Chapter IV. Positive Barrier Screens

> "The significant problems we face cannot be solved at the same level of thinking we were at when we created them."
>
> *Albert Einstein*

This chapter presents an overview of positive barrier screens with detailed planning and design criteria. Positive barrier screens compose a wide range of fish screen concepts that include:

- Flat Plate Screens
- Drum Screens
- Traveling Screens
- Submerged Screens
  - Cylindrical Screens
  - Inclined Screens
  - Horizontal Flat Plate Screens
- Coanda Screens
- Closed Conduit Eicher and MIS Screens

Although these screens vary widely in concept and configuration, they have many common characteristics. In all cases, the screen systems generate a "positive barrier" to passage of fish of the selected design size and larger. This requires that openings in screen fabric at seals and between structural members be small enough to prevent passage of the selected fish. The screens are typically designed to effectively screen both debris and fish from the diverted flow and to quickly and safely guide fish back to the natural water body from which they were drawn. In all cases, cleaning and maintenance requirements are important considerations because debris fouling of the screens will reduce both the screens ability to safely exclude fish and reduce the flow capacities of the screens.

The following chapter explores initial design requirements and issues that are common to all positive barrier screen concepts. In cases where requirements are generally common but allow exceptions, discussion of the exceptions follows the generalized presentation. This is followed by detailed discussions of unique design requirements and issues associated with each specific screen concept, chapter IV.B.

A. Facility Design

> A good scientist is a person with original ideas. A good engineer is a person who makes a design that works with as few original ideas as possible. There are no prima donnas in engineering
>
> *Freeman Dyson, 1923-, British-born American Physicist, Author*

1. Site Selection

This chapter presents more detailed discussions of siting considerations with examples of existing fish exclusion structures. The general preference of fishery resource agencies is to maintain fish in the natural water body and not draw them into the diversion. Keeping the fish in the natural water body reduces fish guidance and fish concentrations and eliminates the need for bypasses. As a consequence, in-river and in-diversion pool screens may be preferred over in-canal or closed-conduit fish screens. However, issues such as shallow depths, high river gradients, heavy sedimentation, potential for damage by large debris and ice, and construction difficulties (cofferdams, site dewatering, and construction windows) often force placement of exclusion screens in the diversion canal.

The overall hydraulic features of the location, including flow patterns, velocity magnitudes, and fish guidance at and past the screen and bypass, are of paramount importance in the design. These features of the site and design are critical to ensuring effective fish and debris movement and to reducing predation. Objectives typically are to sustain uniformly directed, eddy-free flows that efficiently guide fish past the screen and that do not provide locations for predator and debris accumulation. Placement of the structure in the flow field and configuration of transition structures will strongly influence generated flow patterns. For larger structures or unique designs, fishery resource agencies may require documentation of flow fields and will likely require computational or physical modeling.

Site selection considerations will need to address:

- Hydraulic requirements
- Minimization of predation from all fish, two and four legged animals, and birds
- Operation and maintenance costs

- Injury to fish

- The need to keep fish in the river or return fish to the river as soon as possible

a. In-canal siting

The water enters the canal through a headworks. Stream gradients are usually steeper than the diversion canal which tracks away from the diversion with a gentle invert gradient. There is usually sufficient drop to generate gravity flow through the fish bypass conduit. Water levels in the canal are often maintained fairly constant by “checking up” the canal with gate structures along the canal length.

If the fish screens are located in the canal, the following considerations must be included in the design:

- Fish screens should be located as close to the upstream end of the canal as possible, based on canal hydraulics and site constraints. This placement allows fish to return to the river as soon as possible and reduces potential predation.

- Sediment deposition must be addressed. (See chapter IV.A.14 for sediment considerations.)

- The fish exclusion facility should be well aligned with the canal and preferably located in a straight reach of canal where uniform flow velocity distributions are provided and good sweeping flow can be achieved (figure 4).

- Bypass hydraulics, available head (between the canal and bypass outfall location in the river), and the river location for the fish bypass outfall will need to be evaluated.

- Sufficient flow depth must be maintained at the fish screens to ensure that adequate active screen area is provided and that the maximum screen approach velocity is not exceeded.

- Scheduling for construction of the fish exclusion structure and bypass will need to be carefully considered, especially if water deliveries will need to be continued during construction.

- Debris should be captured at the canal headworks.

An example of an in-canal positive barrier fish exclusion facility:
The following example presents an in-canal fish exclusion facility concept and includes plan and section drawings and photographs with brief descriptions.

The Chandler Canal Fish Facility (Prosser Diversion Dam), Yakima River, Washington, is an example of a moderate to large capacity facility where the fish exclusion screen (drum screen facility) is located well downstream from the headworks at a site that provides both suitable space for facility installation and a well aligned straight canal reach. Immediately downstream from the headworks, the canal passes through a highly developed area (homes and roads). Space for the fish exclusion facility was limited and the canal alignment within the upstream reach included numerous bends. The fish screen structure was located in a straight reach of canal 4,300 ft downstream from the headworks. The site had sufficient space for the screens and for auxiliary fish evaluation and holding facilities. An approximately 500-ft-long straight canal reach leading to the screens was available, establishing a uniform channel approach flow distribution to the fish screens. (A hydraulic model study was used to develop and refine hydraulic features of the screen design, including approach and exit channel configurations). At the screen location, the checked water level in the canal is approximately 10 to 15 ft above typical river water surface elevations. Figures 26 and 27 show plan and section drawings of the constructed fish screen. The maximum diversion discharge capacity at the site is 1,500 cubic feet per second (ft^3/s).

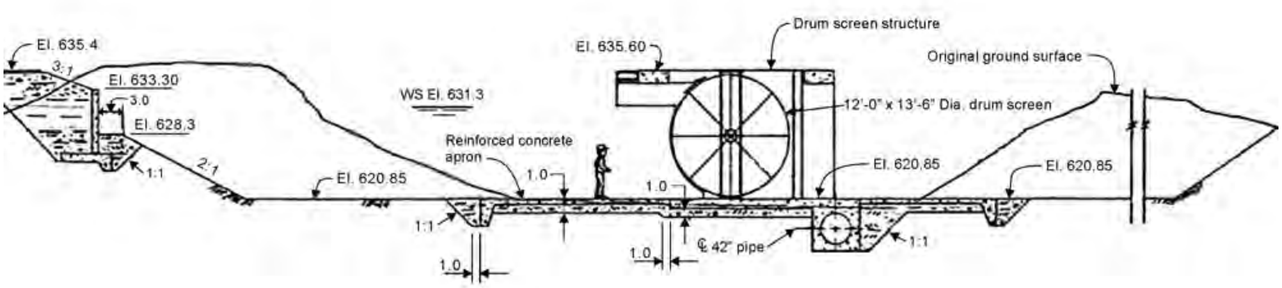


Figure 26.—Elevation view of Chandler Canal Fish Screen, Washington.

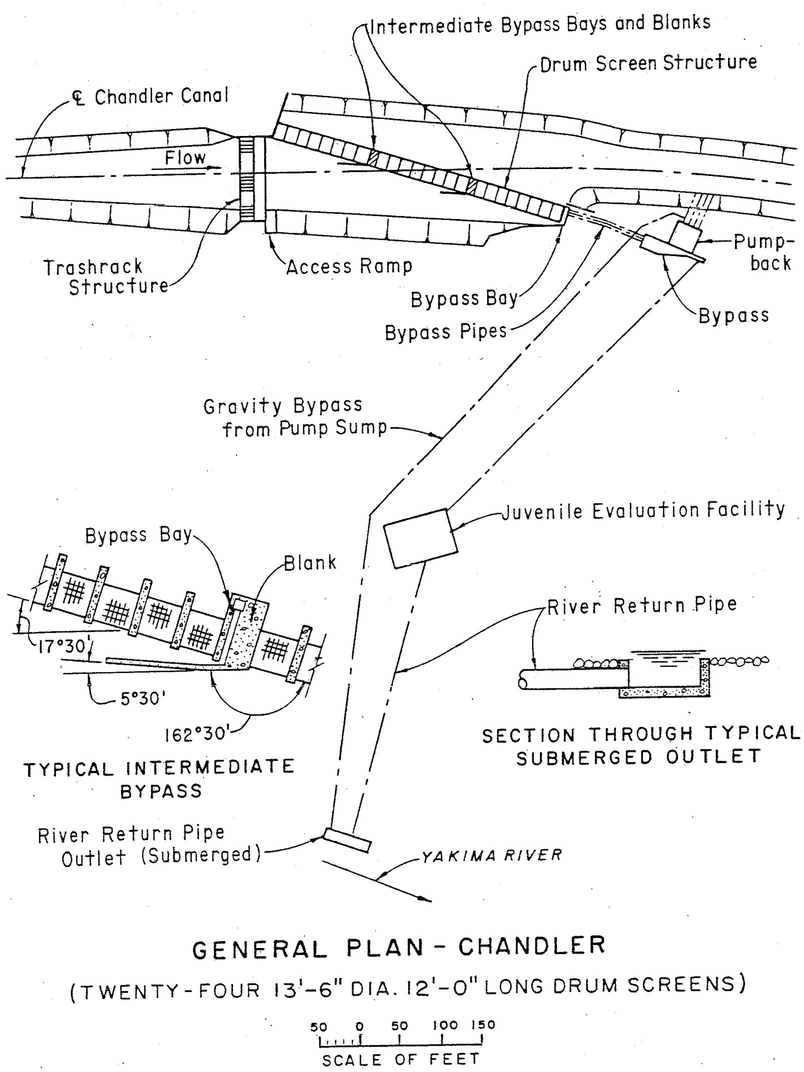


Figure 27.—Plan view of Chandler Canal Fish Screen Structure.

Flow is diverted into the existing canal by a diversion dam. Sediment deposition has occurred within the diversion pool to the point that significant quantities of sediment are diverted into the canal. Sediment sluicing capabilities were not included in the original design for the diversion dam. As a result, sediment accumulates in the low velocity reaches of the canal. The existing canal headworks include submerged vertical slide gates that provide flow control and exclude most floating debris. Trashracks were not included as part of the existing headworks.

The screen facility includes a trashrack and a fish screen structure where the *drum* screens are angled to the channel flow in such a way that fish are guided along the screen to intermediate and terminal fish bypasses that lead to a secondary screen/dewatering facility on the combined bypass. From this secondary facility, a portion of the bypass flow is pumped back to the canal, and the remaining flow and diverted fish pass through a buried bypass conduit to a juvenile fish evaluation facility and then back to the river at the bypass outfall (figure 27).

Other Examples of In-Canal Positive Barrier Screens include drum screens at Kittitas and Three Mile Falls (left bank), and flat-plate screens at Naches-Selah, Yakima-Tietan, Bachelor Hatton, Snipes Allen, Cascade, and New Cascade.

b. In-river siting

From a fishery perspective, it is best to locate the fish screen in the river before the flow enters the canal or pumping plant. However, the in-river fish exclusion facility may be exposed to large variations in flow depth, flow velocity, bed sediment transport, debris load, and ice flows that occur because of seasonal and storm events.

The facility may be placed in the river channel or at the bank. Since fish remain in the river, a bypass structure is normally not required. The exception is for very long flat plate screens such as at Glenn-Colusa Irrigation District (GCID) (which was placed in a secondary oxbow channel of the main river) in figures 5 and 6, where, because of the potentially long fish exposure time, intermediate bypasses were provided.

If the fish screens are located in the river, the following considerations must be included in the design:

- The screen structure should be positioned and oriented with careful consideration of the in-river velocity field for a range of river stage and diversion conditions. This positioning will require evaluation of river flow patterns that will occur at the site at various river stages. The facility must then be oriented to yield a sweeping flow capable of moving fish and debris along and past the facility for all flow conditions.

- Sediment deposition and scour must be evaluated. (See chapter IV.A.14 for sediment considerations.)

- The screen cleaning system must be designed to handle trash and debris which may be significant along rivers. Figure 28 illustrates the use of a debris boom and horizontal debris cleaner at RD 108 (Wilkins Slough).

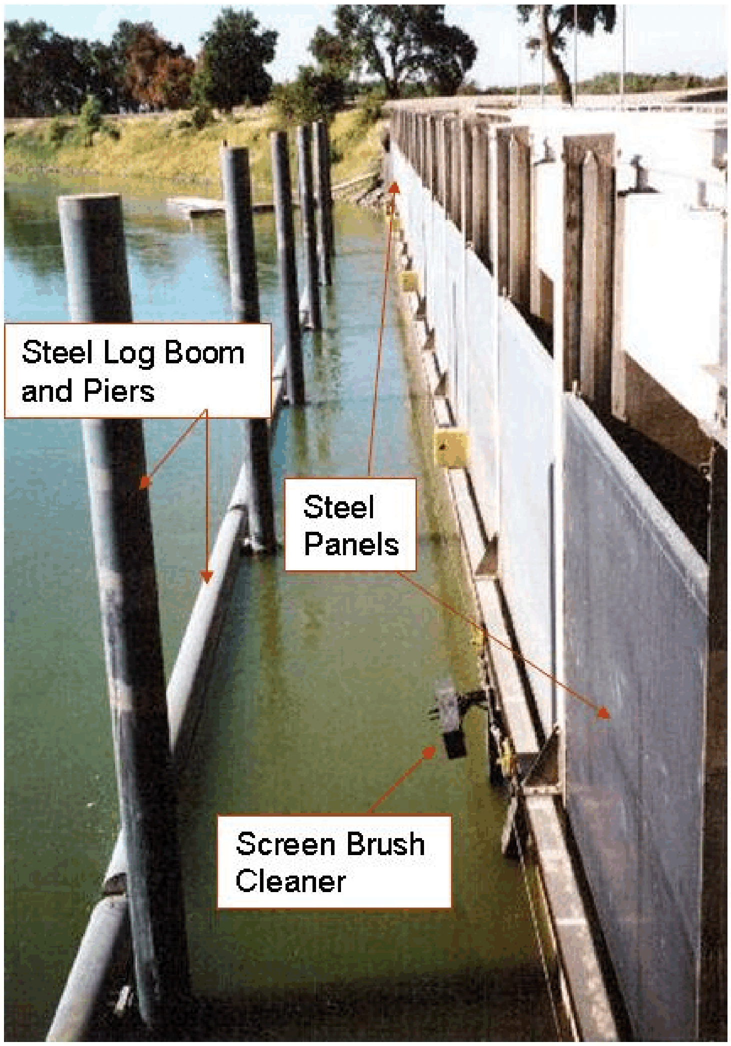


Figure 28.—Debris boom in front of the Wilkins Slough Fish Screen Structure, California (RD-108).

- River topography and bathymetry will need to be gathered.
- Construction access will need to be evaluated.
- Cofferdam construction and dewatering at the proposed fish exclusion construction site will need to be considered.

Examples of an in-river positive barrier fish exclusion facilities:
The following examples illustrate the design ranges of an in-river fish exclusion facility. Included are plan and/or section drawings and photographs with a brief description.

The Wilkins Slough Fish Screen Facility, Bureau of Reclamation (Reclamation) District 108 (RD-108) Wilkins Slough, Sacramento River, California, demonstrates a moderate flow capacity facility with a *flat plate* fish screen sited in the river. The maximum diversion discharge capacity at the site is 830 ft^3/s. The fish screen is a positive fish barrier for the diversion. A hydraulic model was used to develop the screen configuration and flow distribution control features of the design (Vermeyen,1996). Figure 29 shows an aerial photo of the facility. Figure 30 shows a plan layout of the river, screen, and pumping plant.

Figure 29.—Aerial photo of Wilkins Slough Fish Screens (RD-108).

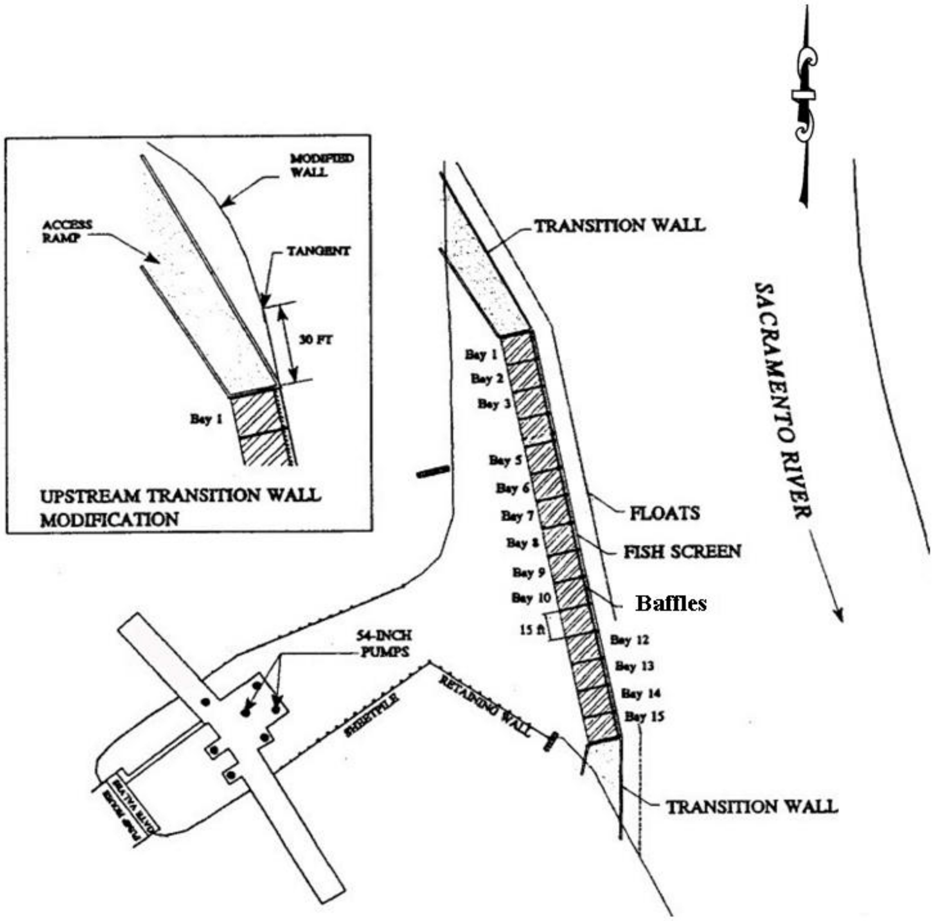


Figure 30.—Plan view of Wilkins Slough positive barrier fish screen (RD-108).

Flow is drawn from the river and through the fish screens by gravity, although pump operation is used during times of low flow in the river. Debris and fish intercepted by the screen remain in the river, thus minimizing fish handling requirements at the facility. The fixed screen structure is a large but relatively simple design that minimizes facility cost. A single-arm mechanical sweeping brush system, similar to the one shown in figure 64, is used for screen cleaning. River velocities passing the screen vary with stage and typically range between 2 and 4 feet per second (ft/s).

During the diversion season (April – December) the normal river flows range from 4,000 to approximately 17,500 ft^3/s. Corresponding, river stages range from elevation 26.0 to 40.2 ft. The river bottom at the site is at approximately elevation15.0 ft. Thus, riverflow depths at the screen facility during the diversion season range from approximately 11.0 to approximately 25.2 ft. Flow depths are substantial, which allows use of a screen with a significant screen height (a 12.0 ft vertical screen height with a 3/32-inch slot size was used). Based on the established fishery resource agency maximum allowable approach velocities and the vertical submerged screen height, a screen length of 225 ft was chosen to pass the 700 ft^3/s design diversion (maximum diversion capability is 830 ft^3/s).

Maximum river flows at the site during flood events exceed 100,000 ft^3/s. Corresponding river stages approach elevation 46 ft. The river transports significant sediment and debris loads during these high flow events. The screen was designed and constructed with the top of the screen fabric set at elevation 27.0 ft, which permits a submergence of at least 10.0 ft below the river water surface for moderate and high flow events. Trashracks, which would protect the screen face, were not included in the design because of concerns with sediment buildup between the trashrack and the screens. Above the screens, from elevation 27.0 to 51.0 ft, the structure face is made up of two solid steel plate panels, each 12.0 ft high. (See figure 28.) A large floating log boom is installed on piles approximately 8.0 ft in front of the screen facility along its length (figures 28 and 29). Thus, large floating debris encounters the boom and steel plate panels and not the screen, which is positioned deep in the water column. The submerged screen panels are pulled and replaced with solid plates containing pressure relief panels to equalize water levels on both sides of the panels from December to March (high flow season), thus further reducing screen damage potential. The design has proven effective. The screen that was installed in 1997 has experienced only limited debris-caused damage. The automated brush cleaning system, which sweeps the entire screen surface every 5 minutes, has proven effective and requires only limited maintenance. Brushes last for the whole diversion season.

Although the screen was installed in the sediment scour zone on the outside of a river bend, the screen is still exposed to significant sediment load. Agency mandated screen approach velocities yield low velocity zones behind the screens. As the model study predicted (Vermeyen, 1996), sediment deposition has occurred at these locations. An air jetting system has been developed by project personnel to keep sediments in suspension immediately behind the screens (further described in chapter IV.A.14 and figure 60). The currents then transport the sediment to the pumping plant forebay area where a drag line and trucks are used to remove sediment at the end of each pumping season (approximately 600 yd^3, figure 30).

The East Unit Pumping Plant is located on the Columbia River, downstream from the town of Wenatchee, Washington, at river mile 460.5. The plant pumps from the river to a reservoir about 2.5 miles from the booster pumping plant. It is an example of an in-river cylindrical screen structure that was installed on an existing pumping plant.

The plant is part of the Chief Joseph Dam Project, Greater Wenatchee Division and was built in 1960 by Reclamation. There are four pumping units at the river pumping plant, which pumps to a booster plant. The combined pumping units have a total capacity of approximately 75 ft^3/s. The pump bays are located about 50 ft from the bank of the river channel.

The existing pumping plant originally included fish screens comprised of four submerged flat plate fish screens about 7.3 ft wide by 7.3 ft high, with clear openings of 3/16 inch and galvanized metal wire mesh. Debris trays were located on the front face of the screens to assist in cleaning. Maximum approach velocity of water at the screens was estimated at 0.5 ft/s. The concrete piers that extended between the screens caused bays that may have trapped fish because sweeping flow was eliminated by the piers.

The pumps operated only during the irrigation season, normally from April 1 to October 15, and provided water for about 4,500 acres. During periods of aquatic vegetation (moss) problems, the old screen panels were raised for cleaning three times a week. Backup screens were installed in the downstream slots when the main screens were cleaned.

The old flat plate fish screens did not meet current screen velocity (approach and sweeping) criteria and exceeded the maximum opening criteria for effective protection of juvenile anadromous fish. Rust on the screen fabric reduced clear openings, and more rust was visible on the screen frames and debris trays. Rubber seals at the top of the screens had gaps, and there were no side or bottom seals.

These original flat plate fish screens were removed and replaced with submerged cylindrical screens. Each of two steel pipe intake manifolds were connected to two of the four bulkheads. Two 36-inch slide gates were attached to the pump side of the manifolded bulkheads. Two pump intake cylindrical Tee-screens were connected to each manifold. Figure 15 is an aerial view of the site just before installation of the four Tee-screens at the East Unit in 1998.

The submerged cylindrical Tee-screens with 36-inch diameter manifolds were chosen to replace the original screens in order to place the screens close to the path of strongest river velocities and to use this velocity for sweeping flows at the face of the screens. The facility includes four Tee-screens with diameters of 48 inches and assembled lengths of 136 inches. The maximum flow through each screen is 8,500 gallons per minute (gal/min) (18.9 ft^3/s). The screens have a conical shroud on the upstream end and are located with the longitudinal axis parallel to the river flow. Sweeping velocity is about 1.3 ft/s at elevation 599.0. The screens use profile bars with 1.75 mm slot openings. Maximum screen approach velocities are calculated at 0.20 ft/s.

Other examples of in-river positive barrier screens:
Flat plate screens are at GCID (chapter VI, Example 2); traveling screens are at Shell Rock Pumping Plant; and various fixed cylindrical screens are at Bonaparte Creek, Cordell, Crater Lakes, Ellisforde, and East Tonasket. Columbia River (figures 31 and 80, chapter VI, Example 5), and Brewster Flat (figure 79) pumping plant, and various retrievable cylindrical screens are at pumping plants on the Sacramento River (figures 16 and 17).

Figure 31.—Cylindrical tee screens on delivery barge for installation at Columbia River Pumping Plant, Oregon.

c. In-diversion pool siting

As with in-river placement, the in-diversion pool fish exclusion facility is the first component of the diversion the fish encounter. The diverted water, after passing through the fish screens, flows through either an open channel section or through a closed conduit to the gravity diversion headworks or to a pump station. The fish exclusion facility may be exposed to variations in flow depth, debris load, and ice load. However, pool and diversion dam flow regulation characteristics will tend to reduce or moderate fluctuations over those found in a river.

Low velocities occurring in the diversion pool may stabilize or eliminate sediment loading at the facility. Icing issues will be less influenced by ice floes and frazil ice loading and more associated with loading from surface ice cover. Without auxiliary structures to influence the flow pattern at the screens, the generated current resulting from diverted through-screen flow in a low or stagnant velocity field will tend to be normal to the screen face and will not produce a sweeping influence.

If the fish screens are located in the diversion pool, the following considerations must be included in the design:

- Although hydraulic and loading conditions are moderated by the diversion pool, the facility design must allow for operation under a wide range of conditions and the design must be secure under seasonally occurring and storm event loading.

- The in-diversion pool facility may require a special configuration or use of supplemental flow guidance features to generate effective approach and sweeping velocities at the screen face. This may lead to requiring a fish bypass structure.

- Sediment deposition and scour must be evaluated (see chapter IV.A.14) for sediment considerations). Sediment deposits at the structure location may negatively impact the performance and operation.

- Construction may require use of a cofferdam with site dewatering.

There are also examples of fish screens being sited in reservoirs. In such cases, the intake should be located off shore and, when possible, in a zone that provides some sweeping velocity for debris removal and to minimize sediment accumulation.

Example of in-diversion pool positive barrier fish exclusion facilities:
The following example presents an in-diversion pool fish exclusion facility concept. Included are plan and section drawings and photographs with brief descriptions.

The Roza Fish Screen Facility, Roza Diversion Dam, Yakima River, Washington, demonstrates a large capacity facility where fish exclusion occurs in the diversion pool upstream from the canal headworks. The *drum* screens were placed in the diversion pool instead of in the downstream canal because the canal, immediately below the dam, enters a steep walled canyon that greatly limits space available for in-canal structures. Figure 32 shows an aerial photo of the facility and figures 7, 33, and 34 show plan and section drawings of the fish screen facility. The maximum diversion discharge capacity at the site is 2,200 ft^3/s.

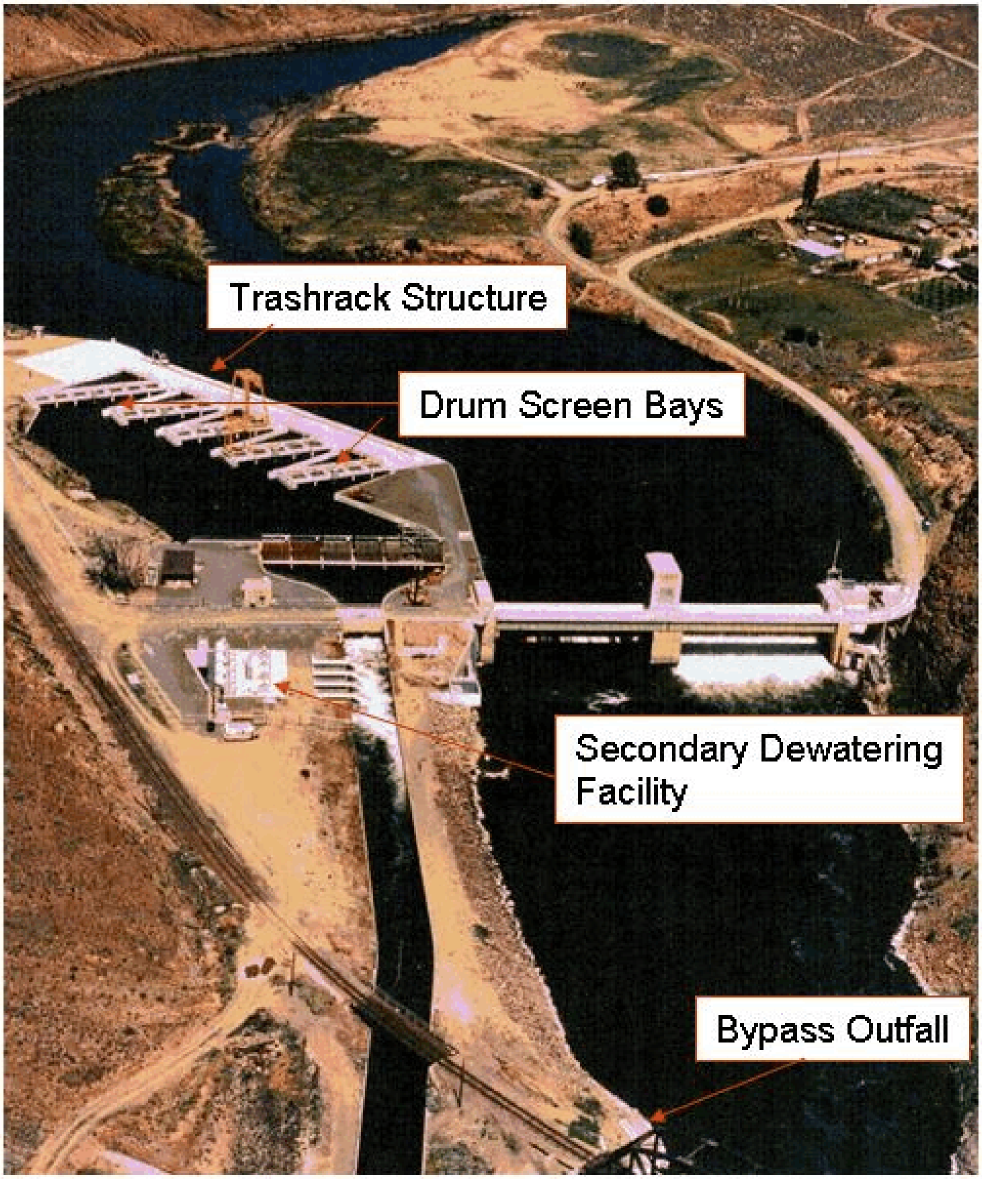


Figure 32.—Aerial view of Roza Diversion Dam and Fish Screen Facility.

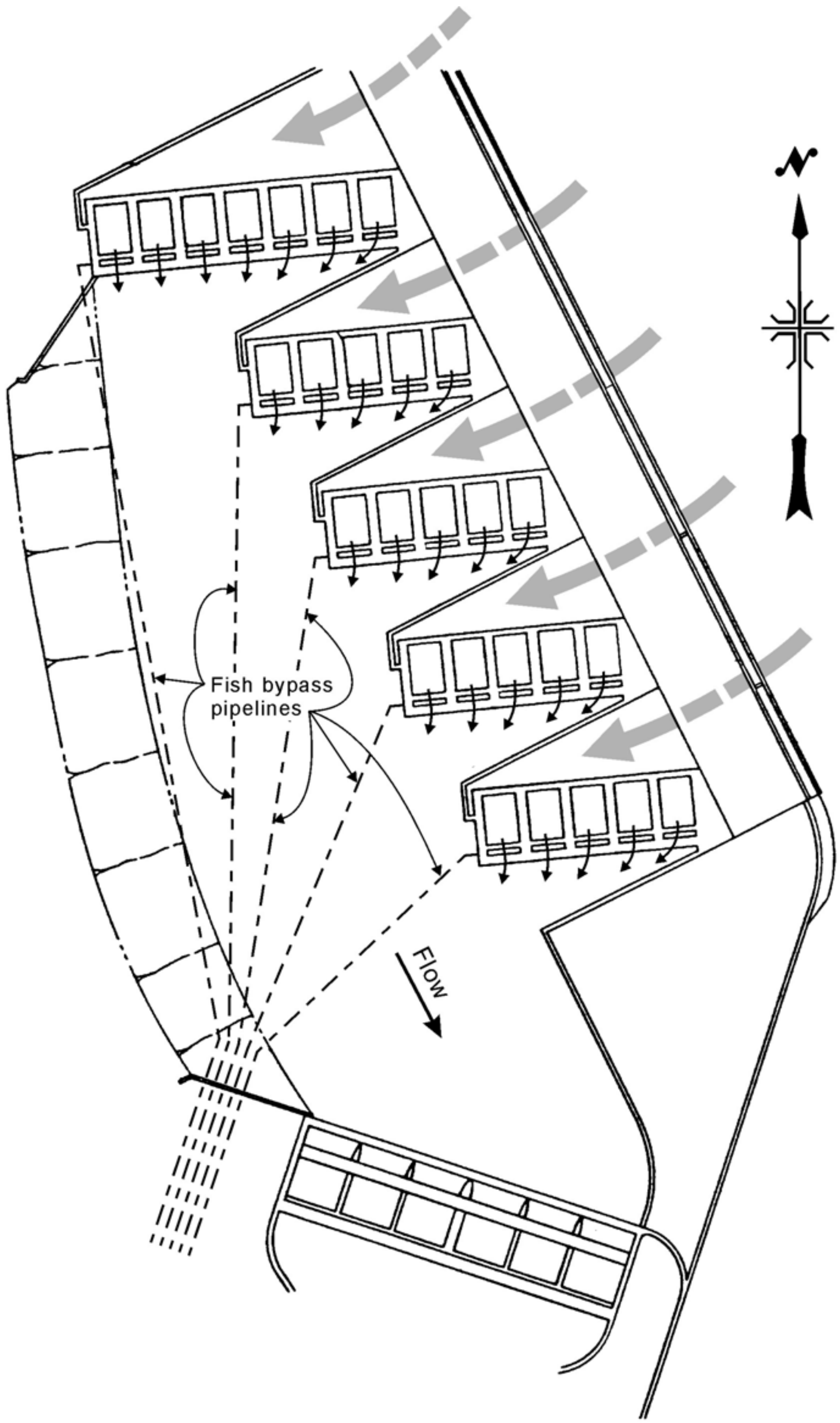


Figure 33.—Plan view of Roza Fish Screen Facility.

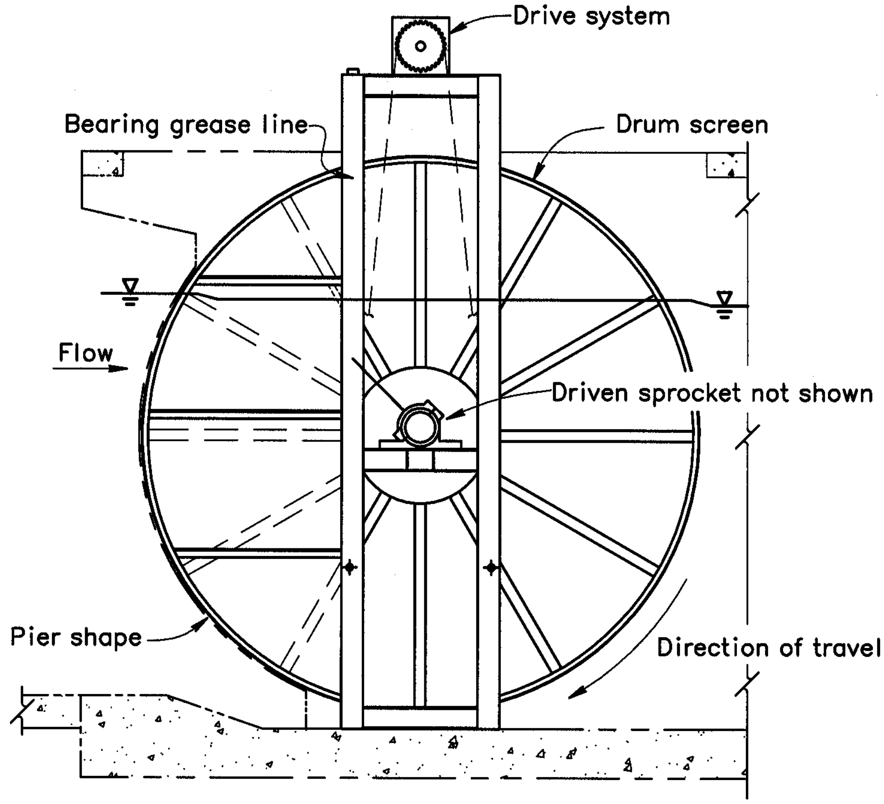


Figure 34.—Sectional view of Roza Fish Facility Drum Screen Structure.

Flow passes from the diversion pool through a trashrack structure, to the fish screens and on to the canal headworks and canal. The diversion pool has limited volume and, consequently, significant velocities are present in the pool during high river flow events. The screen structure is located on the outside of a river bend in a portion of the diversion pool that is historically free of sediment deposition. In addition, the invert of the screen structure intake is positioned approximately 10 ft above the bottom of the diversion pool in an effort to further exclude sediment from the canal diversion. Consequently, sediment deposition both at the fish screens and in the downstream canal was minimized.

Of particular concern with the design was development of a screen configuration that would generate uniform through-screen flow distributions and produce sweeping flows that guide fish by the screens and into fish bypasses. Generation of effective screen hydraulics is a common concern for in-pool screen facilities because velocities through the pool are low. Placement of an operating screen in a low velocity pool without proper consideration for screen hydraulics will generate flows normal to the screen and will not provide the necessary sweeping flow for effective fish movement and debris removal. As a consequence, a poorly configured design may yield "dead-end" hydraulics that will tend to exaggerate fish delay and impingement and debris accumulation on the screen.

As can be seen in figure 33, to generate sweeping flows in the Roza Dam diversion pool, the screens were placed on diagonals within bays created by structural walls. In effect, flume or canal-like flow conditions were established in each of these bays and, thus, at the screens. A hydraulic model study was used to design and evaluate placement of these bays (Julius, 1986).

The screen facility included trashracks, bays of drum screens angled to the approach flow in such a way that fish are guided along the screen to fish bypass entrances (figure 52), a bypass for each screen bay, a secondary dewatering facility on the combined bypass where a portion of the bypass flow is pumped back to the canal (this facility also includes traveling fish screens), and a common bypass conduit that delivers diverted fish to the river at the bypass outfall (figures 7, 32, and 55b).

Other examples of in-diversion pool positive barrier screens:

Diversion pools:

Lilly Pumping Plant – traveling screens

Potter Valley – inclined screens

Reservoirs:

Osoyoos Pumping Plant – cylindrical screens

San Justo Dam, Hollester Conduit Outlet Works – cylindrical screen (half circle).

Clear Lake Dam – flat plate screens

d. In-closed conduit siting

Where flow is diverted directly into a pressurized conduit such as a tunnel or penstock, a fish exclusion structure can be placed directly in the coduit. Closed conduit screens consist of inclined screen panels placed on a diagonal transect within a closed pipe or conduit that could be a turbine penstock, a gravity diversion conduit, a pump suction tube, or a submerged intake (figure 9). As the water and fish flow through the conduit, they encounter the diagonally placed screen. The bulk of the flow passes through the screen and continues on through the conduit. Because of the angled screen placement, fish and debris are guided across the screen face to a bypass entrance and bypass conduit positioned at the downstream end of the screen. A significant drop is required at the site to drive the bypass flow. These facilities are often designed to operate with conduit velocities of up to approximately 6.0 ft/s.

A trashrack is usually included at or above the conduit entrance. If the flow is diverted to the conduit from a diversion pool, then sediment and river generated ice loading (float and/or frazil ice) on the screen may be largely eliminated, assuming the sediments and ice remain in the diversion pool. If the flow is diverted from a river through a canal directly to the pressure conduit, sediment and ice loading may pose larger problems. A back-flush operation (figure 9) can be initiated either by monitored pressure differentials across the screen panel or by a periodic, timed cleaning cycle.

The following considerations must be included in the design development for in-conduit screens:

- The screen should be positioned in the conduit at a location where well directed and uniform approach flow distributions can be achieved across the screen surface. Positioning requires consideration of the influence of entrance and conduit transitions and bends.

- Bypass hydraulics, available head, the on-river location of the bypass outfall, and the resulting configuration of the bypass conduit need to be evaluated.

- Screen cleaning operations (typically rotation of the screen panel to a back-flushing position), procedures for initiating cleaning (periodic intervals, pressure differential), and cleaning influences on fish exclusion need to be evaluated.

- Screen head loss influences on system operation and conduit loading need to be evaluated (including debris fouling influences).

- Access for maintenance and inspection should be identified.

- The time required for construction of the screen and the resulting influence on water deliveries and operation, in particular if the screen is being installed in an existing conduit needs to be considered.

- The risk of installation and testing requirements because the concept may be considered experimental by fishery resource agencies.

Example of a closed conduit positive barrier fish exclusion facility:
The following example presents a closed conduit fish exclusion facility concept. Included are plan and section drawings and photographs with brief descriptions.

To date, a very limited number of closed conduit fish exclusion facilities have been developed. Most installations are associated with hydropower development. Many were developed as prototype facilities that were thoroughly field evaluated but not operated for extended periods (years). As a consequence, extended operation and maintenance experience, as well as fish exclusion performance with closed conduit facilities, is limited.

British Columbia Hydro's Puntledge Facility, Puntledge Hydroelectric Project, Puntledge River, British Columbia, is a production facility that has been operational since 1993 (figure 8). The fish screen facility is located on Vancouver Island in a Pacific marine environment. It includes screens installed in two parallel 10.5-ft-diameter power penstocks. The maximum discharge capacity of each penstock is 520 ft^3/s. Penstock flow velocities at the maximum discharge are approximately 6.0 ft/s.

The closed conduit fish exclusion facility includes trashracks at the penstock entrances. The conduit penstocks provide a well-aligned approach to the screens, including an expansion located between the entrances and the screens. This ensures a good approach flow to the screens, with acceptable flow patterns across the screen face. A physical hydraulic model was used to develop the design (ENSR Consulting and Engineering, 1993). Screens are placed diagonally across the circular cross-section penstock, and a bypass conduit is placed at the end of the screen to guide intercepted fish back to the river. As with other fish exclusion facility designs that have been previously described, the screens are oriented at a flat angle to the flow such that fish will move along the screens and be directed to the bypass conduits. The design of the screen and fish bypass is configured to generate velocity fields that will move fish through the system without delay or injury.

Considering reservoir influences on water temperatures at the diversion depth and infrequent icing at the site, ice loading on the screen is not a concern. Likewise, the reservoir at the diversion point has sufficient depth to exclude sediment from the diversion. Short duration, heavy debris loading on the screen has, on occasion, been a concern beyond the normal fouling and cleaning routine. When operated at partial load, debris collects in the forebay; this debris then hits the screen in one slug when the plant is brought up to full load.

Hydraulic model and field-documented head losses across the clean screen are approximately 1.0 ft. The screens are cleaned by rotating the screen panel about an central horizontal axis into a back-flushing position similar to what is shown in figure 9. The screen back-flushing operation can be achieved without diversion interruption. When the screens are in the back-flush cleaning mode, fish exclusion facilities are not in place and, consequently, fish are then lost to the diversion. Back-flushing a screen at the Puntledge Facility requires approximately 3 minutes to complete. Back-flushes are conducted at intervals, but may also be triggered by monitored pressure differentials across the screen. Considering frequency and duration of back-flushes, the Puntledge screens are in place and fully operational approximately 98 percent of the time. If back-flushing systems or cleaning activation should fail, the screens are designed to withstand complete plugging without structural failure. Venting downstream from the screens is provided to prevent penstock failure.

The Puntledge screens require little maintenance. Routine trashrack cleaning and screen back-flushing are the only common maintenance tasks. Power operations are terminated, penstocks dewatered, and the screens visually inspected and maintained once a year. Each of these inspection and maintenance periods requires approximately 4 hours of system down time.

Other examples:
Other installations include a prototype screen that was installed at Elwah Dam, Washington; a screen that has extended application at the T.W. Sullivan Hydroelectric Plant, Oregon; and a rectangular conduit concept screen (the modular inclined or MIS screen) that was developed using detailed hydraulic laboratory model studies and tested with a prototype at Green Island, New York Reclamation has not installed closed conduit screens and, thus, has no direct experience with these screens.

2. Site Isolation and Dewatering for Construction

Construction activities at fish exclusion structures normally have only minor short-term and localized negative environmental effects.

a. In-canal

Typically, the facilities are constructed in the dry. This can be done following either of two common procedures:

(1) The headworks gate can be closed and the canal taken out of service for an adequate length of time for construction.

(2) A temporary flow bypass can be constructed. A bypass typically requires cofferdams upstream and downstream from the construction site and an open channel bypass or a pipe bypass around the construction site. If an open channel bypass is constructed, the groundwater seepage between the bypass flow channel and the construction site must be evaluated and the seepage may have to be protected from piping embankment material that could cause failure of the embankment between the channels.

The construction site will have to be dewatered, and groundwater control measures will have to be implemented. Groundwater control measures may include a groundwater cutoff such as sheet piles or slurry type trench, sump pumps, or well pumps, figures 35 and 64. A site geologic investigation must be completed to determine suitable design of the dewatering and cofferdam system.

Figure 35.—Site isolation and dewatering for construction, Highline Canal Fish Screen Facilities at Grand Junction, Colorado.

b. In-river and in-diversion pool

To construct the facilities in the dry, a cofferdam must be constructed to isolate the construction site. The cofferdam may be constructed on earth or gravel embankments (depending on State and local regulations) or sheet pile such as used at GCID and T&Y Diversion, figures 64 and 118. When constructing a cofferdam in the river, the river flow frequencies and related water surface elevations must be evaluated to determine the top of the cofferdam. The top of the cofferdam is typically determined by the contractor, who will pick a flow event and freeboard using a cost risk type analysis.

The construction site will have to be dewatered and groundwater control measures may have to be implemented. Groundwater control measures may include a groundwater cutoff such as sheet piles or slurry type trench, sump pumps, or well pumps. A site geologic investigation must be completed to determine suitable design of the dewatering and cofferdam system.

Some small screen installations may be constructed by divers.

3. Foundation Design

The type of foundation and the foundation treatment are determined by the soil and rock conditions present and the designer's intended interaction with the structure. To determine the type of foundation required, the structural design loads that will be carried into the soil or rock should be identified. Site investigations are required to determine surface and subsurface conditions in the area. These investigations will greatly influence what can and cannot be constructed. Information on subsurface conditions at a site is a critical requirement. This information is used to plan and design a structure's foundation and any other below ground work. Typically, such information is obtained through the use of borings or test pits or through geophysical investigative methods. The geologic investigation must take into account the loads to be addressed by the foundation. To determine physical properties of the subsurface, soil samples from appropriate depths can be obtained for laboratory testing. If the in-place soil is suitable, the structures may be placed directly on the soils. If the in-place soils are unsuitable, the foundation material will have to be improved or replaced or the structure will have to be placed on a pile foundation. This determination should be left to the evaluation of a qualified geotechnical engineer.

