

RECLAMATION

Managing Water in the West

Water Resources Technical Publication

Fish Protection at Water Diversions

A Guide for Planning and Designing Fish Exclusion Facilities



**U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado**

April 2006

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Water Resources Technical Publication

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Support for this manual was provided by:

Denver Office Manuals Program
Reclamation's Science and Technology Program
Tracy Fish Facility Improvement Program



**U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado**

April 2006

This manual is dedicated to the memory of Perry Johnson, who passed away December 23, 2005, after a short illness.

Acronyms/Abbreviations

BA	Biological Assessment
BLM	Bureau of Land Management
Corps	U.S. Army Corps of Engineers
DO	dissolved oxygen
EA	Environmental Assessment
EDF	Energy Dissipation Factor
ESA	Endangered Species Act
EIS	Environmental Impact Statement
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
FONSI	Finding of No Significant Impact
FS	U.S. Forest Service
FWCA	Fish and Wildlife Coordination Act
GCID	Glenn-Colusa Irrigation District
HDPE	High Density Polyethylene
Interior	U.S. Department of the Interior
ITA	Indian Trust Assets
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NMFS	National Marine Fisheries Service
NOAA Fisheries	National Ocean and Atmospheric Administration Department of Fisheries
NPPC	Northwest Power Planning Council
NPCC	Northwest Power and Conservation Council
O&M	operation and maintenance

P.L.	Public Law
PVC	Polyvinyl Chloride
Secretary	Secretary of the Interior
Service	U.S. Fish and Wildlife Service
Reclamation	Bureau of Reclamation
USCS	U.S. Code of Standards
UHMW	ultra high molecular weight

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Chapter I. Preface

The purpose of this manual is to provide design guidance for fish protection at small dams and water diversion structures by providing fish exclusion alternatives. This manual is addressed to the water user community involved in assessing, recommending, and designing appropriate fish exclusion facilities at water diversion structures. This manual focuses on Bureau of Reclamation's (Reclamation) fish exclusion experience for water resources projects, presenting design methods and operation standards developed and used in recent years. Fish protection, exclusion and bypass at water diversions and other facilities will be the major theme covered in this first volume. A second volume is envisioned covering fish passages using fish ladders, including upstream and downstream passage for adult and juvenile fish passage structures; improvements in reservoir and river operation for control of temperature and dissolved gases; and habitat enhancement.

Although water resource planners, fishery biologists, and engineers have been aware of the need for fish protection, there has been inconsistent application of criteria and technology, or more importantly, a lack of consensus among fishery resource agencies and the water resource development community as to the scientific basis of past and present criteria. Recently, there have been advancements in the understanding of fish behavior and exclusion methods across a greater number of species and locations in the Western United States. These recent advancements are the result of cooperative efforts among engineers and fishery biologists in various Government agencies, consulting firms and universities to bring consensus to the planning and design of fish exclusion facilities. Reclamation has documented its laboratory and field experience over time, with internal reports and professional papers and various site-specific fish exclusion concepts. However, the need for an application-based manual incorporating these latest advancements in the planning and design of fish exclusion facilities at water diversions has become increasingly evident.

This manual includes recent advancements in fish exclusion concepts, knowledge, and applications to both warm and cold water fish species. The manual will present information on the following topics or subjects:

- Responsible Fish Resource Management

- Regulatory Responsibilities

- Various Fish Exclusion Alternatives

- Design Criteria and Guidelines (biological, behavioral, and hydraulic considerations)

- Design Details for Positive Barrier Screens and Behavioral Barriers

Case Studies

Post Construction and Performance Evaluation

Exclusion Barriers for Upstream Migrating Fish

The body of this manual integrates a comprehensive documentation of past and present Reclamation fisheries engineering projects with a summary of reference material. The manual emphasizes the synergy of biological and engineering disciplines. Specific topics covered under fish exclusion are screens, upstream and downstream barriers, and secondary methods of exclusion enhancement such as behavioral avoidance methods.

