. This allows the screen to have as much as three quarters of its surface area blocked without creating localized areas where the approach velocities exceed 0.4 ft/s. A second concern is that debris accumulations can block bypasses or trash racks, change hydraulics of bypass entrances that block fish movement, or injure fish in high velocity areas such as bypass conduits. In addition to screen and trash rack cleaning, the dimensions of trash racks, bypass entrances, and bypass conduits and the hydraulic design of bypasses are critical to debris management. They should be designed to minimize the capture of debris that should pass through the entire facility.

Debris Exclusion: Trash Rack

The primarily function of a trash rack is to collect larger debris that might damage the screen or get blocked in the bypass system. A typical design is for a sloping (approximately 45 degrees into the flow) bar rack with a spacing of 6 to 12 inches. The bar spacing may depend on type of debris encountered at the site. Bar spacing on trash racks should be at least 5 to 6 inches clear opening at fish screens. Spacing smaller than 3 inches can cause delay or totally block passage of some juvenile salmonids. The closer spacing will also collect debris that could be passed through the entire system. The risk of collecting small debris at the trash rack is that the rack can become matted with material not leaving any route for juvenile fish passage. Left unmanaged, debris accumulations on racks can cause significant injury to fish passing through the debris, particularly if the debris is an abrasive material such as tumbleweeds.

Trash racks that are so large that they 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 is a necessary component of the design.

Screen Cleaning Systems

Several types of screen cleaning systems are described below. Regardless of the type of cleaning system, a route must be available to pass debris downstream once it is removed from the screen face. Some screen designs incorporate a belt and hopper system to collect and remove debris from the site. Failure to provide a debris escape route will allow debris to redistribute on the screen mesh eventually overwhelming the cleaning system. Site hydraulics might also by itself provide or aid debris removal. A cleaner might move the debris away from the screen and depend on currents to move the debris from the site.

Manual Screen Cleaning

Text yet to be written.

When the screen is cleared of debris manually, once or twice daily or at longer intervals, then additional screen area should be incorporated into the design. Debris should be removed from bypass downwells, bypass pipe entrances, trash racks, and along the screen face.

Screen Rotation

Text yet to be written.

Trolley Brush Cleaning

Text yet to be written.
Figure 14

Jet Spray Cleaning

Text yet to be written.

Jet spray cleaning is …
Figure 15

With the jet type cleaner the mechanism is located on backside of the screen, out of the flow path. The disadvantage to the jet spray cleaner is that typically rotary cleaners don't reach the entire screen surface and heavy debris loads could require canal shutdown or screen removal for cleaning. The effective area of the screen should be calculated as the cleaned area.

Water jet cleaning systems have been used successfully for fixed plate screens, pump intake screens, and vertical traveling screens. They have been used as a supplemental cleaner on drum screens at sites with high debris loads. For drum screens, a spray bar can be directed at an oblique angle towards the face of the screen to wash debris off the back side of the screen structure. The spray jets should cover the entire surface area of the screen. Pressures from 30 to 100 pounds per square inch may be required for proper cleaning action depending on the type and amount of debris present at the site.

Air Burst Cleaning

Air-burst cleaning systems **(Figure 16(** are commonly used with pump intake screens. This cleaning system has a variable performance record. With some applications air-burst cleaners have reportedly only removed debris from the upper part of the screen. This appears to be a distribution problem as air is taking a selective travel path through the screen.

PRE-DESIGN CONSIDERATIONS

Determining the Design Flow

The maximum expected diversion flow is fundamental to the design of fish screens and bypasses. In many cases this flow is the water right, certificate, or claim. In Washington State, water rights records are maintained by the Washington State Department of Ecology. If there is any uncertainty as to what the appropriate design flow is, the Ecology Water Resources Program should be consulted. Evidence of a legal water right or water claim should be submitted to WDFW during design consultation. See the Fish Screen Design Summary Form and instructions in Appendix X.

While the water right is a major design parameter, it is just a starting point. The hydraulic design for a fish screen should also consider the potential range of flows around the expected diversion flow. For instance, a diversion may just divert a fraction of the water right for several months during much of the summer period. In drainages where the spring hydrology is determined by snow melt, the potential of flooding should also be considered. In flooding situations, the screen may have to withstand flows greatly exceeding the water right, or design flow. The extreme range or variability in flows is based on a certain risk of occurrence.

If the maximum diversion flow is in question, a flow study is warranted before design can proceed. For minor projects, this may be a discussion with the water user concerning their irrigation needs. For major projects, a formal flow study may be necessary involving gaging sties, data recorders and flow measurements. In addition to the maximum diversion flow, the rate of change of diversion flow may also be a design issue. In many situations a rapid change in stream flow can affect the diversion flow, screen submergence, bypass operation and/or screen approach velocity. If it is likely that such changes will occur unexpectedly or before the screen operator can make necessary operational changes, those change ranges must be included in the design. Flow ranges might be accommodated by automating headworks, modifying headworks control orifices or gates, or by providing a wasteway in the canal to divert excess water back to the river. Operating a wasteway may not comply with project water rights.