It is important that all loads that may act over the lifetime of the structure be considered. The foundation should be designed for the worst conditions that may develop. Typically, the foundation design always includes the effect of the structure's dead plus live loads. It is also important to consider load effects that may result from wind, ice, frost, heat, water, earthquake, and differential water loads. For design, a factor of safety should be applied to these loads in relation to what is known of the foundation material. The less that is known of the soil or rock's physical properties, the greater the factor of safety that should be applied to the design loads.

The various types of structural foundations can be grouped into two broad categories, shallow foundations and deep foundations. The classification indicates the depth of the foundation installation and depth of the soil providing most of the support. Spread footing and mat foundations usually fall into the shallow foundation category. Deep foundation types include piles, piers, and caissons. The floating foundation is actually not a different type, but it does represent a special application of soil mechanics principles to a combination of mat and caisson foundations.

Another foundation consideration is the degree of seepage under the fish screen structure. Typically, fish screens and associated baffles will operate with a small differential in water surface (usually 0.1 ft to 0.5 ft). Water surface differentials will also be increased by upstream trashracks and the use of baffles, weirs, or gates downstream from screens, such as in figures 11 and 67. However, if the trashracks, screens, and cleaning systems malfunction or cannot keep up with the debris load, the water surface differential may increase significantly. Structures have been designed for differential water levels of 2 to 5 ft or more to provide a design capable of withstanding screens plugged with debris. At these higher water level differentials, seepage could occur under the structure.

Seepage can also precipitate piping of material from the foundation. Not all seepage pathways will progress to a piping failure, but the potential should be considered. For piping to occur, the following need to be present:

a. A free exit. This is to say that a seepage exit is free to expel soil particles. A geotechnical engineer should be consulted to select a filter material that would be suitable.

b. Sufficient gradient to facilitate particle movement. If the gradient is sufficient, any particle can be transported. Steep gradients should be reviewed as to foundation particle size and the potential for particle movement.

To prevent the seepage from carrying away foundation materials, a few protective measures should be considered:

a. Cutoffs on the upstream and downstream sides of the structure (also good for preventing scour from undermining the structure foundation).

b. A graded filter (riprap on top of sand filter layer(s)) on the downstream side of the structure. Geotextiles may be substituted for one or more layers of the sand gravel bedding.

4. Location of Screen Structures

Properly orienting and positioning the fish screen structure in the flow field greatly enhances the effectiveness of the structure to safely guide fish to the bypass. Fishery resource agency criteria are specific on flow conditions approaching, sweeping and passing through the screens (attachment A). Hydraulic modeling may be required to develop a design that ensures uniform approach velocity along the screen face. Uniform velocities are typically generated using variable porosity or flow resistance. This subject will be covered in more detail in the next section.

A fish screen structure requires the following general hydraulic considerations/ elements:

- Suitable flow conditions:

- flow must be continuously moving downstream with no dead flow zones
- minimize turbulence
- minimize flow velocity gradients
- provide uniform channel flow approaching the fish facilities (figure 36).

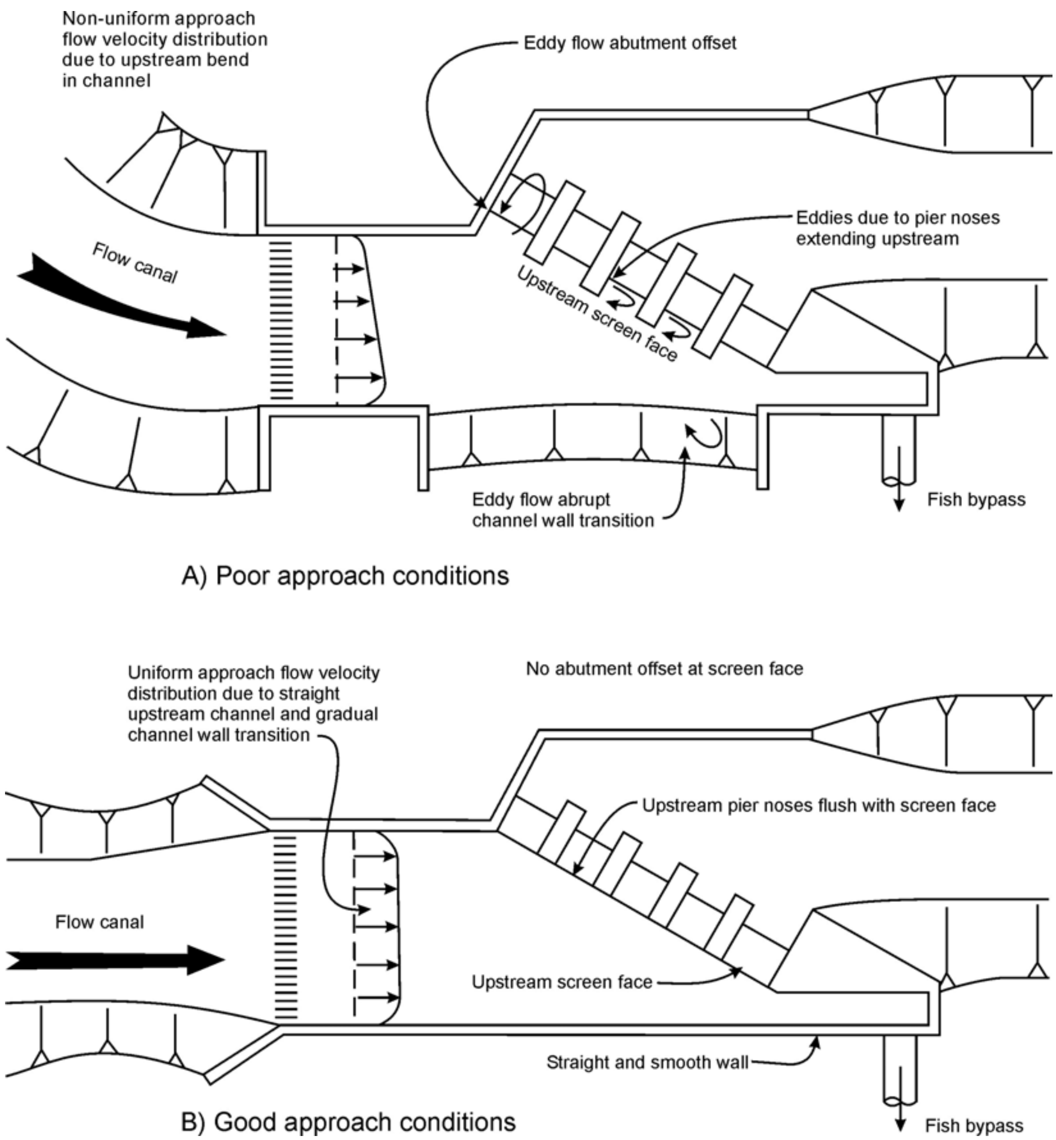


Figure 36.—Effect of approach channel on screen flow distribution (Pearce and Lee, 1991).

- Screen area: Fish screen size must be based on the minimum operating water level at the highest diversion flows. The highest flows will generate the maximum approach velocities. (For required fish screen area, see chapter IV.A.5).

- Screen approach velocity: The fish screen structure should be large enough to provide a screen approach velocity that will not exceed the criteria for the fish size specified over the expected range of diversion flows.

- Screen sweeping velocity: Sweeping velocities must be greater than the screen approach velocity (some agencies require at least twice the screen approach velocity) and some agencies prefer that this velocity be at least 2 ft/s.

a. In-canal

A fish screen structure located in the canal requires the following hydraulic considerations/elements:

- Water level control: A downstream water level control structure (check structure) may be required to ensure adequate water depth on the fish screens. This is critical for drum screens where the water depth should be maintained between 65 and 85 percent of the drum diameter to ensure that debris can pass over the drum screen while fish are swept to a bypass.

- Fish bypass: A fish bypass structure will be required for fish screens located in canals. An effective bypass requires flow that guides fish back to the river. This flow should be free of eddy and slack-water.

- Screen should be located at least 40 times the canal depth downstream from bends in the canal.

b. In-river

A fish screen structure located in the river requires the following hydraulic considerations or elements:

- Water level control: A water level control structure may be required in the river such as the gradient control structure used for the GCID fish screen structure. (See figure 5.) This may, in particular, be the case if the screen installation is in a braided channel reach or an oxbow.

- Fish bypass: For a fish screen on the river, a bypass in not normally required because the downstream river channel serves as the bypass. If the fish screen structure is too long to satisfy time of exposure criteria (normally limited to 60 seconds), intermediate bypass along the screen structure may be required.

c. In-diversion pool

A fish screen structure located in the diversion pool requires the following hydraulic considerations/elements:

- Screen approach and sweeping velocities: Screen approach and sweeping velocities in the diversion pool will likely be low. Therefore, supplemental structures are used to confine and guide the flow past the screen face

- Fish bypass: Conventional bypass structures may be required for fish screens located in diversion pools.

d. In-closed conduit

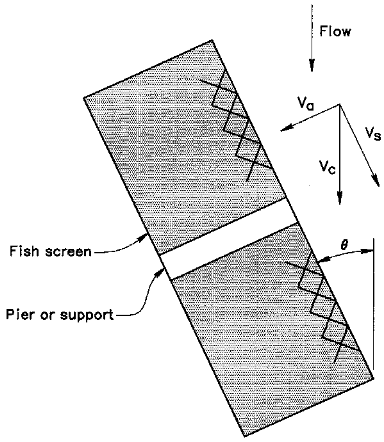
A fish screen structure located in a closed diversion conduit (penstock, pump suction tube) typically requires that the screen converge with the upper conduit surface, thus leading to the bypass entrance.

5. Screen Hydraulics (Sizing Screen Area, Approach and Sweeping Velocities)

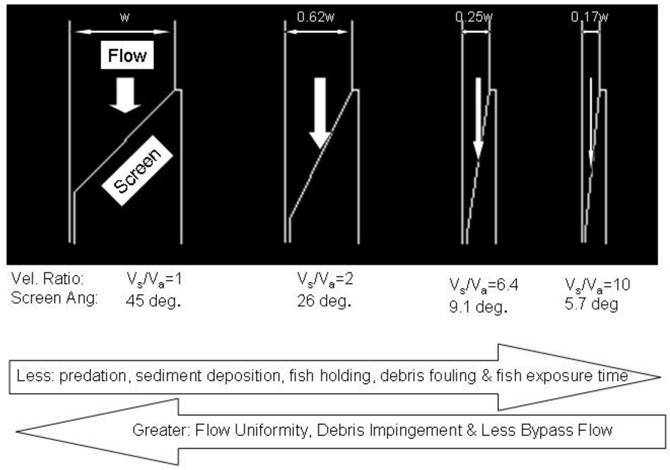
Fish screens are set at an angle to the flow to reduce flow velocity normal to the screens to safe levels for fish and to establish flow parallel to the screen to guide fish past the screen. If screens are oriented normal (90 degrees) to the channel flow, the fish tend to hold in front of the screens or are impinged on the screen. In either case, the fish are not directed to the bypass entrance. Published criteria for the design of screens that are applied for juvenile salmon, National Marine Fisheries Service (NMFS) now called the National Ocean and Atmospheric Administration Department of Fisheries (NOAA Fisheries) (attachment A), require screens to be oriented at angles less than 45 degrees to the flow to create a sweeping flow in front of the screens. The screens are aligned at angles ranging from parallel to the flow (0 degrees) up to 15 degrees. This reduces the width of the structure while increasing the ratio of sweeping velocity to approach velocity.

a. Sizing screen area

The flow approaching the fish screens can be characterized in a vector format (figure 37a). The resultant, or channel velocity, V_c , can be broken into an approach velocity component, V_a, that is normal to the screen face and a sweeping



a. Screen approach velocity and sweeping velocity (Pearce and Lee, 1991).



b. Velocity ratio as a function of screen angle placement.

Figure 37.—Screen hydraulics.

velocity component, V_s , that is parallel to the screen face. The component normal to the screen face V_a, is that part of the channel velocity that draws fish and debris to the screen surface. The component parallel to the screen face, V_s , is that part of the channel velocity that directs fish and debris along the screen

Approach velocity, $V_a = V_c (\sin \theta)$
Sweeping Velocity, $V_s = V_c (\cos \theta)$
Where: V_c = channel resultant velocity and,
θ = Angle between screen face and channel flow line

Computed approach velocity vectors are based on the total flow passing through the screen divided by the effective wetted screen cross-sectional area. This is measured from the top of the screen or water surface (whichever is less) down to the bottom of the screen material and excludes the screen face area blocked-out by structural support members. The total submerged screen area required, A (effective wetted screen cross-sectional area), will be based on the maximum allowable screen approach velocity, V_a, from the resource agencies, and the maximum design flow, Q, diverted through the screens. This required effective area can be calculated by dividing the maximum diverted flow by the allowable approach velocity:

$$A = Q/V_a$$

To account for area lost to the submerged structural components (e.g., guides and support frame), the calculated effective screen area, A, should be increased by a factor of 5 to 10 percent.

Knowing the minimum operating water depth, D_{min}, at the design flow, and the calculated total effective (submerged) screen area, A, based on allowed approach velocity and diversion flow; the required overall screen length, L, can be determined by dividing the effective area by the depth [$L = A/D_{min.}$]. In the event the diverted flow changes with water depth, a complete range of calculations may need to be evaluated to determine the maximum required screen length. The quantity and the length of the individual screens can then be determined. The length of individual fish screens should be based, in part, on the requirements of the screen guides which need to carry the loadings into the structure and/or supports and, in part, on the handling and transporting requirements of the screens.

The ability of fish to avoid impingement on a screen depends on species, size, physical condition, and stamina. Physical condition and stamina can vary widely with water quality and exposure to stressors. Therefore, fish screens must be designed to protect fish from entrainment or impingement under less than perfect conditions. Specific velocity design criteria are available for juvenile salmon; however, few criteria are available for other fish species and sizes. Salmon criteria are discussed in more detail in attachment A; however, it should be recognized that it is appropriate to establish criteria based on the specific fish species and fish sizes for which the screen is being designed.

b. Screen approach velocity

The fishery resource agencies define the screen approach velocity, V_a, as the local channel velocity component vector perpendicular to the face of the screen, measured approximately 3 inches in front of the screen face.

At this time, the maximum permissible approach velocities in California range from 0.33 to 0.4 ft/s for salmonid fry, depending on the screen structure placement, and 0.8 ft/s for salmonid fingerlings (attachment A and table 4). Screen approach velocities as low as 0.2 ft/s are required for screens in California that exclude Delta Smelt. Likewise, the NOAA Fisheries Northwest Region requires that approach velocities not exceed 0.4 ft/s if salmonid fry are present and 0.8 ft/s if fish no smaller than salmonid fingerlings are present (attachment A).

Efforts should be made to generate uniform screen approach velocities on the screen face to eliminate local high velocity hot-spots that might exaggerate fish impingement, fish injury, and debris accumulation. There are several design approaches that can be used to generate uniform screen approach velocities.

These alternative approaches are discussed in more detail in chapter IV.A.4 of this document. NMFS (NOAA Fisheries) juvenile fish screen criteria for screen approach velocity uniformity (see attachment A.1, NMFS 1995, item B.4) states:

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

c. Sweeping velocities

Sweeping velocity is important for achieving good fish guidance and movement of debris past screens. NOAA Fisheries requires a sweeping velocity, V_s, that is equal to or greater than the screen approach velocity, V_a. Following NOAA Fisheries criteria, a screen can be oriented at angles up to 45 degrees to the flow. Other fishery resource agencies criteria may differ. Some State fishery resource agencies require a sweeping velocity of at least twice the approach velocity, which corresponds to a maximum screen angle of 26 degrees to the flow.

When screens are oriented normal to the channel, no sweeping flow is produced to guide fish to a bypass. Instead, fish hold in front of the screen. Therefore, screens are set at an angle to the flow with the objectives of reducing hydraulic forces that would impinge fish against the screen face and establishing a sweeping flow that effectively guides fish along the length of the screen and to the bypass. To allow for unimpeded flow of water parallel to the screen face, the screen support structure should be designed flush with any adjacent screen bay, piers, or walls.

The fish screen structure should be located in the channel where the flow distribution approaching the facility is uniform and well directed. For in-canal sites, the upstream canal section should be straight for at least 40 times the canal flow depths. With in-river, in-diversion pool, and closed conduit siting; the influence of the structure and boundary configurations on the approach flow field must be evaluated. For more complex sites, laboratory physical scale modeling may be required to site the screen and develop acceptable velocity flow fields.

d. Sweeping/approach velocity ratio

The ratio of V_s/V_a affects how debris passes a screen. Generally, higher ratios of V_s/V_a shed debris better than low ratios. The following guidelines were developed from flume tests at Reclamation's Water Resources Research Laboratory using pond weeds passed in front of flat- plate screens. Screens made of profile bar (wedge wire) and punch plate (perforated plate) materials were tested and performed similarly.

$V_s/V_a < 5$, High debris impingement on the screen.
$5 < V_s/V_a < 10$, Moderate to low debris impingement on the screen.
$V_s/V_a > 15$, Very low debris impingement on the screen.

A high degree of debris impingement on the screen is desirable when removal of debris from the flow is an objective. For example, minimizing the debris passing into a bypass is important when designs require long fish bypasses or contain secondary dewatering screens. Screens used at low V_s/V_a ratios to capture debris are typically traveling screens and drum screens

The middle range of V_s/V_a is the most commonly used for screen designs. Sweeping to approach velocity ratios between 5 and 10 generally result in a high percentage of the debris being carried or "rolled" along the screen. Most types of debris that becomes impinged is easily dislodged by common screen cleaning techniques.

Sweeping to approach velocity ratios greater than 15 yields a strong hydraulic cleaning component. These screens can operate for longer periods with minimal cleaning required. However, screen cleaning devices are recommended for high V_s/V_a screens and are generally required by fishery resource agencies.

Designing a screen with the V_s/V_a ratio as a design objective may require expanding or contracting the channel width (or depth) to change V_s and/or increasing the screen area to reduce V_a. Many small diversion screens are designed with an approach velocity less than that required by fish criteria to increase the V_s/V_a ratio and, therefore, reduce cleaning problems. Reclamation field and laboratory experience leads to a guideline of keeping V_a less than 0.5 ft/s when considering debris content. Screens designed to operate in a high sweeping flow are generally aligned at shallow angles or parallel to the channel flow to limit the component of channel velocity directed at the screen, V_a. For example, based on geometry, a screen designed for a maximum approach velocity of 0.4 ft/s in a channel flowing at 2.0 ft/s should, ideally, be angled into the flow 11.5 degrees ($\sin 11.5° = .4/2.0$). In practice, screen angles greater than or less than the geometrically ideal angle can be used.

In general, the flatter the screen angle (lower V_s/V_a ratio) the greater flow uniformity at the fish screen, higher debris impingement, and lower fish bypass flow required. Conversely the steeper the screen angle to the flow the less predation, fish holding, fish exposure time and debris fouling, figure 37b.

6. Uniform Flow Distribution on Screen Surface

Flow passes through the screen because of head (water level differentials) across the screen. These differentials are typically not uniform over an entire screen surface. Local variations in velocities and flow patterns, as influenced by localized approach and exit flow concentrations, structure and channel geometries, and head losses in the system, will yield localized variations in differentials across the screen. Therefore, achieving uniform approach velocities requires either refinement of flow patterns, restriction of flow paths to modify water level differentials, adjustment of actual open areas in or just downstream from the screen to modify local through-screen flow rates, or some combination of the above.

To minimize the potential for fish contact with the screen surface and the potential for fish injury, screen approach velocities should not exceed species and fish size specific magnitudes as established by fishery resource agencies criteria. These approach velocity limits represent local maximum velocities that should not be exceeded on the screen face. To optimize use of the screen surface area and to generate consistent flow patterns across the screen surface, approach flow distributions on the screen face should be as uniform as possible.

a. Criteria

The NMFS (NOAA Fisheries) juvenile fish screen criteria for approach velocity uniformity (see attachment A, NMFS 1995, Portland Office) state:

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

In general, as the design of a screening facility is developed, the designs of the channels and structures need to address the flow distribution and flow controls necessary to ensure that good flow distributions will be generated over the full length of the screen. If there is uncertainty about the flow distributions that will be generated, hydraulic model studies can be used to refine designs and validate performance or adjustable flow distribution controls can be included that would allow field evaluation and adjustment once the facility is built.

In reality, an absolute uniform flow distribution is not possible to achieve across an entire screen surface for all flow conditions. There are no criteria or anything in the literature to quantify acceptable variations from uniform distribution. Experienced fishery resource agency staff and design staff may have a feel for distributions that are acceptable, based on a knowledge of approach velocity distributions and fish injuries experienced at existing sites.

b. Methods of generating uniform distributions

Although the NOAA Fisheries criteria (NMFS, 1995) specifically mentions adjustable porosity control as a method to create approach velocity uniformity, there are numerous techniques available that have been applied and are proven. Alternative methods that can be used to generate uniform through-screen flow distributions include the following:

Flow field geometry **–** Control of flow field geometry is the most effective method of generating uniform flow distributions, especially in large screen structures. Uniform differentials and approach velocities will result from establishing uniform approach flow and uniform exit flow patterns over the entire screen surface. Approach flow distributions are strongly influenced by the configuration of the screen and the configuration of the approach channel. An extended length of straight channel approaching a screen placed on a diagonal across the channel will generate relatively uniform approach flow distributions (figures 36b and 38a). A linearly converging approach flow can also be accomplished by angling the opposite bank toward the screen structure. A bend or change in alignment of the approach channel near the screen and/or section transitions such as expansions or contractions will generate non-uniform velocity distributions (figures 36a, 38b, and c). Placing a well-configured screen in a section with uniform flow direction and magnitudes greatly improves uniform approach velocity distributions on the screen surface. If the placement of the screen is required at a location with non-uniform approach flow, additional studies (hydraulic model studies) and use of supplemental flow distribution control structures (discussed below) will be required.

If a screen structure must be placed a short distance downstream from a bend in the approach channel, turning walls could be used to sustain uniform velocity distributions through the bend and on to the screen (figure 38d). This treatment was effectively applied at the Three Mile Falls Left Bank Fish Screen Facilities, Umatilla River, Oregon, figure 40.

Exit channel geometry and flow conditions also influence water differentials across the screen and, thus, the approach velocity distributions. Sizing and configuration of the exit channel in conjunction with the amount of flow that is locally present can generate varying velocity zones (figure 39). The screen and screen structure may redirect the flow, thus, generating velocity concentrations and areas of reduced velocity in the exit channel (figure 39b) or localized backwater (eddy) effects. These effects often generate reduced exit velocities along the upstream portion of the screen and higher velocities along the trailing portion of the screen (figures 39a and b). The higher exit velocities create greater water differentials across the screen and, thus, in zones where higher exit velocities are present, larger screen approach velocities are produced. As a result, it is common that approach velocities are often greater at the trailing or downstream end of the screen.

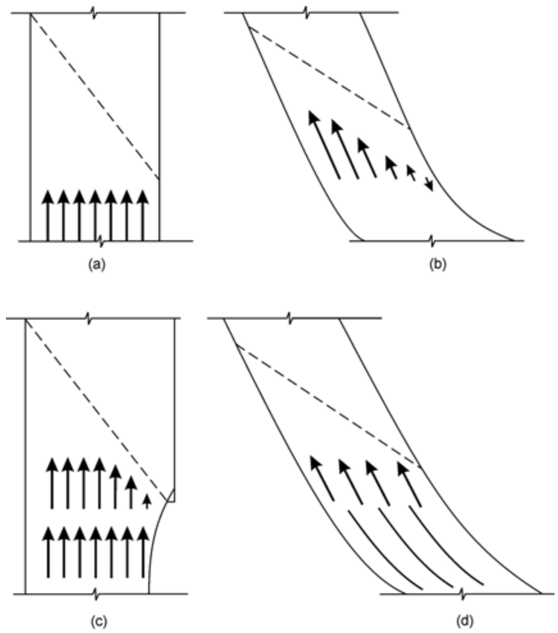


Figure 38.—Approach channel geometry influences on approach velocity distributions.

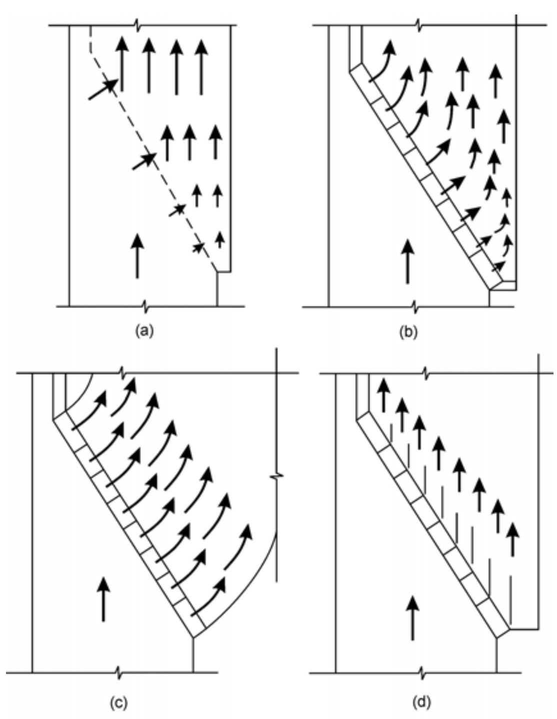
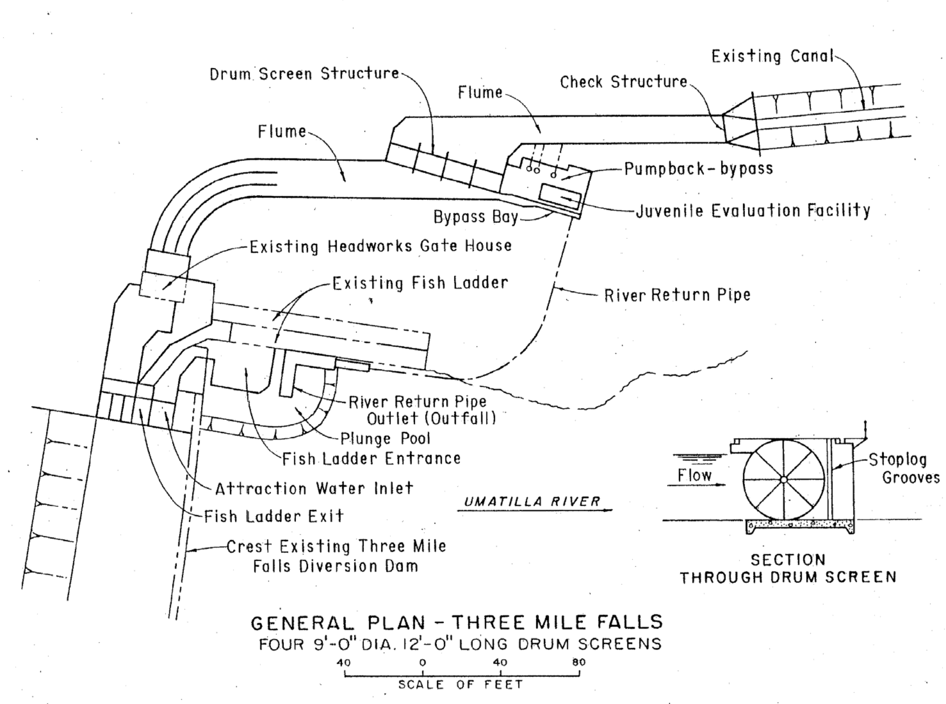


Figure 39.—Exit channel geometry influences on approach velocity distributions.

a. Photo.



b. Schematic of site.

Figure 40.—Curved entrance walls at Three Mile Falls Left Bank Fish Screen Facility, Umatilla, Oregon.

Flow field control options exist that can be used to generate uniform exit velocity distributions. These include configuring the exit channel to generate uniform exit velocities through use of gradual transitions that uniformly turn and redirect the flow as the site requires. The transitions should be configured to be well aligned with the flow exiting the screen and should smoothly redirect the flow without generating velocity and backwater concentrations. Figure 39c shows an example of a possible exit channel transition that might be applied if the screen structure generates a flow that exits the screen at a 90 degree angle to the screen alignment. Model studies that consider the design specific influences of the screen structure and approach and exit channel configurations on the flow distribution should be used to develop and confirm such a design.

Another option is to redirect the exiting flow from the screen using a series of turning walls or fixed turning vanes along the back of the screen (figure 39d). This option may create local approach velocity variations over the reach of screen influenced by each turning vane, but prevents large variations in approach velocity over the entire screen length. The magnitude of velocity variations is reduced with the turning vane spacing and configuration. The turning vanes may also be incorporated in the screen support structure, which would allow the flow to be turned on short cycle lengths (6 inches to a ft), which would generate further refinement and uniformity in the approach flow distribution (Lancaster and Rhone, 1955).

Where screen structures are located in the river or along the river bank, the screens should still be positioned in a location with the best possible approach and sweeping flow conditions. These in-river screen sites are usually a part of a pumping plant facility. The operation of the pumps, therefore, controls the flow that is being passed through the fish screens. The positioning and orientation of the pumping plant and the forebay with respect to the screens and operation of the pumping plant pumps all need to be evaluated to determine how the distribution of the flow through the screens will be affected. If the pumping plant is relatively close to the screen structure, the flow through each screen section may be better controlled by having dedicated channels or bays between sections of the fish screens and associated pumps in lieu of a common channel between the screens and the pumps. A similar control system for a gravity type diversion could have weirs or gates at the end of each screen bay channel to control the exit flow.

Baffling – Supplemental baffling is used behind the fish screens to locally generate head loss. This additional head loss creates a back pressure effect on the screen that locally reduces the water differential across the fish screen and, thus, controls the flow rate and approach velocity through the respective portion of screen surface. This baffling can take a wide range of forms. It could be:

- Stop logs or planks (figure 11) stacked or mounted with spacers in a frame

- Perforated plate bolted to a supporting framework or placed in guides behind the screens (figure 41)

- Vertically adjustable (individually controlled or ganged) baffle vanes that can be rotated to open and close much like a vertical window blind (figure 42)

- Baffles fabricated with an upstream perforated plate capable of being adjusted up or down to vary the open areas and a back support frame fabricated with matching fixed perforated plate holes or horizontal slots similar to figure 41

- Other screen or flow restriction/resistance elements that are placed locally behind the screen

Any of these baffle types can be bolted in place or fabricated to be placed within guides. It should again be pointed out that supplemental baffling will add additional head loss to the system and should be accounted for in the hydraulic design of the system

Use of supplemental baffling that can be adjusted in the field, such as the vertical adjustable baffle vanes or adjusted perforated baffling (figures 41 and 42) should be considered. It is possible that, through the design development process, all the site-specific conditions that could affect the approach velocity distributions would not be considered or, because of site restraints, would not be used. By including supplemental baffling in the screen facility that can be field adjusted, field evaluation and adjustments can be made as needed in response to approach flow distributions in the field. Adjustable baffling is well suited to some screen concepts, such as flat plate screens, but may be difficult to apply to other screen concepts where access is difficult (such as closed conduit and submerged cylindrical screens) or to screens with complex configurations (such as three dimensional screen concepts that may be tailored for specific site applications). It should be noted that supplemental baffling, by itself, will not always be sufficient to create a good uniform approach velocity distribution on the screen if the channel approach and exit geometries are poor.

***Variable porosity* –** In some instances where the backside of the screen is not accessible or where the addition of baffling components to the backside of the screen might pose an operations obstacle (for example: the Eicher or MIS screen is rotated in the flow to generate back-flushing), the porosity of the screen itself can be adjusted. With this treatment, screen material with reduced percentages of open area can be applied in the portions of the screen surface that experience higher flow rates. This reduces net open area in the screen and thus reduces

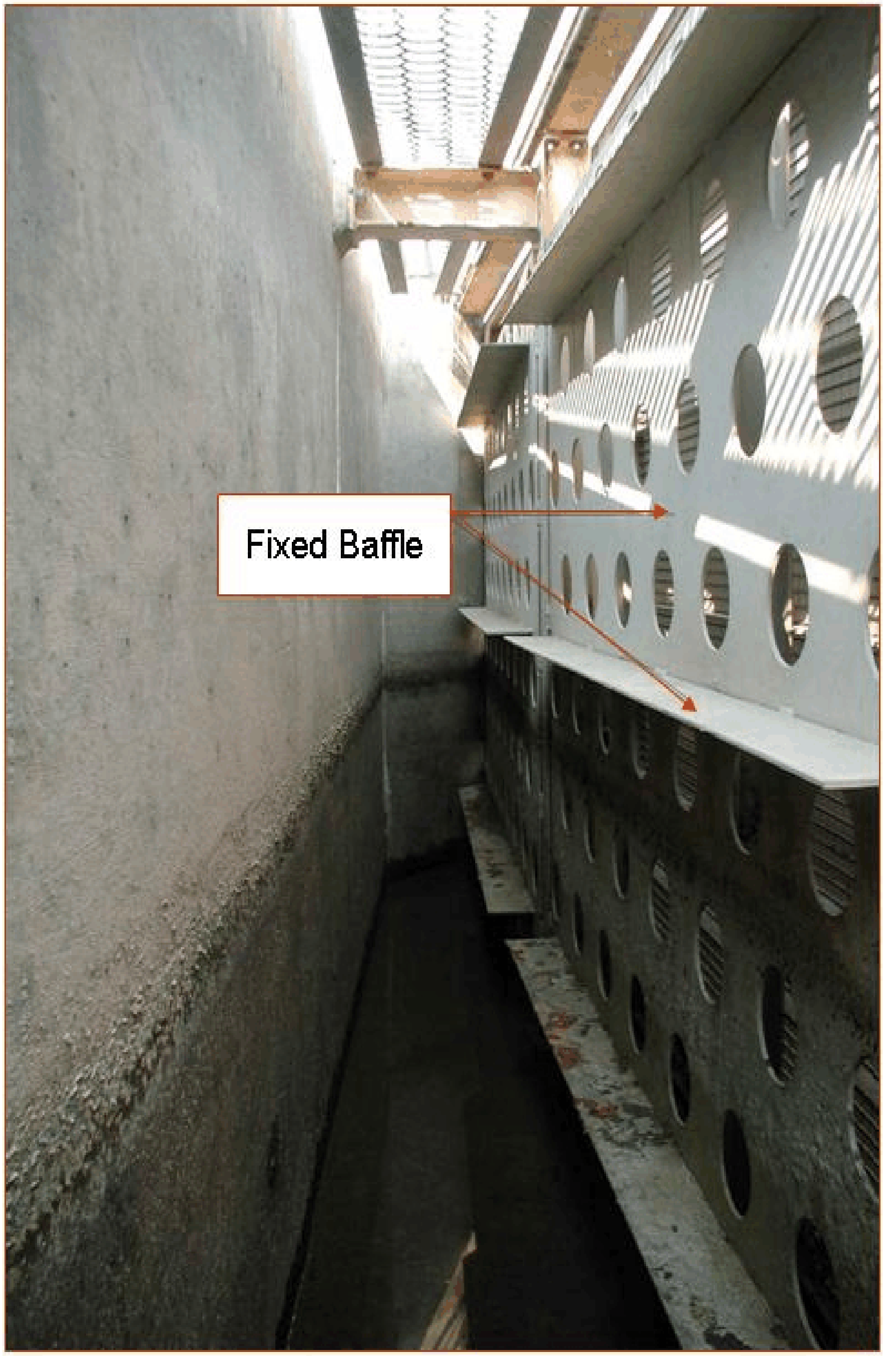


Figure 41.—Fixed perforated plate baffle behind Red Bluff flat plate screen.

Figure 42.—Vertical van-type adjustable baffles behind Red Bluff flat plate screen.

actual flow rates through the screen in these zones. Application of this alternative would likely require use of a detailed hydraulic model study to develop and verify the spacial distribution of the reduced porosities. This alternative cannot be field adjusted and, thus, the design and modeling process needs to be highly accurate. Although the percentage of open area would be locally reduced, the individual slot openings or hole sizes in the screen would be consistent (just fewer openings) and would still need to fully comply with established fishery resource agency criteria.

Uniform high resistance – A final option that can be used to generate uniform approach velocity distributions over an entire screen surface area is to uniformly apply a high flow resistance or high head loss element over the entire screen surface. At sites where sufficient head is available and head losses are not a concern, a high head loss baffle element can be applied. These baffles are designed such that the loss across the screen and baffling dominates and is much larger than losses associated with the flow through the screen. The net effect of this treatment is that near constant water differentials are generated across the entire screen surface and near uniform screen approach velocity distributions result.

Typically, screens developed with this treatment include a uniformly applied baffling or resistance element placed a short distance behind the screen. In the example presented in figure 43, a uniformly perforated plate resistance element is placed behind the profile bar (wedge wire) screen. This baffling element should be selected to generate a desired head loss that is determined through consideration of energy terms in the approach and exit flow. Typically, the baffle element is designed to generate head losses equal to or greater than 80 percent of the energy required on the flow paths. Associated losses may amount to 0.5 to 1.0 ft at many sites.

A common design for the high resistance baffle is to use a perforated plate with a percentage open area that is much smaller than the percentage open area of the screen. Although the percentage open area is small, large opening sizes should be used in the perforated plate to ensure that debris fouling does not occur. This type of baffling is useful in submerged and bottom type screens where access to the screen and baffling may be limited and head loss across the structure is not critical.

c. Other downstream controls

Downstream check gates can also be used in a canal as a method to equalize flows through multiple screen structures. Also, having specific pump bays and channels associated with multiple screen structures can limit the flow drawn through the screens. For example, for long screen structures on a river with common bays between the screens and the pumping plant, excess flow may be drawn into the upstream end of the screen structure.

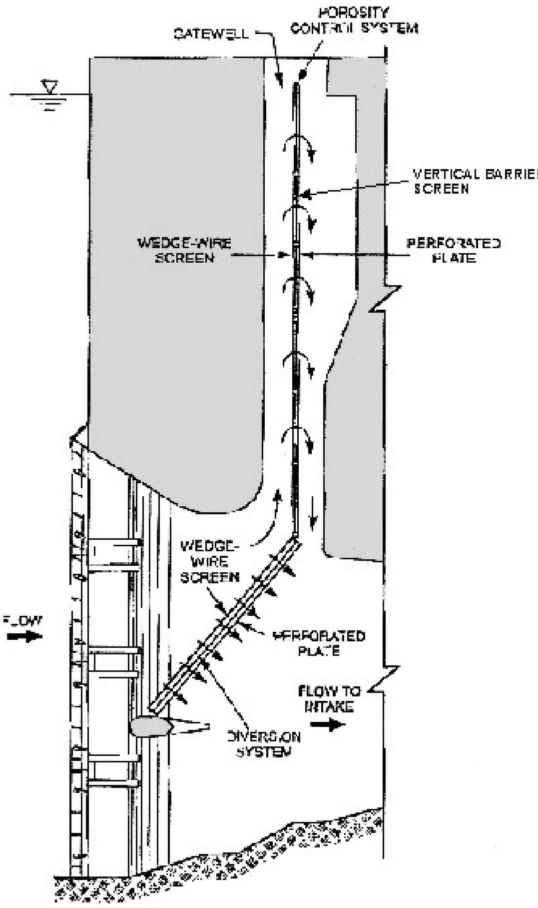


Figure 43.—High flow resistance perforated plated element as used in turbine intake screens, Columbia River (Weber, 2001).

d. Maintenance/operations considerations

The type of screen, how it will be operated and cleaned, and its debris and sediment passage characteristics should all be considered in selecting baffling type and configuration. For example, with a drum screen, smaller sediment can pass through the screen and on downstream. The drum screen can also pass debris over the top to be washed off and moved on downstream by the exiting flow. As a result, stop-log baffling behind the drum screen (figure 11) should include unrestricted flowing sections both above and below the stop-logs to allow sediment and debris passage. When applying any baffling, the type and size of sediment and debris that could pass through or over the screen should be considered. Marine and aquatic growth are other site specific factors to be considered. The baffling should include openings of sufficient size to pass this material and not foul (since access to the baffle for cleaning may be difficult). The distance between the screens and the baffles may be dictated by the type of screen cleaner being used. For example, if the screen is being cleaned from the backside by either a high pressure spray wash system or an air burst backwash system, adequate room for the piping between the screens and the baffles is required.

7. Design flow

Fish screen facilities are commonly designed to pass 90 percent to full design flow of the diversion, plus the bypass flow. If the design flow of a canal is 1,000 ft^3/s, the fish screen structure flow plus bypass flow (which may be 50 ft^3/s) would be 1,050 ft^3/s. Much of the 50 ft^3/s bypass flow is needed to attract the fish to the bypass entrance. A smaller flow can actually guide the fish back to the river through the bypass. In many cases, especially where there are multiple bypasses, some of the bypass flow can be returned to the canal using secondary fish screens and pumps as shown in figure 56. Figures 7 & 27 show secondary screening facilities for Roza Diversion Dam and Chandler Canal fish facilities. The remaining bypass flow with fish goes back to the river.

At some diversion sites, discharges rarely approach maximum diversion capacity. In such instances, with approval from the responsible fisheries resource agencies, the fish exclusion structures might be sized and developed based on a more commonly occurring maximum discharge (a discharge, for example, that is not exceeded more than 1 percent of the time). It should be recognized that, in so doing, the fishery resource agency design criteria will be exceeded on occasion. The potential for future development or changes in water demand that might increase flow rates at a later date should also be considered.

8. Head Loss Estimates

Head losses are normally estimated for the trashracks, fish screen/baffle combination, and for the bypass. To determine the degree head losses will affect water levels in the canal reach near the fish facilities, calculations are conducted to evaluate each component. The available hydraulic head at a site can be a constraint on site location and/or the type of screen design selected. To properly operate a fish bypass, the hydraulic head should be sufficient for:

- Head losses through the trashrack
- Head losses through the screen and baffles
- Head losses through the bypass

a. Head loss through trashracks

Head loss through trashracks depends on bar size, bar spacing, angle of the trashracks to the flow, flow velocity, and debris removal

Several methods can be used to estimate trashrack losses. We have chosen Reclamation's, Design Standards 3, "Canals and Related Structures," chapter 11 of the updated standard

The head loss, H can be calculated by;

$$H = 7.07 * (T/D)^2 *(\sin A/(\cos B)^{1.875}) * (V^2/2g)$$

Where: H = Head loss in ft (m), and

T = Thickness of trashrack bar in inches (mm)

V = Water velocity in ft/s (m/s)

A = Angle of inclination of rack from horizontal (45 to 90 degrees)

B = Angle of channel flow compared to long direction of individual bars (when the trashrack is placed normal to flow, the long orientation of individual bars is B = 0)

D = Center to center spacing of trashrack bars in inches (mm)

Two examples are given below to illustrate typical trashrack head losses.

	Example 1	Example 2
T =	0.5 inch	1.0 inch
V =	2.0 ft/s	3.0 ft/s
A =	75.96 degrees (1:4)	80 degrees
B =	0	45 degrees
D =	6 inches	6 inches

Example 1

$$H= 7.07 * (.5/6)^2 * (\sin 75.9/(\cos 0)^{1.875}) *(2)^2/(2 *32.2)$$

H= 0.00296 ft (0.035 inch)

Example 2

$$H = 7.07 * (1/6)^2 * (\sin 80/(\cos 45)^{1.875}) * (3)^2/(2*32.2)$$

H = 0.0518 ft (0.62 inch)

If maximum loss values are desired, assume 50 percent of the rack area is clogged. This will double the velocity through the trashrack openings.

If the trashracks are hand cleaned intermittently (daily or more often), the following can be conservatively used to estimate head loss:

Based on velocity through the trashracks:
V=1.0 ft/s, H=0.1 ft
V=1.5 ft/s, H=0.3 ft
V=2.0 ft/s, H=0.5 ft

b. Head loss through the screen

As previously described, screen structures include screen fabric (woven wire screen, perforated plate, and profile bar (wedge-wire)) placed on a support frame. The orientation of the screen surfaces vary with the specific screen concept and application. The screen surface is most often placed at an angle to the surrounding flow field, and the angle of convergence between the screen and flow typically ranges from parallel to 15 degrees. (Larger angles of up to 45 degrees may occur with specific designs.) Often, a baffle element is set a short distance behind the screen to create flow resistance and a back-pressure that produces uniform flow through the screen. Baffling may be fixed, creating a uniform flow control across the entire screen surface, or it may be adjustable, allowing local control and refinement of through screen velocity distributions (chapter IV.A.6).

Head losses that result across the screen and baffle are a function of the screen fabric and baffle element design, the angle of convergence between the channel flow and the screen surface, and flow velocities or unit flow rates (flow rate per unit area) through the screen or baffle. Depending on the specifics of the screen design, loss coefficients may also be influenced by flow viscosity and, thus, vary with velocity and flow Reynolds numbers. The angle of the convergence between the flow and the screen face can influence flow passage characteristics at elements of the screen and baffling that modify head loss characteristics. Depending on the screen characteristics, angled placement can result in either reduced or increased flow passage efficiencies and corresponding reductions or increases in head loss. Finally, the higher the flow velocities and unit flow rates, the greater the energy required (head loss) to pass the flow through the screen or baffle.

Typically, head loss characteristics are documented as a head loss coefficient (k) where:

$$k = h_l/(V_a^2/2g)$$

Where h_l is the resulting head loss and $V_a^2/2g$ is the velocity head at the screen face. (V_a is measured 3 inches in front of the screen face.)

The literature includes evaluations of the head loss characteristics of commonly used screen and baffle materials (woven wire screen, perforated plate, and profile bar (wedge-wire)). These losses have typically been evaluated either for site specific applications or as a general evaluation of the loss characteristics of various materials. The site-specific evaluations determine the loss characteristics of a screen with a specific configuration and specific design features operating in a specific flow field (specific flow distributions and flow convergence angles). The general evaluations have nearly all focused on loss characteristics of screen materials oriented normal to the approach flow.

The following discussion attempts to summarize the head loss characteristics of various screen fabrics based on information contained in the literature. Because of the broad range of significant variables that are not fully considered in the presented summary and available literature, losses are approximate and may be in error by ± 40 percent. It should also be recognized that losses presented are for clean screens and that screen fouling will greatly increase resulting losses.

