Chapter V. Behavioral Barriers

> "No human being, however great, or powerful, was ever so free as a fish."
>
> *John Ruskin 1819-1900, British Critic, Social Theorist*

Fish can be guided by various stimuli in an effort to protect them from water diversion intakes and guide them through fish facilities. Some of these stimuli are natural such as ambient light, flow velocity, depth, channel shapes and temperature. Others, such as turbulence, bubbles, electrical charge, and sound are caused by artificial means. In this chapter, some of the more successful methods will be presented. Instream and return flow barriers to exclude upstream migrating fish are covered in chapter VIII.

A. Louver Design

Louvers consist of an array of vertical slats that are placed on a diagonal across a flow field to cause turbulence and, thus, fish avoidance (figure 23). Most often, louvers are applied in canals (open channels); although, they can be applied in diversion pools and in rivers if consistent sweeping hydraulics to the bypass can be maintained for all operating conditions. Louver systems are typically designed in a configuration similar to flat plate screens, with a linear louver line placement that leads to a bypass entrances (figure 94). Advantages of louver systems over flat plate screens are the following:

- The reduced overall structure size and, thus, reduced costs,
- Reduced potential for debris fouling and maintenance (with most debris types) when provided with an upstream trashrack

Disadvantages of louvers over flat plate screens include the following:

- Reduced fish exclusion performance (exclusion performance varies depending on fish species, size, life stage, and swimming strength)
- Increased debris fouling and maintenance (with certain debris types such as long stringy debris; e.g., Egria)
- Acceptance issues by the fishery resource agencies

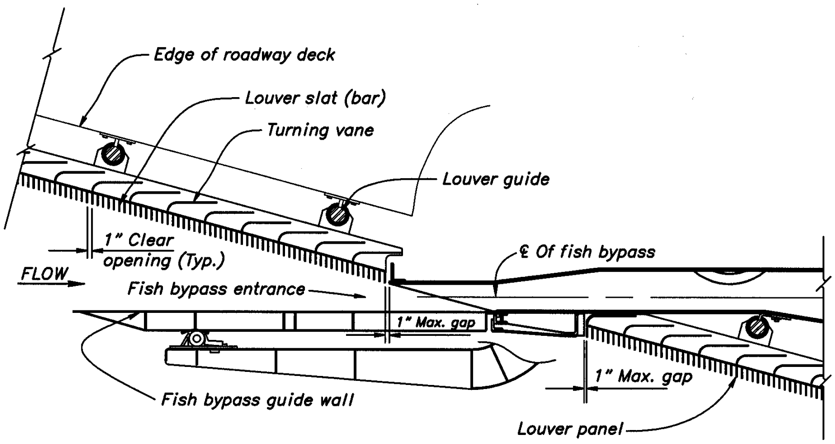


Figure 94.—Louver and bypass entrance design – Tracy Fish Collection Facility.

Parameters to consider when developing an effective louver barrier include louver slat spacing, velocities through the louver, the ratio of the channel velocity approaching the louver, V_c, and velocities entering the bypass, V_b. Studies have shown that, to achieve effective fish exclusion, the fish must efficiently move along the louver and into the bypass. If fish holdup, for example because of avoidance of the bypass, it is more likely that the fish will eventually pass through the louver line (Bates et al., 1960).

As with fish screen structures, a trashrack will usually be provided to protect the louvers and fish bypass from large debris.

Spacing between louver slats is typically larger than the body width of many fish to be excluded. In such cases, louvers do not physically exclude fish from the intakes, but instead, create hydraulic conditions that cause fish avoidance and lead to fish guidance along the louver face. The flow passing the slat array generates turbulence that fish tend to avoid. Louver systems rely on the fact that fish sense pressure fluctuations that guide them around obstacles. Fish tend to move with the passing flow along this turbulence line, maintaining a distance from the louver face, and are guided to bypass entrances (figure 23).

Louvers are, therefore, behavioral devices. The success of these systems depend on fish response to the hydraulic conditions. Louver performance can vary from poor to good in response to changes in hydraulic conditions and variations in fish behavior depending on fish species and size. Exclusion effectiveness varies as a function of flow conditions, fish species, fish life stage, and fish swimming strength.

As a result of field and laboratory evaluations and development of facilities by the Bureau of Reclamation (Reclamation) and the State of California in the 1950s and 1960s, louver systems became a viable alternative for fish exclusion at the time (Bates and Vinsonhaler, 1956; Lancaster and Rhone, 1955; Rhone and Bates, 1960; Skinner, 1974). Louver systems were developed to exclude fish from the large Federal and State pumped diversions (Delta-Mendota Canal and California Aqueduct) positioned on the south side of the Sacramento and San Joaquin Delta. At this site, water is diverted from a water body that is highly productive and includes a broad range of fish species, fish life stages, and substantial aquatic plant growths that produce large and diverse debris loads. The louver systems were developed for these sites because of fish and debris handling difficulties encountered with screen systems and because of the lower cost. Extensive studies were conducted considering hydraulics, configuration alternatives, and fish responses.

Application of louver systems expanded from the south Delta work to a scattering of irrigation and power diversions ranging in flow capacity from 100 cubic feet per second (ft^3/s) to 12,000 ft^3/s (Electric Power Research Institute [EPRI], 1986; EPRI, 1994). Currently, application of louvers is accepted and encouraged by fishery resource agencies at hydropower sites in the Northeastern United States and the Maritime Provinces of Canada. However, because of the documented inconsistencies in fish exclusion performance, and because 100 percent exclusion efficiencies are generally not achievable, State and Federal fishery resource agencies on the west coast of the United States discourage louver application. Louvers do offer a viable exclusion option at sites where 100 percent exclusion efficiencies are not necessary and where site-specific debris characteristics are appropriate (Office of Technology Assessment, 1995).

The fish exclusion effectiveness of louver systems is a function of the fishery, the structural features of the louver, water quality, debris loading, and flow conditions passing across and through the louver. Evaluations of the influences of various parameters on fish exclusion effectiveness have largely been conducted on a site-specific basis. Consequently, in studies conducted to date, the evaluations reflect the site-specific species, life stages, sizes, and conditions. The louver structures evaluated are often existing structures where configuration parameters are fixed and not varied with the evaluation. Water quality and debris loading are, likewise, usually dictated by site characteristics and not varied and often flow and hydraulic conditions are not varied but dictated by site operations. As a result, individual studies that generate a comprehensive design-guide database that is broadly applicable, do not exist. The combined findings from these studies do, however, give insight into parameter influences on louver performance. A summary of fish exclusion performance as obtained from a broad range of studies is presented in table 6. Exclusion efficiencies are the percentage of fish exposed to the water diversion that are excluded by the louvers. Therefore, the higher the percentage the more effective the fish barrier.

Table 6.—Summary of existing louver evaluations

Species	Size/life stage	Site	Exclusion efficiency (%)	Site features
Golden shiner	79 mm average fork length	Alden Laboratory[1]	29 34 22	* Louver line at 45 degrees to flow * 50 mm clear slat spacing * slats oriented normal to louver line * 1.0, 2.0, and 2.5 ft/s corresponding channel velocities * 6-inch-wide bypass * Approx. 1.2 bypass ratio
Smallmouth bass	72 mm average fork length	Alden Laboratory[1]	43 47 13	Same as above
Lake sturgeon	153 mm average fork length	Alden Laboratory[1]	28 0 2	Same as above
American eel	558 mm length	Alden Laboratory[1]	34 61 45	Same as above
Striped bass	20 mm length 40 mm length 60 mm length	Tracy Fish Collection Facility[2]	60 85 90	* Louver line set at 15 degrees to the flow * 25 mm clear slat spacing * Slats oriented normal to approach channel * 3.0 to 5.0 ft/s channel velocity * 6-inch wide bypass * 1.4 bypass ratio
Striped bass	21 mm average length	Tracy Research Facility[3]	93	* Louver line set at 16 degrees to the flow * 50 mm clear slat spacing * Slats oriented normal to approach channel * 2.2 to 3.3 ft/s channel velocity * 4-inch wide bypass * Bypass ratio not defined
Striped bass	20 mm 30 mm 40 mm 60 mm 90 mm	Skinner Fish Facility[4]	50 70 72 76 82	* “V” configured louver without center wall * Louver faces set at 15 degrees to the flow * 25 mm clear slat spacing * Slats oriented normal to approach channel * 1.5 to 3.5 ft/s channel velocities * 12.0-inch wide bypass * 1.2 to 1.6 bypass ratios
Striped bass	20 mm 30 mm 40 mm 60 mm 90 mm	Skinner Fish Facility[4]	78 82 84 85 90	Same as above but with: * “V” configured louver with center wall

Table 6.—Summary of existing louver evaluations

Species	Size/life stage	Site	Exclusion efficiency (%)	Site features
Chinook salmon	35 mm fork length 40 mm fork length 50 mm fork length 60 mm fork length	Tehama Colusa Canal headworks [5]	35 75 97 98	* Louver lines set at 15 degrees to the canal centerline * "V" configured louvers with center wall * A section width expansion was included immediately upstream from the louvers that generated less than optimum flow alignment and distribution approaching the louver lines * 25 mm clear slat spacing * Slats oriented normal to approach channel * Evaluated operating conditions could not be located (probable channel velocities 3 to 5 ft/s)
Chinook salmon	85 to 150 mm (fall) 140 to 295 mm (spring)	T.W. Sullivan Hydroelectric Plant [6]	94 90	* Forebay louver system in front of hydro intakes * Portions of louver line set at 17 degrees to and portions set parallel to approach channel * 25 and 38 mm clear slat spacing * Slats oriented normal to louver line * Channel velocities are variable depending on forebay elevation and position on louver line * The bypass is a terminal turbine intake
Steelhead	159 to 290 mm	T.W. Sullivan Hydroelectric Plant [6]	82	Same as above
Chinook salmon	71 mm average length smolt	Tracy research facility [3]	94 (90 mm) 97 (25 mm)	* Louver line set at 16 degrees to flow * 90 and 25 mm clear slat spacing * Slats oriented normal to approach channel * 1.9 to 2.5 ft/s (90 mm) and 2.4 to 4.5 ft/s (25 mm) channel velocity * 6.0-inch- and 4.0-inch-wide bypass * Bypass ratio not defined

Table 6.—Summary of existing louver evaluations

Species	Size/life stage	Site	Exclusion efficiency (%)	Site features
Atlantic salmon	Out-migrating smolt (length not defined)	Holyoke Canal[7]	92 (3-inch spacing) 80 (12-inch spacing)	* Power canal * Floating, partial depth louver line (extended to a depth of 8 ft) * Louver line set at 15 degrees to the flow * 3-inch and 12-inch clear slat spacing * Slats oriented normal to approach channel * Approaching channel velocities were variable with discharge and position (approx. 1.0 to 3.0 ft/s max.) * Large diameter bypasses ranging from 6 to 15 ft
American shad and blueback herring	Out-migrating juveniles (length not defined)	Holyoke Canal[7]	28 indications were that many fish passed under the louver 83 max velocity 60 half velocity	Same as above Full-depth louver with 2.375-inch slat spacing
White catfish	20 mm 30 mm 40 mm 60 mm 90 mm	Skinner Fish Facility[4]	7 17 25 30 60	* “V” configured louver without center wall * Louver faces set at 15 degrees to the flow * 25 mm clear slat spacing * Slats oriented normal to approach channel * 1.5 to 3.5 ft/s channel velocities * 12.0-inch-wide bypass * 1.2 to 1.6 bypass ratios
White catfish	20 mm 30 mm 40 mm 60 mm 90 mm	Skinner Fish Facility[4]	13 30 44 58 77	Same as above but with “V” configured louver with center wall

[1] Alden Research Laboratory, 2000.
[2] Heubach and Skinner, 1978.
[3] Bates and Vinsonhaler, 1956.
[4] Skinner, 1974.
[5] Vogal et al., 1990.
[6] Cramer, 1997.
[7] Stira and Robinson, 1997.

Effectiveness of fish exclusion – Fish exclusion effectiveness varies with fish behavior and responses to the louver, swimming strength, and fish size. As a result, exclusion effectiveness tends to vary as a function of fish species, fish life stage, fish size, and fish condition. Louvers tend to be most effective in excluding larger, more aggressive, stronger swimming fish and are poorer performers with smaller, weaker swimming, more passive fish. Again, the influence of velocity, water quality (as it influences fish condition), and louver system configuration must be considered with each evaluation. Effective fish exclusion is not ensured with louvers. Care must be taken in the design process, and the characteristics of the fishery and the refined details of the design must be considered.

With respect to fish species, results shown in table 6 indicate that species such as golden shiner, lake sturgeon, American shad, blueback herring, and white catfish display reduced exclusion efficiencies when comparable louver configurations and operations are considered. Conversely, species including smallmouth bass, American eel (larger size), striped bass, Chinook salmon, steelhead, and Atlantic salmon display good exclusion efficiencies for similar conditions.

Note also that behavioral characteristics including preferred habitat and fish distribution can affect performance, as is displayed in the Holyoke Canal studies where Atlantic salmon positioned high in the water column were effectively excluded by the surface based floating louver line while American shad and blueback herring tended to pass under the louver and were not excluded. Also of note from the Skinner Fish Facility studies, the addition of a center wall in the "V" configured louver system attracted and guided fish more effectively to the bypass, thus improving fish exclusion efficiencies.

Bypass system – Bypass systems for louvers are similar to, and should be designed in full compliance with, fish screen bypass criteria as summarized in chapter IV.A.9 of this document. In that louvers are behavioral devices, it is critical that fish efficiently enter the bypass and do not delay or hold. Louver effectiveness depends, in part, on maintaining good sweeping flow across the louver face. If fish hold position, for example in response to avoidance of a bypass entrance, passage through the louver becomes an option in lieu of entering the bypass entrance. Again, the louver is not an absolute barrier for the smaller fish in the system.

Studies conducted at the Tracy and Skinner Facilities (Bates et al., 1960; Skinner, 1974) have shown the bypass velocity ratio (the ratio of bypass velocity, V_b, to channel velocity, V_c, upstream from the louver system, or V_b/V_c) is a parameter that should be considered. Bates et al. (1960) recommend that the Tracy Facility be operated with a bypass ratio of 1.4. Later studies at the Skinner Facility, however, were contradictory to the 1.4 ratio. Skinner (1974) concludes:

> Authorities generally agree that bypass design is critical for fish screens. This appears to be particularly true for louvers. Conventional louver design usually results in an incremental increase in approach water velocity (channel velocity) which distorts the relationship between bypass ratio and the approach velocity (channel velocity). At this point I am convinced that approach velocity (channel velocity), bypass design, and bypass acceleration ratio are so interrelated that the true effects of bypass ratio and approach velocity (channel velocity) are confounded.

Care should be taken in bypass design. Operation with bypass velocity ratios ranging from 1.1 to 1.5 appears to be appropriate.

Channel Velocity – Channel velocity, coupled with the angle of louver line placement across the flow, yields louver approach and through-louver velocity magnitudes that influence turbulence level, fish guidance, and fish entrainment characteristics for the louver surface (similar to screens, see chapter IV.A.5). Higher design velocities approaching the louver (with a specific louver configuration) will permit smaller louver structures. Higher approach velocities may, however, yield an increased potential to entrain or pass fish through the louver, thus yielding reduced exclusion efficiencies. Conversely, low velocities may not supply sufficient fish guidance along the louver, which may also yield reduced exclusion efficiencies. The influence of velocity depends, in part, on the fishery and swimming strength.

As presented in table 6, the Alden Laboratory studies demonstrate that for golden shiner, smallmouth bass, and American eel, best exclusion is obtained with a channel velocity of 2.0 ft/s; reduced exclusion is experienced with higher and lower velocities. In the same study, however, Lake sturgeon showed best exclusion with the low-end velocities. Also shown in table 6, the Holyoke Canal studies with a full depth louver showed best American shad and blueback herring exclusion with maximum local velocities of up to 2.5 ft/s (velocities of 0.8 ft/s occurred over portions of the louver). Reduced exclusion resulted when maximum velocities were reduced to 1.8 ft/s (with velocities of 0.6 ft/s over portions of the louver).

Skinner’s (1974) studies show findings implying that reduced velocities approaching the louver are more effective with smaller, weaker swimming fish. In his cited evaluation that presents exclusion efficiency for juvenile striped bass, Skinner shows that for fish shorter than approximately 30 mm, better exclusion is obtained with a louver operated with a channel velocity of 1.0 ft/s. The results imply that for striped bass longer than approximately 35 mm, best exclusion is obtained with channel velocities of 2.75 ft/s. Again from table 6, comparison of the Tracy and Skinner findings for longer (greater than 40 mm) striped bass indicates that better exclusion is obtained with channel velocities of 3.0 to 5.0 ft/s.

No clear-cut criterion can be established from table 6. However, indications are that if the design is focused on small and weak swimming fish, a design channel velocity of 1.0 to 2.0 ft/s may be appropriate. Likewise, if the design is focused on larger and strong swimming fish, design channel velocities of 2.75 to 4.5 ft/s would be appropriate.

Support structure including louver panel seats, seals, and supports – Louvers are typically supported by a steel frame placed on a concrete foundation (figure 120). Louver panels are usually set in an end to end arrangement (like flat plate screen panels). The louver panels are typically supported by guides positioned behind the louvers, that allow panel removal while maintaining an uninterrupted louver face (figures 97 and 98). Openings between the louver bars are large and the louver does not supply an absolute barrier to fish passage; therefore, seals are not required between louver panels or between the louver panels and the support structure or bypass. Likewise, panel seats do not have to be exactly true. Offsets or changes in alignment along the louver face will modify the fish guidance and entrainment characteristics of the louver for small fish (striped bass under 20 mm long) (Skinner, 1974). Skinner notes that for fish longer than 30 mm, “louver alignment and gaps are probably not critical within the range of misalignment tested.”

Partial depth, floating louver lines have been successfully applied (Stira and Robinson, 1997) at a site with a deep flow section (20 ft deep) and with fish that concentrate near the surface. The floating array minimizes required structure, although access for maintenance and cleaning is not convenient.

Head losses – Head losses across louvers are a function of the louver configuration, the flow rate/velocity, and debris fouling. Louvers are designed to operate with channel velocities that are 2 to 3 times greater than allowed for fixed barrier screens. Therefore, head losses across clean louvers can be up to 10 times greater than losses across clean screens because of the higher channel velocities. Louver bars and the line configuration to the flow generate fish-avoidance turbulence, but also generate flow concentrations that lead to increased head loss. Lancaster and Rhone (1955) note that with louver lines placed at 30 degrees and flatter to the flow, head loss characteristics are independent of louver line angle but depend on slat configuration and orientation of the slats to the flow. Turning vanes were used to reduce total louver line losses by 30 to 40 percent. Findings from the Tracy studies (Lancaster and Rhone, 1955; Rhone and Bates, 1960) indicate that, for louver lines placed at 30 degrees or flatter to the flow, with slats oriented at 70 to 90 degrees to the flow, and with turning vanes, head losses will equal 2 to 4 times the channel velocity head. Thus, for a channel velocity of 3 ft/s, the loss across a clean louver would range from 0.28 to 0.56 ft, varying with specifics of the design.

Head losses of 0.3 to 0.5 ft are commonly observed across clean louvers with uniform channel velocity distributions (using turning vanes or optimized channel configurations, as discussed below under “flow distribution control”). For louvers with non-uniform channel velocity distributions (usually channel velocities are small at the lead end of the louver line and large at the tail end), head losses of 1 ft or greater have been observed at the tail end of the louver line, with clean louvers. Debris fouling will further increase losses. Since automated cleaners are typically not included with louver facilities, conservative head differentials should be applied in the design.

Debris cleaning – Debris fouling and cleaning issues associated with louvers are strongly influenced by debris type. Louvers, by their nature, are composed of large vertical slat elements with intermittent cross-ties or bracing. Louvers, likewise, include fairly large openings that pass smaller debris and sediment. Larger debris, however, will tend to either intertwine in the slat structure (for long fiber debris such as many aquatic plants) or embed between slats (for woody twigs or the like). Large debris fouling has been a major problem at Reclamation sites, including the Tracy Fish Collection Facility, California (fouling with aquatic plants) (figure 95) and the T and Y Canal, Montana (fouling with woody materials). At both of these sites, cleaning is difficult. At the Tracy facility, louvers are physically lifted from the structure and spray cleaned once or twice a day during high debris time periods (figure 96). At the T and Y Canal, woody debris has to be manually removed from the louver.

Because louvers have a large percentage of open area and tend to pass smaller debris, they become severely plugged at a slower rate than screens. Louvers tend to continue to pass flow with significant debris accumulation while fine screens may become plugged. As a result, louvers usually require less frequent cleaning than fine screens.

Even though debris fouling may not result in immediate or significant flow blockage, it modifies the fish exclusion characteristics of the device. Experience with the Tracy Fish Collection Facility secondary dewatering facility indicates that debris fouling will lead to significant reductions in fish exclusion capability. As a result, even though flow rates are sustained, more frequent cleaning might be appropriate to sustain best levels of fish exclusion.

Prevalent debris type and probable cleaning requirements should be carefully considered if a louver facility is pursued.

Figure 95.—Fouling of Tracy Fish Collection louvers by Egria.

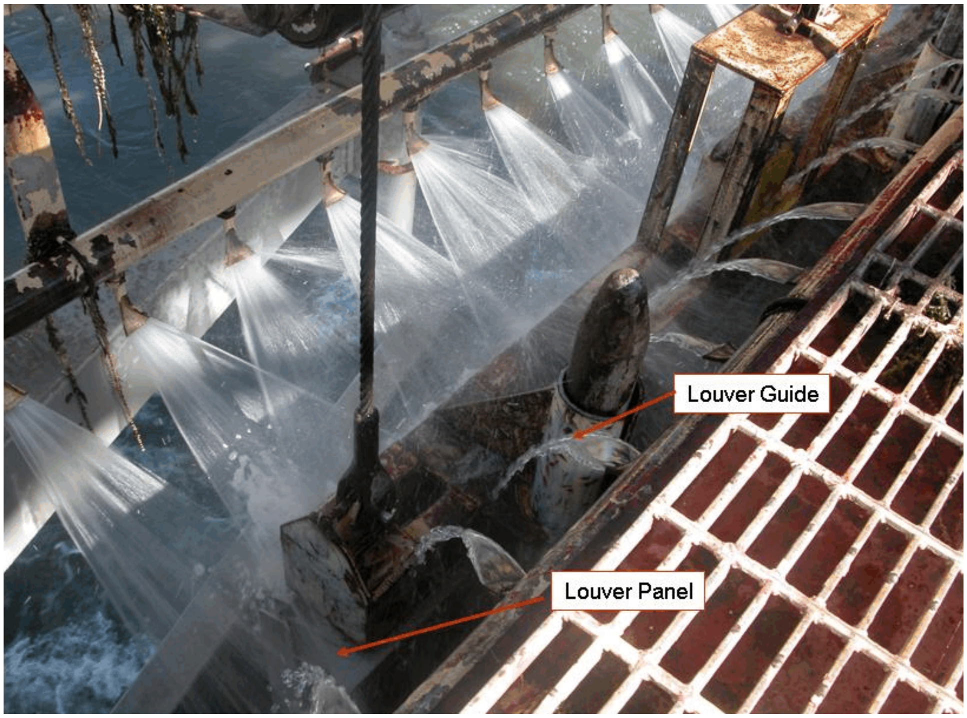


Figure 96.—Spray bar used to clean louvers at Tracy Fish Collection Louvers (downstream spray bar not operating).

Cold weather operation – Little experience is available with the operation of louver systems in cold weather. It appears, however, that louvers should be less sensitive to icing and ice blockage than fish screens because of the larger slat opening sizes. It is likely that, with heavy ice production and frazil ice development, ice fouling would occur and would require shutdown of the diversion or louver panel removal.

Sedimentation – Louvers have relatively good characteristics with respect to sediment passage. Openings in the louvers are large (typically 1 inch or greater). Concentrated velocity zones are generated between each louver slat, which generates aggressive local sluicing. Louvers have been successfully operated at sites that include significant sediment passage including at Reclamation's Tracy Fish Collection Facility and Reclamation's Tehama Colusa Canal headworks. (The louvers have since been removed at Tehama Colusa and replaced with drum screens.)