Easements

It is important to identify and obtain any necessary easements or property for the proposed screen early in the design process. Not having adequately completed this step has created delays in the construction of a number of screen projects. When required, easements should be obtained for: 1) the construction access and staging, 2) operations and maintenance access, 3) the screen site, 4) the bypass return line, 5) power lines, and 6) trap boxes. Easement or separate operational agreements should clearly identify responsibilities and liabilities for operation of the screen facility.

If multiple parties are involved, easements or other operational agreements should clearly define responsibilities and liabilities for operation of screen facilities.

As common courtesy, all potentially affected property owners should be informed of the planned screen. Those property owners directly affected by the project should, of course, be kept well informed of the project design and construction schedule.

Construction Period

The timing of construction, considering constraints of the water user(s) and allowable in-stream work periods is important to project planning. Usually, for irrigation diversions, there are periods when it is possible to construct a screen without affecting canal operation. If a screen is to be constructed in a canal, in-water work periods may not apply, especially if the screen can be constructed in the dry.

This sort of information is easily obtained through consultation with water users. The appropriate work window for in-stream work is best determined through consultation with the Washington Department of Fish and Wildlife regional biological staff. A contact list of area habitat biologist has been provided in Appendix X.

Often, a construction bypass must be constructed to divert around the new screen construction and maintain the diversion flow. In any case, WDFW and NMFS expect any existing screen and bypass system, or temporary replacement facilities, to be in operation throughout the construction period.

Agency Coordination

When considering a site for a juvenile fish screen installation it is important for the designer to ensure that all interested parties have been contacted. Agencies interested in water development projects involving fish screens include: the U.S. Fish and Wildlife Service, National Marine Fisheries Service, Washington State Department of Fisheries and tribal governments. Land use agencies such as the U.S. Bureau of Land Management, U.S. Forest Service, Natural Resource Conservation Service, water managers and users (U.S. Bureau of Reclamation, water districts, irrigation districts), wetland protection agencies (Environmental Protection Agency, Army Corp of Engineers) may also be important contacts. In addition, tribal and local governments should be contacted. It is important to contact all potential interested agencies to see if they have interest or jurisdiction in a screening project, and also to provide their input as to what other agencies need to be involved. Neglecting the required contact with the appropriate agencies can delay construction due to unanticipated permit requirements. If federal funding is involved, certain processes may be required in the design process such as Endangered Species Act consultation and National Environmental Policy Act compliance. Appendix X includes a list of some Federal and State agency contacts within Washington State.

<u>State Hydraulic Project Approval</u>

A State of Washington Hydraulic Project Approval is required for any work that affects the flow or bed of the stream or that modifies the function of a fish screen. Washington State has a number of laws that apply to the necessity, design, and maintenance of fish screens. RCW 77.16.220 indicates that any surface water diversion with the potential to entrain fish must have a fish screen. In addition, if necessary, the diversion must have a means of returning diverted fish back to their waters of origin. RCW 77.16.210 states that persons or government agencies that manage in-stream structures must allow for the free passage of fish. RCW 75.20.040 indicates the actions (penalties, remedies for failure) taken by the state for entities failing to comply with RCW 77.16.220. RCW 75.20.061 and RCW 77.12.425 state that the Washington State Department of Fish and Wildlife Director can modify existing fishways and fish screens if they are found inadequate without cost to the owner. The approval for a fish screen facility is the Hydraulic Project Approval.

Designs must reflect the Northwest Regional Fish Screen Design Criteria (**Appendix X**). Backup information for consultation submittals and permit applications should be submitted on the *Fish Screen Design Summary Form* provided in Appendix X.

NMFS and USFWS Consultation

For projects where the National Marine Fisheries Service (NMFS) or US Fish and Wildlife Service have jurisdiction, such as FERC license applications and Endangered Species Act consultations, a functional design, reflecting NMFS criteria, should be developed as part of the application or consultation. Designs must reflect the Northwest Regional Fish Screen Design Criteria (**Appendix X**).

Consultation Submittals

Design submittals should define the type, location, method of operation, and other important characteristics of the fish screen facility. Design drawings should show structural dimensions in plan, elevation, and cross-sectional views, along with important component details. Hydraulic information should include: hydraulic capacity, expected water surface elevations, and flows through various areas of the structures. Documentation of relevant hydrologic information is required. Types of materials must be identified particularly where potential contact with fish will take place. In addition, a plan of operations and maintenance procedures should be included.

Additional detail of operating plans are described later in this guideline. A *Fish Screen Design Summary Form* is also included in Appendix X.

DATA COLLECTION AND ANALYSIS

Site Survey

A topographic survey is necessary to determine the landscape characteristics of the proposed screen location. This information is used to determine optimal screen location and facility layout and provides critical information necessary to design the screen hydraulics.

The survey should include the proposed point of diversion, screen area, bypass route, access routes, power availability. In addition to existing ground elevations, all man-made features such as the diversion head gate, flow measuring weir, operational spillway, roads etc. and any significant natural features (large trees, bedrock outcropping etc.) within the project area should be located and described in the survey.