Woven wire screen – Padmanadhan and Vigander (1976) conducted general evaluations of the loss characteristics of various woven wire screen fabrics as a function of the alternative fabrics and the Reynolds number, $\mathbb{R}$, of the flow passing the wires of the screen. All these evaluations were conducted with the angle of approach flow perpendicular to the screen surface. The authors first observed that the loss coefficient was constant for a specific fabric when Reynolds numbers were greater than approximately 300. Their defined Reynolds numbers were based on wire diameter and approach velocity [$\mathbb{R}$ = (approach velocity)(wire diameter)/kinematic viscosity]. Padmanadhan and Vigander also observed that the loss coefficient for specific screen fabrics was a function of the fractional open area of that fabric. Figure 44 displays observed loss coefficients as a function of fractional open area (these are coefficients that occur with Reynolds Numbers that are greater than 300). Thus, for woven wire screen with openings 0.09375 inch square (criteria for fry-sized salmonid) with 0.047 inch diameter wire and with a fractional open area of approximately 0.46, the loss coefficient would be approximately 2.0, which would be a constant with approach channel velocities of 0.8 ft/s or greater. Because of Reynolds effects, velocities lower than 0.8 ft/s will produce higher loss coefficients (although actual losses will be smaller because velocities are smaller).

Angled placement – Placement of the woven wire screen face at an angle to the flow will produce increased losses. With angled placement, the wires of the screen tend to mask or block access to the openings in the screen. Very little literature is available that documents the influence of angled placement on head losses across woven wire screens. Evaluation of losses cited in literature sources (Washington Department of Fisheries, 2000; Bell, 1991) indicate that an increase in losses resulting from angled placement can occur. If there is not a proportional increase in screen area to compensate for the angle of placement, there will be increased losses at the screen. The effects of the reduced effective screen open area of each fabric cell appears to be offset by an overall increase in screen area that can result with the angled placement. For example, if the screen is placed at an angle of 30 degrees to the channel flow, the screen length can be doubled ($\sin 30° = 0.5$), which could also double the screen area and, therefore,

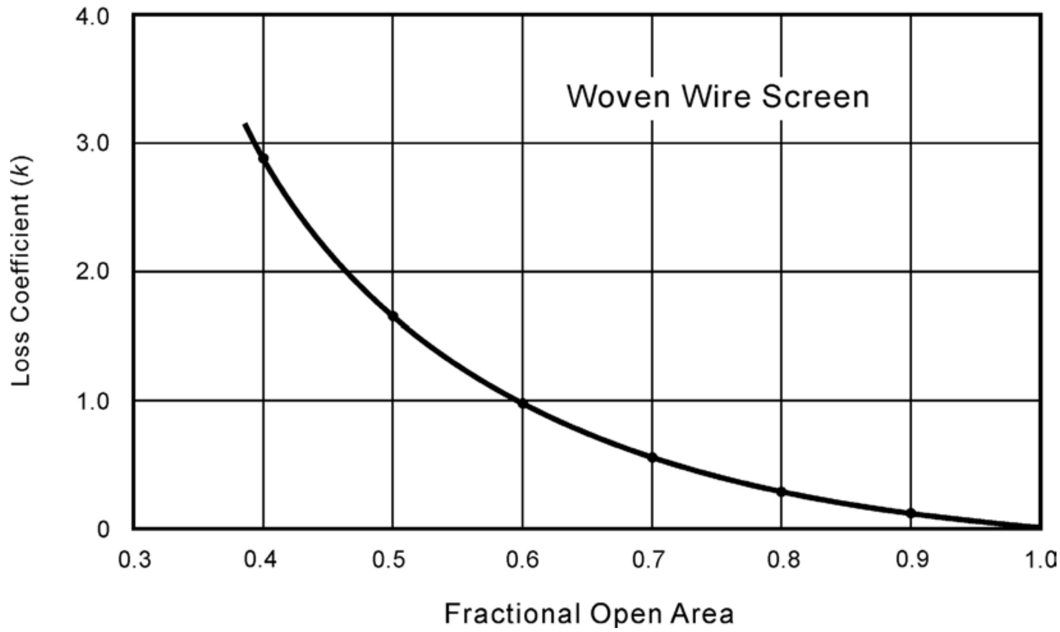


Figure 44.—Head loss coefficient as a function of fractional open area for woven wire screen (Padmanadhan, 1976).

offset the loss in efficiency. As an approximation, it is, therefore, proposed that the loss coefficients for woven wire screen oriented normal to the flow (figure 44) be applied for screen oriented at angles to the flow when there is a corresponding increase in screen area. The limited available literature (Karrh, 1950) indicates that resulting head losses should be computed based on the channel velocity head. Use of a constant coefficient for both angled and normal screen face orientation is generally validated by a material specific study conducted by (Karrh, 1950), in particular, when channel velocity magnitudes equal or exceed 1.0 ft/s.

Perforated plate – Head loss through a perforated plate is a function of orifice velocity, plate thickness, and angled placement. With thicker plates (as a function of orifice diameter) a re-attachment or negative pressure will result around the perimeter of the flow jet passing through the orifice, which reduces the loss coefficient. Head loss characteristics of thin plate (plate thickness/orifice diameter $\leq$ 0.1), as a function of porosity, are summarized in figure 45. The normalized loss coefficient, as a function of perforated plate fractional open area and the ratio of plate thickness to orifice diameter, is presented in figure 46. These figures are used in combination to determine the appropriate loss coefficient for a specific plate. Figure 45 is referenced to determine a loss coefficient as a function of porosity, and figure 46 is referenced to evaluate a multiplier that adjusts the thin plate loss coefficient obtained from figure 39 with consideration of the relative plate thickness.

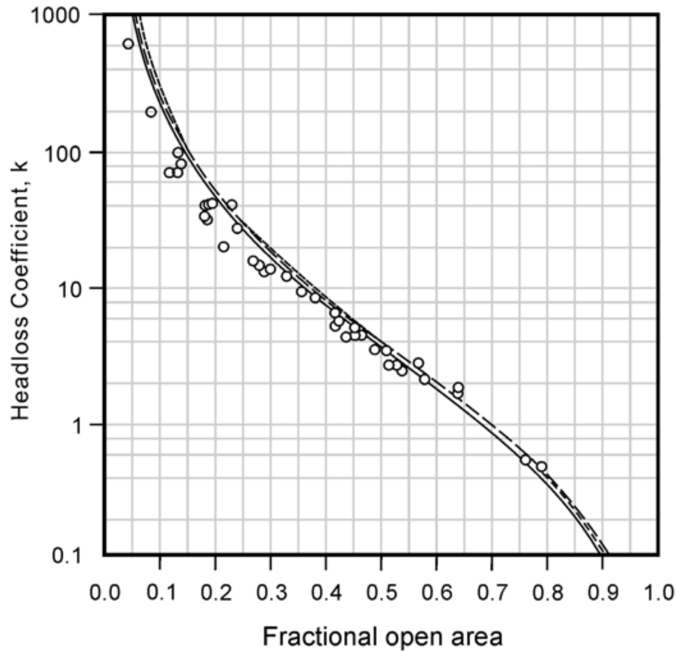


Figure 45.—Head loss coefficient as function of fractional open area for thin perforated plate (Weber, 2001).

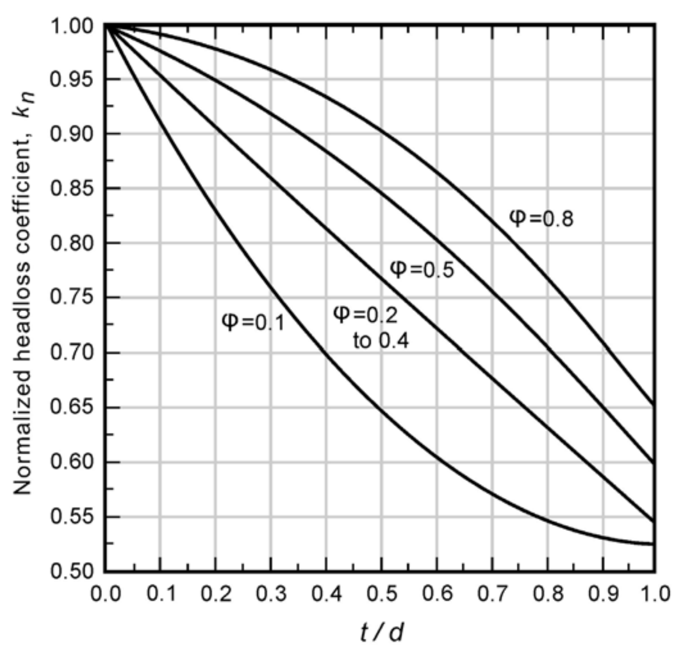


Figure 46.—Normalized head loss coefficient as a functional of fractional open area (Miller, 1990).

Idelchik (1986), Miller (1990), and Weber et al. (2001) have conducted general evaluations of the loss characteristics of various perforated plates as a function of the Reynolds number of the flow passing through the orifices in the plate. All these evaluations were conducted with the perforated plate placed normal to the channel flow. The studies observed that the head loss coefficient was constant for a specific plate fabric when Reynolds numbers through the orifices were greater than approximately 500, where $\mathbb{R}$ = (flow velocity in orifice contracted section)(orifice diameter)/kinematic viscosity. This means that, for perforated plate with orifice diameters of 0.09375 inches (criteria for fry-sized salmonid), the velocity magnitudes through the contracted section in the orifice must be 0.8 ft/s or greater for the loss coefficients in figure 45 to be accurate. Again, reduced velocities will yield higher loss coefficients (although actual losses will be smaller because velocities are smaller).

Angled placement – Placement of the perforated plate face at angles to the flow will produce increased losses if plate area and unit flow rate (flow rate per unit area of plate) are held constant. The projected orifice cross-section presented to the flow is reduced with the angled placement. Karrh (1950) was the only study located that documents the changes in losses associated with the angled placement. Karrh (1950) indicated that if plate and total orifice area is increased with the angled placement, the loss coefficient will decline as an inverse function of the increase in net open area squared. This, basically, indicates that losses are a function of the approach velocity magnitude (component of the velocity normal to the screen face). This same result tends to be generally validated by Yeh and Shrestna (1989) in studies conducted with profile bar (wedge-wire) screen. With limited confirmation, it appears that the effects of the reduced effective orifice cross-sectional area (that is the result of the angled placement to the channel flow) is more than countered by the overall increased plate area associated with the angled placement (and the associated reduction in approach velocity magnitudes).

In general, it is proposed that loss coefficients (k) for perforated plate oriented normal to the flow (figure 45) also be applied with an angled placement, but that associated losses be computed based on the approach velocity magnitudes and not the channel velocity magnitude.

$$h = k\,((\text{approach velocity})^2/2g)$$

Profile bar (Wedgewire) **–** Site specific evaluations of head losses across profile bar screen indicate that loss characteristics vary with screen manufacturer. This is because manufacturers use wire with different cross-sectional shapes and manufacturers also use alternative wire retention and support member design. Generalized evaluations (comparable to those described above for woven wire screens and perforated plate) of the loss characteristics of profile bar screens have not been located. Site specific and single application evaluations indicate that the loss coefficient for profile bar screen (again evaluated with the screen face oriented normal to the approach flow) is approximately 0.7 times the loss coefficient used for thin perforated plate. An evaluation conducted by Yeh and Shrestha (1989) also shows that loss coefficients for profile bar screens are independent of viscous effects for Reynolds numbers greater than 700 (based on the channel velocity applied to the slot width through the profile bar). Consequently, for a slot width of 0.069 inch (criteria for fry-sized salmonid), the corresponding channel velocities would have to be 1.2 ft/s or greater for the presented coefficients to be valid. The head loss coefficient for profile bar (Wedgewire) screens shown in figure 47 is generated by applying the 0.7 adjustment to the thin perforated plate loss coefficient from figure 45.

Angled placement – Since the openings in profile bar screen are linear slots, loss coefficients with angled placement may be influenced by the orientation of the wires and slots of the screen. If the wires and slots are oriented in line with the flow (slots are oriented horizontally), the evaluation by Yeh and Shrestha (1989) indicates that the loss characteristics through the slots will reduce as the angle of screen face placement to the flow is reduced. Consequently, losses will generally decrease as the screen face is placed at flatter angles to the flow. Figure 48 shows the coefficient multiplier (interpreted from Yeh and Shrestha,1989) that can be used to adjust and reduce the loss coefficient with angled screen face placement and the openings slots oriented in line with the flow. These adjusted velocities should be applied to the channel velocity head to compute resulting head losses. Losses across poorly aligned support members may negatively affect resulting coefficients, especially with shallow angle placements (angles less than 30 degrees).

If the wires and slots are oriented perpendicular to the flow (vertical orientation), placement of the profile bar screen face at angles to the flow will yield increased losses. Although no general studies were found to document this increase in losses, specific screen structure evaluations provide an indication of the influence of angled placement on loss coefficient. Single point comparisons between loss coefficients presented in figure 47 and losses evaluated for specific structures with angled screen face placement (Eicher and MIS screen studies – Electric Power Research Institute, 1994) and with slots oriented normal to the flow yield a multiplier increase in losses ranging from 1.0 to 1.7 as the angle of face placement ranges from perpendicular to the flow (profile bars placed vertically) to parallel to the flow (profile bars placed horizontally). This multiplier should be considered linearly dependent on the convergence angle (1.0 at perpendicular to 1.7 at parallel). Again some of these head losses appear to be associated with the influence of the profile bar support and retention elements placed on the backside of the screen. Studies have been conducted to modify the support elements to reduce their influence on head loss (Electric Power Research Institute [EPRI], 1994). Indications are that if this is properly done the head loss multiplier can be

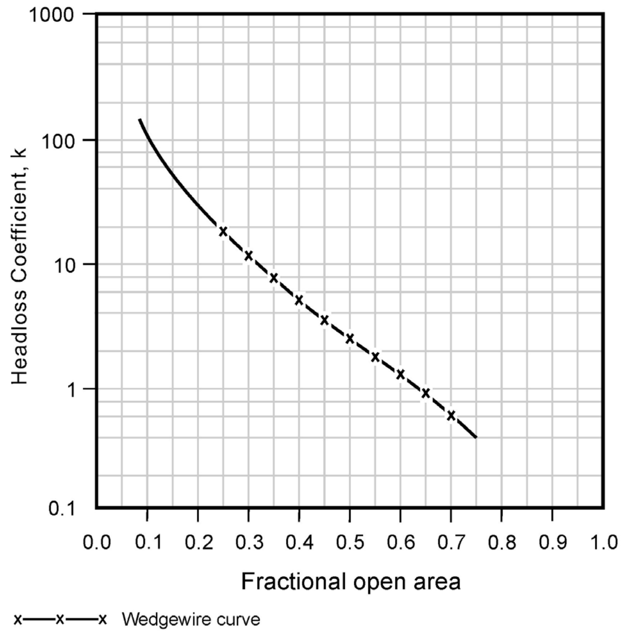


Figure 47.—Head loss coefficient as a function of fractional open area for profile bar (Wedgewire) Screen (based on a coefficient ratio adjustment applied to figure 45) (Weber, 2001).

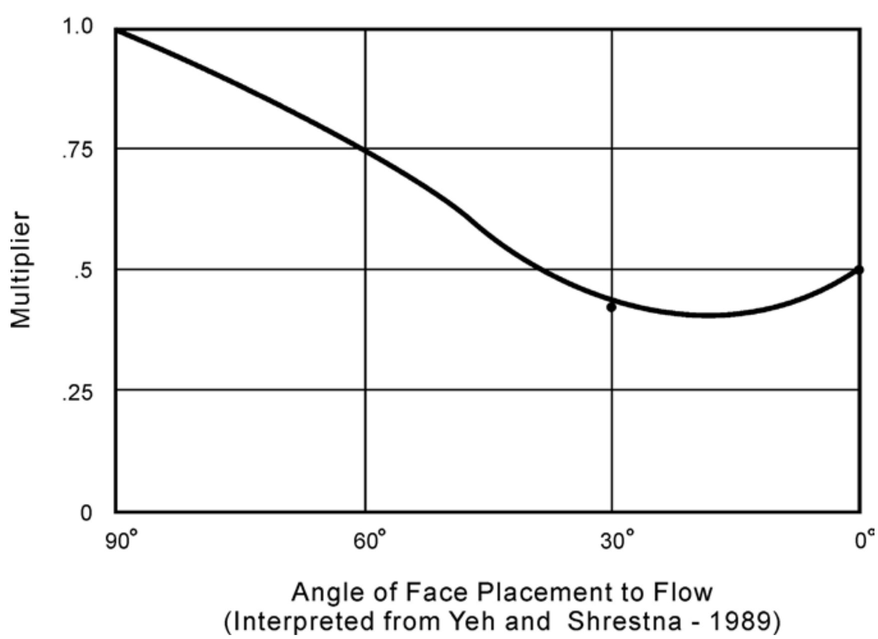


Figure 48.—Multiplier for adjustment of loss coefficients resulting from the angled placement of profile bar (Wedgewire) screen with slots oriented with the flow (Yeh and Shrestna, 1989).

reduce by approximately 20 percent to a multiplier that would range from 1.0 to 1.4. Again it appears appropriate to compute generated losses based on the channel velocity magnitudes.

c. Head loss through baffles

As discussed in chapter IV.A.4, baffle elements create back pressure on the screen to help provide uniform flow through the screens. They may be either fixed or adjustable. Typically, baffle structures include large openings that are not susceptible to debris fouling. Often, perforated plate with large openings (and a relatively small percentage of open area) is used as a baffle element, figure 41. Another common baffle treatment uses vertical slats, much like a vertical blind, that can be rotated to adjust baffle porosity and flow resistance (figure 42). (See chapter IV.A.6.)

Head loss across adjustable baffle elements varies with baffle position. With the vertical slats concept, losses can be quite low when the slats are fully open or can be very large when the slats are closed down. Overlapped perforated plates (that can be slid across each other to modify the open area) can generate relatively large losses when the plates are closed down but will generate more flow resistance and losses when fully open than the vertical slats. Evaluation of the loss characteristics of the overlapped perforated plates in the minimum control position can be estimated by considering the overlapped plates as a single thick plate.

Evaluation of head losses (compound structure) – The following examples demonstrates the process for estimating the head losses that will occur across a compound screen structure that includes both a screen and a baffle element.

Example 1 – The fish screen is made up of 18 gage (0.0478-inch-thick) perforated plate with 3/32-inch-diameter orifices and 30 percent open area set at a 15 degree angle to the channel flow. A fixed baffle constructed from 12 gage (0.1046-inch-thick) perforated plate with 1.0-inch-diameter orifices and 20 percent open area is placed behind the screen to help provide uniform flow. Assume a maximum channel velocity of 2.0 ft/s.

Front plate (fish screen):

Plate thickness/orifice diameter = 0.51 not a thin screen, reference figure 45.

From figure 46, for φ (open area) equals 0.3 and t/d equal to 0.51, the normalized head loss equals 0.75.

Multiplying the normalized head loss (0.75) times the thin plate coefficient (18.0) for φ equal to 0.3 yields a head loss coefficient of 13.5 figure 45). This coefficient is assumed to be appropriate with the angled placement.

The front plate head loss equals the loss coefficient times the channel velocity head or $[13.5][(2 * \sin 15°)^2/64.4] = 0.06$ ft of water. This assumes that the angled screen has been lengthened to extend across the full channel width. A computed screen approach velocity (screened discharge/effective screen area) can also be applied in this calculation.

Baffle plate:

Plate thickness/orifice diameter = 0.1 qualifies as a thin plate, no need to normalize with figure 46.

From figure 45, for a porosity of 20 percent, the head loss coefficient equals 47.0

The average flow velocity exiting the front plate with the 15 degree placement equals 0.52 ft/s (reflects the influence of the extended plate length).

The head loss across the baffle plate equals the loss coefficient times the flow velocity (0.52 ft/s) head ($V^2/2g$) or (47)(0.27/64.4) = 0.20 ft.

Total loss across the compounded screen and baffle plate would thus be 0.26 ft. With an uncertainty of ± 40 percent, the estimated loss for the clean perforated plate with baffle plate would range from 0.16 to 0.36 ft of water.

Example 2 – Profile bar screen with 0.087-inch slot widths (with slats oriented normal to the flow) and 50 percent open area set at a 15 degree angle to the approach flow with a fixed baffle constructed from 12 gage (0.1046-inch-thick) perforated plate with 1.0-inch-diameter orifices and 20 percent open area. Assume a maximum channel velocity of 2.0 ft/s.

Front plate:

A profile bar with a 50 percent open area oriented normal to the flow will have a loss coefficient of 2.5 (figure 47).

Based on the 15 degree placement this coefficient for screen with slots oriented normal to the flow would be increased by (0.75)(75/90) or 0.625. This is a linear adjustment of the coefficient based on the angle of placement. The loss coefficient for the profile bar would thus be (1.625) (2.5), or 4.06.

The front plate head loss equals the loss coefficient times the approach velocity head, or $(4.06)(2^2/64.4) = 0.25$ ft of water. This could be reduced by approximately 20 percent if care was taken to streamline the support and retention members. Note that by orienting the slots parallel to the flow (horizontal slots), this loss could be reduced by approximately 60 percent (figure 48).

Baffle plate:

Plate thickness/orifice diameter = 0.1 qualifies as a thin plate, reference figure 46.

From figure 45, for a porosity of 20 percent, the head loss coefficient equals 45.0.

The average flow velocity exiting the front screen with the 15 degree placement equals 0.52 ft/s (reflects the influence of the extended screen length).

The head loss across the baffle plate equals the loss coefficient times the approach transport velocity (0.52 ft/s) head, or $(45.0)(0.27/64.4) = 0.19$ ft.

Total loss across the compounded screen would thus be 0.44 ft. With an uncertainty of $\pm$ 40 percent, the estimated loss for the clean profile bar screen with baffle plate would range from 0.26 to 0.62 ft of water.

d. Head loss through the bypass

Bypass conduits may be either open channel or closed conduits. For closed conduits, there are entrance losses, exit losses, and frictional losses. However, depending on the bypass design, losses may also result because of drops, bends, expansions, and contractions.

Depending on the entrance approach, the entrance loss can be up to 0.5 of the pipe velocity head. The exit loss can be up to the whole velocity head. Frictional losses through the bypass can be calculated by any of a number of commonly used friction loss equations. Chapter IV.A.11 has more design detail for fish bypasses.

9. Hydraulic Laboratory Model Studies

At locations where approach flow requirements are not met or where other unusual conditions exist (less than ideal site configurations, unusual bypass requirements, etc.), it is often appropriate to conduct a hydraulic laboratory model study to evaluate the best methods for refining design features to meet required flow conditions. The fish screen structure should be designed to eliminate undesirable hydraulic effects, such as eddies and stagnant flow zones that may delay or injure fish or provide predator habitat or predator access.

Laboratory model studies have been used to study various components of fish exclusion systems, including approach flow patterns and distribution, possible flow splits, and fish bypasses (Mefford et al., 1997). Model studies that are conducted in a hydraulic laboratory apply scaled discharges to a scaled replica of the project geometry/topography to simulate flow conditions at the fish exclusion facility. The model study provides a highly visual representation of flow conditions at the screen structure and also quantifies flow variables, thus, ensuring compliance with fishery resource agency criteria. Properly applied, model studies can lead to relatively quick selection and refinement of design features. Various interest groups (including regulatory agencies), upon observing the simulated fish exclusion structure and complex hydraulic conditions, often come to consensus on differing issues. Often, adverse hydraulic conditions such as eddies and slow velocity areas that subject fish to predators, unacceptable alignment effects, nonuniform flow, and inadequate attraction flows can be identified and solved during the hydraulic model study. Laboratory hydraulic model studies are especially recommended when large projects are under study.

Mathematical models using computational fluid mechanics software have also been used to help identify and resolve hydraulic issues related to fish exclusion facilities. Sometimes, such computer models are used to give a general evaluation and overview of options that lead to selection of preferred design features that can then be further refined and evaluated through use of the more expensive laboratory models. Computer models expedite the laboratory modeling process and allows consideration of a broader range of design options. When designs are developed without modeling, project managers for fish exclusion facilities often have to provide additional flexibility in the design to permit fine tuning of hydraulic performance in the field once the project is built.

10. Screen Design

a. Screen material and fabric

Consider the size of fish to be excluded, marine and aquatic growth, screen durability and corrosion resistance, debris type, debris loading, and water quality when selecting screen material and fabric. Failures in any one of these areas can substantially increase system and operation costs and reduce the effectiveness of the screen's operation. A wide range of screen materials has been effectively applied in fish exclusion facility applications. Commonly used screen materials include:

- Woven wire screen (figure 49)
- Perforated plate screen (figure 50)
- Profile bar (Wedgewire) screen (figure 51)

The fish handling and exclusion requirements of the screen fabric depend on fish species and fish sizes and vary with flow conditions through and past the screen. The fisheries agencies of the West Coast States and the NMFS (NOAA Fisheries) (attachment A) have published criteria that establish allowable opening sizes of alternative screen fabrics for specified ranges of salmon size. Comparable opening-size criteria are not generally available for non-salmonid species, but can be deduced through comparison of fish sizes and susceptibility to injury. For screens designed to operate with higher flow velocities, the potential for fish injury increases. Screen fabrics with smooth surface finishes are recommended.

Although fish handling and exclusion characteristics should be considered when selecting screen material and fabric, the final selection is often influenced by review of debris type, debris loading, and water quality. If the screen will be exposed to larger woody debris, use of either perforated plate or profile bar screen is recommended. (Extensive backing support of the perforated plate may be required to avoid damage and displacement of the screen.) If growth of aquatic plants on the screens or attachment of aquatic organisms (clams, mitten crabs) to the screens appears to pose a potential problem, the use of high copper content alloys should be considered as a means of control. Some fisheries resource agencies have indicated that use of aluminum perforated plate has proven functional on their screens. However, others indicate that aluminum experiences excessive corrosion and most recommend the use of stainless steel. In the State of Washington, UV Polypropylene screen belt material for traveling belt screens has recently gained acceptance. Locations where UV Polypropylene has been applied include the Shellrock Pumping Plant, the Burton Ditch headworks, and the Gleed headworks.

The cleaning characteristics of screens are largely related to the specific type of positive barrier screen, screen fabric used, flow patterns across the screen, and debris types and quantities. Depending on shapes and sizes of openings in the screen, shapes and sizes of debris, and flow pattern and its influence on debris orientation, debris might be deflected along the screen with minimal fouling, or debris might wedge into openings in the screen and be very difficult to remove. For example, on the Lower Snake River in eastern Washington, wheat straw is a common debris type. As seen in figure 51, profile bar screens have

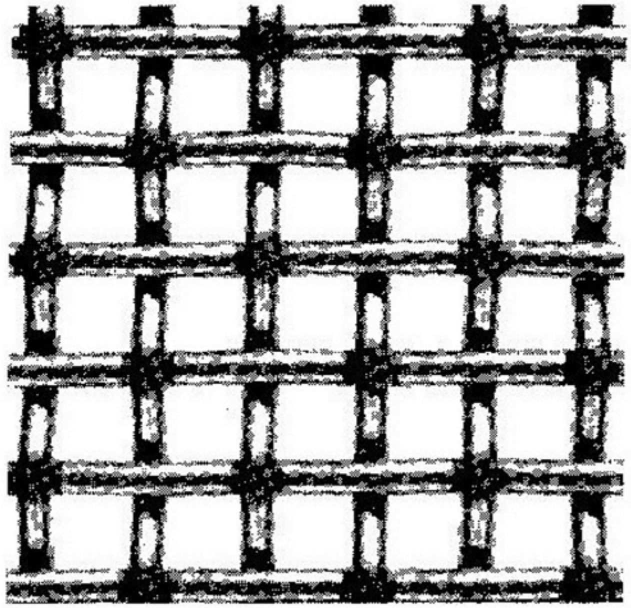


Figure 49.—Woven wire screen.

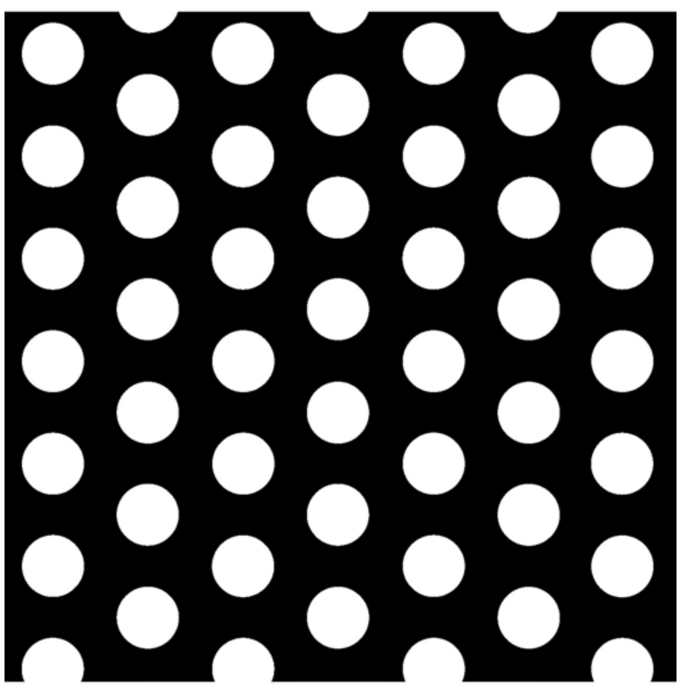


Figure 50.—Perforated plate screen.

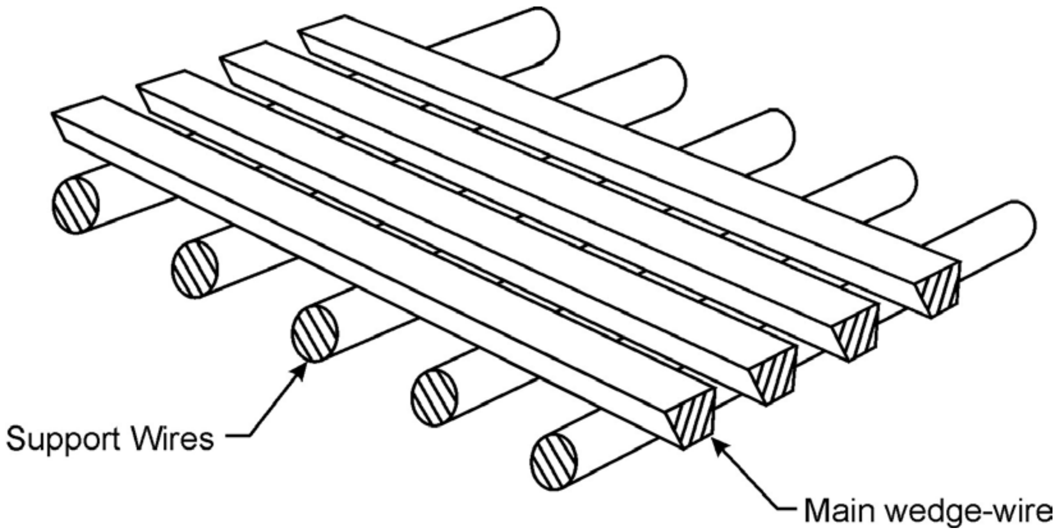


Figure 51.—Profile bar screen.

two-dimensional slot openings. On the Lower Snake, if the slot openings are oriented parallel to the sweeping flow, the straw tends to align with and wedge into the slots. On the other hand, if the screen is installed with the slots oriented normal to the flow (vertical), screen fouling can be greatly reduced. When considering a screen design, including the screen fabric and material selection, debris types and quantities should be documented and experienced individuals contacted to verify that the screen fabric, opening orientation, and debris match-up are appropriate

The advantages and disadvantages of commonly used screen fabrics and materials are shown in table 2. The percent open area in the table is based on meeting the screen opening sizes for fry-size salmonid criteria presented in attachment A.

Capital and operating costs of screens are important considerations. However, it is essential that the selected screen fabric yields effective fish handling and exclusion. Secondarily, a fabric and material should be selected that is durable and that can be effectively cleaned. Replacement of damaged screen and screen cleaning can become major cost items that will substantially increase overall system cost. Selection of lowest capital cost systems may lead to ineffective operation and high maintenance demands. Operation and maintenance issues of the screen fabric should be carefully considered with design development.

Table 2.—Screen fabrics and materials

Screen fabric	Screen type	Material	Advantages	Disadvantages
Woven wire screen (Typical open area mid 30%) (figure 49)	Flat plate, drum, traveling, and cylinder	Galvanized steel, stainless steel, copper alloy, or synthetic monofilament (nylon or polyester)	Often used on mechanical (moving) screens, traveling screens, and drum screens	May yield rougher screen surface finishes (may reduce cleaning effectiveness); requires support backing
Perforated plate (open area 27% to lower 30%) (figure 50)	Flat plate, drum, inclined, horizontal, and cylinder	Galvanized steel, stainless steel, aluminum, plastics (holes – round ed or slotted), polyethylene, polypropylene, or UV resistant acetate	Lower cost, sheds debris well	Reduced percent open area, may warp with fabrication, which may reduce cleaning effectiveness. Requires extensive support backing. Higher potential for damage because of hole sizes and thinness of plate
Profile bar screen , Wedge wire screen, or vee wire (open area 40 % to lower 50%) (figure 51)	Flat plate, drum, inclined, horizontal, coanda, cylinder, eicher, modular inclined	Stainless steel copper alloy	Excellent quality control, durable, Smooth uniform finished surface, higher percent open area, sheds debris easily, strong screen	Higher cost

b. Screen connectors, seals, support backing

The type of screen selected will determine the connection requirements, sealing requirements, and what is required to support or back the screen**.** See chapter IV.B (Screen Specific Design Details) for specific details relative to the various positive barrier screen types.

Screens may be installed within guides (flat plate screens, drum screens, or traveling screens); may be bolted directly to the structure or the structural supports (flat plate screens, submerged screens, or coanda screens); may be bolted directly to the intake piping, conduit, or intake tower (flat plate screens and submerged screens); may be bolted to a movable support frame (submerged screens, closed conduit Eicher screens, or MIS screens); may be bolted to intake conduit piping for cylindrical screen; or the screen may be supported between the floor and a support member (inclined screens). Guides allow the screen panels to be more easily removed for inspection, maintenance, and additional cleaning and to be raised if necessary because of ice conditions.

The maximum size openings (holes, slots, etc.) allowed in the screen will be based on fishery resource agency criteria. This maximum allowable opening size also applies to any openings at the screen connections and at the seals to prevent fish passage (i.e., if the maximum allowable screen slot opening is 1.75 mm, no openings at the connections or at the seals may exceed 1.75 mm). Seals are usually required around all edges of the screen panel except when the screen is rigidly bolted in place. An example of an exception would be where flat plate screens are bolted to the structural support along its two sides, but this may still require a seal between the bottom of the screen and the floor. Seals are also required between the rotating parts of the screen (such as for drum screens and traveling screens) and its frame. For Eicher and MIS screens, the screens are bolted to a support frame, but seals are still required around all edges because the frame rotates to clean the screen. Seals are usually fabricated from neoprene or rubber sheets, strips, and formed seals (e.g., music note seal), figure 72. Brushes have also been used as seals and are usually fabricated from nylon, polyethylene, or polypropylene bristles.

Screens will usually require structural backing support members, either as a part of the screen or as a separate member, to help carry and distribute the loads (figures 62 and 70). The backing support members may be fabricated from the same material as the screen or, to reduce costs, may be fabricated from different materials (e.g., stainless steel screen face and steel frame backing). Isolating gaskets, sleeves, and washers may be required between dissimilar metals to reduce the risk of corrosion.

11. Fish Bypass System

The fish bypass system is the element of the fish exclusion system that guides the intercepted fish back to the natural water body from which they were diverted or to fish handling facilities that might be used for evaluation, collection, or holding for transport. A fish bypass system will be required when fish are transported with the diverted flow to a canal or closed conduit. A bypass system may be required for diversion screening on rivers or in diversion pools, depending on the type of screen, the structure arrangement, and the available hydraulics. The bypass system is a critical feature of the screen design in that it channels the fish that have been excluded by the screen and returns them to the natural water body.

By its nature, the bypass passes high concentrations of fish. It, therefore, must pass fish efficiently, minimizing fish injury and delay, and return fish to the natural water so they can quickly orient and avoid predation.

A typical fish bypass consists of an entrance intake that is integral with the fish exclusion facility, a conduit (open or closed) that transports the fish to the release point, and an outfall that is positioned and configured to generate a controlled transition to the receiving water that will not endanger the fish. To achieve effective fish guidance and passage, the bypass system must be designed with consideration of the screen structure configuration and its associated approach flow field, flow conditions through the conduit, and the flow field and boundary conditions in the receiving water body. Poor fish handling performance by the bypass will greatly reduce the overall performance of an otherwise well designed fish exclusion system.

Criteria – Specific bypass design criteria have been established by the resource agencies (attachment A) for many of the bypass system components. These criteria depend on fish species, size, and behavioral and swimming characteristics. The criteria have been largely developed for salmonids. Bypass components for which criteria are available include the following:

Bypass entrances – Where bypasses are required, the screen and bypass should work in tandem to move fish to the bypass outfall with minimum injury or delay. Bypasses must be positioned to effectively intercept fish and limit fish exposure time to the screen (excessive exposure could lead to fish injury). The bypass entrance should be of sufficient size to minimize debris blockage and to encourage fish to enter the bypass (fish may avoid excessively narrow bypasses). To improve intermediate bypass collection efficiency, some fishery resource agencies recommend a training guide wall that extends into the approach channel at an angle to the screens. The guidewall intercepts fish passing along the screen and guides them to the intermediate bypass entrance.

Bypass entrance velocities – The bypass entrance should be provided with independent flow-control capability. The criteria establishing the magnitudes of entrance velocities vary with fishery resource agency and fish species. Typically, the minimum bypass entrance flow velocity should be greater than or equal to the channel velocity at the screens. A gradual acceleration of flow into the bypass entrance will optimize capture of the fish in the bypass.

Bypass Conduit features – Fishery resource criteria also establish acceptable conduit surface conditions, conduit configurations and through conduit flow conditions. All criteria are established to expedite fish passage and minimize the potential for fish injury or disorientation.

Bypass outfall structure – The outfall structure reintroduces the fish bypass flow back into the natural water body, (figure 55). Published criteria establish fish bypass location and flow conditions that will minimize bird and fish predation on the released fish.

a. Bypass entrance

Bypass entrance placement – The fish bypass entrance should be positioned, configured, and operated such that:

- Fish are guided to the entrance
- The entrance will then intercept the fish, minimizing exposure with the screen or barrier
- The fish will enter the entrance without reluctance or delay that might result from fish avoidance prompted by confining geometries, lighting changes, or changes in hydraulic conditions.

In summary, the entrance should be positioned at a point where the fish are naturally guided by the screen. The entrance should provide a fish passageway that is a continuation of the channel approach conditions and that does not generate pronounced changes in conditions that could cause fish avoidance. A safety cable with floats and an escape ladder may be desirable at each bypass entrance.

Migrating fish tend to follow the flow and are guided along boundaries (such as screen faces, banks, and walls) as they approach and pass through screen facilities. By positioning bypass entrances at the downstream (terminal) end of the screens (figures 4, 10, and 22) and at the intermediate locations along the screen face for long screens structure (figure 27), the entrances effectively guide the fish along the screen surfaces and direct them into the bypass conduits, which expedite fish passage (figure 52). A well directed sweeping velocity field along the fish screen supplies effective fish guidance that keeps fish moving towards the bypass entrances. If fish cannot readily locate the bypass entrances, they will collect upstream from the screen until they are exhausted or prayed on by predators. Substantial disruption of fish passage at fish screen structures can result from a poorly designed fish bypass and bypass entrance. For some screen structures (such as screens placed in canals with well directed flow), velocity fields and screen configurations are well defined, and appropriate bypass positions can be selected without extensive study (figure 36b). For other screen bypass concepts (figure 53), with complex velocity field, screen, and structure configurations, there may be uncertainty with fish guidance and where best to locate fish bypass entrances. For such configurations, physical and computational hydraulic model studies coupled with analysis of fish responses (possibly with validation from field fisheries investigations) should be used to guide the selection of bypass entrance positions. Operational changes may also provide viable alternatives.

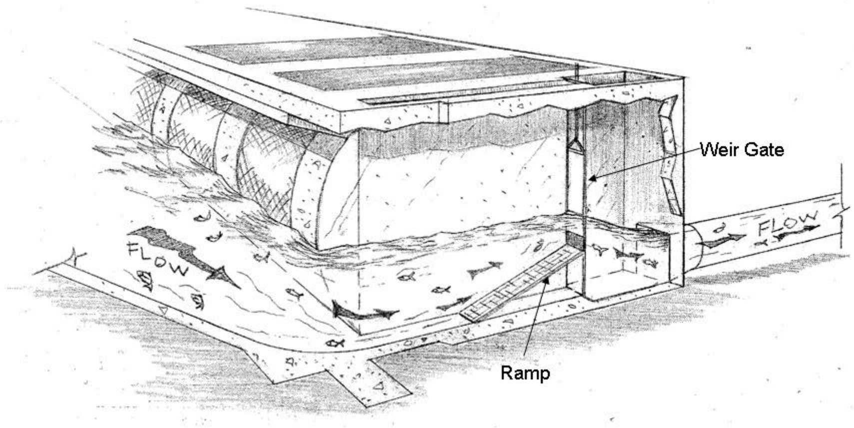


Figure 52.—Bypass entrance design for drum screen concept.

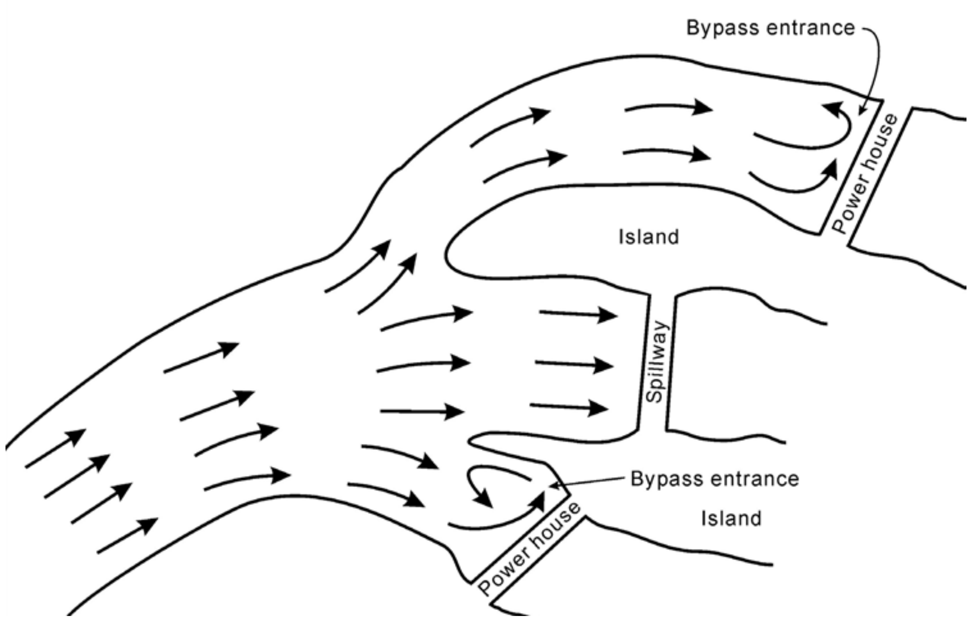


Figure 53.—Bypass placement with a complex geometry and approach flow – Bonneville Dam Forebay (Corps, 1999).

Intermediate Bypass entrances/duration of screen exposure **–** With time, fish can tire and impinge on the screen surface. Bypass entrances may be placed at intermediate locations when extended lengths of fish screen are used. The intermediate bypasses intercept passing fish and limit fish exposure time to the screen. Laboratory and field studies conducted for select fish species, fish life stages, and fish sizes and for specific approach velocities have determined what screen face exposure duration times will cause fish impingement and potential injury (Smith and Carpenter, 1987). Fish impingement and injury will result when exposure time to the screens is too long. Available findings have been interpreted, and exposure duration criteria have been established. Typically, when criteria are established based on interpretation of study findings, they are conservative because they will be broadly applied. It is recognized that site specific factors including fish condition, water temperature, and water quality will also influence swimming strength. For example, the Smith and Carpenter (1987) study that evaluated duration of exposure for salmon fry found that over 98 percent of the salmon fry tested were able to swim for at least 1 minute (and up to 3 minutes) before impinging on the screen with a screen operating at the NOAA Fisheries approach velocity criterion. These fish were in good physical condition and water quality was good. Based on these findings, a NMFS (NOAA Fisheries) – Northwest and Southwest Regional criterion (NMFS 1995) for maximum exposure time for juvenile salmonids along a screen face to a bypass entrance was set at 60 seconds. Exposure duration studies have been conducted for only a limited number of species, life stages, and operating conditions. As a consequence, for many species and life stages, exposure duration criteria and design guidelines do not exist.

Exposure duration criterion influences bypass design in that the criterion limits the continuous length of screen faces that can be used. Exposure duration can be calculated by dividing the fish screen length by the design sweeping velocity magnitude (chapter IV.A.5). The length of screen divided by the sweeping velocity yields an indication of fish exposure time, assuming that the fish are moving with the current (screen length/V_s = exposure time). The exposure time should comply with established criteria (if available) for the fish species and life stage present. If calculated exposure times exceed criteria, an intermediate bypass may be required. For example, if a total screen length is 270 ft and the maximum sweeping velocity is 3 ft/s, the exposure duration would be 90 seconds. This exceeds the NOAA Fisheries salmonid fry criterion of 60 seconds; therefore, an intermediate bypass entrance should be provided within the screen length if salmonid fry are present. Based on a 3 ft/s sweeping velocity, the maximum screen length allowed without intermediate bypasses or the maximum spacing between bypass entrances would be 180 ft.

Note that when the screen operates with diversion flow rates that are smaller than design capacity, the exposure duration criterion can be exceeded. Longer exposure duration may also be acceptable if screen approach velocities are reduced. Ultimately, bypass entrance locations should be developed based on the design flow rates and velocities.

Changes in ambient light **–** Changes in light is an environmental influence that can generate fish avoidance and holding. Fish will avoid entering a dark closed conduit from a sun-lite location. Where these conditions occur, there is often a strong difference between day and night passage characteristics, and more fish at night when changes in lighting do not occur. If the site characteristics require the use of closed conduit or pipe sections, the bypass entrance through the bypass flow control and trapping velocity section should be open to the atmosphere (figure 52). Downstream from this section, the conduit can transition to an unlit closed conduit once the fish are captured by the high velocity at the entrance. Where this is not possible or where additional lighting is desired, underwater lighting can be installed within the bypass entrance section (figures 108 and 109).

Sizing bypass entrances **–** The general philosophy for sizing bypass entrances is that they should be large enough that fish will not avoid the entrance because of its confining size. The entrance intake should extend over the full vertical range to allow fish to enter the intake directly without having to change their vertical position (figure 52). In open channel applications, this requires that the bypass entrance extend the full depth of the water column.