Design guidelines – A scattering of studies have been conducted that evaluate the influence of slat depth, slat thickness, slat spacing, slat orientation, angle of louver line placement to the flow, and flow velocities and velocity distribution control on both the hydraulic and fish handling performance of the louver system. As with the fish exclusion studies summarized in table 6, a limitation of most of these studies is that they tend to focus on site-specific applications considering specific fish species and site configurations. Broader, generic studies have not been conducted. The combined findings do supply some insight and design guidance.

Slat dimensions – Louver slat thickness and depth (figures 97 and 98) are typically based on structural and rigidity considerations. Within the structurally acceptable limits, indications are that louver slat dimensions have little effect on fish guidance and hydraulic performance. In the Tracy Facility developmental studies (Bates and Vinsonhaler, 1956), 2.5-inch-deep steel slats were evaluated with slat thickness ranging from 0.125 to 0.5 inch and with clear spacings of 1.0 to 3.5 inches. A 0.1875-inch slat thickness was selected for the permanent facility design. Schuler and Larson (1975) evaluated steel louvers with 2.0-inch slat depths and 0.125-inch slat thicknesses, considering alternatives in slat and louver line orientation that showed that coastal salt water fishes could be effectively guided by louver systems. The Alden Laboratory (2000) studies evaluated plastic slats that were 4 inches deep and 0.5 inch thick. The plastic slats were applied only in a laboratory setting. The Holyoke Canal evaluation used 2.5-inch-deep by 0.375-inch-thick polypropylene floating slats with 2, 3, and 12-inch clear spacings. Louvers were evaluated extending 4 and 8 ft down from the water surface. The floating configuration minimizes differential loading on the slats. The final selected design used a 2.0-inch clear spacing between slats.

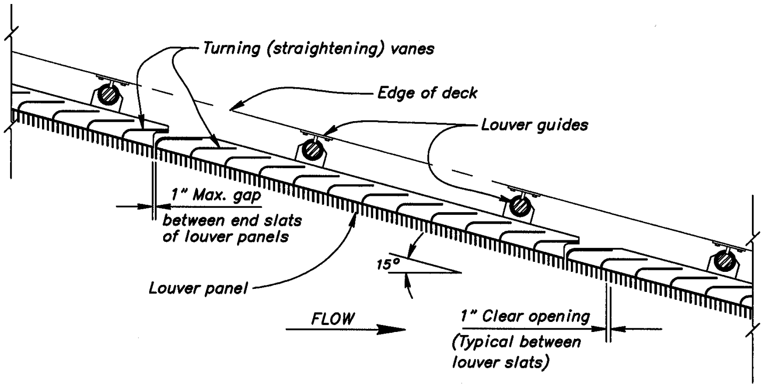
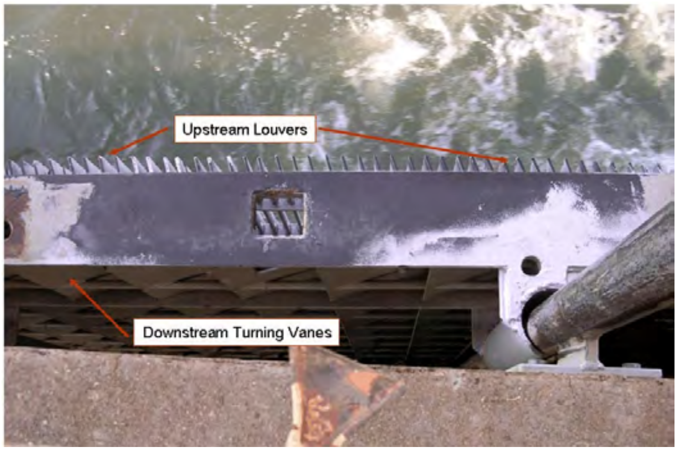


Figure 97.—Detailed louver layout.



a. Louver in louver guides.

b. Looking at downstream side of removed louver.

Figure 98.—Tracy louver panel.

Clearly, slat material and strength characteristics, structure size and configuration, and potential hydraulic and debris loading should be considered in sizing members. Typically, however, it appears that, for steel slats with a 1- to 3-inch clear spacing, precedence indicates a 2.5-inch slat depth with approximately a 0.2-inch material width is appropriate.

Slat spacing – Evaluated and applied slat spacings to (figures 94 and 97) range from 1.0 to 12.0 inches. Appropriate spacings appear, in part, to depend on the size of the fish to be excluded. Study findings (Bates and Vinsonhaler, 1956; Stira and Robinson, 1997) indicate that clear slat spacings of 1.0 to 3.0 inches supply comparable fish exclusion performance in many cases. However, permanent installations typically use a conservative free spacings of 1.0 to 2.0 inches.

Slat orientation – Slat orientations ranging from parallel to the channel flow to normal to the channel flow have been evaluated. Head loss is reduced with reduced angles of attack (angle of placement with the flow); however, fish exclusion and guidance characteristics are also reduced as slat orientation approaches parallel alignment with the flow. Bates and Vinsonhaler (1956) evaluated slats placed at 90 (normal to), 70, and 0 (parallel to) degrees to the flow. They note that the parallel slat orientation did not divert fish but that the 70 and 90 degree orientations were effective. Schuler and Larson (1975) evaluated slats oriented at 90, 70, 60, and 52 degrees to the flow. These slat orientations correspond to slat placement either normal to the approach channel or normal to the louver line with louver lines placed at 20, 30, and 38 degrees across the channel. They observe that best fish guidance characteristics were obtained with the louver line placed at a 20 degree angle to the channel and with the louver slats oriented normal to the louver line (oriented at 70 degrees to approach channel and channel flow).

Permanent installations have generally been developed either with slats placed normal to channel flow or with slats placed normal to the louver line. The louver lines are most commonly oriented at angles ranging from 0 parallel to) to 17 degrees to the approach channel and channel flow. This places the slats at angles ranging from 90 degrees to 73 degrees to the approach flow. Figure 98a illustrates the Tracy Louvers as they are installed at the Tracy Pumping Plant. The slats are placed normal to the channel flow. The louver is shown in a raised position for cleaning in figure 98b. The turning vanes are easily seen on the backside of the lower frame.

Angle of louver line placement – Louvers are placed at an angle across the flow to generate a sweeping flow that provides fish guidance across the louver face and to the bypass entrances (figure 23). The objectives are similar to guidance objectives pursued with an angled screen placement (chapter IV.A.5). Generating effective fish guidance and maintaining fish passage across the louver face is likely more critical for achieving effective fish exclusion performance with louvers than with screens in that louvers depend on fish avoidance. Indications are that if fish hold position in front of the louver, the louvers tend to lose effectiveness (field observations indicate that in zones where fish do not sweep across the louver face there is an increased tendency for the fish to pass through the louver).

Louvers have been evaluated placed at angles ranging from parallel to the flow to 45 degrees to the flow. Typically, and particularly for permanent facilities, louvers are placed at flat angles to the flow. The Alden Research Laboratory (2000) evaluations indicate that steeper angles of placement produce substantially reduced fish exclusion. Note, in table 6, that except for the large American eels evaluated (558-mm mean length), observed exclusion efficiencies were less than 50 percent with the 45 degree placement. These efficiencies are lower than nearly all other efficiencies observed (table 6) even with very small fish. Based on Reclamation laboratory and permanent facility observations, it is recommended that designs be developed based on louver line placements ranging from parallel to the flow to 17 degrees to the flow.

Flow distribution control/turning vanes - Localized high velocities through louvers should be avoided. These local high velocities will likely increase entrainment and passage of fish through the louver and reduce fish exclusion efficiency. As with screens, velocities approaching the louver structure are a function of local hydraulics and differentials (chapter IV.A.5). Local variations in differential are influenced by approach and exit flow concentrations, structure and channel geometries, and head losses in the system.

A common flow distribution along the louver line includes low channel velocities at the lead end of the louver line and high channel velocities at the tail end of the line. These high velocities, therefore, occur at and near the bypass entrances, which are critical locations in that fish concentrations are high and a potential exists for fish to hold as a result of avoidance responses to the bypass entrance. This is demonstrated in the Alden Research Laboratory (2000) study where a differential of 1.2 cm was documented at the lead end of the louver and a differential of 34.4 cm was documented at the tail end of the louver, with the louver operating with a channel velocity of 2.5 ft/s. This is a relatively low channel velocity and, yet, severe differential gradients were generated as fish move downstream along the louver line. This differential distribution yields a fivefold increase in through louver velocity magnitudes over the louver line length.

Unlike with screens, flow resistance or baffling behind louvers is typically not used to modify flow distributions. This may be because debris and sediment can pass the louvers and accumulate on baffling behind the louvers. An exception would be use of treatments such as partial stop logging (chapter IV.A.6) that would still allow sediment and debris passage while generating flow rate controlling back pressure.

Preferred techniques for controlling approach velocity distributions include optimizing approach and exit channel configurations and using turning vanes placed behind the louvers (chapter IV.A.6). Lancaster and Rhone (1955) developed a turning vane system for the Tracy Facility that incorporates the turning vanes in the louver support panels (figure 97). This has proven to be an effective approach velocity distribution control technique that allows simplification of approach and exit channel geometries while maintaining good approach velocity distributions. Rhone and Bates (1960) noted that, for this design:

> Tests showed that, if the flow emerging from the louvers was turned by vanes to flow downstream, backwater effects were minimized and good approach flow resulted. Improved flow/outflow conditions might also have been achieved by re-alinement of the stream channel downstream from the louvers but this would have been very expensive and impractical in this case.

B. Electrical Fields

Electrical fields have not proven to be very successful in guiding fish and have had limited success as fish barriers. Electrical fields are used to cause an avoidance response by fish. The effectiveness of the electrical fields depends on site specific physical parameters such as: flow velocities, conductivity, and water temperature (EPRI, 1986). Issues such as fish fatigue near an electrical field and balancing the power of the electrical field depending on fish size have not yet been resolved.

Several commercial products are available and have performed with various degrees of success. A system was evaluated by Bengeyfield (1989) at Puntledge Diversion Dam. The system was deployed to divert outmigrating coho salmon smolts from a hydro power intake and toward a bypass structure. The strength of the electrical field increased in the downstream direction as the barrier was placed at an angle to the intake. The effectiveness of diverting fish from the intake ranged from 2–22 percent. Factors such as unstable flow patterns, incomplete electrical fields, ineffective bypass structures, and combinations of all these caused the barrier to fail.

Wilkins Slough Pumping Plant personnel and Reclamation staff worked with various behavioral suppliers in testing experimental acoustical and electrical fish fields for over 4 years to try to evaluate and develop a more cost-effective barrier than the positive barrier screens. Although there was considerable and valuable data gathered, these experimental devices did not prove as effective as positive barrier screens and, in most cases, are not acceptable as proven fish barriers by fishery resource agencies.

More recently, the U.S. Army Corps of Engineers (Corps) has been working to deploy an electrical fish barrier in the Chicago Sanitary and Ship Canal (Hansen, 2004). Because the waterway is possibly the only direct connection between the Great Lakes and the Mississippi River and invasive, very aggressive carp species have been found in the Mississippi River, the Corps is looking for a creative way to keep the fish from swimming upstream through the ship channel to the Great Lake watersheds. The challenge is to develop a barrier where barge traffic can continue to use the channel but fish will be repelled from moving through the channel to the lakes. The barrier selected will emit an electrical field intense enough to reach the surface and repel fish even as barge traffic passes through the barrier. Much of this effort is directed by the National Invasive Species Act of 1996.

C.   Strobes and Lighting

Strobes and lighting systems use light to either attract or repel fish. These can be used either to drive fish away from water diversions and intakes, thus excluding fish from the diversion, or to attract or guide fish to a desired location or elicit some desired response. Many devices generating wide ranges of lighting intensity, wave band frequency, and lighting durations have been applied. These are purely behavioral devices that depend on fish behavioral responses to achieve control. Lighting systems offer a low capital and operation and maintenance (O&M) cost option for fish control. They can be applied at difficult sites that are either very large, pass large flows that would be difficult or expensive to screen, or that are inaccessible (such as a deep intake in a reservoir). Lighting systems might also be considered for application at sites where cost would otherwise not allow installation of fish exclusion devices. The primary drawback of lighting systems is their inconsistency in excluding or guiding fish. They have proven effective at some sites with specific fish species and life stages and ineffective at other sites. The performance of lighting systems, particularly when applied at shallower depths, is also strongly influenced by the daylight or ambient sun lighting which will dominate over any artificial lighting effects. Consequently, lighting systems, when applied at shallower sites, are typically effective only at night. Lighting systems are generally seen by fishery resource agencies as developmental and unproven technology, which is a valid perspective. Lighting and strobe systems are commercially available and are actively promoted.

Lighting systems may be found more useful for improving the performance of conventional fish exclusion devices, for example, by using lighting to attract fish to the fish bypass entrances and away from the diversion intakes and screen structures. Lighting of bypass entrances may also encourage fish entrance into bypasses, thus expediting fish passage.

Optional devices – Lighting devices that have been used include strobe lights to repel fish from intakes or to guide fish toward desired locations by using an avoidance response; mercury vapor lights that attract fish to bypass entrances or safe locations and away from intakes; and incandescent, fluorescent, overhead sodium vapor, and drop lights that have been investigated both as attractants and deterrents (EPRI, 1994; EPRI, 1999).

Underwater strobe or flashing lights have been shown to be more effective than continuous lighting in repelling fish. Response has, however, been shown to depend on fish species, fish life stage, and as addressed above, on the influence of ambient lighting. Studies have also shown that flashing rate (number of flashes per minute) and flash intensity influence the fish response to the particular light source.

Mercury vapor lights are used primarily to attract fish, although in some applications, they will cause avoidance (a function of species and life stage). Mercury vapor lights have been effectively applied to attract out-migrating salmonid smolt to bypass entrances. As with other lighting options, mercury vapor lights can be used to supplement and improve the performance of conventional screening devices.

Underwater incandescent lights have been examined as fish attractants and deterrents, and underwater fluorescent and drop lights have been tested as fish deterrents. Overhead sodium lights have been assessed as attractants. Attempts have also been made to use existing facility lighting to improve fish passage characteristics. Mixed success has been achieved in these studies. Lighting does show potential for supplemental improvement of conventional fish facility performance.

Experience with alternative systems is summarized in table 7. The table provides a partial listing of field experience cited in EPRI, 1999. This table is included to display the extent of application efforts conducted and the mixed results achieved. More detail can be found in EPRI, 1999.

Laboratory/caged evaluations – In many cases, laboratory and caged evaluations of fish response are initially conducted to determine if the fish species and life stages of interest show response to the light or strobe stimuli being considered. Often, fish show response in these caged studies but then show little or no response in field applications. Field applications indicate that some fish species and life stages will respond to strobes; however, field results are often inconsistent and difficult to interpret because of confounding parameter influences. These inconsistencies may be due to the light intensities that the fish

Table 7.—Summary of field application experience with lighting and strobe systems (summarized from EPRI, 1999)

Site	Fish species	Lighting device	Effectiveness
Mattaceeunk (Weldon Dam)	Atlantic salmon	Strobe (200 fl/min)	Effective on upstream units but not downstream
Rolfe Canal	Atlantic salmon	Strobe (300 fl/min)	Ineffective
McNary Dam	Pacific salmon smolt	Strobe (150, 200 fl/min)	Effective in repelling from juvenile bypass screen
Rocky Reach Dam	Pacific salmon	Strobe	Ineffective at improving submerged traveling screen performance
Puntledge	Coho salmon	Strobe (60 fl/min)	Ineffective when coupled with hanging chains
Burbank No.3	Pacific salmon	Strobe (300 fl/min)	Inconclusive
Hiram H. Chittenden Locks	Sockeye salmon	Strobe	Effectively repelled away from rock filled culvert
Four Mile Dam	Bullhead, shiner	Strobe (300 fl/min)	Reduced entrainment
York Haven	American shad	Strobe (300 fl/min)	Effective in driving fish through sluice
Hadley Falls	American shad	Strobe (300 fl/min)	Ineffective in excluding from canal
Mattaceeunk (Weldon Dam)	Atlantic salmon	Mercury light	Increased bypass use with back-light inlets
Turners Falls	Atlantic salmon	Mercury light	Overhead light attracted fish to sluiceway
Wapatox	Pacific salmon, steelhead	Mercury light	Improved bypass rates with correct light intensity
Wanapum	Pacific salmon steelhead	Mercury light	Inconclusive
Poutes Project	Atlantic salmon	Mercury light	3 to 5 fold increase in bypass use
York Haven	American shad	Mercury light	No effect
Hadley Falls	American shad blueback herring	Mercury light	No effect
Annapolis Tidal Station	American shad blueback herring	Mercury light	Slight attraction
Richard B. Russell	Blueback herring	Sodium lights	Attracted fish away from pump storage
Mattaceeunk	Atlantic salmon	Incandescent	Increased collection
Rolfe Canal	Atlantic salmon	Incandescent	Ineffective
Rocky Reach Dam	Pacific salmon	Incandescent	Back-lighting trashrack did not improve collection

are exposed to in the caged studies are greater than what the fish are exposed to in the field, where a broad expanse of open water (with turbidity) dissipates the lighting. Structure configurations, environmental conditions, and operational influences also may affect the lighting field and fish responses. A consideration in the laboratory/caged studies would also be reflection of light off of hard surfaces within the cage and the effect of these reflections on the fish exposure. When trying to identify the potential for strobe and light application through the use of cage and laboratory studies, care must be taken to generate light intensities and a light field that is representative of what will occur in the field application.

Example installation: Wapatox Canal, Washington – Supplemental mercury vapor lighting was added to the bypass entrances on an aging drum screen structure in an attempt to improve the screen structure's fish guidance and bypass capabilities (primarily for Chinook salmon and kokanee). The Wapatox Canal delivers flows ranging from 300 to 500 ft^3/s for irrigation and hydropower production. The canal had an aging drum screen (the screen has since been replaced) that included six 6.6-ft-diameter drums placed normal to the channel flow. The fish bypass entrances located on each abutment of the structure were relatively small. The combined effect of the normal screen placement (with no angled configuration that would supply fish guidance to the bypass entrances) and the small bypass entrances lead to poor fish guidance to the bypasses and, thus, delayed fish passage.

As a research effort EPRI (1999) and Pacific Power and Light (the facility owner) installed a 1,000-watt underwater mercury light on the left side of the canal, illuminating the zone around the left bypass entrance. In addition, a mercury vapor light was located inside the left bypass entrance to illuminate the bypass slot entrance. A paired testing program was used to evaluate performance with and without the lights on. Resulting rates of fish passage and fish impingement of the drum screens were monitored.

As testing progressed, it was found that light intensity was a consideration. With high intensity lighting, fish would approach the lighted zone but would not enter the intake. Immediately after the lights were turned out, however, the accumulated fish would pass through the bypass. The next phase of testing was conducted with reduced lighting intensity. When this was done, a substantial increase in fish passage resulted. With the reduced light intensity, nearly twice as many fish were passed through the bypass when the lights were on than when the lights were off.

Support structure – Strobe and lighting systems require minimal support structure. Most commonly, lights are attached directly to the intake structure or associated wing walls. Deployment may require a large framework to support the lights, and to provide a sufficient array of lights. On occasion they are also deployed from bridge piers, safety cables, debris booms, and from buoy lines. Protection of lights from debris loading is a concern and should be considered.

Head loss – Lighting systems have no effect on the head loss characteristics of intakes.

Debris cleaning – Debris and debris cleaning is typically not an issue with lighting systems. Routine maintenance demands associated with debris and debris removal should be minimal. A significant concern is protection of lights and cables from damage from debris during flood events. Lights require unobstructed access to the approach water body. Submerged placement of lights may protect them from floating debris. Removal of lights and cables during severe flood events (when exclusion may not be a high priority) may be an option.

Cold weather operation – With submerged placement, light exclusion systems should be functional with minimal maintenance requirements during icing conditions. Again, ice loading and potential surface and float ice damage should be considered in developing the system design.

D. Sound

Sound systems are used to elicit a response to either drive fish away from diversions and intakes, thus excluding the fish from the diversion, or to guide or direct the fish to a desired location. Many devices generating wide ranges of sound magnitude and sound frequency have been used. As with light systems, sound systems offer a low capital and O&M cost fish control option. Sound systems can be applied at difficult sites that are either very large, that pass large flows that would be difficult or expensive to screen, or that are inaccessible (such as a deep intake in a reservoir). Sound systems might also be considered for application at sites where cost would otherwise not allow installation of fish exclusion devices. The primary drawback of sound systems is their inconsistency in generating fish exclusion and guidance. They have proven effective at some sites with specific fish species and life stages and ineffective at other sites. Sound systems are generally seen by fishery resource agencies as developmental and unproven technology. Sound systems are commercially available.

Optional devices – Devices that have been used include low-frequency mechanical sound generators (hammers, poppers, fish drones) and sonic transducer systems that generate a wide range of frequencies (EPRI, 1994; EPRI, 1999). Mechanical devices that have been used include the hammer (or fishpulser), which is an impact device that uses a spring-driven mass to excite the resonant modes of a submerged structure. It produces a high-energy, low-frequency sound with a duration of approximately 200 milliseconds that is repetitively generated. Poppers are pneumatic devices that produce low-frequency (20 to 100 Hz,) high-amplitude sound through the valve controlled release of air from a pressurized chamber. Poppers produce an acoustic signal that has a rapid peak (2 milliseconds in duration) followed by a low ringing that lasts for about 150 milliseconds. The fishdrone is a device that uses sonic vibrations to excite metallic structures. Frequencies ranging from 20 to 1,000 Hz can be generated either continuously or intermittently, producing regular or irregular pulses. These mechanical sound systems have not been consistently effective in repelling fish species. Their application and evaluation were actively pursued in the 1980s. Currently, little activity and interest exists with mechanical sound systems.

Transducer systems use speaker-like systems or oscillating pistons to generate sound with frequencies ranging from less than 100 Hz to 190 kHz. Lower frequency transducer based systems (100 Hz to 20 kHz) have generated avoidance responses from many species in cage studies but little response and exclusion effectiveness in field trials. In EPRI (1999), it was observed that “the use of low frequency transducer based sound systems does not appear to be a viable alternative for protecting fish at water intakes.” High-frequency, transducer-based systems have been highly effective in generating avoidance and exclusion for clupeid species (shad and herring) and alewife at intakes. High frequency systems have shown mixed and partial success with salmonid species (salmon and trout) guidance and exclusion.

Infrasound generators that generate sound or flow fluctuations with frequencies less than 100 Hz (typically 10 to 60 Hz) using either an oscillating piston or a rotating valve with openings in it have recently shown potential. These systems include substantial water displacement, which generates more particle motion than acoustic pressure fluctuations. Studies have indicated that they may generate effective fish response in the near field; however, substantial uncertainty still exists with infra sound system performance. The extent of the zone of influence does not appear to be well documented.

Experience with alternative systems is summarized in table 8. This table provides a partial listing of experience cited in EPRI (1999). This table is included to display the extent of efforts conducted and the mixed results achieved. If more detail is desired, reference EPRI, 1999.

Laboratory/caged evaluations – In many cases, laboratory and caged evaluations of fish response are initially conducted to determine if the fish species and life stages of interest show response to the sound stimuli. Often, fish will show response in these studies similar to the response to lighting systems, but then will not show response and exclusion in field applications. This may be because the sound magnitudes that the fish are exposed to are greater in the laboratory/caged evaluations than in the field where a broad expanse of open water with sound dissipation at soft boundaries could reduce sound intensities.