The site plan should describe and indicate the location of the project benchmark (vertical elevation control) and survey baseline (horizontal control) used to locate project features.

If the screen receives flow from a diversion canal, then the hydraulic characteristics of the canal should also be determined during the survey. Channel physical characteristics important in flow modeling include the determination of the slope of the canal (above and below the screen) from the headworks to the screen, along with representative cross-sections (capacity) along its length. It is important to identify the ordinary high water (or typical discharge water surface elevation) when conducting the cross-section surveys.

A *Fish Screen Design Summary Form* is also included in Appendix X with more detail for the site survey.

Flow Survey

An understanding of the expected range in diversion flows is critical to the proper design of fish screens and bypass systems. Fish screen design is based on an expected water surface elevation to provide proper screen submergence and bypass flow requirements. For this reason, all records of discharge should be obtained early in the design process. In instances where actual flow measurements are not available then the water right (claim or certificate) can be used as a starting point. But the full range in expected flow levels should be anticipated and incorporated into the screen facility design. The relationship between discharge and water surface elevation must be established for the full range of diversion flows. At least one point can be determined during the initial survey. Time permitting, a staff plate or water level recorder should be set into the canal diversion and a series of flow measurements taken over a period when the full range of flows are expected. With time and data in short supply, Manning’s equation, calibrated with a series of discharge/water surface elevation points, could be used to synthesize water surface elevations over a greater flow range.

The relationship of water surface to stream flow must be established at the bypass outfall location. The extreme low and high flow situations and the dominant high flow situation during the peak outmigration season are most critical. This information is most easily gathered by installing a water level recorder at the site for a winter to spring season and then surveying a low flow point in the low flow season. This data must be correlated to streamflow and flow frequency data.

The screen and bypass facility are initially designed based on the maximum diversion flow and the river flow expected the majority of the time. However, ultimately, the design should accommodate the full range of concurrent diversion and river flows expected. That is, through the full range of flow, the approach velocity criteria should not be exceeded, the screen submergence must be within acceptable levels, and bypass flows maintained at a sufficient quantity to accommodate fish passage at the low flows.

A *Fish Screen Design Summary Form* is also included in Appendix X with more detail for the flow survey.

Effectiveness and Compliance Monitoring

Hydraulics

Following the construction of a fish screen facility, water velocities should be measured at critical locations to determine whether it is operating as designed. Important velocity points include a determination of flow and velocity 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. The angle of the flow at that point is also measured so the approach and sweeping velocity components can then be calculated. The direction of flow can be recorded with a vane attached to a rod or frame. Eventually a series of measurements should be taken across the entire screen (approximately every two feet) at several points through the water column beginning about a half foot below the water surface and then at approximately quarter depth points below that. More measurements should be taken in locations where more complex flow situations occur for instance, near piers and at the screen edges. If flow distribution baffles are included in the facility, a less precise hydraulic survey may be done initially to optimize the baffles. If there are no flow distribution baffles and it is determined that the approach velocity and bypass flow are not at design levels, then the installation and adjustment of a baffle system may be necessary.

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 gauges should be installed at the control points (i.e. bypass weir) so fast and accurate flow adjustments can be made. Staff gauges should be placed both immediately upstream and downstream of flow control structures, within operator view, and in hydraulically stable flow. Staff gauge datums and readings and flow control operations must be checked with the operations manual to verify accuracy of the manual.

Prior to any major hydraulic testing, a study plan must be developed in consultation with the interested agencies.

Biological Evaluation

Once hydraulic testing is complete and the screen is operating as designed, biological testing can be conducted. Biological testing examines how successful the screen facility is in passing juvenile salmonids with success evaluated by fish passage time and health. Biological testing is necessary for screen styles and configurations for which extensive biological evaluations have not previously been conducted or where unique characteristics make previous evaluations irrelevant.

The main points for biological evaluation are passage past the screen and through the bypass. Elements of passage commonly include entrainment through the screen, impingement on it, and fish health through the entire screen system. Timing of passage through system might also be required in large installations. An method commonly used for screen evaluations is the mark recapture technique. Fish are marked such as an adipose fin clip. Depending on the numbers of juveniles moving past the screen, marking may not be necessary. A common evaluation procedure is to then capture the released fish in a screened collection box downstream of the bypass outfall and at a point where there is minimal risk of damage to the fish. Initially, an overall facility examination should be made; releasing fish upstream of the facility and capturing them at the end of the bypass. If problems are identified, a closer examination should be undertaken.

Fish health is based primarily on a visual examination of scales and fins for damage that might have been caused by the screen or other obstructions. Periodic biological testing after the initial test period might be recommended to identify any problems that develop over time.

Prior to any biological testing, a study plan must be developed in consultation with the interested agencies.

OPERATION AND MAINTENANCE

Once built, all facilities should have an operations and maintenance plan to ensure, among other considerations, the proper adjustment of flow through the screen and bypass, the clearing of debris, and checking of seals. For a fish screen to adequately serve its function of protecting fish, attention to operational detail is necessary.