Based on the available data, conservative interpretations have been used to establish design criteria. Criteria published by NOAA Fisheries do not specifically stipulate required bypass entrance widths; however, they do require that full depth slot entrances be provided. Coordination with NOAA Fisheries on development of designs indicates that widths of 12 to 24 inches should be applied; however, they advocate use of bypasses that are 24 inches wide. The State of Washington, in its screen criteria (Washington Department of Fish and Wildlife, 2000), indicates that the width of the bypass entrance should be a minimum of 18 inches and the entrance should extend from the invert to the water surface.

Bypass entrance width has other design and operation implications. Larger bypass widths will yield larger bypass cross-sections and the need for larger bypass flow rates. In particular, for smaller screen structures, a wide bypass may generate excessive bypass flow rates. On the other hand, larger bypasses are less susceptible to debris fouling and, thus, may require less maintenance.

Bypass entrance velocities **–** Velocities in the bypass entrance, V_b, should be compared to the maximum flow velocity vector or channel velocity, V_c (figure 37a). The bypass entrance velocity is required to generate a velocity field that will maintain or even encourage fish movement. Numerous studies have been conducted to determine optimum bypass entrance velocity as a function of the channel velocity, V_c. This relationship between bypass entrance velocity, V_b, and channel velocity, V_c, is defined as the bypass ratio where:

$$\text{Bypass Velocity Ratio} = V_b/V_c$$

Study findings relating bypass ratio to fish species are summarized in table 3. Typically, the preferred bypass ratio ranges in value from 1.0 to 1.5. This means that, as the flow enters the bypass, it will experience either a steady continuation of the channel velocity in front of the fish screen or a controlled acceleration. The studies noted in table 3, except (EPRI, 1994), agree that operating bypass ratios should be 1.2 to 1.4. NOAA Fisheries requires a bypass ratio of 1.0 or greater and requires that any flow accelerations should be gradual. The State of Washington Department of Fish and Wildlife (2000) suggests a design with a bypass ratio of 1.27. The bypass ratio is typically sustained over the full range of screen operations. Thus, as the diversion flow rate through the screen changes, the flow rate through the bypass may need to be adjusted. Studies have shown that the optimum bypass ratio depends on the fish species. Thus, operation (bypass ratio and entrance velocities) of a specific screen and bypass should be set based on the fish species at the site that are of primary interest.

Table 3.—Fish screen bypass ratios

Fish species	Bypass velocity ratio V_b/V_c	**Study**
Juvenile sockeye and coho salmon	1.4	Ruggles and Ryan, 1964
Chinook salmon smolt and striped bass (under 1.5 inches long)	1.2 to 1.4	Bates and Vinsonhaler, 1956
Brown trout, coho, and chinook salmon smolt	greater than 0.7	EPRI, 1994 (Eicher and MIS screens)
Striped bass, white catfish, chinook salmon, and steelhead	greater than 1.2	Heubach and Skinner, 1978

Where V_b= bypass entry velocity and V_c = channel velocity at screen

The resulting discharge or flow rate through the bypass is computed by multiplying the bypass entrance velocity (channel velocity times the selected bypass entrance ratio) by the bypass entrance cross-sectional area. To sustain optimum bypass operation, entrance velocities, and bypass flow rates should change when diversion rates and water depths change.

Fishery resource agencies prefer that the design for fish bypass flow be in the range of 5 to 10 percent of the total flow approaching the fish screen structure. Fishery resource agencies have recently indicated that they may set a minimum bypass flow at 5 percent of the total flow.

The flow rate through the bypass, Q_b, is defined as:

$$Q_b = (b)(d)(V_c)®)$$

Where b equals the bypass entrance width, d equals the flow depth in the bypass entrance, V_c equals the channel velocity vector, and r equals the selected bypass velocity ratio.

As discussed above, bypass entrances should extend over the full water column height; in which case, the entrance flow depth is equal to the approach flow depth. The bypass discharge increases with wider bypass entrances. Consequently, the tradeoff between bypass flow rate and increased bypass widths (which may improve fish collection efficiencies) must be balanced in design. Required bypass widths may be stipulated by the responsible fishery resource agencies, and, thus, design flexibility may be minimal.

The bypass entrance should be provided with independent flow-control capability. This allows adjustment of entrance velocities to sustain desired bypass ratios as diversion discharges and water depths change. Bypass entrances often include a ramp and adjustable weir arrangement (figures 52, 54, and 108) that controls flow rates into the bypass and that accelerates the flow to the point that the entering fish cannot back out of the bypass (the control generates a trapping velocity). This trapping velocity occurs at the overflow weir. Desired trapping velocities should exceed the darting swimming speed for the fish species and life stage of interest (chapter III.A.1). For example, by generating velocities over the bypass weir of 5 ft/s or more, juvenile steelhead will be trapped and forced to pass on through the bypass. By limiting the slope of the ramp to 2:1 or less, gradual accelerations that will not cause fish avoidance can be generated. Ramp slopes as low as 10:1 have been effectively used. The weir section may include a vertically adjustable blade that allows adjustment and control of bypass flow rates and, thus, bypass entrance velocities with changing water surface elevations and diversion flows (figure 108). To prevent fish injury, it is preferred that flow depths over the weir be equal to or exceed 6 inches. This may require that a contracted or reducing width weir treatment be included that allows the 6-inch depth to be maintained with reduced flow rates. Flow from the weir might be passed into a down-well or pool, as presented in figures 54 and 108, or it could pass into a chute that would transition into the bypass conduit. In addition to the strong velocity in the bypass conduit, a drop of approximately 1 ft between the bypass upstream water level and the water level downstream from the weir will further prevent the juvenile fish from going back upstream.

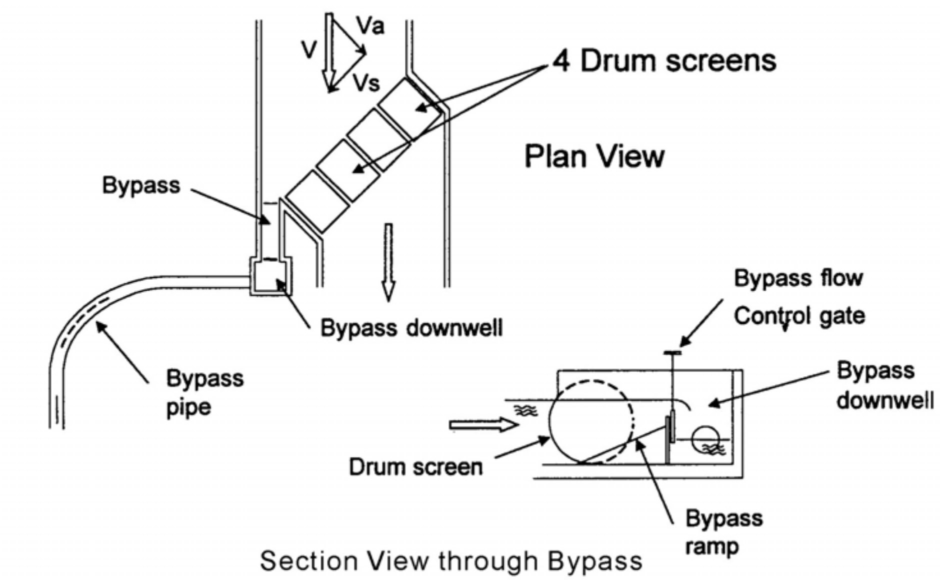


Figure 54.—By pass entrance and conveyance system with downwell (Rainey, 1985).

b. Bypass conduit

Facility layout and the topographic characteristics of a site may dictate whether an open flume or closed pipe will be used for the bypass conduit. Open flumes tend to be preferred in that they allow easy access for maintenance, debris removal, and monitoring. In addition, lighting is consistent in open flumes with ambient conditions in the approach to the bypass entrance. The bypass conduit functions to guide fish back to the river. The bypass conduit is designed to efficiently guide fish while minimizing fish disorientation and injury.

The bypass conduit may include open channels, pipe, drop structures, or flumes. To provide fish passage and minimize delays and fish holding, well directed flows without slack-water or eddy zones should be provided throughout the bypass. There should be no hydraulic jump in closed conduits that could cause fish injury or delays. The NMFS (NOAA Fisheries) (1995) indicates that velocities in the conduits should be 2.0 ft/s or greater. Typically, Reclamation designs to sustain conduit velocities of 3.0 to 10.0 ft/s to minimize sediment deposition. Many conduits are designed to limit maximum velocities to 10 ft/s, although this criterion is not specifically stated by NOAA Fisheries. The concern with higher velocities is the increased potential for fish injury.

Published criteria (attachment A) do not permit negative pressure zones in the bypass and require that pressure in bypass pipes be equal to or above atmospheric pressure. Fishery resource agency criteria allow for use of both pressurized closed conduit bypasses and open conduit bypasses. The appropriate use of open or closed fish bypasses will depend largely on site characteristics and what constitutes a workable design. The Washington Department of Fish and Wildlife (2000) in its screen design guidelines (which go beyond published criteria) states a preference for conduits with free surface flow that do not expose fish to changing pressures. This would require that the conduit be placed above the maximum river tailwater elevation to eliminate tailwater effects on flow depths, velocities, and pressurization of the conduit. This preference may not provide an effective and workable design at many sites.

Published criteria (NMFS, 1995; Washington Department of Fish and Wildlife, 2000) require minimum flow depths in open channel bypass conduits to be at least 0.75 ft (9.0 inches). The pipe or conduit gradient should be selected to sustain these flow depths over the full possible range of bypass discharges. Diversions of less than 25 ft^3/s capacity (NMFS,1993 and 1997), with screens, where bypass flow depths can be as small as 1.8 inches at the minimum flow rate are excpeted. A drawback of shallow bypass flow depths is that fish in the flow will always be near the conduit boundary. Being near the conduit boundary increases the potential for fish injury.

Debris fouling that would reduce hydraulic capacity and thus limit bypass entrance operations should be prevented. Accumulated debris also places materials in the conduit that could cause fish injury. Access for inspection, maintenance, and debris removal must be provided. To reduce debris clogging, pipe bypasses should have a diameter of 24 inches or greater (attachment A.1). Diversions with screens passing 25 ft^3/s or less are excepted (attachments A.1.K. and A.3.K). For these small installations, fishery resource agency criteria allow minimum bypass pipe diameters as small as 10 inches. It should be recognized that smaller diameter conduits are more susceptible to debris fouling and may pose a significant maintenance problem, particularly if access is difficult.

Recognizing that fish bypass conduits transport high concentrations of fish in relative high velocity flow, conduit surfaces should be smooth and free of boundary features that could cause fish injury. Published criteria require smooth interior pipe surface and conduit joints that reduce the risk of injury, minimize turbulence, and facilitate the passage of debris. Surface treatments and materials should be selected that are durable and that will maintain a high quality smooth surface with minimal maintenance**.** Reclamation typically uses concrete open channels and mortar lined steel, high density polyethylene (HDPE), concrete, or polyvinyl chloride pipe.

Flow through most bypasses and bypass conduits is gravity driven. Typically, screen structures are placed in diversion structures and canals at locations that are physically higher than the water surface at the bypass outfall. Consequently, drop or head is available to move the flow through the bypass system. Velocities through the conduit are often controlled by placing the outfall conduit at a grade that generates the desired velocities. Again, the full range of bypass discharges should be considered in design development.

Bypass down wells **–** In some cases, excessive head is available over the length of the bypass. Available head will vary with tailwater elevation. The design should be based on maximum tailwater to ensure that the bypass will be functional under all operating conditions. Management of excess head is a design consideration with lower tailwater.

Using pipe or conduit friction losses (with flow velocities of 10 ft/s or less) to dissipate energy and control velocities is a workable option at some sites where ranges of tailwater variation are limited. At sites where tailwater ranges are larger or where the drop from the fish exclusion facility back to the natural water body is large, use of friction loss to dissipate energy can yield excessively long conduits that do not offer viable designs.

Drop structures or downwells (a single drop or multiple drops) can be included in the bypass to dissipate energy. There are various options for the design of these drops. The Washington Department of Fish and Wildlife indicates that options, in order of preference, include:

1. Use of supercritical chutes (as long as minimum depth can be maintained) in which there is no chance for fish holding up in rollers and little possibility of debris blockage (figure 124). Reaches of higher gradient chute coupled with flatter gradient sections can be used to manage energy and velocities in the bypass. This option largely eliminates tumbling and turbulence that can lead to fish injury.

2. Use of transitions from the bypass flow control weir (figures 57 and 108) to the bypass conduit that eliminates the plunge pool with roller. As noted above, the drop from the bypass flow control weir may vary with changes in tailwater elevation. By using a downwell geometry that includes confining the flow in the transition to the bypass conduit, development of a roller can be excluded.

3. Drop the flow from the bypass flow control weir into a downwell pool where energy dissipation occurs (figures 52 and 54). Flow then exits the downwell typically into a closed conduit that may operate either with free surface or pressurized flow.

Drop structures with an associated energy dissipation pool should be designed to prevent fish injury and disorientation. High energy dissipation rates and direct flow impingements on structure surfaces should be avoided. The Washington Department of Fish and Wildlife (2000) observes that drop structures are often needed to quickly reduce the water surface elevation from the screen structure to the ultimate discharge location, particularly at sites where space is limited. A pipe designed to comply with smoothness, flow, and depth criteria will be at a very low slope and, therefore, very long. Drop structures can be much more compact. They have the added risk, however, of causing injury due to turbulence or clogging with debris.

The State of Washington (2000) document suggests use of a weir with a reducing overflow section that provides at least 6-inches of overflow depth with the reducing flow rates, and says:

> A typical range of drop heights is 2 to 4 ft. Cushioning should be provided in the downwell (the dissipation pool that receives the flow from the weir) by countersinking the floor of the downwell at least several ft below the minimum water surface. Provide enough water volume in the downwell to dissipate the energy entering the downwell to limit turbulence and circulation patterns that may trap debris or fish.

The drop height is usually limited to a height of 10 ft. The sidewalls need to be spaced so the plunging flows do not contact the walls before entering the dissipation pool. Common drop designs are shown in figures 52 and 54.

Energy dissipation factor (EDF) rates (dissipated energy in ft pounds (lbs)/s per pool volume in ft^3) occurring in downwell pools have been evaluated by both Reclamation and the Washington Department of Fish and Wildlife (2000). It has been suggested that a guide for sizing the downwell or dissipation pool based on these field observations indicates that the maximum energy dissipation factor should be no larger than 60 ft lbs/s/ft^3. If fragile fish such as button-up fry are present, development of the design based on a more conservative EDF of 25 ft-lbs/s/ft^3 is recommended. Typically, the pool volume is its smallest at minimum tailwater. For typical designs (EDF of 60) the required pool volume is thus computed as:

$$V_{pool} = [\gamma/\text{EDF rate}](Q_b)(h)$$

$$V_{pool} = [(62.4\ \text{lb/ft}^3)/(60)](Q_b)(h) = 1.1(Q_b)(h)$$

where V_{pool} is the required effective energy dissipation volume of the pool in cubic ft at minimum tailwater, Q_b is the flow rate entering the pool in ft^3/s, and h is the total energy head of the flow entering the pool in ft (velocity head plus free drop).

Non-gravity driven bypass – At some sites, insufficient drop or head is available to generate a gravity driven bypass flow. These tend to be sites in flat terrain where the river gradient is low. In such cases, the use of a fish-friendly lift/pumped bypass may be considered. The use of pump driven bypasses is in conflict with currently published criteria (NMFS, 1995; Washington Department of Fish and Wildlife, 2000) that say "There should be no pumping of fish within a bypass system." Use of pumps, however, allows use of bypasses where, otherwise, bypass operation would not be possible. Pumps selected for fish bypass should be proven to pass the species and life stages of fish that are present with minimal injury or mortality. The Archimedes and helical (centrifugal screw) pumps show promise as pumps capable of pumping fish. Research has been conducted in recent years at the Red Bluff Fish Evaluation Facility to develop and validate such pump designs (McNabb et al., 2003). This work may lead to future fishery resource agency acceptance of pumped bypasses. Figure 83 shows the use of a helical pump in the fish bypass at Potter Valley diversion.

Bypass bends – Bends should be avoided, if possible, in bypass conduits. Bends generate uneven flow disruption and turbulence that can injure fish and may result in catch points where debris can accumulate. If bends are included, NOAA Fisheries and State of Washington criteria require use of long bend radii. The long radii criteria require that the bypass pipe center-line radius of curvature ratio (R/D) be greater than or equal to 5, where R is the centerline bend radius and D is the conduit width or diameter. The criteria also state that if supercritical flow is present, radii should be longer yet.

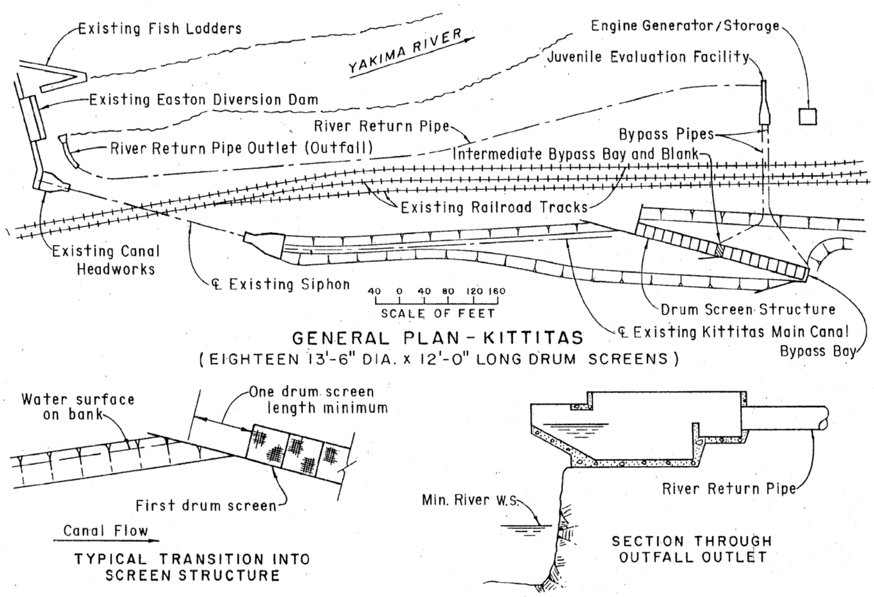
Valves and gates in bypass – Typically, flow control and closure valves and gates are not to be included in bypass conduits. Since valves and gates control the flow by restricting the flow path, the modified flow characteristics generate fish avoidance and delay fish movement. Valves and gates also generate obstructions in the flow path that can lead to fish injury and debris accumulation. NOAA Fisheries criteria state, "Closure valves of any type are not allowed within the bypass pipe, unless approved by NOAA Fisheries." Rubber pinch valves have been used in bypass conduits to control flow, but more often as isolation valves. They are smooth, with no protrusions. Debris blockages have been experienced with pinch valves, so they should be used with caution and monitored continuously. Gates (slide or knife gates, stoplogs, or bulkhead gates) are typically included in the bypass system (usually at the bypass entrance or the bypass outfall) to allow isolation for maintenance, inspection, and repair.

c. Bypass outfall

The fish bypass outfall is the final major component of the system (figures 55, 104, 115, and 124). The outfall functions to release fish from the bypass conduit and, in most cases, to return the fish to the natural water body. There are typically two types: submerged figures 55a and 55b, and vertical drop figure 55c. The outfall should release fish into naturally sustainable reaches of river that lack predator potential and have sufficient pool depth and flow velocity to minimize body impact. Normally, sediment does not deposit in such sites; they are self-sustaining without significant maintenance, and they do not require design and

a. Looking upstream at Red Bluff Fish bypass outfall, Sacramento River.

b. Roza Diversion Dam Fish Bypass Right Bank outfall.



c. Kittitas Canal bypass outfall, Yakima River, Washington.

Figure 55.—Bypass outfalls to natural water.

construction of a receiving pool. Surveys of potential outfall locations should be conducted to support the design development. These sites and the resulting conduit gradients, conduit flow conditions, and extent of the bypass structure are considered in the resulting bypass layout and analysis.

In some instances, the bypass outfall or conduit will supply fish to an evaluation facility or to a fish collection and holding facility from which fish can be transported (by truck or barge) to another location.

Primary operational goals for the outfall are to safely return or release the fish from the bypass, prevent predation on the fish released from the outfall, and limit attraction by and possible injury to upstream migrating fish (that might be attracted to the bypass flow).

Sources for fish injury at outfalls include the turbulence and shear that occur between the flow or jet exiting bypass and entering the receiving water pool. If velocities in the outfall jet are high enough, physical injury to or disorientation of the fish can result. Physical injury can lead directly to mortalities. Injuries or disorientation can also increase the fishes susceptibility to predation.

Fish injury can also result from impingement of the released fish on the bottom or on physical boundaries of the receiving pool. Thus, the hydraulics and depth of the receiving pool and jet impingement potential on boundaries of the pool need to be considered. Excavated receiving pools may experience sediment deposition that would eliminate the pool and its fish exclusion benefits. It should also be noted that the outfall design should be functional over the full range of tailwater elevations. Where the bypass conduit outfall is positioned above normal and low tailwater elevations to prevent tailwater influences on the bypass conduit flow, the outfall design will generate a plunging flow into the tailwater for most operations. Published criterion (NMFS, 1995; Washington Department of Fish and Wildlife, 2000) requires that outfall impact velocities (from vertical drops) not exceed 25 ft/s to prevent injury and disorientation.

An outfall supplied from a submerged bypass conduit may be positioned at a lower elevation and thereby reduce or eliminate plunging effects in the release and the potential for boundary impingement and resulting fish injury. Transition conditions from the outfall to the receiving water body will, however, likely change with changing tailwater elevations. Analysis or modeling efforts should be used to ensure that acceptable flow transitions occur over the full operating range of the fish bypass.

Another consideration in outfall design is control of predation of the released fish. By the nature of the outfall function, particularly at locations where out-migrating juvenile fish are present, there will be high concentrations of juvenile fish in the outfall flow. Predatory fish will be attracted to these locations to feed. A recommended way to prevent the predatory fish from holding at the outfall sites is to position the outfall in the river at a location where river flow velocities are 4.0 ft/s or greater. The predatory fish may not be able to hold in these velocities for extended periods of time. If possible, the outfall should also be located in areas of the river that are free of eddies, reverse flow, and bottom and boundary conditions that supply predator holding habitat. These outfall siting objectives may be more achievable in large rivers where broader and deeper sections are present even with lower flows. Optimum outfall receiving pool flow conditions may be difficult to achieve in smaller streams and rivers where flow sections are shallow.

A final consideration is that the outfall may attract upstream migrating fish, especially if the volume of flow passing through the outfall is significant as compared to the total streamflow. (If the bypass flow is relatively small, most of the fish will be attracted to the larger flow sources such as the river flow, spillways, and fishways.) Attraction is also increased if velocities are high with a plunging flow. When designing the outfall, it should be generally assumed that upstream migrants will be attracted to it. If a plunging flow is included in the design, it is likely that upstream migrants will jump at it. In such cases, features should be included in the design that would prevent fish from striking the bank or structural surfaces and also prevent fish from being stranded on the bank. Cantilevered outflow designs are one option that should be considered.

The implications of the established outfall operating objectives on the outfall design are that flow conditions in the conduit should be analyzed and conduit exit velocities determined. The contribution of the drop to the tailwater (at minimum tailwater) should then be included to determine the maximum outfall impact velocity. If this velocity exceeds 25 ft/s ($h = V^2/2g$), options that reduce the velocity in the conduit flow or drop should be considered. For example, if the exit velocity in the conduit is 10 ft/s, a maximum 8.2 ft drop could occur at the outfall while limiting the outfall impact velocity at the tailwater to 25 ft/s (additional drop of $h= (25^2 – 10^2)/64.4=8.15$ ft). Such a drop would allow for an 8.0-ft range on tailwater elevations (seasonal variation in streamflow) that is likely workable at many sites. There may, however, be sites with greater tailwater ranges where deviations from established velocity criteria must be considered under extreme operating conditions.

#### *d.	Bypass supplemental features*

To improve bypass entrance collection efficiency, guide walls are typically included at intermediate bypass intakes. These are vertical walls that extend out from the screen face that function to intercept fish moving along the screen face and direct them to the bypass entrance. While screen faces are typically placed at an angle to the flow, guide walls are generally placed parallel to the flow. This results in the wall being placed at an angle to the screen that corresponds to the angle of the screen to the channel flow. With the wall aligned with the flow, it has very little influence on screen approach flow patterns. The converging guide wall at intermediate intakes may be an obstacle for screen cleaning equipment, and, thus, it may hinder the cleaning process. The benefits of the wall need to be evaluated against the negatives.

The invert for the screen structure should be designed to allow fish to be routed back to the river safely if the canal is dewatered. This may involve a drain with a small gate and drain pipe or similar provisions. Often, having a team of qualified biologists on site to salvage fish during canal shutdown is recommended. Other design features that are typically included in bypass entrances include stop-log guides that allow for facility dewatering and trashracks at the intermediate bypass entrances on in-river placed screens.

e. Secondary screening

In many cases, the full bypass flow is passed on through the bypass conduit and outfall and returned to the river or natural water body. This process reduces the actual flow rate diverted from the natural water body. If resulting bypass flow rates reduce the diversion discharge to an unacceptable level or to where additional attraction bypass flows are required at the bypass entrance, a secondary screening facility is often included in the bypass system. This secondary screening facility returns a portion of the bypass flow back to the diversion and, thus, reduces the bypass flow returned to the natural water body.

Design options for a secondary screening facility include:

- An independent secondary screening facility can be included as part of the bypass system. The secondary facility is usually separate from the primary main screening facility. When multiple bypasses are included in the primary screening structure, the bypass conduits typically run to the common secondary screening structure where the flow from the multiple bypasses are merged (figures 7 and 27). Screening with a pump-back operation is used to return a portion of the bypass discharge to the canal or diversion, thus, reducing flow rates through the remainder of the bypass conduit and outfall (figure 32). With this concept, a single bypass conduit and outfall is used beyond the secondary screening facility. The Chandler Canal (figure 27) secondary dewatering facility is a typical example of this concept. Traveling screens are often used in these facilities (figure 76). A typical layout of a pump-back secondary screening facility is shown in figure 56.

- A recently developed concept includes the secondary screening facility in the bypass channel immediately downstream from the main bypass entrance. In this case, secondary screening occurs upstream from the flow control and velocity trapping section of the fish bypass conduit. Because very little head loss occurs in the bypass before the secondary screening, it is possible that flow can be returned to the diversion by gravity (resulting from the drop between the bypass conduit and the diverted flow channel behind the primary screen). A conceptual design of this type of secondary facility is shown in figure 57.

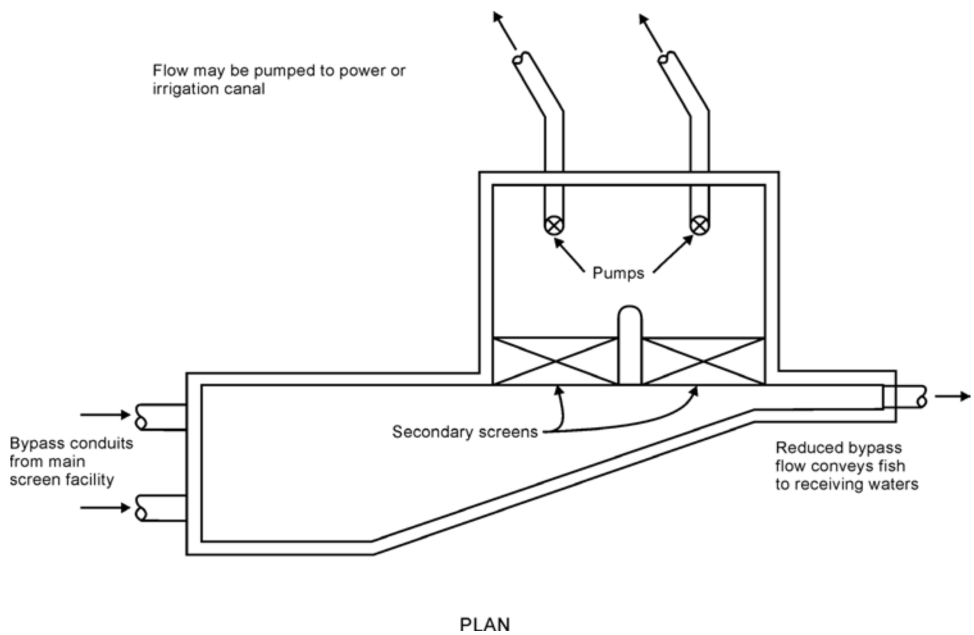


Figure 56.—Secondary screening layout with skewed wall.

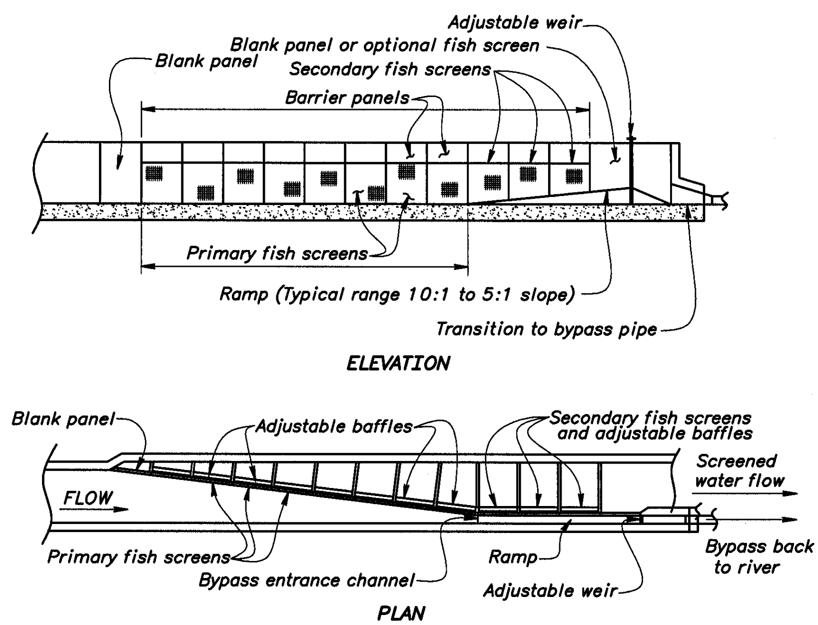


Figure 57.—Secondary screening without pumping.

Secondary screening facilities are designed in full compliance with fish screening criteria. This is of particular importance because of the high concentrations of fish and debris that occur in bypass flows. The secondary bypass structure must be designed to provide a sustaining velocity field that will effectively guide fish past the secondary screens and on to the bypass conduit. Typically, the section in which the screens are installed is reduced either vertically (using a ramp) or horizontally (using converging walls) (figure 56) to maintain velocities, sweeping flows, and fish guidance.

Screen cleaning, debris removal, and maintenance are concerns. Debris loading is often concentrated in bypasses and secondary facilities. It is critical for effective fish passage that debris-free screen operation be sustained. In addition, these facilities are often small, with limited space available for cleaning and maintenance equipment. As a result, vertical traveling screens have frequently been used in these secondary screening facilities to effectively handle debris with no need for intrusive debris handling and cleaning equipment in the passing flow.

12. Cleaning and Maintenance

a. Fish screens

Positive barrier screens are normally designed for either self-cleaning or use where an automatically operated screen cleaner is provided. There may be rare cases where screens that are only manually cleaned may be used if they are approved by fishery resource agencies. These screens might require more screening area than normal and would still require cleaning once the specified approach velocity is exceeded. Fish protection criteria states that screens be automatically cleaned as frequently as necessary. This is to prevent accumulation of debris that results in flow impedance and violation of the approach velocity criteria. The cleaning system and protocol must be effective, reliable, and satisfactory to the fishery resource agencies. Proven cleaning technologies are preferred.

Structural features may be required to protect the integrity of the fish screens from large debris and also to prevent plugging of the fish bypass. A trashrack, log boom, sediment sluice, and other measures may be necessary to provide this protection. In certain cases, a profile bar screen design can be substituted for a trashrack (e.g., a profile bar flat plate screen installed along the river bank).

Debris fouling and cleaning characteristics of fish exclusion facilities depend both on specific characteristics of the facility and on debris types and quantities. Some screen fabrics are susceptible to severe fouling from particular debris types that might embed or intertwine in the screen fabric. Screens located in diversion pools or that receive water directly from biologically productive water bodies may be exposed to heavy debris concentrations. On the other hand, screens that are placed in canals directly behind effective debris exclusion headworks or screens that draw water from water bodies of low biological productivity may experience only minor debris loading. If heavy debris loads are expected, automated cleaning systems with high capacity debris handling and disposal methods will be required. Conversely, fishery resource agencies might allow cleaning manually or with an automated cleaner for smaller facilities with light debris loads. The fishery resource agency criteria will need to be met. Information concerning potential debris loading may be obtained from existing screens or structures located near the site under study, but where possible, information should be gathered from direct field observation of debris at the proposed site. Input should also be solicited from experienced Reclamation designers, project operation and maintenance staff, and from fishery resource agency staff. The capital and operating cost of alternative cleaning and debris handling systems should be balanced against associated labor costs when selecting the fish exclusion facility final design. Achieving effective cleaning and debris handling is critical to maintaining effective fish exclusion structure operation and to minimizing demands on maintenance and operating staff.

Screen Cleaning System – Selection of the screen cleaning system will vary depending on the type of positive-barrier fish screen chosen and the site conditions. The screen cleaning systems may be operated manually or automatically. Usually, the controls for an automated cleaning system use an adjustable timer to initiate startup and operation of a cleaning cycle when a preset time interval is reached. Water level measuring probes (similar to those used for trashrack cleaners) are usually included to provide a warning system to tell the manual operator or the automated cleaning system that the screens need additional maintenance or cleaning. The screen cleaning system should be designed for both continuous and intermittent operation. Although many screen cleaning systems are developed as unique designs that are applied only at a specific screen site, this approach to the development of the screen cleaning systems can be very costly. Commercially available cleaning systems and proven fabricated cleaning technologies are available and have been broadly applied. Application of such cleaning systems is straight forward, minimizing the need for designing, system testing and development, and operational time to achieve effective operation. Equipment suppliers are experienced and can support concept development for a specific system. Specific screen cleaning requirements for the various types of positive barrier screens are presented in detail in chapter IV.B.1-6.

b. Trashracks

Most open channel (canal) diversions with downstream positive barrier fish screens require an upstream trashrack to protect the screens and the bypass system. For in-river installations, trashracks are often not used, but some type of log boom structure is included to provide screen protection from large debris while maintaining an effective near-bank sweeping flow across the screen face.

The required clear openings of the trashrack (open space between the trash bars) will depend on criteria from the fishery resource agencies. This spacing should be based on site location of the trashracks (e.g., within the canal or along the side of the river), the type and size of fish species present, and the size and types of debris. Where possible, the trashrack structure is usually located upstream from a gated headworks so that the rack can also protect the gates. The clear, open spacing may range from 2-inch clear openings (e.g., trashrack intake along the side of a river where there is good sweeping flow past the trashracks and where it is desired to discourage fish from entering the intake), to clear open spacings in the range of 3 to 9 inches (e.g., trashrack structure located within the canal downstream from the headworks – opening sized to allow fish to pass through the trashracks and continue on downstream to the screen and bypass structures). A study conducted by Hanson and Li (1983) found when trashrack bar spacings of 6 inches or greater were used, juvenile Chinook salmon passed through the trashracks with minimal delay. See chapter IV.A.15 for more detail on trashrack bar spacing and its effect on fish movement through the rack.

Trashrack cleaning system – A trashrack will usually be required to protect the screens and fish bypasses from large debris. To keep the trashracks clear of debris, the racks will require either manual hand raking or a mechanical type cleaning system (trash rake). There are numerous mechanical type cleaning systems commercially available. Operation of these cleaners may range from manual operation systems that operate continuously (ON-OFF switch) to systems that are semiautomatic or fully automated (figure 58). The controls of the automated cleaning systems are usually set to initiate startup and operate a cleaning cycle when a preset time interval and/or a preset water differential measured across the trashracks is reached. The cleaning system may also include a debris conveyance (conveyor) system to transport the raked debris to a desired deposit location.

Water level measuring probes or sensors, similar to those shown in figure 75, are usually provided as part of the cleaning system's operating controls or as part of a warning system to tell the operator that the trashracks need cleaning. One sensor is located upstream and one sensor is located downstream from the trashrack. The water level sensors continuously measure and compare the water levels. This water level differential can then be compared with specific set points, usually a low differential set point that activates a relay signaling the trash rake to start its cleaning cycle or warning the operator that the trashracks should be cleaned. A higher set point may also be provided that warns the operator that the trashrack is becoming excessively loaded. The excessive loading may require shutdown of pumps or gates.

Figure 58.—Mechanical driven rake on trashrack structure (Atlas Polar – Hercules Hydro Rake).

c. Backup power

Since most of the screens need power to be cleaned, lost power may lead to excessive loads during times of high debris. An engine-generator set may be required to provide backup power as part of the screening facility equipment. The engine-generator set needs to be sized to provide backup power to operate any or all of the following essential equipment: headworks gates, trashrack cleaning system, screen cleaning system, crane, lighting, water level measuring equipment, winch for retrievable cylinder screens, alarm systems, and bypass weirs and gates.

Where fish screens are located at intakes that are part of a pumping plant, it may not be critical to have an engine generator as long as the cleaning system is on the same power source as the pumping plant (i.e., if the pumps are not pumping, the screens do not need to be cleaned).

d. Maintenance

A reliable, on-going preventative maintenance, inspection, and repair program is necessary to ensure that the facilities are operating effectively, that the log boom, trashracks, positive barrier screens, and bypasses are being kept free of debris, and that the screen mesh, seals, drive units, cleaning systems, level or pressure sensors, and other components and controls are functioning correctly and have not been damaged. Debris cleaned from the trashracks and the screens (if vertically cleaned) will need to be properly disposed of, which may include transporting the debris to a disposal site.

13. Gantry/Lifting Equipment

A gantry crane, overhead traveling bridge crane, monorail hoist system(s), or combination of hoists figures 16 and 17 and cranes can be provided as part of the fish screen structure to allow installing or removing the screens and associated metalwork (figure 59). Jib cranes may also be used for small screen structures or for picking equipment at isolated areas (figure 84). Purchasing or renting a mobile crane is another alterative for installing and removing the screens and may be more economical for smaller screen structures (figure 15). Equipment that may require lifting at fish screen structures includes fish screens, baffle panels, stoplogs or bulkhead gate, trashracks, pumps and motors, fish screen cleaners, water or fish tanks, and fish trapping or evaluation equipment.

a. Red Bluff gantry crane.

b. Cascade Canal fish screen monorail hoist.

Figure 59.—Drum screen gantry crane and monorail hoist.

When a crane or hoist is to be used, numerous factors need to be studied to choose the right system. The following are some of the items requiring consideration:

- Individual equipment that requires lifting
- Location of equipment with respect to other equipment (this will determine whether more than one crane or hoist system is required)
- Type of structures (concrete, metalwork, deck, piers, roads, etc.)

- Equipment location within the buildings
- Support structure that will be required for the particular hoist or crane system
- Individual equipment weights, any additional loadings (e.g., additional loadings may be caused by friction forces as a result of water differentials), and the maximum capacity to be lifted
- Height to which the equipment needs to be lifted (high hook elevation)
- Overhead electrical cables
- Lowest level the hook has to reach (low hook elevation)
- Location where items need to be lifted from and to
- Manual or motorized lifts and travel
- Available power
- Speed of lift and travel (speed control)
- Need for lifting slings or lifting beams

Where anchor or frazil ice are present during winter operation, the situation may dictate that the screens need to be raised and pinned above the water surface so they are not damaged. Lifting and pinning screens may also require that the canal system be shut down because these types of ice conditions can also damage the trashracks, cleaners, and other equipment. At some sites, a dedicated gantry crane or hoist system is assigned to automatically pull a screen in the event that an excessive water level differential is reached because of excessive icing or debris loading conditions. This protects the screen structure from possible failure and damage; however, it opens a fish passage into the diversion. If this occurs, an alarm system should be activated to warn the operators.

14. Sediment Management

Sediment deposits are a concern whether the fish screen is located in a river, in a canal, or a diversion pool. Sediment can move along the bottom of the water column (bed load) or be dispersed throughout the water column (suspended sediment). Bed load is usually a coarser grained material such as sand and gravel. Suspended sediment is fine-grained material such as silts, clay, and fine sand. When water velocities are lower, deposition can be expected if sediment (especially bed load) is present. An evaluation of potential sediment concerns (quantity and particle sizes) can be made by: (1) reviewing historic records of the river and canal, and (2) sedimentation mathematical model studies.

Typically, velocities through fish exclusion facilities are held relatively low to minimize the potential for fish injury. Unfortunately, these lower velocities allow sediment to settle out of the flow and deposit in front of and in the fish exclusion facility. Keeping sweeping velocities high might prevent sediment deposition in front of the screens. Quantities and location of deposits are a function of the specific structure configuration, generated flow patterns, velocity magnitudes, and sediment quantities and properties. Sedimentation potential can be determined by evaluating velocities in and around the structure and by using computational and/or physical modeling and coupling the results with field and laboratory documentation of sediment volumes and settling properties. Sedimentation may be reduced by placing in-river and in-diversion pool fish screens in scour or non-deposition zones or by placing the fish exclusion facility in a canal below a headworks that includes effective sediment exclusion capabilities (sluicing).

Often, maximum sediment transport occurs in early spring with high flow events on the stream or river. These high-flow, heavy sediment transport events may not coincide with high diversion periods.

The design should consider means for removing sediment. If periodic sediment removal from fish exclusion facilities is required, it has typically been achieved either by dredging, sluicing, or by dewatering the structure, then physically removing the sediments. Dredging may require an access ramp into the structure, a pipe distribution system, and settling ponds. Dredging may be limited by fishery resource agencies to times of the year when potentially adverse influences on the fishery are minimized. Dewatering and physical removal may be a convenient option for in-canal sites where the canal is annually dewatered for maintenance. Proposed designs should recognize the need for access with cleaning and sediment removal equipment. Sediment disposal options must also be provided.

Fish exclusion facilities usually operate better if sediment is not deposited at the fish screen site. Sediment deposits near the fish screens can create difficulties with the operation of the facility. Also, sediment deposited at the fish screen structure is usually relatively difficult to remove. If sediment deposition is a concern, several possible measures may be taken:

- A settling basin may be constructed upstream from the fish screen structure; this can be done in a canal or sometimes in a river location. The settling basin can then be cleaned out at regular intervals.

- The invert of the fish screens should be at least 6-inches above the channel invert.

- Channel and/or sweeping velocities should be maintained to keep the sediment moving and prevent the sediment from settling out. The baffle behind the drum screen in figure 11 can be used to effectively keep sediments in suspension at the screen by causing increased velocities near the channel invert.

- A sediment sluice may be constructed upstream from the fish screens and at other locations as required.

- Some projects in the Pacific Northwest are experimenting with “ecology blocks” placed a few ft upstream from the drum screens to control sediment deposition in the forebays. These blocks are similar to 2 ft by 2ft by 4ft long gabbions placed in the forebay approximately 3 ft in front of and parallel to the Sunnyside Diversion Dam fish facility drum screens. They are stacked two high and provide excellent sediment transport in front of the screens.

- An air nozzle may be installed on the bottom of the horizontal cleaner brush to help move sediment and debris from in front of the screens (figure 66).

- Air bursts or water jets may be installed in the base of the screen panel.

- A bubble curtain may be created around fixed cylindrical screens.

- A water spray system may be used downstream from the screens and baffles to keep sediment suspended.

Operation and maintenance personnel at RD 108 (Wilkins Slough) have developed an air burst system (figure 60) that keeps in suspension sediments that normally deposit immediately behind the screens. The sediments eventually reach a zone downstream from the screen but upstream from the pumping plant where the material can be easily removed. During low river flows, project personnel will enter the area between the screen structure and pumping plant with earth moving equipment and annually remove (dredge) 600 yd^3 (figure 29). Hydraulic laboratory studies identified this sediment deposition problem in the laboratory and it has now been verified in the field, Vermeyen, 1996.

Figure 60.—Air burst device placed in the bay immediately downstream from the Wilkins Slough Fish Screen (RD-108).

15. Predation Control

Predation of juvenile fish approaching, passing through, and exiting the fish exclusion facilities can yield significant fish losses. These losses can result in a poorly performing fish exclusion facility even if the facility is otherwise well designed. Potential predators include both fish and birds, although for typical fish exclusion facilities, predation by fish is the more prevalent problem.

a. Locations of predation

Predation occurs throughout the facilities but tends to be predominant at locations where: fish are holding and thus more easily accessed, fish concentrations are high and thus chances for successful predation are increased, and fish are weak or disoriented and, thus, less capable of escape. Consequently, predation will be concentrated:

(1) At trashracks where narrow bar spacing generates fish passage delays and holding in front of the racks.

(2) At and near bypass entrances where changes in lighting, hydraulics, and possibly restrictive passageways may cause fish passage delays and holding.

(3) In the bypass structures (if predators are present) where fish densities are concentrated and turbulent flow conditions might cause fish disorientation.

(4) At the bypass outfalls where fish densities are concentrated and hydraulics may cause fish injury and disorientation

b. Alternatives to reduce and control predation

Predation can be reduced or minimized by reducing or eliminating the sources of fish passage delay and keeping fish moving through the facility. It is important to develop designs that provide flow conditions and hydraulics that disperse or eliminate predators from zones of potentially high predation, but do not generate excessive turbulence that may cause fish injury and disorientation.

Hanson and Li (1983) observed that juvenile fish passage delays at the State of California's Skinner Fish Exclusion facility (which uses a trashrack with a 3-inch bar spacing) caused heavy fish concentrations and resulting predation. The trashrack bar spacings should be as large as possible to minimize fish delays while still providing protection from debris for the fish structure equipment and downstream bypass. Increasing the trashrack bar openings may yield increased debris loading at the fish exclusion structure (fish screen, louver, etc.) which could cause problems and increase cleaning and debris removal requirements, depending on the types and quantity of debris.

Studies of a limited range of species and operating conditions have provided an indication of the influence of bar spacing on fish passage through trashracks (Ruggles and Ryan, 1964; Bronoski and Vandenberg, 1984; Hanson and Li, 1983; Reading, 1982). Although these studies focused on the influence of trashrack bar spacing on fish passage, they do give an indication of fish avoidance responses for confined passages. The studies indicate that a free spacing of 12 inches or greater will minimize fish avoidance responses and fish passage delays.
Figure 61 displays data presented by Reading (1982) that are based on juvenile American shad response to trashracks. These data are based on a very limited study scope but do indicate representative fish responses. Comprehensive data for wide ranges of fish species, spacings, and operating conditions are not available. Thus, there is substantial uncertainty in these findings. From this figure, there is an obvious improvement (90 percent) in fish passing through the trashrack when the bar spacing increases from 7.6 cm to 30.5 cm.

