

Chapter III. Overview of Fish Exclusion

“Fish got to swim, birds got to fly.”

*Oscar Hammerstein II “Can’t Help Lovin’
Dat Man,” Show Boat (1927)*

This chapter provides an overview of fish exclusion options and related issues at water diversions. It gives direction to selection of appropriate concepts to pursue through the planning and design process. The need for and importance of fish protection has been presented in previous chapters. The planning and design process for fish exclusion has also been briefly presented. Exclusion barriers for upstream migrating fish is covered in chapter VIII.

A. Design Guidelines

“Everything should be made as simple as possible, but not simpler.”

Albert Einstein

This chapter summarizes key design considerations that will strongly influence the type and design of fish exclusion facilities. It includes an overview that will aid in the selection of concepts for more detailed design. Expanded presentations on each of these considerations are presented in chapter IV of this document.

1. Identifying Characteristics of the Target Fish Species

The selection of fish exclusion facilities and, correspondingly, the effectiveness of an appropriate design depends on the physiological and behavioral characteristics of the targeted fish species including size, life stage, behavior, and swimming ability. The criteria focuses on the specified species in their most vulnerable life stage and under adverse environmental conditions. For example, National Ocean and Atmospheric Administration (NOAA Fisheries) (formerly National Marine

Fisheries Service [NMFS]) developed the screen criteria for juvenile salmonids in the Pacific Northwest and Southwest regions based on protecting the weakest swimming fish. It is presented in attachment A.

The composition and seasonal variations in the fishery should be considered in establishing protection objectives and in design development. This requires identification of targeted fish species, their sizes, and life stages present during diversion or operating periods. If smaller, weaker swimming fish are to be excluded from diversions without injury, opening sizes in fish screens will have to be reduced and approach velocities also reduced to prevent fish impingement and injury at the screen. This may result in a fairly large fish exclusion facility. On the other hand, if the objective is to exclude larger, stronger swimming fish, use of a smaller facility with larger screen openings and higher velocities may be acceptable.

Composition of the fishery can be determined through review of pertinent literature and local sampling records from State or Federal agencies, universities, or consultants or may be determined through active sampling when it is clear that not enough local fisheries information exists. Sampling may need to be undertaken seasonally or throughout an entire year using a variety of sampling devices to ensure that all life stages and species are evaluated. Fishery resource agency staff should be contacted early in the process to seek their assistance in identifying the target fish species.

2. Establishing Fish Protection Objectives

State and Federal resource agencies are responsible for protecting and managing fishery resources. Consequently, these resource agencies may have established fishery resource management policies that strongly influence the selection of fish protection objectives. The resource agencies can also be expected to take a regulatory role in which they identify fishery protection needs and review and approve proposed designs. Often, agencies have established design criteria and design guidelines that will directly affect and guide the fish exclusion design effort. The resource agencies should be contacted early in the planning and design process and fishery resource agency involvement should be encouraged throughout the fish exclusion facility design development.

Resource agencies that are typically involved with fish facility design include:

- ▶ State agencies such as fish and game departments, State fish and wildlife departments, and State fish, wildlife, and parks departments
- ▶ NMFS (NOAA Fisheries), when anadromous or ocean-going fish are involved

- ▶ U.S. Fish and Wildlife Service (Service), when listed fresh water fish are involved
- ▶ Tribal governments

NOAA Fisheries (Northwest Region and Southwest Region) have published screening and protective design criteria (NMFS, 1995 and 1997) and a position paper on application of experimental technology (NMFS, 1994). These are widely accepted standards in the field. The States of Washington and California have also published screen criteria. Criteria published as of 2005 are presented in attachment A. These criteria are constantly evolving and will always need to be verified with the appropriate regulatory agencies.

Fish protection objectives may vary widely with site and fisheries concerns. Possible fish protection objectives could be as follows:

- ▶ Exclusion of all fish from the diverted flow without regard for fish species, life stage, and size
- ▶ Exclusion of fish of a specific size or greater
- ▶ Exclusion of fish of specific species and size (recognizing that, although the design is directed at a specific species and size of fish, other fish will at least be partially excluded, some possibly with injury)
- ▶ Partial exclusion

If *listed, threatened, or endangered* fish species are present, they can be expected to represent key design species and will move to the top of the fish protection objectives list. The selected design criteria will be based on effectively protecting the listed species. Exclusion requirements for threatened and endangered fish are often specified based on a set minimum body length.

The challenges, capital, and operating costs will increase substantially when smaller, weaker swimming fish must be excluded.

To determine fish protection objectives, the following are needed:

- ▶ *Identification of fish species, fish life-stages, and fish sizes to be protected.*
- ▶ *Determination of the level of protection required.* Is absolute exclusion required or would effective exclusion of a percentage of the population be acceptable? Facility options are available that may yield

partial exclusion of varying effectiveness while greatly reducing capital and operating costs and the required maintenance. It should be determined if these facility options are acceptable.

- ▶ *Establishment of times of the year when fish exclusion will be required.* This may affect and be influenced by operations, particularly if operations are seasonal or if diverted flows are reduced during specific times of the year (e.g., winter stock water). Other considerations will include the need to define periods when exclusion is not needed; e.g., winter periods when icing might be a problem or during high flow periods when debris and sediment loading will be excessive.
- ▶ *Requirement for the canal to provide over-winter rearing.* (In rivers where rearing areas have been severely lost, this becomes a major consideration; e.g., the Yakima River Basin at the T-Jossem and LaFortune screen sites.)

Examples of Fish Protection Objectives:

Example No. 1 – Chandler Canal at Prosser Diversion Dam, Yakima River, Washington

The following conditions exist:

- ▶ **Fishery:** A fish ladder is included at Prosser Diversion Dam that allows upstream passage of migrating salmon and steelhead. Consequently, both adult and juvenile salmon can be encountered at the diversion intake. The primary fish exclusion concern is juvenile salmon that are in the system both from natural spawning and from upstream hatchery releases. Juvenile salmon (fry) that are shorter than 2.4-inches (60-mm) may be present at the site.
- ▶ **Operation:** The Prosser Diversion Dam provides for both irrigation and a power diversion. Power operations continue throughout the year. The maximum diversion discharge is 1,500 cubic feet per square (ft³/s).
- ▶ **Debris, sediment, ice:** The Yakima River at the diversion site is a moderate to high gradient stream. Significant sediment and debris transport occurs, in particular, with spring high-flow events. The headworks for the Chandler Canal at the Prosser Diversion Dam supplies flow to the canal through submerged slide gates. The gates largely exclude floating debris. Trashracks are not included with the

headworks but are included within the canal upstream from a fish screening facility. With high flow events, substantial sediment is diverted into the canal. Historically, sediment deposition has occurred in low velocity sections of the canal. During cold, mid-winter events, the river can generate frazil ice which could severely foul fish screens.

Selection of fish protection objectives – Because of on-going efforts to reestablish and strengthen salmon and steelhead runs in the Yakima River basin and with consideration of the general fish exclusion positions of the involved resource agencies, NMFS (NOAA Fisheries) and Washington Department of Fish and Wildlife, the preferred fish protection objective is:

100 percent exclusion of all salmon fry (and larger)

[fish greater than 1.0-inch (25-mm) long]

However, during the winter when water temperatures are low, fish movement is greatly reduced. Consequently, it was agreed that installed fish screens could be removed from November to April, the period when potential icing posed a major operation and maintenance (O&M) problem.

**Example No. 2 – T and Y Canal and Twelve Mile Diversion Dam,
Tongue River, Montana**

The following conditions exist:

- ▶ **Fishery:** The fish protection issues at the T and Y Canal deal with both the blockage of in-river migratory behavior of the native fish and fish losses associated with canal entrainment. As documented 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. None of the present species is listed by the fishery resource agencies as *threatened* or *endangered*. Present are sport fishery species including rock bass, smallmouth bass, white crappie, channel catfish, and sauger.
- ▶ **Operation:** The diversion supplies irrigation water typically from early spring to late fall. The maximum diversion discharge is 237 ft³/s.
- ▶ **Debris, sediment, ice:** Varying debris, sediment, and ice loadings occur at the site throughout the diversion season. Maximum debris loading occurs during high stream-flow events (mid-April to mid-July). Heavy sediment and water-logged material loads are diverted

into the canal particularly during periods of low river flow and high diversion. Ice conditions may occur both early and late in the diversion season.

Selection of fish protection objectives –The fish exclusion facility is operated by a small irrigation district. Limited capital is available to support initial construction, and funding for maintenance is limited. In addition, the fish protection effort was focused on generally reducing adverse influences of the diversion on the fishery resource and was not driven by *threatened* or *endangered* species considerations or by fishery resource agency concerns. Therefore the preferred fish protection objective is to:

Protect fish above a determined size

3. Siting Options

This section discusses common generic siting alternatives. Each siting alternative includes specific features that are required to make the site functional. In some cases, the number of in-river diversions can be reduced by consolidating several existing diversions at one site. The siting of fish exclusion facilities can limit the types of exclusion devices that can be used, will influence O&M capabilities of the design, and can strongly influence both capital and maintenance costs. Careful site selection can lead to simplification of the structure, improve fish exclusion and fish guidance, reduce maintenance demands, and reduce costs. Normally, it is preferred to keep fish within the body of water they are presently occupying.

Required easements for construction and O&M at the site should not be overlooked in the planning process. These easements include easements for the fish screening site, O&M access, and power and other utility lines. Sometimes, the easement is donated to the agency, but this should be clarified early in the design. This section presents four siting options:

- ▶ In-canal
- ▶ In-river
- ▶ In-diversion pool
- ▶ Closed conduit

Site selection considerations are covered in more detail in chapter IV.A.1.

a. In-canal

Description - figure 4 illustrates a typical layout for placement of an in-canal fish exclusion facility. Water is generally diverted from a stream or river using a diversion dam. Fish entering the canal are then guided by the exclusion facility to the fish bypass through which they are returned to the river.

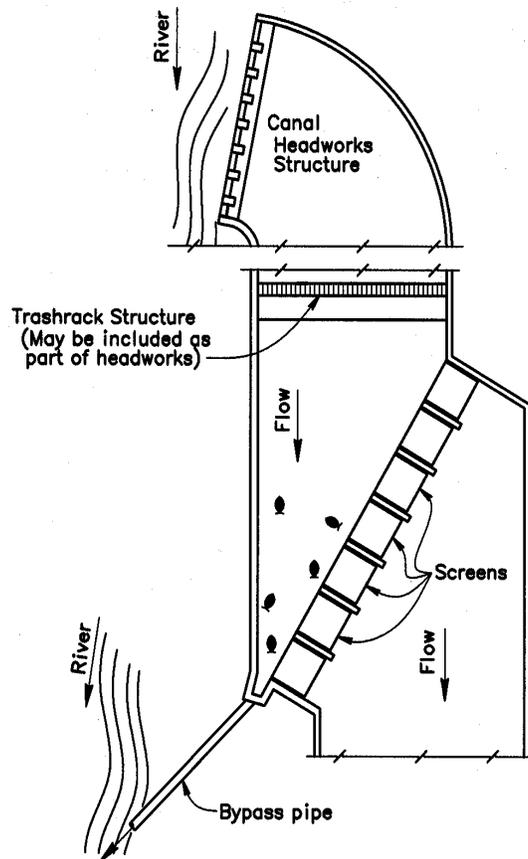


Figure 4.—In-canal fish exclusion structure.

Advantages – Advantages associated with an in-canal fish exclusion facility placement include:

- ▶ Operates in a controlled environment away from floods, heavy debris, heavy sediment, and ice that can occur in the natural water body.
- ▶ Provides for an isolated construction site using cofferdams or diversion channels, depending on the water diversion season.

- ▶ Provides in-canal fish rearing opportunities for canals with year-round water. Sometimes, sufficient canal area is available upstream from the in-canal screen to provide rearing habitat if predators are not present.
- ▶ Provides maintenance access if there is a non-operating period.

Disadvantages – Disadvantages associated with an in-canal placement of the fish exclusion facility include:

- ▶ Fish are taken from their natural habitat and diverted with the flow and then returned to the stream.
- ▶ If the diversion season does not allow sufficient shutdown to allow construction, a parallel isolated canal may have to be constructed to allow continued diversion during the construction period. See chapter II.B.2 for adverse effects that may occur during construction of fish exclusion projects.

b. In-river

Figures 5, 6, 29, and 30 illustrate layouts and photographs for in-river fish exclusion facility installations. With this placement, the fish exclusion facility is the first element of the diversion that the fish encounter. The facility may be placed in the river channel but, more likely, at the river bank. Since fish remain in the river, a bypass structure is normally not required.

Advantages – Advantages associated with an in-river exclusion facility placement include:

- ▶ Fish remain in the river. Consequently, required fish handling and fish contact with the facility is minimized. (A fish bypass may not be required.)
- ▶ It is possible to leave all encountered debris in the river, thus minimizing debris handling and transport.
- ▶ A trashrack structure may not be required.

Disadvantages – Disadvantages associated with an in-river fish protection facility placement include:

- ▶ The design must be more robust and allow for operation under a broader range of river flow conditions and severe loading since the fish exclusion facility will be exposed to varying flow depths, flow velocities, debris, sediment, and in some cases, ice loads.

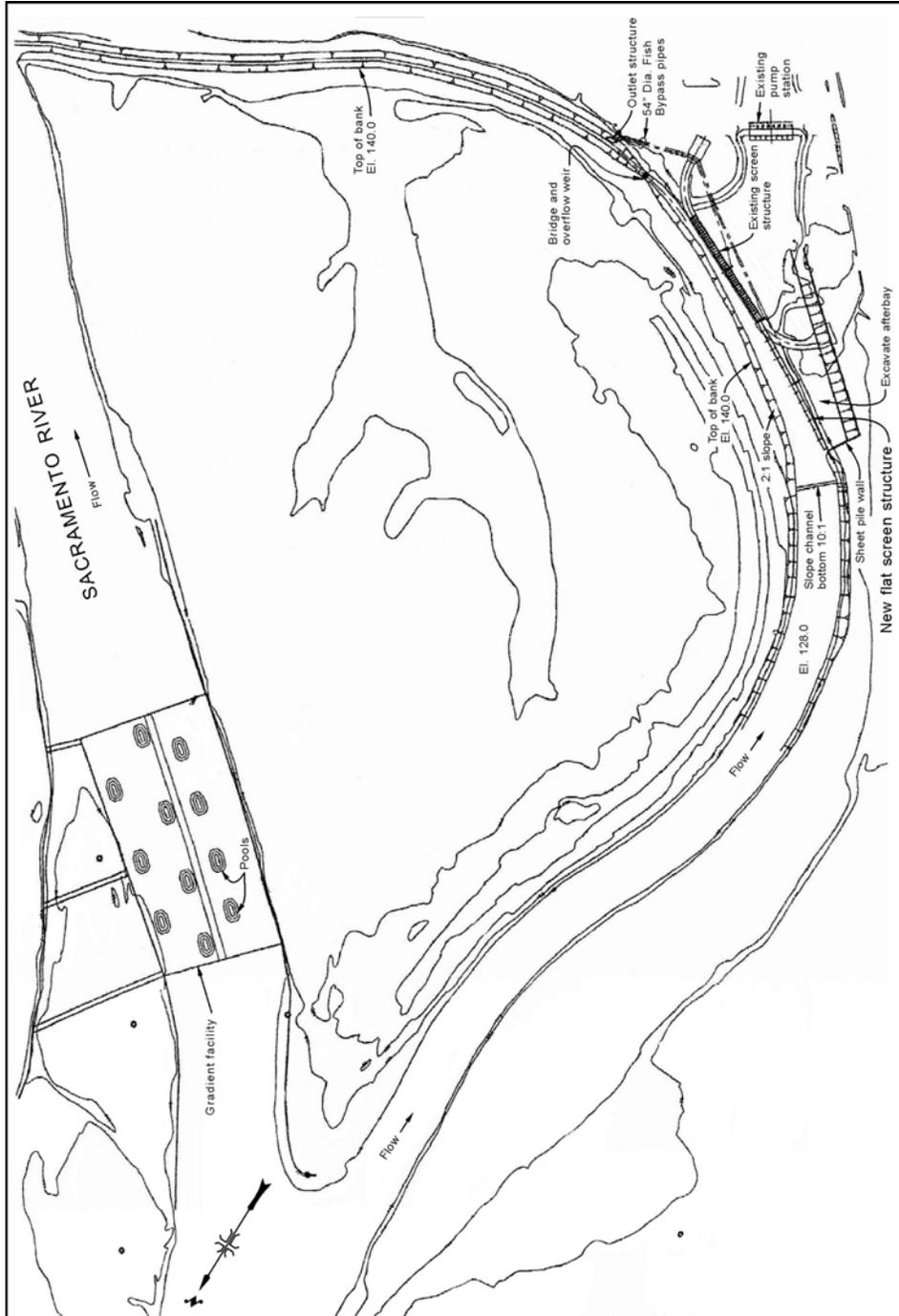


Figure 5.—In-river fish exclusion structure – Glenn Colusa Irrigation District (GCID) on the Sacramento River, California.