Operation and Maintenance Manual

An operations manual should serve as a reference to operating and managing the fish screen facility. Providing concise operating criteria for a screen site also ensures that, despite personnel changes, the facilities operation doesn't change. An example operation manual for a paddlewheel drum screen is provided in Appendix X.

All the relevant hydraulics information should be included in the manual. This information includes rating curves (water surface and flow relationships) for the various staff gauges, bypass flow requirements, and screen submergence. All operations should be based on staff gauges or marks on the facility or other easily identified parameters. The operations manual should also include a schedule for routine maintenance of specific components of the screen facility.

Routine Maintenance

The components of the screen facility requiring routine maintenance might include:

Seals - Screen seals must be checked frequently for wear, and for debris that might be trapped by the seals.
Debris accumulation / Cleaning Systems – Large material should be removed from the trash rack and the screen cleaning system must be checked frequently to ensure it is working properly.
Sediment Removal - A method employed to remove sediment from a screen forebay is to temporarily reduce flow through the screen and open the bypass return pipe fully, to sluice sediment away from the site. Sediment should be removed from the forebay of the screen site before it starts passing through the seals. Sediment should only be sluiced during high streamflows. Sediment may have to be removed mechanically where there is any risk of it affecting habitats or fish in the stream. Detailed sediment management prescriptions may be included for specific sites.
Moving components should be greased (with environmentally benign grease) on a regular basis.

When it is necessary to drain the canal for maintenance or at the end of the irrigation season fish in the canal must be directed back to the river. 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. Depressions in the canal or structure where fish might become stranded should be inspected and fish might have to be carried or herded to the bypass.

The application of herbicides and pesticides, as part of a routine facilities maintenance, has the potential to harm juvenile salmonids. Care must be taken to ensure that there is no possibility for any toxicant to be released into areas where it might come in contact with fish or wildlife. It is important to develop a plan for the application of toxicants should they be necessary. The plan might include: 1) notifying fish and wildlife authorities before application, 2) salvaging or bypassing fish from a ditch prior to application, and 3) ensuring all gates and valves are closed so no possibility of leakage into the riverine environment is possible. In the case of an irrigation canal, herbicides should only be applied when the canal is dry thereby avoiding any potential harm to fisheries resources.

Screen Submergence

If the river level or diversion flow changes, adjustments must be made as necessary to ensure that the screen is properly submerged for the amount of flow being diverted. Bypass flow levels should also be adjusted at that time. The bypass pipe entrance and exit should also always be checked during each site visit.

The percent of submergence should be painted at a prominent location on the screen. This allows the water surface elevation to be verified at a glance. Some sites, especially those with large diverted flows, will require staff gages to verify proper water surface elevation and screen submergence.

Corrosion Control

A corrosion control system for a fish screen can significantly increase the life of a facility. Providing isolation of dissimilar metals will prevent the electrolysis process that results in corrosion. Neoprene washers and silicon bolt sleeves should be used when attaching mesh to the structural frame of the screen. Sacrificial anodes are also be used at sites with corrosion potential. These are welded directly to the screen frame and work by providing a more attractive location for electrolysis to occur and produce corrosion. Another potential cause of corrosion occurs when electric motors are grounded to the screen frame. Stray currents produce minute charges in the frame sometimes increasing the potential for electrolysis to occur.

Winter Operation

In some locations freezing conditions have to be considered for screen operation during winter months. Ice can quickly clog screens, causing loss of flow to the diversion. Some screens are located in heated enclosures, if the full diversion flow is needed in cold weather situations. Another technique that has been used successfully to provide small amounts of winter stock-water, is to allow the canal to freeze at full canal flow. After the water surfaces freezes with a solid layer of ice, the canal flow is reduced to lower stock water flow and the frozen upper layer remains in place to help insulate the flow beneath it. Before doing this cleaning mechanisms and drum screen drives must be disconnected.

GLOSSARY

Anadromous – Fish species that migrate from the sea to freshwater systems in order to spawn.

Approach Velocity – The water velocity vector component perpendicular to the screen face.

Bypass System – The fish bypass system collects fish from in front of the 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.

Bypass Water – A portion of the diverted flow is used to transport fish from in front of the fish screen back to the stream through the fish bypass system.

Diversion Headgate – A structure, usually equipped with a control gate, that controls the flow of water from the surface water source into a gravity conveyance facility (canal, ditch, pipeline, etc.).

Diversion Entrainment – The voluntary or involuntary movement of fish from the stream into the surface diversion.

Effective Screen Area – The gross submerged area of the screen that effectively passes water and excluding areas that are not cleaned or are blocked by major structural members. This is not the screen open area as described below.

Entrainment – Entrainment is the voluntary or involuntary movement of fish through, under or around the fish screen resulting in loss of fish from the population. Entrainment is a function of screen mesh opening size and gaps between the screen frame and canal structure walls.

Fish Screen – A fish protection device installed in a surface water diversion to prevent entrainment, injury or death of fish. Fish screens physically preclude fish from entering the diversion.
Fork Length – The straight line distance measured from the tip of the nose to the fork of the tail of a fish.