Bypass entrances, likewise, should be designed and operated to readily pass intercepted fish (chapter IV.A.11). Such a design requires that the bypass entrances should be properly positioned, sized, and operated with entrance velocities that are compatible with the channel flow velocity approaching the structure.

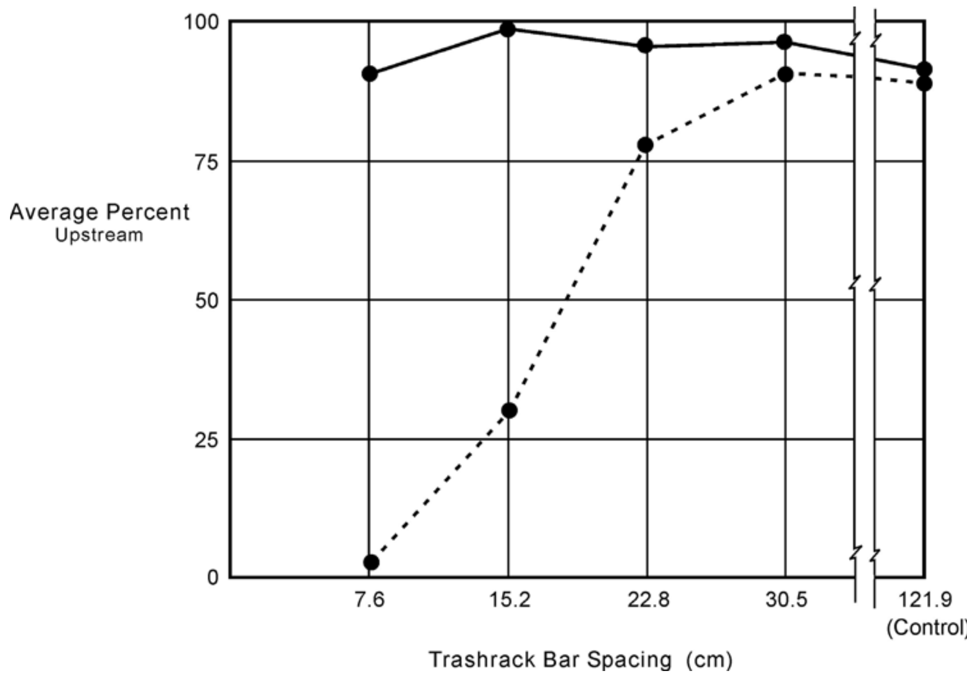


Figure 61.—Average percent of juvenile American shad found upstream from trashracks with various bar spacing – channel velocity of 1.0 ft/s (Reading, 1982).
Fish released upstream from trashrack - - - - - - -
Fish released downstream from trashrack ————

To minimize the potential for fish injury and disorientation that are likely to lead to predation, hydraulic jumps should be avoided, particularly in confined spaces and within closed conduits. Likewise, high velocity jets (with velocities greater than 25 ft/s) entering low velocity flows or pools should be avoided to eliminate shear zones that may injury fish.

Flow zones should be eliminated where predators can easily hold and feed on passing fish with minimal energy output of their own. Slack water and eddy zones should be eliminated from the facility. Flow through bypasses should be well directed with velocity magnitudes equal to or exceeding 2.0 ft/s. By positioning bypass outfalls in areas of the river where velocities are above 4.0 ft/s, flow zones are created where predators cannot maintain a sustained position, and may be flushed out of the mainstreamflow. In such situations, the predators can and will go to the boundary looking for holding zones near the boundary layer and in eddy zones generated by boundary roughness. To prevent predation near boundary zones, the boundaries should be smooth and well aligned to maintain good flow velocity. Fish bypass outfalls should stay clear of these potential predator holding areas.

Finally, if predation is particularly severe and cannot be addressed with the above control options, predator removal or clearing might be considered. At the Tracy Fish Exclusion Facility, California, Reclamation has periodically shutdown and dewatered the secondary louver facility of the bypass. During this shutdown, predators that have taken up residence in the facility are netted and removed from the facility.

It has also been speculated that behavioral stimuli might also be used to irritate and disperse predators. Electrical fields or sound (chapter V.B. and D.) should be considered in zones where predation is of particular concern. A concern with use of stimuli is that they might also affect the protected fish. If the stimuli deflect the protected fish and cause passage delays, no gain has been achieved. The influence of stimuli is often species and fish-size dependent; consequently, it may be possible to disperse large predators of a particular species while passing juvenile fish of other species. No definitive information is available for application of stimuli for these purposes. It may offer potential; however, any applications in this area would be considered experimental with uncertain benefits.

16. Fish Behavioral Influences

Fish behavioral characteristics strongly influence locations where fish are present and fish responses. If properly recognized, facilities can be developed that use behavior influences to optimize performance. If neglected, behavioral responses can adversely affect the performance of fish-protection and exclusion facilities to the point that their benefits may be largely negated.

If preferred fish habitats are recognized and stimuli that generate desired fish responses are used, fish can be guided to desired locations and passed through facilities without delay.

a. Habitat

Fish prefer specific habitats partly because of behavioral characteristics and partly because of physical requirements. Conversely, water quality or flow conditions may not sustain life (high temperatures or low dissolved oxygen) or may not allow fish to remain in a local (high velocity) zone.

Some fish species prefer being near banks, structures, and physical boundaries, while other species prefer open water. Some fish species prefer being at shallow depths while other species prefer deep water. Some species prefer confined areas while others prefer open water. Migrating species will often be attracted to and will follow velocity fields.

Migrating salmonid smolts' preference for near boundary and structure surface habitat and their attraction to downstream directed flow have been documented and used to optimize bypass performance for fish passage around dams. Dam bypass entrances in the Snake and Columbia River systems are often placed at locations where structure and bank geometries and flow fields converge (Bonneville First and Second Powerhouses [U.S. Army Corps of Engineers (Corps), 1999] and Rocky Reach Dam [Wells et al., 1999]). Convergence creates a focal point to which fish are guided. Figure 53 demonstrates the bypass entrance locations and the configuration of the flow fields at Bonneville Dam. These behavioral characteristics are also typically considered in locating bypass entrances on screen structures. From a design perspective, consideration of facility layout and generated flow patterns is important for design of fish structures and placement of intakes.

Preferred depth positions of fish are of particular importance. Where intake structures are located in deeper water bodies such as upstream from high dams, the depth position of fish is particularly important. Studies have shown that fish passage can be improved if the fish bypass intakes are vertically positioned to match fish locations (Reese, 1999; Johnson et al., 1992). Conversely, fish can be excluded from an intake by positioning the intake at a depth where fish are not present. The detailed studies conducted at Wells Dam, Columbia River, Washington (Johnson et al., 1992), have established standards for juvenile salmonid passage at dams in the Columbia and Snake River systems. The studies show that the out migrating juvenile salmonid smolts are located in the upper 60 ft of the reservoir water column. As a consequence, vertical slot intakes that extend over the full 60 ft vertical height of the upper portion of the water column have been developed and installed at several sites (Wells Dam, Rocky Reach Dam, and Lower Granite Dam). This collector slot configuration, as developed at Wells Dam, has become a standard at Columbia and Snake River Dams.

It should be noted that the behavioral response and distribution of salmonids in flow fields and site configurations is fairly well known and documented. The response and distribution of non-salmonids is not well understood. Fish distribution surveys (at the existing site, if the structures being designed are additions or retrofits or at similar sites if the design is for a new facility) are recommended if the design is to address exclusion or passage of species for which behavior is poorly known. Design and construction of a fish exclusion facility without a knowledge of fish response and distribution will often lead to failure.

As noted, water quality and hydraulic characteristics of a site may also dictate locations where fish are present. In particular with stratified reservoirs, the development of summer temperature stratifications may actually yield water temperatures in portions of the reservoir that are not life sustaining or acceptable for certain fish species. In such cases, the fish will move to locations and depths in the reservoir where water temperatures and water quality conditions are suitable. Such location shifts may temporarily reflect seasonal changes in water temperature. Fish may return to behaviorally preferred habitat after fall cooling of surface water temperatures.

In similar fashion, for biologically productive reservoirs, the development of a summer temperature stratification that reduces vertical mixing in the reservoir isolates the cooler deep water from the surface water. If there is sufficient oxygen demand in the reservoir, deep level oxygen concentrations can slump or even go anoxic. Fish avoid zones with low dissolved oxygen levels and look for zones where both water temperature and dissolved oxygen satisfy their life requirements. In some reservoirs where these life-sustaining elements are not available, fish die-off occurs. This search for life sustaining habitat can, at times, frustrate fish exclusion efforts. The Corps, in the tailwater of Richard B. Russell Dam and Powerhouse (Savannah River, Georgia/South Carolina) attempted to use sonic devices to exclude fish from entrainment by pumped storage units during pumpback operation. However, they could not drive fish from the immediate zone of the draft-tube/suction-tube intake because that was the only zone in the tailrace with adequate life sustaining water quality.

Flow velocity characteristics of a site can also strongly influence the presence of fish for in-river settings. As discussed with bypass outfall placement (chapter IV.A.11), strong steady flow will prevent fish holding because the fish physically cannot sustain position for extended periods. Sustainable swimming velocities vary with species and life stage (Bell, 1991). NOAA Fisheries design criteria (NMFS, 1995) require that bypass outfalls be located at sites with ambient river velocities of 4.0 ft/s or greater specifically to locate the outfall in zones where predator fish cannot hold. They also recommend that outfalls be located to minimize predation through placement in areas “free of eddies, reverse flow, or known predator habitat.”

b. Turbulence

Fish can detect pressure fluctuations and turbulence. This ability allows them to avoid physical contact with obstacles that generate flow turbulence. This response and the resulting fish avoidance is used with louvers to exclude fish and guide them along the louver face, chapter V.A. It has been proposed that turbulence or pressure fluctuations actually be generated and used to achieve fish avoidance and exclusion. However, use of features such as bubble curtains and water jet barriers have usually proven ineffective (chapter III.B.2.c.).

c. Lighting

Light can be used to both attract and repel fish. As discussed in detail in chapter III.B.2.b. and chapter V.C., strobe lights have been used to repel and guide fish. The use of other light sources, including underwater mercury vapor, underwater incandescent, and overhead sodium lights, to attract fish has been evaluated (EPRI, 1999). Underwater fluorescent and drop lights have been evaluated for repelling fish (EPRI, 1999). Typically, lighting has been used in attempts to supplement the performance of other fish exclusion or protection systems. Lighting, in itself, does not offer a consistently effective fish guidance and/or exclusion option. Successes and benefits associated with the use of lighting are inconsistent and variable, depending in part on fish species, fish-life stage, and other environmental influences. Depending on the specific installation, the effects of lighting are often negated during the day, when the influence of the sun dominates.

Underwater mercury vapor lights have been used to attract out-migrating salmonid smolts to bypass entrances and to light the interior of the entrances so that fish will more readily enter them. Mercury vapor and overhead sodium lights have been used to attract fish to safe areas away from fish entraining intakes, thus reducing entrainment. Underwater incandescent and flourescent lights have been effectively applied to exclude American eel from intakes. Effects of lights are inconsistent but should be considered in design development and in efforts to improve the performance of existing systems.

An additional consideration is the effect of general facility lighting on fish exclusion and guidance. The experiences presented above indicate that fish may respond to various kinds of lighting. General facility lighting may attract fish to unwanted locations or exclude fish from desired locations. The type and location of lighting should be considered in design development. It may, for example, be beneficial to place mercury vapor or sodium lighting near bypass entrances, particularly if the facility is designed for juvenile salmonids.

d. Diurnal effects

Diurnal (day/night) variations in fish response have been investigated at many sites. Loss of visual reference at night can yield changes in fish location and behavior. Studies conducted at Wells Dam (Columbia River) showed that juvenile salmon tended to stay within 30 ft of the reservoir water surface during the day but that they tended to drift deeper (down to a depth of approximately 60 ft) at night (Johnson et al., 1992). At sites where fish avoid bypass entrances because of the narrowness of the entrance or light conditions, fish- collection efficiencies often increase at night. It should be recognized in design development that fish location and preferred habitat may change at night. Evaluation of fish responses and fish facility performance should consider both day and night operations.

e. Sound

Beyond issues associated with sound generators that are specifically used to repel or disperse fish (chapters V.D. and III.B.2.b), environmental or ambient sound may also affect fish responses. Agencies, at times, will express concern that equipment (e.g., continuously operating pumps) associated with fish facilities might cause fish avoidance, which could adversely affect fish bypass performance.

The documented responses of fish to sound generators/sound systems (chapter V.D. and EPRI, 1999) indicate potential influences of ambient sound. As with other behavioral factors, influences are species and life-stage dependent and vary with site-specific applications. Impact (periodic thumping or pounding) and low frequency (4 kHz and below) sound often generated no fish response; although, in some cases, limited or partial responses have been documented (EPRI, 1999). Higher frequency (120 to 160 kHz) systems routinely produced fish responses with certain species, including blueback herring, alewife, and American shad. Salmonid responses to higher frequency systems have not been well documented. In general, it appears that sub 4 kHz sound sources are, at most, of limited concern, and that ambient sound sources with frequencies of 100 kHz and higher should be avoided in the vicinity of fish guidance and collection facilities.

17. Summary Table

Table 4 is a partial summary of NOAA Fisheries – Northwest Region juvenile salmonids criteria. If we look at the fish exclusion facility design as discussed in this chapter, we can find the criteria for the specific design feature. A more complete summary of NOAA Fisheries as well as several State agency criteria are presented in attachment A.

Table 4.—Summary table – fish screen criteria (juvenile salmonids – NMFS Northwest Region)[1]

Design feature	Variations	Criteria
Approach velocity[2] (Measured 3 inches from screen face)		Not to exceed 0.4 ft/s for fry or 0.80 ft/s for fingerling
Sweeping velocity		Greater than approach velocity (some State agencies prefer twice approach velocity – greater than 2 ft/s)
Screen material and maximum opening	Perforated plate	**Fry** – 3/32" – 2.38 mm **Fingerling – 1/4"** – 6.35 mm
Fry – minimum open area 27%	Profile bar	**Fry** – 0.0689" – 1.75 mm **Fingerling** – 1/4" – 6.35 mm
Fingerling – minimum open area 40%	Woven wire	**Fry** – 3/32" – 2.38 mm **Fingerling** – 1/4" – 6.35 mm
Structural features		* Unimpeded fish movement parallel to screen and into bypass * Oriented at angle up to 45° to the flow * Piers and walls flush with screen face * Screen placed at an angle to flow, and downstream end terminates in bypass entrance
Bypass	Layout	* Multiple bypasses are needed when fish exposure time is more than 60 seconds. * Entrance and all components sized to minimize potential for debris blockage * Training walls may be placed at an angle to the screen to aid fish movement toward the bypass and for intermediate bypasses.
	Entrance	* Bypass entrance has independent flow control capability * Entrance velocity is greater than or equal to maximum flow velocity vector near screen * Good ambient light * Bypass entrance extends from floor to water surface
	Conduit	* No pumps, free fall, valves, or hydraulic jumps within the conduit. * Smooth pipe surfaces * Pipe bends shall have radius/diameter ≥ 5 * Pipe velocity≥ 2 ft/s * 24" minimum diameter with 9" minimum flow depth
	Outfall	* Ambient river velocities of at least 4 ft/s * 25 ft/s maximum outfall impact velocity * Locate to minimize predation
Operation and maintenance		* Automatic screen cleaning to prevent accumulation of debris * Head differential on screen of 0.1 ft triggers screen cleaning * Screen and bypass evaluated for biological and hydraulic effectiveness

[1] Varies according to NMFS regions
[2] Uniform flow required

B. Screen Specific Design Details

> "Many things difficult to design prove easy to performance."
>
> *Samuel Johnson (1709-1784)*
> *Rasselas. Chap. xvi.*

1. Flat Plate Screens

Flat plate screens can be used for fish exclusion as part of the headworks to a canal intake, at pumping plant intakes on-river or at diversion dams, or as part of a fish exclusion facility within a canal system. The flat plate screens may be configured in a linear (straight line) arrangement or in a "V" shaped arrangement. A fish bypass or bypasses will be required to return the screened fish from canal sites back to the river or to the desired location dictated by the fishery resource agency. For in-river, linearly arranged screens where a large portion of the flow continues on down river, a bypass is not usually required.

Flat plate fish screens are typically designed to be vertical, or nearly vertical (about 15 degrees off vertical) for several reasons:

- Near vertical and vertical screens allow for easy transition to the fish bypasses.

- The bypass transition must maintain or accelerate screen sweeping velocity at the bypass entrance to meet fishery resource agencies' bypass criteria

- The more the screen angle is off vertical, the greater the bypass entrance area, which results in a larger required bypass flow to achieve the desired entrance velocity.

- Near vertical screens facilitate easier removal and reinstallation of fish screens and baffles when designed with guides for drop-in capability

- Automated screen cleaning systems use proven technology for vertically to near-vertically aligned screens.

At locations with shallow water depths, inclining the flat plate screens to increase the wetted screen area while reducing the screen length may be desirable. Check with fishery resource agencies concerning their criteria about inclined screens. Inclining screens at very flat angles (i.e., screens sloped at greater than 45 degrees off vertical) is not recommended when the submerged screen extends to the water surface. Chapter IV.B.4.b presents details for inclined screens. Screens sloped at shallow angles yield a thin, shallow flow along the edges that can increase fish abrasion and subject fish to increased predation. Other major issues to be addressed are the bypass transition and how to clean the screens.

The support structures associated with fish screens are usually constructed with a reinforced concrete foundation (figures 101 and 102). The support structure for flat plate screens and trashracks may be either reinforced concrete or structural steel. If the support structure is structural steel, the deck will be metal grating (figure 101). If the support structure is reinforced concrete, the deck can be either cast in-place concrete, precast concrete, or steel beams with metal grating (figure 107). The deck should be wide enough to accommodate a walkway and any operating equipment such as screen cleaners, conveyors, gantry crane or monorail hoist, and trash rakes. The facility operators may want the deck wide enough to accommodate vehicles or operate truck-mounted cranes. The upstream channel walls leading to the screens may also be vertical concrete or sheet pile walls, thereby providing improved sweeping hydraulics that will assist with predation control (both avian and aquatic).

In-canal screens are constructed at an angle to the approaching flow. Screen surfaces should be placed flush with adjacent screen bays, pier noses, and walls to allow fish unimpeded movement parallel to the screen face and easy access to the bypass route. Flush surfaces also enhances cleaning of the screens. The downstream end of the screen should terminate at the entrance to the bypass system.

The top of the fish screen should extend above the maximum operating water surface. If the screen height required by the fishery resource agency to meet the screen area criteria is met at a lower water depth, an upper barrier panel may be provided above the fish screen panel in lieu of having a taller, more costly, screen panel (figures 28, 57, and 107). The upper barrier panel may be bolted directly to the top of the fish screen panel or may just sit on top of the panel within the same guides. This upper panel extends the fish exclusion structure above the maximum operating water surface and is usually fabricated from structural-steel members. At locations where the fish screens are bolted in place, fixed concrete or metal walls may be located above the required screen height to provide fish exclusion to the maximum operating water surface (figure 67). All these options may be less costly than providing fish screens that extend above the maximum operating water surface. In addition, if a rake type screen cleaning system is chosen, the height of the screen or upper barrier panel may need to extend above the deck so debris may be deposited into a conveyor (figure 58).

A screen installation can consist of a single screen at smaller sites or can include a series of screens placed end to end in guides, with concrete piers or metal supports between them. If profile bar or wedge wire is used, it may be desirable to fabricate the screen into square shaped panels so operators have the option of rotating the screens to change the direction of the screen slot openings.

For in-canal and "V" screening structures, the line of the screens with the downstream end terminating at a fish bypass entrance should be constructed at a skewed angle to the approaching flow to create a sweeping flow (figures 10 and 100). In-river screening structures may be located along and parallel to the river bank (figures 28 and 29). Reconfiguring the river bank opposite the screens to enhance the hydraulics along the screens may be desirable (figures 5 and 105).

The screen facility design must provide for uniform flow distribution over the surface of the screen. (See chapter IV.A.6). Providing for uniform flow usually requires some type of control (baffle panel) located directly behind and downstream from the screens. The control could include fixed or adjustable baffles (figures 41 and 42). Uniform flow distribution control may not be required where there is an individual channel (bay) for each screen and the flow passing through that screen is being controlled by a pump or adjustable weir located in the downstream channel.

A physical hydraulic model and/or a mathematical model study may be required to:

- Evaluate and provide good flow conditions in the waterways leading to and through the screens
- Identify and possibly avoid localized high velocity areas along the screens
- Ensure adequate attraction flow to the bypasses

Such model studies were used by Vermeyen (1996) to design the screen intake and baffles for GCID.

Proposed designs should be based on screen approach velocities, V_a, that recognize fish swimming strength to minimize the potential for fish impingement on the screen surface and potential injury. Specific velocity design criteria are available for juvenile salmon; however, limited criteria are available for other fish species and sizes. These criteria are discussed in more detail in chapter IV.A.5 and attachment A of this document. However, it should be recognized that it is important to establish these velocity criteria based on the specific fish species and fish sizes for which the screen is being designed.

For both the linear and "V" flat plate screen configurations, the upstream face of the screen surfaces should be placed as flush as possible with any adjacent screen bay, metal guide, pier nose, and wall to provide unimpeded fish movement parallel to the screen face with easy access to bypass routes. This also enhances the cleaning of the screens.

Concrete piers or metal supports are usually supplied between individual flat plate screens where multiple screens are required. The piers, walls, supports, deck, and floor need to be able to carry the loads from the screens and associated equipment and from the water loads. The piers and walls may also need to support a crane or hoist system and the maintenance/access deck. The deck should be sized for the cleaning equipment and for a walkway or vehicle access (figures 101 and 107). Electrical continuity should be considered in the design of structural steel members of the fish facilities to provide future cathodic protection. However, care is advised when dealing with members of dissimilar metals and any kind of cathodic protection.

The fish bypass system should be designed from the fishery resource agency criteria and may include ramps, weirs, open channels and/or pipes, and fish bypass outlet structures. The bypass is used to direct fish back to the natural water body. If an upstream trashrack has not already been provided, a trashrack may be required at the bypass entrance to keep large debris out of the bypass. See chapter IV.A.9 for more details on fish bypasses.

***Screen guides* –** Screen guides allow for screen panel removal. The guides for each flat plate screen may be embedded metalwork guides within the concrete piers or walls, or they may be a combination metal guide and metal support, or both types of guides may be used. The metal guides protect the concrete corners from being damaged and provide a wearing surface. The concrete floor that the flat plate screen support frame sits on should be as flat and level as possible to prevent point loading on the flat plate screen frame and to prevent excessive openings (gaps) between the screen and the floor where fish could pass. Embedded metalwork seats in the floor is an option that can be considered to maintain acceptable tolerances (figure 107).

An alternative to screen guides is a support structure that the screens can be directly bolted to. This alternative may also require dewatering capability at the screening facilities to allow future screen removal. Seals may still be required along the screen panel edges.

***Flat plate screen* –** The screen panels are either retained in guides as described above or attached directly to the leading face of the support beams. In either case, care should be taken to maintain a smooth, continuous face along the full length of the screen. (If support beam faces are exposed, maintain the beam faces as flush with the screen face as possible.) Smooth and flush screen faces are desired both to minimize hazards to fish passage and to simplify screen cleaning The screening panel may consist of a support frame, a flat plate screen, and seals. (See figures 62 and 63.) The support frame members are sized and

Figure 62.—Downstream view of flat plate screening panel, support frame, and screen.

spaced to support the screen material so it is not over stressed and to carry and transfer the design differential loading from the screen to the guides or supports. The support frame may be fabricated from the same material as the flat plate screens or it may be fabricated from structural steel to reduce the costs. The support frame should be designed with lifting lugs or lifting eyes to allow the screen to be lifted with a crane or hoist system. The flat plate screen is usually fabricated from 304, 304L, 316, or 316L stainless steel with a profile bar (also called wedge or Vee wire) (figure 51). Perforated plate is another screen material option (figure 50). Bio-foul resistant screens (copper-nickel) can also be provided. The maximum size openings allowed in the screen fabric and the minimum open screen area allowed should be based on the fishery resource agency's criteria (table 4). The support frame and the flat plate screen may be welded or bolted together to make up the screening panel. Wear strips may also be bolted to the screen panel. The strips not only eliminate the direct contact of the metal guides and the screen support frame, but also reduce friction when removing the screens from the guides. The wear strips are fabricated from ultra high molecular weight (UHMW) polyethylene, delrin, brass, etc.

Seals – Seals are required as part of the flat plate screen to prevent fish passage past the screen. (See chapter IV.A.10.b.) The seals should be designed and installed so that the maximum openings past the screen do not exceed the allowed openings in the screen fabric material. The seals are usually fabricated from neoprene or rubber for sheets, strips, and formed seals (i.e., music-note seals). Brushes have also been used as seals and are usually fabricated from nylon, polyethylene, or polypropylene bristles similar to those depicted in figure 72 for the drum screen. A seal may be attached to the screen panel with a clamp bar and bolting system. Side seals may be required between the screen panel and the side walls or guides. Bottom seals may be required between the screen panel and the floor. A top seal is also required where the screen panel does not project above the maximum water surface or where the upper barrier panel is not directly bolted to the top of the screen. Side seals are also required for the upper barrier panel above the screen. For screens bolted in place, caulking or putty can be provided between the screens. (See figure 63.)

Figure 63.—Joint with caulking – Red Bluff flat plate screen (screens bolted to supports).

Debris cleaning **–** Flat plate screen installations usually benefit from the high ratio of sweeping velocity to approach velocity associated with the water sweeping towards the bypass. As water is diverted through the flat plate screens, debris will gradually build up on the screen surface. The following are the most common methods of cleaning screens:

- A horizontal brush cleaning system (figures 64 and 65)
- A cleaning system that uses either a high volume of water or high pressure water to back flush the screens
- A vertical trash rake type brush cleaning system

The most appropriate cleaning system will vary with screen design and debris type. As a general rule, the design of the cleaning system should allow completing a cleaning cycle every 5 minutes (California Department of Fish and Game) or as necessary so the water differential across the screens does not become excessive (NOAA Fisheries). The screen cleaning system will usually be designed for both continuous and intermittent operation.

For the horizontal brush cleaning system and the backwash cleaning system, once the debris is brushed or washed off the screens, the bypass flow carries the debris on downstream. If in a canal, all the debris will have to pass through the fish bypass. Therefore, the fish bypass needs to be designed to also handle and pass the expected debris loading. In a few cases, trashracks and cleaning equipment are required at the entrances to the bypass.

The horizontal brush type of screen cleaning system is the most common system used for flat plate screens. It is commercially available or can be a designed and fabricated as at the Red Bluff Fish Evaluation Facility (figures 10 and 65). This cable-driven brush cleaning system cleans during both upstream and downstream travel and may include brush cleaning arm(s), a brush arm wheel, a trolleys and travel beam (monorail type), a cable and fittings, a cable take-up or adjustment system, a screen cleaner drive and controls, idler sheave(s), a return sheave, cable pulley guides, cable and drive guards, counterweights, ramps, and supports. The cable drive cleaning system can be designed to operate more than one brush cleaning arm at a time, depending on the cleaning travel speed, loadings, and the length and configuration of the screen structure. An adjustable speed drive will normally be provided as part of the cable drive system to allow adjusting the horizontal travel speed of the brush cleaning arm(s). Ramps, which let the brush arm wheel push the brush away from the screen face, should be installed at the upstream parking area and also at the downstream turn-around area of the brush arm. This allows debris to be washed off the brush and be passed on downstream.

Figure 64.—Flat plate screens with horizontal brush cleaner (GCID).

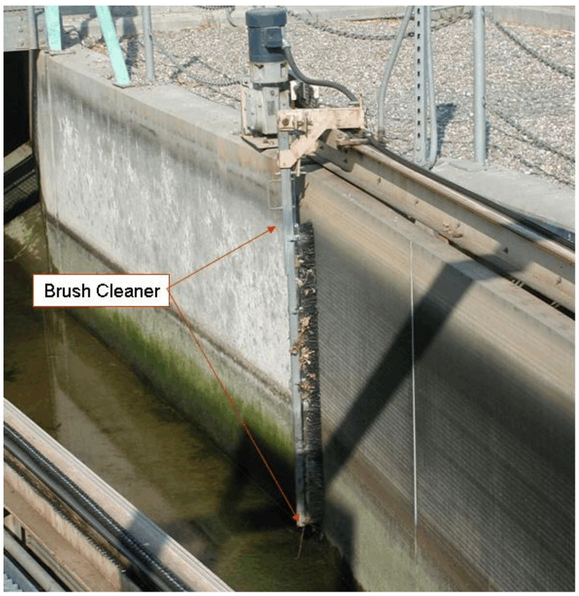


Figure 65.—Mechanical brush cleaner and drive mechanism at Red Bluff Fish Evaluation Facility.

The Yakima-Tieton project uses an air nozzle at the bottom of the horizontal brush cleaning arm to help remove pine needles lodged in the vertically placed profile bar screen (figure 66). This helps clean sediment and debris that may deposit below the brush arm. The air supply system may include an air compressor or blower, piping, flexible air hoses with festoon system, valves, a control system, and supports. This air system may also help to keep sediment suspended along the screen face.

Figure 66.—Flat plate screen with horizontal brush cleaner and air nozzle at bottom of cleaner arm.

Where possible, the cleaning cycle should start upstream and work downstream so the debris is not recycled. The cleaning cycle of all the screen cleaning systems may be started manually or automatically. Usually, an intermittent, automated cleaning system uses an adjustable timer to initiate startup and operation of a cleaning cycle when a preset time interval is reached. Water level measuring probes (mounted upstream and downstream from the screens) are usually included as part of the cleaning system's operating controls or to provide a warning system to tell the manual operator or the automated cleaning system that the screens need additional maintenance or cleaning.

Where debris needs to be removed from the system, a vertical trash rake type brush cleaning system(s) that lifts the debris up and off the screens, similar to the rake in figure 58, may be used. This trashrack cleaning system may need to be designed and modified to clean flat, plate- type screens (instead of trashracks). Such a system may also require a debris conveyance system to remove the raked debris from the deck. Because of the sweeping water velocity along the face of the screens, modifications to the rake's cleaning head or cleaning bars may also be necessary to restrict debris from being carried off by the water's sweeping component during the cleaning operation.

Alternative flat plate screen cleaning systems have been used at specific sites but have not been widely applied. These systems include a vacuum cleaner-like head that tracks back and forth over the screen (California Department of Water Resources, Skinner Fish Facility Secondary) and a rotating back-flush spray system (Eugene Water and Electric Board, Leaburg Hydroelectric Project). Development of alternative cleaning systems may be required to address specific screen cleaning problems. The development process will likely be time and labor intensive.

A blocking panel may be used to allow removal of a screen panel by inserting the blocking panel just downstream from a flat plate screen. The blocking panel prevents an unacceptable opening that fish could pass through when a screen is pulled for cleaning, maintenance, or repair, but still allows water to be diverted through the remaining screens. The guides used for the blocking panel may be the same as those used for the baffle panels, or they may be separate guides. Spare screen panels are usually included to allow quick replacement of a damaged screen.

A gantry crane or monorail hoist system is usually provided as part of the screen structure to allow installing or removing the flat plate screens and associated metalwork for maintenance or repair. A mobile crane provides an alterative method for installing and removing the screens and may be more economical for smaller screen structures. (See chapter IV.A.13.)

Cold weather operation **–** Flat plate screens have been installed in climates where icing may occur. In these cases, additional features, loadings, and/or operating controls should be investigated and provided where applicable. Cold weather operation will affect the screen's cleaning system and may dictate that the screen cleaner be removed from the water during winter operation. If using a backwash cleaning system, the system may need to be wrapped with heating cable and insulated or turned off and drained to prevent the backwash pump and piping from freezing. Freezing at or near the water surface can also damage the structural metal components of the flat plate screen, frame, and supports. Situations where anchor and/or frazil ice are present may dictate pulling the screens so they are not damaged or so that they do not completely block the diverted flow. Winter conditions may also require that the intake system be shutdown because ice can also damage the trashracks, cleaners, pumps, and other equipment.

If there is sufficient water depth for the required screen area to be maintained below the ice level, an upper concrete head wall may be used to bear the ice loads while the water is diverted through the screens below the ice cover. (See figure 67.) Cleaning the screens during winter operation may not be possible; therefore, monitoring the water levels across the screens becomes more critical. A more expensive alternative is to enclose the screening structure within a building, using head walls that extend below the operating water surface.

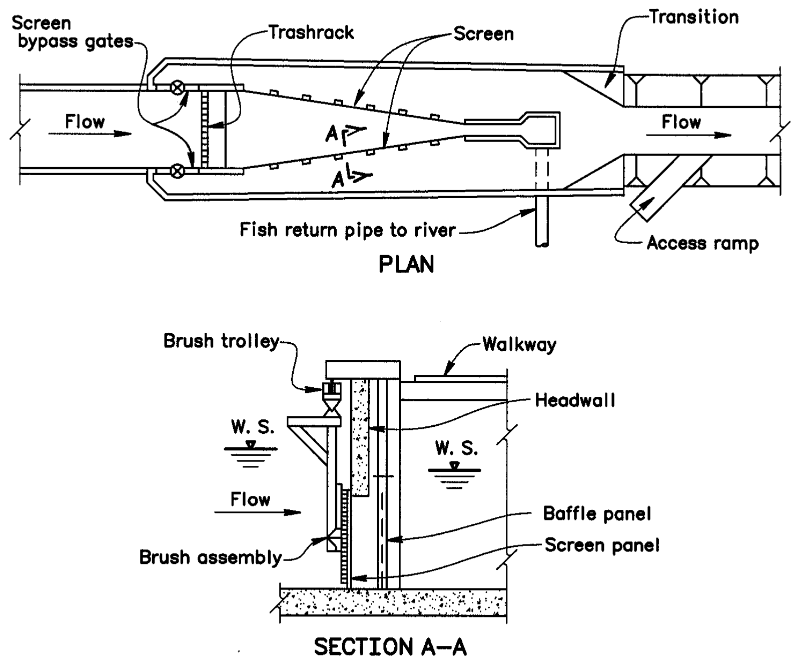


Figure 67.—Intake with concrete head wall – Ice protection at Wapatox (Rainey, 1985).

Screen guides may be installed with heating cables to keep ice from forming on the guides, thus allowing the screens to be pulled, if necessary. Often a dedicated gantry crane or hoist is available to automatically pull a screen in the event ice or debris cause an excessive water level differential. This protects the screen structure from possible failure and damage; however, it opens a fish passage.

Other possibilities may use a sluice gate or relief system built within the structure to prevent overloading and damage to the structure (figure 67).

Installations where there is a diversion pool may be able to incorporate a bubbler system that raises the warmer, deeper water to the surface to keep ice from forming or propellers may be used to circulate the diversion pool water to prevent ice from forming against the screens. Diversion pools with as little as 5 ft depth have found enough warm water to make a bubbler system effective.

Fishery resource agencies allow some diversion sites in the northwestern United States to pull their fish screens during cold weather because of the lack of fish movement during this season of the year.

2. Drum Screens

Drum screens can be used for fish exclusion where the water surface elevation can be controlled. There are a few cases where drum screens have been built as part of the headworks to an in-river or diversion dam pumping plant or canal intake (figures 7, 32, and 33), but most drum screens have been installed within canal systems, (figures 4, 26, and 27). A controlled water surface is required because the drum submergence should not exceed 85 percent or be less than 65 percent of the drum diameter (NOAA Fisheries criteria, attachment A) (figure 34). If the water surface is too high, fish may be carried over the top of the fish screen. If the water surface is too low, debris may not be carried over the screen. To achieve and maintain the submergence requirement in canals, an upstream gated headworks structure and a downstream check structure are usually required. Where possible, the trashrack structure is usually located upstream from the headworks so that it can also protect the gated headworks. Although, in some cases, trashrack structures are placed immediately upstream from drum screens. For trashrack and cleaner details, see chapter IV.A.12.b.

The effective screening height can be computed by subtracting the bottom height of the drum screen support frame from the minimum water depth. In lieu of this calculated value, some fishery resource agencies may allow the upstream, submerged portion of the drum screen circumference to be used for the overall screening height. However, recent NOAA Fisheries draft criteria suggest that, in the future, the fishery resource agencies may allow calculations based only on vertical height and not the circumferential length. Using the effective screening height, the operating water depths, and the required submerged screen area, A, based on the allowed approach velocity, V_a , and diversion flow, Q, the diameter, length, and number of drum screens can be chosen. The drum screen should be sized for a design submergence of 75 percent of the drum diameter at the design flow and water depth. The diameter should also meet the maximum and minimum submergence requirements previously stated to ensure correct operation.

A screen installation can consist of a single screen at smaller sites. Portable paddle-wheel screens have been installed in numerous locations in Idaho, Washington, and Oregon (figure 68). They are usually a standardized design, fabricated and installed by each State's screen shop, with maximum directed flow of up to 5 ft^3/s. They are assembled in sections. Figure 68b shows the drum screen dismantled and elevated out of the canal for winter storage. Reclamation has worked with State screen shops in setting locations and elevations as well as analyzing hydraulics.

a. Operation – in the dry.

b. Dismantled from drive shaft and raised.

Figure 68.—Small paddle-wheel drum screen (2.5 ft^3/s) located on Deep Creek near Adel, Oregon.

The drum screen facility more likely will include a series of screens placed end to end with piers between the drums (figure 12 a and b). The drum screens are placed flush with adjacent screen bay pier noses and walls (figure 34) to allow fish unimpeded movement parallel to the screen face and easy access to the fish bypass. The downstream end of the screens should terminate at the entrance to the fish bypass system. For in-canal and for most in-diversion pool screen structures, the line of screens should be constructed at an angle to the approaching flow to create adequate sweeping flow (figures 27, 33, and 52). Although not that common, in-river screening structures can be located along and parallel to the river bank.

The screen design must provide uniform flow distribution over the surface of the screen. (See chapter IV.A.6.) This may require a type of uniform flow control (baffle panel) located directly downstream from the screens (figure 11). A physical hydraulic model and/or a mathematical model study may be required to ensure good flow conditions in the channel leading to the screens, to identify and possibly avoiding localized high velocity areas along the screens, and to ensure good hydraulics into the bypasses (figure 36).

The face of the upstream screen surfaces should be placed as flush as possible with the adjacent screen bay, pier noses, and walls (figure 34) to provide unimpeded fish movement parallel to the screen face and ready access to bypass routes. When multiple drums are used, support piers are placed between the drums with the upstream pier face, which is shaped to match the circular face of the drums.

The piers, walls, and floor are structurally designed to carry the loads from the drum screens and associated equipment and, possibly, to support gantry crane deck beams and vehicle decking. The fish bypass system should be designed using the fishery resource agency criteria (flow, velocity, width, etc.) and may include ramps, weirs, open channels and/or pipes, and fish outlet structures. (See chapter IV.A.11 and figures 52, 113, and 114.) If sufficient hydraulic head is not available to operate the bypass system, another means such as fish friendly pumps or a trapping and transport system may be required.

***Screen guides* –** The guides for each drum screen are usually embedded within the concrete piers or walls. The guides protect the concrete corners from being damaged and provide a wearing surface. The concrete floor that supports the drum screen frame should be as flat and level as possible to prevent point loading on the drum screen frame and to prevent excessive openings (gaps) between the frame and the floor where fish might pass. Embedded metalwork seats in the floor are an option that can be considered to maintain acceptable tolerances.

***Screen design* –** The drum screen consists of a support frame, a cylindrical drum, seals, and a drive system. (See figures 34, 69, 71, and 72.) The cylindrical drum consists of a horizontal torque tube with shafts at each end of the tube (small drum screens may use a solid shaft), spokes running between the torque tube and the outer support rim members, the outer support rim members, and the screening fabric (figures 59a and 70). The outer support rim members are spaced and positioned to allow attaching (bolting or riveting) the screen fabric to the rim members and to support the screen fabric so the fabric is not over stressed while carrying and transferring the design differential load from the screening fabric through the spokes into the torque tube. The screen fabric is usually a woven wire material (figure 49); however, both perforated plate and profile bar have been used as the screening fabric for drum screens. The screen fabric material is usually fabricated from 304 or 316 stainless steel, and the rest of the drum and frame is usually made of structural steel. The allowable opening sizes of the screen fabric and the required minimum percent of allowable screen openings should be based on fishery resource agencies criteria. (See attachment A.) Passive type anodes (see figure 70) can be attached to the structural steel members of the drum and frame to provide cathodic protection, if desired.

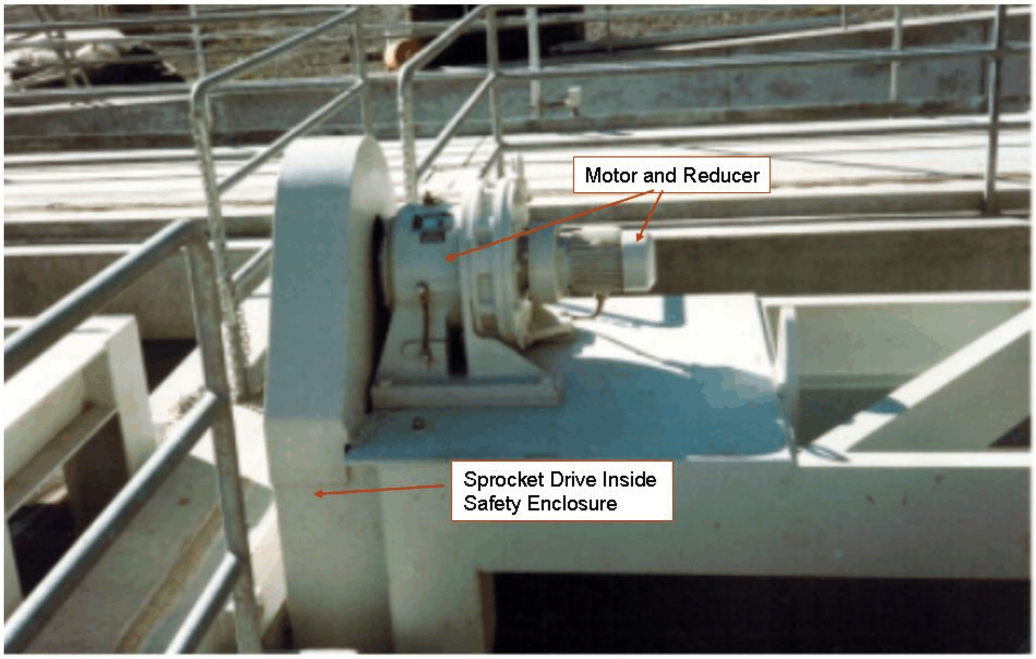


Figure 69.—Drum screen drive system.

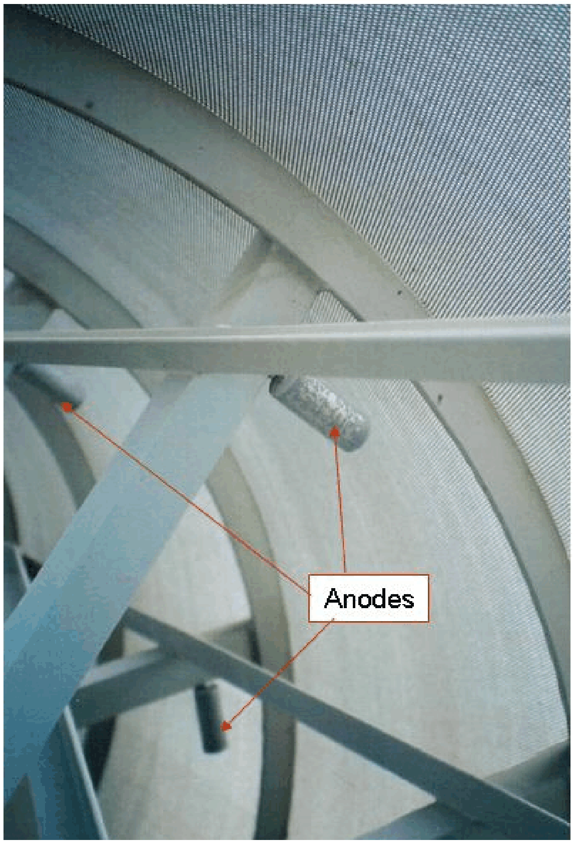


Figure 70.—Sacrificial anodes inside drum screen at Tracy Fish Facility, California.

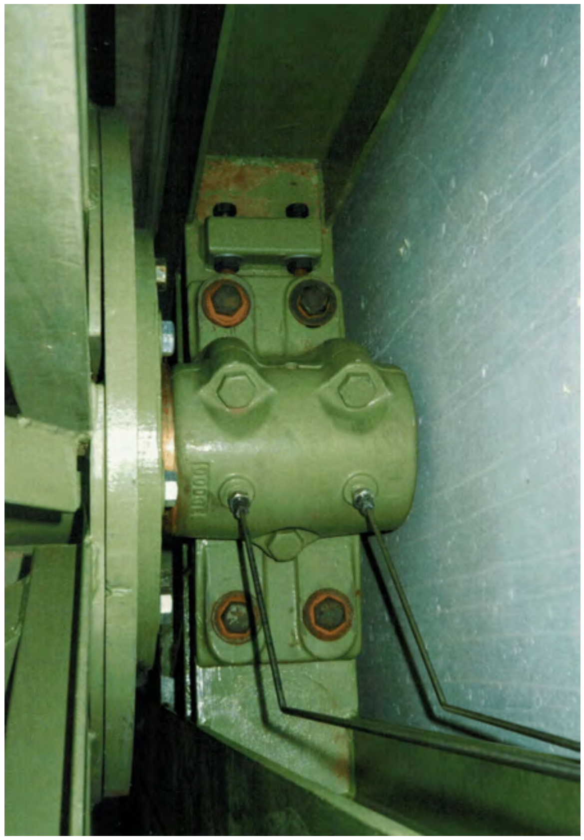


Figure 71.—Looking down on drum screen pillow block bearing with grease tubing.

Figure 72.—Drum screen bottom brush seals and side neoprene seals.

The drum screen support frame is designed to carry the structural loads from the cylindrical drum into the guides and floor. Bearings are bolted to the support frame to accomplish this. The bearings are usually of a flange or pillow block type construction and need to be designed for underwater service. (See figure 71.) The support frame is also designed with lifting lugs to allow the screen to be lifted with a crane.

Seals **–** Because the screens rotate, seals are included between the drum screen frame and the structure walls (piers), between the frame and the floor, and between the frame and the rotating drum to prevent fish past the screen. (See chapter IV.A.10.) All the seals should be designed and installed so the maximum openings past the screen frame do not exceed the allowed openings in the screen fabric material. The seals are usually fabricated from neoprene or rubber for sheets, strips, and formed seals (i.e., music-note seals). Brushes have also been used as seals and are usually fabricated from nylon, polyethylene, or polypropylene bristles. (See figure 72.) Maintenance of seals that may need to be serviced annually is an additional demand.