Table 8.—Summary of field application experience with sound systems (summarized from EPRI 1999)

Site	Fish species	Sound device	Effectiveness
Hiram M Chittenden Locks	Sub-yearling and yearling Pacific salmon and steelhead trout	Transducer (300/400 Hz)	Ineffective
Bonneville Dam turbine intakes	Pacific salmon smolt	Transducer (300/400 Hz)	Ineffective
Georgiana Slough	Chinook salmon smolt	Transducer (300/400 Hz)	Less than 60% effective
Wilkins Slough	Chinook salmon	Transducer (300/400 Hz)	Inconclusive
Reclamation District 1004	Chinook salmon	Transducer (300/400 Hz)	56 to 60% effective
Berrien Springs	Chinook salmon steelhead trout	Transducer (mixed frequency between 100 and 1000 Hz)	Unquantified reduction
Buchanan	Chinook salmon steelhead trout	Transducer (mixed frequency between 100 and 1000 Hz)	81% guidance chinook salmon 94% guidance steelhead
Puntledge	coho salmon	Popper	No effect
McNary Dam	Pacific salmon	Infrasound/piston (≤20 Hz)	Inconclusive
Sandvikselven River (Norway)	Atlantic Salmon	Infrasound/piston (10 and 150 Hz)	10 Hz - potentially effective 150 Hz no effect
Roza Diversion Dam	Chinook salmon	Infrasound/piston (rotating valve 10-50 Hz)	No response
Hiram M. Chittenden Locks	Pacific salmon -sub yearling chinook	Infrasound/piston (10 Hz) and rotating valve (10-30 Hz)	Piston - mild avoidance valve - ineffective
Rolfe Canal	Atlantic salmon	Infrasound (air-driven pneumatic oscillators)	Mild avoidance
York Haven	American shad	Transducer (120-125 kHz)	Repelled juveniles from powerhouse guiding them to a sluice
Vernon	American shad	Transducer (125 kHz)	Repelled juveniles from powerhouse
Hadley Falls	American shad	Transducer (161.9 kHz)	Generate strong avoidance and guidance
Hadley Falls	American shad	Hammers	Inconclusive
Lennox	Yellow perch, pumpkinseed, black crappie, rock bass	Fish drone (27, 64, 99, and 153 Hz) Hammer	Little effect at 27, 64, and 99 Hz, noticeable response at 153 Hz. hammer - no effect

Many field installations include multiple sound generators that are used to generate a continuous, complex, overlapping sound field. A concern in the laboratory/caged studies would also be reflection of sound off hard surfaces within the cage and the effect of these reflections on the sound field. When trying to identify the potential for sound application through the use of cage and laboratory studies, care must be taken to generate sound intensities and a sound field that is representative of what will occur in the field.

Example installation: Georgiana Slough, Sacramento River, California – A prototype sonic barrier was installed and evaluated over several years in the early 1990s at the confluence of Georgiana Slough and the Sacramento River (figure 24). This effort was supported by State and Federal water and fisheries agencies including Reclamation (San Luis & Delta-Mendota Water Authority, et al., 1996; Hanson, et al., 1997). Georgiana Slough is a channel within the Sacramento-San Joaquin Delta. Pumping at State and Federal pumping plants located on the south side of the delta draws Sacramento River water into the slough and consequently into and through the delta. A particular concern is that out-migrating juvenile salmon smolt might be attracted into the slough and the delta and, thus, diverted from a direct out-migrating path down the Sacramento River to the ocean. The objective for use of the sonic barrier was to divert out-migrating Chinook salmon smolt in the river to the opposite bank, away from the slough entrance. It was recognized that the facility likely would not be 100 percent effective. The testing was conducted to evaluate exclusion efficiencies that could be achieved and to address and evaluate other performance concerns, including the possible delays with both upstream and downstream fish movement in the river caused by the sound generators.

Both the river and the slough are low gradient channels (slow moving water). The site experiences tidal influences that cause variations in flow velocities and may, on occasion, cause flow reversals. Maximum flood events typically occur in the winter and spring with storm events that may be influenced by snow melt runoff. Debris loading may be substantial and may include trees and other large components. In addition, both recreational and commercial navigation occurs at the site. The range of river flows during testing was from 1,600 ft^3/s to 15,000 ft^3/s.

The sound system deployed at the mouth of Georgiana Slough consisted of a 800 ft-long linear array of acoustic transducers suspended from buoys that were placed approximately 1,000 ft upstream from the slough entrance. The acoustic barrier angled out from the slough-side shore with the objective of deflecting the out-migrating fish to the far side of the river, away from the slough entrance (figure 24). The transducers generated sound with a 300–400 Hz frequency. Observed fish guidance/exclusion efficiencies were influenced by flow and hydraulic conditions, with efficiencies ranging from 50 to 80 percent for typical operating conditions. Observed efficiencies, however, dropped to 8 to 15 percent (quite inefficient) during flood events. On occasion, damage occurred to the sound barrier facility during flood events. Generally, however, O&M costs were low.

Support structure – Transducers and sound generators require minimal support structure. Most commonly, they are attached directly to the intake structure or associated wing walls. On occasion, they are deployed from bridge piers, safety cables, debris booms, and buoy lines. Protection of sound generators from debris loading is a concern and should be considered.

Head loss – Sound generators have no effect on the head loss characteristics of intakes.

Debris cleaning – Debris and debris cleaning is typically not an issue with sound exclusion systems. Routine maintenance demands associated with debris and debris removal should be minimal. A significant concern is protection of transducers and sound generators from large debris, primarily during flood events. Sound generators require unobstructed access to the channel water body. Submerged placement of transducers may protect them from floating debris. Removal of transducers during severe flood events (when sound exclusion effectiveness may be reduced) may be another option.

Power availability and need for backup power – Power is necessary to drive the sound system. Backup power may be needed if continuous fish exclusion is required. Power requirements, which vary with specific device, may be up to 500 watts per transducer.

Cold weather operation – With submerged placement, sound exclusion systems should be functional with minimal maintenance requirements during icing conditions. Again, ice loading and potential surface/float ice damage should be considered in development of the system design.

Chapter VI. Fish Manual Case Studies

“By far the best proof is experience.”

Sir Francis Bacon

A. Design Examples

“In theory there is no difference between theory and practice.
In practice there is.”

Yogi Berra, American Baseball Player

The following case studies cover design requirements and layout for several types of fish exclusion structures at water diversions but do not include the following important consideration in any final design for a fish exclusion structure:

- Site availability and access considerations
- Geotechnical considerations
- Actual design of structures, mechanical equipment, and electrical equipment
- Construction considerations such as constructing cofferdams and dewatering
- Coordination with fishery and other agencies
- Post construction evaluation and testing

1. Example 1 – Flat Plate Screen in Canal – “V” Configuration (Based on concept study for Intake Canal)

The diversion dam and canal are existing facilities without provision for fish exclusion. The canal diverts a maximum of 850 cubic feet per second (ft^3/s) from the river (figure 99). The diversion dam consists of an overflow weir, a sluiceway, and the canal headworks. The diversion season is from mid-March through mid-October.

It is desired to use a positive barrier fish screen to prevent fish from being entrained in the canal, but if entrained, safely diverted from the canal back to the river.

a. *Fishery*

Salmon

Size – fry, fingerlings, adults

Move downstream – early spring

Move upstream to spawn – early spring

Swimming – It is anticipated that fry will be present throughout the water column.

and

Bull trout

Size – fry, fingerlings, adults

Move downstream – late spring

Spawning – late summer to early fall and emerge in spring

Swimming – The fry generally drift with the current and have little strength and endurance to swim against the current. Fry occur throughout the water column.

b. *River design data*

- The river flow is significantly affected by snow melt and reservoir releases. The peak river flows occur from May through July.

- The canal can divert 850 ft^3/s when the river flow is as low as 5,000 ft^3/s.

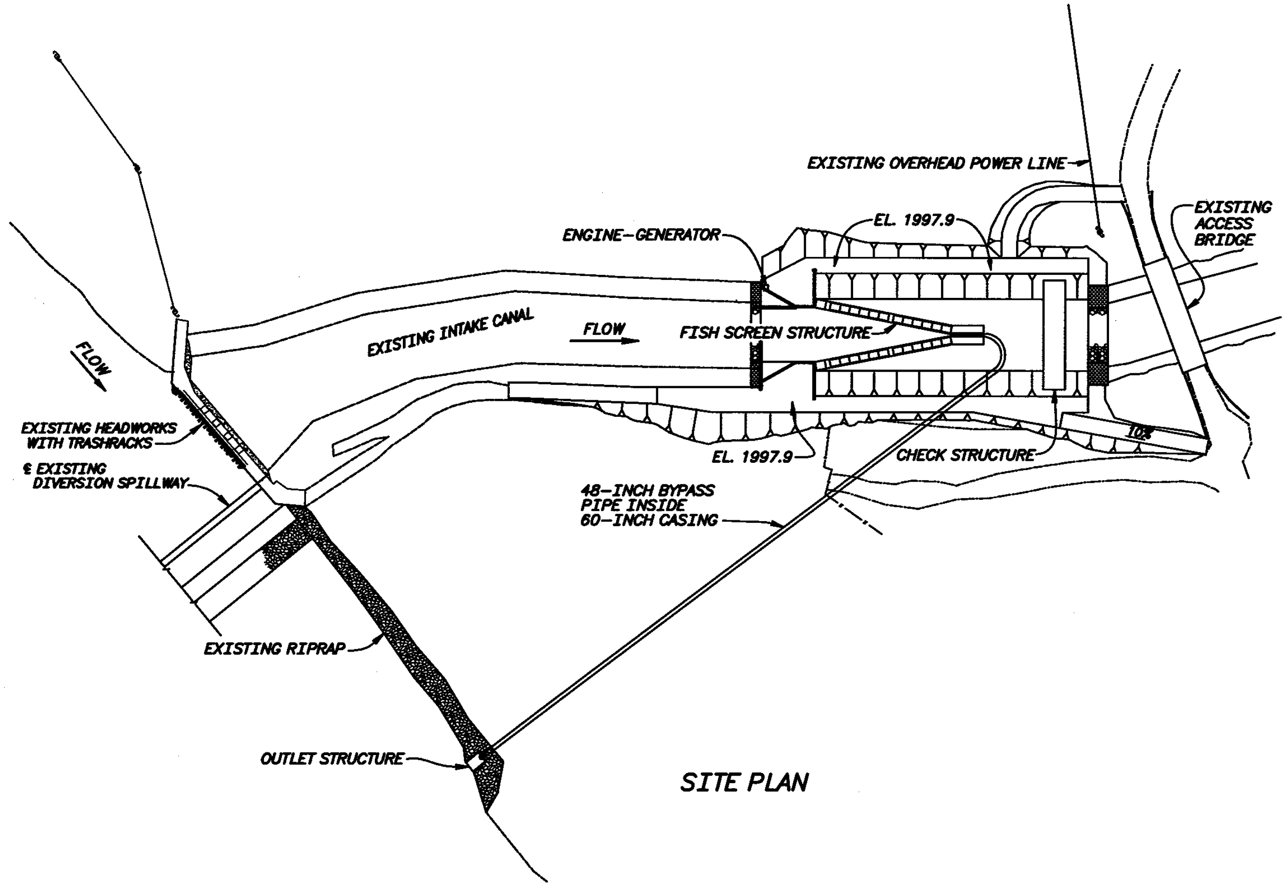


Figure 99.—Site plan – Example 1.

- River water surface elevations at headworks intake (based on 850 ft^3/s in canal):
    - Water surface is adequate to provide 10 ft water depth in the canal at the fish screens
    - Water surface at fish bypass outlet structure:
        - Low flow (5,000 ft^3/s) – 3.0 ft less than water level in canal.
        - High flow (38,000 ft^3/s) – 1.5 ft less than water level in canal.

c. Design data

The canal data and section properties are:

Bottom width = 50 ft
Side slopes = 2 (horizontal): 1 (vertical)
Maximum flow = 850 ft^3/s
Depth at 850 ft^3/s = 10 ft
Bank height = 13 ft
Lining – none
Water surface is controlled by a downstream check structure and does not vary significantly with flow.
Velocity in canal = 1.21 feet per second (ft/s)
Operating season – Mid-March through mid-October

Construction – The fish exclusion facilities can be constructed during the non-operating period from mid-October through mid-March (5 months). A canal bypass is not feasible because of right-of-way restrictions. Construction may have to occur over two separate periods.

Debris – Trashracks are located at the existing headworks, and only small amounts of debris enter the canal through the diversion dam gates.

Sediment – Deposition is expected to be minor and can be removed in the off-season.

d. Fish screen structure design criteria

- Fish species – Salmon, bull trout.
- Fish size – The screens should be able to safely exclude fish as small as fry (25–60 mm).
- The design flow through the fish screens is 850 ft^3/s. The operators can divert 850 ft^3/s when the river flow is as low as 5,000 ft^3/s.

- The fish screens must also be able to operate satisfactorily when fish are migrating downstream and the river flow is as high as 38,000 ft^3/s (90 percent of the maximum river flow).

- Maximum fish screen approach velocity is 0.4 ft/s (based on National Ocean and Atmospheric Administration Department of Fisheries [NOAA Fisheries] – Northwest criteria for salmon fry).

- Uniform approach velocity required along fish screens.

- Channel velocity is 2 ft/s or greater; sweeping velocity is 2 times the screen approach velocity or greater. The ratio of sweeping velocity to approach velocity should be between 5 and 10 to facilitate cleaning the fish screens.

- The invert of the screen structure will be located 0.5 ft above the canal invert to prevent sediment deposits from interfering with the operation of the fish screens and cleaning devices. Water depth on fish screens is 9.5 ft.

- Exposure time – The maximum exposure time of fish to the screen structure is 60 seconds.

- Bypass to river:

  - Entrance width is 2 ft or greater
  - Entrance velocity is channel velocity or greater
  - Minimum pipe diameter is 24 inches
  - Bypass pipe velocity is 3 to 10 ft/s
  - Minimum pipe bend radius is at least 5 times the bypass pipe diameter

- Fish screens

  - Maximum opening (NOAA Fisheries – Northwest Region)

    I. Perforations – Rectangles and circles maximum openings – 3/32 inch in narrowest dimension.
    ii. Slots – 1.75 mm (0.0689 inches)
    iii. Minimum open area percentage is 27 percent (table 4)

  - Maximum design cleaning cycle time is 5 minutes

- Assumed head loss across fish screen and baffle is 0.5 ft

- With the fish screens located downstream from the headworks, which has trashracks, an additional trashrack will not be required.

e. Location of fish screen structure

Two locations are considered for the fish screen structure: (1) placing the fish screen upstream from the headworks to prevent fish from entering the canal (in-river structure), or (2) placing the fish screen in the upstream end of the canal and bypassing the fish back to the river (in-canal structure). For this facility, it is desirable to locate the fish screens in the canal as close to the headworks as possible (figure 99). Placing the fish screens upstream from the headworks would create the following concerns:

- The screens would be adjacent to the sluiceway, which is not continuously operated. Thus, there would not always be a good sweeping flow past the fish screens.

- Ice conditions would require removing the fish screens. If fish screens remain in the canal, there will be no flow in the winter and the canal can be unwatered to prevent damage to the fish screens and to allow maintenance.

- Constructing the fish screens upstream from the headworks would require a cofferdam in the river. This would increase the construction cost and possibly have environmental impacts.

It is desirable for the fish screen structure to be located as close to the upstream end of the canal as possible to minimize the time fish are out of their natural environment and minimize potential predation. For this example, the fish screen structure should start a suitable distance downstream from the canal curve, which begins immediately downstream from the headworks. To attain the uniform flow condition, it is desirable to locate the fish screens approximately 40 times the canal depth downstream from the headworks or any bends. This distance is required to ensure uniform channel flow at the fish screens (figure 99).

The downstream distance from the curve is:

Distance = 40 * 10 = 400 ft.

The distance from the canal bend is limited by the existing roadway bridge (approximately 250 ft from the bend), so the distance downstream cannot be fully met to provide uniform approach flow at the screen structure. It is anticipated that the adjustable baffles will adequately adjust the flow to provide uniform approach flow at the screens; however, laboratory model studies may be required.

f. Design of Fish screen structure (figures 99 and 100)

The fish screen facility will consist of the following:

- Fish screen structure
- Transition from upstream canal to fish screen structure
- Fish screens
- Baffles behind the fish screens
- Brush cleaner system for cleaning the fish screens
- Fish bypass to the river including: the bypass entrance, the bypass pipe, and the outlet structure
- Area for trapping fish within the bypass entrance channel
- Canal check structure (not shown) to provide a more constant water surface for the fish screens and adequate head for the fish bypass

g. Fish screen structure (figure 101)

The fish screen structure will consist of a steel guide/support frame placed on a concrete slab. The fish screen surface will be vertical and flush with the structural members and abutments to allow unimpeded fish movement parallel to the screen and to maintain an easily cleanable screen surface. In addition to designing for dead loads and live deck loads, the structure will be designed to withstand a 4-ft differential head on the fish screen. The concrete foundation will include upstream and downstream cutoffs to prevent undermining by scour and to reduce problems caused by under seepage.

The required area of fish screens is the design flow divided by the maximum allowable approach velocity:

$$A = (850 \text{ ft}^3/\text{s}/0.4 \text{ ft/s}) = 2{,}125 \text{ square foot (ft}^2)$$

The required area does not include structural support members. Structural support members normally occupy 5 to 10 percent of the fish screen area. For this example, we will use 5 percent. Thus, the required gross area will be:

$$A_g = 1.05 * 2{,}125 = 2{,}232 \text{ ft}^2$$

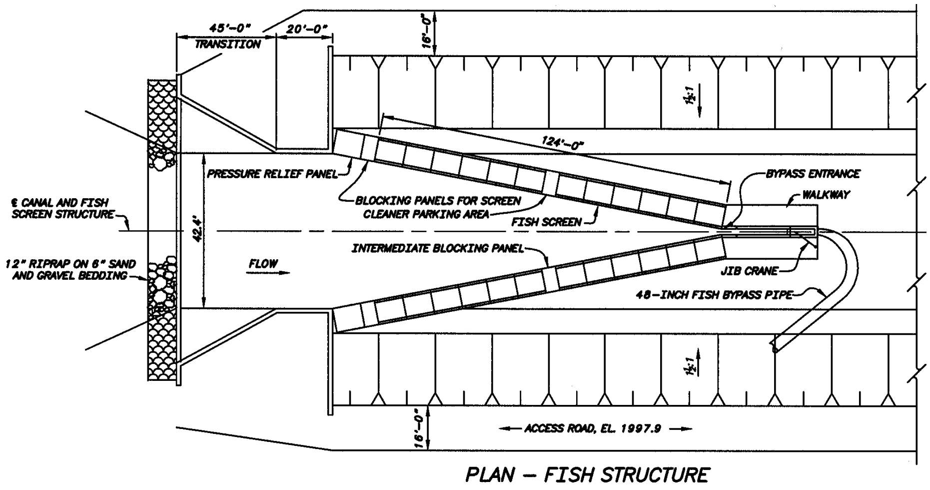


Figure 100.—V-Configured fish screen – Example 1.

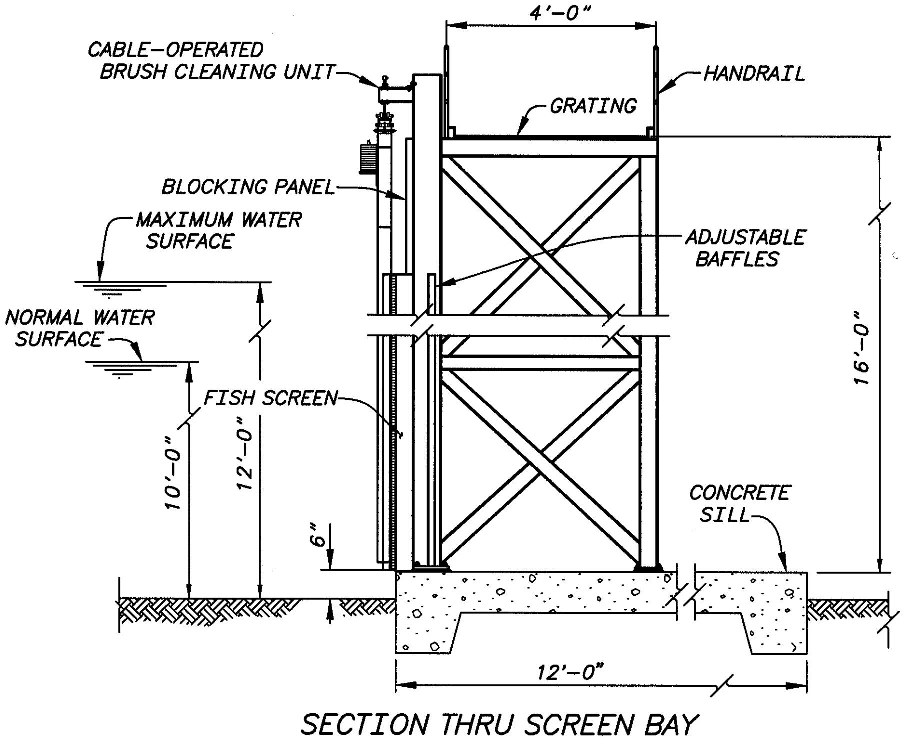


Figure 101.—Steel support structure – Example 1.

The length of the fish screens is obtained by dividing the required area by the depth. The invert of the fish screens is 0.5 ft above the canal invert; therefore, the depth on the fish screens is 10 ft –0.5 ft = 9.5 ft. The required length of the fish screens is the area divided by the depth:

$$L = (2{,}232/9.5) = 235 \text{ ft}$$

(Use 240 ft to accommodate 10-ft square screen panels).

The exposure time for the fish will determine the layout of the screen and the number of bypasses required. The maximum exposure time is 60 seconds. The maximum distance to a bypass, or between bypasses, is:

$$L = 240 \text{ ft}/(2 \text{ ft/s}) = 120 \text{ ft}$$

There are two potential configurations for the fish screen structure:

- "V" configuration with a terminal bypass
- Straight line configuration with an intermediate bypass located at the middle of the structure and a terminal bypass

The required bypass flow is based on the bypass entrance velocity, width, and flow depth. The bypass flow velocity, at the bypass entrance, will be equal to the sweeping velocity of 2.0 ft/s. The bypass flow per bypass would therefore be:

$$\text{Flow} = 2.0 \text{ ft/s} * 2 \text{ ft width} * 10 \text{ ft depth} = 40 \text{ ft}^3\text{/s/bypass}$$

The 240-ft fish screen length is too long for a straight-line fish screen structure without an intermediate bypass.

Of the two options available, the "V" configuration is preferable because of the following:

- The "V" configuration requires only one bypass with a flow of 40 ft^3/s.
- The straight-line configuration requires two bypasses with a total flow of 80 ft^3/s (40 ft^3/s for each bypass). If two bypasses were used, a secondary screened return flow facility might be required. The return flow facility would return flow from the bypasses to the canal and allow a reduced bypass flow with fish. The return flow structure would contain traveling water screens and pumps.
- The straight reach of the canal where the facility is to be located is not long enough to contain a straight-line structure and have enough upstream straight reach for acceptable flow conditions.

A "V" configuration does, however, make access to the channel area in front of the screens more difficult, and design and operation of the screen cleaners more complex. The screen cleaners on a "V" configuration facility must be designed or coordinated to prevent hitting each other at the apex of the "V."

The desired channel velocity determines the channel width at the upstream end of the fish screens. It is desirable to have a minimum channel velocity of 2.0 ft/s to both keep the fish moving and the trash moving without either impinging on the fish screens.

The fish screen structure will be located in a trapezoidal canal section with a transition from 2:1 canal side slopes to vertical concrete walls at the upstream end of the screens. The channel bottom width at the upstream end of the fish screen structure is determined by the area needed for a velocity of 2.0 ft/s. In calculating the required area, the bypass flow of 40 ft^3/s is added to the screen flow of 850 ft^3/s for a total flow of 890 ft^3/s. The required area to produce a 2.0 ft/s velocity is the flow divided by the velocity (890 ft^3/s/2.0 ft/s) = 445 ft^2. Since the depth is 10 ft, upstream bottom width is calculated to be 44.5 ft.

***Checking exposure time* –** The screen angle to flow is 10 degrees, and the sweeping velocity is 1.97 ft/s. Therefore, the exposure time is 120 ft/1.97 ft/s = 61 seconds, which is acceptable.