Fry – Salmonid juveniles with less than 60 mm fork length.

Fingerling – Salmonid juveniles with 60 mm or greater fork length.

Impingement – Entrapment of fish onto the face of an intake screen. Impingement may be temporary or permanent.

Open Screen Area – The area of all open slots, mesh or perforations on the screen available for the free flow of water.

Screen Entrainment – The voluntary or involuntary movement of fish through, under or around the fish screen resulting in loss of fish from the population. Entrainment is a function of screen mesh opening size and gaps between the screen frame and canal structure walls.

Salmonid-

Surface Water Diversion – A man-made structure or installation for diverting water from a stream, river or other surface water body for a beneficial purpose (municipal, industrial, agricultural, hydroelectric generation, etc.) Surface diversions fall into two general categories: gravity and pump.

Sweeping Velocity – The component of approaching true water velocity that moves parallel to the face of the screen. It is a function of screen orientation, and the amount of fish bypass flow and geometry of the approach channel.

True Water Velocity – The actual velocity of water rather than vector components of it.

Bibliography

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 - FISH SCREEN PROJECT WORK SHEET

APPENDIX B - SCREEN OPERATING PROCEDURES EXAMPLE

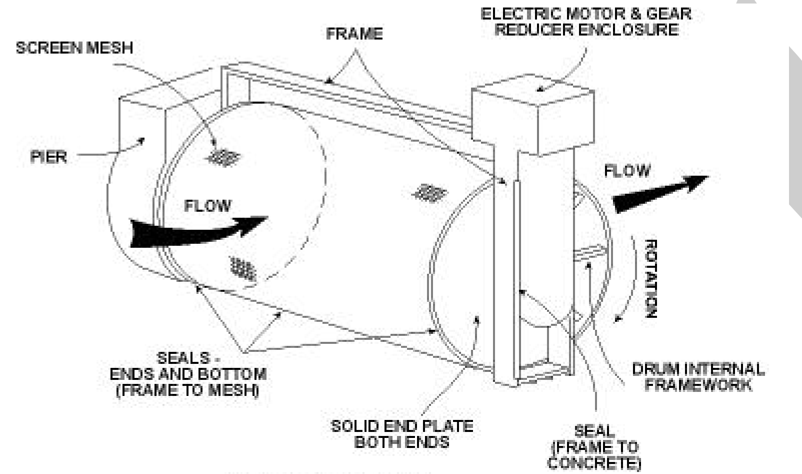
APPENDIX C FISH SCREEN SKETCHES

APPENDIX D SOURCES OF COMMERCIAL SCREEN PRODUCTS

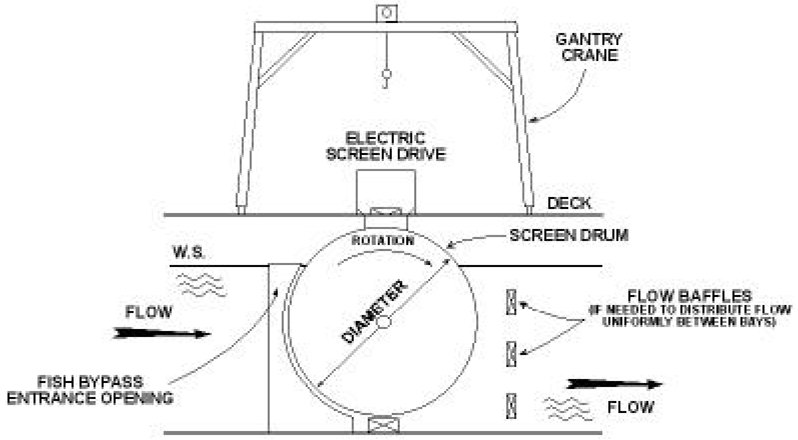
APPENDIX E - REGIONAL FISH SCREEN CRITERIA