Drive system **–** Normally, each drum screen is provided with an electric motor operated drive system designed to continuously rotate the drum (figures 34 and 69). Where power is not available, a water-powered paddlewheel has sometimes been provided directly downstream from each screen and connected to drive the drum (figure 68). Another option may be a solar-powered system to provide electricity. Non-electric power sources are usually applied at sites where there is a small diversion (under 5 ft^3/s). The electric operated drive system consists of a motor, a gear reducer, sprockets, drive chain, and chain take-up or tensioning system. The drive system is usually designed to operate the drum screen under a maximum differential water loading, between 2 and 5 ft. The drive system loadings also need to include loadings because of seal forces against the rotating drum. The reducer and sprockets are used to slow the speed from the motor output speed to the desired rotation speed of the drum. The drum screen should be rotated slowly about its axis, usually around 10 ft per minute at the outer screen diameter. Sprockets are keyed to the reducer output shaft and to the shaft on the cylindrical drum. The drive sprocket is usually a shear-pin type sprocket to protect the drive system from damaging overloads. The drive chain may need to be enclosed in an environmentally friendly, food-grade-oil bath. An alternative drive system arrangement uses the outer diameter of the drum as the drive sprocket to turn the drum in lieu of the sprocket on the drum shaft. This may keep the drive chain out of the water; however, the drum shaft bearings are still needed and will be submerged. Gear box sizing is important. Gear boxes have been found to be much more dependable than the old worm-drive design.

Debris cleaning **–** Drum screen installations usually require an upstream trashrack (figure 4). The continuous rotation of the drum screen creates a self-cleaning feature (figures 11 and 34). Debris that contacts and sticks to the screen will be lifted out of the water and carried over to the downstream side, where the diverted flow passing through the screen washes the debris off the screen surface and on downstream. Therefore, it is suggested that the drum screen configuration have a lower ratio of sweeping to approach velocity than other screens to ensure debris will attach to the drum screen and be carried out of the water. This is generally the case; however, certain types of the debris may cling to the screen and require additional cleaning. A high pressure spray (spray water pump and piping with connections for spray hoses or spraybars) may be provided to periodically clean the screens. Another cleaning source may be a rotating brush located against the drum at the downstream water surface.

Water level measuring probes (mounted upstream and downstream from the screens) are usually included to provide a system to warn the operator that the screens may need additional maintenance or cleaning. Note that during cold weather, the drum rotation may need to be turned off and the screens removed to prevent an ice sheet from freezing onto the screen.

A full bay width blocking panel should be designed that can be inserted just downstream from each drum screen. This is required to prevent an undesirable opening that fish may pass through when the screen is pulled for maintenance or repair. Guides used for the blocking panel and uniform flow control system (baffle panels) may also be used for the blocking panel and are embedded in the concrete walls (piers) (figure 11).

A gantry crane or monorail hoist system is usually provided as part of the screen structure to install or remove the drum screens and associated metalwork. (See figure 59). A mobile crane is an alterative method of installing and removing the screens and may be more economical for smaller screen structures. (See chapter IV.A.13.)

Cold weather operation **–** Drum screens have been installed in climates where icing may occur. In these cases, additional features or operating controls should be investigated and provided where needed. Since the drum continuously rotates, freezing can occur on the wet screen fabric rotating above the water surface. Ice accumulation at or near the water surface can also damage the structural metal components of the drum and frame. Operation may dictate that the screen be left in place, but turned off to prevent it from rotating and freezing. Other situations where anchor or frazil ice are present may dictate that the screens need to be raised and pinned above the water surface so that they are not damaged. This may also require that the canal system be shutdown because these types of ice can also damage the trashracks, cleaners, and other equipment. The screen guides can also be constructed with heat cables to keep ice off the guides, thus allowing the screens to be pulled if necessary. At some sites, a dedicated gantry crane is provided to automatically pull a screen in the event of an excessive water level differential caused by ice or debris loads. This protects the screen structure from possible failure and damage; however, it opens a fish passage. Other solutions may use a sluice gate or relief system built within the structure to prevent overloading and damage of the structure. Some installations may be able to incorporate a bubbler or propeller system that raises or circulates the warmer, deeper water to keep ice from forming on the surface. At Roza Diversion Dam, small propellers are used to circulate diversion pool water as a means of preventing ice from building up against the screens.

3. Traveling Screens

Traveling screens are commercially available equipment and can be used as a combination debris removal system and fish exclusion screen. Traveling screens can be used for fish exclusion as part of the main screening structure or, more frequently, as part of a secondary screening/pumpback structure. (See figures 56 and 76). The traveling screen may be a vertical or inclined screen. (See figures 73 and 74.) The angle of inclination may vary from a few degrees off vertical to up to 45 degrees. The traveling screen may use screening baskets or trays (figure 73) or a continuous belt (figure 74). A few horizontal traveling screens have been tested and built; however, operation and maintenance problems, usually with the lower track, make this type of screen undesirable.

The overall effective screening height can be computed by subtracting the screen support frame bottom height (boot) from the minimum associated water depth. In some cases, the floor beneath the traveling screen may be lowered below the upstream channel floor elevation to increase the effective screening height. (See figure 75.) Control of sediment deposits needs to be evaluated before lowering or widening the channel to increase the effective traveling screening height.   Multiple screens will be required if the necessary screen width is greater than 12 ft (larger screen widths may be commercially available). Note that the screen width mentioned above refers to the tray or basket width and not the width of the entire traveling screen system. Depending on the type of traveling screen and the type of guides being installed (embedded or bolt-on), the required spacing between the concrete walls (piers) of the screen may be up to 2 ft wider than the tray or basket width. The height of commercially available traveling screens may range up to 60 ft.

A screen installation can consist of a single screen at smaller sites or can include a series of screens placed end to end with piers between them. On-river and in-diversion pool screening structures are usually located along and parallel to the river bank. In canal locations, the line of screens should be constructed at an angle to the channel approach flow to create adequate sweeping flow and the downstream end should terminate at a fish bypass system entrance. An alternative is to place the screens along one of the channel side walls (parallel to

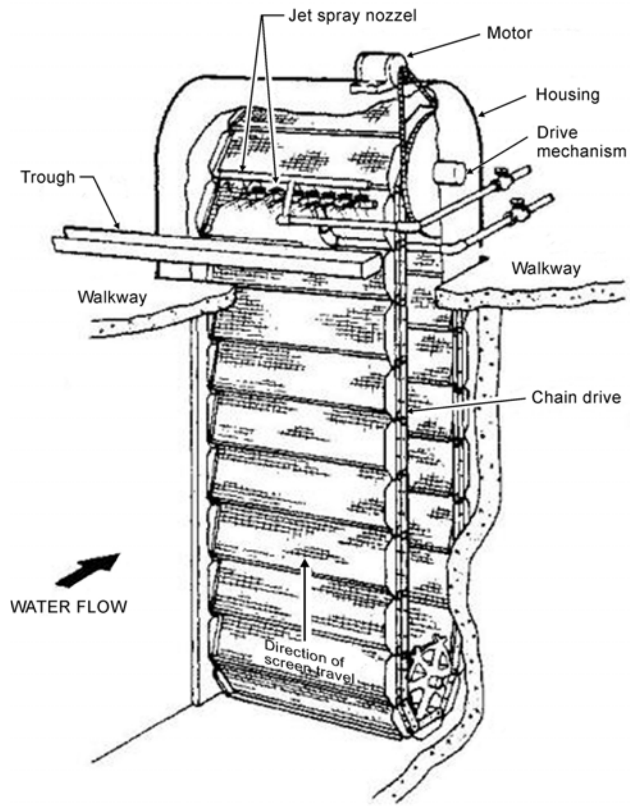


Figure 73.—Vertical traveling screen (EPRI, 1986)

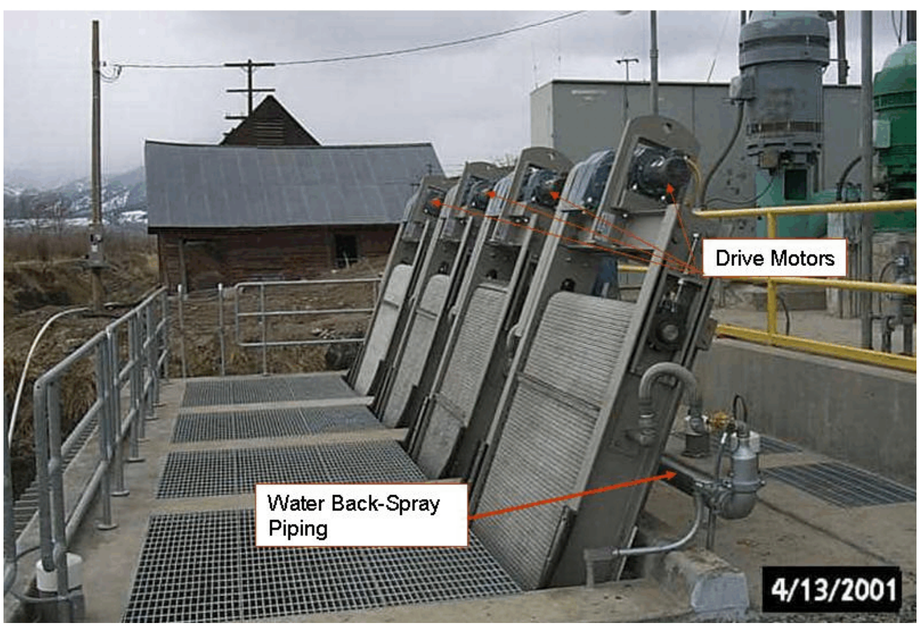


Figure 74.—Inclined traveling screen with continuous belt – Lilly Pumping Plant, Oregon.

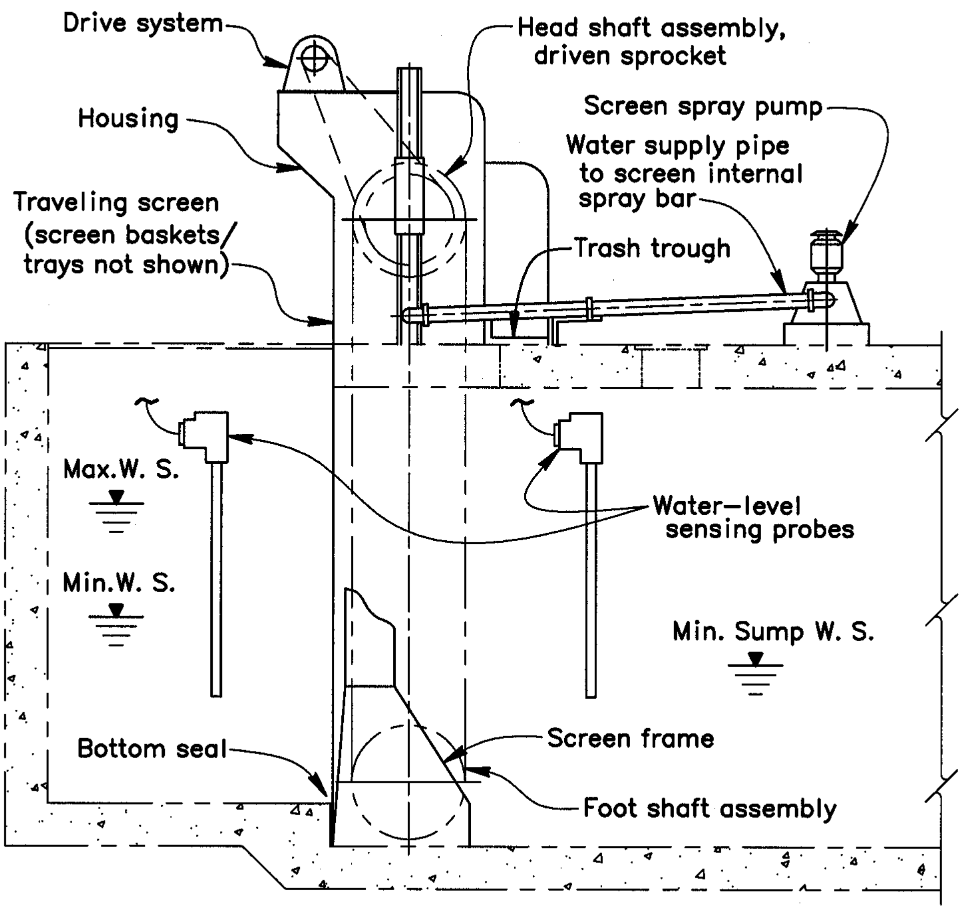


Figure 75.—Vertical traveling screen with increased effective screen height.

the incoming channel flow) and skew the opposite channel side wall. (See figures 56 and 76.) Skewing both the line of screens and the opposite channel wall is also an option. In a fish holding or rearing type channel, traveling screens have been used as the end screen across the channel. In these cases, the channel flow and channel velocity are usually small and the screen approach velocity is usually less than the normal criteria set by the resource agencies for positive barrier screens with a fish bypass.

The hydraulic design for the screen should provide for uniform flow distribution over the surface of the screen. This may require a uniform flow control (baffle panel) located directly downstream from the screens. A physical hydraulic model and/or mathematical model study may be required to evaluate flow conditions and to provide good flow conditions in the channel leading to the screens by identifying and possibly avoiding localized high velocity areas along the screens.

Figure 76.—Traveling screen field site with angled wall – Chandler Canal secondary screen/pumpback structure.

The face of the upstream screen surfaces should be placed as flush as possible with adjacent screen bays, piers, and walls to provide unimpeded movement of fish parallel to the screen face and easy access to fish bypass (figures 56 and 76). For traveling screens with trays or baskets, the screening material face should be installed as far upstream (forward) on the basket or tray frames as possible. (See figure 77.) This reduces the potential for the basket lip to carry fish up and over the screen. Normally, on commercial traveling screens that are being used for debris removal only, the screen is bolted as far back on the basket frame as possible to increase the debris carrying capability. This is just the opposite of what is needed for fish screening protection. Continuous belt screens do not have trays or baskets, but the more the screen is inclined, the greater the potential for fish to be carried over the screen.

Where multiple screens are used, concrete piers are placed between the individual traveling screens. (See figures 74 and 76.) The piers, walls, deck, and floor are designed to carry the loads from the screens and associated equipment. The pier is normally 3 to 4 ft thick to provide sufficient separation between multiple screens and to allow access for maintenance of the screens. Different screen designs may require that the dead weight of the screens be supported completely from the deck, from the floor, from the guides (inclined), or from a combination

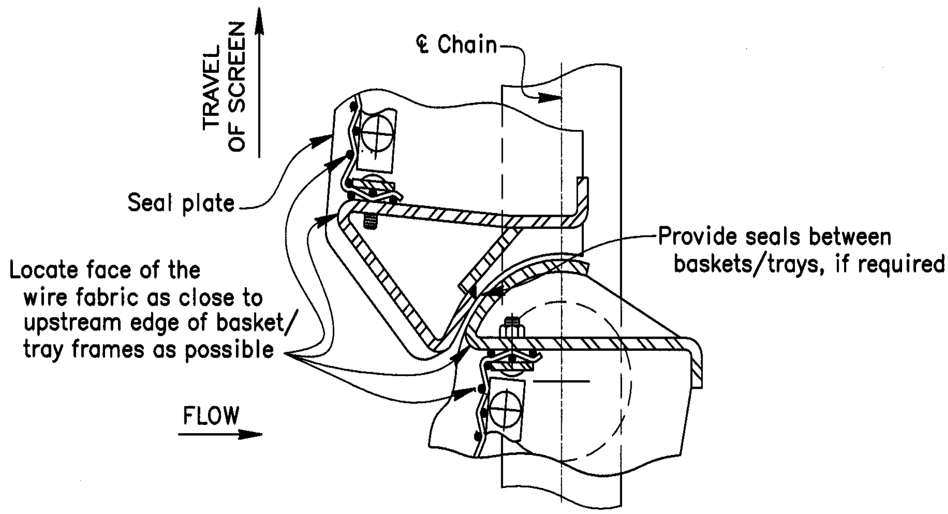


Figure 77.—Location of vertical traveling screen basket frame relative to screen material.

of any of these. The concrete floor below the screen should be as flat and level as possible to prevent point loading on the screen frame and to prevent excessive openings (gaps) between the frame and the floor that may be difficult to seal from fish pass. Screens should be placed at an angle to the approaching flow. The downstream end of the screen should terminate at the entrance to the fish bypass system.

Where multiple fish bypasses are used, the required bypass flow is often more than what is needed to guide the fish back to the river. To retrieve some of this excess bypass water, a secondary screening/pumpback structure may be used. The secondary screening facility allows some of the bypass water to be screened and pumped back to the canal while returning a reduced amount of flow, with fish, back to the river. Traveling screens are often used in these secondary screening/pumpback structures. See chapter IV.A.11, for more detail on fish bypass design.

Screen guides – The guides for each traveling screen may be either embedded within the concrete piers or walls or bolt-on type guides. The metal guides protect the concrete from being damaged and provide a wearing surface. The embedded guides are usually cast iron or stainless steel. Bolt-on guides require a larger screen bay opening than embedded guides. Note that the manufacturers of the traveling screens have their own specific size and location requirements for the guides. For inclined traveling screens, the guides may need to be designed to allow the screen to be raised from the inclined position to a vertical position before being removed.

Traveling screen **–** The traveling screen usually consists of the screen frame, head shaft assembly, ft shaft assembly, screening baskets or continuous belt screen attached to screen carrying chains, upper enclosure housing, seals, drive system, spray water system, and trash trough. (See figure 13, 73, 74, and figure 75.) For most commercial vertical traveling screens, the centerline of the head shaft assembly is located at least 3 ft 4 in above the deck to allow spray cleaning debris into a trash trough or conveyor. The screen frame and screening baskets are usually fabricated from structural steel members; however, non-metallic (fiberglass) baskets may be available through some companies. The screen frame is designed to carry the loads from the screen into the guides, floor, or deck. The screen frame also is designed with lifting lugs to allow the screen to be lifted with a crane. The head shaft assembly is a horizontal torque tube with shafts at each end that are supported by adjustable bearing blocks. The head shaft contains the sprockets that turn the screen carrying chains and also the drive sprocket that drives the system. The foot shaft assembly is usually a shaft that rotates in bronze bushings. Follower sprockets guide the screen carrying chains around the foot. An option that eliminates the foot shaft assembly and, specifically, the lower bearings is a roll-around rail track in the foot section of the screen frame that guides the screen carrying chains. Some continuous belt screens use a solid shaft (drum) at the bottom that the screen belting goes around. The screen cloth fabric is usually woven wire (figure 49), and 304 or 316 stainless steel is commonly used; however, galvanized steel and plastic have also been used. Where screening baskets and trays are used, a synthetic (nylon or polyester) monofilament mesh may also be used. Both perforated plate and profile wire could be substituted as the screening fabric where trays or baskets are used. The allowable opening size of the screen fabric and the required minimum percent of screen opening should be based on fishery resource agencies criteria. (See attachment A.) The upper enclosure housing can be fabricated out of metalwork or fiberglass figures 73 and 75. The upper housing covers the top portion of the screen above the deck, providing safety and splash protection, and is provided with inspection and maintenance doors and windows. Most inclined traveling screens do not have this upper enclosure housing (figure 74).

Seals **–** Seals are required as part of the screen to prevent fish past the screen. (See chapter IV.A.10b.) Seals are located between the screen frame and the structure walls (piers), between the frame and the floor, and between the frame and the rotating screen belt or trays. (See figure 78.) Seals may also be required between the individual screening basket frames (figure 77). The seals should be designed and installed so that the maximum openings past the screen do not exceed the openings allowed in the screen fabric material. The seals are usually fabricated from neoprene or rubber for sheets, strips, and formed seals (i.e., music-note seals). Brushes have also been used as seals and are usually fabricated from nylon, polyethylene, or polypropylene bristles.

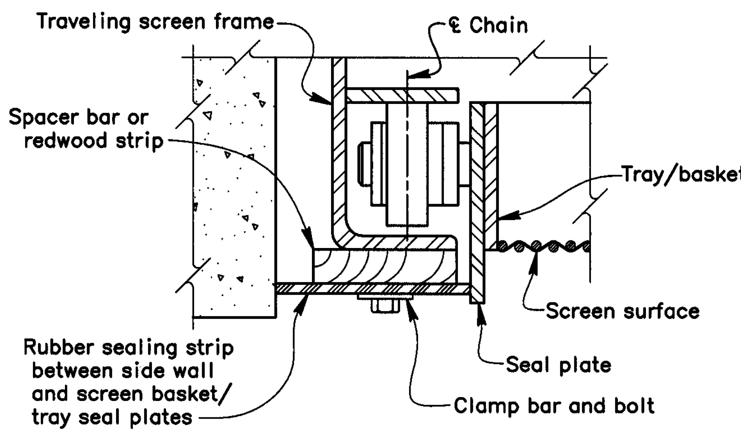


Figure 78.—Vertical traveling screen seals (basket or tray type).

Drive system – Each traveling screen is provided with a motor operated drive system (electric or hydraulic motor) to rotate the screen when cleaning is needed. The drive system consists of a motor, a gear reducer, sprockets, drive chain, and drive chain take-up or tensioning system. The drive system is usually designed to operate the screen under a maximum differential water loading of between 2.5 and 5 ft. The drive system loadings should also include the loadings caused by the seal forces against the rotating screen. The reducer and sprockets are used to slow the motor speed to the desired rotation speed of the screen (approximately 10 ft/minute for commercial vertical screens). Sprockets are keyed to the reducer output shaft and to the head shaft. The drive sprocket on the reducer is usually a shear pin type to protect the system from damaging overloads. Maintenance demands include servicing the drive mechanism, bearings, spray cleaning system, and seals on both the sides and the bottom of the screen belt. Removal of fine sediments near the channel invert will have to be considered when designing submerged drive mechanisms, bearings, and seals.

Debris cleaning – Traveling screen installations usually require an upstream trashrack. For details of trashrack and cleaners, see chapter IV.A.12.b. The traveling screen removes debris that contacts and sticks to the screen by lifting the debris out of the water with the upward travel of the screen or baskets. Water jets flush the debris from the screen either back into the upstream water to be carried away or into a trash trough where it is sluiced or conveyed away for disposal (figures 13, 73, 74, and 75). A high pressure water source needs to be provided. This source can be a separate deck mounted vertical pump, a submersible pump, or an inline booster pump that uses available water and pressure head from a downstream pumping plant if the pumping plant discharge line has sufficient line pressure and flow. The required water flow and pressure varies between screen manufacturers, and pressures range between 40 and 100 pounds per square inch (psi). Flow is up to 30 gallons per minute per ft (gal/min/ft) of screen width. Multiple spraybars may be used. For multiple screens, a common trash trough may be desired. For inclined traveling screens, the cleaning process sprays the debris into a trash trough mounted on the downstream side of the screen. The trash trough may be fabricated metalwork mounted on top of the deck or a concrete trench built within the deck. The cleaning system may include a debris conveyance (conveyor) type system to transport the debris flushed from the trash trough to a desired deposit location. This conveyor may also require a spray water cleaning system.

The traveling screens may be operated continuously or intermittently. The normal cleaning control for operating an intermittent, automated traveling screen uses an adjustable timer. A preset time interval can initiate startup and operation of a cleaning cycle. A cleaning cycle includes starting the spray water pump, starting the screen motor and rotating the screen through at least 1.3 to 2.3 complete revolutions to clean the screen, turning the screen motor off, and turning the spray water pump off after sufficient time has passed to flush the debris from the trash trough. The cleaning cycle controls may also include starting and stopping a conveyor located at the end of the trash trough. Water level measuring probes are usually included to protect the screen from damaging differentials that could occur between the normal cleaning cycles by automatically initiating startup of the traveling screen cleaning cycle when exceeding a predetermined differential across the screen (figure 75). This system may also provide a warning system to tell the operator that the traveling screens may need additional maintenance or cleaning. The designs should include a method to return the spray water used on the traveling screen and conveyor back to the channel.

A full-bay blocking panel or stoplogs should be designed to allow insertion just downstream from each traveling screen. These are required to prevent an undesirable opening that fish may pass through if the screen is pulled for maintenance or repair. Stoplogs also allow dewatering downstream from the screen bay, if required. Guides used for the blocking panel or stoplogs may also be combined with the uniform flow control system (baffle panels) and are usually embedded in the concrete walls (piers).

A gantry crane or mobile crane system may be provided or rented to allow installing or removing the screens, spray water pump and blocking panel, or stoplogs for maintenance and repair. (See chapter IV.A.13.)

Cold weather operation **–** Traveling screens have been installed in climates where icing may occur. In these cases, additional features and/or operating controls should be investigated and provided where needed. Freezing can occur on the wet screen fabric rotating in the cold air above the water surface. Ice accumulation on or near the water surface can also damage the structural metal components of the screen and frame. Ice may also damage the seals. Operation may dictate that the screen be left in place, but turned off, so that it won't rotate and freeze. Other situations where anchor or frazil ice are present may dictate that the screens be removed so that they are not damaged. Removal of screens will require that the canal or pumping system be shutdown since these types of ice conditions can also damage the trashracks, cleaners, and other equipment. Because spray water cleaning is used, the system piping may need to be wrapped with heating cable and insulated or turned off and drained to prevent the spray water pump and piping from freezing. The screen guides may also be constructed with heat cables to keep ice off the guides, thus allowing the screens to be pulled if necessary. Some installations may incorporate a bubbler or propeller system to raise or circulate the warmer deeper water to keep ice from forming.

4. Submerged Screens

Submerged screens are defined as positive barrier fish screens that are totally submerged. (There are times when the inclined screens do not totally meet this characterization.) The screens are, typically, placed horizontally or with a slight upward slope as the diverted flow passes through the screen. Often, back pressure on the screen controls the diverted flow and provides uniform approach flow velocities. Information on three types of submerged screens is presented.

a. Cylindrical screens

Fixed and retrievable cylinder screens can be used for fish exclusion as part of an intake structure in a river, lake, or reservoir. Other screen intakes may use removable cylinder screens. By controlling the quantity of diverted flow and, therefore, approach velocity, V_a, impingement and entrainment of debris and aquatic life are minimized. Cylinder screens are commercially available and are used in low-flow screening applications, usually for diversion flows ranging from 0.5 to 400 ft^3/s, where multiple screens are required at the higher flows. The screens are normally installed in rivers or streams where the flow can be used to assist with fish sweeping velocity and cleaning properties of the screen. In reservoirs and lakes, cylinder screens may be used as part of an intake tower that allows withdrawal from selected levels, thus allowing water quality and/or temperature selection. Cylinder screen installations should be avoided in backwater areas, dead ends, and the ends of canals because debris tends to accumulate in these areas and there are no means of removing debris from screen surfaces. These areas are also common breeding areas for fish and other aquatic organisms.

The screened intake should be totally submerged and may be a fixed installation designed to allow raising a portion of the intake piping with the screen or an installation for just raising the screen itself.

The intake may use single or multiple screens. Cylinder screens are usually fabricated in either a drum or Tee shape. (See figures 14 and 31.) The Tee shaped screens provide a higher flow capacity than the single drum shaped screens. The screens may be installed either vertically, horizontally, or on an incline. The screens are normally oriented parallel to the streamflow to create less debris and fish impingement and greater sweeping velocity. Once installed, the fixed cylinder screen does not usually require removal. Most fixed screens have no moving parts, so no seals are required. The self propelled, rotating screens, and retrievable type screens require seals for mating surfaces (both for the rotating and the docking surfaces). The seal gaps must meet fishery resource agency allowable screen opening criteria. (See attachment A.)

Unlike many of the other positive barrier screens, cylinder screens do not require a trashrack structure or a fish bypass system. Screen installations consist of a single screen for a single intake pipe or pump, multiple screens for a single intake pipe manifold, or multiple screens and multiple intake pipe manifolds. (See figure 31.) The intake piping from the screens may be arranged in several different connected configurations. It may be connected directly to a pump or pumps or connected to a wet well for the pump(s), or it may be the containment pipe (conduit) inside which a submersible or inclined pump is placed. The intake pipes may also be connected into larger piping, conduits, or tunnels extending to the pumping plant. The intake piping will usually be buried or may require some kind of protection if not buried.

The pumping plant may be located on a pump platform in the river, along the shore, or on the bank of a river (figures 15, 16, and 17) or located relatively close inland (figures 79 and 80) where there is access to the pumping plant for operation and maintenance. Usually, the pump motors and controls are located above the maximum flood stage (100-year flood event). The cylindrical screens require some type of debris cleaning system. The operating control equipment for the cleaning system will usually be located above the 100-year flood event and sometimes next to or inside the pumping plant, which allows access for operation and maintenance.

The cylinder screen manufacturers recommend that the outer screen surface be at least a distance of one-half the screen diameter away from any river or reservoir boundary (whether a bottom or a side wall) and at least one-half the screen diameter below the minimum water surface. The latest NOAA Fisheries criteria call for a minimum of one screen diameter clearance completely around the screen centerline. The screen manufacturers also require a minimum of one screen diameter between multiple screens, when screens are installed side by side. Therefore, the distance between screen centerlines should not be less than 2 times the screen diameter. Multiple screens will be required if the calculated single-screen diameter is greater than one-half the minimum water depth. Multiple screens will usually be placed end to end (in line) to improve not only the hydraulics, but to produce a smaller target for the debris and fish to encounter. Other items that need to be evaluated because they can affect the size of the screen and the intake location are sedimentation, icing, and navigational clearance requirements.

Head losses through the screening surface will usually not be greater than 0.1 psi for clean screens. However, additional losses caused by internal baffling, the Tee configuration, pipe or intake docking bends, and the frictional losses may make head losses for the total screen intake system, extending to the pump, in the range of 1-2 ft.

***Sizing screen areas* –** The total submerged screen area can be calculated by dividing the maximum diverted flow by the allowable approach velocity [$A = Q/V_a$]. This calculated area should not include the area of structural components (e.g., dished or cone head(s) and the solid portion of the tee). The screen manufacturers also recommend that a maximum through slot velocity, V_t , not be exceeded for proper operation of the screen. The velocity of the water passing through the screen slot openings should not exceed 0.5 ft per second (ft/s). Therefore, the required total submerged screen area, A_t , based on the through-slot velocity needs to be computed and compared to the fishery resource agency required screen area, A. To compute A_t, the fractional screen open area, E, is also required and is based on the screen slot openings and the size of the screen wires. These all can be obtained from the screen manufacturer; however, the fishery resource agencies may dictate the minimum allowable fractional screen open area and the maximum allowed screen slot size. The total submerged screen area, A_t, based on the through-slot velocity, can be calculated by dividing the maximum diverted flow by the through-slot velocity multiplied by the fractional open area [$A_t = Q/(V_t * E)$]. For sizing the screen(s), use the larger of the calculated total submerged screen area values (use largest value of A or A_t). Knowing the required screen area and the minimum water depth, the screen diameter and the quantity of fixed cylinder screens can then be determined. Fixed cylinder screen sizes may range from 12 to 84 inches in diameter, and individual flow capacities can reach 22,000 gallons per minute (gal/min). Retrievable, brush-cleaned screen sizes may range from 24 to 66 inches in diameter. The self-propelled, rotating cylinder screen sizes have normally ranged from 15 to 24 inches in diameter, and individual flow capacity has been as high as 2,400 gal/min; larger capacities can be obtained using multiple screens.

The hydraulic design of the screen should provide for uniform flow distribution over the surface of the screen. An internal baffling system is usually provided by the screen manufacturer as part of the screen. The system is used to try to create uniform withdrawal over the length of the screen. A physical hydraulic model, bathymetry and hydro-acoustics studies, a sedimentation study, or mathematical model study may be required to ensure good flow conditions and depths at the site, specifically in the channel leading to and past the screens. These studies can identify and provide solutions for high-velocity areas that could damage the screen if not properly protected and for low-velocity areas that could bring sediment to the screen.

Support structure **–** Concrete piers, piles, or supports are needed to support the screen and piping. Figures 16, 17, 79, and 80 show arrangements where fixed or retrievable cylinder screens were added to existing river intake pumping plants. Figure 80 shows an arrangement for a new pumping plant on the Columbia River. The piers, piles, and supports need to be able to carry the loads from the screens and piping, the loads resulting from the river velocities, ice and debris loads and may also need to be designed for scour. The intake pipe will need to be designed for the possibility of collapse loads similar to the screens, the loads due to supporting the screen, encasement loads, and earth loads resulting from being buried.

Fixed cylinder screens or the retrievable screen docking intakes can be attached to the ends of the intake pipe(s), pump conduit(s), or in some cases, the pump bowl. Therefore, the support structure for the screen can become the structure required to support the cantilevered section of pipe, conduit, or pump column. Depending on the member sizes, this may be accomplished with support piles, by embedding the pipe or conduit, by building a concrete foundation for or around the pipe or conduit, or by building a concrete or metal wall. A concrete slab is usually provided to mount the air compressor and air receiver tank for the air burst cleaning system for cleaning fixed cylinder screens. A concrete slab would also provide a platform for the winch and the cleaning system for the retrievable cylinder screens. Where vandalism or noise may be a problem, or where there are needs for storing out of sight or out of the weather, a building may be provided to house the cleaning system. This building may be a separate structure or may be part of the pumping plant.

Screen design **–** A cylindrical screen consists of a screen in either a Tee or single drum shape, an intake pipe or docking connection (figure 14), and an internal cleaning system. The screen structural members are usually fabricated from stainless steel, either 304, 304L, 316 or 316L, depending on the type of water. Bio-foul resistance screen materials (such as copper-nickel) can also be provided. A standard fixed cylinder screen is designed to withstand a minimum differential pressure of 10 ft of water across the screen surface (hydrostatic collapse load) and the loads from the air burst cleaning system; however, stronger screens can be provided. Retrievable screens may be designed for smaller loadings because access for inspection, maintenance, and repair or replacement is provided. The screen will usually be designed with lifting lugs to allow the screen to be initially installed with a crane (figure 15). The fixed and retrievable cylinder screens typically use profile bar as the screening fabric. (See figures 51 and 81.) However, the self-propelled, rotating type screen have also used woven wire mesh and perforated plate screening material. The maximum allowable slot or mesh

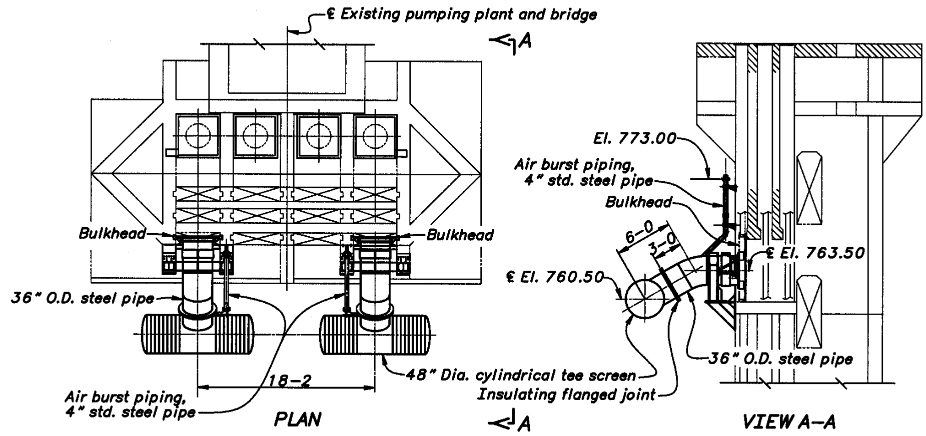


Figure 79.—Intake retrofit using fixed cylinder screen with air burst cleaning at Brewster Flat River Pumping Plant, Washington.

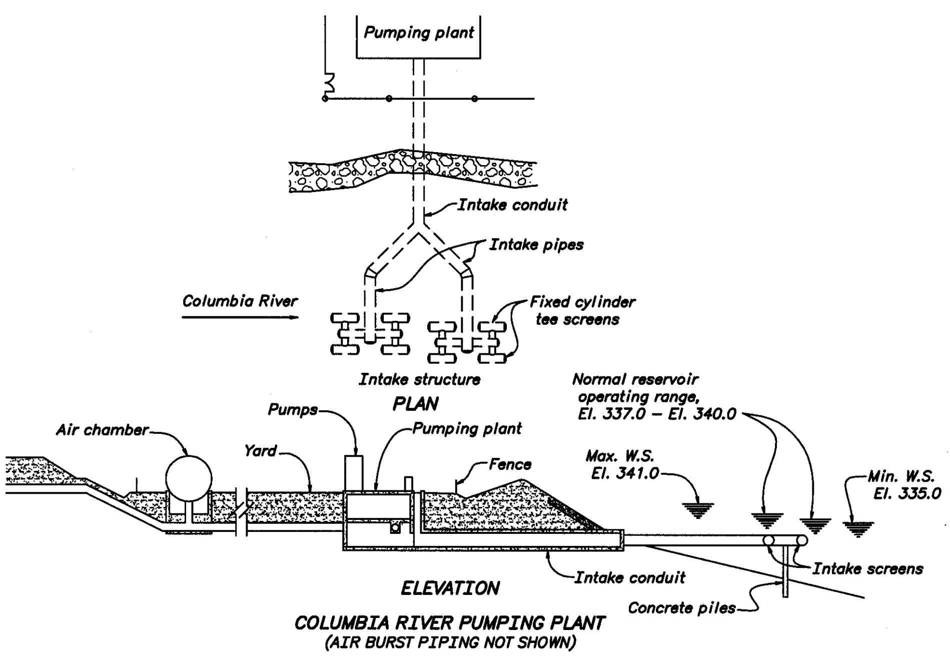


Figure 80.—Plan and elevation of Columbia River Pumping Plant.

a. Internal brush projecting through the screen.

b. External brush.

Figure 81.—Brush cleaners for retrievable cylinder screens (ISI).

openings of the screen and the minimum required screen percent opening should be based on criteria from the fishery resource agencies, attachment A. The fixed and self-propelled rotating cylinder screens will also be provided with internal air or water distributor piping as part of the cleaning system. The flanged connections on the fixed and self-propelled rotating cylinder screen should be designed to mate with the flanges of the intake piping and the cleaning (air burst or water back flush) piping. The sizing of these pipes is usually dictated by the screen manufacturer, based on the screen size. Isolating gaskets and bolting system are usually required between the dissimilar metals of the flanges of the screen and the flanges of the intake and air burst pipes.

The retrievable cylinder screens will also be provided with a track and winch system to allow removal of the screen. This track system will be attached to the in-river pump support platform or the inclined pump supports or conduit. A docking intake will be attached to the end of the pump bowl, pump intake conduit, or the extended intake pipe. Sensors are provided to indicate that the screen has been properly seated with the docking intake. End cones may be provided on the cylinder screens to streamline the river flow past the screen and to deflect debris that could cause physical damage.

Debris cleaning – Cylindrical screens may be fixed (figure 14) or retrievable (figure 16) and may require additional protection from large, floating debris such as trees and large limbs and from ice because they are usually installed in lakes and rivers. This protection may be a pile system placed upstream from the screen. Trashracks are not usually provided.

As water is diverted through the cylinder screen, debris will gradually build up onto the screen surface. The most common method of cleaning the fixed cylindrical screen is an air burst cleaning system (figures 31, 79, and 80). This system requires a high pressure air receiver tank, air compressor, concrete slab, piping between the screen and the air receiver tank, valves, and controls. The system may be designed for outdoor service, but it may be installed within the pumping plant building or its own shelter. A less common cleaning method uses either a high volume of water or high pressure water to back flush the screen. In either cleaning method, once the debris is lifted off the screen by the river flow, it is carried on downstream.

The sizing of the air compressor and air receiver tank will depend on may factors which include:

- The maximum water depth above the screen
- The internal volume of the cylinder screen
- The volume of the air burst piping
- The number of screens to be cleaned simultaneously (probably not more than 2 or 3 screens at a time because of the massive burst effect and possible sediment and water surface disruption)
- The screen manufacturer's screen volume ratio factor (usually 2 to 3; check with screen manufacturer)

The sizing of the air compressor will also depend on how frequently the air receiver tank needs to be recharged. The frequency may be dictated by the fishery resource agencies as part of their cleaning requirements. The pressure of the air receiver tank is usually in the range of 100 to 175 pounds per square inch (psi). The following formula may be used to determine the approximate size and pressure of the air receiver tank.

$P_1 * V_1 = R_f * N * P_2 * V_2$, where:
P_1 = Air receiver tank pressure, psi
V_1 = Air receiver tank size, ft^3

P_2 = Ambient screen pressure, psi, $(14.7 + d * 0.4334)$, where d = Maximum depth of water above the screen (ft)
V_2 = Volume of screen + volume of air burst pipe, ft^3
N = Number of screens to be cleaned simultaneously
R_f = Screen volume ratio factor

Another type of commercially available cylinder screen uses a self-propelled rotating screen and an internal backwash cleaning system (internal spraybar with nozzles). A pump and piping will be needed to provide cleaning water to the backwash spraybar. The required backwash pressure from the pump will usually range between 50 to 100 psi, depending on the size of the screen. The spray water is used to not only clean the drum shaped screen but also to power the rotation of the screen by pushing against internal propelling vanes.

The retrievable cylinder screen is usually cleaned by using hydraulic motors that rotate the screen part of the assembly past brushes located on both the interior and exterior of the screen. (See figure 81.) This requires hydraulic motors, flexible hoses, a hydraulic pump, a hydraulic fluid tank, and controls. A cleaning cycle will start by operating the upstream cylinder screen and motor, then rotating the screen every 2-5 minutes, stopping, and then reversing the direction for another 2-5 minutes. Once this is complete, the downstream screen cylinder is cleaned in the same manner. The screen is attached to a hoist and runs on a track, so it can be easily removed for inspection and maintenance or removed during river floods, when there may be an increased chance of damage, or during non-operating periods (figures 16 and 17).

The fixed and retrievable cylinder screen cleaning systems can be operated manually or automatically. A differential water level measuring system across the screen or water level measuring system at the screen and in the pump intake wet well is usually included to protect the screen, piping, and pumps from damaging differentials or low water levels. Water level measurements are used to start the cleaning cycle in an automated system, to shutdown pumps if a low sump water level occurs, and to provide a warning system to tell the operator that the screens need additional cleaning or maintenance. Usually, the controls for an automated cleaning system also use an adjustable timer to initiate startup and operation of a cleaning cycle when a preset time interval is reached.

A cleaning cycle for an air burst cleaning system includes starting the air compressor and operating it until the predetermined air pressure in the air receiver tank has been reached. In areas where people may be present above the screen intake, an alarm warning horn may need to sound to inform people to evacuate the area around the screen. Warning buoys or a safety boom in the area of the screens may also be required for safety. Once people are clear of the area, the screen can be cleaned by opening a quick acting valve to supply a burst of air inside the screen (figure 82). Depending on the pump and pipe arrangement, the pump may need to be shutdown before releasing the air burst to prevent air entrainment in the intake piping. Where multiple screens are present, a cleaning cycle may be required for each screen. The cleaning cycle for multiple screens should clean the screen(s) farthest upstream first and work downstream.

Figure 82.—Surface disturbance resulting from the air burst cleaning of fixed cylindrical screens.

At screen installations where debris and sediment concentrations are known to be high, an additional system that provides a continuous, low pressure bubble curtain around the screens may be installed. The bubble curtain has been shown to extend the time between the screen's cleaning cycles. As the bubbles rise, they lift debris up and over the screen, thus reducing the amount of debris that may contact the screen. Bubbler systems are beneficial where icing conditions may occur during the winter. Bubbler systems include an air blower, piping from the air blower to the curtain manifold, and the curtain manifold piping. The air blower should be designed with sufficient pressure and air flow to work at both the minimum and maximum depth of water above the screens. The screen installation may also require protection from large floating debris such as trees and large limbs and from ice. Piles that extend above the screen elevation may be required upstream from the screens.

Cold weather operation **–** Fixed cylinder screens have been installed in cold weather climates where icing may occur. The screens should be set as deep as practical and located below any possible ice scour to prevent damage during breakup of an ice cover. Also, cylindrical screens should not be installed directly downstream from rapids because of the possibility of frazil ice forming within the rapids and adhering to the screens. The screen manufacturer should be contacted to provided any additional features, site options, or operating controls that may need to be investigated and applied. Most deep screen installations should not be affected by cold weather operation, but it may be desirable to incorporate a bubbler system which raises the warmer deeper water to the surface to keep ice from forming near or on the screens. Retrievable screen systems do not have a history, yet, of operating in cold weather. However, if the irrigation season does not extend into the winter season, the winch can raise the screen and store it above flooding events. If cold weather operation is necessary, heaters and a recycling system for the hydraulic fluid (for cleaning) may be required. For self-propelled, rotating cylinder screens, the backwash piping and pump should be protected from freezing.

***Sedimentation* –** Sediment may be a problem at submerged screening structures. Intakes and screens should not be placed in areas of high sediment dropout such as the delta area of reservoirs. For sediment control, it may be beneficial to elevate the screen as high as possible within the water column while still meeting submergence, cold weather, and navigational requirements. Sediment removal around the screens may be accomplished by earth moving equipment, drag lines, or a dredging system. The cleaning process may require an access ramp into the river, a dredge pipe distribution system, and settling ponds. Care needs to be taken not to damage the screens, supports, and piping during this sediment removal process. Where allowed, a sedimentation basin may be installed in the river upstream from the screens to intercept sediment. At some installations, low head pumps designed to pump sediment laden water were provided to pump the screened water with the sediment to an on-shore settling basin. Sediment was then dropped out in this basin and the cleaner water pumped using a second pumping plant located at the end of the basin.

b. Inclined screens

Inclined screens can be used for fish exclusion as part of the headworks to a canal intake, as part of an intake for an on-river or diversion-dam sited pumping plant, or as part of a fish exclusion structure installed in a canal or along a river bank. Inclined screens are also used as a component of the fish bypass system providing secondary screening or fish sampling or counting or as a component of a fish evaluation facility. Inclined screens have been applied in two general configurations. Both concepts include flat plate screen panels that are placed on a slope.

One configuration includes a fully submerged screen that is placed on an adverse slope to the flow. The flow passes from the toe or deep end of the screen to the high end of the screen as water is drawn through. Since the screen remains fully submerged, a portion of the flow passes over the downstream (high) end of the screen providing a fish bypass flow. The adverse slope screen may be fully fixed or it may be hinged allowing the screen to be raised or lowered at the downstream end to follow changing water surface elevations (figure 83) (Potter Valley Project). Fish must pass over the full length of the screen to reach the bypass (figure 18). Constant sweeping flow can be sustained across the length of the screen because the flow discharge passing over the screen decreases as the flow depth and flow cross-section decrease toward the downstream end. The closed conduit Eicher and MIS screens are special types of inclined screens that are addressed in chapter IV.B.6.