The grating and walkway deck of the fish screen support structure are set just above the canal bank elevation, which is 3 ft above the normal water surface. The deck must be wide enough for access by maintenance personnel and is 4 ft wide (figure 101). The deck will have handrails for the safety of the operators.

h. Upstream transitions

At the upstream end of the fish screen structure there is a converging transition from the canal section (trapezoidal channel) to the fish screen structure, which is a rectangular section. The transition must be sized and shaped to provide a uniform transition of flow without eddies. To accomplish this, the transition wall angle should be 25 degrees unless the regulating agencies want a flatter angle. The length of the upstream transition is:

$$\text{Transition length} = (2 * 10)/\tan 25 = 42.9 \text{ ft (use 40 ft)}$$

***Fish screens* –** The fish screens may be either woven wire, perforated plate, or profile bar (wedge wire) flat plate screens. Profile bar was selected for the fish screens because it is commonly available, has a high percentage open area, and is normally easy to keep clean (table 4 and chapter IV.A.10a). Perforated plate has a open area of approximately 30 percent. The profile bar has a open area between

40 and 50 percent, which is greater than the 27 percent open area required. The high slot velocities of the perforated plate also may increase the difficulty of handling trash and reduce the fish exclusion capability.

The screens must be durable and have a smooth finish. The profile bar will have a clear opening of 1.75 mm (table 4). The fish screens will be stainless steel to increase longevity and minimize maintenance requirements. The support panels will be coated steel for economy. Each screen will be square and measure10 ft by 10 ft. The screens are made square so that they can be rotated and have the profile bar slots oriented either vertically or horizontally. Experience indicates that a vertically oriented slot type screen is often easier to keep clean; however, this depends on the type of debris. Because of the 6-inch offset at the invert, the top of the fish screens will be 0.5 ft above the minimum required height (the design water depth in the canal). To prevent overtopping, 2-ft-high solid panels will be located above the fish screens.

The screens can be either bolted to the upstream flange of the steel support structure or placed in guides. Placing the screens in guides facilitates removal and replacement, but also increases the construction cost. For this facility, the fish screens will be bolted to the steel support structure (figure 101). A metal sill plate can be embedded in the concrete fitting for seating the screen bottoms. Screen removal will be accomplished by placing a mobile crane on the canal bank (50- ft reach); therefore, an overhead monorail on the fish screen structure is not necessary. This is feasible because the canal is unwatered in the winter. Unwatering in the winter also allows the screens to be cleaned in place.

Baffles **–** Fish screen baffling is normally required to create a uniform approach velocity along the fish screens. The baffles are located immediately behind the fish screens and should be adjustable to allow setting them to accommodate the specific site conditions. A vertical slat baffle has been commonly used. The slats, which are normally 8 to 10 inches wide, can be individually rotated and positioned for adjustable flow control. Baffling could also be two pieces of perforated plate. The downstream perforated plate would be fixed and the upstream perforated plate would be adjustable, similar to figure 41. Raising or lowering the upstream plate to adjust hole openings can control the flow through that section of the fish screens. The perforated plate option will be used because the construction cost is less and it is easier to adjust. It is anticipated that once the baffles are properly adjusted, they will perform well for the remaining life of the structure.

Fish screen cleaning **–** The fish screens must be kept clean to provide acceptable performance. To ensure clean screens for large screen structures, an automated cleaning system is often required by fishery resource agencies to adequately clean the screens. Two sources of screen cleaning systems are commonly available:

(1) cable operated brush system (individually designed) and (2) commercially available systems. For this fish screen structure, the cable type system is selected (figure 65).

It is normally necessary to clean the fish screens at least once every 5 minutes. One cleaning system will be installed on each side of the V configuration. The cleaning systems will have variable speed adjustable drives that move the brush arms between 0.25 ft/s and 1.0 ft/s. Thus, using two brush arms, the cleaning time cycle can range from 1 to 4 minutes, which is satisfactory. Each cleaner will require a 4-ft-long runout parking area at the upstream end, a 4-ft-long intermediate blank panel for parking and turnaround similar to figure 65, and a 1-ft-long turnaround area at the downstream end. At the parking and turnaround areas, a metal ramp will push the brush away from the blank panels to allow debris removal by the sweeping flow. The cleaning system will have four modes of controls:

- Operate at predetermined time intervals
- Operate continuously
- Operate at a predetermined head differential
- Operate locally

Operators may select the option that best suits their conditions.

Some operators have found that including an air nozzle system with the screen cleaner is helpful for removing sediment at the base of the structure and loosening impinged trash from the fish screens. The air nozzle system is not included in this system. It is anticipated that sediment deposition can be removed when the canal is unwatered during the non-irrigation season.

Facilities for emergency operation due to potential screen plugging **–** The facilities are not designed to hold back the full depth of water in the canal or river. Intermediate alarms should be actuated to allow maintenance personnel to correct the situation before the emergency measures are necessary. In case the screens plug, either a flow bypass mechanism to relieve the water pressure should be provided or the canal headworks gates should close. The emergency flow bypass and headworks closure are best operated automatically. The emergency flow bypass can be items such as automated bypass gates (slide or radial), panel(s) which rise automatically, or a relief (blowout, shear pin, or spring-loaded) panel(s). The emergency flow bypass should be sized to pass an adequate amount of flow to prevent overloading the structure. If the headworks gates are automated to close during a screen blockage, the gates must be operated in a manner that does not cause the canal to draw down too quickly and cause bank or lining failure.

Screen facility head loss estimate **–** The head loss across the fish screen facility will cause the upstream water level to increase. If the increase in upstream water level is not acceptable, the flow capacity of the canal may have to be reduced. The head loss estimate includes losses for the following items, which are summed up:

- Upstream transition from canal to fish screen structure
- Fish screens and baffles behind fish screens

The upstream transition loss, assuming a broken back type transition, is 0.3 times the difference in velocity heads between the upstream trapezoidal canal section and the section at the fish screen structure. When there is a downstream transition (assuming a broken back type transition), the loss is 0.7 times the difference in velocity heads between the upstream trapezoidal canal section and the section at the fish screen structure.) The transition head loss is as follows:

Transition	**Canal**	**Fish screen structure**
Upstream	Velocity = 1.27 ft/s	Velocity = 2 ft/s
	H_v = 0.025 ft	H_v = 0.062 ft

Head loss = 0.3 * (0.062 – 0.025) = 0.011 ft

Fish screen and baffle head losses **–** The head loss through fish screens and baffles is usually assumed to range between 0.3 ft and 0.5 ft. The smaller head loss through the baffles would occur when the approach flow conditions are ideal, and the larger head loss through the baffles would occur when the approach flow conditions are poor. In this example, the fish screen is located too close to the bend to ensure uniform approach flow and may require significant baffling to attain a suitable uniform flow through the facility.

The total head loss for a clean fish screen and baffles may, therefore, range from 0.3 to 0.5 ft, and most of the head loss would occur through the baffles. Depending on the adjustable baffle setting, generated head losses (required to generate a uniform approach velocity distribution) for the clean screen and baffle may exceed 0.5 ft.

I. Fish bypass description

There is one bypass for returning fish to the river. The bypass entrance is at the downstream end of the fish screen structure in the apex of the “V” configuration. The bypass consists of the entrance (figure 102), the bypass pipe (figure 103), and the outlet structure (figure 104).

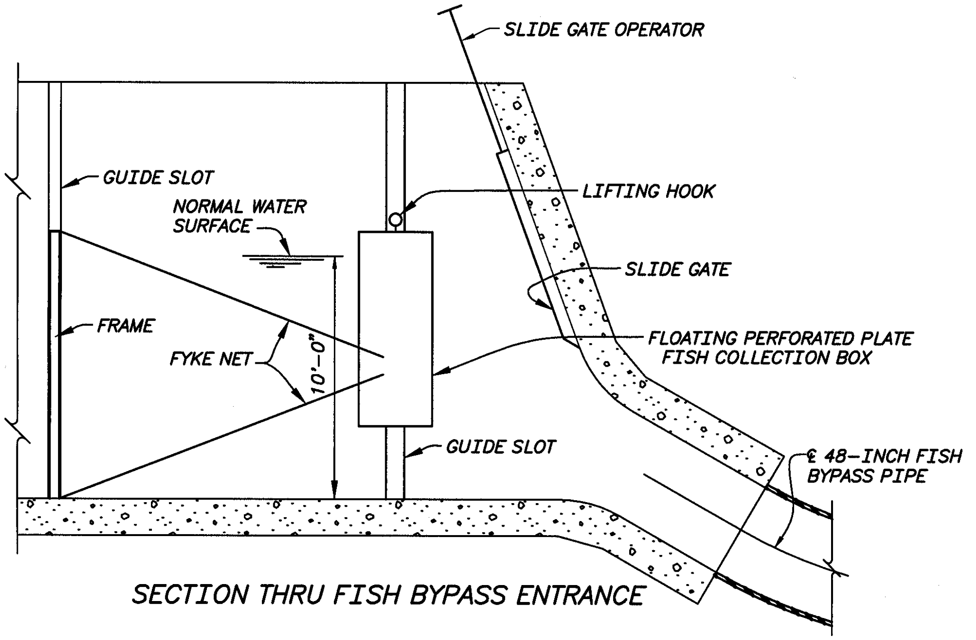


Figure 102.—Bypass entrance – Example – 1.

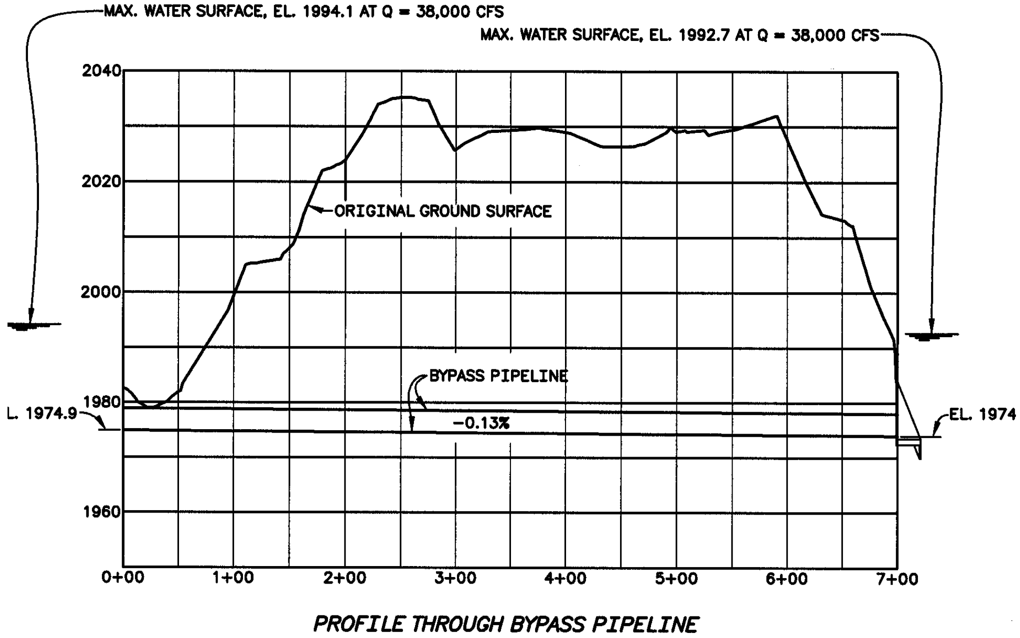


Figure 103.—Profile of bypass pipe – Example 1.

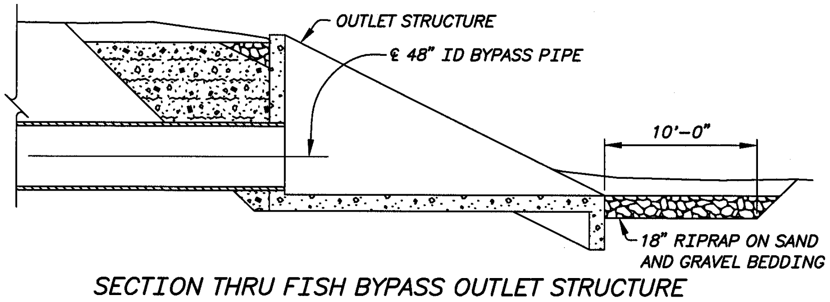


Figure 104.—Bypass outlet structure – Example 1.

Entrance – The entrance (figures 100 and 102) is 2.0 ft wide, which is adequate to pass trash and fish, and meets criteria. The channel upstream from the gate should be open topped to allow light in and not elicit an avoidance response from the fish. As previously estimated, the minimum bypass flow is 40 ft^3/s. Options for controlling the flow through the bypass are: (1) using an adjustable weir with an upstream ramp or (2) using a slanted type gate. A slanted slide gate at the entrance will be used to control the flow in the bypass channel and isolate the facility from the river. The slanted gate can be used to control the flow if it is not required to close more than half way to accomplish this.   An alternative to the slanted gate would be an adjustable weir with ramp (similar to figures 52, 54, and 108). For this example, the slanted gate is selected because there is minimal head loss available to drive the bypass flow. A drop well is sometimes required just downstream from the gate or weir to accommodate excess available head. However, in this example, a drop well is not required.

The bypass channel is also designed to allow for use of a fish trap to evaluate the effectiveness of the fish passage and any possible injury to the fish. The opportunity for evaluation is accomplished by providing guides in the sidewalls so that a removable net and trap box can be inserted. Also, a jib crane will be provided to allow insertion and removal of the net and trapping equipment.

Bypass return flow channel – The difference in water level between the bypass entrance and the river is 3 ft during low river flow (5,000 ft^3/s) and 1.5 ft during high river flow (38,000 ft^3/s).   A canal check structure is required to ensure adequate head for the bypass flow during high river flows. Buried pipe will be used for the bypass flow to the river (figure 103). The flow must have a velocity between 3 and 10 ft/s, and the bypass pipe must be smooth, with no protrusions that might injure fish. To meet velocity criteria, the pipe diameter may be between 2.26 ft (10 ft/s) and 4.12 ft (3 ft/s). For economy and to keep fish moving, it is desirable to make the diameter as small as possible while not exceeding head loss requirements. Head loss through the bypass system must be estimated and must not exceed available head. The pipe diameter from the bypass entrance to the river is 48 inches. With a flow of 40 ft^3/s, the velocity is 3.2 ft/s (within criteria of 3 to 10 ft/s). Reinforced concrete, steel, and high density polyethylene (HDPE) pipes were considered for the bypass. The joints in the reinforced concrete pipe would be mortar filled to make them smooth, and the joints in the HDPE would be butt welded.

Outlet structure location and design – The outlet structure is a concrete transition (figure 104). The following items must be considered in locating the outlet structure: river flow depths, possibility of future river changes such as degradation and changes in alignment, sedimentation, and locating an area of the river with good sweeping velocity.

Head loss through the bypass system – The head loss consists of the sum of the entrance loss, pipe friction and bend losses, and exit loss. The gate is assumed to be fully open for estimating the minimum head loss. The entrance is a smooth transition to the pipe, and the head loss can be estimated by multiplying an entrance coefficient by the difference in velocity heads. For this entrance, a coefficient equal to 0.2 is assumed. The entrance head loss is therefore:

$$\text{Entrance head loss} = 0.2 * (3.2^2/64.4 - 2.0^2/64.4) = 0.019 \text{ ft}$$

For this example, the pipe friction loss will be estimated using the Darcy-Weisbach Equation, and the friction factor is estimated using the Colebrook-White Equation. The Darcy-Weisbach equation is:

$$H = f * (L/D) * (V^2/(2g))$$

Where:

H = total friction loss (ft)
L = length of conduit (ft) = 120 ft.
V = flow velocity (ft/s) = 3.2 ft/s
D = diameter of conduit = 4 ft.
f = friction factor
g = acceleration of gravity

The Colebrook-White equation is:

$$1/f^{0.5} = -C_3 * \log((e/C_5D)+(C_4/\mathbb{R}f^{0.5}))$$

Where:

$C_3 = 2$
$C_4 = 2.51$
$C_5 = 3.7$
The roughness, $e = 0.0002$ for smooth pipe and 0.001 for rough pipe

$\mathbb{R}$ is the Reynolds number = $4*(A/Wp)*V/v$, where
A is the pipe area = 12.57 ft^2
Wp is the wetted perimeter
D is the pipe diameter = 4 ft
V is the flow velocity = 3.2 ft/s
v is the kinematic viscosity = 0.0000141

Solving the equation, f = 0.01527
Friction loss/ft = $f * (V^2/2g)/D = 0.0006$
The friction loss is therefore pipe length * head loss/ft:

$$H = 120 * .00060 = 0.072 \text{ ft}$$

The bend loss[1] is estimated: $0.0035* (3.2)^2/2g*$bend angle =
0.0035*0.159*140 = 0.078 ft.
The exit loss is estimated to be one velocity head: $1.0 * (3.2)^2/2g$ = 0.16 ft.
The entrance loss is estimate to be 0.5 * velocity head = 0.080 ft.
The total head loss in the bypass system is then 0.072 + 0.078 + 0.16 + 0.080 =
0.390 ft.

The head loss is less than the available head and the gate will have to be used to control the flow.

[1] Bureau of Reclamation (Reclamation), Design Standard No. 3, 1967.

j. Operation and maintenance

For an overall scope of operation and maintenance (O&M) requirements, see Chapter VII, Post Construction Evaluation and O&M Plans.

Often, an evaluation of the fish being bypassed is required. Nets and collection devices can be placed in the bypass to collect fish to determine numbers, physical condition, species, and sizes.

The fish facilities are designed to be as flexible as possible to maximize successful fish passage. Items that are adjusted in this facility are the baffles for uniform flow velocity, the gate in the bypass entrance to set the desired bypass flow, and the operation of the fish screen-cleaners. In addition, water-level measuring equipment is located upstream and downstream from the fish screens, and a flow meter can be placed in the bypass channel or pipe, if desired.

Cleaning criteria requires that the screens should be kept clean enough to prevent the head loss, across the fish screens only, from exceeding 0.1 ft. Therefore, the fish screens should be kept as clean as possible at all times. With the baffles located immediately behind the fish screens, it will be feasible to measure only a combined head loss of the fish screens plus baffles. Normally, the head loss through clean fish screens is relatively minor, while the head loss through the baffles is relatively large. An alarm system is installed that will sound if the differential head across the fish screens and baffles reaches a predetermined level (usually set between 6 and 12 inches). The screens may have to be thoroughly cleaned with a high-pressure water system once or twice a year. This cleaning can be accomplished with the screens in place with the canal unwatered. A backup power generator is included with the facilities that will power the screen cleaning system, area lights, sensors, and alarm systems.

During normal operation, the bypass entrance gate is set to obtain the desired flow.

2. Example 2 – Flat Plate Screen in River (Based on Glenn Colusa Irrigation District)

The Water District diverts (pumps) up to 3,000 ft^3/s from the river. The diversion site is located on an oxbow of the river (figures 5 and 6). Originally, the pumping plant was unscreened. There have been two previous efforts to screen fish from the diversion. The first effort consisted of installing drum screens. The drum screens were 17 ft in diameter and could operate successfully for a river depth range of 11.1 to14.5 ft on the screens (0.65 to 0.85 times the screen diameter). There were two problems with the drum screen installation: (1) failed seals and (2) limited operating range because of fluctuating water levels. It was decided to retrofit the structure with flat plate fish screens with a horizontal brush cleaning system. The flat plate screens were installed at a 5-degree angle to vertical.

The flat plate screens provided better sealing capability and could operate at a much greater range of river depths. The flat plate fish screens were designed for an approach velocity of 0.5 ft/s when the river water surface elevation was low. After the flat plate screens were installed, the downstream river channel was straightened by a flood flow and the water level at the fish screens dropped 3 ft lower than anticipated in the design. Also, subsequent criteria for screening fish at this specific site required a maximum approach velocity of 0.33 ft/s. It was then decided to replace or modify the fish screen structure.

Planning of the fish screen structure involved the following organizations:

- California State Agencies
    - Department of Water Resources
    - Department of Fish and Game

- Federal Agencies
    - NOAA Fisheries
    - Reclamation
    - U.S. Army Corps of Engineers (Corps)
    - U.S. Fish and Wildlife Service (Service)

- Glenn Colusa Irrigation District

The technical support and final design groups consisted of:

- Reclamation
- Corps and consultants
- Glenn Colusa Irrigation District and consultants

a. Fishery

Species – salmon and steelhead

Size – fry through adults

Move downstream – throughout the year

Swimming – The fry generally drift with the current and have little strength and endurance to swim against the current. Fry occur throughout the water column.

b. River design data

- River flows and water surface elevations at the fish screen structure are given in table 9.

- Rivers are dynamic in nature and, in this case, can either meander over time or become braided, depending on slope, velocity, and sediment conditions of the channel. The potential for river relocation will likely affect the water surface elevation at the fish screens. The river water surface elevation for various flows is currently near it's lowest, and future river changes may raise the river water surface elevation.

- Sediment – Sediment deposits at the upstream end of the oxbow and is periodically dredged.

- Debris – Large debris, which is carried by the river, especially during high flood flows. However, the existing fish screens had been exposed to high river flows with little or no damage. A log boom would offer little protection against large debris in this case because it is submerged in the river flow. Therefore, a log boom was not included.

- Boating safety – A float boom should be placed across the oxbow channel upstream from the fish screens to prevent boaters from entering the oxbow channel where the fish screen and adjustable overflow weir are located.

Table 9 – Flows and water surface elevations at fish screen structure

Flood frequency	River flow (ft^3/s)	Water surface elevation at fish screen structure (ft)
Low irrigation design water surface	7,000	137.0
Normal high irrigation water surface	20,000	141.5
2-year	91,000	152.8
	100,000	154.0
5-year	119,000	154.5
10-year	162,000	156.4
50-year	258,000	160.0
100-year	343,000	161.0

c. Design Data and fish screen structure design criteria

The data and criteria listed below where agreed to by the Technical Advisory Group, which consisted of State and Federal agencies, the irrigation district, and the designers.

Fish screens – Design flow for fish screens is 3,000 ft^3/s at a river flow of 7,000 ft^3/s and an associated water surface at El. 137.0. Historic diversion records were reviewed, and it was found that in only 1 in 20 years is the pump demand of 3,000 ft^3/s required when the river flow was less than 7,000 ft^3/s. Maintaining this water level requires a grade control structure (gradient facility) in the main river channel and an adjustable flow control structure (overflow weir) in the oxbow channel figures 5 and 6. Additional pumping criteria are set for river flows less than 7,000 ft^3/s and for river flows during times of the year when downstream fish migration is most likely. The water district and the environmental and fishery resource agencies agreed to these criteria.

Fish screens are based on fry sized salmon criteria from NOAA Fisheries, Southwest Region (attachment A.3) and the State of California Department of Fish and Game (attachment A.6).

The screen approach velocity is 0.33 ft/s for the fish screen design flow at the water surface elevation for the minimum river design flow. Higher river elevations will produce lower approach velocities because of the greater screen area.

The minimum required screen open area is 27 percent. The maximum screen openings are 3/32 inch for square or round openings and 1.75 mm wide for slotted openings.

The sweeping velocity should be equal to or greater than the channel velocity. The approach velocity should be uniformly distributed along the fish screens. Baffling will be required to attain a uniform screen approach velocity.

Bypass system **–** The bypass system will consist of the open channel bypass at the end of the fish screens and intermediate (intermediate) bypasses (with bypass pipes which extend downstream past the fish screens). Fish migrating upstream should be able to swim up the oxbow and past the fish screens. Intermediate bypasses must be located to limit the exposure time to 60 seconds (this was subsequently revised with a variance from the fish agencies). The minimum oxbow bypass flow should be 500 ft^3/s at 7,000 ft^3/s river flow, and the minimum pipe diameter is 24 inches.

The intermediate bypass entrance, figure 108, should:

- Have a minimum width of 2.0 ft.
- Extend from structure invert to top of water surface.
- Provide artificial lighting (shadows may frighten fish).
- Provide a flow control device in the bypass entrance channel with a minimum head drop of 0.8 ft

Trashracks will be required at the intermediate bypass entrances to keep trash from plugging the bypass system.