APPENDIX F - WDFW FISH PROTECTION AND TECHNOLOGY DEVELOPMENT POLICY

Figures



ISOMETRIC VIEW



SIDE ELEVATION VIEW

FIG. 1 - ROTARY DRUM SCREEN

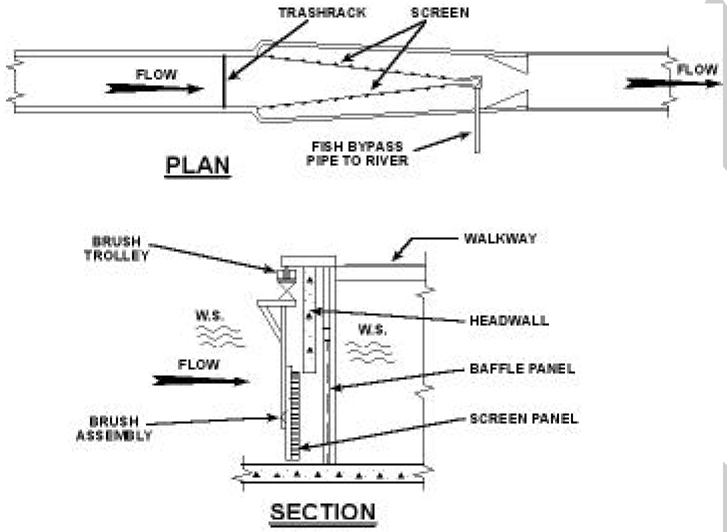


FIG. 2 - VERTICAL FIXED PLATE
SCREEN WITH TROLLEY BRUSH

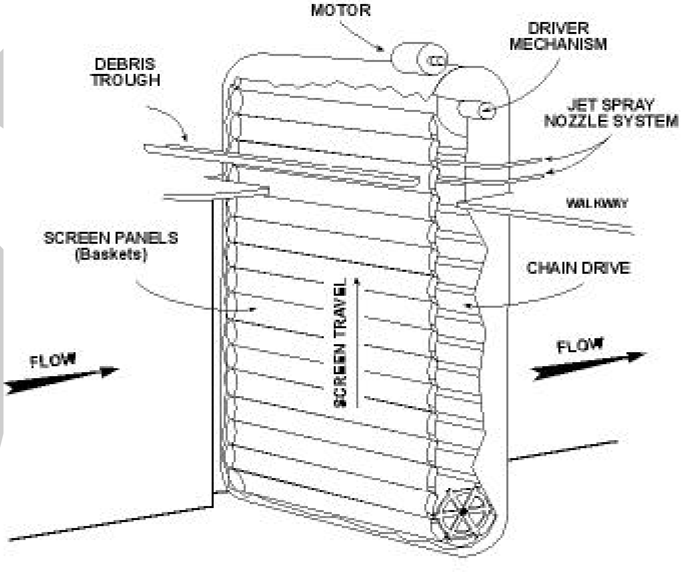


FIG. 4 - TRAVELING SCREEN PANEL TYPE

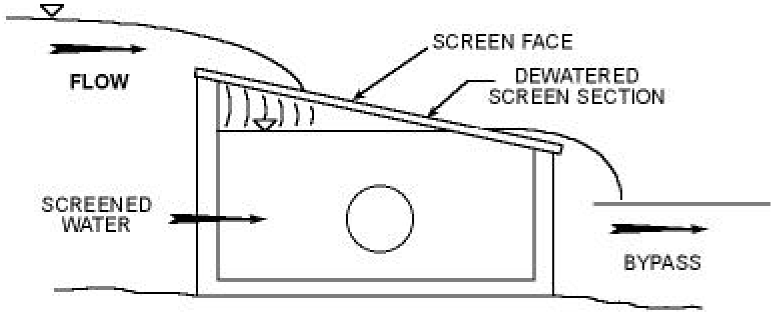


FIG. 6 - DOWNWARD SLOPING FLAT PLATE SCREEN