The second configuration is similar to a vertical flat plate screen where channel flow approaches the inclined screen from the side. The screen may be placed to match the canal bank at an angle across a canal, but more commonly is placed along a river bank, forming an in-river fish exclusion facility. The inclined placement increases active screen area over what could be achieved with a vertical flat plate screen. This allows the screen to be effectively applied at shallower depths. These screens should be fully submerged (figure 19).

From the calculated screen area (chapter IV.A.5.a.), the number, size, and configuration of the screens can be determined. It should be noted that some fishery resource agencies may allow only the vertical height (projection height) to be used in calculating screen area. Fish exposure time criteria, as established by the fishery resource agencies (chapters IV.A.5.a. and IV.A.9.); the screen's support structure requirements; the width of the screen panel for adverse slope screens, and minimum channel depths for the inclined flat plate screen are considered when selecting the size and length (in the direction of flow) of individual fish screens. Handling and removal requirements for the screen panels and associated equipment should also be considered. Exposure time criteria may dictate that wider screens with shorter length be used which may lead to use of multiple screens, wider screen bays for adverse slope screens, or flatter screen placements for inclined screens. Depending on the type of debris, the screen material, and the screen cleaning system used, it may be desirable to fabricate the screen from square screen panels that could be rotated 90 degrees to change the orientation of screen openings.

For adverse slope screens, the downstream (high) end of the inclined screen should be positioned to control bypass flow rate and depth of flow transitioning to the bypass. Adjustment of the elevation of the downstream end of the screen may be required where water surface elevations fluctuate. Where the downstream end of the adverse slope screen is fixed, water surface fluctuations can result in reduced sweeping velocities, shallow flows, or excessive bypass discharges. Adverse slope screens should be inclined at angles of 10 degrees or less (from horizontal) to reduce the potential for fish holding; however, the criteria do allow steeper angles (up to 45 degrees) to be used.

For inclined flat plate screens, placing the screen in a canal will require a bypass. The canal approach channel section, as influenced by the inclined screen, should transition carefully to the bypass entrance (which typically is a vertical slot) to ensure that bypass approach velocities do not decrease. Decreasing velocities

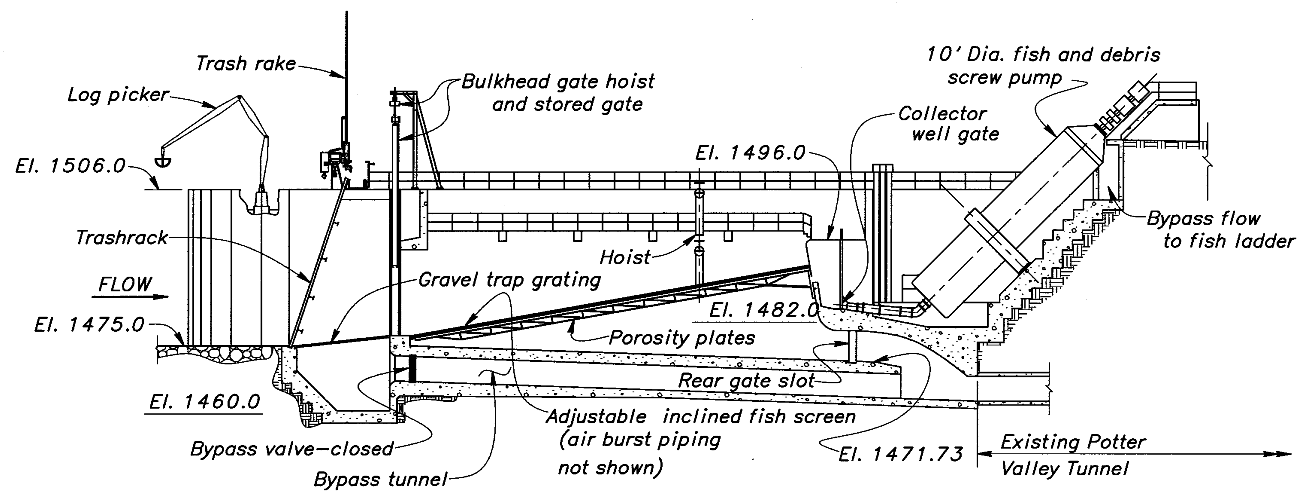


Figure 83.—Potter Valley inclined screen, California (Pascific Gas & Electric).

could cause fish to either delay entering or avoid the bypass entrance. A bypass entrance that is configured to match the approach channel cross-section might be considered, even though it may require larger bypass discharges. Inclined screens applied in-river with a sweeping or passing flow will not usually require a bypass. As with other in-river installations, care should be taken to position and orient the screen so that effective sweeping flows are sustained across the screen face over the full range of river stage.

A screen installation can consist of a single screen panel at smaller sites, a series of screen panels placed end to end on a support structure or frame, or multiple screens. The screen facility design must provide for uniform approach flow distribution over the surface of the screen. This usually requires use of porosity control or flow resistance elements as shown in figures 18 and 19 (chapter IV.A.6).

A physical hydraulic model and/or a mathematical model study may be required to:

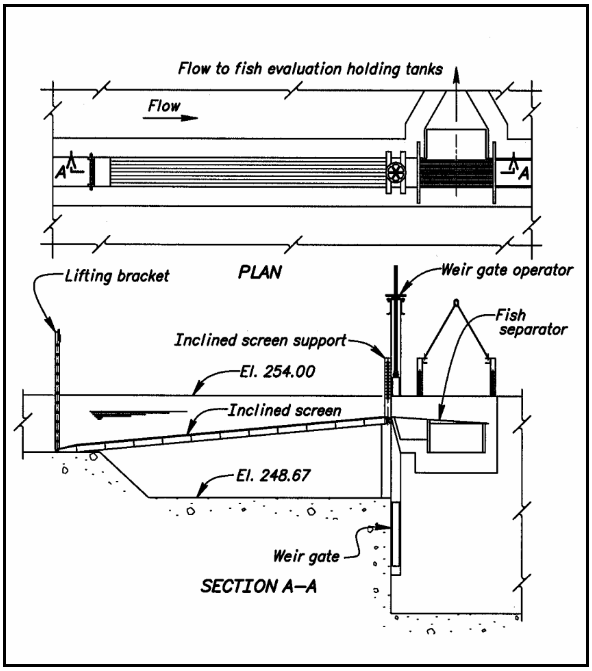
- Evaluate and provide good flow conditions in the channel leading to and passing over the screens (particularly where more complex channel and screen configurations are applied)

- Identify and possibly avoid localized high and low approach velocity zones

- Ensure adequate bypass approach conditions

The structure included with the screen should be sufficient to carry loading from the screens, associated equipment, and from water loads and differentials. The structure may also need to support a crane hoist system and may include a maintenance access deck. The deck may need to be sized to allow for cleaning equipment and vehicle access.

For adverse sloped screens, the number of fish bypasses will depend on criteria from the fisheries resource agencies, but will usually be at least one per each screened channel bay if the screen is not located on the river. The fish bypass system should be designed from the fishery resource agency criteria and may include transitions, weirs, ramps, open channels or pipes, and fish outlet structures. Inclined screens (adverse sloped screens) are often used in fish bypass channels separate fish for testing and evaluation purposes. (See figures 84 and 85.)



a. Schematic of screen structure.

b. Photo of inclined screen.

Figure 84.—Red Bluff inclined screen in fish bypass/evaluation channel.

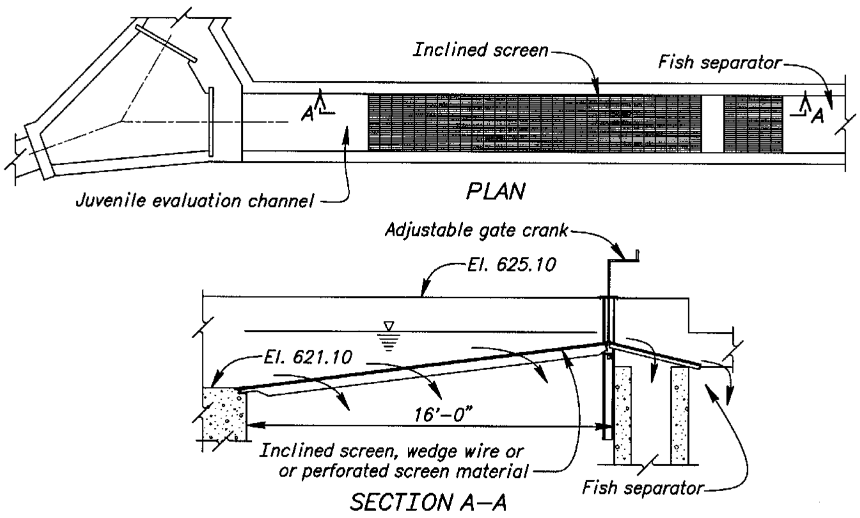


Figure 85.—Chandler inclined screen in juvenile fish bypass facility with downstream adjustment capability.

Screen seats and supports – An embedded metalwork seat in the floor at the upstream end of the screen is provided to maintain acceptable tolerances, provide a wearing surface, and allow the upstream end of the screen panel to slide easier (if not pinned) when adjusting the downstream end. This seat is also used to recess the upstream end of the screen so the top of the screen is flush with, or just below, the floor elevation. (See figure 85.) Seals are usually provided along this upstream edge.

The supports for a fixed inclined screen may be metalwork embedded within the floor and walls, metalwork bolted to the walls, or both types. The support system should allow the screen panels to be removable. A fixed inclined screen system may not need side seals if supported along all edges. The supporting metalwork (backing frame) for an adjustable inclined screen system allows the screen panels to be bolted directly to it and may have to be designed to carry the loadings only at the two ends. The downstream end may be connected to an adjustment system (wire rope hoist, cylinders, adjustment screws, etc.). (See figures 83, 84, and 85.) Seals may be required along all edges of this screen panel. The support structure for either the fixed or adjustable inclined screen system should be designed to carry the full water load in the event that the screen becomes plugged. The loadings may be reduced based on the type of screen cleaning system that is provided, the capability to monitor the water differential across the screen, and how the screen operating system reacts to this differential (e.g., starts the screen cleaning process and the alarm/warning system). Vent piping from below the screen to the atmosphere may be required to prevent pulling a vacuum if the screen becomes plugged. Piping to allow supplying water below the screen may also be desired to equalize or reduce water loading in the event that the screen becomes plugged and cannot be cleaned or removed.

Screen design – The screening panel will usually consist of a backing frame, a flat plate screen, and seals. The backing frame members are sized and spaced to support the screen material so it is not over stressed and to carry and transfer the design differential loading from the screen to the supports. The backing frame may be fabricated from the same material as the flat plate screens or from structural steel to reduce the costs. The backing frame/screen panel may be designed with removable eye bolts to allow the screen to be lifted with a crane or hoist system. The flat plate screen is usually fabricated from 304, 304L, 316, or 316L stainless steel with profile bar shape, figure 51. Perforated plate is another screen material option (figure 50). Bio-foul resistant screens can also be provided. The largest openings allowed in the screen fabric and the minimum allowable screen, percent open area should be based on the resource agencies criteria. The screening panel consists of the backing frame and the flat plate screen, which are welded or bolted together. The screen panels are usually bolted to the supporting metalwork. Wear strips are bolted to the screen panel or supporting metalwork to reduce the friction when adjusting the screen. Common types of wear strips are fabricated from UHMW polyethylene, nylon, delrin, Teflon, and brass.

It may be desirable for the structural steel members of the fish facilities to be designed to provide electrical continuity for the addition of an impressed current or the attachment of passive type anodes to the structural steel members to provide cathodic protection. However, care is advised when dealing with members of dissimilar metals and any kind of cathodic protection.

For either configuration, isolation gates may be used to dewater screen sections allowing access for maintenance and inspection or for river installations. The facility may be designed so that screens and associated equipment can be removed by divers.

***Seals* –** Seals may be required as part of the inclined screen to prevent fish passage past the screen. The seals should be designed and installed so the maximum openings past the screen do not exceed the allowed openings in the screen fabric material. The seals are usually fabricated from neoprene or rubber for sheets, strips, and formed seals (i.e. music-note seals). Brushes have also been used as seals and are usually fabricated from nylon, polyethylene, or polypropylene bristles. A side seal is attached to the screen panel with a clamp bar and bolting system. The upstream seal is usually attached to the floor or embedded seat.

***Debris cleaning* –** Inclined screen installations, especially for screens in canals, bypasses, or fish collection or evaluation locations, usually require an upstream trashrack (figure 83). As water is diverted through the inclined screen, debris will gradually build up onto the screen surface. The most common methods of cleaning the screens are a brush cleaning system or a cleaning system that uses compressed air to back flush the screens. Another possible method would be to lower the water surface below the screen and clean the screen with a high pressure spray hose. For any cleaning system, the cleaning cycle should start upstream and work downstream so the debris is not recycled. Once the debris is brushed or flushed off the screens, the flow of the current carries the debris on downstream.

Inclined screen cleaning systems can be either manually operated or automated. Usually, the controls for an automated cleaning system use an adjustable timer to initiate startup and operation of a cleaning cycle when a preset time is reached. Water level measuring probes (mounted upstream and downstream from the screens) may be included to provide a warning system to tell the manual operator or the automated cleaning system that the screens need cleaning or additional maintenance.

A crane (jib, gantry, or mobile) or monorail hoist system may be provided as part of the screen structure to allow installing, adjusting, or removing the inclined screen and associated metalwork for maintenance or repair. (See chapter IV.A.7.) The mobile crane alternative for installing and removing the screens may be more economical for smaller screen structures, but may also be more inconvenient.

***Cold weather operation* –** Inclined screens have been installed in cold weather climates where icing may occur. In these cases, additional features, loadings, or operating controls should be investigated and provided where applicable. Cleaning of the screens during winter operation may not be possible, so monitoring of the water levels across the screens becomes more critical. The screen cleaning system will also need to be protected from freezing.

Freezing at or near the water surface can also damage the seals and the structural metal components of the inclined screen, frame, supports, and adjustment system. The presence of anchor or frazil ice may dictate that the screens be removed to avoid damage. The intake system may also have to be shutdown because these ice conditions can also damage the trashracks, cleaners, pumps, and other equipment.

An alternative method of ice protection is to enclose the screening structure within a building that has headwalls that extend below the operating water surface. Some installations may be able to incorporate a bubbler system that raises the warmer, deeper water to the surface to keep ice from forming or propellers to circulate the diversion pool water to prevent ice from forming against the screens.

c. Horizontal flat plate screens

Horizontal flat plate screens consist of fully submerged horizontal screen surfaces placed in a channel invert. Flow passes over the screen (figure 20), and diverted water passes through the screen while fish and debris remain in the flow passing over the screen. The screen can be placed in a canal downstream from the headworks where it would be used to separate fish from the diverted flow or, more likely, placed in a natural channel or river. The primary advantage of applying the horizontal flat plate screen is that a large, active screen area can be developed and used with shallow flow conditions. Consequently, a compact screen structure can be constructed at sites where shallow flow depths would exclude application of other screen concepts.

The Horizontal flat plate screen concept has been patented by the Farmers Irrigation District of Hood River, Oregon. NOAA Fisheries has accepted the horizontal flat plate screen concept as a proven technology for fish exclusion and does not consider the concept experimental. However, it would be wise to check with the local fishery resource agency for acceptance and criteria related to installation of this screen.

As the diverted flow passes through the screen, the flow passing over the screen is reduced. The flow diverted through the screen causes severe reductions in flow depth and screen sweeping velocity result. Sweeping velocities must be maintained across the screen to ensure cleaning characteristics and to guide the fish over and off the screen surface. If a significant portion of the passing flow (more than approximately 25 percent) is diverted through the screen, the active screen width should be gradually reduced over the length of the screen allowing sweeping velocities to be maintained with reduced flow rates passing along the screen surface. Consequently, for canal applications where all the flow except for a small bypass discharge is passed through the screen, a linear reduction in screen width over the length of the screen is necessary, as shown in figures 20 and 86.

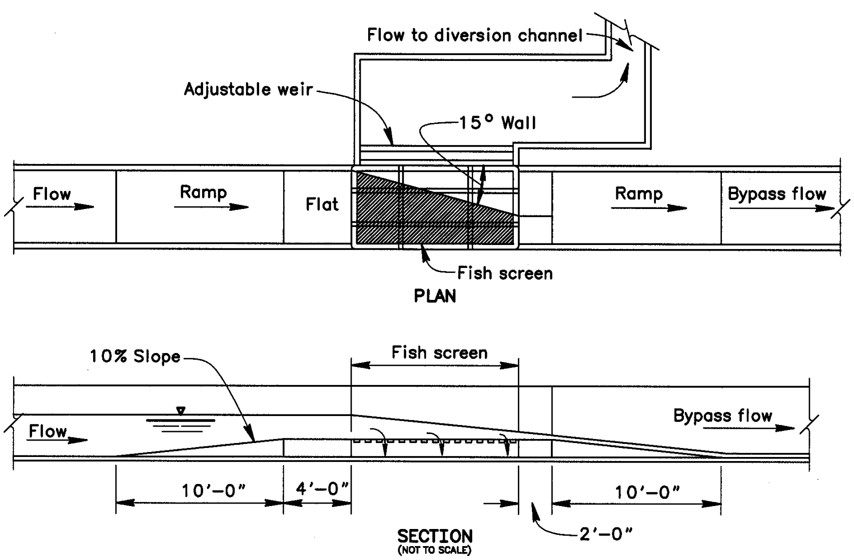


Figure 86.—Horizontal flat plate screen schematic-Reclamation laboratory model.

Desired flow characteristics along the screen surface include uniform flow velocities through the screen and uniform sweeping velocities with no eddy or slack water zones. Hydraulic jumps (flow transitions from supercritical to subcritical flow) should not occur on the screen face. Higher sweeping velocities of 2 to 6 ft/s improve fish guidance across the screen and screen cleaning characteristics. Physical hydraulic model investigations (Frizell and Mefford, 2001) indicated that maintaining high sweeping velocities across the screen may improve fish passage and cleaning characteristics. An invert drop should be included at the downstream end of the screen. The drop will generate critical flow conditions at the exit (bypass) end of the screen. This critical flow prevents slumps in the sweeping velocity over a wide range of operating conditions (figure 87). The screen should be designed to provide approach velocities (flow normal to the screen, V_a) that comply with fish species and fish size specific criteria (table 4).

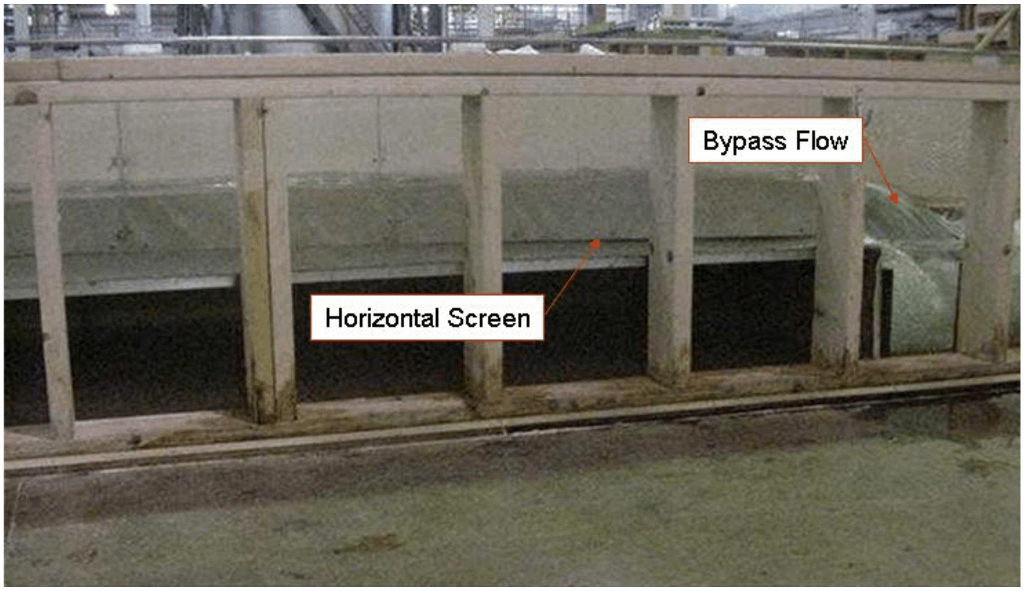


Figure 87.—Side view of horizontal screen in laboratory model showing good flow depth over screen.

Uniform sweeping velocities can best be generated by:

- Placing the screen in a well aligned channel
- Diverting 25 percent or less of the total approach flow for rectangular screens (or converging the channel over the length of the screens if larger percentage diversions are made)
- Maintaining high sweeping velocities over the screen surface
- Proper use of ramps approaching and exiting the screens

Laboratory modeling results indicate that improved self cleaning conditions may be maintained if approach velocities, V_a, are held at or below 0.2 ft/s. Designing an approach velocity, V_a, of 0.2 ft/s may be appropriate where no supplemental screen cleaning is included; fishery resource agency criteria may require a smaller approach velocity depending on how they define this type of screen (self-cleaning or not self-cleaning). The required screen area should be considered when designing the approach velocity and the active screen area (screen area less area blocked by structural members).

Typically, as stated in NOAA Fisheries criteria (see attachment A), a minimum bypass width of 2.0 ft is required. Where screen convergence is used to maintain sweeping velocity, the hydraulic modeling indicates that the angle of the sidewall convergence should be 15 degrees or less (figures 20 and 86) to prevent the buildup of flow depth and development of cross-waves. (The side wall convergence will also depend on the flow velocity and Froude number). With higher sweeping velocities, the convergence angle should be minimized.

The screen surface may be placed at the invert elevation of the channel or it may be placed at a higher elevation with a ramped approach and a drop in the invert (either ramped or a vertical offset) exiting the screen. A chamber (plenum) is supplied beneath the screen which allows a lateral withdrawal of the diverted flow (figure 86). An adjustable weir is included in the diverted flow exit channel to control screen approach velocity, V_a, and provide sufficient back pressure on the screen figure 86. The top of the weir is set at approximately the elevation of the screen surface. The adjustable weir also prevents draining of the plenum below the screen if the screen should substantially foul. This prevents excessive loading of the screen, which could cause screen damage.

Fish passage and fish response investigations (Beyers and Bestgen, 2001) have been conducted in conjunction with the physical hydraulic model study at Reclamation's Water Resources Research Laboratory. The studies used juvenile bull trout that ranged in length from approximately 1–2 inches. No significant fish injury or mortality was documented (as compared to the control groups). With sweeping velocities of 2–4 ft/s, the smaller fish tended to stay high in the water column and quickly passed over the screen. The larger fish swam deeper in the water column and, on occasion, stayed in contact with the screen face (they appeared to maintain position by using the downward pressure generated by the screen approach velocity) to hold position over the screen. This behavior increased passage time to up to 10 minutes with larger fish and may need to be further examined if large predator fish are present at the stream site. The laboratory studies indicated that the screen offered effective juvenile fish handling capabilities.

In-canal horizontal flat plate screen installations should include canal headworks gates that allow control of flow rates across the screen and dewatering of the screen for access and maintenance. Trashracks are used upstream from the head gates to exclude large debris that could damage the screen and foul the screen bypass. Hydraulic model investigations indicate that the screen box configuration will generate sufficiently uniform approach velocity distributions across the screen surface without the use of intermediate flow resistance and baffling elements.

When the horizontal screen is placed in a natural channel or river, operational procedures and facilities for maintenance access to the screen must be developed. Supplemental features, including control gates on the river section and trashracks, are typically not included. Access should be provided that is functional during high flow periods in the natural channel because high flow periods tend to generate the heaviest debris and sediment loading. Bed-load sediment exclusion and control facilities should be included to prevent passage of sediment across the screen surface.

***Screen seats and support* –** Metal work embedded in or bolted to the structure walls and the associated support frame should be constructed with tolerances that maintain acceptable seating. Seals will likely be included with retention brackets. The screen support structure should allow screen panel removal for maintenance, screen replacement, and access to the plenum zone below the screen.

The support structure should be designed to carry full water load in the event of excessive screen fouling. The design loading may be reduced based on the capability of the screen cleaning system (if a cleaning system is included) and the capability to monitor the water differential across the screen. The monitoring capability could either initiate cleaning or sound an alarm that signals the need for cleaning action or shuts down of the diversion.

***Screen design* –** The screen fabric (screen opening sizes and percentage open area) applied should comply with fishery resource agency criteria that is appropriate for the site-specific fishery characteristics (table 4). Screen materials could include perforated plate, profile bar, or woven wire screens. However, profile bars are the most common material for these invert screens. Depending on the screen fabric selected, alternative screen backing frames will be required. The backing frame members are sized and spaced to support the screen and transfer design loads from the screen to the support frame. The backing frame may be fabricated from the same material as the screen or may be fabricated from structural steel to reduce cost. The backing frame and screen panel should be designed with removable eye bolts that allow for screen removal with a crane or hoist system. The screen material is usually fabricated from 304, 304L, 316, or 316L stainless steel. Bio-fouling resistant screens that use high copper content may also be provided. The backing frame and the screen fabric may be welded or bolted together to make up the screen panel. The screen panels can be bolted to the support frame. Wear strips can be bolted to the screen panel or supporting metalwork to reduce friction when adjusting the screen position. Common types of wear strips are fabricated from UHMW polyethylene, nylon, delrin, Teflon, and brass.

Seals **–** Seals will be required as part of the horizontal screen to prevent fish passage past the screen panels. The seals should be designed and installed so that the maximum openings past the screen do not exceed the opening size in the screen fabric itself. Seals are usually fabricated from neoprene or rubber for sheets, strips, and formed seals. Side seals between panels may be attached to the screen panel with clamp bars. Structural surface seals usually attach to the embedded seat or support frame.

Debris cleaning **–** The strong sweeping flows that occur across the screen surface will tend to keep the screen clean; however, fouling, particularly with neutrally buoyant aquatic plants, algae, and fine water logged materials, can occur. Debris cleaning experience with this type of screen is limited, but screen designs have been considered that include air-burst and back-spray cleaners. For either system, the cleaning cycle should start at the upstream end of the screen surface and work downstream, moving debris downstream and off of the screen. The sweeping bypass flow will help to transport debris off the screen. Field experience is not extensive with horizontal flat plate screens, so debris fouling and handling issues have not been fully evaluated. Laboratory studies indicate that the screens offer good self-cleaning characteristics.

To date, automated or integral cleaning systems have not been included with field installations. Typically, fishery resource agencies require a four-fold increase in screen surface area if no cleaning mechanism is included to ensure compliance with approach velocity criteria even with partial screen fouling. This requirement has not been imposed on existing horizontal flat plate screen installations; however, the possibility always exists that it will be required.

Cleaning systems can be operated manually or automatically. To date, applied cleaning systems have been manual. The biggest fouling problem that has been encountered at existing field installations is algal growth on the bottom of the screen plate. This growth can accumulate fine sediment and lead to screen fouling. A removable vertical barrier device that is swept across the screen from the upstream to the downstream end has effectively been used to clear this algal fouling. The vertical barrier functions to generate a water surface differential (water levels are higher on the upstream side and lower on the downstream side of the barrier). This differential generates an effective flushing action through the screen.

A crane (jib, gantry, or mobile) or monorail hoist system may be provided as part of the screen structure to support installing, adjusting, or removing screen panels and associated metalwork for maintenance or repair. (See chapter IV.A.13.) The mobile crane alternative may be more economical for smaller screen structures.

Cold weather operation **–** If horizontal flat plate screens are installed where icing may occur, winter operation design considerations will be needed. In these cases, additional features, loadings, or operating controls should be investigated and provided where applicable. Cleaning of the screens during this winter operation may not be possible, so monitoring of the water levels across the screens becomes more critical.

Freezing at or near the water surface can also damage the structural metal components of the screen, frame, supports, and adjustment system. The presence of anchor or frazil ice may dictate that the screens need to be removed to avoid damage. The presence of ice may also require that the intake system be shutdown because these conditions can also damage the trashracks, cleaners, pumps, and other equipment.

Sedimentation **–** Sediment can pose a major fouling and operating problem with horizontal flat plate screens because bed load materials will tend to pass over the screen coming into direct contact with the screen surface. With sufficient velocity, larger sediment (with diameters larger than the openings in the screen) will pass over the screen with the natural flow (bypass) and move beyond the screen. Sediment smaller than the screen openings will pass through the screen with the diverted flow or will remain in suspension in the bypass flow. Debris and sediment approximately the size of the openings in the screen can become lodged in the screen. Dislodging gravel wedged in the screen fabric may be difficult. There is concern that bedload sediment of a specific size might wedge into screen openings and be difficult to remove. There is also concern that sediments will deposit in the chamber below the screen and be difficult to remove. Air-burst back-flush cleaning systems could be added if needed.

If significant sediment loading is expected, placing sediment capture and exclusion facilities upstream from the screen should be considered**.** Settling basins and other sediment traps, including vortex tubes, should be considered. The screen, and thus the diversion, may need to be shut down and isolated during periods of heavy bedload movement. Sediment removal from sediment traps and the screen structure should be considered in the design. Sediment removal options include using earth moving equipment within the isolated and dewatered structure, drag lines, sluicing, and dredging systems. If earth moving equipment is to be used, access must be provided. Dredging may require an access ramp into the structure, a pipe distribution system, and settling ponds.

Application experience **–** Field experience with Horizontal Screens is currently limited to screens on a few irrigation deliveries in Oregon and Idaho. Two state-of-the-art installations were cited by Farmers Irrigation District personnel. An 80 ft^3/s screen was installed at Davenport Stream, Oregon, in spring 2002. A second screen was installed at East Fork Ditch, Idaho (16 ft^3/s), in summer 2004. To date, sediment and debris handling characteristics of these screens has proven good. Laboratory evaluations and design refinement studies are limited to the referenced Frizell and Mefford (2001) hydraulic investigation and the Beyers and Bestgen (2001) fisheries investigation. Debris and sediment handling and removal have not been throughly investigated and refined.

5. Coanda Screens

Coanda screens consist of screen panels arranged in an array and placed at a hydraulic drop, typically at the crest of a small dam or diversion structure (figure 88). As the water flows over the crest and down the screen, most of the flow passes through the screen to a collection trough and then on to the diversion. The remainder of the flow (bypass flow), with fish, debris, and sediment, passes across the screen and to the tailwater.

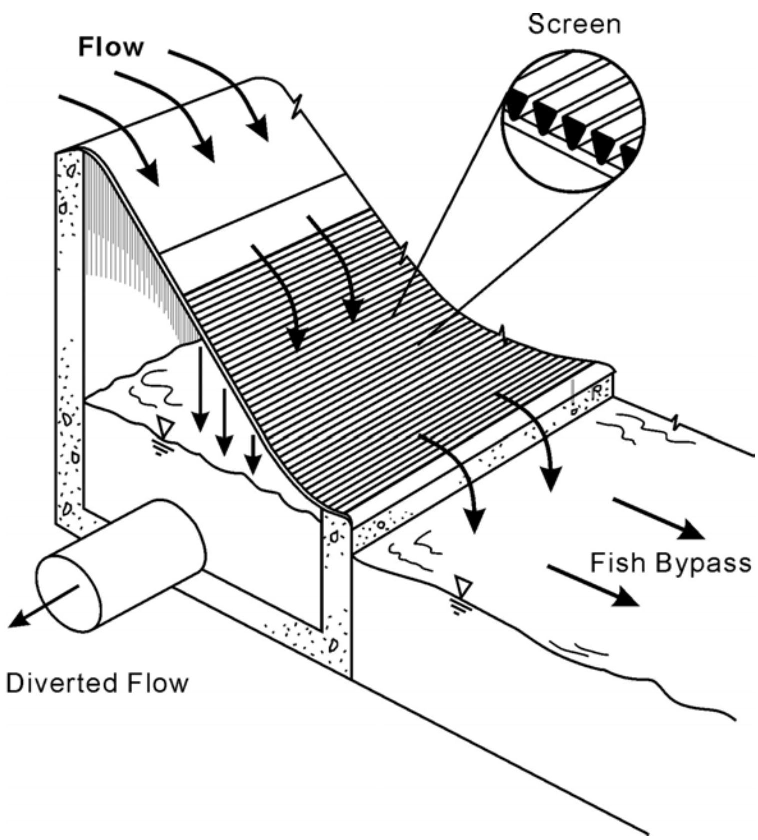


Figure 88.—Coanda screen.

Coanda screens can be used for both fine-debris screening and fish exclusion as part of a river diversion and canal headworks or as part of a fish exclusion structure located within a canal. Advantages of Coanda screens are their self-cleaning nature; their simplicity (no moving parts needed for cleaning); their ability to screen fine debris, sediment, and small organisms; and their relatively large flow capacity as compared to traditional screens of a comparable physical size. Disadvantages are the need for a significant head drop and the lack (at this time) of exhaustive evaluation of the biological performance (fish passage characteristics) of the screen. The Coanda screen is a non-traditional fish screen design. The screen is not fully submerged in the flow. Instead, an accelerating flow sweeps across the screen face as flow drops through. With the Coanda screen, design flow passes over the control weir and over a short acceleration plate and then sweeps tangentially across the face of a profile bar screen with wires oriented perpendicular to the flow (figure 89). The screen panel is sloped downward at angles ranging from 5 to 60º. Each wire in the panel is tilted slightly (usually about 5º) in the downstream direction, so that the leading edge of each wire intercepts a thin layer of the flow passing over the screen.

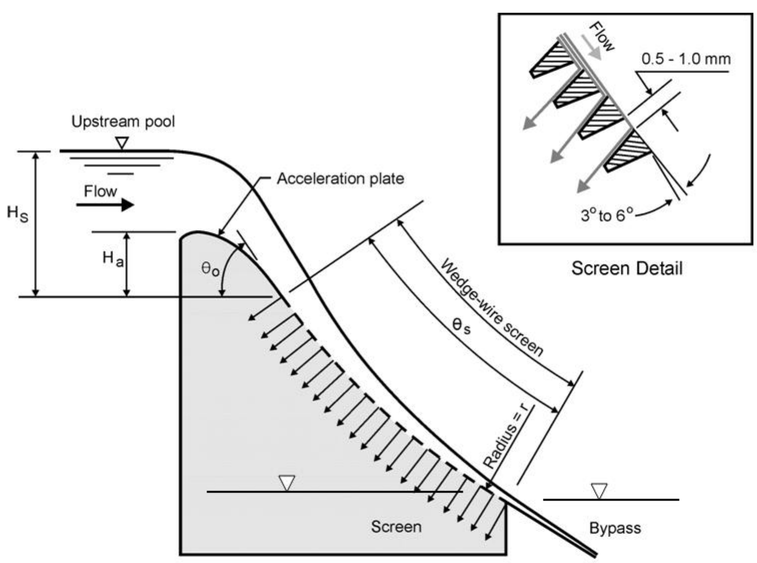


Figure 89.—Features of Coanda screen – Typical arrangement and design elements.

The Coanda effect keeps the flow attached to the top surface of each wire, preventing the flow from skipping from the tip of one wire to the tip of the next, thus improving screen efficiency to divert water (figure 89). Screen opening slot widths are typically 0.5 to 1.0 mm. The slope of the screen combined with the high sweeping velocity causes the screen to exclude a significant fraction of the debris, including debris smaller than the slot width. High sweeping velocity across the screen also helps to minimize debris accumulation. Screens with a Reynolds number ($R_e = V_s * b/v$, where V_s is the sweeping velocity, *b* is the slot opening, and *v* is the kinematic viscosity) greater than 1,000 are reported to have the best self-cleaning action. For screens with slot openings of 1.0 mm, this equates to a necessary sweeping velocity of about 3.44 ft/s. Sweeping velocities of 5 to 10 ft/s are typical.

The Coanda screen was originally developed in the 1950s for the mining and mineral processing industry for dewatering mineral slurries. The configuration of the structure and the shallow angle of attack of the flow on the screen slots provides effective exclusion for material smaller than the actual slot width. A 1.0 mm slot width can effectively exclude material with a diameter of 0.5 mm. These developed performance features yield a screen that is resistant to fouling and excludes small sediment, debris, and biological particles.

The screen fabric applied is typically uniform over the full screen surface area. Uniform flow control or baffling behind the screen is not needed. Typical designs include a free drop from the lower end of the screen to the tailwater (figure 88). The tailwater at the toe of the screen should be configured with a standing pool that will receive fish from the screen surface without excessive bottom impingement (minimizing potential fish injury). This treatment often takes the form of an excavated channel that runs the length of the toe of the screen. The excavated channel also provides energy dissipation during high flow events.

Flow should be maintained across the lower end of the screen to wash debris off of the screen and to maintain a fully wetted screen surface that passes fish with minimal screen contact and injury. To provide bypass flow, screen flow capacity and potential ranges of operating flow rates should be carefully considered in the design development. If screen capacity is underestimated or if extreme low flow events occasionally occur, bypass flow on the screen surface may not be maintained, which could lead to stranding of fish and accumulation of debris on the screen surface. Screen flow capacity, operating ranges, and resulting screen bypass flow should be well documented before design development. These determinations may require hydraulic laboratory evaluations of screen performance if adequate documentation of performance is not available for the specifically proposed design. Variations in streamflow, diversion pool elevation, and resulting head on the crest should be determined. If, on occasion, pool elevations and flow rates drop below design levels, alternatives that provide screen bypass flow should be considered.

Coanda screens have been applied at small hydro diversions, irrigation diversions, and diversions to wetlands. (See figure 21.) Coanda screens have also been successfully used for exclusion of non-native fish from wetland habitats and fish nursery areas. Coanda screen structures can be installed across the full width of a river so that bypass flow off the toe of the screen carries fish and debris downstream, or screens may be installed at a river bank or in the first reach of a canal, with bypass flow returned to the river a short distance downstream.

Commercially available screen structures typically require 4 to 5 ft of head drop for operation. They use concave screen panels with an arc radius, **r,** of about 10 ft (figure 89). Screens are typically inclined 60º from horizontal at the top, reducing to about a 35º incline at the toe, depending on the arc radius and length of screen. The requirement for 4 to 5 ft of head drop may be prohibitive for their use at many sites.

Hydraulic laboratory testing performed by Reclamation (Wahl, 2001 and 2003) showed that screens with much lower drop heights (approximately 2 ft) could also be effective. Very small structures with planar screen slopes as low as 15º and drop heights of about 1 ft have been successfully applied in western Colorado for debris screening at farm turnouts supplying sprinkler irrigation systems. These small structures (figure 90) begin to blur the distinction between Coanda screens and horizontal flat-plate screens. One major distinction is the orientation of the profile bar normal to the flow for Coanda and parallel to the flow for horizontal flat-plate screens. This *Coanda effect*, which occurs only because the profile bars are placed normal to the flow, is what makes the screen so efficient.

Fish passage – From a biological standpoint, the design philosophy and concerns for Coanda screens are much different from those for traditional screens. Traditional screens are primarily a physical barrier in a flow that induces a fish behavioral response to avoid the screen. Screens are designed with a very low approach velocity, V_a, so that fish can maintain a distance from the screen surface as they are swept past the screen by the flow. Traditional screens are sized such that approach velocity magnitudes, V_a, will not cause fish impingement on the screen that could yield fish injury. Traditional screens are sized for sweeping velocity magnitudes, V_s, which limits fish exposure time to the screen. Intermediate bypasses are included if screen length, sweeping velocity, and estimated time of passage from the upstream to downstream end of the screen (exposure time usually 60 seconds) exceeds fishery resource agency criteria.

By contrast, the design philosophy for the Coanda screen is to pass fish over the screen as quickly as possible. Some physical contact with the screen is expected, but impingement against the screen is prevented by the high velocity of the sweeping flow across the screen. Screen slot openings are typically 1 mm or less, while the width of the screen wires placed transverse to the flow is usually

Figure 90.—Coanda screen with low screen slope (Planar) Wildcat Ranch, Carbondale, Colorado.

1.5 mm or greater, producing a screen with a relatively smooth top surface. Fish swimming abilities are not a design consideration because fish are not expected to "swim" in the high velocity flow passing over the screen. Rather, they are simply carried by the flow. Exposure times to the screen are normally less than a second.

Concerns about descaling or disorienting fish passing over Coanda screens focus largely on the effects of the high sweeping velocities and the close proximity of the passing fish to the screen surface. Extensive evaluations of fish passage characteristics of Coanda screens have not yet been conducted. Depending on the screen location, concerns with upstream fish passage may also need to be addressed.

Two notable efforts have been made thus far to evaluate the biological suitability of Coanda-effect screens. Buell (2000) conducted biological tests with salmon and steelhead fry and salmon smolts at a Coanda screen installation on the East Fork of the Hood River near Parkdale, Oregon. These tests indicated that Coanda screens could safely screen and pass juvenile salmon.

Bestgen et al. (2001) tested exclusion and mortality effects of laboratory screens (0.5 mm and 1.0 mm slot sizes) on fathead minnows with nominal total lengths ranging from 5 mm to 45 mm. All fish longer than 12.5 mm were excluded by the screens. Mortalities observed with the tested fish were not attributable to screen effects (observed mortalities were likely associated with fish handling and collection procedures). About 96 percent of the 12.5 mm length fish were excluded. Exclusion rates dropped markedly for fish 5 mm and 7.5 mm long. For the smaller fish, the screen slot size had a significant effect on fish exclusion rates.

***Screen capacity* –** Coanda screen capacity is expressed as the discharge passing through the screen per unit width of screen (the unit discharge). There are three unit discharges of interest, the inflow to the screen (flow over the crest and on to the screen), the flow through the screen (diverted flow), and the bypass flow off the downstream toe of the screen. At very low inflow rates, all flow will pass through the screen and there will be no bypass flow; a portion of the downstream end of the screen is dry. As inflow increases, the wetted length increases until the screen is fully wetted, at which point bypass flow begins. As the inflow continues to increase, the depth of flow over the screen increases and the flow through the screen and the bypass flow both increase; the bypass flow increases faster.

Flow passes through the screen by a combination of two mechanisms. First, the tilted profile bars shear off thin layers of the flow from the bottom of the water column and direct them through the screen (figure 89). Second, the pressure of the water against the screen causes flow to pass through the slots as though they were simple orifices. Both phenomena act simultaneously in varying degrees, depending on the properties of the screen surface and the characteristics of the flow over the screen. The shearing action is primarily related to the amount of wire tilt and the velocity of the flow across the screen. As the velocity is increased, the shearing action becomes more dominant. The orifice behavior is primarily related to the porosity, or percentage of open screen area (i.e., the slot width relative to the bar thickness), and the pressure against the screen surface, which is proportional to the flow depth. For curved screens, the pressure is also increased by radial force exerted on the flow, causing it to follow the curved surface (assuming a concave screen). This radial force is proportional to the depth of flow, the square of the flow velocity, and the degree of curvature. Other factors also have a minor influence on the screen capacity (e.g., Reynolds number effects).

***Screen panel including screen seats, seals, and supports* –** The design of the screen panel (that spans the diversion collection trough) and its associated structural support and seats is typically developed by the screen manufacturer. These screen panels include heavy duty backing frames that provide durable screen surfaces that can pass large flows and large debris with minimal damage to the screen. Such performance has been throughly documented at several small hydropower sites in California (Ott et al., 1988). The accelerator plate, backing frame, and screen face are typically fabricated from 304 stainless steel. The accelerator plate is welded to the backing frame so that it is flush with the screen surface at the leading edge of the screen. By its nature, only profile bar screen fabric is used. Copper-nickel plated metalwork and screens are sometimes used at sites where the potential for biological growth on the screen is high, but this practice is not widespread and is of questionable economy.

Screen design – A number of design parameters affect the capacity of a Coanda screen structure. Some of these parameters are primarily related to the structure (figure 89):

- Drop height, H_s, from the upstream pool to the start of the screen (or from the upstream weir crest to the start of the screen)
- Screen slope, θ_o
- Curvature, **r** (arc radius), of the screen
- Length of the screen

while others are properties of the screen material:

- Slot width
- Wire (bar) width
- Wire tilt angle

Finally, the hydraulic operating conditions also affect the flow through the screen:

- Bypass flow requirements
- Back pressure beneath the screen surface
- Tailwater depth against the screen

Wahl (2003) used a numerical model to analyze the sensitivity of screen capacity (diverted flow) to the structure and screen material parameters and the bypass flow percentage. This analysis assumed that there was no back-pressure beneath the screen surface and that tailwater levels were below the toe of the screen. This numerical model is available to the public in a Windows-based computer program that can be downloaded from <http://www.reclamation.gov/pmts/hydraulics_lab/twahl/coanda/>.

The screen surface area is a primary factor influencing screen discharge capacity. The choice of screen angle will be dictated somewhat by the head available and the length of screen needed to obtain a desired flow rate. To increase the total capacity of a given structure, a designer may choose between increasing the screen length (in the flow direction) or increasing the weir length (the structure length or screen width perpendicular to the flow direction).

To minimize the need for cleaning, steeper screens with a significant accelerator drop are desirable if the site conditions permit their use. When steeper screens are being considered, it may be wise to consider the use of a concave panel because it will reduce the discharge angle at the toe and increase the flow through the screen (by 5 to 20 percent, depending on other factors).

When there is less than 3 ft of head available, low angle planar screens will likely be needed unless the required flow is very small. Curved screen panels are probably not applicable in this case because they further flatten the slope at the toe of the screen, which may lead to debris accumulation problems, and the small increase in capacity probably will not offset the increased cost.

The accelerator plate is an important part of the screen. It ensures sufficient velocity at the head of the screen to make the screen self-cleaning and conditions and aligns the flow as it approaches the screen. Accelerator plates can be constructed to a standard ogee crest profile or may consist of a circular arc or other smooth transition. The accelerator plate transition shape should be gradual enough that the flow does not attempt to separate from the crest. At the Kanaka Creek and Kekawaka Creek screens, it was necessary to modify the original accelerator plate profile to prevent flow separation at large discharges. These projects are operated by STS Hydropower, Ltd., a subsidiary of Northbrook Energy. A vertical drop of at least 0.25 ft is suggested to provide sufficient velocity at the leading edge of the screen to promote self-cleaning.

When operating with bypass flow on the screen, flow depths above the screen are greater than they would be if there were no bypass flow. This tends to increase the amount of orifice-type flow through the screen and increases the sensitivity of the screen performance to other variables that affect orifice-type flow. The effect of bypass flow is most pronounced for concave screens and screens with relatively flat slopes, where orifice-type flow is dominant over shearing flow.