Figure 6.—Aerial view of GCID fish screen structure.

- ▶ Construction may require use of a cofferdam with site dewatering.
- ▶ The screen structure will be difficult to dewater for maintenance access.

c. In-diversion pool

Description – figures 7 and 32 illustrate a layout of a fish exclusion facility in a diversion pool (the small reservoir created upstream from a diversion dam). As with in-river placement, the in-diversion pool fish exclusion facility is the first element the fish encounter during the water diversion.

Advantages – Advantages associated with an in-diversion pool fish exclusion facility placement include:

- ▶ Fish remain in their natural habitat in the pool and/or river. Consequently, fish guidance structures may not be required. (Roza Diversion Dam is an exception with an in-diversion pool fish facility that still requires a bypass).

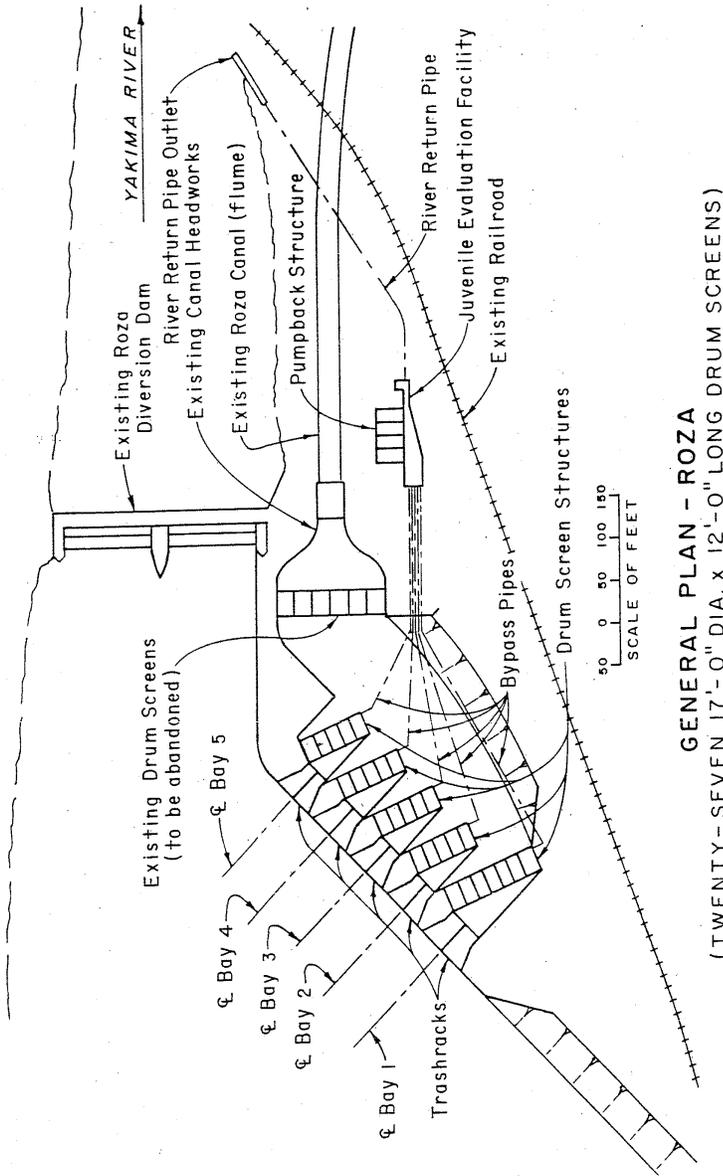


Figure 7.—In-diversion pool fish exclusion structure – Roza Diversion Dam, Washington.

- ▶ Debris encountered in the pool can often be flushed downstream.
- ▶ A deeper flow section in the pool can provide a more compact design of the fish exclusion facility.

Disadvantages – Disadvantages associated with an in-diversion pool fish exclusion facility placement include:

- ▶ The facility will be exposed to varying flow depths and debris, sediment, and ice loads and, thus, must allow for operation under a wide range of flow conditions.
- ▶ Construction may require use of a cofferdam with site dewatering.
- ▶ The facility could require a special configuration or flow guidance features to generate effective sweeping flow across the screen face for fish guidance and debris transport to the bypass.

d. Closed conduit

Description – figures 8, 9, and 93 illustrate typical layouts for a fish exclusion facility placed within a closed conduit pressure line. Closed conduit fish screens consist of a flat screen panel placed on a diagonal to the flow within a circular or rectangular cross-sectional conduit. The fish intercepted by the screen are guided to a fish bypass conduit that releases them to the river below the diversion dam. Closed conduit screens are normally cleaned by temporarily rotating the screen panel around a center pivot to provide a back-flush flow on the screen all the while maintaining constant diversion operation (figure 9).

Advantages – Advantages associated with closed conduit fish exclusion devices include:

- ▶ The screen is compact, which can reduce screen structure cost.
- ▶ The back-flush cleaning design to-date has proven effective and mechanically simple.
- ▶ Costs associated with maintaining and operating the facility are low.
- ▶ Typically, the site can be isolated and dewatered for construction and maintenance by closing existing gates.

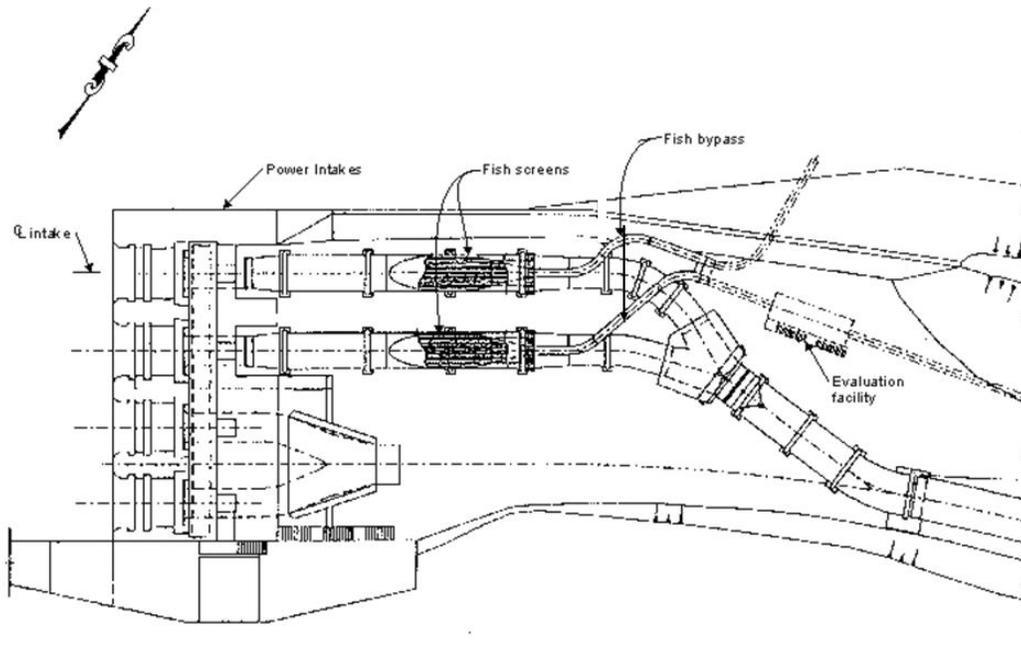


Figure 8.—Plan view of Puntledge screens, British Columbia (Rainey, 1985).

Disadvantages – Disadvantages associated with closed conduit fish exclusion devices include:

- ▶ Although experience exists at several sites with closed conduit screen concepts and with a range of fish species and fish sizes, the concept is still considered experimental by some fishery resource agencies.
- ▶ Construction likely will require suspension of diversion.
- ▶ Access to the screen for inspection or maintenance is limited and requires shutdown and dewatering of the conduit.
- ▶ Fish exclusion is not provided during the back-flush screen cleaning process.

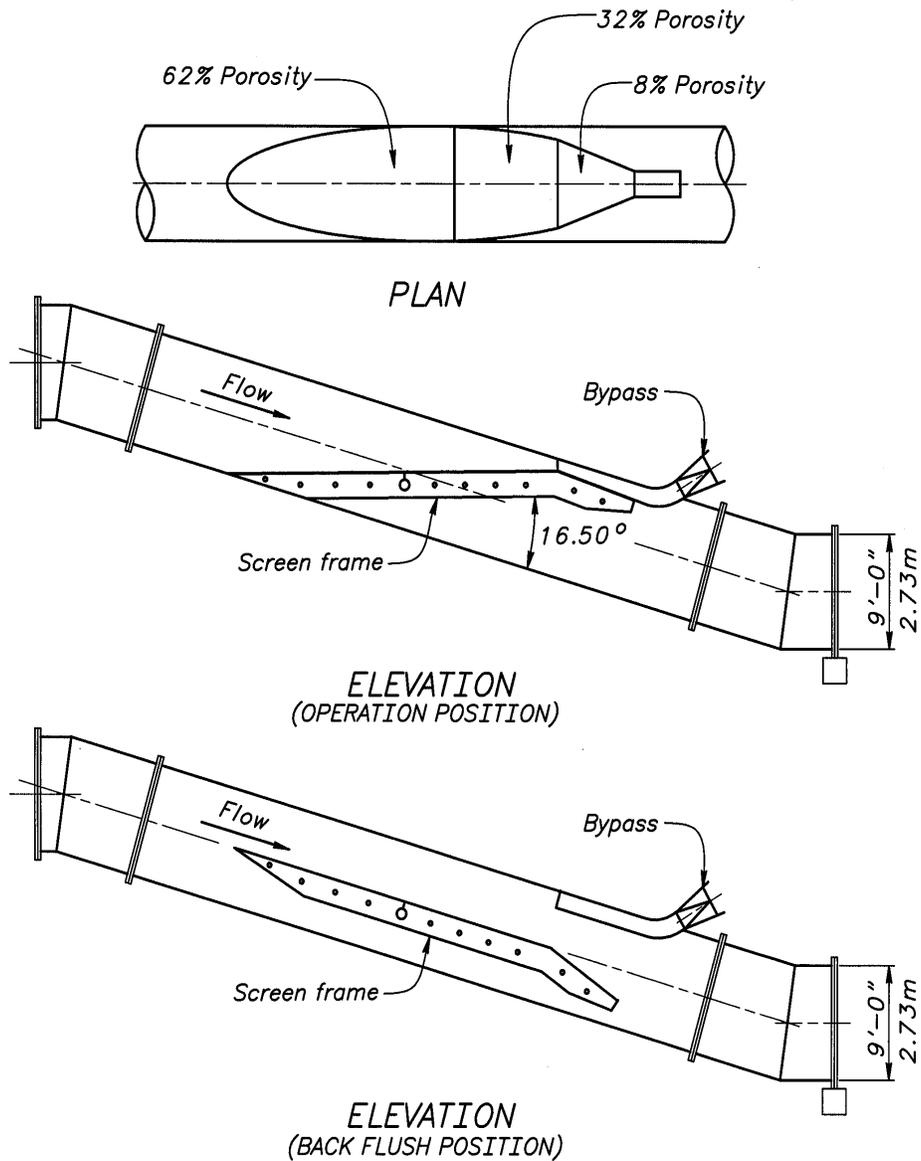


Figure 9.—Fish exclusion structure in a closed conduit (Electric Power Research Institute – EPRI, 1994).

4. Design Discharge

Designs for fish exclusion facilities are typically developed and sized based on 90 percent of the maximum possible diversion discharge (the diversion water right). In some cases, the water right is in terms of volume over a period of time

instead of flow rate. A flow study may be needed to establish the design flow before conceptual development for the fish screen can begin.

Diversions are typically made based on demand, therefore diversion discharges are commonly smaller than the maximum or design discharge. Thus, a fish exclusion facility developed based on a maximum possible discharge may operate most of the time with conservative screening velocities. Since generated water elevation differentials and head losses are a function of the velocity squared, water surface differentials and losses that result with reduced flow rates are significantly reduced from design levels. Loading on structures, fouling potential, and potential for fish injury are all reduced with reduced diversion flows. More information regarding screen hydraulics and design discharge is presented in chapter IV under Screen Hydraulics.

5. Debris and Sediment Loading

Debris fouling of fish exclusion facilities and sediment deposition at and around the facility can significantly influence facility operation and performance. Cleaning and removal of debris from surfaces of the structure, handling and disposal of debris, and sediment removal often become the primary maintenance requirements at fish exclusion structures. Debris fouling and cleaning characteristics of facilities depend both on specific characteristics of the facility and debris types and quantities. Quantities of debris that will be encountered will affect fouling rates and consequently will dictate the types of cleaning and debris handling systems required. For development of an appropriate design, both expected debris types and debris quantities should be carefully determined. More detail on fouling, cleaning, and debris and sediment handling systems is included in chapter IV of this document under Cleaning and Maintenance and Sediment Management.

6. Fish Predation

A major source of juvenile fish loss at and around fish exclusion facilities is predation. Juvenile fish that are screened from diversion flows may be delayed or concentrated at specific locations. This concentration, which exposes the fish to predation, is the result of fish being guided to a bypass and then reintroduced to the river downstream from the diversion structure. The juvenile fish may also be somewhat disoriented if they pass through turbulent flow zones in the bypass. Concentrated populations of juvenile fish in such situations are an attraction to both fish and bird predators. Experience has shown that predators may also take up residence within the fish exclusion structure itself. If this occurs, the facility may have to be dewatered and the fish predators removed from the facility. Predation can be controlled by limiting the hydraulic turbulence intensity of the

flows that the fish are exposed to and by providing sufficient velocities through the fish exclusion facility and the fish bypass outfall location in the river to make it difficult for predator fish to hold and feed for extended periods of time. Generalized criteria to guide in the design of velocity and turbulence issues are available in chapter IV.A.5 and 11 and in attachment A. Details on design features that will limit predation are presented in chapter IV.A.15 of this document.

7. Operation and Maintenance Requirements

O&M requirements at fish exclusion facilities vary widely depending both on the particular fish exclusion concept applied and on local site conditions and characteristics. Demands on staff can be substantial. Fish exclusion facility options should be selected with strong consideration of anticipated availability of financial and human resources to perform O&M activities. If the proposed concept cannot be operated and maintained in efficient working order, either effective fish exclusion will be compromised or water deliveries may have to be curtailed. (Refer to chapter VII.)

Possible O&M issues that depend on and vary with specific fish exclusion facility characteristics include:

- ▶ Maintenance of mechanical components including bearings, seals, and mechanical cleaning equipment
- ▶ Handling and removal of debris
- ▶ Control and removal of sediment deposits
- ▶ Screen removal and/or icing control during periods of ice formation
- ▶ Adjustment or curtailment of water deliveries during maintenance periods
- ▶ Maintenance of water surface elevations at levels that will ensure efficient and correct facility performance (some screen concepts require maintenance of specific checked water surface elevations)
- ▶ Adjustment of bypass controls to maintain effective bypass operation as water delivery requirements change
- ▶ Adjustment of screen velocity distributions with adjustable baffles or porosity boards located immediately downstream from the screens within the screen structure.