The pipe walls should be smooth. The minimum bend radius should be at least 5 times the pipe diameter. The bypass pipe velocity should be between 3 and 10 ft/s, and changes in velocity should be gradual.

Fish screen structure **–** The deck width is 13 ft and 8 inches clear to allow the district crane to operate from the deck. The design loading is HS20 (highway truck load) (figure 107).

The extended fish screen structure deck El. is 154.8, to match the existing deck. The deck will be overtopped during high river flood flows. The existing fish structure deck is overtopped when the river flow exceeds approximately 120,000 ft^3/s, and this will continue to be acceptable criteria.

The barrier panels can be placed above the fish screens to prevent them from being overtopped by flows of less than 120,000 ft^3/s.

The top of the concrete base slab must be at least 0.5 ft above the channel invert.

The invert is at El. 126.5 for the extended fish screen structure. The existing fish screen structure invert is at El. 127.0. The depth of water at minimum river flow on the existing fish screen structure will be 10.0 ft. The existing structure must be able to continue operation while the modifications are made for the extended structure.

The location, amount, and type of sediment deposition should be considered.

Electrical power is available at the site.

d. Location of fish screen structure

A concept study (Glickman et al., 1996) that included physical model studies was conducted to determine the most suitable location for the fish screen structure. Two sites were considered, one at the upstream end of the oxbow and the other at the existing site in front of the pumping plant (Mefford et al., 1998). The screen structure at the upstream end was laid out in a "V" configuration with four separate bays. The fish screens at the pumping plant were in a straight-line configuration. Each site was evaluated with a physical model, and modeling indicated that each site would perform satisfactorily (Mefford, 1997). Also, evaluation of the existing sediment deposition characteristics and mathematical modeling of the potential future sediment deposition at both sites were included as part of the concept study as an input in making the final decision. The straight-line configuration in front of the pumping plant was selected. Reasons for selecting this site and configurations were:

(1) The upstream end of the oxbow is used as a settling basin for sediment. Dredging operations are required in the upstream end of the oxbow every 1 to 3 years. Dredge volumes have been as high as 60,000 yd^3. Sediment will continue to collect when the new facilities are constructed, and dredging would be very difficult if the structure is located at the upstream site.

(2) Sediment deposition is not a problem at the existing downstream fish screen site.

(3) The straight-line configuration may allow fish to stay in the river (oxbow bypass open channel) without being guided into a pipe bypass system.

(4) Trash will be kept in the river and not have to be removed and trucked away.

(5) Construction at the existing site will allow use of the existing fish screen structure as part of the facilities. The existing fish screen structure does, however, require some modifications.

e. Design of fish screen structure

The design of the fish screen structure includes the following:

- Modifying and extending the existing fish screens structure
- Upstream and downstream access/guide walls to the fish screen structure
- A gradient facility in the main river channel and an adjustable overflow weir in the oxbow channel downstream from the screen structure to maintain a minimum river water level at low flows – details of these modifications are not covered in this example
- A float boom at the entrance to the oxbow channel to protect boaters by keeping them out of the channel

f. Fish Screen structure

The fish screen structure consists of the existing structure and a new structure that butts up against the existing structure and extends upstream (figures 105 and 106). Included in the fish screen structure are the screens and brush cleaning system, three intermediate bypasses, baffles, an operating deck, a dredge bay, and guides for flow barriers. A terminal bypass is at the downstream end of the fish screen structure. The opposite bank of the oxbow channel across from the fish screen structure was modified to attain suitable sweeping flow conditions. The desired sweeping velocity range is 2 to 4 ft/s.

The fish screens in the new structure are installed at a 5-degree angle to the vertical to match the existing fish screens. Barrier panels are installed from the top of the fish screens to the deck. The baffles will be used to attain a uniform approach velocity through the screens. The baffles extend from the invert to

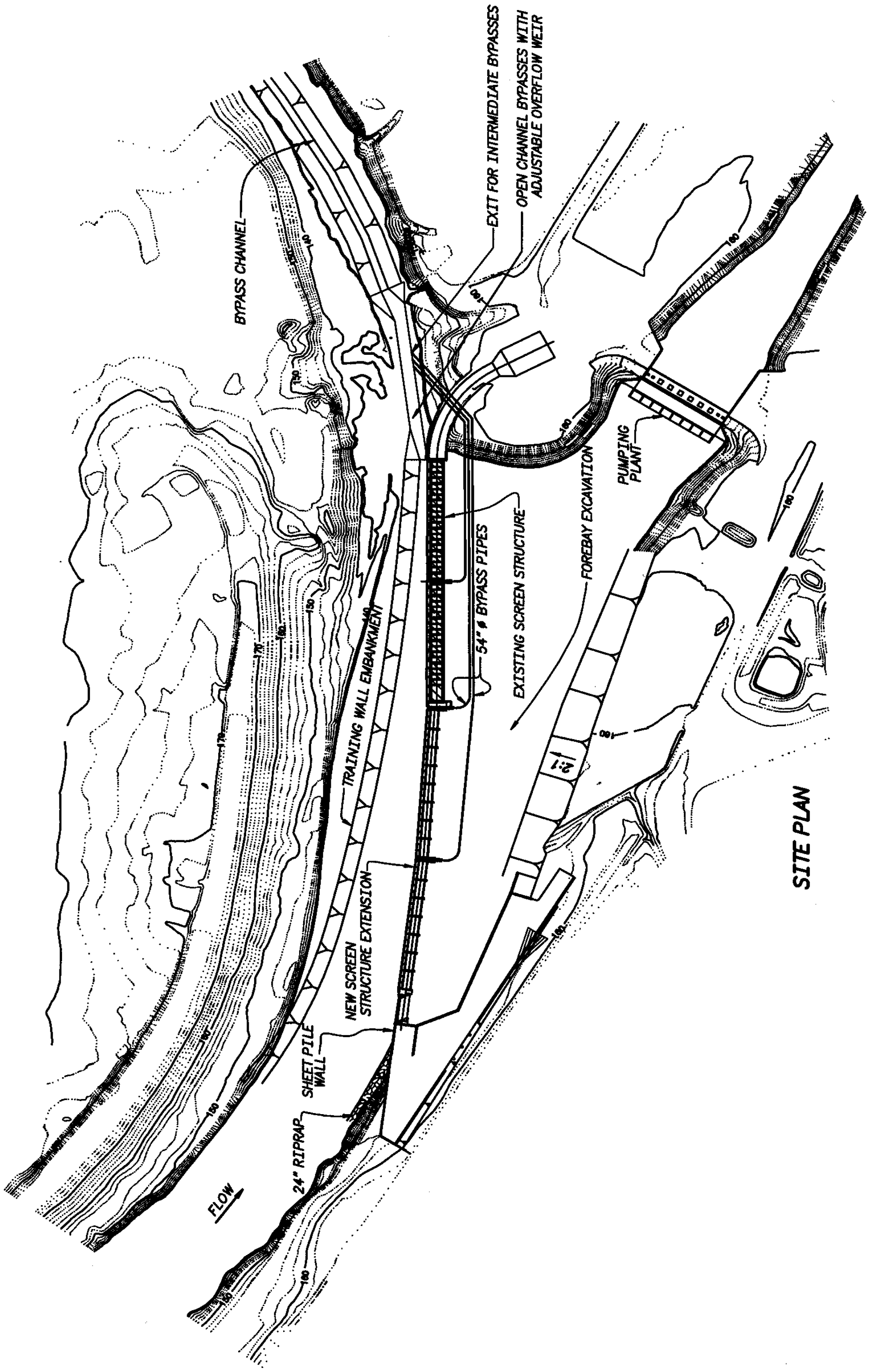


Figure 105.—Site plan –Example 2.

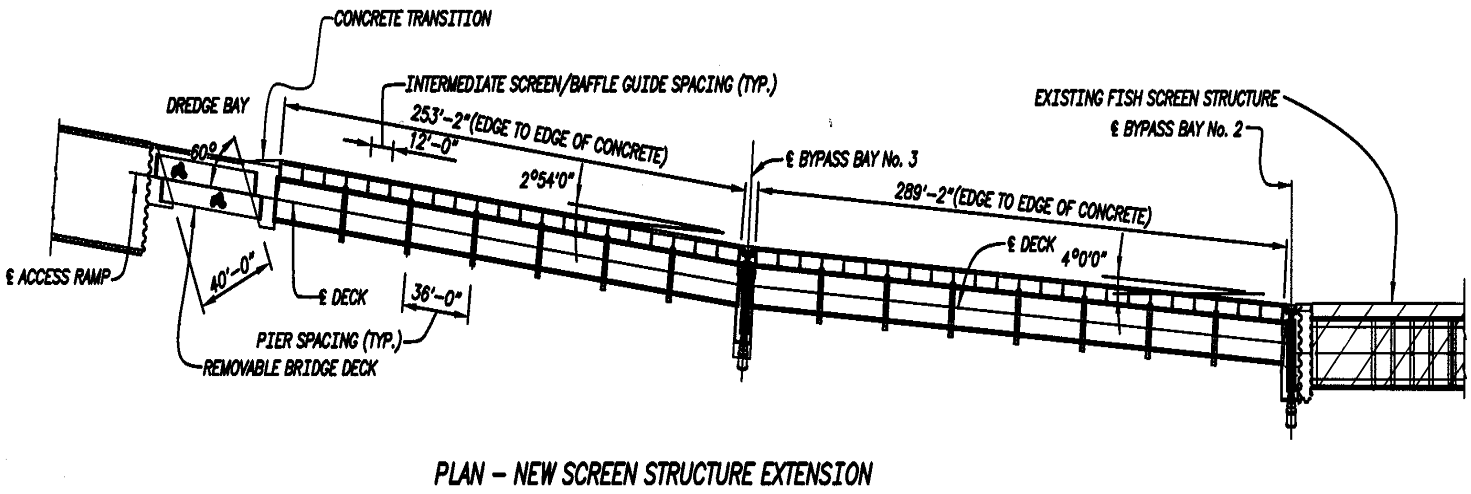


Figure 106.—New screen structure — Example 2.

El. 143.0. The dredge bay has a removable deck and allows the dredge to pass between the pumping plant forebay and the river. The flow barriers can be installed if a screen is removed for maintenance.

The length of the total fish screen structure is based on the river at a flow of 7,000 ft^3/s and the maximum design pumping flow. The existing fish screen structure is 478 ft long, including existing bypasses, or 470 ft not including the bypasses. The capacity of the existing structure at an approach velocity of 0.33 ft/s and a depth of 10 ft (El. 137 – El. 127) is the gross screen area multiplied by the reduction for structural members and the approach velocity:

> Allowable flow through existing fish screens = 470 ft (length of fish screen) * 10 ft (depth) * 0.9 (correction for structural members) * 0.33 ft/s (approach velocity) = 1,395 ft^3/s

The required flow through the extended fish screen structure is:

> Required flow through fish extension screens = 3,000 ft^3/s – 1,395 ft^3/s = 1,605 ft^3/s.

The required length of the extension is therefore:

> Gross length of extension screens = 1,605 $ft^3/s/(0.33\ ft/s * 10.5\ ft * 0.90)$ = 515 ft.

The total length of fish screens would, therefore, be 985 ft (470 + 515 ft.). The fish screen structure length would also need to be increased to include openings for intermediate bypasses.

g. Modifications to Existing structure

The existing structure will be modified by constructing the following:

- New screen sweeps
- Baffles
- Barrier panels
- One intermediate bypass

h. Modifications to the oxbow channel

The oxbow channel was modified across from the fish screen structure. Also, the adjustable overflow weir (check structure) located just downstream from the fish screen structure and the remaining channel back to the main river channel (figure 5) were modified.

The oxbow channel was narrowed across from the fish screen structure to maintain a minimum velocity of 2.0 ft/s in the channel. The hydraulic model study was also used to assist in this part of the design (Mefford et al., 1997). The downstream reach of the oxbow channel returning to the river was modified to maintain a minimum 2.0 ft/s velocity.

The adjustable overflow weir, just downstream from the fish screens, controls flow in the open channel bypass. The adjustable overflow weir has precast concrete planks and is ramped upstream and downstream. Planks can be inserted or removed to set the crest elevation of the ramped weir, thus setting the flow desired for the river flow and elevation. The drop over the adjustable overflow weir is approximately 2.0 ft for a river flow of 7,000 ft^3/s. The drop across the adjustable overflow weir decreases as the river flow increases.

The facilities will be evaluated and tested after construction to determine the most effective bypass configuration.

I. Fish screens and baffles

Fish screens **–** According to agency criteria, alternatives for the fish screens included profile bar and perforated plate. The profile bar criteria require a maximum slot opening of 1.75 mm (measured at the narrowest point) and the perforated plate criteria require a maximum 3/32-inch opening. It was decided to use the stainless steel profile bar option for the following reasons:

- Easier cleaning, as demonstrated by the existing fish screens
- Larger percent open area
- Structurally stronger because no upstream trashracks are provided

The fish screens are constructed of stainless steel profile bar in 12.5 ft by 12.5 ft square panels. The fish screens will extend along the length of the fish screen structure (except at intermediate bypass entrances). Steel barrier panels are installed above fish screens to the deck. The screens and barrier panels are installed in vertical guides for easy placement and removal (figures 64 and 107). The screens are constructed in square panels, which allows aligning the slot openings either horizontally or vertically. In most cases, screens are usually easier to clean with the wires aligned vertically, but because of the cleaning experience with the existing profile bar screens, a horizontal alignment was preferred by the district.

Baffles **–** According to the model study, baffling is required along the entire length of the fish screens to provide a uniform screen approach velocity. The baffles will be placed in guides behind the fish screens (figure 107). Two types of adjustable baffling can be used on facilities of this size:

- Vertical slats (vanes): Each slat can be rotated from fully open (normal to the plane of the screen) to approximately closed (parallel to the face of the fish screen to provide adjustable flow control.

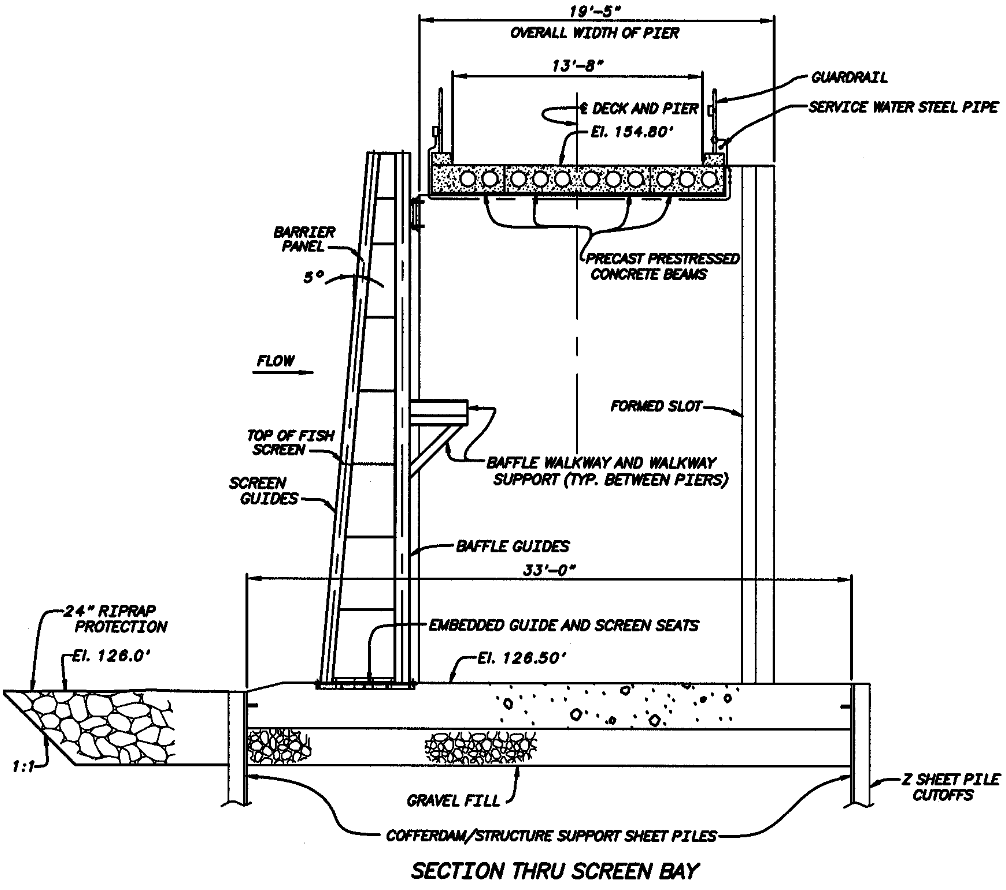


Figure 107.—Cross section of screen bay – Example 2.

- Perforated plate adjustable baffle: The upstream perforated plate section can be raised to adjust the net open area. The back support frame can have either matching diameter holes or slotted openings.

The vertical slat baffles were chosen at this site. Use of the vertical slat baffle can minimize head loss, depending on the required baffle setting.

j. Fish screen cleaning

Cleaning the screens is accomplished by two means: (1) horizontal cable operated sweeps (brush cleaners) and (2) periodically raising each fish screen and power washing with a high-pressure water spray. The sweeps keep the screens clean during operation. The sweeps must be able to clean the full length of the fish screens every 5 minutes. Power washing with the high-pressure spray may be used periodically, usually at the end and beginning of the irrigation season, to clean debris attached to the screens which was not cleaned off by the sweeps (especially for the back side).

Two cable operated systems were selected for cleaning the existing fish screen structure and two cleaning systems were selected for the extended fish screen structure. Each screen cleaning system has a variable-speed, motor-operated drive/cable pulley system that moves two carriages with brush arms back and forth along the structural track/guide system in front of the fish screens, as shown in figure 64. The variable speed drives provide a sweep-travel velocity range between 0.5 and 1.5 ft/s. The sweep operation is computer controlled with several options for flexibility:

- Clean continuously
- Clean intermittently at some preset time interval
- Clean when the differential head across the fish screen reaches some predetermined level.
- Local control

Water level sensors measure the differential water levels upstream and downstream from the fish screens and baffles and the differential head is calculated. If the differential head exceeds 6-inches, the sweeps startup automatically; and if the differential head exceeds 12-inches, an alarm sounds for the operators. Operators will be able to set the operation of the sweeps based on local river conditions.

k. Fish bypasses (intermediate)

The design criteria stated that the maximum exposure time is 60 seconds. With a screen length of at least 985 ft and a channel velocity of 2.0 ft/s, the exposure time is estimated to be approximately 493 seconds for fish traveling from the upstream end of the fish screens to the open channel bypass at the downstream end of the fish screens. To meet the criteria, eight intermediate bypasses would be required; the bypasses would be approximately equally spaced.

The minimum total bypass flow is 500 ft^3/s. The bypass flow will be a combination of open channel flow and the flow from the intermediate bypasses. Flow for an intermediate bypass is based on the flow entering the bypass at a minimum velocity of 2.0 ft/s, a 10.5-ft depth, and a minimum bypass entrance width of 2.0 ft.

Minimum flow for the intermediate bypass = 10.5-ft depth x 2.0-ft width x 2.0 ft/s velocity = 42 ft^3/s

Each intermediate bypass flow was rounded up to 50 ft^3/s to ensure the 2 ft/s approach velocity at higher river flows.

If eight intermediate bypasses are constructed and used, the total flow from the intermediate bypasses will be 400 ft^3/s and only 100 ft^3/s would be available in the open channel bypass at the downstream end of the screens.

The large intermediate bypass flows were thought to be less desirable for fish passage in this circumstance, since the most beneficial bypass for fish was thought to be the open channel at the downstream end of the fish screens. This downstream bypass is the preferred bypass option because it does not take fish out of their natural element in the river channel. Because more flow would be available for the open channel bypass, it makes the bypass system more effective. A decision was made to construct three intermediate bypasses and one downstream bypass. A physical hydraulic model was used to help configure the screen/bypass layout. The bypasses are approximately equally spaced.

The intermediate bypass locations are shown in figures 105 and 106. The intermediate bypass pipes terminate just downstream from the adjustable overflow weir, which is just downstream from the fish screen structure. Each intermediate bypass consists of (1) an upstream bulkhead to allow isolating the bay, (2) a trashrack at the entrance, (3) a curved entrance, (4) artificial light in the entrance, (5) an adjustable weir gate, (6) a transition and conveyance pipe, and (7) an exit structure (common to all intermediate bypasses). A section through the entrance is shown in figure 108. The adjustable overflow weir in the oxbow provides the differential head needed to drive the flow through the intermediate bypasses in addition to providing a minimum water level for the fish screens.

The bypass entrance trashrack prevents large trash from entering and plugging the bypass. The center-to-center spacing of the trash bars is 9 inches to allow passage of fish but not trash.

The bypass entrance and adjustable weir configurations and hydraulics were determined by physical modeling (Campbell, 1998). A curved entrance (figure 109) is used to minimize the velocity gradient between the open channel and the bypass entrance and to also minimize the fright response of fish. The entrance top is open as much as possible and the entrance also includes artificial lighting to prevent shadows from frightening the fish and impeding their movement. The weir gate located within the bypass entrance channel is adjustable to control the bypass flow and also to act as a barrier to fish trying to move back upstream (figure 108). To prevent fry from moving back upstream over the weir gate, the minimum required drop over the weir gate is 0.8 ft.

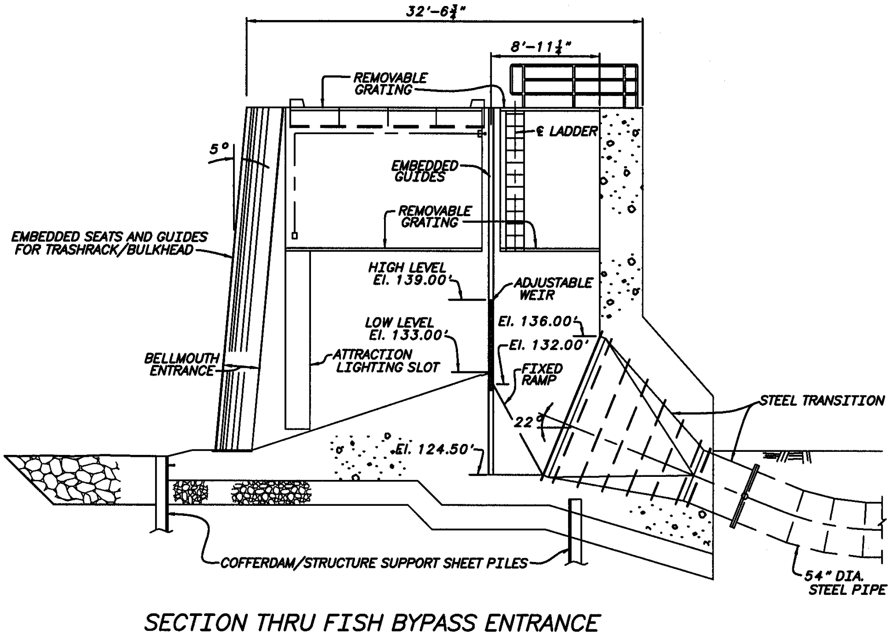


Figure 108.—Bypass entrance – Example 2.

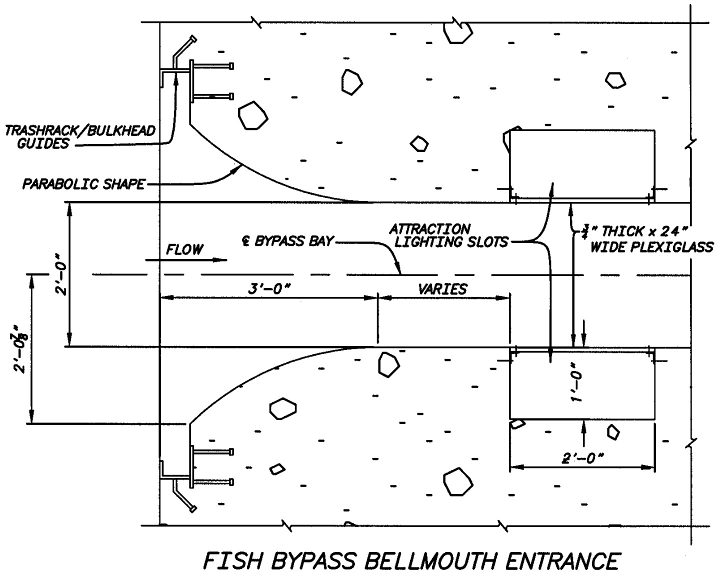


Figure 109.—Bypass Bellmouth entrance – Example 2.