The Wahl (2003) study evaluated the hydraulic performance of a wide range of Coanda screen structures. Wahl considered variations in screen configuration and slope, slot width, wire size, and wire tilt. Both concave and planar screen configurations were evaluated. The study used a numerical model to generate relationships between unit discharge passing over the weir crest, wetted screen length, unit discharge passing through the screen, and unit bypass discharge. These relationships define the rating curve of a screen structure. Figure 91 shows rating curves for a concave screen with a 0.25 ft accelerator drop (this is representative of commercially available Coanda screens), and figure 92 shows the rating curves for a 3 ft-long planar screen placed on a 15° slope (this is typical of a screen that might be applied in a small irrigation canal where head losses would have to be limited).

To apply the developed relationships presented in figures 91 and 92 in a design process, the minimum approach discharge (a function of the minimum diversion pool elevation and the screen weir elevation), the required diversion discharge (flow through the screen), and the minimum unit bypass flow rate should be established. The bypass flow rate requirement could be expressed as a percentage of the total approach discharge or as a minimum unit discharge off the toe of the screen. Requiring a specific bypass unit discharge may be the best approach for ensuring adequate passage of fish over a screen regardless of the total discharge approaching the screen. However, bypass discharge requirements are not well established at this time. By designing to the minimum possible diversion pool and approach discharge, a screen is developed that can satisfy diversion requirements under all possible operating conditions. For the specific screen configuration and design proposed, an iterative process considering screen width (and corresponding weir length) and required unit flow rates should be pursued.

For example, for the commercially available screen shown in figure 91, if a diversion discharge of 50 ft^3/s with a unit bypass flow rate of 1.0 $ft^3/s/ft$ is required, then:

Screen width	Minimum approach flow	Bypass flow fraction
10 ft	(50 $ft^3/s/10$ ft) + 1.0 ft^3/s = 6.0 $ft^3/s/ft$	(1/6) = 0.167 (rating curve shows 0.21)
11 ft	5.55 $ft^3/s/ft$	1/5.55 = 0.18 (matches predicted value)

Diversion discharge = (5.55 – 1.0) (11 ft) = 50.05 ft^3/s

As a consequence, an 11 ft wide screen with a minimum unit approach discharge of 5.55 $ft^3/s/ft$ will supply the required diversion discharge (50 ft^3/s) and required unit bypass flow rate of 1.0 $ft^3/s/ft$ for this example. The minimum pool elevations necessary to generate 5.55 $ft^3/s/ft$ minimum unit approach discharge must be considered when setting the crest elevation that will supply the screen. Note that when the diversion pool is at higher elevations and greater unit approach flows are generated, both the bypass flow rate and the flow rate through the screen (diverted flow) will increase (figure 91). The conveyance channel receiving the screened flow will then have to be regulated to limit the diversion to the 50 ft^3/s maximum. (See the paragraph below.)

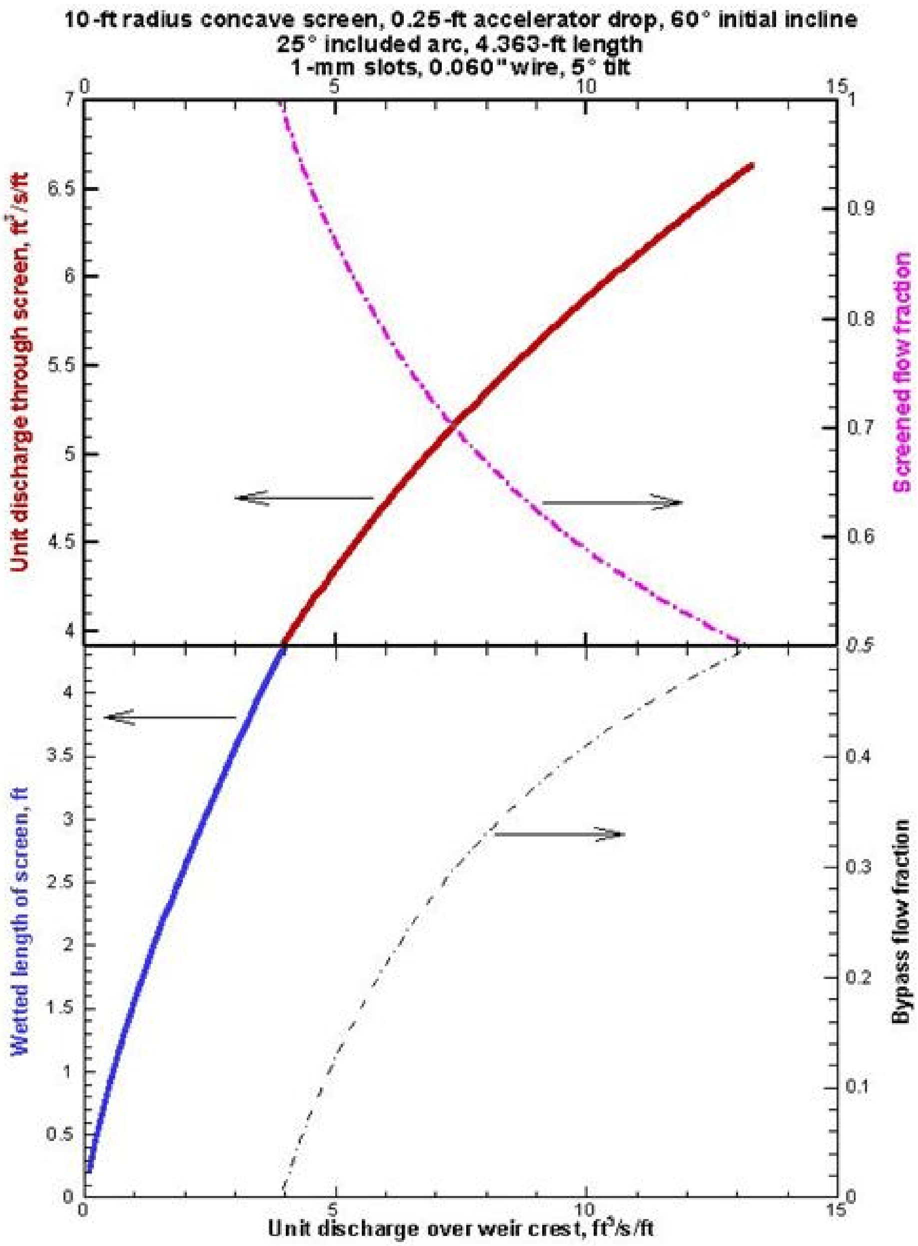


Figure 91.—Concave Coanda screen (commercially available) (Wahl, 2001).

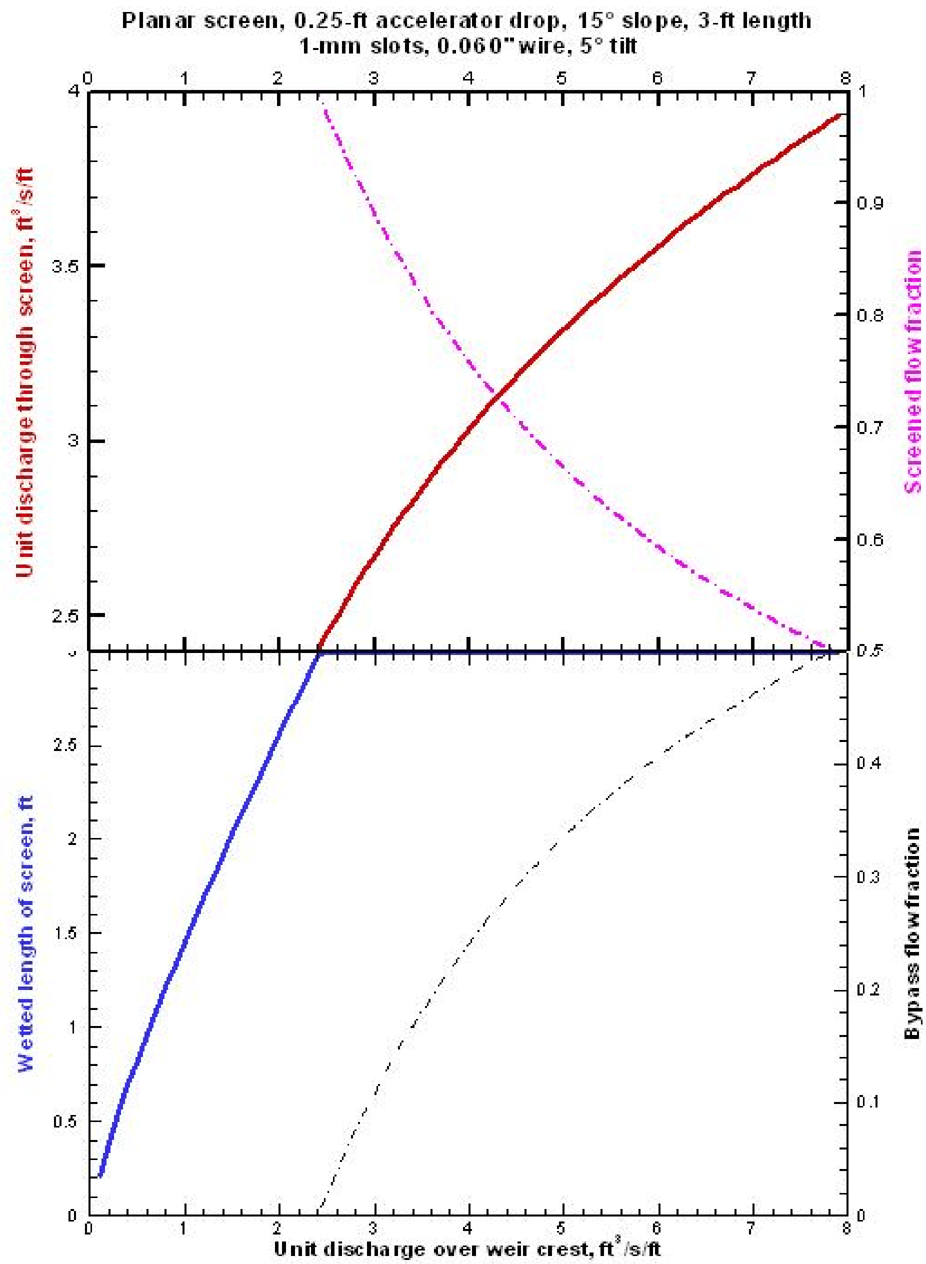


Figure 92.—Planar reference screen on 15 degree slope, 3-ft long with 1-mm slots (Wahl, 2001).

As mentioned previously, screens designed for fish exclusion should operate with sustained bypass flow. At sites where discharge varies significantly and the screen is not specifically designed for operation under low flow conditions, either on a daily or seasonal basis, some means of concentrating flow onto a section (shorter width) of the screen structure may be needed to guarantee sufficient bypass flow during low-flow periods. Flow could be concentrated by using a set of flash boards along the crest of the structure or, perhaps, by using several sections of inflatable weir or other automated crest-gate control. When available flow is low, a portion of the structural width is blocked by the crest-gate or flash boards, increasing the unit discharge on the remainder of the screen.

Another alternative is to regulate the screened or diverted flow with a gate in the collection trough below the screen, in the bypass flow, or in both. Regulating the screened flow will cause water levels to rise within the collection trough. When the water level rises so that it is slightly above the level at which the last of the overflow would pass through the screen, the diverted flow will be controlled by the regulating gate and some bypass flow will occur. There will also be some reverse flow out of the toe of the screen, which should not be harmful. Forces acting to lift the screen off the structure should be anticipated during design if this type of operation is expected. Reverse flow out of the toe of the screen can be eliminated by also raising the tailwater level in the bypass receiving channel so that it is equal to the water level within the screened flow receiving trough. This also reduces the total drop height experienced by fish passing over the screen and reduces the amount of energy that must be dissipated in the tailwater pool at the bottom of the screen, which may be beneficial.

***Debris cleaning* –** This type of screen does not usually require an upstream trashrack. Clogging and debris fouling of this type of screen is a minor factor because the screens were developed to supply effective debris and sediment exclusion with few or no maintenance demands (figure 21 and 88). If fouling occurs, it will be most prevalent at the top of the screen where flow depths and hydrostatic pressures on the screen surface are greatest and sweeping velocities are not fully developed. Small amounts of debris may, occasionally, build up near the bottom of the screen and may require manual cleaning. Automatic screen cleaning equipment is not necessary. At sites where cleaning requirements are expected, an access walkway should be constructed above the crest of the structure. An operator can then work from the walkway with a broom or a squeegee to dislodge debris while the screen is operating. Algae growth attached to the bottom side of the screen panels may require annual removal by brushing (scrubbing with soap and water) or by cleaning with a high-pressure washer.

Field experience has shown that the most problematic debris is large leaves and pine needles. Leaves can become plastered against the screen face tightly enough that the sweeping flow does not easily dislodge them, and pine needles can become lodged in the slots and are often resilient enough that the flow does not easily break them off.

The outstanding cleaning characteristic of Coanda screens make them well suited for application at remote sites where access for maintenance is difficult. California Coanda screens (Ott et al., 1988) have operated effectively, maintaining diversion even during flood events with large flows passing over the screens. During these events, large debris (tree limbs, logs, and large rocks) have passed over the screens with only minor damage resulting.

Cold weather operation – Screens applied at mountainous locations in California have maintained effective operation under icing conditions (Ott et al., 1988). It is noted in the Ott et al. paper that: “This design has been very effective in passing flow under heavy icing conditions including frazil ice. The Prather Ranch Hydroelectric site screen has been in operation for over 5 years without ice clogging, debris, or fish impingement problems.” The severity of the icing at these California sites is not well documented, and, consequently, performance under severe icing conditions is uncertain. However, effective screen operation can be maintained at least under mild icing conditions.

Sedimentation – As previously mentioned, Coanda screens were initially developed to dewater mineral slurries. They specifically are effective in excluding sediment (ranging from fine sediment to large rock) from diversions. Likewise, the screens handle sediment with little or no fouling of the screen fabric. As a performance example, Ott et al. (1988) note that, at the Bluford Creek hydroelectric site, existing sediment exclusion facilities became heavily fouled with sediment during high flow events. The fouling would require termination of diversions until the facility was mucked out. When this existing facility was replaced with a rock trap, sluice, and Coanda screen, a self-cleaning, maintenance free facility was achieved.

Screening of heavily sediment-laden flows is a strength of these screens, as one would expect from their mining heritage, but also creates special maintenance concerns. An example is a pair of screens installed on powerplant diversions at Kanaka Creek and Kekawaka Creek in northern California. These projects are operated by STS Hydropower, Ltd., a subsidiary of Northbrook Energy. The screens were installed during initial construction of the powerplants in 1988 and 1989 for the purpose of excluding fish (rainbow trout) and debris. The screens divert 35 and 70 ft^3/s, respectively, from streams carrying heavy bed loads and organic debris consisting of leaves and alder buds. The screens are truly self-cleaning and require no manual cleaning, but the bed load traveling over the screens gradually wears down the leading edge of the wires, reducing the flow capacity of the screens. The operators regularly replace screen panels because of this and estimate the average life span of a panel to be about 3 years.

6. Closed Conduit Eicher and MIS Screens

Closed conduit screens consist of inclined screen panels placed on a diagonal transect within a closed pipe or conduit that could be a turbine penstock, a gravity diversion conduit, a pump suction tube, or a submerged intake (figure 9). The screen might be installed in a conduit with a circular cross section (an Eicher screen), in which case the screen face has an elliptical shape (figure 22), or it could be installed in a conduit with a square or rectangular cross-section (a Modular Inclined or MIS screen), in which case the screen face has a rectangular shape (figure 93). In either case, as the water flows through the conduit, it encounters the diagonally placed screen. The bulk of the flow passes through the screen and continues on through the conduit. Because of the angled screen placement, fish and debris are guided across the screen face to a bypass entrance and bypass conduit positioned at the downstream end of the screen and at the crown of the conduit. Closed conduit screens are typically cleaned by rotating the screen panel within the conduit to a position that generates back-flushing (figures 9 and 93). Closed conduit screens are applied primarily for fish exclusion. Advantages of closed conduit screens are their compact size, their applicability within the delivery conduit (which at some confined sites may be one of the few options for screen siting), their relatively low maintenance requirements, and their relatively low cost. Disadvantages are head losses associated with screen use, the general perception that closed conduit screens are developmental technology, and the lack of exhaustive field evaluation of the biological performance (fish passage characteristics) of the screen for broad ranges of fish species.

The Eicher screen (figure 22) was developed for hydroelectric applications. The concept does, however, offer application potential in a broad range of closed conduit diversions, although experience is limited to larger hydro-power installations. The concept was patented in the United States and Canada by George Eicher. The screen concept has been developed through extensive use of laboratory and field investigations of hydraulic, fish handling, and mechanical features of the design (summarized in Electric Power Research Institute, 1994). The Eicher screen has a significant history of field application, being applied at Portland General Electric's T.W. Sullivan Plant, Oregon, since 1980, and at BC Hydro's Puntledge Plant (figure 8), British Columbia, since 1993 and being studied for many years as a prototype installation at the Elwah Hydroelectric plant, Washington.

The MIS screen (figure 93) was developed for application in a broad range of diversion and water intake structures including hydro-power and pump intakes. The concept was developed as a standard design screen module with an inclined screen placed in a length of rectangular cross section conduit. Details of the developed module configuration and performance characteristics of the module are presented in Electric Power Research Institute (1994). The MIS screen

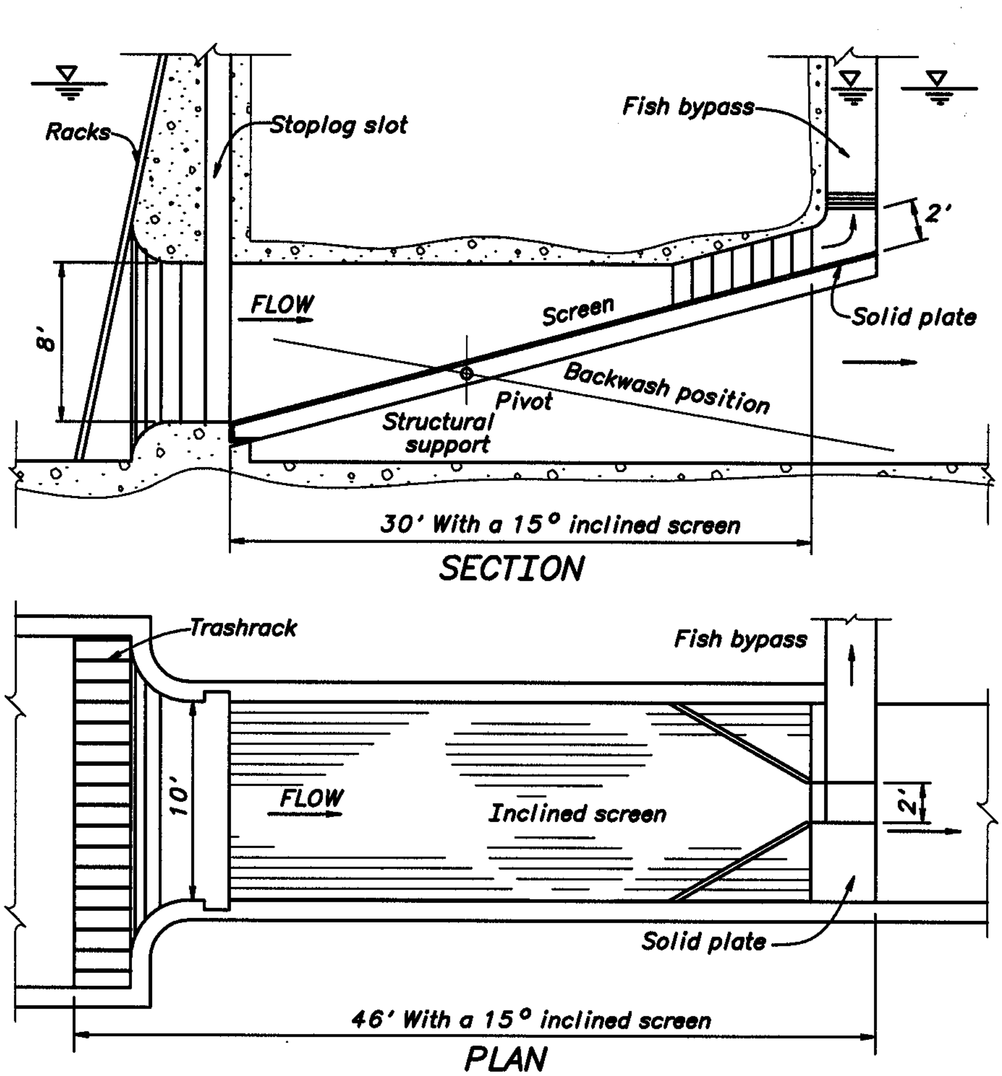


Figure 93.—Features and typical arrangement for a rectangular conduit MIS screen (EPRI, 1996).

modules were developed to be included in the intake structure positioned immediately downstream from the intake trashracks. The configuration of the module with included transitions was developed for this specific application configuration and the specific hydraulic flow patterns generated. The MIS module concept was not developed for application within extended lengths of delivery pipe or conduit, although site specific studies could be used to develop MIS screens for such applications. The MIS concept is patented in the United States by EPRI. The screen concept was developed through use of laboratory studies that refined and evaluated hydraulic and fish passage characteristics of the design. Field application experience is limited to a pilot facility evaluation that was conducted at Niagara Mohawk Power Corporation's Green Island Hydroelectric Project, New York, in 1996. As a consequence, the field experience base with MIS screens is marginal.

Closed conduit screens (either Eicher or MIS) are viewed as a non-traditional fish screen design both because the screen is within the pressurized conduit and because flow velocities past and through the screen greatly exceed velocities established in standard fish screen design criteria. With closed conduit screens, the velocities that the screen is exposed to are the flow velocities through the pipe or conduit. Typically, the conduit is sized for and the screen is designed to operate with maximum conduit velocities of 6.0 ft/s (these velocities consider documented fish injury potential), although screen performances have been evaluated over velocities ranging from 2 to 10 ft/s. Studies indicate that for velocities above 6.0 ft/s, fish injuries and mortalities begin to increase. Conduits may have to be oversized or multiple conduits may have to be used to limit maximum velocities to 6.0 ft/s. Considering a balance between required screen panel length and fish guidance characteristics, screen panels are sloped upward at angles ranging from 10 to 20º off the slope of the penstock. Flatter screen placement tends to improve fish guidance and reduce fish impingement, and steeper placement shortens panel length. Screen approach velocities, V_a, of 1.8 to 2.0 ft/s typically result at design flow conditions. Closed conduit screens are generally fabricated from profile bar screen with opening sizes that comply with standard screen criteria, table 4. High sweeping velocity across the screen helps to quickly move fish across the screen and to the bypass, thus minimizing fish exposure time and fish impingement potential.

Extensive laboratory studies have been conducted with scaled or reduced size closed conduit screens (EPRI, 1994). These studies have focused on development of the hydraulic design. Qualitative laboratory studies have also been conducted evaluating passage of a broad range of fish species through the reduced size laboratory models. A limited number of field applications and evaluations of closed conduit screens have also been conducted. These field applications have all been conducted at hydro-power sites. Applications include the relatively short-duration pilot-scale evaluation of a MIS screen at Niagara Mohawk Power Corporation's Green Island Hydroelectric Project on the Hudson River, New York (EPRI, 1996); the multiple-year evaluation of a prototype Eicher screen at the Elwah Hydroelectric Project on the Elwah River, Washington (EPRI, 1994); and extended production use of Eicher screens at BC Hydro's Puntledge Hydroelectric Project, Puntledge River, British Columbia (Smith, 1997; EPRI, 1994) and Portland General Electric's T.W. Sullivan Plant on the Willamette River, Oregon (EPRI, 1994). Fish passage and handling characteristics have been evaluated in detail at all the field installations. The Northwest screens have focused on salmon exclusion; consequently, experience with a wide variety of fish species is limited. Evaluation of the performance of the MIS screen has considered much broader ranges of fish species.

Field screens have been constructed using both uniform screen fabric applied over the full screen panel surface area and screen fabric with selectively variable percentages of open area (figure 9). Variations in the percentage of open area have been used to adjust and control through-screen flow distribution. Adjustable porosity control using resistance elements placed behind the screen has not been used primarily because of concerns about screen rotation and back-flush cleaning.

Although closed conduit screens, to date, have been applied only in laboratory settings and at hydropower facilities, there are, no doubt, situations where closed conduit screens would be serviceable and well applied at irrigation diversions. Closed conduit screens might be considered for application in situations where space is insufficient for more traditional screen concepts.

Laboratory screens have been tested that effectively exclude fish with minimal injury or mortality. These laboratory installations were applied in conduits with diameters ranging from 2.0 ft to approximately 3.2 ft. Corresponding flow rates with a flow velocity of 6.0 ft/s range from 19 to 48 ft^3/s. Effective fish handling performance was also observed in these models when operating with reduced velocities and correspondingly reduced discharges. These laboratory studies indicate that smaller size closed conduit screens are potentially feasible for field application. The hydropower installations that have been field validated were installed in conduits with diameters ranging from 9.0 to 10.5 ft. At a velocity of 6.0 ft/s, corresponding discharges ranged from 380 to 520 ft^3/s. These larger facilities have proven fully functional in field applications.

In general, closed conduit screens require detailed, site-specific investigations for design development with each application. The MIS screen module placed within an intake structure with specific required configurations may be the exception. Because of variations in configuration of the conduit where the screens are installed and the effect of the conduit configuration on the resulting flow velocity distributions approaching the screen, physical hydraulic model studies should be used to develop specifics of the screen and screen porosity design. The MIS design was developed through application of detailed research studies that establish design criteria on sizing, module configuration, required porosity control, and siting (submergence and approach flow conditions) requirements. It is likely that, through similar studies, other closed conduit screen concepts could be developed as off-the-shelf screen components that could potentially be fabricated in multiple quantities. Application of off-the-shelf designs, however, require that approach flow conditions applied in the development studies be exactly duplicated in field installations (approaching flow velocity magnitudes, distributions, and directions must be the same).

***Fish passage* –** From a fish protection and exclusion perspective, the design objective and concerns for closed conduit screens are much different from those for traditional screens. Traditional screens are primarily a physical barrier in a flow that gently guides the fish to the bypass. The screens are designed so that fish can avoid or maintain a distance off of the screen surface as they swim along the screen and into the fish bypass. Traditional screens are sized such that approach velocities magnitudes, V_a, will not cause fish impingement on the screen that could yield fish injury. Traditional screens are sized by considering the sweeping velocity that will limit the time fish are exposed to the screen. Intermediate bypasses are included if screen length, sweeping velocity, and estimated time of passage from the upstream to downstream end of the screen (exposure time) exceeds criteria.

By contrast, the design objective for closed conduit screens is to pass fish over the screen as quickly as possible. Some physical contact with the screen will likely occur because of the high screen approach velocities, V_a. Screen lengths, however, are relatively short (40 ft or less), which, coupled with conduit sweeping velocities of 6 ft/s, yield fish exposure time to the screen of less than 7 seconds. Observations of fish contact with the screen surface indicate that, if fish impinge on the surface, and then squirm and lift off the surface, the flow will carry the fish past the screen and into the bypass. As with the Coanda screen, the fish do not swim past the screen. At best, they hold body orientation in the flow and are carried to the fish bypass. As with the Coanda screen, profile bar (wedgewire) screen fabric is used, which supplies a smooth screen surface that tends to minimize de-scaling and fish injury.

Concerns with fish passage over closed conduit screens focus largely on the effects of the high approach velocities and the potential for descaling, fish injury, immediate mortality, and delayed mortality that would result from fish impingement on the screen surface. Another concern is the injury to or loss of fish during the cleaning (back-flushing) operation. The laboratory fish passage evaluations conducted in support of the MIS development (EPRI, 1994) were conducted on a 1:3 scale model, where the length and duration of potential screen exposed in the laboratory was substantially less than what would occur with a full-size field screen. As a consequence, laboratory findings indicate the potential for fish injury but do not supply a rigorous evaluation of screen performance in the field. Species evaluated in the MIS laboratory studies include: bluegill, walleye, rainbow trout (fry and juveniles), channel catfish, aliased juveniles, coho salmon, Chinook salmon, golden shiner, Atlantic salmon, and brown trout. Length of fish evaluated varied with species and ranged from 1.9 to 6.7-inches (48 to 170 mm). Control adjusted injury rates (gross injury rates observed with correction for injuries observed with control fish that were handled but not passed by the screen) vary with species and operating velocity. With a conduit velocity of 6 ft/s, injury rates were less than 2 percent for all species expect bluegill and golden shiner, which were less than 5 percent. Similar findings were observed for delayed mortality (the fish were held for 72 hours after passing the screen and mortalities were evaluated). Control adjusted delayed mortalities were less than 1 percent for all species expect the golden shiner and aliased juveniles. Mortality rates for the aliased juveniles ranged from 10 to 20 percent (the aliased juveniles tested were stressed and had experienced scale loss associated with collection, transportation, and handling).

Extensive fish passage evaluations have been conducted at the Sullivan and Elwah Eicher screen field installation (EPRI, 1994). Fish passage evaluations have also been conducted at the Puntledge (Smith, 1997) Eicher screen and Green Island MIS screen facilities, as shown in table 5. The Green Island evaluation is the least comprehensive of the field evaluations conducted, but still provides an indication of probable fish passage performance. Note that, in almost all cases, fish survival rates (reflecting the combined losses from immediate and delayed mortalities) exceed 95 percent. Tests were also conducted in the Puntledge evaluation with hatchery supplied coho and Chinook salmon smolt. Survival rates for the hatchery supplied smolt ranged from 92 to 96 percent. It was thought that these higher mortalities resulted from Saprolegnia and Proliferative Kidney Disease (PKD) infections in the hatchery fish. Fish mortalities observed in the Green Island MIS studies were similar to those observed in the laboratory studies, as discussed above.

Fish injuries consisting primarily of limited descaling have been documented in both the laboratory and field studies. The extent of scale loss observed varies with fish species, conduit flow velocities, the specific screen design and installation, and the extent of debris fouling of the screen. With a 6.0 ft/s conduit velocity and a clean screen, typically less than 5 percent of the passing fish experienced scale loss of over 3 percent. An exception was Chinook salmon smolt at Elwah for which 2.8 percent of the fish that passed the screen showed in excess of 16 percent scale loss on one side of the fish. Chinook salmon smolt appeared to be particularly susceptible to scale loss, although observed initial and delayed mortalities were no higher than those observed with the other species tested at Elwah (EPRI, 1994).

Fish passage tests were conducted at Elwah with varying levels of debris accumulation on the screen surface. Water logged leaves and green leaves were applied. Increases in head loss, changes in fish diversion efficiency, fish mortality, and scale loss were all evaluated. The study shows that fouling has minor influences of fish diversion efficiency and fish mortality (changes of less than 5 percent of net values), but will increase the number of Chinook salmon smolt descaled (16 percent or greater) by over 40 percent and coho salmon smolt by approximately 30 percent (EPRI, 1994). This was with associated increases in head loss of as little as 0.10 to 0.16 ft. Water logged leaves seemed to be somewhat worse than green leaves in causing descaling. The findings clearly show the importance of keeping the screens clean.

Table 5.—Field documented fish survival rates for closed conduit screens (EPRI, 1994)

Study site	Conduit velocity ft/s	Species and life stage	Length (mm)	Survival rates (percent)
Sullivan (Eicher)	5.0	Spring Chinook salmon	140 to 295	98.68
	5.0	Fall Chinook salmon	85 to 150	97.95
	5.0	Steelhead	159 to 290	99.68
Elwah (Eicher)	6.0	Steelhead smolt	174 (mean)	99.6
	6.0	Coho salmon smolt	135 (mean)	99.5
	6.0	coho salmon pre-smolt	102 (mean)	99.9
	6.0	Chinook smolt salmon	99 (mean)	99.7
	7.8	Chinook salmon pre-smolt	73 (mean)	99.5
	7.8	Steelhead fry	52 (mean)	99.3
	6.0	Coho salmon fry	44 (mean)	94.8
Puntledge (Eicher)	6.0	Wild coho salmon smolt	84 to 135	99.8
	6.0	Wild Chinook salmon smolt	69 to 115	99.3
	6.0	Trout	264 to 310	100
	6.0	Chum salmon fry	41 to 54	96.5
	6.0	Wild sockeye salmon smolt	96 to 155	96.1
Green Island (MIS)	6.0	Golden shiners	47 to 88	95 (approximate)
	6.0	Rainbow trout	47 to 88	100 (approximate)
	6.0	Blueback herring	47 to 88	≥95
	6.0	Largemouth bass	47 to 88	≥95
	6.0	Smallmouth bass	47 to 88	≥95
	6.0	Yellow perch	47 to 88	≥95
	6.0	Bluegill	47 to 88	97 approx.

Screen bypass – Alternative bypass entrance designs have been developed (EPRI, 1994). Typically, the designs include reducing sections with screened boundaries that yield continued reduction of the bypass flow rate as the section reduces. These reducing transitions yield a controlled, constant velocity or gradual flow acceleration (as desired) into the bypass conduit. Studies have shown that to achieve efficient fish guidance and collection by the bypass, the velocity approaching and in the bypass conduit must be equal to or greater than the velocity in the primary conduit (penstock, pump suction tube, etc.) and across the screen surface. Consequently, if the screen is operating with a conduit velocity of 6.0 ft/s, velocities in the bypass conduit should be 6.0 ft/s or greater. Conduit flow rates and velocities will vary with changes in operation; therefore, methods are required to control and adjust bypass velocities and flow rates. One option that was developed for the MIS screen is to include an adjustable overflow weir in the bypass. Any control treatment applied in the bypass must have minimal influence on fish passage.

Of particular concern in sizing the bypass conduit is conduit fouling. The closed conduit screen bypasses are not readily accessible and, thus, not easily cleaned. Debris removal would likely require shutdown and dewatering of the conduit and screen. NOAA Fisheries criteria (NMFS, 1995) typically requires a minimum 24-inch-diameter bypass conduit specifically to minimize debris fouling potential. This large diameter bypass conduit will, however, yield large bypass flow rates that may be excessive and unacceptable for smaller screen installations. For instance, a 24-inch bypass requires a minimum of 19 ft^3/s to achieve a 6 ft/s velocity.

Bypass conduit diameters and configurations for the Eicher and MIS field installations typically were designed to comply with National Marine Fisheries Service (NOAA Fisheries) criteria (NMFS, 1995) and, thus, are sized with a minimum 2.0 ft diameter. These, however, are large-diameter conduits screens. Bypass flow rates at these hydropower sites are less than 5 percent of the total screened flow rate. For screens with conduit capacities of less than 25 ft^3/s, NOAA Fisheries criteria allows bypass conduit diameters as small as 10 inches. It may be appropriate to consider smaller diameter bypasses for irrigation screen applications. Hydraulic model studies may have to be conducted to develop and refine such a hybrid design. In such studies, fouling potential should be carefully evaluated. Details on the standard NOAA Fisheries bypass conduit criteria are presented in chapter IV.A.11 of this manual and attachment A.

Screen Capacity – Closed conduit screen capacity (diversion capacity) is a function of conduit diameter, conduit velocity, and the volume of flow diverted into the screen bypass conduit. With 6.0 ft/s as the current maximum design velocity for the Eicher and MIS screens, total discharge is only a function of conduit diameter. A 2-ft-diameter conduit would yield a conduit discharge of 18.8 ft^3/s; a 4-ft-diameter conduit would yield a conduit discharge of 75.4 ft^3/s.

Flow rates passed through the bypass must be subtracted from these values to determine delivered flow rates. A 1-ft-diameter bypass, operating with a velocity of 6 ft/s, would pass a discharge of 4.7 ft^3/s. For the above examples, the 2-ft- and 4-ft-diameter conduit screens operating with a 1-ft-diameter bypass (4.7 ft^3/s)would deliver discharges of 14.1 and 70.7 ft^3/s, respectively.

Screen panel, screens, seats, seals, and supports **–** The design of the screen panel and its associated structural support and seats, to date, have been independently developed for each application. A standard design was developed for the MIS modules. The closed conduit screen panels include heavy duty backing frames that provide durable screen surfaces that can support a heavily debris fouled screen. It is noted in EPRI (1994) that:

> The screen, the screen transverse support bars, and the longitudinal support frame must be designed for the differential pressure across the screen face with the screen operating at maximum design flow. A minimum differential pressure of at least 2.5 times the expected screen head loss is recommended for design of the screen and support members. When feasible, designing for a fully clogged screen or inclusion of a fail-safe means to ensure screen rotation (to an open position) when clogged is advisable. Screen deflection under normal operating conditions should be limited to provide a maximum gap equal to 50 percent of the profile bar clear opening along the conduit boundaries and at the bypass entrance.

Except during cleaning periods, closed conduit screens actively screen all diverted flow. It is possible that if the pivoting operator failed or cleaning was not correctly activated, the screen could foul to the point that it would block the conduit. A heavily fouled screen could restrict flow passage such that negative pressures develop behind the screen, causing conduit evacuation and failure. As a result, it is critical that the screen be design with a failsafe mechanism for tilting or opening the screen when differentials become excessive. Locating the pivot shaft upstream from the center of the screen will yield a positive opening moment (a force that tends to move the screen panel to the open position) under load and, thus, is advisable. Venting of the conduit downstream from the screen should also be considered as a means to ensure against negative pressure development and conduit collapse from severe screen fouling.

The designs developed to date have not specifically dealt with seating surfaces. Seals included on the screen panels seat directly on the conduit wall. Establishing a tight seal between the screen panel and the conduit wall is critical to prevent fish injury. A “J” seal used at Elwah supplied a tight and effective seal. No fish impingements were observed along the seal edge. Using a 2- to 3-inch-wide seal (a seal that extends out from the conduit wall 2 or 3 inches) also excludes through-screen flow near the conduit wall, which may, depending on the local configuration and flow patterns, include a corner effect that may trap fish or increase impingement potential. (This is particularly a concern where the sealed intersection is converging on the flow.)

Head loss **–** Head losses across the screen panels are affected by the configuration of the screen panel and bypass, the screen fabric used, the support structure configuration, the flow velocity, and debris fouling. Summary details on the specific structure and component influences and observed head losses are included in EPRI (1994). To reduce head losses, the support structure should be streamlined with structural elements well aligned with the flow. The configuration of backing members and the screen retainer design for the particular profile bar fabric applied will also affect losses. Developmental studies on the Eicher screen showed that, through proper streamlining, head losses can be reduced by 50 percent or more. Observed losses, which vary with screen concept and details of the screen design, range from 0.7 to 1.3 ft for clean screens operating with a flow velocity of 6.0 ft/s. As is typical, the observed head losses vary as a function of the velocity squared. Debris fouling can also substantially increase losses

Back-flush operator mechanism **–** Back-flushing is created by rotating the screen as shown in figures 9 and 93. At some field sites, back-flushing is routinely conducted once a week. At other sites, it is conducted routinely at 6-hour intervals. Duration of each back-flushing cycle depends on operator design and may range from a few minutes up to 10 minutes. Typically, the duration of operation with no fish exclusion is from 1.0 percent to 0.1 percent of the time. Periodically, the screens are accessed, inspected, and physically cleaned. This may be no more frequent than once a year. Access, inspection, and physical cleaning requires shutdown and dewatering of the conduit.

Options for back-flush operator mechanisms include motor driven mechanical operators or a hydraulic piston system or both. A mechanical operator with a relatively slow motor was used at the Elwah facility and at the Sullivan Plant. It was observed at Elwah that back-flushing would effectively clean the screen panel with the panel in the cleaning position for as little as 1 minute. The Elwah operator required approximately 10 minutes to cycle from the fish exclusion mode to the back-flush position and back. For the T.W. Sullivan Plant, Cramer (1997) notes that:

> The pressure difference across the screen is monitored continuously. Screen cleaning is an automated process and can be controlled remotely since the Sullivan Plant is only manned for a 40 hour week. When the differential across the screen reaches 18 to 20 inches, the cleaning sequence is started. The load on the turbine unit is reduced to 5 percent by closing the wicket gates down. It takes approximately 4.5 minutes for a long stem torque motor to rotate the screen to the

> back-flushing position. Load is brought back up to 55 percent for 10 minutes, then dropped back down to 5 percent while the screen is rotated back to the fish exclusion position. The total cleaning sequence takes approximately 19 minutes.

When the screen is going through this cleaning mode, the screen is not excluding fish. If frequent back-flushes are required (because of relatively high debris loads), the associated time and loss of fish exclusion may become a significant concern. In such cases, use of more rapid operators should be considered.

For the Puntledge Plant, Smith (1997) notes that:

> The screens were designed to rotate on an axle by means of hydraulic pistons. Control of the screens, for cleaning purposes, consisted of two mechanisms; a timing device used to periodically backwash the screens, and pressure transducers installed in 1994 to avoid negative pressure development in the woodstove pipe below the screen.

This pressure sensing control mechanism provides further assurance of protection against developing negative pressure downstream from the screen by comparing the pressure above and below the screen. A pressure differential across the screen results in automatic screen rotation to sweep debris from the screen surface.

> On two occasions in 1996, the two cleaning mechanisms were unable to manage debris load and the penstock intake gate closed to protect the penstock and turbine. This results in two problems; an immediate reduction in discharge from the turbine into the tailrace area, and loss of plant energy/capacity from the integrated power system. Following a system inspection, it was determined that the transducers, which were laboratory quality, were too sensitive to debris and dirt and were failing during critical periods. Consideration is being given to replacing the transducers with field quality units.

The operator developed for Puntledge completes a back-flush cycle in approximately 3 minutes.

It is noted in EPRI (1994) that:

> The operator system should be equipped with a failsafe system to assure proper seating of the screen each time it is returned to the fish protecting position. Experience from the Elwah studies showed that even a slight gap on the downstream edges of the screen can result in significant loss of fish.

Debris cleaning **–** These types of screen installations require an upstream trashrack at the intake. These screens receive some cleaning benefits from the high velocity water sweeping towards the bypass. Debris fouling rates and fouling and cleaning characteristics vary with debris type and debris loading concentrations. The screen is cleaned by pivoting (rotating) to a back-flush position. Once cleaned, the screen is pivoted back in place (figures 9 and 93). The equipment for back-flushing includes either a motor driven mechanical operator or a hydraulic piston operating system. The pressure difference across the screen needs to be continuously monitored. Screen cleaning will usually be automated. Cleansing certain types of debris, such as pine needles from the screen, may require periodic shutdown and manual cleaning (mechanical or pressure washing). Note that when the screen is being cleaned (rotated mode), there is an intermittent loss of fish exclusion.

Debris fouling will vary seasonally with changes in debris type and load. If back flushing is initiated by measured increases in head loss, it can be expected that the back-flush frequency will also vary seasonally. As discussed above under "back-flush operator mechanism," back-flushing requires screen rotation, which results in intermittent loss of fish exclusion. As a consequence, the duration of periods without fish exclusion will also vary seasonally.

The back-flushing mechanism has generally proven to be very effective in cleaning the screens. Debris cleaning tests conducted at Elwah and in conjunction with the MIS biological evaluations have indicated that leaves and aquatic plants are effectively washed off of the screen by back-flushing. Pine needles are generally washed off, although some needles do wrap around screen support elements. The quantity of these residual pine needles increases with time and repeat back-flushing cycles. Pine needle debris loading may require periodic shutdown and mechanical cleaning. It is noted in EPRI (1994) that "At sites where entrainment of significant quantities of pine needles is expected, at least a seasonal program of manual cleaning should be planned."

For the T.W. Sullivan Plant, Cramer (1997) notes that:

> Generally, debris loading on the screen only is a problem during the fall due to leaves and during high water events. In the fall the screen may need to be cleaned twice a day. Heavy loading events usually last one day and may require up to 24 cleaning cycles in a 24-hour period. From early spring through early fall the screen goes extended periods without cleaning. . .. The Eicher pressure screen has been used at the Sullivan Plant for 16 years. The screen shows no sign of wear and has needed repair only once when a piece of debris caused a small section (8-inch square) of bars to separate. Automation of the cleaning cycle

> has decreased labor and the time it takes to cycle. Also, since heavy debris loads tend to coincide with high water events, automation allows the operators to focus on other critical functions.

For the Puntledge Plant, Smith (1997) notes that in a system of lakes, a debris boom, and a trashrack with a 2-inch clear spacing buffer variations in watershed runoff and exclude large debris. Small debris enters the penstock. Smith also notes that:

> Inspections determined that certain pieces of small debris such as twigs, grasses and leaves, passed into the penstock and contacted the screen. Much of this material traveled along the screen and exited through the bypass, however, some material became lodged in the screen support bars. Lodged material then tended to capture additional material as it moved along the screen. The amount of debris on the screen influences head loss across the screen as well as fish passage efficiency, particularly for fry which may contact the screen. . .. During the test period, the screens were rotated on a four hour cycle and this was generally found to be sufficient in 1993. Annual inspection and screen cleaning as well as regular trashrack cleaning is considered to be important to reduce fish impingement and scale loss. Effective management of debris is essential to optimization of fish survival as well as to ensure the integrity of the powerplant. Annual outage time to pressure wash and maintain the screens has been limited to four hours per year.

Finally, Smith (1997) observes:

> Over the five years of operation of the screens, there has been little need for maintenance beyond routine trashrack cleaning and periodic screen cleaning. An unexpected occurrence has been the colonization of the screen and screen frame by an invertebrate (black flies) *Simulium* spp. of the Diptern family. The simulids adhere to the screen frame and back side of the screen and can restrict screen porosity. The proposed solution to this situation is to pressure wash the screen as required prior to the migration period. This has not proven to be necessary on a routine basis. The screen has not been subject to any damage as a result of either bed load movement or large debris. Rubber seals around the perimeter of the screen have remained intact and functional. All hydraulic systems regulating the back-wash system have functioned well.

***Power availability and need for backup power* –** Power is required to operate the backwash system. With closed conduit screens, it is critical that effective cleaning be maintained both to prevent fish injury and descaling and to ensure that flow blockage resulting in negative pressures downstream from the screen does not occur. As a consequence, power and backup power are typically required at closed conduit screen sites. An option might be to develop a screen design that would open (go to the neutral or back-flush position) with loss of power.

Cold weather operation **–** No experience is available with closed conduit screen operation under icing conditions. The screen is fully submerged and isolated from the free atmosphere, thus insulating metal components from atmospheric temperatures. The screen also draws from submerged intakes with trashracks that should exclude floating ice. Diversions from rivers with active frazil ice production (high gradient streams with no ice cover and low atmospheric temperatures) would, however, likely foul the screen and lead to system shutdown.

Sedimentation **–** Experience with significant sediment passage through the screen section is not available. To date, these screens have been developed for application at hydropower sites where submerged intakes draw from an impoundment. Therefore, significant sediment issues have not been encountered or addressed. Sediment handling may pose a substantial problem with the application of closed conduit screens with diversion intakes off shallow water bodies.