Possible site-dependent issues that may influence O&M of fish exclusion facilities include:

- ▶ Hydrologic variability (characteristics of flood events to which facilities would be exposed)
- ▶ Debris types and quantities
- ▶ Sediment load and sediment size distributions
- ▶ Icing potential
- ▶ Water quality (corrosion potential)
- ▶ Variability in delivered flow rates
- ▶ Water delivery season (are there extended periods when the facility is dewatered that could be used for maintenance?)
- ▶ Associated hydraulic characteristics of diversion pools/canals in which the facility might be installed (possible use of control gates and spill operations to maintain acceptable hydraulic conditions for effective facility operation?)
- ▶ Timing and size of fish runs

In addition to proper maintenance, adequate consideration of overall *project operation* should be addressed in the design of new screen facilities or retrofitting existing diversions for fish exclusion. Sometimes, these considerations are beyond the control of the designer but should be discussed with the operators. Haphazard operation can entrain fish before screen installation or completion of adequate maintenance at the end of the non-diversion season. Care should be taken when a diversion is shut off to not trap fish in pockets or shallow areas in the canal or bypass. Using proper “ramping rates” in the startup or closure of a diversion is important to providing adequate time for fish to enter or exit the diversion area. Care in applying weed or pest control agents in a diversion canal is another consideration that project operators need to understand and appreciate. Often having a team of qualified biologists on site to salvage fish during canal shutdown or before applying herbicides or toxins is recommended.

Winter operation can bring a unique set of operational challenges. Some screens are located in heated structures if winter diversions are necessary (Hayes, 1974; Logan, 1974). At some western diversions where minimal amounts of winter stock water are needed, ice forms on the canal water surface and then the diversion is lowered slightly to ensure an insulating ice cover over the freely

flowing water under the ice cover. The screen and other mechanical equipment may be removed under some winter conditions where the canal flow returns to the stream.

Detailed discussion of maintenance requirements for specific types of facilities will be included with the presentation on those specific facilities in chapter IV under Screen Specific Design Details.

8. Capital Cost

Capital costs depend largely on the type of facility required, site characteristics, fishery resource agency criteria, and facility size (flow rate). Unit costs for a facility (cost per delivered ft³/s) can vary widely because of site characteristics. It is unrealistic to state specific unit costs in a document such as this. However, cost is a major consideration in concept selection. Fish exclusion facilities can be developed for delivered flows ranging from a few cubic ft per second to thousands of cubic ft per second; therefore, it is clear that the size and cost of systems will vary widely simply because of size. Unit costs offer a parameter that can be used to estimate cost and allow comparative studies for several facility concepts applied over a wide range of sizes. Typically, unit costs go down for larger structures. Relative cost considerations are included with the discussion of each fish exclusion option. The Decision Chart (figure 25), presented in chapter III, provides some guidance on fish exclusion options.

B. Fish Exclusion Alternatives

“An undefined problem has an infinite number of solutions.”

Robert A. Humphrey

This chapter summarizes fish exclusion facility alternatives and how they function. There are two general types of fish exclusion alternatives: (1) positive barrier screens and (2) behavioral barriers. Advantages and disadvantages of each are presented. A decision chart (figure 25) that can be used to assist in selection of fish exclusion alternatives is included in chapter III. Detailed design criteria and guidelines for positive barrier screens are presented in chapter IV under Facility Design and Screen Specific Design Detail. Behavioral barrier options are presented in detail in chapter V.

1. Positive Barrier Screens

The method most widely used and accepted by fishery resource agencies to protect fish at water diversions is to provide a physical barrier that prevents fish from being entrained into the diversion. For off-river barriers, the fish are diverted through a “bypass” that safely returns the excluded fish to the water body from where the water was diverted. Hundreds of these positive barrier screens have been built and function very successfully. The most common types of positive barrier screens are presented in this chapter. Table 1 summarizes these screen alternatives.

Table 1.—Positive barrier screen alternatives

Type screen	Typical locations	Comments
Flat plate screen <i>figure 10</i>	River, canal, diversion Pool	Widely used in rivers and canals Wide range of diversion flow rates
Drum screen <i>figure 11</i>	Canal, diversion pool	Suitable where water level is stable (controlled to 0.65-0.85 drum screen diameter) Currently used mostly for small flows, although has been used for large flows
Traveling screen <i>figure 13</i>	Secondary screening in bypass, River	Because of expense, usually used for small flows
Cylindrical screen <i>figures 14 & 17</i>	River, Diversion Pool	Typically applied at intakes to pumping plants
Inclined screen <i>figures 18 & 19</i>	Secondary screening in bypass, canal, diversion pool, river	Adverse slope – Suitable where water level is controlled Inclined plate – Best applied along river banks
Horizontal flat plate screen <i>figure 20</i>	Canal, river	Typically applied in river with good sweeping flow Currently used for small diversions (less than 100 ft ³ /s)
Coanda screen <i>figure 21</i>	River, canal	Limited to small diversions (less than 150 ft ³ /s)
Eicher <i>figure 22</i>	Closed conduit diversions	Experience limited to application in power penstocks
Modular inclined screen (MIS) <i>figure 93</i>	Closed conduit diversions	Experience limited to application in power penstocks

a. Flat plate screens (diagonal or “V” configuration)

Modern flat plate screens consist of a series of flat plate screen panels set between support beams or guides and placed at an angle to the approach flow (figure 10). The screen is fixed and does not move. Rather, the diverted flow passes through the screen excluding fish and debris, which are guided to the bypass.

Flat plate screens have been effectively installed at in-canal, in-river, and in-diversion pool sites. When flat plate screens are applied at in-canal sites, a fish bypass or bypasses are typically included. Fish bypasses may also be required at in-river and in-diversion pool sites.

With all three siting alternatives, care must be taken to orient the screen in the flow field in such a way that a relatively uniform approach and sweeping flow occurs across the full length of the screen. These concepts of approach and sweeping flow are described in detail in chapter IV. under Hydraulics, and shown in figure 37a. Establishing desired flow conditions across the screen face requires consideration of flow patterns generated at the specific site and resultant angle to the flow placement of the screen. Baffling to generate uniform approach velocity distribution is required as well. Screens may be placed on a diagonal across the flow, figure 4, parallel to the flow with a reducing upstream channel section, figure 6, or in a “V” configuration, figure 10.



Figure 10.—Flat plate screen “V” configuration with terminal fish bypass – Red Bluff Fish Evaluation Facility, California.

A wide range of screen materials has been effectively applied in fish exclusion facilities. More detail on screen fabric and screen materials is presented in chapter IV under Screen Design.

The most common mechanical equipment used in association with flat plate screens is related to cleaning and debris handling at the screens. (This is discussed in more detail in chapter IV under Cleaning and Maintenance.) To minimize maintenance requirements and to maintain efficient screen operation, effective screen cleaning must be included with any fish exclusion facility. With small screens and low debris loads, cleaning systems may be no more than a manually operated rake, brush, or squeegee. (Check fishery resource agency criteria.) For larger systems, mechanically driven rakes, brushes, or squeegees may be required.

Because of their excellent fish protection performance and generally low operating cost, flat plate screens are currently widely applied at small to large irrigation diversions in Washington, Oregon, and California where total fish exclusion is required.

There are two flat plate screen case studies presented in chapter VI. *Design Details are presented in chapter IV.B.1.*

Advantages of flat plate screens

- ▶ They are effective barriers to fish entrainment.
- ▶ They do not require a controlled operating water depth as needed for drum screens.
- ▶ They have a proven cleaning capability that removes debris from the screen.
- ▶ The screen itself has no moving parts, thus simplifying screen and screen support structure and reducing screen costs.
- ▶ Their performance has been widely applied and proven and is accepted by fishery resource agencies.

Disadvantages of flat plate screens

- ▶ Mechanical screen cleaners require maintenance and add to both the capital and operating cost of the structure.
- ▶ Shallow depths caused by low flow rates can result in excessively long screens to meet screen area requirements.

- ▶ The bypass will usually have to pass the debris cleaned off the screen.

Examples of flat plate screen installations include:

- ▶ Glenn Colusa Irrigation District, Sacramento River, California, maximum flow rate 3,000 ft³/s (in-river)
- ▶ Bureau of Reclamation (Reclamation) District 108 (Wilkins Slough), Sacramento River, California, maximum flow rate 830 ft³/s (in-river)
- ▶ Pump Diversion at Red Bluff Diversion Dam, Red Bluff, California., 100 ft³/s per fish pump bay channel
- ▶ Union Gap, Yakima, Washington, 76 ft³/s (in-canal)
- ▶ Clear Lake Dam Outlet Works, Oregon, 200 ft³/s (in-diversion pool)

b. Drum screens

Drum screens consist of screen covered (typically woven wire) cylindrical frames that are placed at an angle to the flow with the cylinder axis oriented horizontally (figures 11 and 12). A screen installation can consist of a single screen at smaller diversion sites or a series of screen cylinders placed end-to-end.

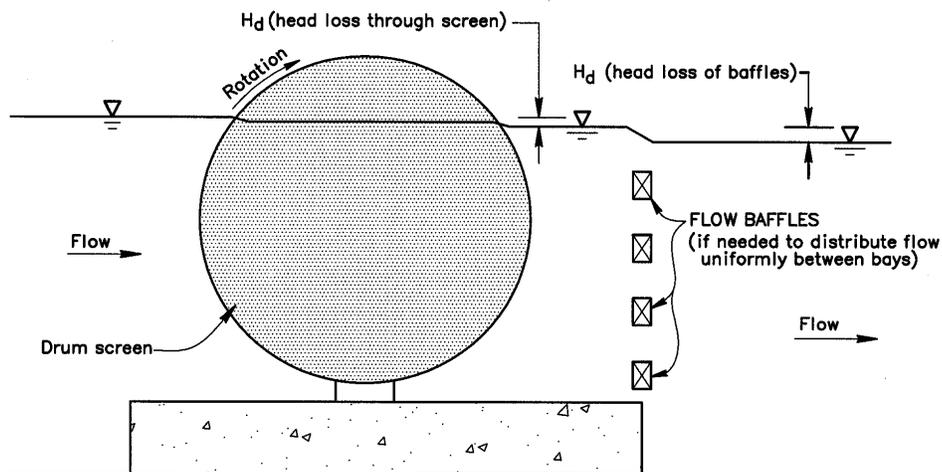


Figure 11.—Sectional view of drum screens (Pearce and Lee, 1991).



a. Construction 1986.



b. Operation.

Figure 12.—Drum screens at Roza Diversion Dam, Washington. Note: Concrete piers are shaped to match drum screens.

The installed drums slowly rotate about their horizontal axis. With the rotation, the lead surface of the drum rotates up and out of the flow while the trailing surface rotates down. The rotation carries any debris up on the drum and it is washed off on the backside as the flow passes through the screen. To provide sufficient fish screen area and optimize debris handling, drum screens must operate 65 to 85 percent submerged. With this submergence, debris that encounters the screen face will cling to the drum. Drum screens consequently tend to have excellent debris handling and self-cleaning characteristics. It is rare that supplemental cleaning systems are required.

Because of the specific submergence requirements, drum screens are typically not used for in-river sites. Drum screens are most often used with in-canal installations and have been used in the pool of some in-diversion sites.

As with flat plate screen concepts, modern drum screen installations place the drum line at an angle across the flow to provide a sweeping velocity, figure 4. With pier faces shaped like the drum and aligned with the drum, fish that encounter the facility find a fairly continuous screen face guiding them to the bypass (figure 12). Screen flows, sweeping and approach velocities, and other design criteria are applied to drum screens as previously described for fixed, flat plate screens, including in-diversion pool auxiliary and flow guidance structures. Baffling to generate uniform approach velocity distributions may also be required (figure 11).

Numerous drum screen installations exist in Oregon, California, Idaho, and Washington with flow rate capacities ranging from a few cubic ft per second to 1,000 ft³/s or more. Drum screens have been widely applied on small to large size irrigation and power diversions (now used mostly for small flows).

A drum screen case study is presented in chapter VI. Design details are presented in chapter IV.B.2.

Advantages of drum screens

- ▶ They are considered self-cleaning and have excellent debris handling characteristics.
- ▶ Proper cleaning is independent of the bypass flow.
- ▶ They have been widely applied, have an excellent performance record, and are accepted by fishery resource agencies.

Disadvantages of drum screens

- ▶ They pose a more complex design and bypass structure than flat plate screens. Consequently, capital costs tend to be higher than flat plate screens.
- ▶ They are applicable only to sites with well-regulated and stable water surface elevations such as canals and in-diversion pool and reservoir sites where water surface elevation can be controlled.
- ▶ The seals at the bottom and sides of the drum require maintenance and special attention to prevent undesirable openings where fish may pass.
- ▶ They have moving parts that require maintenance. Special attention is needed for the bearings and drive chains because they operate in submerged conditions.
- ▶ Continuous rotation (operation) of the drum screen is required for proper cleaning.

Examples of drum screen installations include:

- ▶ Tehama Colusa Canal, Sacramento River, California, Reclamation – maximum flow rate 3,060 ft³/s (in-canal)
- ▶ Chandler Canal and Power Plant, Yakima River, Washington, Reclamation – maximum flow rate 1,500 ft³/s (in-canal)
- ▶ Roza Canal and Power Plant, Yakima River, Washington, Reclamation – maximum flow rate 2,200 ft³/s (in-diversion pool)
- ▶ Kittitas Canal, Yakima River, Washington, Reclamation – maximum flow rate 1,170 ft³/s (in-canal)
- ▶ Three Mile Falls Diversion Dam, Left Bank Facilities, Umatilla Project, Oregon – 180 ft³/s (in-canal)
- ▶ Site L-6, Lemhi River, Idaho, 45.6 ft³/s
- ▶ Deep Creek, Oregon 2.5 ft³/s (paddle wheel; in-canal)

c. *Traveling screens*

Traveling screens are mechanical screens installed vertically or on an incline that include screen panels, baskets, trays, or members connected to form a continuous

belt (figure 13). The screens operate with the screen rotating or traveling (intermittently or continuously) to keep the screen clean. The screens with baskets, which were originally developed for debris removal, move up on the leading (upstream) face and down on the back. The screen drive mechanism is positioned above the water surface; however, a spindle with bearings, guide track system, or drum is required at the submerged bottom of the screen. Sediment in and around this lower area may increase maintenance requirements.

Traveling screens have excellent debris handling characteristics and, consequently, may offer a viable alternative at sites with debris problems. Vertical traveling screens are widely applied at process and cooling water intakes. The flatter the incline (slope) of the traveling screen the greater the chance that fish may be carried over the screen. Because of the relatively high costs, traveling screen application would most likely be limited to small to moderate size facilities.

The most common application for traveling screens at irrigation facilities is for fish exclusion in the secondary dewatering structures used to reduce the bypass flow rates (covered more fully in chapter IV under “Fish Bypass System”). With such applications, the bypassed flow conveying fish and debris from the primary screen are passed through a second screening facility (traveling screen) where a portion of the bypass flow is pumped back to the irrigation supply canal, thus reducing the flow lost to the diversion, (figure 56); however, both the fish and debris are further concentrated in this reduced bypass flow.

Traveling screen installations are normally configured with the screen face (or faces, in the case of multiple screen installations) placed parallel to or at a shallow angle to the flow. As with other concepts, this generates good sweeping flow and provides fish guidance along the screen face, thus reducing fish contact with the screens.

Design details are presented in chapter IV.B.3.

Advantages of traveling screens

- ▶ They have excellent debris handling characteristics.
- ▶ They are commercially available which reduces design costs.
- ▶ They do not require a controlled operating water depth for proper cleaning as required for drum screens.
- ▶ They have been widely applied for many years and have a good performance record and are accepted by the fisheries resource agencies as positive barrier screens.