Although this manual is focused almost exclusively on the planning and design of fish exclusion facilities, it is important that those involved in the design of such facilities be familiar with the requirements of the Endangered Species Act, Federal and State fish screen criteria, and the full range of existing technologies. There should also be an appreciation for the complexities of competing demands on the limited water resource.

This manual was prepared by engineers and fishery biologists of the U.S. Department of the Interior, Bureau of Reclamation. The Denver Technical Service Center and regional, area, and project office staff have provided invaluable assistance in the writing of this manual. The Science and Technology Program of Reclamation has played a significant role in funding research associated with the development of fish exclusion at water diversions. In addition, many others participated in the preparation of the text. Special recognition is given to the five member team who coordinated, wrote, and edited this first edition:

Philip Burgi, P.E. Consultant, Retired Manager, Hydraulics Laboratory

Rick Christensen, Mechanical Engineer

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Tony Rozales, Pete Mazza, and Victor Aguirre drew or modified many of the illustrations. Numerous engineers, technicians, and support personnel participated with this team in the preparation of this first edition, and their efforts are greatly appreciated. The following individuals provided invaluable assistance in the review and editing of the draft manual: Eugene Humbles, Denny Hudson, Stephen Grabowski, Charles Liston, John Dyson, and Bob Norman.

The Bureau of Reclamation expresses grateful appreciation to those organizations that have permitted the use of material from their publications, especially National Ocean and Atmospheric Administration, Department of Fisheries (formerly the National Marine Fisheries Service), U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, California Department of Fish and Game, Washington Department of Fish and Wildlife, Electric Power Research Institute, and BC Hydro.

There are occasional references to proprietary materials or products in this publication. These references must not be construed in any way as an endorsement because Reclamation cannot endorse proprietary products, processes of manufacturers, or the services of commercial firms for advertising, publicity, sales, or other purposes.

The users of this manual should verify the criteria published herein with the latest fish resource agencies draft criteria before advancing into the predesign and final design phases of a fish exclusion project.

Chapter II. Fish Protection

“In all things of nature there is something of the marvelous.”

Aristotle (384 BC – 322 BC)

A. The Need for Fish Protection

“We do not inherit the land from our ancestors, we borrow it from our children.”

Native American Proverb

As the Western United States was settled, aquatic habitats were altered, particularly as a result of water diversions. Recent declines of native western fish species have resulted in numerous listings of species as threatened or endangered under Federal and/or State laws (Minckley and Deacon, 1992). The general decline in fish and wildlife species can be traced to the pressures that an expanding population put on the environment, including fish and wildlife habitat. These recent species declines are an indication of environmental degradation that can potentially affect human health and well being. Solutions to stopping the declines lie in applying the best scientific knowledge to maintain species in a viable ecosystem. There are many issues that place societal development in direct conflict with conservation of sustainable natural habitat. This has certainly been true in the case of water resource development and our natural environment. However, the relationship between water resource development and conservation of the natural environment does not have to be an “either-or situation.” The two interests, development and management on the one hand and conservation on the other, can work effectively together. If these interests are to work together to maintain a viable ecosystem and maximize fish protection efforts, the public must receive reliable scientific information to ensure an adequate understanding of the issues. Public values have shifted from an emphasis on water resource development to management of Western waters, the Bureau of Reclamation’s (Reclamation) contemporary hydraulic research program has also changed. The program now centers on infrastructure protection (safety of dams), water conservation, and fish protection (Burgi, 1998). The intent of this manual is to facilitate responsible resource development and management by providing guidelines and viable fish exclusion alternatives at water diversion structures.

1. Responsible Resource Management

“All the waters of all the arid lands will eventually be taken from their natural channels. And there is not sufficient water to supply the land.”

Major John Wesley Powell

Water resource projects developed by the Reclamation over the past century have significantly contributed to sustained economic growth and enhanced quality of life in the Western United States. Effective resource management balances competing interests and needs and requires managing lands, water, and other resources in the most responsible way possible. The challenge lies in striking a balance.