The bypass pipe must have smooth walls and smooth joints to prevent injury to the fish. Pipe material alternatives considered were mortal lined steel pipe and HDPE. Because the existing screen structure needed to remain operating while building the extended structure, some of the bypass piping needed to be installed in the wet. Therefore, steel pipe was used because it was easier to place underwater.

The intermediate bypass exit structure (figure 105) is located downstream from anticipated turbulence caused by the adjustable overflow weir. It is also located in an area of flowing water so fish going through the intermediate bypasses will continue moving downstream after exiting and will be in an area where predators will not hold.

The intermediate bypass pipes are sized to meet velocity requirements (3.0 ft/s to 10 ft/s) and to operate under available head. The available head is 2.0 ft. The bypass pipe diameter selected was 54-inches, and the velocity for 50 ft^3/s is 3.14 ft/s. The farthest upstream intermediate bypass has the longest pipe, which is 1,100 ft long. Head loss was estimated for this upstream bypass from the entrance to the exit. (See table 10*).*

Table 10.—Head loss in the intermediate bypass

Feature	Head loss (ft)
Trashrack and bypass entrance – The trashracks will be kept clean and head loss through the trashracks held to less than 0.01 ft. due to the 9-inch bar spacing and 1.2 ft/s velocity at the trashracks. The head loss estimate for the entrance is 0.5* $v^2/2g$; for an entrance velocity of 2 ft/s, the head loss estimate is 0.03 ft. Use 0.1 ft.	0.1
Adjustable weir (the required drop is 0.8 ft)	0.8
Pipe transition head loss = $0.2 * (8.0^2 – 3.14^2)/64.4$	0.168
Bypass pipe (friction loss for longest pipe using Darcy Weisbach eq.) (See Example #1)	0.56
Pipe Bend Loss = $0.0035*90*(3.14^2/64.4)$	0.048
Exit loss = one * (pipe velocity head – channel velocity head) $1.0 * 3.14^2/64.4$	0.153
Total	1.829

I. Evaluation and O&M after construction

For an overall perspective of evaluation and operation requirements, see Chapter VII, Post Construction Evaluation and O&M Plans.

The fish facility is designed to be as flexible as possible to ensure reliable diversion flow and maximize successful fish screening. Items that are adjusted in this facility are the baffles for uniform flow velocity, the weirs in the intermediate bypass entrance channels to set the desired bypass flows, the operation of the fish screen cleaning sweeps, and the adjustable overflow weir in the oxbow channel to set the bypass channel flow. In addition, water level measuring equipment is located upstream and downstream from the fish screens and baffles and the adjustable overflow weir in the downstream oxbow channel.

At initial startup, velocity measurements are made along the fish screen structure and the baffles are adjusted to obtain a uniform approach velocity along the fish screens.

During normal operation, the adjustable overflow weir in the oxbow channel is set to provide the desired water level and bypass flow in the channel and the adjustable weir in each intermediate bypass is set to obtain the desired intermediate bypass flows. The screen cleaners should be set to operate a cleaning cycle at a predetermined cleaning time interval unless the amount of debris in the river is high, then the cleaners should be set to operate continuously.

Successful fish passage should be evaluated, specifically looking at the following:

- Fish survivability in the open channel bypass
- Fish survivability in the intermediate bypasses
- The best operating combination of open channel and intermediate bypasses

Backup power is not necessary because the diversion pumping plant will also shut down with interrupted power.

3. Example 3 – Drum Screen in Canal – Small Screen Facility (Based on Lemhi River Site L-6 by Reclamation’s Pacific Northwest Region)

This example presents improvements to a diversion on the Lemhi River in Idaho (Pacific Northwest, 1993). The improvements are part of a project that will improve several diversion facilities. The improvements are required to prevent stranding fish in canals, provide upstream fish passage, and increase river flows. A smaller than desired population of spring and summer Chinook salmon and steelhead exists. The gravel berm diversion dams, when in place, prevent upstream fish migration. The diversion for this example is referred to as Site L-6 on the Lemhi River. Site L-6 is an existing diversion with a maximum diversion capacity of 50 ft^3/s. The water is diverted for irrigation of pasture and hay crops. At certain times of year, excess water is diverted in an attempt to buildup the groundwater table. The groundwater then helps maintain river flows late in the season.

The diversion into the existing canal is started each spring by constructing a temporary gravel berm in the river to provide adequate head for the canal flow. Because of the lack of an adequate headworks, the diversion flow often exceeds demand. The canal contains an existing fish screen, which does not meet current fish protection criteria. The existing fish screen design was based on a screen approach velocity that is too high. The existing screen contains a small 6-inch bypass pipe.

Modifications to the canal and diversion will include the following (figure 110):

- Constructing a permanent adjustable crest overflow weir across the river. This will allow upstream fish passage when diversions are not required.
- Constructing a fish ladder for upstream passage.
- Constructing new canal headworks. The headworks structure will allow limiting diversion flows to those required for irrigation and bypass. The headworks will be a constant head orifice type structure, which will control and measure the flow into the canal. It will also have trashracks.
- Constructing a fish screen facility in the canal, that meets current fish protection criteria.
- Improving the intake canal upstream from the fish screen structure.

a. Fishery

Species – spring Chinook salmon and steelhead

Size – fry through adults

Downstream migration – Juvenile rearing occurs throughout the year. The migration to the ocean occurs from April though June

Upstream migration – Mid-May to mid-September. The peak migration normally occurs from mid-June to late August.

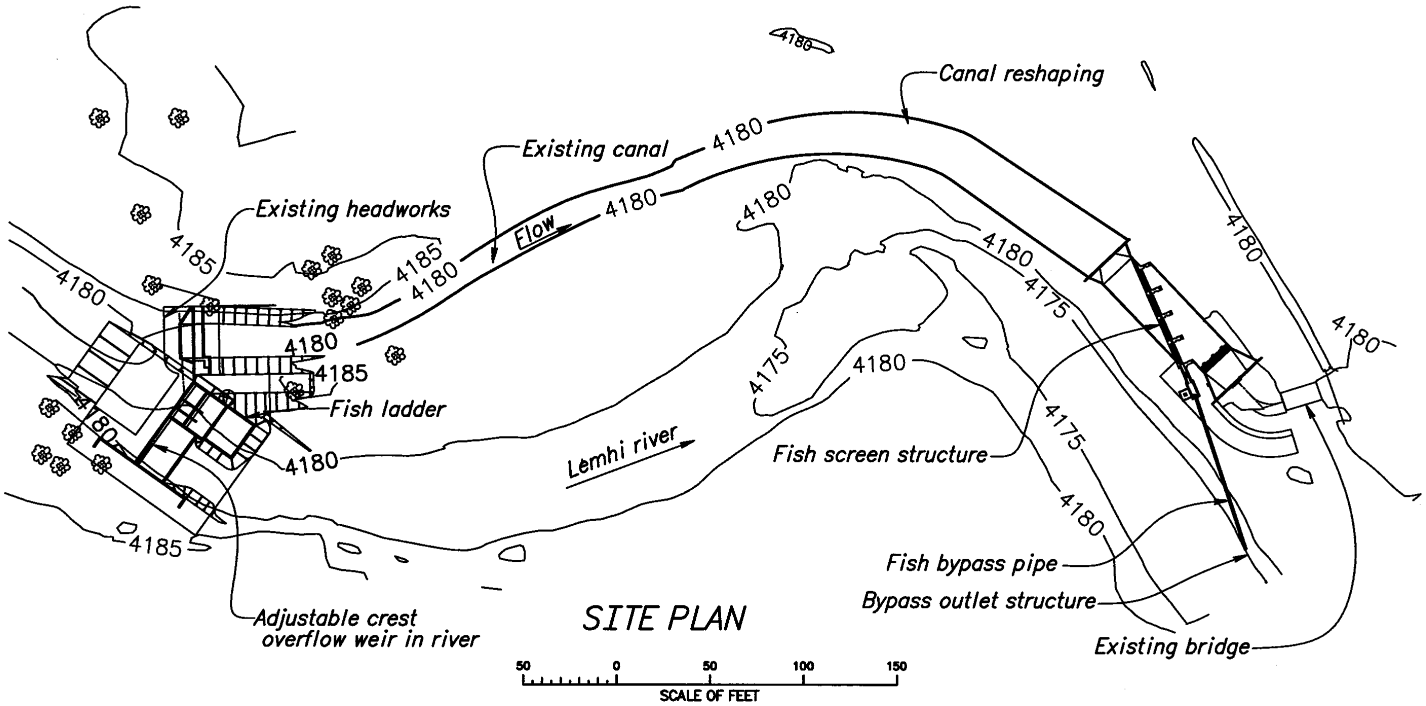


Figure 110.—Site plan – Example 3.

Swimming – The fry generally drift with the current and have little strength and endurance to swim against the current. Fry occur throughout the water column.

b. River design data

The river flow is significantly affected by snow melt and reservoir releases. The peak river flows occur from May through July. The fish protection facilities must be able to operate satisfactorily for river flows up to 500 ft^3/s. Ninety-five percent of the time, the river flow will not exceed the 500 ft^3/s. A minimum water surface of El. 4181.5 is required in the diversion pool to provide the maximum diversion flow of 50 ft^3/s.

c. Design data

The diversion season is from approximately mid-March to mid-October. Canal flow and water surface elevation and depth at the fish screen were evaluated for the existing canal and are shown in table 11.

Table. 11 – Canal flow versus water surface elevation

Screen flow (ft^3/s)[1]	Canal water surface elevation	Channel invert elevation	Channel depth (ft)	Bypass flow (ft^3/s)[2]	Total upstream flow[4] (ft^3/s)	Channel velocity (ft/s)	Sweeping velocity[5] (ft/s)	Wetted screen area (ft^2)	Screen approach velocity (ft/s)
50[6]	4180.22[3]	4176.33	3.89	4.66	54.66	0.69	0.65	128.5	0.39
45.6[7]	4179.88	"	3.55	4.26	49.86	0.69	0.65	113.4	0.40
39.6[8]	4179.52	"	3.19	3.83	43.43	0.66	0.62	98.20	0.40

Notes:

1. Determined by evaluating existing canal.
2. Bypass flow is based on bypass entrance velocity = 0.8 ft/s.
3. Elevation 4180.22 is the high water mark in the canal.
4. Total upstream flow is screen flow plus bypass flow.
5. The sweeping velocity is based on the screen installed at a 20-degree angle.
6. Maximum flow at high water mark in existing canal.
7. Design flow.
8. Flow at minimum allowable depth on drum screens.

The canal section properties are:

	Upstream	**Downstream**
Bottom width	10 ft	15 ft
Side slopes (horizontal/vertical)	1.5:1	1.5:1
Bank height	4.5 ft	4.5 ft
Lining	Compacted earth earth	Compacted

River water surface profiles have been evaluated for a range of flows to ensure that the fish screen facilities will operate for a range of river flows up to 500 ft^3/s.

***Debris* –** Trashracks will be located on the new headworks, and only minor amounts of small debris will enter the canal.

***Sediment* –** Sediment deposition is expected to be minor, and deposits can be removed during the non-irrigation season.

***Access* –** Access to the screen structure will be along the canal O&M road.

***Electrical power* –** Electrical power is locally available.

d. Fish screen structure design criteria

The criteria listed below were agreed to by the Technical Advisory Group, which consisted of State and Federal agencies, the irrigation district, and the designers.

Irrigation district requirements:

- Base the screen design flow on existing canal capacity. It should be 45.6 ft^3/s (table11).
- Design the fish screen facility so that it is easy to operate and maintain.
- Don’t allow construction to interfere with canal operations. Construction in the canal can occur from mid-October through mid-March (5 months), which is the non-operating period.
- Locate the screens in the canal so that they will provide good access for O&M.
- Use drum screens because of the anticipated ease of O&M. The drum screens will be 3 ft 6 inches in diameter and 12 ft long. These are standard dimension screens that are available in the area. The drum screens are self-cleaning, and, because of the small screen size, maintenance on the seals is not anticipated to be difficult.

e. NOAA Fisheries and State criteria

***Fishery* –** The screens should be able to protect salmon and steelhead juveniles as small as fry (25 to 60 mm). At times during the irrigation season, the irrigation flows in several of the diversions on the river will be reduced and the flow in the river will be increased (flushing flow) to help both upstream and downstream fish migrations. If downstream river flows are too low to allow downstream fish migration, the fish can be held in the canal for later release or captured in the bypass and trucked downstream.

Screen structure – The screen structure should be placed in the canal as close to the headworks as possible. This is to minimize the time fish are out of their natural environment and minimize potential predation. Orient the screen structure so that the sweeping velocity is greater than the screen approach velocity and fish are guided to the bypass entrance. Size screens for a maximum screen approach velocity of 0.4 ft/s.

A uniform screen flow distribution must be provided. All structure surfaces exposed to fish shall be flush with the drum screens (piers and end walls). The maximum exposure time shall not exceed 60 seconds. The flow depth on the drum screens shall be maintained between 0.65 and 0.85 of the screen diameter. Provide a 6-inch lowered slab upstream from the fish screens if sediment accumulation is expected to be a problem. A downstream check structure will be required to maintain the water level. The gates should be at least two drum screen diameters downstream from the screens.

Fish screens – The material for the drum screens shall be stainless steel woven wire. The maximum opening shall be 3/32 inch. The minimum wire diameter shall be 0.080 inch (14 gage) for rotary drum screens. Screen material shall provide a minimum of 27 percent open area.

Bypass to river – The bypass will operate satisfactorily up to a 500 ft^3/s river flow and at the minimum allowable channel depth (0.65 x screen height).

The bypass entrance shall meet the following requirements:

- The bypass entrance shall have independent flow control.
- The minimum bypass flow shall be 0.8 ft^3/s.
- The velocity at the entrance to the bypass shall be equal to or greater than 1.1 times the upstream channel velocity or greater if possible.
- The entrance shall have ambient lighting.
- The invert of the entrance shall be at the same elevation as the upstream channel.
- Construction in the river can occur from late August to the beginning of March.

The bypass conduit shall meet the following requirements:

- The pipe shall be smooth.

- A 10-inch minimum pipe diameter is acceptable for a small diversion (attachment A.1.K).

- Bends shall be avoided, if possible.

- The pipe velocity shall be between a minimum 2.0 ft/s to a maximum 10.0 ft/s.

Monitoring shall meet the following requirements:

- The Positive Integrated Transponder (PIT) tag detectors shall monitor juvenile fish passage.

- A more extensive juvenile monitoring facility will be constructed at another diversion site. The monitoring facility will provide for PIT tag installation and detection, and juvenile sorting and counting.

- An adult monitoring facility will be constructed at a fish ladder at another location. The fish ladder will include a viewing window, which will allow video monitoring.

f. Location of fish screen structure

The fish screens will be located in the canal downstream from the headworks and curves (figure 110).

The existing canal will be realigned to provide as straight an approach channel as possible at this site. For uniform approach flow conditions, it is desirable to locate the fish screens approximately 40 times the canal water depth downstream from the headworks or any bends.

Desired distance from curve to fish screens = 40 * 3.55 = 142 ft.

The upstream channel is 94 ft long and is straight except for a small curve (figure 110). Non-uniform approach flow should be anticipated at the fish screens. It is anticipated that slide gates just downstream from the screens can be adjusted to provide a uniform flow through the fish screens. A physical model study was not considered necessary.

g. Design of fish screen structure

The fish screen facility (figures 111 and 112) will consist of the following:

- Fish screen structure and associated guide walls

- Transitions from the upstream canal and downstream trapezoidal canal section to the rectangular fish screen structure channel

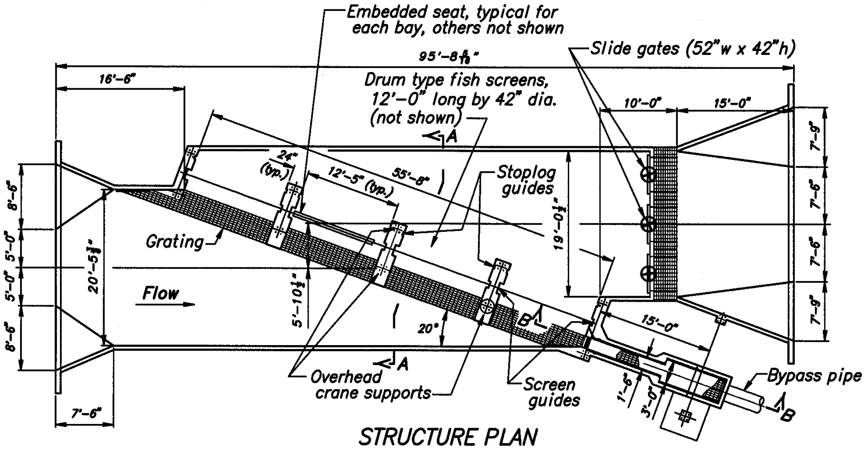


Figure 111.—Structure plan – Example 3.

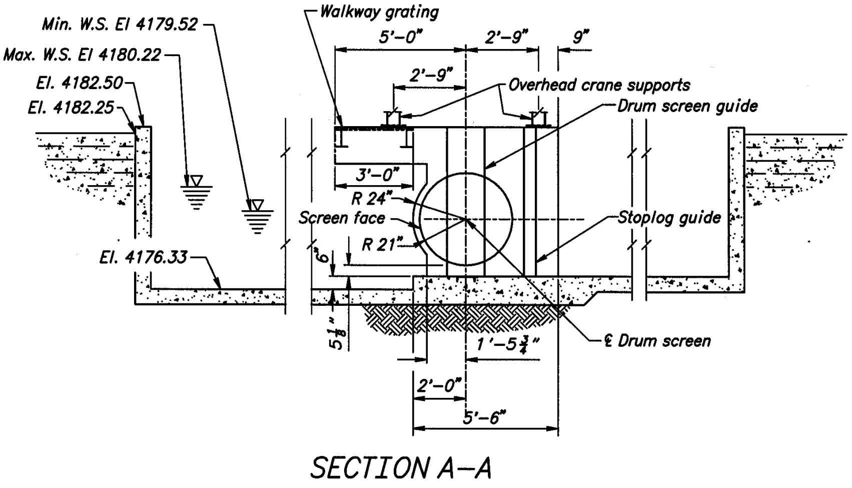


Figure 112.—Section through drum screen structure – Example 3.

- Fish screens – drum screens

- Overhead monorail to remove and replace the drum screens, etc.

- Grooves for installing adjustable stoplogs or baffles behind the fish screens

- Fish bypass to the river including: the bypass entrance, the bypass pipe, and the outlet structure

- Three downstream slide gates for controlling the water level at the fish screens

Fish Screen Structure – The fish screen structure (figures 111, 112, and 113) will consist of the following:

- Foundation slab
- Drum screens
- Intermediate piers
- Guide walls
- Metal grating walkway
- Monorail

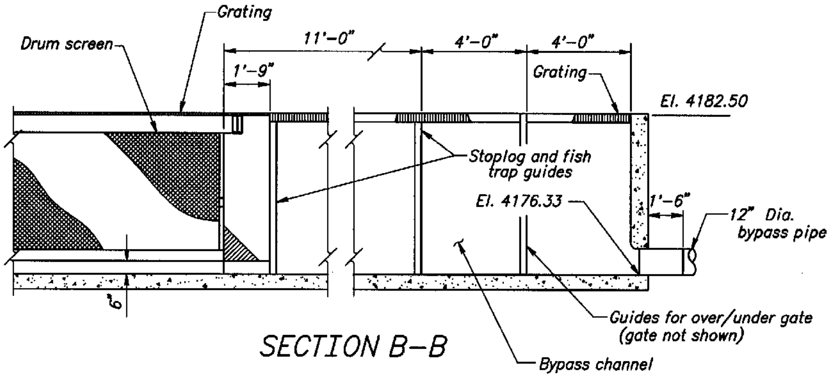


Figure 113.—Section through bypass entrance – Example 3.

The concrete slab under the fish screens is elevated 0.5 ft above the invert of the approach channel to allow for sediment deposits.

The required net area of fish screens is the design flow divided by the maximum allowable approach velocity:

$$\text{Net area} = (45.6/0.4) = 114 \text{ ft}^2$$

The required area does not include structural support members. Structural support members normally occupy 5 to 10 percent of the fish screen area. For this example, we will use 10 percent. Thus, the required gross area will be:

$$A_g = 126.7 \text{ ft}^2$$

The minimum length of the fish screens is obtained by dividing the required area by the submerged screen depth. The depth on the fish screens at the design water level is 0.75 * 3.5 = 2.625 ft. The required length of the fish screens is:

$$L = 126.7/2.625 = 48.3 \text{ ft}$$

Four 12-ft-long drum screens were selected. During low flows, two of the screens can be shutdown by placing stoplogs behind them.

An upstream channel width of 20.45 ft results in the hydraulic properties shown in table 11.

$V_s/V_a = 0.65/0.4 = 1.65$, which is satisfactory because any impinged debris will be carried over the drum screens and washed downstream.

With a sweeping velocity = 0.65 ft/s and a 55.72 ft length, the exposure time is:

$$\text{Exposure time} = 55.7/(0.65) = 86 \text{ seconds.}$$

This is greater than the 60 seconds allowed by the criteria, and a variance will be sought from the fishery resource agencies**.**

The walkway deck (steel grating) was set 3 inches above the canal bank elevation. The deck must be wide enough for access by maintenance personnel and is typically 3 to 4 ft wide. A deck width of 3 ft was selected (figure 112).

The deck is designed for dead loads and live loads.

Upstream and downstream transitions – At the upstream and downstream ends of the fish screen structure, there are transitions from the canal (trapezoidal channel) to the rectangular fish screen structure channel. The transitions must be sized and shaped to provide a non-turbulent transition of flow, without eddies. To accomplish this, the transition wall angle, at the flow line, should be 25 degrees or less. The upstream transition is 7.5 ft long, and the downstream transition is 15 ft long and the water surface angles are 0 and 22 degrees, respectively, thus meeting criteria. Cutoffs are provided to prevent undermining by scour and reduce seepage and piping of foundation materials. Riprap should be provided upstream and downstream from the structure, as required, for scour protection.

Fish screens **–** The screen material will be woven wire with a maximum 3/32-inch opening. The screens will be fabricated from 6 mesh (6 wires/inch) – 14-gage (0.08") wires with 27.2 percent open area. For durability, stainless steel wire will be used. The fish screen frames can be structural steel. Anodes may be required for corrosion protection. Electric drive motors will be provided to continuously rotate the drums. Shear pins will be provided to protect the drive system. Seals will be provided on the bottom and sides of the fish screens. Lifting lugs will be welded to the frames.

Flow control **–** Three slide gates are provided in the canal downstream from the fish screens to control the water surface elevation at the fish screens at .65 – .85 percent of drum screen diameter. The slide gates can also be adjusted to affect the flow distribution through the fish screens.

If necessary, baffles can be installed in the guides that are provided immediately downstream from the fish screens to obtain a uniform flow distribution along the screens. The baffles will consist of stop logs similar to those shown in figure 11. The stop logs can be located off the bottom and spaced apart from each other to achieve the desired effect while allowing debris passage.

h. Fish bypass

The bypass consists of the entrance, the return flow channel, and the outlet structure.

Entrance **–** The bypass entrance is at the downstream end of the fish screens (figure 111). The entrance is initially 1.5 ft wide, which is adequate to pass trash and fish. At the downstream end, it widens to 3.0 ft for the over/under gate. The bypass entrance velocity is 0.8 ft/s (greater than 1.1 x the upstream channel velocity) and the bypass flow will range from 3.8 to 4.6 ft^3/s, depending on the channel depth (table 11). An over/under gate, installed in the downstream guides, will be used to control the bypass flow. The gate can be set to pass flow over the top and flow and sediment underneath. The gate also acts as a drop structure for excess head. The bypass channel is designed to allow a fish trap to be installed and allow PIT tags to be detected (figure 113). This is accomplished by embedding guides in the sidewalls so that a removable net and trap box (or other equipment) can be inserted and removed.