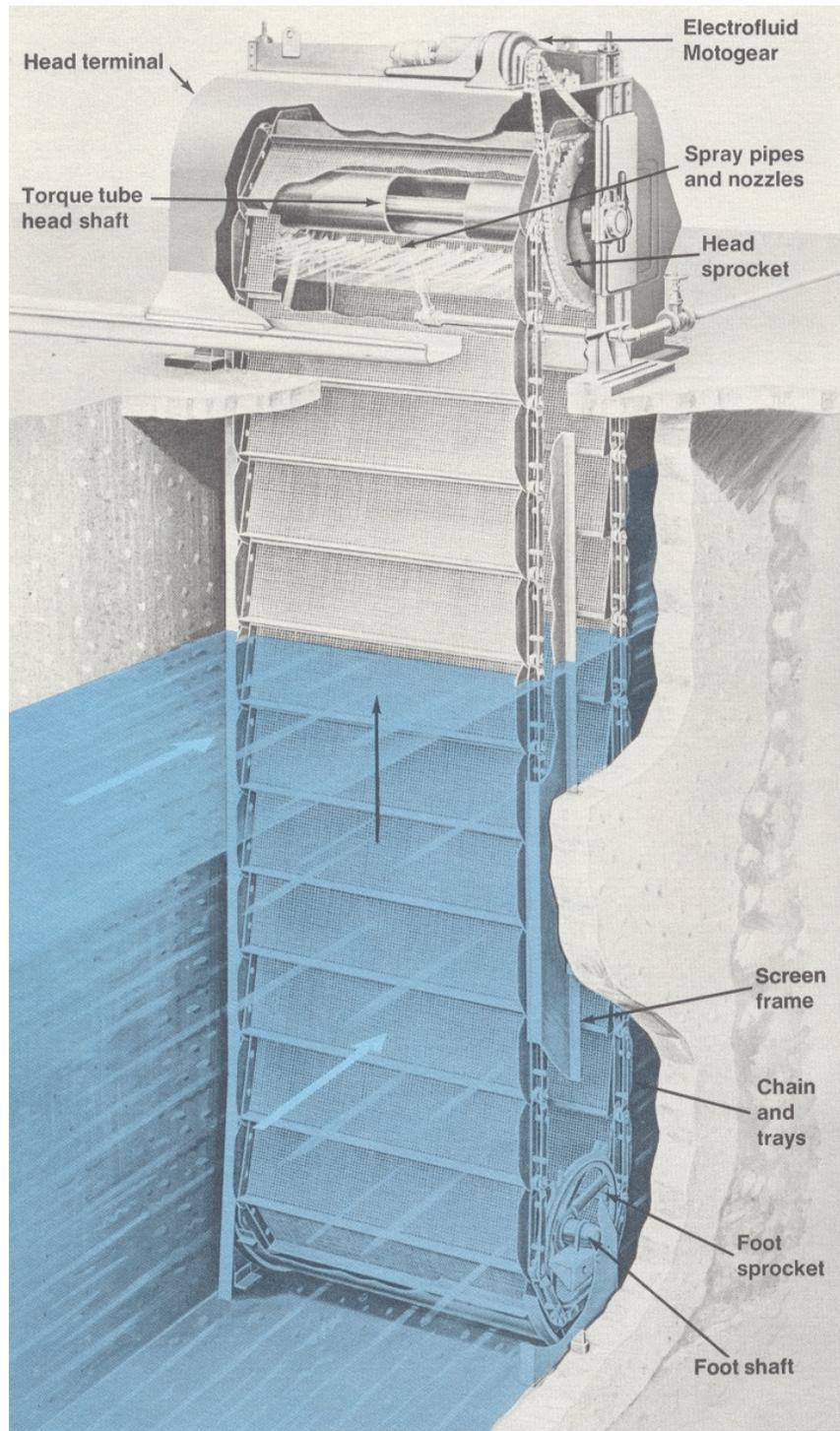


Figure 13.—Traveling screen.
(Courtesy of USFilter, A Siemens Business.)

Disadvantages of traveling screens

- ▶ They are not as economically viable for large diversions. They are more commonly used where less flow is diverted such as at small diversions or at secondary dewatering (pumpback) structures in fish bypasses.
- ▶ The seals require maintenance and special attention to prevent undesirable openings where small fish may pass. The traveling screen, spray water pump, and conveyor have moving parts which require maintenance.
- ▶ Special fabrication may be required to prevent fish passage between the screening trays or baskets and to prevent fish from being trapped on the lips of the basket frames.

Examples of traveling screen installations:

- ▶ Vertical traveling screens are applied as secondary dewatering screens on bypasses for the Chandler (35–40 ft³/s) and Roza Fish Screen facilities (230 ft³/s) and on Three Mile Falls Diversion Dam (20 ft³/s), Left Bank Fish Facilities, Umatilla Project, Oregon
- ▶ Shellrock Pump Station, Okanagan River, Washington, (vertical continuous belt, traveling screen) (25 ft³/s)
- ▶ Lilly Pumping Plant, Oregon, inclined traveling screens (68 ft³/s)
- ▶ Weeks Falls Hydroelectric Project, South Fork Snoqualmie River, Washington, maximum flow rate 750 ft³/s
- ▶ Marmot Diversion, Bull Run Hydroelectric Project, Sandy River, Oregon, Portland General Electric – flow rate 500 ft³/s
- ▶ Spring Hill Pumping Plant, Tualatin Project, Oregon, 180 ft³/s

d. Submerged screens

There are several submerged screen module designs commercially available. Typically, these modules are installed on pump diversion intake tubes at sites where the screen module is fully submerged. These commercially available screen modules have been effectively applied both in rivers and lakes. River applications are preferred because the river flow carries fish and debris away from the screen while diversion flow passes through the screen. Alternative module designs include conical screens with rotating brush cleaners, horizontal flat plate screens, rotating cylindrical screens with fixed brush or spray cleaners, and fixed

cylindrical screens with air burst or backwash spray cleaners. Typically, the modules include internal baffling elements that generate uniform screen approach velocity distributions.

Although cylindrical and conical screens are commercially available, there are also submerged screens including the horizontal and inclined screen concepts that are designed for the specific site. Cylindrical screens are commonly used at pumped water diversions, and the inclined and horizontal submerged screens are commonly used at gravity flow diversions.

Cylindrical screens

Submerged cylindrical screens, which compose the most widely applied submerged screen concept, consist of fully submerged screen modules placed at the intake end of pumped or gravity diversion conduits for supplying water for irrigation, process, cooling, and small hydropower applications (figure 14). These designs may include a single screen module or multiple screen modules where larger diversion flow rates are required.

The screens are placed fully submerged in the water body from which the flow is pumped. An aerial view of the new replacement installation of cylindrical Tee-screens just before installation at the East Unit Pumping Plant in Washington are shown in figure 15. For irrigation installations, the screens would likely be placed at in-river sites, although they have been applied at in-reservoir or diversion pool sites as well. The fish excluded by the screen remain free swimming in the river or pool and, therefore, a fish bypass is not needed. Screen designs are based on screen approach velocities and screen materials that fully comply with fishery resource agency criteria. Consequently, the potential for fish impingement or injury resulting from contact with the screen is minimal.

A retrievable type cylindrical screen has recently been developed and is used as another alternative to the fixed mounted cylindrical screens. It is typically mounted on a track placed on a canal or river bank (figures 16 and 17).

Components of submerged cylindrical screens typically include the screen with an interior baffling concept that generates uniform through-screen velocity distributions, a water differential measuring system, and a cleaning system. Brushes external or internal to the cylinder are used to clean debris from the screen surface (figures 17 and 81). Commercial concepts are available that generate back flushing through injection of compressed air into the screen cylinder (air-burst cleaning). These cleaning systems are more effective if the debris is flushed off the screen face. The passing ambient flow also helps to guide fish downstream and away from the screens.

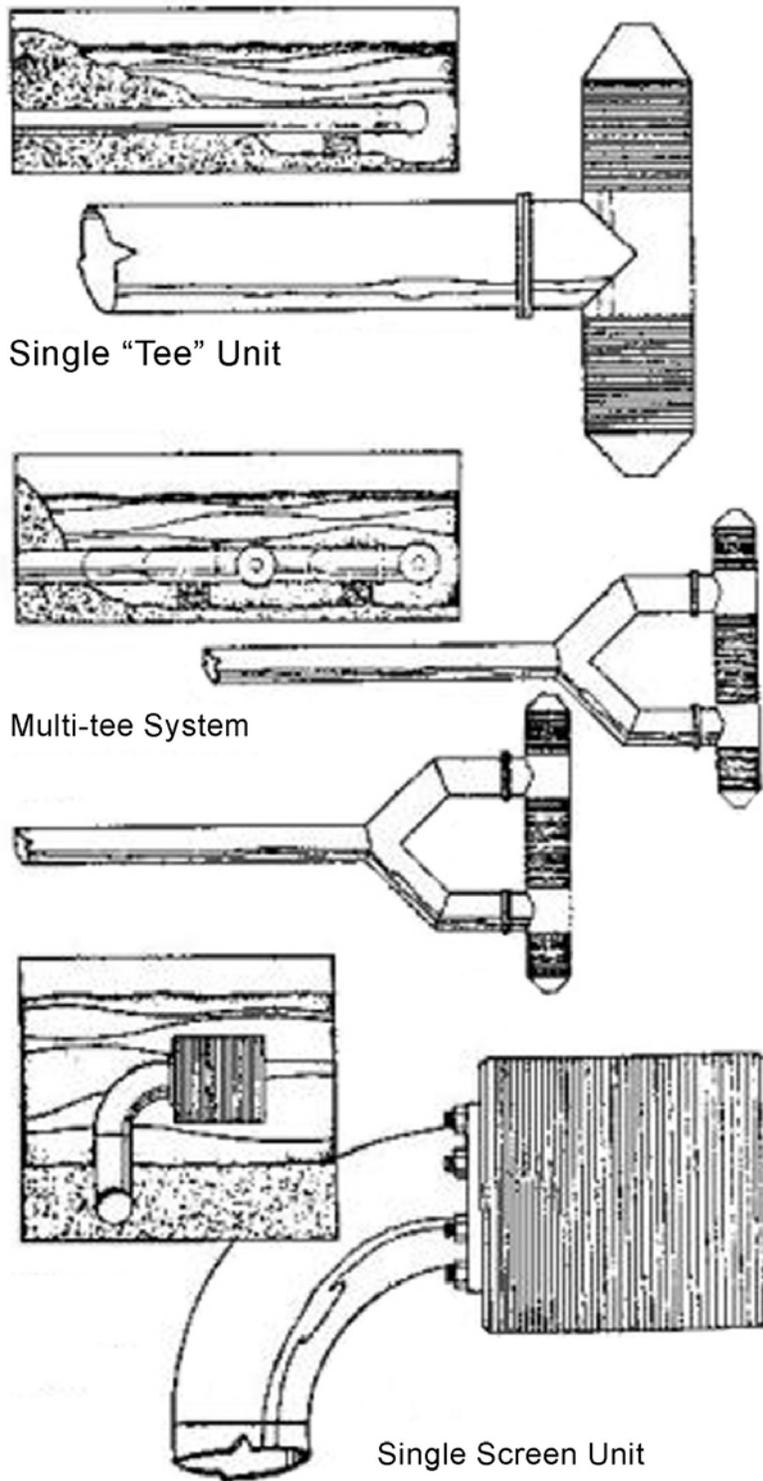


Figure 14.—Fixed cylindrical screens (Johnson screens).



Figure 15.—Installation of cylindrical tee-screens at East Unit Pumping Plant, Washington.



Figure 16.—Installation showing three raised retrievable cylinder screens – Davis Ranches Site #1, California (intake screens incorporated).



Figure 17.—Track mounted, retrievable rotating cylindrical screen with fixed brush cleaner (intake screens incorporated).

screens are placed in rivers where the passing flow will transport the debris away. Cylindrical screens are commercially available from multiple sources. Substantial experience with a wide variety of fish species and fish development stages exists for application of these screens. Screens have been designed for both fixed and retrievable installations.

A cylindrical screen case study is presented in chapter VI. Design details are presented in chapter IV.B.4.a.

Advantages of cylindrical screens

- ▶ They have no need for fish bypass, trashrack, or seals resulting in lower maintenance cost.
- ▶ They have a proven cleaning capability that removes debris off the screen.
- ▶ A varying water surface is not as critical as with surface screens for proper operation if screen axis elevation is deep enough.
- ▶ They are commercially available.

- ▶ They have been widely applied, have a good performance record, and have been accepted by the resource agencies as positive barrier screens.
- ▶ They provide easy access for inspection, maintenance, replacement, or removal during non-irrigation seasons.

Disadvantages of cylindrical screens

- ▶ They have size limitations that may limit applicability to only smaller diversions.
- ▶ Minimum depth of water and clearance requirements may require multiple screens and increased costs.
- ▶ An air burst cleaning system is often required, and underwater maintenance of the screens presents more difficult challenges than other screen options (not so much a problem for retrievable screens).
- ▶ Sweeping flow is needed to move debris away from the screen.
- ▶ Strong sweeping velocity may affect uniformity of flow through the screen.
- ▶ Retrievable cylindrical screens have additional moving parts that require maintenance. These parts are for retrieval of the screen and also to rotate the screen for brush cleaning.

Examples of Cylindrical Screen installations include:

Submerged cylindrical screens are widely applied at irrigation and process water intakes with flow rates typically less than 100 ft³/s. The most common applications are at pump intakes.

Fixed Cylindrical Screens

- ▶ Brewster Flat Unit River Pumping Plant – Chief Joseph Dam Project, Maximum diversion is 47 ft³/s.
- ▶ Small Scale Irrigation Pumps (Burbank Pumping Plants) – Columbia Basin Project, McNary National Wildlife Refuge, Maximum pump discharge for four small pumps 0.7–2.23 ft³/s.
- ▶ East Unit River Pumping Plant – Chief Joseph Dam Project, approximately 75 ft³/s.

- ▶ Arbutle Mountain Hydroelectric Project, Middle Fork Cottonwood Creek, maximum flow rate 115 ft³/s.
- ▶ Oroville-Tonasket Unit Extension-Chief Joseph Dam Project – Ellisforde, East Tonasket, Bonaparte Creek, Cordell, Crater Lake, and Osoyoos Pumping Plants, Washington (pumping plants range from 19–32 ft³/s).
- ▶ Hollister Conduit Outlet Works, San Justo Dam, 80 ft³/s
- ▶ Columbia River Pumping Plants – Umatilla Basin Project, Oregon (240 ft³/s)
- ▶ Evansville Water Plant Intake, Wyoming (5 ft³/s)

Retrievable cylindrical screens

- ▶ Davis Ranches Site #1, 72 ft³/s diversion flow
- ▶ Jerry Foster Poker Bend Ranch, 40 ft³/s diversion flow
- ▶ Roberts Ditch Company, 27 ft³/s diversion flow
- ▶ Boeger Land Company, 23 ft³/s diversion flow
- ▶ Tom Gross Site #2, 23 ft³/s diversion flow
- ▶ Tisdale Irrigation and Drainage, 19 ft³/s diversion flow
- ▶ Oji Brothers Farm, 18 ft³/s diversion flow
- ▶ Butte Creek Farms Site #3, 10 ft³/s diversion flow
- ▶ Steidlmayer, 10 ft³/s diversion flow

Inclined screens

Inclined screens have been applied in two configuration concepts. One configuration places the screen at an adverse slope on the channel invert (figure 18). The screens are angled in line with the flow and are completely submerged. The flow, with fish and debris, sweeps over the length of the screen. Due to the adverse slope, sweeping flow velocities across the screen are maintained while flow depths are progressively reduced. The sweeping flow provides a mechanism to guide fish and debris across the screen surface and to the bypass at the upper or downstream end of the screen, while the diverted flow passes through the screen.

Typically, inclined screens are fabricated from non-moving flat screen panels. However, there are installations where the inclined screen panels are installed in a movable support frame that elevates the downstream end of the frame to follow or

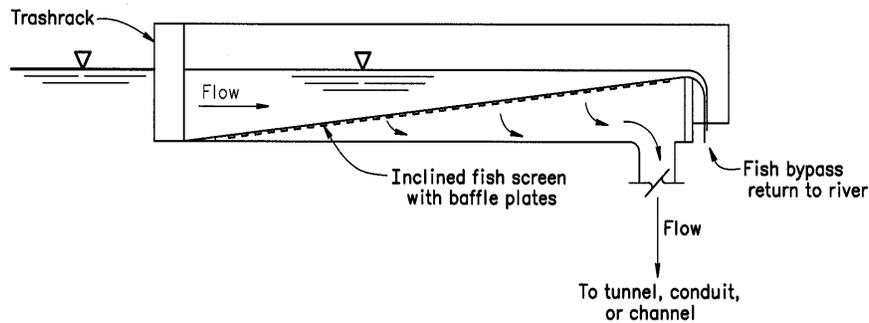


Figure 18.—Fixed inclined screens.

adjust to changing water surface elevations. Inclined screens have been used successfully at the Roza and Chandler diversion dams fish evaluation facilities (figures 84 and 85). Often, flow resistance elements placed behind the screens are included in inclined screen facilities to generate uniform approach velocities across the screen face. The most common methods used to clean the screens are a brush cleaning system (either manual or mechanically operated), a cleaning system that uses compressed air (air burst), or spray water back-flushing. For either cleaning system, the cleaning cycle should start at the upstream end of the screen and work downstream so that the debris is moved off the screen with the passing flow.