Many dams in the Western United States are more than 75 years old and were constructed for irrigation, power generation, recreation, and flood control as part of the development of the Western United States. “Human habitation in the West as we know it would not be possible without this kind of active control and use of its surface water resource. Though vilified by many for the environmental damage they have caused, dams provide important, essential functions now relied upon to some degree by virtually every person who lives in the West” (MacDonnell, 1999). During early development, there was little information available about the life history requirements of resident and migratory fish species, and little consideration was given to their needs, especially in-stream migratory behavior. In many cases, dam construction has impeded fish movement and contributed to declining fish populations by limiting access to suitable spawning, rearing, and foraging habitat. Although significant attention has been given to understanding anadromous fish behavior and passage needs, very little attention has been given to other native fish. During the past 100 years, some 21 species and subspecies among 6 fish families have become extinct from the 17 Western States; some 64 species and subspecies are now Federally listed as threatened or endangered (Minckley and Deacon, 1992). Most of these species declines are related to alteration of habitat and the detrimental effects of non-native fishes. Recovery of threatened and endangered fish species requires reestablishing access to natural spawning, rearing, and forage areas.

Quartarone’s (1993) interesting historical perspective gives insight to people’s attitudes toward endangered species in the Upper Basin of the Colorado River in the early years of the 20th century. “The increase in opportunities for fishing for catfish and trout in the upper basin figured greatly into people’s opinions of the native species. When faced with the option of catching the endangered fish or trout and catfish, people chose the latter two. The endangered fish fell into

disfavor and seemed to become a scapegoat for criticism. My idea is they're just a trash fish; you can't eat them, and they're not much fun to catch. If you put trout or something in there that you could eat, and people could use them... why I think it'd be a benefit to have. Some people got different ideas." George Anderson (Quartarone, 1993).

It has been only in recent years that the scientific community has started to study the behavioral and physiological characteristics of native fish species. Efforts are underway through "recovery programs" to restore native fish species in western rivers such as the Colorado River. Studies include:

- ▶ The impacts of stocked fish versus a naturally reproducing population
- ▶ The amount and timing of in-stream flows needed to provide a sustainable fishery
- ▶ The need for shallow wetlands in the stream corridor to provide fish spawning during high flows
- ▶ Providing rearing areas for young fish
- ▶ Conservation plans by western irrigators to provide additional in-stream flows
- ▶ The control of non-native fish that either compete for habitat or consume native fish

Fish protection is an important aspect of fishery management at water diversions. Fish protection is often defined as fish exclusion from water diversions. Protection includes not only limiting entrainment of fish at diversions, but also protecting fish from injury or mortality resulting from operation of the diversion. The death and injury of fish at water diversions have long been identified as major sources of fish mortality (Spencer, 1928; Hallock, 1977). Fish entrained into agricultural or municipal and industrial diversions can experience nearly 100 percent mortality. Fish entrained into power intakes incur high mortality, and also experience injuries and disorientation that can lead to increased predation losses. A recent study on a seasonal irrigation canal associated with the Shoshone River in northwestern Wyoming provided insight into the potential for fish entrainment into these irrigation diversion systems. A total of 5,732 fish of 11 species were collected from a combined 5 miles of three canals by electro fishing, block netting, and draining techniques (Karp et al., 1993).

The numbers of fish entrained by a diversion are in part a function of diverted flow rates (higher flow rates will likely entrain more fish) and the concentrations of fish in the water body that the flow is diverted from. If the flow is diverted

from a biologically productive water body that both supplies habitat for adult fish and also supplies habitat for spawning and juvenile fish rearing, the potential exists to entrain large numbers of fish. For example, studies conducted by the California Department of Fish and Game (1987) indicate that Reclamation's Tracy Pumping Plant entrains millions of fish each year (Helfrich, Liston, and Weigman, 1996).

Most of these fish are less than 6 inches long, and of the fish that are less than 6 inches long, most are less than 1 inch long. The Tracy Pumping Plant pumps from the Sacramento – San Joaquin Delta, which is a highly productive water body composed of numerous intertwined channels. Pumping rates at the Tracy Pumping Plant are also high, averaging over 4,000 cubic ft per second.