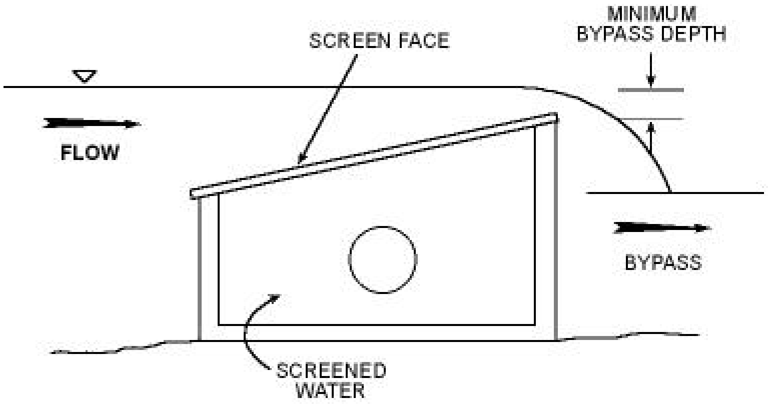


FIG. 8 - UPWARD SLOPING FLAT PLATE SCREEN

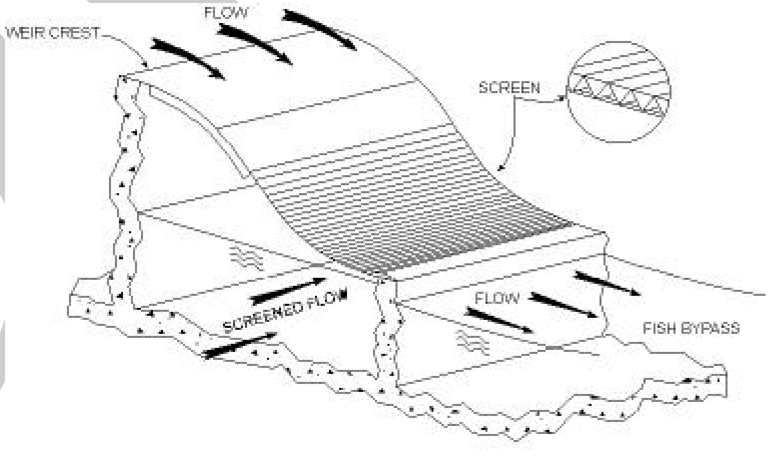


FIG. 7 - COANDA SCREEN

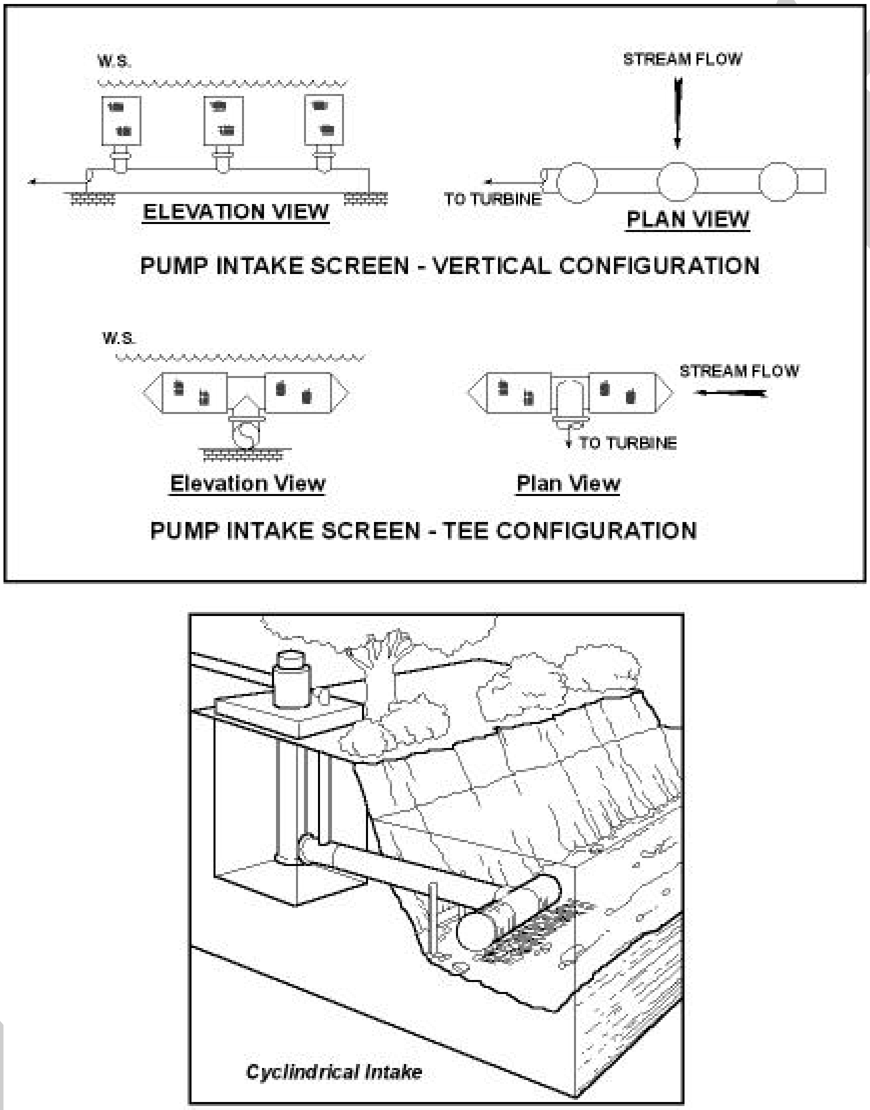


**FIG.9 - PUMP SCREENS,
END-OF-PIPE, FIXED DRUM, TEE SCREENS**

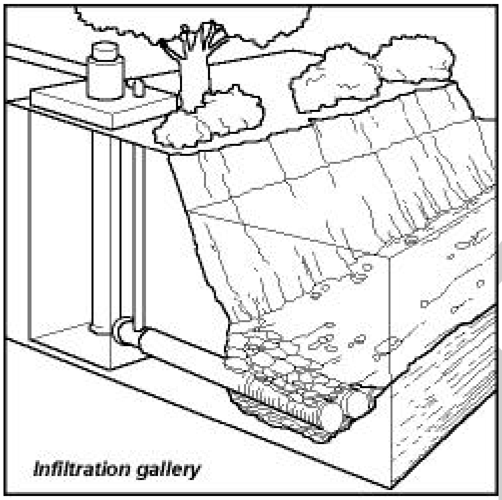


FIG. 10 - INFILTRATION GALLERY

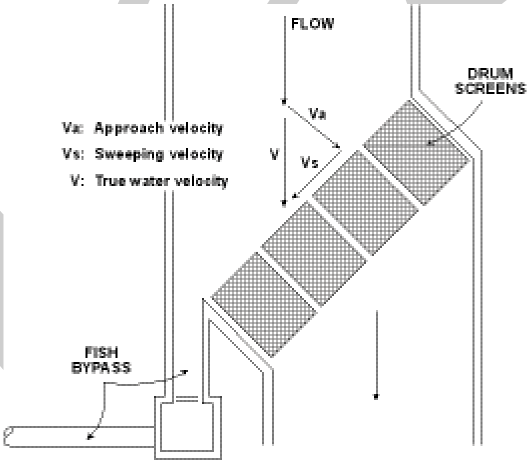