Installations are designed in compliance with fishery resource agency velocity and screening criteria. Although existing concepts have been developed based largely on juvenile salmon criteria, screen development based on alternative, non-salmonid criteria is achievable (as is the case for most of the screen concepts presented).

Bypass design issues vary with the screen configuration applied. With inclined screens placed parallel to the passing flow, the bypass discharge and bypass entrance velocities depend on water surface elevations and submergence over the top of the screen. Such screens are best applied at sites with controlled water surface elevations and are generally not applied at in-river sites. Inclined screens are widely applied in juvenile fish sampling and collection facilities that are operated in conjunction with fish screen bypass facilities.

Another configuration places flat plate screens on an incline along the bank of a channel. Typically, these screens are installed with the approach flow sweeping across the screen face from side to side. They may be placed at an angle across a canal, on the canal bank, or, more commonly, on a river bank as an in-river facility (figure 19). The inclined placement increases the active screen area and

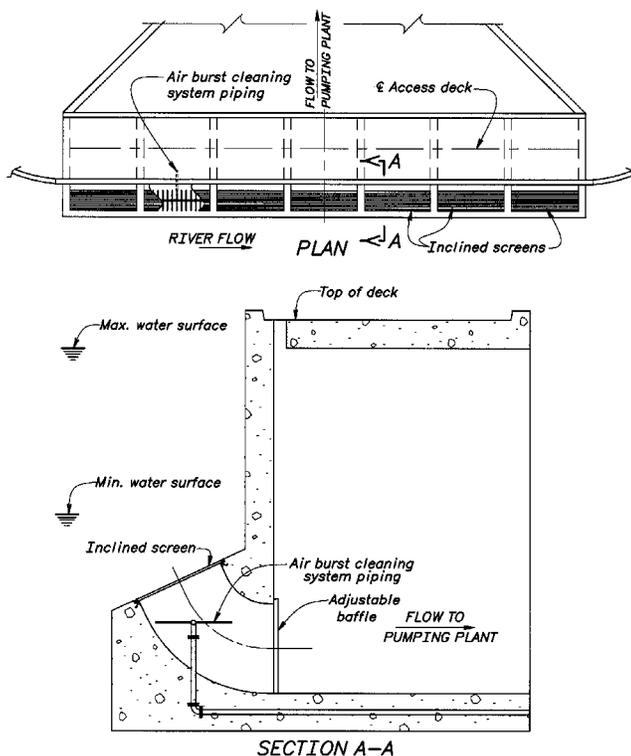


Figure 19.—Inclined screen along river bank.

allows the screens to be applied in shallower flow depths. These screens are usually fully submerged; however, there may be locations where the top of the screen may be above water when operating with shallower flow depths.

Inclined screens placed in canals require bypasses. The approach channel section defined by the inclined screen must transition carefully to a vertical slot bypass entrance to ensure that bypass approach velocities do not slump and cause fish to either delay or avoid the intake. Use of a bypass entrance configured to match the approach channel cross-section might be considered even though it may require larger bypass discharges.

Inclined screens applied in-river with a sweeping or passing flow would not require a bypass unless the screen was sufficiently long to exceed exposure duration criteria.

Design details are presented in chapter IV.B.4.b.

Advantages of inclined screens

- ▶ They can provide effective screen surface areas even with shallow flow applications.
- ▶ They have a simple design with few or no moving components, thus minimizing maintenance and reducing capital and maintenance costs.
- ▶ They have proven cleaning capability that removes debris off the screen.
- ▶ They have been applied for many years, have a good performance record, and are accepted by the fisheries resource agencies as positive barrier screens.

Disadvantages of inclined screens

- ▶ Sediment and debris (large trees and boulders) may be a major problem, because the inclined screen is a bottom type screen.
- ▶ If a cleaning system is used, it will have moving parts that require maintenance.
- ▶ The diverted flow rates may vary as a function of water surface and screen fouling.
- ▶ The intake channel may require dewatering capability for maintenance.
- ▶ Future fishery resource agency criteria may limit the calculated screen area based on the vertically projected height.

Examples of inclined fish installations include:

- ▶ Red Bluff Fish Evaluation and Sampling System, Red Bluff, California (10 ft³/s per pump bay)
- ▶ Chandler Juvenile Fish Evaluation Facility, Yakima River, Washington (32 ft³/s)
- ▶ Roza Juvenile Fish Evaluation Facility, Yakima River, Washington (30 ft³/s)
- ▶ Kittitas Canal, Yakima River, Washington (40 ft³/s)

- ▶ Three Mile Falls Diversion Dam, Left Bank Fish Facilities, Umatilla River, Oregon (5 ft³/s)
- ▶ Potter Valley Project, Eel River, Pacific Gas and Electric Company, maximum flow rate 310 ft³/s
- ▶ Twin Falls Hydroelectric Project, South Fork Snoqualmie River, Washington, maximum flow rate 710 ft³/s

Horizontal flat plate screens

The horizontal flat plate screen concept uses a screen with a horizontal face placed near the bottom (invert) of a natural channel (figure 20). In 2001, Reclamation and the Farmers Irrigation District, Hood River, Oregon, cooperated on the design of a horizontal flat plate screen (Frizell and Mefford, 2001; Beyers and Bestgen, 2001). The horizontal screen is used as an in-river installation that would usually be applied in small rivers. The screen can be used in conjunction with either a pumped or gravity diversion. The concept allows placement of a screen with significant active surface area in a shallow stream. The horizontal screen concept is, consequently, more applicable at shallow river diversion sites than flat plate screens and fixed cylindrical screens, both of which require greater river depths. Horizontal screens also offer a cost effective option for a positive barrier screen that complies with agency criteria.



Figure 20.—Horizontal flat plate screen, East Fork Ditch Company, East Fork, Weiser River, Idaho.

Hydraulic laboratory studies (Frizell and Mefford, 2001) evaluated screen configurations and flow conditions across and through the screen. Studies showed that flow conditions were influenced by river channel geometry, depth of flow on the screen, use of a rectangular or converging screen, the percentage of flow diverted through the screen to the total river flow, and apron treatments approaching and exiting the screen face. Efforts should be made to generate uniform parallel flow patterns across the screen face. Because of the diversion and loss of flow, sweeping velocities tend to decrease as flow passes down the length of the screen.

Probable components of a horizontal flat plate screen include the screen, an adjustable side weir that controls the diverted flow rate and ensures that the chamber below the screen will not be dewatered even with a complete debris blockage of the screen, and a sediment trap positioned upstream from the screen that would prevent bedload passage across the screen. A schematic view of a horizontal screen, as tested in the laboratory, is shown in figure 86. The design usually does not require interior baffling to generate uniform screen approach velocity distributions.

Horizontal screens can be designed to fully comply with fishery resource agency screen approach velocity criteria; however, like the inclined screens, resource agencies should be consulted to ensure acceptable screen area is being provided. Screen designs have been considered that include air burst and backspray cleaners; however, cleaning systems have not been installed in the screens that have been constructed to date.

The horizontal screen concept has been patented by the Farmers Irrigation District of Hood River, Oregon. Fees must be paid to the district for application of the concept. NOAA Fisheries has accepted the horizontal flat plate screen concept as proven technology and does not consider it experimental.

Design details are presented in chapter IV.B.4.c. under “Horizontal Flat Plate Screens.”

Advantages of horizontal flat plate screens

- ▶ They can be effectively applied at shallow in-river diversion sites.
- ▶ They have a simple design with no moving parts.
- ▶ They offer a cost effective positive barrier screen concept that complies with fishery resource agency criteria.

Disadvantages of horizontal flat plate screens

- ▶ Debris and sediment handling characteristics are not fully proven and may be a problem.
- ▶ Diversion flow rates will vary as a function of water surface elevation and screen fouling.
- ▶ Applications are likely limited to relatively small diversions (less than 100 ft³/s).
- ▶ The concept may be considered developmental by fishery resource agencies.
- ▶ There may be high exposure of bottom-oriented fish to the screen surface.

Examples of horizontal screen installations include:

Two state-of-the-art installations were cited by Jerry Bryan of the Farmers Irrigation District:

- ▶ Davenport Stream, Oregon, 80 ft³/s screen
- ▶ East Fork Ditch, Idaho, 16 ft³/s screen

To date, debris and sediment handling characteristics of these screens has proven good. The biggest fouling problem that has been encountered is algal growth on the bottom of the perforated plate. This growth traps fine sediment and leads to screen fouling. A removable barrier device that sweeps across the screen to generate increased differential across the screen face, creating a flushing action, has proven effective in removing the algal growth.

e. Coanda screens

The Coanda screen is typically installed on the downstream face of an overflow weir, as shown in figure 21. Flow passes over the crest of the weir, down a solid acceleration plate, and then across the screen panel, which is constructed with profile bar (wedge-wire), with the wire oriented perpendicular to the flow. The weir crest provides a smooth acceleration of the channel flow as it drops over the acceleration plate and flows tangentially onto the screen surface. Typically, the screen panel is a concave arc, although a planar (flat) screen panel could also be used. Diverted flow, passing through the screen, is collected in a conveyance channel below the screen, and the overflow (bypass flow), which may include fish, and debris pass off the downstream end of the screen (figures 88 and 89). Flow velocities across the face of the screen are relatively high, varying as a function of the drop height from the upstream pool to the start of the screen.

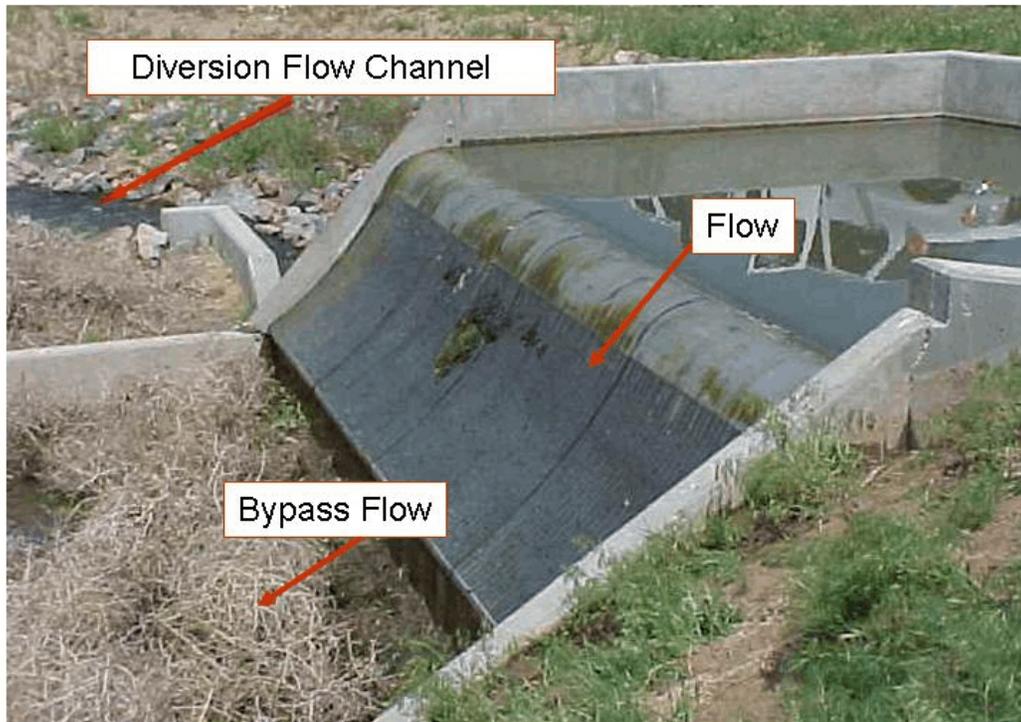


Figure 21.—Field site Coanda screen, Rocky Mountain Arsenal, Denver, Colorado.

Sufficient flow depths must be maintained over the lower end of the screen to prevent excessive fish contact with the screen surface, which could result in fish injury or mortality.

The Coanda screen is a non-traditional design in that relatively shallow; high velocity flows occur on the screen face. Coanda screens are very efficient at diverting large quantities of flow for their size. They are essentially self-cleaning and have the ability to exclude very fine debris and small aquatic organisms. The high velocity flow across the screen face, typically in the range of 6 to 12 ft/s depending on the specific design of the structure, provides the self-cleaning characteristic. In recent years, this self-cleaning screen with no moving parts has been successfully used for debris and fish exclusion at several water diversions.

Compared to traditional fish screen structures, impingement of fish against the screen is not a significant concern, since the sweeping velocity carries fish immediately off the screen. However, additional biological testing is still needed to demonstrate fish survival and evaluate other side effects of fish passage over the screen (e.g., descaling injuries, disorientation, delayed passage, etc.). Researchers (Buell, 2000) have obtained promising results from evaluations of passage of salmon fry and smolt over a prototype Coanda screen installed at the

East Fork Irrigation District's sand trap and fish screen facility located on the East Fork Hood River, near Parkdale, Oregon. Limited evaluations of fish injury potential were also conducted.

Another benefit resulting from application of Coanda screens is improvement of water quality at sites with low dissolved oxygen (DO) levels or in waters supersaturated with total dissolved gases (e.g., below spillways and dam outlet facilities). The fine jets of water discharged through these screens are exposed to the atmosphere, which allows for stripping of excess gas or reaeration of low-DO waters.

Coanda screens have been found to be essentially self-cleaning in field installations and are easily cleaned when debris accumulates. Working with a brush or other implement from a walkway over the crest is an effective cleaning technique. The sweeping flow down the face of the screen will carry debris off the screen.

Design details are presented in chapter IV.B.5.

Advantages of Coanda screens

- ▶ They have good self-cleaning characteristics that minimize maintenance requirements.
- ▶ They are relatively compact and include no moving parts.
- ▶ They can be effectively used to exclude sediment from the diversion.

Disadvantages of Coanda screens

- ▶ Available commercial designs require several ft of head drop (approximately 4 ft), which may be restrictive where there is insufficient available head.
- ▶ To satisfy minimum flow depths at the bottom of the screen, a substantial amount of bypass flow may be required.
- ▶ Fish injury and mortality characteristics of the screen have not been fully evaluated and documented.
- ▶ The concept may be considered developmental by fisheries resource agencies.
- ▶ Applications are likely limited to relatively small diversions (less than 150 ft³/s).

Installations include:

- ▶ East Fork Irrigation District, East Fork Hood River, Parkdale, Oregon, 127 ft³/s.
- ▶ Denver Metro Reclamation District- Farmers Reservoir and Irrigation Company, Denver, Colorado
- ▶ Panther Ranch Hydroelectric Project, Shasta County, California, maximum flow rate 4 ft³/s.
- ▶ Bear Creek Hydroelectric Project, Shasta County, California, maximum flow rate 70 ft³/s.
- ▶ Montgomery Creek Project, Shasta County, California, maximum flow rate 120 ft³/s.
- ▶ Bluford Creek Hydroelectric Project, Trinity County, California, maximum flow rate 30 ft³/s.

f. Closed conduit (Eicher and MIS) screens

There are essentially two options that have been developed for closed conduit fish screen exclusion. The Eicher Screen and the MIS. These are considered high velocity screens.

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

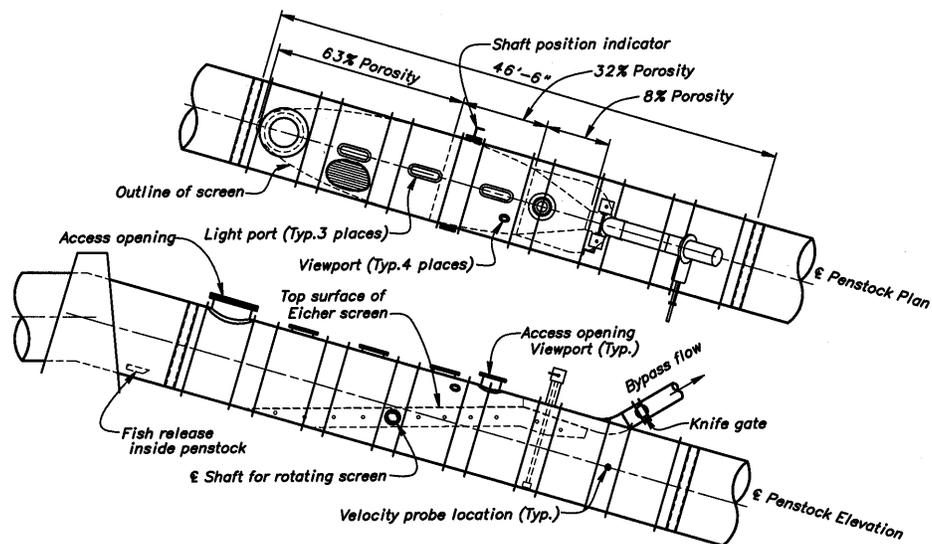


Figure 22.—Eicher screen (EPRI, 1994).