Fish exclusion approaches include numerous technologies. Positive barrier screens have long been considered the best technique to prevent entrainment of fish into a diversion. These structures, although highly effective, can be expensive to install and the need to clean the screens, remove trash, deal with sediments, and provide regular maintenance adds to the costs.

Since the early 1960s, behavioral methods have been studied as an alternative to positive barrier screens. Behavioral methods offer fish exclusion options that reduce capital costs and operation and maintenance (O&M) requirements. For example, louvers were first used in 1957 by Reclamation at the Tracy Pumping Plant Central Valley Project, California. The hydraulic turbulence associated with louvers affects the behavior of fish and directs them away from water diversions and to a fish bypass. Other behavioral methods include startle-response techniques such as lights (strobes), sound, and electrical fields. There is skepticism over the use of such behavioral devices. Where behavioral devices have been installed and used at diversions, evaluations have shown fish exclusion efficiencies that are considerably less than 100 percent. (Vogel, 1990; Electric Power Research Institute, 1986; Karp, Hess, and Liston, 1993).

Fish protection and recovery programs that are defined or set up to actually allow water development to proceed to meet the needs of society while protecting or recovering the endangered fish are not without controversy or problems. However, many water resource managers see the recovery programs as the best way to avoid conflict between laws enacted by the Congress to protect and preserve listed species and the use of the water resource to meet societal needs and to enhance the quality of people's lives. The alternative of endless litigation is not in the public interest.

Following is a list of typical questions often asked by owners of diversions who have serious concerns about their ability to continue diverting water and pay for the improvements but wish to cooperate in restoring fishery resources that have been listed:

- ▶ Is the Biological Opinion a law, rule, or just an opinion?
- ▶ How much power does a Biological Opinion have over the delivery of diverted water?
- ▶ Does installation of a fish screen structure specified in a Biological Opinion put the owners of the diversion in jeopardy or risk of being fined or imprisoned for incidental take?
- ▶ If a fish screen fails to perform as designed, will the regulatory agencies remove the structure or require additions or modifications?
- ▶ Will State, local, or Federal Government lay claim to the water right and/or portion of land that the proposed fish screen structure occupies?
- ▶ If the fish screen is installed and later abandoned, who owns the structure?
- ▶ What are the benefits of installing a fish screen on or near our diversion structure?
- ▶ What are the liabilities or risks of installing a fish screen on or near a diversion structure?
- ▶ Who will maintain, update, and operate the fish screen as proposed?
- ▶ If funding for the endangered species program ends, how will the proposed fish screens be operated? Or if removal is required, will funding be available for removal?
- ▶ Who will own the fish screen and related structures?
- ▶ What type of operational guarantees will come with the proposed screen and its related structures?
- ▶ Will there be some kind of a damage clause in the contract to cover the diversion shareholders in the event of crop damage?

These are typical issues that owners of water diversions and regulatory agency staff will need to address before proceeding to design and construction.

2. Fish Protection Legislation

“Rarely has a law with such humble beginnings had such a far-reaching effect on the American people as the Endangered Species Act”

*William D. Ruckelshaus
First Administrator, EPA*

Fishery resources associated with water development are protected by State and Federal laws. Wildlife protection law can be traced to various decisions and proclamations from the Roman Empire through feudal European history to the beginning of the United States as a sovereign nation. In England before the signing of the Magna Carta in 1215, wildlife was the property of the king, who granted hunting and fishing rights to the nobility. Later, Parliament assumed the right to control the harvest of wildlife. In the United States, Federal statutes and regulations, executive orders, treaties, and other international agreements govern the action of Federal agencies, while State laws, administrative orders, and court decisions provide the authorization for action at the State level (Shogren, 1998).