Bypass return flow channel – The bypass must be able to operate during the most limiting conditions, which occur during the high river flow (500 ft^3/s) and a diversion flow (screen flow) of 45.6 ft^3/s . Buried pipe will be used for the bypass to the river (figure 114). For economy and to keep fish moving, it is desirable to make the diameter as small as possible. Head loss through the bypass system must be estimated and must not exceed available head. The selected pipe diameter from the bypass entrance to the river is 12-inches. With a flow of 3.8 to 4.6 ft^3/s, the velocity will be 4.8 to 5.8 ft/s (which is within criteria). Polyvinyl chloride (PVC) pipe is used for the bypass. The joints in the PVC pipe will have rubber gaskets.

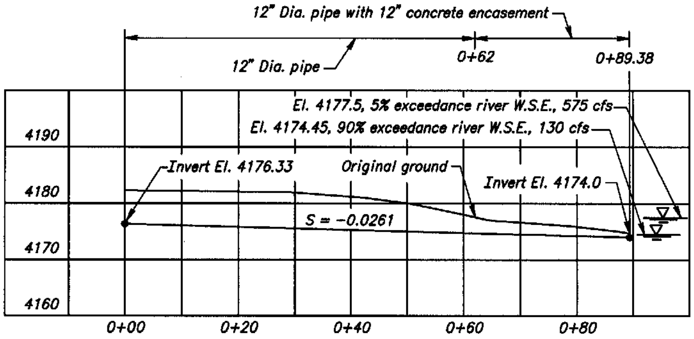


Figure 114.—Fish bypass pipe profile – Example 3.

Bypass outlet structure – The outlet structure is a concrete transition (figure 115). The following items must be considered in locating the outlet structure: the river flow velocity and depths, the possibility of future river changes such as degradation and changes in alignment, and sedimentation. The outlet structure is in a straight reach of the river that has a good river velocity. Also, the site is not subject to significant scour or sediment deposits. Riprap on a sand and gravel bedding is placed about the structure to protect against scour.

I. Screen facility head loss estimate

Head loss through the fish screen facility must be considered when designing the diversion dam and canal section.

For this example, the total head loss estimate will be assumed to be 0.3 ft. This will account for baffling and minor screen plugging by debris.

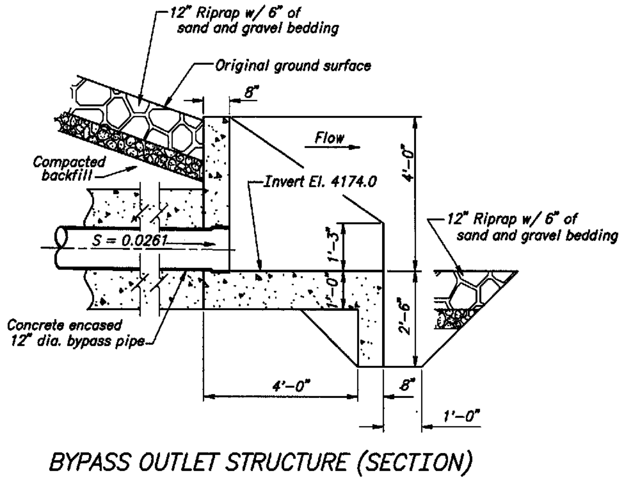


Figure 115.—Paypass outlet structure section – Example 3.

j. Operation and maintenance

For an overview of Operation and Maintenance issues, see Chapter VII, Post Construction Evaluation and O&M Plans.

The fish facilities are designed to be as flexible as possible to maximize successful fish exclusion and protection.

Flow in the canal is controlled and measured at the new headworks.

The fish screens are self-cleaning, because of the rotation of the drum screens and require maintaining the upstream water level between .65 and .85 of the diameter of the drum screen. The drum screen motors and seals will require maintenance. The screen drive system will have to be maintained (oiled and greased).

The monorail used to lift screens and the stoplogs used for baffling will be maintained.

Flow to the bypass can be adjusted with the over/under gate. The over/under gate can also be used to sluice sediment from the bypass entrance. The gate also acts as a drop for excess head.

The water surface elevation at the fish screens is maintained with the three downstream slide gates.

At initial startup, velocity measurements should be made along the fish screens. Baffles can be installed to obtain a uniform flow distribution along the fish screens.

Sediment deposits can be removed during the non-irrigation season when the canal is unwatered.

PIT tags can be detected in the bypass entrance

4. Example 4 – Louver in Canal (Based on T&Y Canal and Diversion)

The diversion dam and canal are existing facilities. The T&Y Canal and 12 Mile Diversion Dam are located on the Tongue River, Montana, approximately 20 miles upstream from the confluence of the Tongue River with the Yellowstone River. A 10 ft-high concrete capped timber crib dam diverts up to a maximum discharge of 237 ft^3/s from the river into the canal. The dam and diversion include an overflow ogee weir and the canal headworks. A sediment sluice structure was included to bypass sediments that will accumulate at the entrance to the headworks, which include vertical slide gates. The headworks are positioned such that floating debris is largely sluiced over the dam ogee spillway. The dam and diversion are owned and operated by the T&Y Irrigation District. Liston et al., 1995, and Mefford et al., 1997, document, in detail, the fish exclusion and concept selection and design process.

The irrigation district has limited financial and labor assets. The district recognized that fish entrainment occurred at the diversion and, as a consequence, desired to add a fish exclusion structure to the diversion that would reduce impacts on the Tongue River fishery. The diversion season extends from April to October.

a. Fishery

The fishery issues at the T&Y Diversion include both the impact of the diversion on the migration and habitat range of native fish in the Tongue River and the loss of fish to entrainment to the diversion canal. The dam is a barrier to upstream passage of migratory Yellowstone River fish. These include the endangered pallid sturgeon. The addition of a fishway that would allow upstream passage at the dam might be considered at a later date.

As established in fishery surveys conducted by the Montana Department of Fish, Wildlife, and Parks and by the Montana Department of Natural resources and Conservation (Backes, 1993; Clancy, 1980; and Elser, et al, 1977), approximately 16 species of fish are present in the river reach above the diversion. These are the species that could be entrained in the diversion canal. None of these species is listed as threatened or endangered. Present are sport fish species including rock bass, smallmouth bass, white crappie, channel catfish, and sauger. Supplemental stocking of juvenile (possibly 2.0-inch long) smallmouth bass and channel catfish has been explored. Seasonal variations in fish species and fish sizes present at the diversion are not well documented. If, in the future, fish passage was added to the dam, the species of concern would be expanded. Adding passage would likely increase the need to exclude smaller juvenile fish from the canal because fish migrations would occur during spawning.

In coordination with the Montana Department of Fish, Wildlife & Parks and with recognition of the lack of endangered species, it was concluded that total exclusion of all fish from the T&Y Canal was not required. It was decided that a reasonable design should exclude a relatively high percentage (preferably a 70 percent exclusion efficiency or higher) of fish that are 2 inches long or longer. It was also recognized that, if fish passage were added to the dam, high (approaching 100 percent) exclusion would be required for all fish 1 inch long or longer. Since additional passage is possible, concepts that allow future retrofit modifications to improve fish exclusion efficiencies should be considered.

No salmonid species were identified either above or below the diversion dam. Salmonids are the species for which most design criteria are available. Only limited criteria are available for non-salmonids that are the target species for this design application. Existing non-salmonid data would have to be reviewed to select criteria that would be applicable for this design.

b. Selection of preferred exclusion concept

The primary screen options considered in the selection process were linear flat plate, drum, inclined screens, and louvers.

Linear flat plate, drum, and inclined screens meet the stated fish exclusion objectives. However, their performance is sensitive to debris, sediment, and ice fouling which could be a major factor at this site. Consequently, the maintenance demands and the capital cost of a screen that complies with fishery resource agency criteria would be greater than preferred. These screen concepts exceed proposed fish exclusion performance objectives for this site at this time.

Although not a positive barrier, louvers meet the current stated fish protection objectives except for a limited potential that debris and ice fouling will generate moderate maintenance demands (maintenance demands will likely be less than that required for screen concepts). Where threatened and endangered species are present, louvers are not considered an acceptable means of fish protection by fishery resource agencies. However, the lower capital costs are in line with the district's capabilities.

The flat plate screen and louver concepts were selected and conceptual designs were developed for the T&Y site. Cost estimates indicated that the louver structure could be constructed for approximately $240,000 (1997 costs). Comparable cost estimates for the linear flat plate screen were approximately $340,000.

Noting that the louver concept is less affected by debris, sediment, and ice fouling and has reduced operations and maintenance demands as compared to the alternative flat plate screen concept and that a louver structure can be constructed for a substantially reduced capital cost, the louver concept was selected for development. It was anticipated that a louver facility design could be developed that would meet the stated fish exclusion objectives (70 percent exclusion efficiency or greater for fish that are 2 inches long or longer). A linear flat plate screen could be used as a retrofit (in place of the louvers) as a future upgrade, if upstream fish passage is proposed at some future date for the dam.

c. River design data (diversion flows and associated water surface elevation data)

Data establishing the hydraulic characteristics of the site were collected and developed through analysis and on site documentation. Hydraulic characteristics of the site include:

- The Tongue River flow is significantly affected by snow melt, storm events, and reservoir releases. The peak river flows occur in the spring (up to 1600 ft^3/s) while river flows in the late summer and fall are typically low (fall minimum flow can be as low as 190 ft^3/s).

- Pool water surface elevations just upstream from the dam are:

  2448.4 with 200 ft^3/s over the dam weir
  2448.75 with 600 ft^3/s over the dam weir
  2449.0 with 1,000 ft^3/s over the dam weir

- Diversion discharges range from 100 ft^3/s to the design discharge of 237 ft^3/s.

- Water surface elevations in the first reach of canal (based on checking the existing canal):

  2447.0 with canal flow of 250 ft^3/s
  2446.8 with canal flow of 235 ft^3/s
  2446.0 with canal flow of 150 ft^3/s
  2445.4 with canal flow of 100 ft^3/s

- Tailwater elevations below the dam vary between 2443.0 and 2439.0 during most diversion periods.

The maximum allowable diversion is 237 ft^3/s. The bypass operation will reduce delivered discharge accordingly. Thus, the fish facility operation will reduce deliverable discharge by up to 8.0 ft^3/s.

d. Design of fish louver facilities/structure

The new fish louver facility consists of:

- Modification to the existing headworks
- A transition from the headworks section to the louver section
- Lined louver approach and exit channels that ensure consistent velocity fields on both sides of the louvers, thus helping to maintain a constant differential across the louver
- A diagonally placed louver with support structure
- Turning (straightening) vanes placed behind the louvers that prevent exit velocity concentrations that could yield variations in differential across the louvers (figure 122)
- Open chute fish bypass to the river, including embedded guides that allow placement of stoplogs for bypass flow rate control

e. Fish louver structure design criteria

- The fish species present are rock bass, smallmouth bass, white crappie, green sunfish, channel catfish, sauger, suckers, carp, shorted redhorse, and forage species.
- The louvers should exclude fish longer than 2.0 inches.
- The design flow through the louvers is 237 ft^3/s; this flow may be diverted with an upstream river flow as small as 427 ft^3/s (190 ft^3/s is the fall minimum streamflow below the diversion dam).
- During low river flow periods, the facility is operated without bypass flow (which maximizes the diversion). Periodically, in such water periods, fish have to be removed by netting from the zone ahead of the louvers and returned to the river.
- The diversion and louvers must operate effectively with river flows up to 1,600 ft^3/s, which is the spring maximum flow.

- The differential water level between the canal and the river, immediately downstream from the dam, varies as a function of river flow and diversion discharge. With minimum streamflows below the dam, differentials will range from 6.4 to 7.8 ft, while with high streamflows, differentials will range from 2.4 to 3.8 ft.

- Maximum louver approach velocity criteria are poorly defined for the fish species present at the T&Y diversion dam. Interpretation of table 6, chapter V.A. of this report indicates that a maximum louver approach velocity of 1.3 ft/s for bass and 0.9 ft/s for catfish may be appropriate. Lower approach velocities would be appropriate for other weaker swimming species**.** Use 1.0 ft/s.

- Uniform approach velocities are required across the louver face.

- Sweeping velocity criteria are poorly defined for the fish species present at the T&Y diversion. Interpretation of table 6 in chapter V.A. of this report indicates that sweeping velocities of up to 5.0 ft/s are appropriate for bass and 3.0 ft/s are appropriate for catfish. At Reclamation’s Tracy Fish Collection Facility, which also excludes many non-salmonid species, 3.0 ft/s is the operating criterion maximum.

- The invert of the louvers was positioned 1.0 ft above the canal invert to improve sediment sluicing and to generate a sill that would function to guide bottom oriented fish directly to the bypass. Water depth on the louvers ranges from 1.4 to 2.8 ft, varying with diversion discharge.

- Fish should be exposed to the louvers for no more than 60 seconds.

- The criteria for the bypass to river are:

    - Entrance width – 2.0 ft

    - Entrance velocity – Sweeping velocity or greater (up to 1.4 times sweeping velocity)

    - Constructed as an open chute to allow easy access for maintenance

    - Bypass channel (chute) velocities – 3 to 10 ft/s

- The criteria for the louvers are:
    - Clear spacing between louver slats – 1.0 inch, figure 122 (based on experience summarized in table 6, chapter V.A.)
    - Slat size 2.5 inch by 3/16 inch, based on previous experience
    - Slat orientation to flow – slats placed normal to approach channel flow
    - The louver line should be oriented at angles ranging from parallel to 17 degrees to the channel flow (chapter V.A.). The louver face was placed at a converging angel of 15 degrees to the flow.
    - Turning vanes were used behind the louvers to generate uniform approach velocity distributions (chapter V.A.) and improve hydraulics through and past the louvers.

Although debris fouling will affect fish exclusion effectiveness, the woody material does not greatly reduce louver open area and does not greatly increase head loss. As a result, there is little need for emergency shutdown or louver bypass facilities. If flow is diverted from a highly biologically productive water body, fouling with aquatic plants could produce excessive head loss that could require emergency shutdown or louver bypass operation. A trashrack will be included to prevent large debris from entering the headworks.

f. Location of louver structure

There are a number of reasons why the in-canal placement was selected. The gravity diversion is made from an existing diversion dam and pool; therefore, in-river placement of exclusion facilities was not an option. Heavy sediment deposition within the diversion pool yields shallow depths within the pool that would require an extended fish exclusion facility if placed in the diversion pool. This would also require an extended flow guidance structure to generate sweeping flows across the fish exclusion facility. This structure would be costly. In addition, placement of the facility within the diversion pool would expose the facility to severe sediment, debris, ice, and water loading. As a consequence, placement in the diversion pool was also eliminated as an option.

The canal, land surrounding the canal for several hundred feet below the headworks, and access to the site are owned or controlled by the T&Y Irrigation Company. As a result, property did not have to be acquired for fish facility construction, fish bypass construction, construction staging, or access.

The alignment of the existing canal with respect to the headworks was well suited to generate uniform, well directed approach flow for the angled louver facility. A short distance downstream from the headworks, the canal turns approximately 6 degrees away from the river. By using this 6 degrees with a 5-degree convergence of the louver into the flow, the required louver length could be placed on a diagonal across the canal (figure 121).

An additional advantage of placing the louver structure immediately downstream from the headworks is that this placement reduces the potential for predation. The placement also minimizes the required length of the fish bypass chute because the canal is close to the river.

g. Design and construction of headworks and canal reach

Design – The canal headworks and initial reaches of the canal were in disrepair. As a consequence, rebuilding the headworks and canal reach with specific consideration of installation of the in-canal louver facility was necessary (figures 116 and 117). The developed headworks include three 3-ft-high by 5-ft-wide, manually operated slide gates. These gates can supply the maximum diversion discharge of 237 ft^3/s with approximately 0.5 ft of head differential between the diversion pool and the canal. The headworks gates were also positioned across the full width of the canal to generate uniform channel flow conditions leading to the louver.

Figure 116.—Overview of T&Y Diversion with fish louver structure – Example 4 (T&Y Irrigation District).

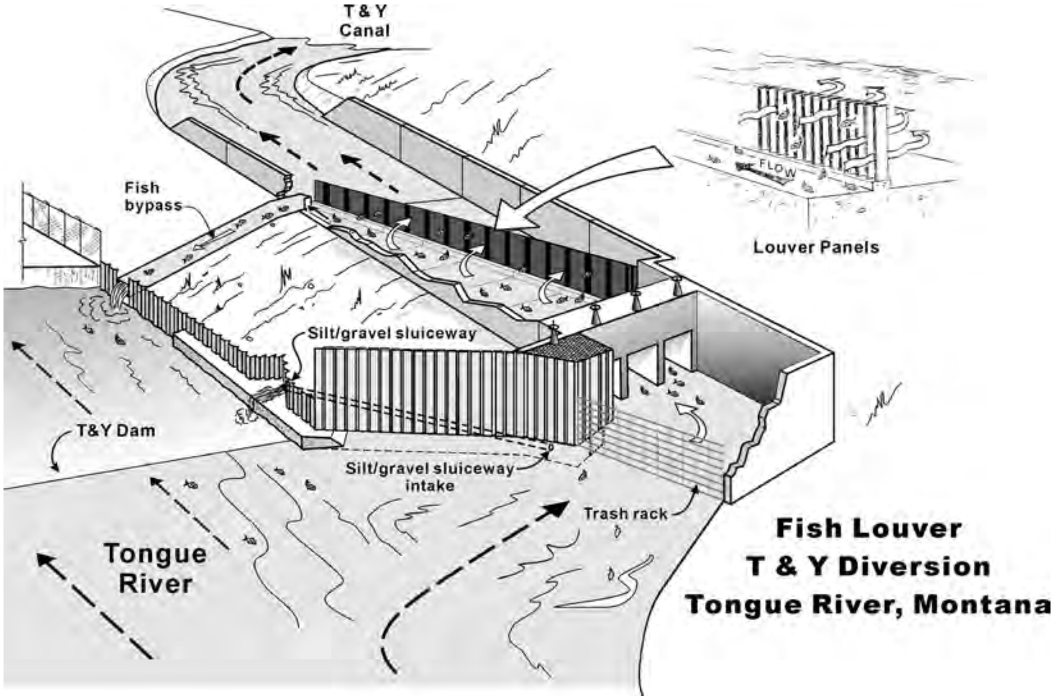


Figure 117.—Layout of T&Y Diversion Project – fish louver structure – Example 4 (T&Y Irrigation District).

Approximately 150 ft of canal immediately downstream from the headworks was lined with a concrete invert and vertical concrete walls (figures 116 and 118). This section of canal was configured to accept the louver fish exclusion structure. The canal data and section properties follow:

- Bottom width = 20 ft (downstream from the headworks to the louver structure) 24 ft (downstream from the louver structure)
- Side slopes = vertical
- Maximum flow = 237 ft^3/s
- Depth at 237 ft^3/s (at louvers) = 3.8 ft
- Bank height = 7.0 ft
- Lining = reinforced concrete from the headworks past the louver
- Bottom slope = horizontal through louver structure

Figure 118.—T&Y Diversion Dam trashrack structure – Example 4 (T&Y Irrigation District).

- Velocity in canal at maximum diversion (at louvers) = 2.6 ft/s
- Operating season = April to October

The water surface is controlled by a downstream check structure and varies as previously noted.

Construction – The existing headworks structure was replaced with a new headworks, flume, and fish exclusion facilities. The construction work was accomplished during non-operating periods from October to April. Therefore, a canal bypass to deliver diversion during construction was not required.

The concrete foundation for the replacement headworks includes upstream and downstream cutoffs to prevent undermining of the headworks by scour and to reduce problems caused by seepage. In that a continuous wall and invert lining was used in the reach of canal that includes the louver, cutoffs were not required in the foundation of the louver.

A sheetpile wall was placed across the intake channel to provide for dewatering the headgate structure during construction. The sheetpile was initially installed to an elevation of 2454.0 (figures 117 and 118). When construction was completed, a 35-ft notch was cut to elevation 2446 in front of headworks entrance. Because the sheetpile is 2 ft above the headgate invert, it will serve as a weir across the intake channel. This should reduce sediment entrainment at the headworks. A 24-inch low-level sluice has been placed adjacent to the headgate structure in front of the trashracks (figures 117 and 121).

Louver support structure **–** The louver support structure consists of a steel support frame placed on the concrete slab canal invert lining (figures 119, 120, 121, and 123). The louver face is vertical and retained by bolting louver panels to the support frame. The louver panels form a continuous louver face that is not broken by structural members that could collect debris, injure fish, or disrupt fish guidance along the louver. A foot bridge is included with the support structure to allow access to the full length of the louver face for maintenance and inspection. The invert of the louvers was positioned 1.0 ft above the canal invert to improve sediment sluicing and to generate a sill that would function to guide bottom oriented fish directly to the bypass (figures 117 and 121).

Louvers **–** As summarized in the presentation on criteria, the 90-ft-long louver line was installed in a section in which the maximum occurring sweeping velocity would be 2.6 ft/s. Based on the maximum diversion discharge and the corresponding active louver face area, the maximum approach velocity to the louver is approximately 1.0 ft/s. This velocity complies with the experienced-based criteria.

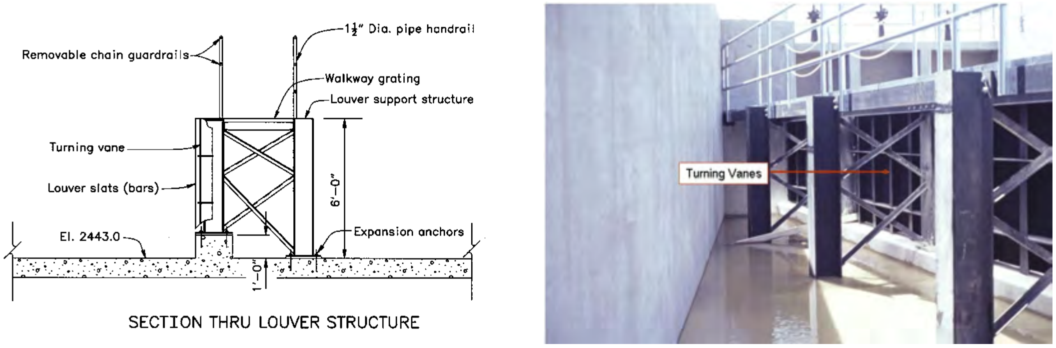
This sweeping velocity yields a 35 second exposure time for fish passing along the 90-ft-long louver face.

Again, relying on experience-based criteria, the 2.5-inch by 3/16-inch louver slats were set with a 1.0-inch clear spacing between slats. The slats were oriented normal to the approach flow (figure 122).

To minimize costs, the louvers were fabricated from coated steel. Each louver panel is 5 ft high by 10 ft long (figures 120 and 122). This positions the top of the louvers approximately 2 ft 2 inches above the maximum water surface elevation and at the same elevation as the walkway deck. This height allows the louvers to be manually raked to the walkway.

The louvers could have been either bolted to the support frame or placed in guides. Placing the louvers in guides facilitates removal and replacement; however, it also increases facility cost. For this facility, the louver panels were bolted to the support structure (figure 120). Removal of panels would be accomplished using a mobile crane. The louver structure is unwatered from mid-fall to mid-spring. Unwatering allows convenient access for maintenance, including debris and sediment removal.

Figure 119.—View looking upstream at the T&Y louver placed at an angle to the canal flow – Example 4 (T&Y Irrigation District).



a. Flow is from left to right through the louver.

b. View through support structure on backside of louvers.

Figure 120.—Louver structure setting on 1-foot curb – Example 4 (T&Y Irrigation District).