The MIS screen was developed for application in a broad range of diversion and water intake structures including hydro-power and pump intakes. The concept was developed as a standard design screen module with an inclined screen placed in a length of rectangular cross section conduit (figure 93). Details on the developed module configuration and performance characteristics of the module are presented in EPRI, 1994. The MIS screen modules were developed to be included in the intake structure positioned immediately downstream from the intake trashracks. The configuration of the module with included transitions was developed for the specific hydraulic flow patterns generated by this configuration. The MIS concept is patented in the United States by EPRI. The screen concept was developed through use of laboratory studies that refined and evaluated hydraulic and fish passage characteristics of the design. Field application experience is limited to a pilot facility evaluation that was conducted at Niagara Mohawk Power Corporation's Green Island Hydroelectric Project, New York, in 1996. As a consequence, the field experience base with MIS screens is marginal.

Extensive laboratory and field prototype studies have been conducted to support development of the Eicher and MIS screens. These include detailed studies to develop the hydraulic characteristics of the design and extensive evaluations of fish passage characteristics with numerous fish species and development stages.

Closed conduit fish screens typically include a flat screen panel placed on a diagonal to the flow within a circular or rectangular cross-section conduit (figure 22). In a gravity diversion pipe or pump suction tube, the screen might be a component of a closed conduit intake structure. The screen panel is supported by a pivot-beam that runs horizontally across the panel at mid-section of the conduit. As with other angled screen placement concepts, the flow approaching and passing the screen guides fish over the screen surface and to the fish bypass. The intercepted fish are then transported through a bypass conduit and released back to the river, usually in the diversion dam tailrace (a significant head drop is required at the site to provide sufficient bypass flow).

Generation of uniform flow velocities across the screen is simplified by placing the screen panel in a conduit section that has uniform, well-aligned flow. Flow patterns across the screen can be adjusted and uniform through-screen flow distributions established by use of flow resistance screen backing or variable screen porosity (adjustment of screen percentage open area). Head or energy losses across clean screens are generally less than 1.0 ft of water.

Closed conduit screens, by their nature, are installed in a very confined space. Velocities through the screen section are a function of velocities in the conduit itself. The in-conduit fish screen involves significantly higher approach velocities than conventional types of screens. Typically, screen approach velocities greatly exceed normal fishery resource agency velocity criteria. This increases the potential for fish injury. However, fish exposure time to the screens is often less than 10 seconds, which minimizes fish contact potential. Field and laboratory studies have shown that near zero mortality and injury rates can be achieved for many fish species and life stages (EPRI, 1994; Smith, 1997).

The screens are cleaned by pivoting the screen panel about the support beam to a position that generates a back-flushing flow to the screen. Backflushing may be initiated periodically as part of a routine cleaning operation or may be initiated by a monitored pressure drop across the screen. Fish protection and exclusion is lost during the cleaning operation. Frequency of cleaning depends on debris load.

Design details are presented in chapter IV.B.6 under “Closed Conduit Eicher and MIS Screens.”

Advantages of closed conduit screens

with a wide variety of fish species and fish development stages.

- ▶ Closed conduit screens can be directly incorporated in diversion conduits, which minimizes required civil structures and allows application at sites with little space.

- ▶ The back-flush cleaning design has proven effective and mechanically simple.
- ▶ Costs associated with maintaining and operating the facility are low.

Disadvantages of closed conduit screens

- ▶ Both the Eicher and MIS screen concepts are patented.
- ▶ Bypass flows can be significant for small conduits. Bypass diameters of less than 24 inches have not been field evaluated.
- ▶ During back-flushing operations, the screen does not exclude fish from the diversion.
- ▶ Head losses of up to 2.5 ft may occur with fouling, although under typical operation, head losses of approximately 1.0 ft can be expected.
- ▶ Access to the screen for inspection or maintenance is limited and requires shutdown and dewatering.
- ▶ Potential fish injury may be associated with high velocity flow across the screen surface.
- ▶ Although experience exists at several sites with closed conduit screen concepts and with a range of fish species and fish sizes, the concept may be considered experimental by fishery resource agencies.

Closed conduit screens have been applied primarily in penstocks at hydro-power sites. The concept is however applicable at closed conduit irrigation diversions. Documented hydropower applications of closed conduit installations include:

- ▶ Puntledge Hydroelectric Project, Puntledge River, British Columbia, British Columbia Power, maximum flow rate 520 ft³/s per screen (the site includes two Eicher screens).
- ▶ Elwha Hydroelectric Project, Elwah River, Washington (Eicher screens); wide range of velocities and flow rates were tested) 255–496 ft³/s.
- ▶ T.W. Sullivan Hydroelectric Project, Willamette River, Oregon, Portland General Electric (Eicher screens) (475 ft³/s).

2. Behavioral Barriers

A behavioral avoidance or exclusion barrier, as compared to a positive screen barrier, requires volitional action on the part of the fish to avoid entrainment. Behavioral devices in many cases are experimental and performance capabilities may not be well documented. The literature contains enough documentation, however, to give indications of possible beneficial performance. Use of behavioral devices often offers a lower capital and operating cost option that may at least partially reduce fish entrainment. Behavioral devices might also offer a fish exclusion option at sites that would otherwise be difficult to screen, such as at penstock entrances positioned at great depth in a reservoir.

a. Louvers

Louvers consist of an array of vertical slats that are placed on a diagonal structure across a channel (figure 23). Spacing between louver slats is typically larger than the width of the smallest fish that are being excluded. Louvers achieve fish exclusion by creating a series of elements that generate flow turbulence that the fish tend to avoid. Fish will maintain their position off the louver face while the sweeping flow (generated by the angled louver placement) guides the fish along the louver line to bypasses.

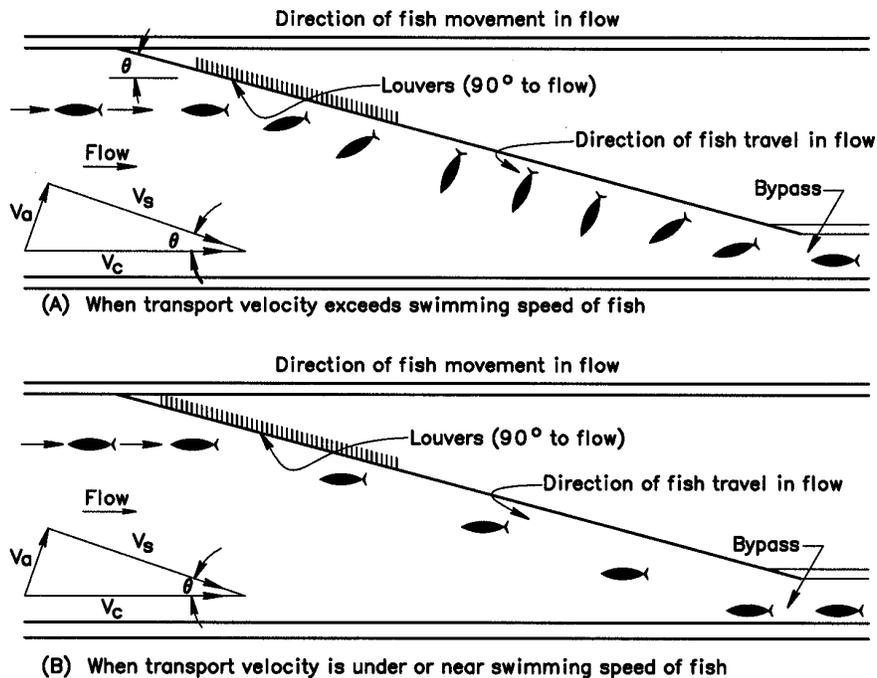


DIAGRAM ILLUSTRATING REACTION OF FISH TO LOUVERS

Figure 23.—Louver concept (Rhone, 1960).

Louvers are, therefore, a behavioral device that depends on fish avoidance for effective exclusion. Behavioral barrier effectiveness varies as a function of fish species, fish life stage, fish size, and fish swimming strength. Documented exclusion efficiencies for louvers range from greater than 90 percent for juvenile Chinook salmon with fork length longer than 45-mm to efficiencies below 30 percent for juvenile Chinook salmon with fork length shorter than 30-mm, for striped bass with length shorter than 10-mm, and for white catfish with length shorter than 45-mm (Skinner, 1974; Vogal et al., 1990). Although numerous studies have been conducted to evaluate louver efficiencies as a function of design parameters, substantial uncertainty still exists with development of a specific louver design for a specific fishery.

Louver structures are an attractive fish exclusion option in that they are fairly inexpensive and the openings between slats are large, which may allow sediment and debris passage. Louvers also operate at higher velocities than typical screens, which allows for a smaller overall structure. Mechanical equipment is required for cleaning and debris handling facilities. Depending on debris type and quantity, cleaning and debris handling demands may be minimal or may be substantial.

Design details for louver barriers are presented in chapter V.A. under “Louver Design.”

Advantages of louvers

- ▶ Louvers typically operate with higher approach velocities than screens, which leads to reduced overall structure size and cost.
- ▶ Louvers will pass small debris and sediment, which can reduce debris and sediment handling requirements.
- ▶ Louvers have a reduced sensitivity to flow blockage caused by debris fouling as compared to fine mesh screens. Consequently, more time is available between required cleaning cycles, and automated cleaners are typically not used.
- ▶ Louvers offer an effective exclusion option for larger, stronger swimming fish and may provide a reduced-cost fish exclusion option at sites where 100 percent fish exclusion is not required..

Disadvantages of louvers

- ▶ Louvers are not absolute fish barriers (not a positive barrier screen). Fish exclusion efficiency varies as a function of fish species, life stage, size, and fish swimming strength.

- ▶ Some debris types (fibrous aquatic plants and woody plants) will intertwine or embed in the louver, which leads to difficult debris removal and cleaning.
- ▶ Louvers are not broadly accepted by resource agencies and are typically opposed by resource agencies on the West Coast.

Examples of louver installations include:

- ▶ Clifton Court Diversion, California, maximum flow rate of approximately 6,400 ft³/s, California Department of Water Resources
- ▶ Tracy Diversion, California, maximum flow rate of approximately 5,000 ft³/s, Reclamation
- ▶ Hadley Falls Hydroelectric Project, Connecticut River, Massachusetts, Northeast Utilities Service Company, maximum flow rate 7,000 ft³/s
- ▶ Grand Falls Hydroelectric Facility, Newfoundland, Canada, maximum flow rate 9,040 ft³/s
- ▶ T.W. Sullivan Hydroelectric Plant, Willamette River, Oregon, Portland General Electric, maximum flow rate 5,200 ft³/s
- ▶ T&Y Diversion, Miles City, Montana, maximum flow rate 237 ft³/s

b. Light and sound behavioral devices

Behavioral devices have had wider application at hydroelectric facilities and process (cooling) water intakes than at irrigation diversions. However, the observed performance characteristics and evaluation at these facilities are applicable for irrigation diversions.

Some behavioral devices attempt to exclude or guide fish away from intakes and diversions through use of stimuli (typically light or sound). Strobe lights or sound of specific frequencies and magnitudes can serve as an irritant to direct fish away from a diversion. However, in other cases, Mercury lights might be used as an attractant. Work has also been done with numerous other lighting options in attempts to generate attraction or avoidance. Effectiveness of behavioral devices varies with fish species and fish size, site conditions (including layout and flow patterns), and ambient conditions (including water turbidity and naturally occurring light).

A prototype *sonic barrier* that demonstrates behavioral device application was installed and evaluated at the confluence of Georgiana Slough and the Sacramento River (figure 24). This effort was supported by State and Federal water and fisheries agencies (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 delta and, thus, would be diverted from the direct out-migrating path down the main channel of the Sacramento River to the ocean. The objective was to direct out-migrating chinook salmon smolt away from the slough entrance. It was recognized that the device likely would not be 100 percent effective. However, physical screening at the site would be very expensive and require a complex structure that would need to be functional through variations in tidal cycle and river flows. Also, the screening would have to function without blocking the slough to upstream adult passage.

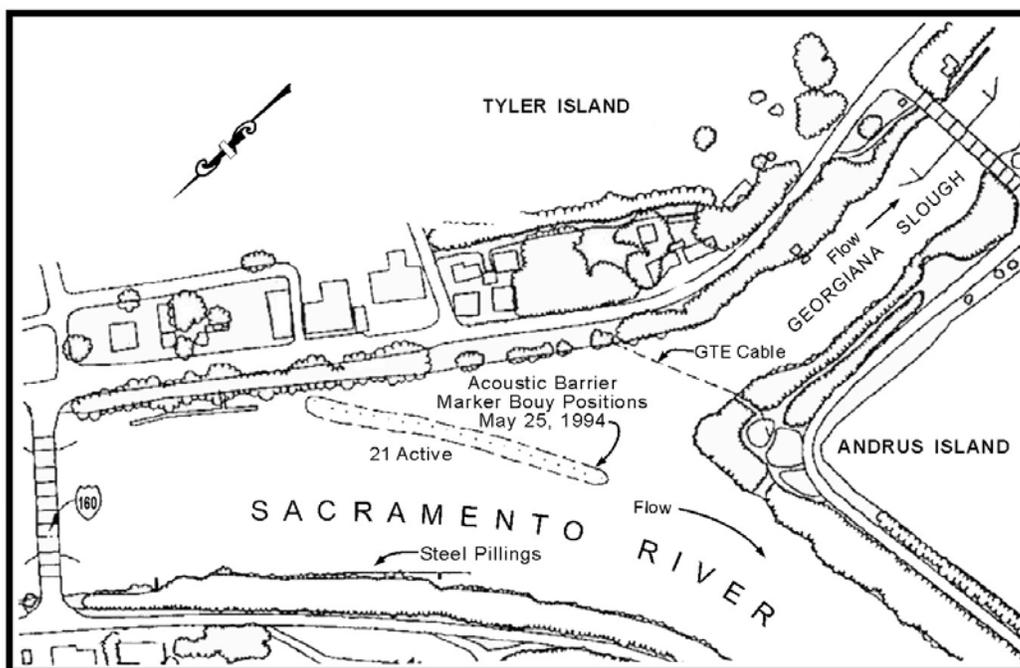


Figure 24.—Georgiana slough facility, California.

The sound system deployed at the mouth of Georgiana Slough consisted of an 800-ft-long linear array of acoustic transducers suspended from buoys that were located approximately 1,000 ft upstream from the slough entrance. The acoustic barrier angled out from the shore with the objective of diverting the out-migrating

fish to the far side of the river, away from the slough entrance. Observed fish guidance/exclusion efficiencies (percentage of fish excluded from the slough) were influenced by flow and hydraulic conditions. Observed efficiencies ranged from 50 to 80 percent for typical operating conditions. Observed efficiencies, however, dropped to 8 to 15 percent (very inefficient) during flood events on the river. On occasion, damage occurred to the sound barrier system during flood events.

Performance and Design details are presented in chapter V.C. under “Strobes and Lighting.”

Advantages of behavioral devices

- ▶ Light and sound systems have a relatively low capital and maintenance cost.
- ▶ They are applicable at sites that would otherwise be difficult to screen.

Disadvantages of behavioral devices

- ▶ They do not create an absolute exclusion barrier (not a positive barrier screen).
- ▶ Exclusion efficiencies can vary with fish species, fish development stage, and ambient conditions (river flow discharge and patterns, water quality, and ambient lighting).
- ▶ They are not generally accepted by fishery resource agencies for fish exclusion applications.