Moss (1967) points out:

Since early times, Americans have shown concern for the protection of fish and the water they inhabit. Before 1750, local laws had been enacted: Middlesex County, Virginia, prohibited the use of ‘jack lights’ for night fishing; New York City permitted the taking of fish from fresh-water ponds with “angle rod, hook and line only.” In 1871 Congress appointed the Commissioner of Fish and Fisheries; 1903 the Bureau of Fisheries was designated and in 1956 the Fish and Wildlife Act created the U.S. Fish and Wildlife Service (Service) in the U.S. Department of the Interior (Interior) made up of two Bureaus: Commercial Fisheries (became National Marine Fisheries Service [NMFS]) and Sport Fisheries and Wildlife.

More than a century and a quarter has passed since this nation began formal attempts to conserve and sustain its valuable fishery resources. In that time impressive studies in fishery science, habitat management, and the enactment of protective laws have combined to provide managers the tools to conserve recreational fisheries.

Shogren (1998) summarizes the history of Endangered Species Regulations in the United States:

- 1926**– Passage of the Black Bass Act – Passed and later amended to regulate importation and transportation of black bass and other fish.
- 1934**– Passage of the Fish and Wildlife Coordination Act (FWCA) – Specifically emphasized the impact of water development projects on wildlife.
- 1956**– Passage of the Fish and Wildlife Act – Created the Service.
- 1966**– Passage of the Endangered Species Preservation Act – Directed the Service to prepare and maintain an official list of endangered native animals. It also authorized funds for management and research for listed species.
- 1969**– Passage of the National Environmental Policy Act (NEPA) – Established the policy that Federal decision making should include evaluating the effects of Federal actions on the quality of the human environment.
- 1973**– Passage of the Endangered Species Act (ESA) – Conserved ecosystems upon which endangered and threatened species depend, provided a program for the conservation of such endangered and threatened species, and took appropriate steps to achieve the purposes of the treaties and conventions set forth in the ESA. Recognized “threatened” species and provided protection for species before they were placed in imminent danger of extinction. Encouraged public participation in the listing process. Allowed people to request a public hearing in addition to the normal public comment period. Also allowed any person to bring action in the U.S. District Court for alleged violation of the ESA.

The goal of the ESA process is to restore listed species to a point where they are secure, self-sustaining components of their ecosystem so as to allow “delisting.” As a result, ecosystems upon which endangered and threatened species depend may be conserved. The ESA provides a program for conservation and management of such species and their habitat (Shogren, 1998).

Since fishery protection is so closely associated with the quantity and quality of water, water law becomes an important issue in protection of the fishery resource. Water law does not operate by providing for the ownership of water in the way that real property law allows for ownership of land. Rather, water law generally grants rights to the use of the water. More recently, laws have been instituted pertaining to minimum flow requirements of rivers to maintain viable fish populations. These requirements have, at times, come into direct conflict with water rights as defined by riparian or prior appropriation rights. Riparian rights

come from the English common law and are law in the 31 Eastern States where the use of water is a property right. The essence of the system is that only the owner of a parcel of land touching a watercourse has riparian rights (Laitos,1992). Prior appropriation started in the 1880s as a result of the miners and settlers in the Western States seeking water rights not necessarily associated with the property. In prior appropriation States, the water right resides with the first person to divert water (appropriate) from a stream or creek, and that person is granted a vested right to that amount of water: “First in time, first in right.” Appropriated waters may be used anywhere, regardless of the distance from the watercourse. The quantity of the water right is the amount that historically was put to a beneficial use. The Western States are essentially divided into two “doctrines.” The California Doctrine includes nine States (North and South Dakota, Nebraska, Kansas, Oklahoma, Texas, Oregon, Washington, and California) and allows for both riparian and prior appropriation rights. The Colorado Doctrine uses prior appropriation only and includes Colorado, Utah, Wyoming, Idaho, Montana, New Mexico, Nevada, and Arizona. These early laws were based on “beneficial use” of the water which was often defined as resulting in economic benefit (Dzurik 1990). In Western States where water has often been over used or over appropriated, it is often difficult to find the needed water to provide fish protection because there is no excess natural flow. In some cases, storage reservoirs in the Western States have provided the answer to supplying fishery water needs.