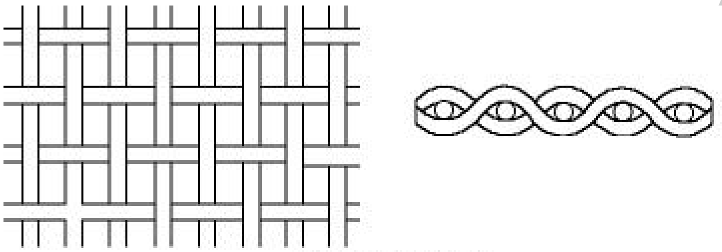
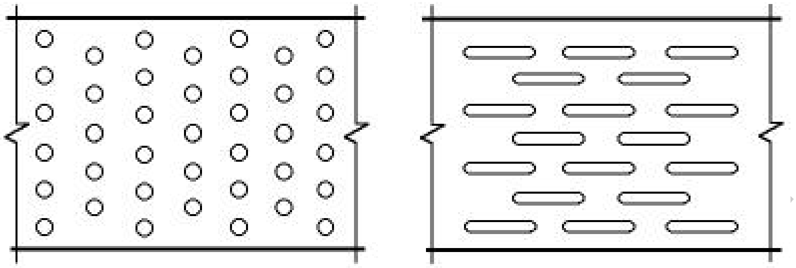


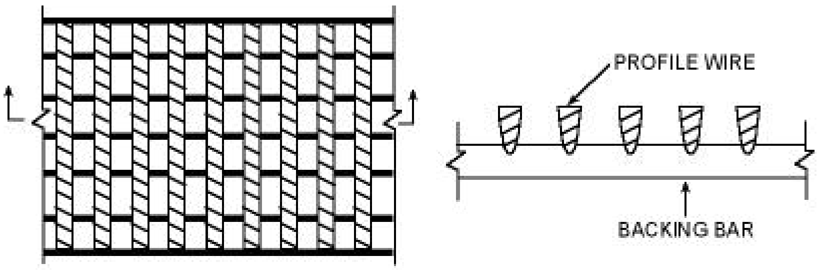
FIG. 11 - APPROACH VELOCITY
AT DRUM SCREEN INSTALLATION



WOVEN WIRE MESH

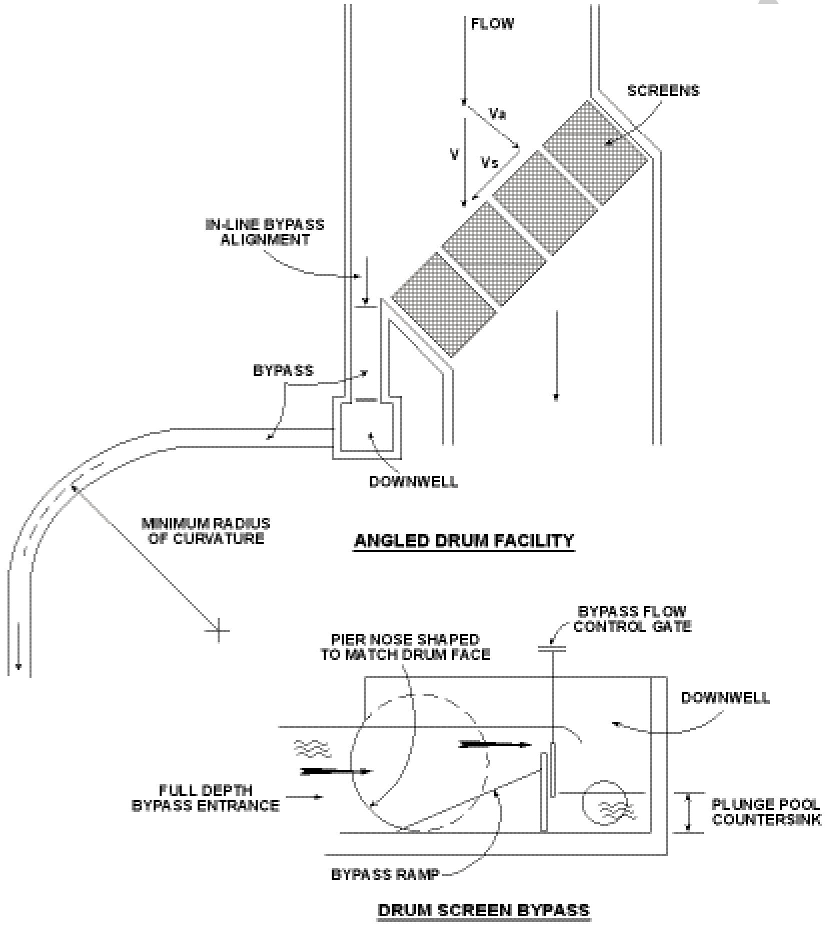


PERFORATED PLATE



PROFILE WIRE

FIG. 12 - COMMON FISH SCREENING MEDIA



ANGLED DRUM FACILITY

DRUM SCREEN BYPASS

FIG. 13 - BYPASS SYSTEM AT DRUM SCREEN INSTALLATION