Examples of Light and Sonic Behavioral Device installations include:

Lights have been applied, generally in a prototype or developmental mode, at numerous hydroelectric facilities. Fish exclusion and guidance objectives, design and ambient conditions, and observed fish responses vary widely. Hydroelectric sites at which strobes have been applied include:

Kingford Hydroelectric Project, Menominee River, Wisconsin

White Rapids Hydroelectric Project, Menominee River, Wisconsin

Mattaceunk Hydroelectric Project, Penobscot River, Maine

Four Mile Hydroelectric Project, Michigan

Fort Halifax Hydroelectric Project, Sebasticook River, Maine

Rolfe Canal Hydroelectric Project, Contocook River, New Hampshire

Hadley Falls Hydroelectric Project, Connecticut River, Massachusetts
Rocky Reach Dam, Columbia River, Washington
Puntledge Generation Station, Comox Lake, British Columbia
York Haven Hydroelectric Project, Susquehanna River, Pennsylvania
Dworshak Dam, Clearwater River, Idaho
Roza Diversion Dam, Yakima River, Washington
McNary Dam, Columbia River, Washington

Mercury vapor and other overhead lights have been most often applied in a prototype or developmental mode at numerous hydroelectric facilities in attempts to either attract fish to safe areas or to attract fish to bypass entrances. Again, fish guidance objectives, design and ambient conditions, and observed effectiveness varied widely. Hydroelectric sites at which attraction lights have been applied include:

Turners Falls Hydroelectric Project, Connecticut River, Massachusetts
York Haven Hydroelectric Project, Susquehanna River, Pennsylvania
Wanapum Dam, Columbia River, Washington
Wapatox Canal, Naches River, Washington
Hadley Falls Hydroelectric Project, Connecticut River, Massachusetts
Priest Rapids Dam, Columbia River, Washington
Richard B. Russell Pumped Storage Project, Savannah River, South
Carolina/Georgia

Reclamation used lights at the Glenn-Colusa Irrigation District bypass structure as a way to attract fish to the bypass.

Sonic barriers have been evaluated in experimental applications at irrigation water delivery sites including:

Georgiana Slough, Sacramento River – River flows of 1,600–15,000 ft³/s
Wilkins Slough (Reclamation District 108), Sacramento
River – Maximum pumped flow of 830 ft³/s

Various sonic systems, likewise, have been applied in prototype or developmental mode at numerous hydroelectric facilities in attempts to generate fish avoidance and through either fish guidance or exclusion. Again, fish guidance objectives, design and ambient conditions, and observed effectiveness varied widely. Hydroelectric sites at which sonic systems have been applied include:

White Rapids Hydroelectric Project, Menominee River, Wisconsin

Bonneville Dam, Columbia River, Washington/Oregon

Crescent and Visher Ferry Hydroelectric Projects, Mohawk River, New York

Richard B. Russell Pumped Storage Project, Savannah River, South
Carolina/Georgia

York Haven Hydroelectric Project, Susquehanna River, Pennsylvania

Racine Hydroelectric Plant, Ohio River, Ohio

Berrinen Springs Hydroelectric Project, St. Joseph River, Michigan

Vernon Hydroelectric Project, Connecticut River, New Hampshire/Vermont

c. Other behavioral barriers (air bubble curtains, hanging chains, water jet curtains, electric fields)

A variety of concepts that establish curtain-like barriers have been developed and applied. These behavioral avoidance concepts potentially discourage fish passage to diversions. Included are manifolds that release a series of compressed air driven bubble plumes that, in combination, form a bubble curtain, a series of hanging chains forming a curtain of chains, manifolds that release a series of submerged water jets that form a turbulent jet flow curtain, and electrodes that form electrical fields.

These concepts have been evaluated at a scattering of sites over the years. All of them have generally proven ineffective. In EPRI (1999), it is noted that

The results of these studies, combined with conclusions of ineffectiveness from past studies, do not support further testing of air bubble curtains. . . . A variety of other behavioral devices have been evaluated in the past with little or no success. These include water jet curtains, electrical barriers, hanging chains, visual keys and chemicals.

An exception is the possible coupling of multiple exclusion concepts into a hybrid. Studies conducted at a hydroelectric site in Michigan (McCauley et al., 1996) indicate that the coupling of air bubble curtains with strobe lights can increase strobe light exclusion efficiency. It may be that other combinations of behavioral systems can yield improved fish exclusion and guidance characteristics. In EPRI (1999) it is observed that:

Fish protection systems that incorporate the use of fish deterrent and attraction devices may be more appropriate than systems with multiple deterrents. At the Richard B. Russell project, the use of high-frequency sound to repel blueback herring from pumpback intakes and overhead lights to attract them to low-velocity safe areas proved to be very effective.

Options that couple potentially effective (based on the site specific fishery, application, and ambient conditions) behavioral concepts can provide a viable fish exclusion and guidance option.

Design details for electrical fields are presented in chapter V.B. under Electrical Fields.

Advantages of behavioral barriers

- ▶ Capital and maintenance costs of behavioral systems are relatively low.
- ▶ They might be applicable at sites that would otherwise be difficult to screen (complex sites with odd configurations that might not be accessible for maintenance).

Disadvantages of behavioral barriers

Their performance capabilities are very uncertain. Fish exclusion and guidance efficiencies are likely to be low.

- ▶ Fishery resource agencies will likely not accept behavioral barriers as a fish exclusion alternative or will likely require extensive field evaluation to verify effectiveness.

Examples of these devices include:

- ▶ Electric Fish Barrier for Chicago Canal
- ▶ Saint Mary's Irrigation District

C. Design Process

“For a successful technology, reality must take precedence over public relations, for nature cannot be fooled.”

Richard P. Feynman – American Author

The following chapter is intended as a guide that can be used to refine and focus the design process on a few appropriate fish exclusion alternatives and on a well-directed design process. A decision chart is included that may be helpful to sort through the alternatives allowing selection of a limited number of alternatives for further consideration. An itemized summary of the design process is included.

1. Design Process

The process for developing a fish exclusion concept design and selecting a preferred concept includes the following tasks:

- ▶ Establish a multidiscipline design team
- ▶ Establish fish protection objectives and requirements
- ▶ Collect and identify design data and identify limitations
- ▶ Identify and develop alternative conceptual designs
- ▶ Select the preferred concept
- ▶ Develop a detailed design of the preferred concept

Each of these tasks is summarized in the following discussion. References are made to chapters of this document that supply detailed support of the process.

a. Establish a multidiscipline design team

To properly plan and design fish exclusion facilities at water diversions, some thought should be given to creating a multi-discipline team. The design team should include disciplines such as biology, architecture, planning, and engineering that will have input into the design. This approach will ensure:

- ▶ A comprehensive and thorough analysis and a design with no omissions
- ▶ That required issues are addressed in a sequence that will help avoid design delays and backtracking
- ▶ Strengthened interaction and coordination with resource agencies

A typical design team should include at the least:

- ▶ A structural engineer
- ▶ A mechanical engineer
- ▶ A hydraulic engineer
- ▶ A fisheries biologist (preferable from a fishery resource agency)
- ▶ A planning and assessment specialist

Other disciplines would be accessed and included as required. This could include a construction manager, specification preparation and cost estimating specialists, geotechnical and foundation engineers, an electrical engineer, and hydrology and sedimentation engineers.

b. Establish fish protection objectives and requirements

As discussed in chapter II under “The Need for Fish Protection” and in chapter III under “Identifying Characteristics of the Target Fish Species” and “Establishing Fish Protection Objectives,” fish protection objectives should be established through a process of reviewing the composition of the fish community and the potential impact on the fishery during the diversion operation. Seasonal changes in both the fish community and the diversion operation should be considered. Input from the responsible resource agencies as well as diversion owners and the public should also be solicited. The selected protection objectives will strongly influence fish exclusion concept selection and the design development process.

c. Collect and identify design data and identify limitations

A wide range of data should be gathered to support fish exclusion concept selection and design. Specific constraints and limitations that may eliminate concepts from consideration because of the site, future O&M, and cost considerations should be identified, including:

- ▶ Documentation of fishery composition
- ▶ Design criteria and design guidelines as established by the responsible State and Federal fisheries and resource agencies
- ▶ Maps and plans of the site layout showing natural water bodies, diversion structures (diversion dams and diversion head-works), canals and constructed waterways, and topography
- ▶ Drawings and photos of existing structures
- ▶ Data establishing the hydraulic characteristics of the site
- ▶ Estimates of quantities and types of debris and times of occurrence
- ▶ Estimates of sediment and ice loading and probable times of occurrence
- ▶ Documentation of water rights
- ▶ Review of site geology
- ▶ Documentation of land ownership and potential easement needs for construction access with identification of preferred locations for structure placement

- ▶ Identification of the irrigation season and operating constraints that would affect construction
- ▶ Identification of construction season constraints
- ▶ Identification of limitations on river access for construction
- ▶ Determination of the availability of electric power at the site
- ▶ Determination of the maintenance capabilities and desired limitations on maintenance
- ▶ Quantification of the capital cost considerations

Details on these individual design data elements will be presented in chapter IV.B. under “Screen Specific Design Details.”

d. Identify and develop alternative conceptual designs

The decision chart, figure 25, provides a method to document and support selection of alternative concepts that could be developed for a conceptual design. Criteria, guidelines, and procedures for design development are presented in this chapter, in chapters IV and V, and in attachment A.

e. Select preferred alternative

Select the preferred fish exclusion alternative based on the results of the conceptual design process.

f. Develop detailed design of preferred alternative

Detailed design development follows the selection of an alternative.

2. Decision Chart

Using a decision chart, as shown in figure 25, helps to introduce a number of parameters considered in the design process. The screening alternatives selected through use of such a decision chart can then be further developed to the concept design level. At the concept level, the design alternatives lead to evaluation of relative costs, determination of fish exclusion performance and associated construction and O&M issues. An alternative or alternatives to be further developed in the design process can then be selected.

	Siting	In - Canal	In - River	In - Diversion Pool	Closed Conduit	In-Secondary Dewatering or Evaluation Facilities	Exclusion Effectiveness (Fish Species and Size Dependence)	Diversion Discharge	Equipment Operation and Maintenance	Debris Handling & Cleaning	Sediment Influences	Ice Influences	Proven Technology	Acceptable by Resource and Regulatory Agencies	Capital Costs
Positive Barrier Screens															
Linear Flat Plate Screen	○	○	○	NA	●	○	QQQ	○	●	○	●	○	○	○	\$\$\$
Drum Screen	○	●	○	NA	●	○	QQQ	●	○	○	●	●	○	○	\$\$\$\$
Traveling Screen	○	○	○	NA	○	○	QQ	●	○	○	●	●	○	○	\$\$\$\$
Submerged Screen															
Cylindrical	○	○	○	NA	NA	○	Q	○	○	○	○	○	○	○	\$\$
Inclined	○	○	○	NA	○	○	QQ	○	○	○	○	○	○	○	\$\$\$
Horizontal	○	○	○	NA	○	○	Q	○	○	○	○	○	○	○	\$\$
Coanda Screen	○	○	○	NA	NA	○	QQ	○	○	○	○	○	○	○	\$\$\$
Closed Conduit Screen (Eicher and MIS)	●	●	○	○	NA	○	QQ	○	○	○	○	○	○	○	\$\$
Behavioral Devices															
Louvers	○	○	○	NA	NA	○	QQQ	○	○	○	○	○	○	○	\$\$
Sound	○	○	○	NA	NA	○	QQ	○	○	○	○	○	○	○	\$
Light (Strobes)	○	○	○	NA	NA	○	QQ	○	○	○	○	○	○	○	\$
Electric Fields	○	○	○	NA	NA	○	QQ	○	○	○	○	○	○	○	\$\$
Other (air bubble curtains, hanging chains, water jets)	●	●	○	NA	NA	○	QQ	○	○	○	○	○	○	○	\$

Rating	Costs	Diversion Discharge
○ Good	\$	Q < 200 cfs
○ Fair	\$\$	QQ < 1000 cfs
○ Poor	\$\$\$	QQQ < 10,000 cfs
NA Not applicable	\$\$\$\$	

Figure 25.—Decision chart.

Summaries of the ratings included in the chart are:

Siting – A rating of “good” indicates that the identified fish exclusion concept is fully applicable for the particular siting option and stated fish protection objectives and that documented applications of the concept in that siting mode are available. A rating of “fair” indicates that application of the concept in the particular siting mode is possible but that previous experience is limited. A rating of “poor” indicates that the concept is not applicable in the particular siting mode.

Exclusion effectiveness/performance – A rating of “good” indicates that full exclusion of fry and larger fish is achievable. A rating of “fair” indicates that exclusion of a portion of the entrained fish (that may depend on size and species) can be expected and/or that injury of certain sizes and species of fish is possible. A rating of “poor” indicates that the concept may be ineffective in excluding fish.

Diversion discharge – Although fish exclusion concepts might be applied to wide ranges of flow rate, the size of existing installations tends to indicate discharge ranges that the specific concepts are best suited for. Application discharges presented in the decision chart (figure 25) summarize sizes of existing installations. Application ranges are typically limited by structural, functional, hydraulic, and cost considerations.

O&M demands/debris handling and cleaning – A rating of “good” indicates that infrequent maintenance and repair would be required and that adverse influences on performance caused by debris is unlikely. A rating of “fair” indicates that periodic maintenance would be required and that debris fouling could substantially reduce concept performance. A rating of “poor” indicates that frequent maintenance and repair would be required, depending on site conditions, and that poor performance caused by debris loading is likely.

Sediment and ice – A rating of “good” indicates that the presence of sediment and ice will have minimal effect on performance and will not yield equipment damage. A rating of “fair” indicates that sediment and ice may reduce concept performance and may yield increased maintenance demands. A rating of “poor” indicates that sediment and ice can substantially reduce performance (which could require shutdown) and result in equipment damage.

Proven technology – A rating of “good” indicates that the concept has been widely applied and that effective performance for the stated fish protection objectives has been widely validated. A rating of “fair” indicates that limited application experience exists and that documentation of performance shows either mixed effectiveness (the concept has proven effective at some sites and ineffective at others) or that related adverse impacts on components of the fishery are possible (e.g., injury of certain sizes and species of fish is possible). A rating of “poor” indicates that either application experience is very limited or that documentation of performance shows substantial uncertainty.

Acceptance by fishery resource agencies – A rating of “good” indicates that resource agencies (Federal and State) currently accept the technology for the stated fish protection objectives. A rating of “fair” indicates that some resource agencies may accept the technology and some may not and that field validation of performance may be required. A rating of “poor” indicates that resource agencies will generally not support application of the concept.

Cost – This column is approximate and qualitative. It indicates capital cost of concepts relative to each other. Actual costs will be established through the design process. Costs are highly depend largely on the fish exclusion option, fish species and sizes, and site requirements (the characteristics of the specific application site greatly affect cost).

Application of the chart includes evaluation of all eight parameters:

- ▶ Identifying the siting possibilities that could work for the specific application (in-canal, in-river, etc.) and the size of the diversion.
- ▶ Identifying the acceptable fish exclusion requirements. The designer may want to solicit input from the responsible fishery resource agencies (complete exclusion, exclusion of most larger fish, partial exclusion, etc.)
- ▶ Identifying acceptable levels of O&M requirements
- ▶ Operational issues associated with debris, sediment, and ice
- ▶ Deciding whether application of unproven technology (uncertain effectiveness and possible requirements for field verification of performance) is acceptable
- ▶ Acceptance of fishery resource agencies
- ▶ Determining whether capital cost are acceptable
- ▶ Determining the applicable discharge range

Based on the above requirements, the chart can be referenced and concepts identified that comply with desired requirements. For example, louvers are a good option if:

- ▶ Diversion sites allow placement of the facility either in the canal or in the diversion pool
- ▶ Partial exclusion (exclusion of predominately the larger fish, for example) is acceptable
- ▶ Limited maintenance is desired
- ▶ Limited sediment and ice issues exist
- ▶ The desired assurance of intended performance is fair to high
- ▶ Capital costs are to be maintained at a moderate level or below
- ▶ The diversion discharge is large

On the other hand, linear flat plate screens, drum screens, traveling screens, and inclined screens are options if:

- ▶ Siting is limited to the canal
- ▶ All fish are to be excluded
- ▶ Increased maintenance is acceptable
- ▶ High endurance of performance is required
- ▶ Acceptance by fishery resource agencies is required
- ▶ Moderate to high capital costs are acceptable
- ▶ Diversion discharge range is medium or large

3. Design Data

The gathering of design data is an integral part of the design process and needs to be actively pursued early in the design process. As introduced in chapter III.A. under “Design Guidelines,” design support data needs to be gathered and design objectives and limitations established. Design data and limitations that need to be addressed include the following:

a. Fishery documentation

- (1) Determine the seasonally varied composition of the fish community at the diversion location
- (2) Identify threatened and endangered species
- (3) Identify upstream and downstream migration seasons of fish species
- (4) Determine biological requirements of the species; e.g., spawning, rearing, or foraging habitats that require protection

b. Project goals

- (1) Exclude fish at water diversions
- (2) Identify fish species, fish life-stages, and fish sizes to be protected
- (3) Determine the exclusion requirements for the fish species. This is often specified based on a minimum body length (e.g., fry or larger or fingerlings or larger). Determine if all fish of the required size or larger must be protected or if a percentage exclusion is acceptable.
- (4) Establish the times of year that fish exclusion will be required.