There are numerous State and Federal agencies that have authority over fishery resources. The following list includes some of the agencies involved with fish management or that, because of their actions, are involved in fishery resource issues:

- ▶ Environmental Protection Agency
- ▶ NMFS (National Ocean and Atmospheric Administration, Department of Fisheries [NOAA-Fisheries])
- ▶ Fish and Wildlife Service (Service)
- ▶ U.S. Army Corps of Engineers (Corps)
- ▶ U.S. Forest Service (FS)
- ▶ Bonneville Power Administration
- ▶ Northwest Power and Conservation Council
- ▶ Federal Energy Regulatory Commission
- ▶ Bureau of Indian Affairs
- ▶ Solicitor’s Office of the Department of the Interior
- ▶ Bureau of Reclamation (Reclamation)
- ▶ Bureau of Land Management (BLM)
- ▶ Indian Nations

- ▶ State water resource agencies
- ▶ State fish and game agencies

Following is a listing of Federal legislation affecting fishery resources (Service, 1992):

Federal Power Act of 1920 – Where there is the possibility for power development at a diversion site, Section 18 of the Act 16, United States Code of Standards [USCS] §811, states in part:

“The commission shall require the construction, maintenance and operation by a licensee of....such fishways as may be prescribed by the Secretary of Commerce or the Secretary of the Interior.”

Currently, the Service will issue a Decision Document called a Prescription for a Fishway pursuant to Section 18 of the Federal Power Act. The document is typically developed with input from fisheries biologists and fishway engineers from the Service and other appropriate agencies. The document will present the record on the decline of the specific fish species, discuss the management goals for the fish species for which improved fish passage is targeted, and provide details about where the fishway is to be located, its size, the quantity of water needed to effectively operate the fishway, and other pertinent items related to the design and operation of the fishway.

“Federal Energy Regulatory Commission (FERC) Section 18 of the Federal Power Act gives the Federal resource agencies authority to prescribe mandatory fish passage conditions to be included in FERC license orders.”

Although FERC has sole authority under the Federal Power Act of 1920 to approve power projects, the Act did not provide FERC sole authority to determine all the conditions associated with that approval. The original Federal Power Act provides for cooperation between FERC and other Federal agencies, including fishery resource agencies, in licensing and relicensing power projects. In deciding whether to issue a license, FERC is required to give “equal consideration” to the following purposes: power and development; energy conservation; protection of, mitigation of damage to, and enhancement of, fish and wildlife (including spawning grounds and habitat); protection of recreational opportunities; and preservation of other aspects of environmental quality. The time frame for a license can not exceed 50 years.

FERC is required to mandate the construction, maintenance, and operation of fish passage facilities as prescribed by the Secretary of Commerce or the Secretary of the Interior (Secretary). The 1986 amendments to the Federal Power Act, entitled the Electric Consumers Protection Act, mandated several fish and wildlife

provisions. Each license is to include conditions to protect, mitigate, and enhance fish and wildlife affected by the project. The conditions are to be based on recommendations received pursuant to the FWCA from the Service, the NMFS (NOAA Fisheries), and State fish and wildlife agencies (Service, 1992).

Fish and Wildlife Coordination Act (FWCA) of 1934 and amendments of 1946 – Require consultation with the U.S. Service and the fish and wildlife agencies of States where the “waters of any stream or other body of water are proposed or authorized, permitted or licensed to be impounded, diverted. . . or otherwise controlled or modified” by any agency under a Federal permit or license. A formal FWCA compliance memorandum or report to the Federal agency should be included as an appendix in the final NEPA document.

National Historic Preservation Act (NHPA) – Section 106 of the NHPA requires Federal agencies and other entities spending Federal funds to take into account the effect of their undertaking on historical properties. Federal agencies are required to take the lead in complying with Section 106 even if funding is provided to other entities. There are several steps that make up the Section 106 compliance effort. These steps must be followed in the event an archeological or historical property is found within an area of potential effect. These steps include:

1. **Inventory** – Site-specific inventories are required for each project or action.
2. **Evaluation** – The lead Federal agency evaluates each property for possible inclusion in the *National Register of Historic Places* in consultation with the State Historic Preservation Officer.
3. **Determination of Effort** – Avoidance of impacts is the best alternative to preserve the qualities that make the property eligible for inclusion in the National Register. If direct or indirect impacts are expected, then mitigation measures must be developed in cooperation with the State.
4. **Mitigation** – Mitigation measures will be developed if a project will adversely effect eligible historic properties.