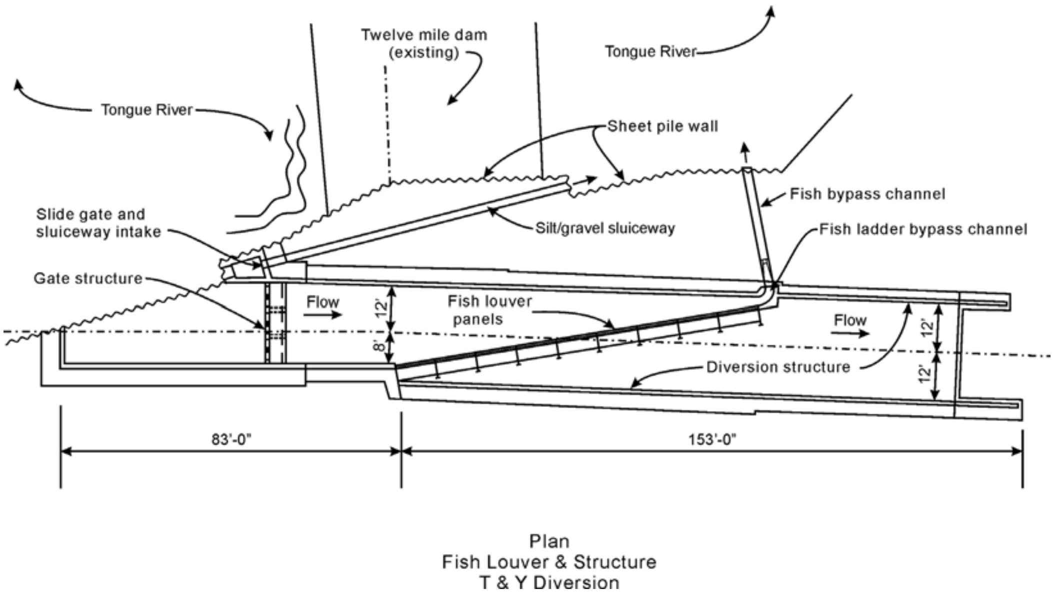


Figure 121.—Schematic layout of T&Y Diversion Project – Example 4 (T&Y Irrigation District).

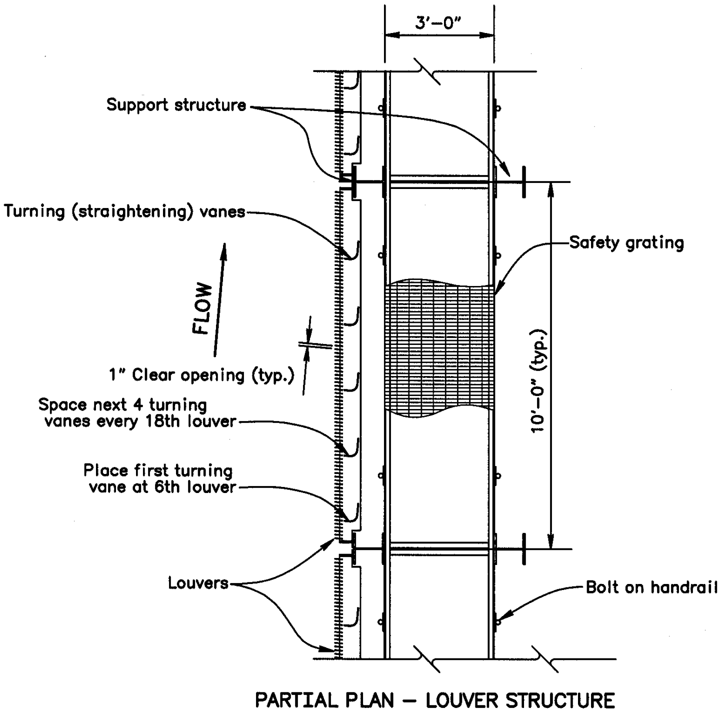


Figure 122.—Louver structure detail – partial plan – Example 4 (T&Y Irrigation District).

Figure 123.—Louver and walkway. Note river on the left and canal downstream beyond the louver – Example 4 (T&Y Irrigation District).

***Turning vanes* –** Turning vanes were placed directly behind the louver array to turn the flow that has passed through the louvers and direct it down the canal (figure 122). This treatment maintains a uniform velocity field on the back side of the louvers. The turning vanes assist in generating uniform approach velocities across the louvers without the need for refined analysis and development of hydraulic flow distributions in the approach and exit channels (figure 97) (chapters IV.A.6. and V.A.).

***Louver facility head loss estimate* –** Assumed louver head losses range from 2 to 4 times the channel velocity head (chapter IV.A.5. and 8.) which yields estimated losses of 0.3 to 0.6 ft of water at the maximum diversion. These head losses result from the effect of both the louvers and the turning vanes.

h. Fish bypass channel

A 2-ft-wide bypass channel is placed at the downstream end of the louver structure. The open chute bypass allows natural light and allows convenient access for cleaning. The 2-ft-wide channel will produce excessive bypass flow as well as excessive exit velocities if not restricted. Control is achieved using stop logs placed in a guide placed immediately downstream from the fish bypass entrance (figure 124). Stoplogs have to be adjusted with changing diversion flows and flow depth to supply adequate control and allow continued bypass flow

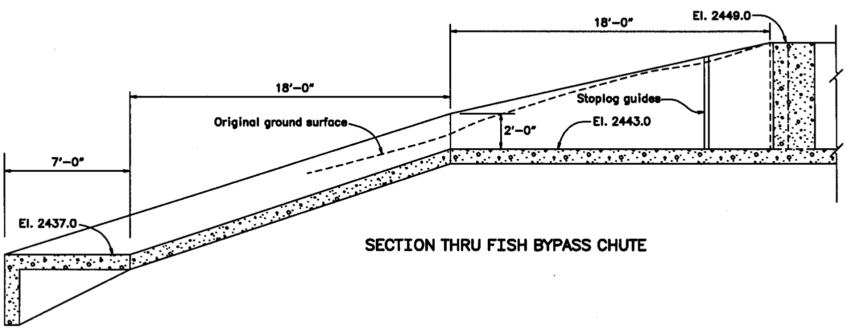


Figure 124.—Section through bypass outlet – Example 4.

for various river conditions. The bypass channel produces exit flow velocities in the range of 3 to 10 ft/s. The bypass flow, normally less than 8.0 ft^3/s, returns to the river in a distance of approximately 30 ft.

Debris and cleaning – Debris loading varies seasonally and includes heavy loading of floating debris during the high-river-flow events (the headworks design tends to exclude most floating debris), loading with water logged woody materials, and limited loading with aquatic plants and leaves (in the fall). A trashrack is included upstream from the gate structure when the replacement headworks structure was built (figures 116, 117, and 118). The trashrack combined with sluicing action generated by the overflow weir effectively sluices most floating debris away from the headworks and over the ogee weir. This sluicing is optimized by the close placement of the headworks to the weir and the tangential orientation of the trashrack to the weir approach flow. The primary debris management problem at the site is associated with the smaller, water-logged, woody materials that are embedded in the deposited sediment upstream from the dam. In the mid to late summer, streamflows decrease and, thus, the sluicing action generated by the overflow weir is reduced. However, irrigation diversion demands during this time are high. Headcutting occurs in the sediment in the diversion pool, and as a result, sediment and water logged materials are transported into the canal. The water-logged materials may become wedged between the louver slats and making cleaning difficult. Manual removal (raking) of this debris has been required.

Facilities for Emergency operation due to potential louver plugging – Although woody debris accumulation on the louver has proven to be a problem that may adversely influence fish exclusion performance, the louver maintains diversion capacity even when fouled with woody debris. Consequently, emergency operations have not been required at the site.

Sediment management **–** Heavy bedload sediment is transported in the river, particularly during high flow events (primarily in the spring). As a result, sediment deposition in the diversion pool is near the elevation of the overflow weir crest. A sediment sluice was included with the replacement headworks (figures 117 and 121). Operating this sluice during high river flow events will help reduce sediment deposition at the headworks. Because of limited river flow, the sluice cannot be routinely used during late summer. Consequently, sediment will be diverted into the canal as sediment head cutting occurs in the diversion pool. The louver structure was constructed with the louvers placed on a 1.0 ft high concrete sill (figure 120). This sill elevates the bottom of the louver above the floor of the approach channel and functions to direct bedload sediment along the louver and to the fish bypass, which also functions as a sediment sluice. Louvers can also effectively pass suspended sediment and are less sensitive to sediment influences than positive barrier screens.

Ice loading **–** Icing can occur in both the spring and fall, particularly near the start and end of the irrigation season. Although severe icing conditions are typically not anticipated, icing might be sufficient to yield fouling of fine mesh screens. Snow and ice will accumulate in the canal during the winter. Because of potential ice damage, winter screen removal is likely.

I. Post construction adjustments and testing

Post construction evaluations of the louver facility performance were conducted. Operation of the facility has proven generally effective. Debris is manually removed from the louvers. Evaluation of fish exclusion performance by the Montana Department of Fish, Wildlife and Parks has shown approximately 90 percent effectiveness in keeping fish out of the canal.

Options available for modification of hydraulic operation of the T&Y louver structure were limited to adjustment of louver approach flow distribution between the three slide gates of the headworks and placement of stop logs in the bypass structure to modify bypass flow rates and bypass velocities. The turning vanes (positioned behind the louvers) are not adjustable, and experience has shown that adjustment of the turning vanes will not be required. Figure 119 shows a view looking upstream at the louver structure and walkway.

5. Example 5 – Cylindrical Screening Facility (Based on Columbia River Pumping Plant, Oregon)

This example presents a cylindrical screening facility located in a river/diversion pool with an on shore pumping plant. The screening and pumping plant facilities are a key feature in a project to restore salmon runs and enhance steelhead fishing in the Umatilla River (Reclamation, 1994). The Columbia River Pumping Plant, part of the Umatilla Basin Project, delivers water from Lake Wallula to the

Columbia-Cold Springs Canal, which then transports the water to Cold Springs Reservoir. The pumping plant will pump approximately 40,800 acre ft of water annually (240 ft^3/s plant design capacity) from the Columbia River. This water will replace water previously diverted by two irrigation districts from the Umatilla River. These previous diversions from the Umatilla River will be eliminated to meet target flows for fish passage.

a. Fishery

Species **–** Salmon and steelhead

Size **–** Fry, fingerlings, and larger

Move downstream **–** Critical time for screening is from late April through mid-July

Swimming **–** The fry generally drift with the current and have little strength and endurance to swim against the current. Fry occur throughout the water column.

b. Reservoir/river design data

The water surface of Lake Wallula is controlled by McNary Dam and the upstream dams in the Columbia River system. The fish exclusion facilities for this pumping plant must be able to operate satisfactorily at the following water surface elevations and conditions of Lake Wallula:

- Maximum water surface: El. 341.0 (all elevations in ft mean sea level)
- Normal reservoir operating range: El. 337.0 to El. 340.0
- Minimum water surface: El. 335.0
- Daily fluctuations could be as large as 2 ft
- Severe wind and boat wave action can be expected (up to 6 ft high)

c. Design data

Construction **–** No in-river work including operation of equipment can be performed in the active flowing stream between April 1 and November 30, unless otherwise coordinated with the Division of State Lands and Oregon Department of Fish and Wildlife.

Sediment **–** Sediment deposition is expected to be minor.

Debris **–** During the months of April and May, tumbleweeds are blown into the river, become saturated, and sink and move along the lake bottom. The tumbleweeds are not expected to be a problem with blocking the screens. In June and July, increasing amounts of Eurasian water millfoil (yew plant) have been found in small clumps floating down the river toward McNary Dam.

Pumping plant design capacity – The pumping capacity for the Columbia River Pumping Plant was based on an operations study conducted in Reclamation's Pacific Northwest Region. The studies determined that the canal needs to be able to deliver an average of 220 ft^3/s in any given month. The design pumping plant capacity was then increased to 240 ft^3/s to account for allowances of minor seepage losses and for operational flexibility to permit down time for power outages, routine maintenance, and emergency repairs.

Site layout – The visual and audio impacts on the surrounding area need to be considered in the site design, both on river and off river. Extensive landscaping is required to help reduce the impact of the plant on the surrounding area. Electrical power is available in the general area and can be extended to the fish screen facilities. The electrical equipment for the switchyard will be provided by Umatilla Electric. A short access road to the site will be required off an existing highway. Five different geologic reports on sites close to or at the pumping plant site were provided for use in preparing the designs and specifications for the Columbia River Pumping Plant.

d. Fish screen structure design criteria

The criteria were agreed to by a group consisting of State and Federal agencies, the water districts, and the designers. Design criteria for the fish screen structure are based on juvenile fish screening criteria of the NOAA Fisheries northwest division. Note that the plant was designed in 1991 and 1992; at that time, NOAA Fisheries screen criteria for juvenile salmonids were slightly different from their current criteria. (See the current criteria in attachment A.)

Fishery

- Fish species – The fish species are salmon and steelhead.
- Fish size – The screens should be able to safely exclude fish as small as fry (25–60 mm).

Screen structure

- Positive barrier screens are required.
- The preferred screen location is in the river.
- Generally, the screen face should be parallel to the river flow.
- The screened intakes should be offshore to minimize fish contact with the facility.

- The screened intakes should be in areas with sufficient sweeping velocity to minimize sediment accumulation in or around the screen and to facilitate debris removal and fish movement away from the screen face.

- The screens should be sized for a screen approach velocity not to exceed 0.40 ft/s.

- The screen approach velocity should be uniform across screens.

Fish screens

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

- For profile bar (wedge or “Vee” wire) screen, the narrowest dimension in the screen openings (slot opening) should not exceed 0.125 inch in the narrow direction (old criteria).

- Screen material to provide a minimum of 27 percent open area.

- Fish screens should be cleaned as frequently as necessary to prevent accumulation of debris. The cleaning system and protocol must be effective, reliable, and satisfactory to NOAA Fisheries. Proven cleaning technologies are preferred.

e. Location of Fish screens and pumping plant

An in-river location of the fish screen structure with fixed cylindrical screens and an off-site pumping plant were chosen (Reclamation, 1995). Some of the reasons for this selection were:

- This screen allows the fish to stay in the river.

- With this in-river structure, fish bypasses would not be required.

- Sediment deposition is not a problem.

- Trash will remain in the river and will not have to be removed and trucked away.

- Since the screens are always submerged, icing and visual impacts are reduced.

- Air burst cleaning systems are a proven technology for cleaning cylindrical screens.

- It was determined that the screen and intake piping could be installed in the wet, on piles, thus reducing the cofferdam and dewatering requirements.

- An off site pumping plant reduces concerns with visual and sound issues.

- With the intake conduit extending to the pumping plant sump, entrapped air can be vented before the flows reach the pumps.

f. Design of Fish screen structures (figure 80)

The fish screen facility will consist of:

- Intake screens (cylindrical tee screens)
- Concrete piles
- Intake pipes
- Intake conduit (concrete box culvert)
- Air burst cleaning equipment
- Pumping plant, discharge piping and valves, flowmeter, and spherical air chamber

Fish screen intake – Cylindrical fixed screens were chosen to allow mounting the screened intake offshore, in the river, and below the water surface. This type of screen is a positive barrier screen. The screens prevent entrainment of fish and aquatic organisms in three ways. First, the 0.125 inch wide screen slots prevent the entry of small fish. Second, the surface area and net-through-the-screen openings are designed so the screen approach velocity does not exceed 0.40 ft/s. And finally, the cylindrical design creates a small cross-sectional target, thus, reducing the time (or the likelihood) that fish may be exposed to the cylindrical screens.

The cylindrical screen manufacturers recommend that the through-slot velocity be not greater than 0.5 ft/s. For this case, the through-slot velocity requirement will govern the sizing of the screens because it will give a smaller screen approach velocity than the maximum allowed by the fish resource agency's criteria.

$$V_{\text{approach}} = V_{\text{through slot}} \times \text{Screen percent open area}$$

Assuming: $V_{\text{through slot}} = 0.5$ ft/s and the maximum screen slot
openings = 0.125 inch.

From the screen manufacturers products data sheets: The screen percent open area is approximately 64 percent for 0.125" slot openings and their standard (wedge or "Vee") wire. Therefore, the maximum screen approach velocity used for sizing the screen is:

> $V_{approach} = 0.5 \text{ ft/s} \times 0.64 = 0.32 \text{ ft/s}$ (this is less than the fish resource agencies allowed maximum approach velocity of 0.40 ft/s)

The required screen area ($A_{required}$) is equal to the flow (Q) divided by the screen approach velocity ($V_{approach}$). So the required screen area is:

$$A_{required} = Q/V_{approach} = (240 \text{ ft}^3/\text{s})/(0.32 \text{ ft/s}) = 750 \text{ ft}^2$$

The manufacturers of fixed cylindrical screens recommend that the bottom of the screen be at least half a screen diameter above the lake or river bottom and that the top of the screen be at least half a screen diameter below the minimum water surface. (They also recommend checking navigational requirements.) At this site, the centerline of the cylindrical screens was set at El. 328.17 to be above sediment deposition and the potential for bottom submerged tumbleweeds, and to be as high as possible to limit excavation requirements to the pumping plant. This placed the centerline of the screens approximately 18 ft above the lake/river bottom (silt) and 6.83 ft below the minimum water surface.

Eight 60-inch diameter cylindrical tee screens, each sized for 30 ft^3/s flow, were chosen after looking at the screen manufacturers' product data sizing charts and sheets (recommended screen size based on percent open area and flow in gallons per minute). This size of screen provided at least 52 inches of submergence above the top of the screen at the minimum water surface. Larger diameter cylindrical tee screens were available in the catalogs (up to 84 inch), but were not selected since they are fabricated in a less streamlined assembly. Each screen contains a 42-inch diameter flanged outlet connection, a 6-inch diameter flanged connection for the air supply piping for the air burst cleaning system, and an air burst distribution pipe within the screen (figure 31). (Note that the construction specifications need to clearly indicate the installed position of the screens so that the screen manufacturer can properly position the internal air distribution piping and nozzles within the screens.) The screens will be fabricated from 304 stainless steel and will use profile bar (wedge wire or "Vee" wire) with 0.125 inch slot openings. (See figure 51.) The screens were specified to withstand a differential hydrostatic collapse load of 18 ft of head without damage to the screen.

The configuration and spacing of the screens and intake piping are designed to balance the flow of the intake water and to allow silt and debris to flow away from the screens during the air burst cleaning operation. Each cylindrical screen is bolted to a 42-inch-diameter pipe. These pipes tee into 54-inch-diameter header pipes, which tee into two 72-inch-diameter steel intake pipes. These larger pipes will convey the intake flows to a single, rectangularly shaped concrete box culvert (10-ft-wide by 7-ft-high conduit). (See figure 80.) The screens are installed so that their centerlines are parallel with the river flow. The two branches of screens are offset from each other so the centerlines of the installed screens are not directly in line with the centerlines of the other branch of screens. This reduces the potential for fish to be exposed to the full line of screens. The box culvert conveys the flow to the pumping plant sumps and allows venting of entrapped air before the flows reach the pump bowls. The differential pressure that drives the flows through the screens is caused by the difference between the lake elevation and the sump elevation of the pumps. The minimum operating water surface at the pumping plant sumps is El. 333.0.

The submerged cylindrical tee screens and the intake steel piping will be supported on concrete piles, thus, allowing installation in the wet without a cofferdam. (See figures 31 and 80.) Saturated alluvium overlaying basaltic bedrock will be encountered during drilling operations of the offshore piles. Braces on the intake support structures will be installed underwater and may require some excavation. The intake steel pipes will be designed to span the distances between the piles and the box culvert. The intake pipes and the air-burst supply piping will be assembled underwater. Insulating gaskets, sleeves, and washers are installed between the mating flanges and bolt surfaces of both the 42-inch flanges and the 6-inch air burst flanges to prevent galvanic corrosion caused by contact of dissimilar metals.

Pumping plant – A cofferdam and dewatering system will be required to allow construction in the dry of the intake concrete box culvert and the pumping plant. The groundwater table in the pumping plant area closely reflects the level of Lake Wallula. The concrete box culvert was chosen to reduce costs over extending the intake steel pipes all the way to the pumping plant (recommended proposal during the value engineering study). The pumping plant is an outdoor plant. The space requirements of the pumps controlled the layout of the pumping plant. The depth of the plant was set by the submergence requirements of the pumps. The pumps are situated to equalize the size of the sumps to the maximum extent possible. Most of the pumping plant and the discharge valves are located below the service yard elevation to reduce the overall visual impact of the plant. Berms were provided around the plant to visually screen the pumping plant and to simultaneously screen pumping plant sounds from adjacent properties. An air chamber was required to prevent water column separation in the discharge line. Stoplog guides were also included at the pumping plant entrance to allow isolation of the pumping plant from the river, if required.

Screen cleaning system – The screens are cleaned by bursting air to flush debris and organisms from the screens without removing this material from the water. (See figure 82.) A separate 6-inch air supply line will connect to each screen to allow cleaning one screen at a time. This also reduces the size of the air burst cleaning equipment required. The air burst cleaning equipment will be at the pumping plant and consists of:

- one air compressor
- one horizontally mounted air receiver tank
- one set of actuator air supply controls
- eight butterfly valves and actuators

The size of the air receiver tank (V_r) and the pressure (P_r) required for the air burst system were based on the following equation:

$$V_r \text{ x } P_r = 3 \text{ x } [P_s \text{ x } (V_s + V_p)]$$

Where V_r = receiver tank size in ft^3
P_r = receiver tank pressure in lb/ft^2
P_s = pressure above screen centerline
V_s = volume each screen
V_p = volume air supply line

Max. water surface = El. 341 ft Centerline fish screen = El. 328.17 ft

Volume each screen, V_s = 334 ft^3 (cross sectional area of screen times screen length)

Volume air supply line, V_p = 50 ft^3 (cross sectional area of pipe times pipe length)

Pressure above screen centerline, P_s = [(341 – 328.17) x 0.434 psi/ft] + 14.7 psi = 20.3 psi

Therefore,
$V_r \text{ x } P_r = 3 \text{ x } [P_s \text{ x } (V_s + V_p)] = 3 \text{ x } [(20.3) \text{ x } (334 + 50)] = 23{,}386$
If try P_r = 150 psi, then V_r = 23,386/150 = 156 ft^3 = 1167 gallons

Based on these calculations, an air burst pressure of 150 pounds per square inch and a receiver tank size of 1,200 gallons were selected. The size of the air compressor was then chosen (72 cfm minimum displacement at 150 psi discharge pressure) based on the operating pressure, air receiver tank size, and the desired cleaning cycle time of the screens.

The time required to charge up the air receiver tank can then be determined. First find the required inlet volume (V_1) by using the following equations.

$$V_1 \text{ x } P_1 = V_r \text{ x } P_r \quad \text{or} \quad V_1 = (V_r \text{ x } P_r)/P_1$$

Then divide this calculated inlet volume by the air compressor displacement capacity to get the time (T) required to pressurize the air receiver tank to the desired pressure.

So, given that the receiver tank capacity is: $V_r = 1200$ gallon (160.4 ft^3), the receiver tank is to be pressurized up to $P_r = 150$ psi, the inlet air pressure is $P_1 = 14.7$ psi, and the compressor displacement capacity is 72 ft^3/minute (cfm). Therefore, the inlet volume required is:

$$V_1 = (160.4 \text{ x } 150)/14.7 = 1636.7 \text{ ft}^3,$$

and the time to charge up the receiver tank is:

$$T = 1636.7/72 = 22.7 \text{ minutes.}$$

So, it will take approximately 23 minutes to pressurize the air receiver tank to clean one screen and approximately 200 minutes to clean all eight screens.

The air burst cleaning system can be manually or semi-automatically operated. Full automation was not desirable at this site, mainly because of boating in the area.

Differential water level controls are provided to monitor the differential water level across the screens. One sensing element will continuously measure the water surface elevation of Lake Wallula and the other sensing element will continuously measure the water level in the pump sump. When the difference in these water levels meets or exceeds a preset point, an alarm will be initiated to indicate that the screens have reached an unsatisfactory level of plugging. This system is designed to allow for future remote monitoring. Additional monitoring of the water surface in the pumping plant intake sump will be provided and will initiate a low water alarm and shutdown of the pumps if the water level in the sump goes below the minimum sump water level.