- (5) Determine if there are additional requirements for over-winter rearing in the canal, fish collection and evaluation facilities, or other requirement.

c. *Appropriate fish exclusion design criteria determination*

- (1) Determine if allowable exclusion devices include both positive barrier screens and behavioral devices.
- (2) NMFS (NOAA Fisheries) Northwest and Southwest Regions and some State fish and game departments (California and Washington) have established and published design criteria and guidelines for fish exclusion facilities (attachment A). The Service may also have specific criteria and guidelines. State and Federal resource agencies that have not established criteria of their own. They normally recognize and accept criteria and guidelines from the sources listed in attachment A. Design criteria should be established with the approval of the responsible Federal and State fishery resource agency. The available criteria tend to be focused on salmon, although some data and guidelines are available for other species.
 - (a) Positive barrier screens
 - (I) Determine which acceptable screen material options are acceptable: woven wire, profile bar, perforated plate, or possibly others.
 - (ii) Determine which types of screen structures are allowed by resource agencies and preferred by operators: flat plate, drum screen, etc.
 - (iii) Determine if trashracks are required to protect the fish screens:
 - ▶ Location
 - ▶ Bar spacing requirements
 - (iv) Determine potential screen structure locations.
 - (v) Determine the allowable approach velocity and required sweeping velocity.
 - (vi) Establish screen opening requirements.

(vii) Determine O&M requirements:

- ▶ Maximum allowable head loss across fish screens
- ▶ Allowable decrease, if any, in canal capacity – decrease could be caused by head loss created by new facilities and fish bypass flow requirements
- ▶ Types of cleaning equipment
- ▶ Cleaning cycle time requirements

(b) Behavioral Devices:

- (I) Determine which if any devices are acceptable: louvers, sound, etc. and the criteria for each of them.

d. *Determination of the appropriate bypass criteria (if required):*

- (1) Determine the requirements for bypass entrance, conduit, and outlet structure.
- (2) Determine suitable types of bypass: submerged, ramped, perched.
- (3) Determine the appropriate bypass entrance:
 - ▶ Minimum width and height
 - ▶ Minimum flow/velocity
 - ▶ Flow control and isolation requirements
 - ▶ Requirement for a velocity barrier, such as a weir, to prevent fish from returning upstream
 - ▶ Are trashracks required at entrance (clear opening requirements)
- (4) Determination of Appropriate Bypass Conduit:
 - ▶ Bypass pipe or open channel bypass
 - ▶ Minimum open channel width and depth
 - ▶ Pipe type options
 - ▶ Minimum bypass pipe diameter
 - ▶ Minimum and maximum allowable bypass pipe velocities
 - ▶ Required bends in bypass pipe

- ▶ Required pool volume for drops (energy dissipation factor or other criteria covered in chapter IV.A.11. under “Fish Bypass System”).

(5) Evaluation of potential bypass outlet locations:

- ▶ Ensure relatively high river flow velocities in receiving water
- ▶ No eddies near outfall
- ▶ Outfall in an area not subject to significant sediment deposits or scour.
- ▶ Outfall location limits avian and aquatic predation
- ▶ Ensure sufficient channel depth

e. *Data on existing facilities:*

(1) State the purpose of the diversion facility:

- ▶ Junior or senior water right holder
- ▶ Supplemental canal flow sources or return use

(2) State the survey requirements:

- ▶ Topography that assists evaluation of required excavation gradients and flow depths.
- ▶ River and diversion pool bathymetric surveys included for underwater zones where construction and/or site dewatering may be required.
- ▶ River thalweg located.

(3) Ensure that the site map includes the following:

- ▶ Land ownership and land acquisition requirements
- ▶ Accessibility for construction and O&M forces

(4) Ensure that a location map showing township, range, section, river mile, proximity to towns and roads, power and utilities, and access to the site is provided.

(5) If several diversions are close to each other, determine if it is possible or practical to consolidate them.

- (6) Evaluate existing structures and document the flow conditions through those structures. A site visit to verify existing conditions and obtain a better understanding of site design issues is essential.
- (7) Ensure that drawings of existing facilities are available.
- (8) Determine if existing facilities such as headworks require modification.
- (9) Ensure that photographs of existing site features and existing aerial photographs from other sources, such as the highway department or the Internet, are available.
- (10) Determine river water surface elevations, at the diversion, for a range of flows from minimum to maximum. This is especially important for in-river and in-diversion-pool fish screen facilities.
- (11) Determine if additional land or construction easements will be required.

f. Documentation of diversion facility hydraulics:

- (1) Determine design flow for fish screens. Design flow is often based on one of the following:
 - ▶ The design flow of the canal or pumping plant
 - ▶ The historic high flow of the canal or pumping plant
 - ▶ A diversion flow that is exceeded only a set percentage of the time (normally 90 percent flow, which is exceeded 10 percent of the time), based on a flow exceedence curve
 - ▶ An assessment of future flow requirements
- (2) Establish the diversion season and the times of year the fish exclusion facility will be in operation.
- (3) Determine the water elevation at the fish screens for a range of diversion flows. The water elevation and flow range are required to determine the length of fish screens and ensure availability of bypass flow capacity. If the water elevation is significantly lower for lower flows, determine if a downstream control structure is required. The control structure would maintain a constant water surface elevation for all flows and may allow a shorter length fish screen structure.

- (4) The bypass flow is returned to the natural water body (with fish). To support the bypass operation, flow rates in excess of the appropriated water right may have to be diverted. Address and resolve the availability of water.
- (5) Develop secondary screening concepts as needed to minimize the fish bypass flow, which is returned to the natural water body.

g. Documentation of river hydraulics:

- (1) Locate the nearest river gages.
- (2) Determine flood frequencies for a range of flood events from as small as the 2-year flood to as large as the 100-year flood. Flood flows for the low flood flow events will affect the cofferdam designs and flood flow estimates for the high events will affect the facility design.
- (3) Develop a flow exceedence curve. This may be necessary to determine river flow range requirements for suitable operation of the fish screen facilities.
- (4) Determine the minimum river flow when diversion can still occur.
- (5) Calculate and field verify upstream and downstream water surface elevations for the range of river flows. This will be required for designing structures located on the river and to verify bypass hydraulics. This often requires river cross sections for input into a computer program for flow analysis and stream gage readings or site surveys of water surface elevations.

h. Estimates of debris types, quantities, and times of occurrence:

- (1) Document the timing of debris loading. Make special cleaning facilities and equipment available if heavy debris loads are expected. Fouling and ineffective cleaning can result in the shutdown of fish exclusion facilities and possibly even the diversion. Effective cleaning and debris handling is influenced both by debris type and quantity. Debris loading might be limited to short duration high flow events that are associated with storm events or spring runoff. If water demand (and potential fish entrainment) at the times of these events is small, operational options might include removal of the fish exclusion equipment or limiting diversions during these high flow high debris-loading periods.

- (2) Determine how debris is currently handled and how it will be handled.

I. Evaluation of sediment and ice potential at screen location and at headworks:

- (1) Evaluate the amount and size distribution of sediment which may occur in the flow.
- (2) Determine how sediment is handled on existing facilities and how it will be handled on new facilities.
- (3) Determine if facilities will be subject to ice loadings. If facilities will be subject to ice loadings, determine how this concern will be addressed: remove screens during periods when ice occurs, construct a bypass around the fish screen facilities for this time period, maintain operational integrity by heating and/or enclosing the structure.
- (4) Address sediment and ice problems either through development of specific designs that effectively handle the problem or through shutdown or removal of the fish exclusion facility during high loading periods. Both sediment and ice can pose major operational problems that can lead to expensive maintenance demands or require operational restrictions to maintain effective fish exclusion.

j. Determination of electric power and communications requirements:

- (1) Determine if electric power is economically available. What is the available voltage and amperage? Is a new switchyard or transformer required? Who is the power company? Where is the closest power source? Reliability of power?
- (2) Determine if paddle wheel or solar power options are feasible for small facilities.
- (3) Determine whether a backup generator is required for screen cleaning operation and other facility needs in case of a power failure.
- (4) Determine the type of communications facilities that are required between the screen site and district O&M office.

k. Determination of site security requirements:

- (1) Protect against vandalism (fencing, gates, security cameras, etc.).
- (2) Determine the lighting requirements

l. Evaluation of geology of the site:

- (1) Consider the geologic characteristics of the site to identify foundation and excavation issues. Geologic information may be available from studies conducted in support of the initial diversion design development.
- (2) Determine the dewatering requirements.
- (3) Provide additional drill holes and pump out tests, as required.

m. Identification of cultural and historical properties in the area:

- (1) Identify, evaluate, and define potential mitigation measures for historical properties. In many States, the State Historic Preservation Office can provide assistance.

n. Determination of the steps necessary to prepare for construction:

- (1) Obtain the permits required for construction
 - (a) U.S. Army Corps of Engineers 404 permit for dredging or filling in a waterway
 - (b) Federal, State, and local permits (the list in chapter II.A.2. may be useful)
- (2) The construction season may be limited by diversion operations, extreme river flow events, and consideration of impacts on the fishery. Often, construction in a canal is limited to the non-diversion period unless a canal bypass is constructed. Constructing facilities in a river may be limited to low river flow periods to minimize cofferdam construction costs. The presence of listed and endangered species in the water body, upstream and downstream migration periods and rearing activities, and possible influences of construction activity in the water body on fish habitat (disturbed sediment and sedimentation, etc.) can limit dates when construction activities will be allowed.
- (3) Determine availability of material for embankments, backfill, riprap, sheetpile, etc.
- (4) Locate waste areas.
- (5) Determine cofferdaming requirements: acceptable materials, methods of placement and removal, etc.

- (6) Identify river access for construction.
- (7) Determine if the project will need to be revegetated.
- (8) Determine if a contractor staging area is available
- (9) Determine if power and water are available for the contractor's use.

o. Post construction evaluation and testing:

- (1) Determine the requirements and the procedure for evaluating the uniformity of approach velocity along the screen surface.
- (2) Determine if the following fishery items will be required:
 - (a) Netting
 - (b) Tagging
 - (c) Counting
- (3) Determine if evaluation and/or collection features be required as part of the main construction (e.g., juvenile evaluation or collection facilities).

p. Operation and maintenance:

- (1) Determine who accepts responsibility for O&M of the new facility.
- (2) Determine if screens have to be removed for maintenance or operation and, if they do, what the requirements and methods of removal are.
- (3) Determine the automation requirements: screen and trashrack cleaning, adjusting weirs and gates, etc.
- (4) Determine water surface measurement and flow measurement requirements.
- (5) Establish the maintenance capabilities and limitations of the district, such as equipment availability and manpower.
- (6) Determine if gantry cranes, monorail hoists, or jib cranes are required or whether the district's mobile cranes or rental cranes are adequate.

4. Design Criteria and Elements

The appropriate fish exclusion design criteria for application at a specific site depends on the State and Federal fishery resource agencies that have jurisdiction for the site, the specific characteristics of the fishery, and the fish species that the facility is designed to protect. Appropriate fisheries resource agencies should be contacted early in the planning process to determine their fish exclusion concerns and to obtain any fish protection criteria. The criteria and design considerations that are generally applicable to the various screen concepts are reviewed below. For example, NOAA Fisheries developed the screen criteria for juvenile salmonids in the Pacific Northwest region based on protecting the weakest swimming fish. It is summarized in table 4 and presented more fully in attachment A.

a. Criteria

Established design criteria that address many of the features and performance requirements for positive barrier screens are typically based on generalized research or generalizations from site investigations. Attachment A presents NMFS (NOAA Fisheries) Northwest and Southwest Regions and the States of Washington and California fish screen criteria for juvenile salmonids. These criteria represent the type of criteria from Federal and State fish resource agencies available at the time of this publication. Established criteria are broadly applied to sites with varying fisheries, fish sizes, fish condition, water quality, and site characteristics. They are typically conservative and oriented toward protecting the fish community under the poorest conditions. Fishery resource agencies may accept alternative criteria, but typically require thorough justification and often may require either laboratory or on-site validation.

b. Supplemental site investigations

Resource agencies are responsible for protecting the fishery resource. Their acceptance of a fish exclusion structure design indicates that they feel that the structure will function properly and will adequately meet the established fish protection objectives of the site. Resource agencies are in a position to determine if available design data (chapter III.C.3) are incomplete. If incomplete data compromise the development of an effective fish exclusion structure, the agencies can require further investigations. For example, the agencies may request better documentation of the fish species and abundance, debris types and quantities, sediment loading, site hydraulic conditions, potential for icing, or any of numerous other studies.

c. Required formats for agency submittals

Fishery resource agencies often require design and site documentation data for their review. Typically, this will require documentation of the fish exclusion design objectives and design data, design criteria applied, pertinent hydraulic information (ranges of water surface elevations and flow rates), and design details

for structure surfaces that will directly influence fish guidance. Specific fishery resource agency review submittal requirements should be established through agency contacts early in the design development process. The Planning Checklist in chapter II.B.2. presents a typical checklist for predesign of fish screens, and figures 1 and 2 are helpful in gaining a better understanding of the regulatory process.

d. Design criteria elements

Attachment A provides positive barrier screen design criteria elements from three fishery resource agencies: NMFS (NOAA Fisheries) Northwest and Southwest Regions; Department of Fisheries, State of Washington; and Department of Fish and Game, State of California. These criteria elements are discussed in more detail in chapter IV. Positive Barrier Screens. The criteria address the following design elements that should be carefully considered when designing a positive barrier fish screen:

- (1) **Structure placement guidelines** – These are siting considerations that generate good hydraulics and minimize adverse effects on the fishery (chapter IV.A.1-3).
- (2) **Flow conditions required at and around the screen** – Established criteria are specific on what flow conditions are required for flow approaching, sweeping and passing through the screens with the objective of efficiently guiding fish past the screen while minimizing fish injury (chapter IV.A.4–8).
- (3) **Screen material characteristics** – The size of fish to be excluded, should be considered when selecting screen durability and corrosion, debris type, debris loading, water quality, and screen material and fabric. Agency criteria stipulates acceptable opening sizes in the screen as a function of fabric type, fish species (salmonids), and fish size (chapter IV.A.10)
- (4) **Screen structure features** – Fishery resource agencies have developed specific criteria for design of features including trashracks, sediment sluices, use of training walls, pier shapes, positioning and use of support members, and screen configuration that are intended to expedite fish passage (chapter IV.A.9–16 and IV.B).
- (5) **Bypass design** – The bypass system is a critical feature of the screen design. It guides the fish that have been excluded by the screen back to the natural water body. By its nature, the bypass system transports high concentrations of fish. Therefore, it must pass fish efficiently,

generating little or no injury. Specific criteria have been established for the design of the bypass entrance, the conduit, and the bypass outfall (chapter IV.A.11).

- (6) **Operation and maintenance requirements** – Fishery resource agencies will require maintenance, cleaning and debris handling, and inspection criteria that will be addressed in the design. The cleaning system and operations plan should be effective and reliable. Proven cleaning technologies are preferred. Some agencies have established maximum allowable head loss permitted across the screen that will automatically force cleaning of the screen and may also have a required cleaning cycle time. Open channel intakes may include a trashrack to protect the screen facility and equipment. Fishery resource agencies often require a follow up inspection and evaluation after construction of a screen and bypass facility. The purposes of the inspection and evaluation are to verify that hydraulic design objectives are achieved and that operational criteria are being followed and to ensure biological effectiveness (chapter IV.A.12 and 14).