If an initial inventory fails to reveal the presence of a cultural resource, a properly documented project may proceed.

Mitchell Act of 1938 – Specifically directs establishing salmon hatcheries in the Columbia River Basin, conducting engineering and biological surveys and experiments, and installing fish protection devices. Federal activities in the basin

are carried out by the Department of Commerce. (Federal Land Policy and Management Act of 1976 [BLM])

Fish and Wildlife Act of 1956 – Confirmed the position of Commissioner of the Service under Interior. It also established a comprehensive national fish, shellfish, and wildlife resources policy with emphasis on the commercial fishing industry. It also directed that the act be administered with regard to the inherent right of every citizen and resident to fish for pleasure, enjoyment, and betterment and to maintain and increase public opportunities for recreational use of fish and wildlife resources. Two bureaus were established: Commercial Fisheries (in 1971 renamed NMFS of the Commerce Department) and Sport Fisheries and Wildlife.

NEPA of 1969 – Requires that all Federal agencies prepare detailed environmental impact statements (EIS) for “every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment.” The act created the Council on Environmental Quality in the Executive Office of the President. All Federal agencies have a responsibility to protect Indian Trust Assets (ITAs). The NEPA compliance process addresses ITAs. The affected environmental consequences chapters of the NEPA document must have a separate section that shows that the ITAs have been considered.

Federal Water Pollution Control Act of 1972 – Clean Water Act/Rivers and Harbors Act – Fish protection and passage projects in the United States may involve the dredging or filling of waters or occur in navigable waters that require a section **404 permit** under the Clean Water Act or a section 10 permit under the Rivers and Harbors Act or both.

ESA of 1973 as amended – Provides for the conservation of ecosystems upon which threatened and endangered species of fish, wildlife, and plants depend, both through Federal action and by encouraging the establishment of State programs.

The ESA:

- ▶ Authorizes the determination and listing of species as endangered or threatened
- ▶ Prohibits unauthorized taking, possessing, selling, and transporting of listed species
- ▶ Authorizes establishing cooperative agreements and grants-in-aid to States that establish and maintain active and adequate programs for endangered and threatened wildlife and plants

- ▶ Authorizes assessing civil and criminal penalties for violating the ESA or regulations
- ▶ Authorizes paying rewards to anyone furnishing information leading to the arrest and conviction for any violator of the ESA or any regulation issued thereunder

Pacific Northwest Electric Power Planning and Conservation Act

(Public Law [P.L.] 96-501) of 1980 – Authorizes establishing and operating the Pacific Northwest Electric Power and Conservation Planning Council, also referred to as the Northwest Power and Conservation Council (NPCC). There are two individuals appointed to the Council from each of the States representing the Columbia River drainage: Idaho, Montana, Oregon, and Washington. Among other things, the Council is responsible for preparing a regional conservation and electric power plan as well as a fish and wildlife protection, mitigation, and enhancement program to deal with the operation of hydroelectric facilities on the Columbia River and its tributaries. A 1984 amendment authorizes the Secretary to design, construct, operate, and maintain fish passage facilities within the Yakima River Basin in accordance with this statute. In 1991, the NPCC amended program included measures that are to be undertaken to help improve the survival of salmon. Amendment 1.1 (f) asks Reclamation, along with the FS and BLM, to require, as a condition of authorization, diversion structures to have functional fish screens and other passage facilities that meet current NMFS (NOAA Fisheries) criteria for salmon and steelhead.

National Energy Policy Act of 1992 – Section 1701(b) P.L. 102-486, Title XVII, §1701(b), 106 Stat. 3008, states:

The items which may constitute a “fishway” under Section 18 [16 USCS §811] for the safe and timely upstream and downstream passage of fish shall be limited to physical structures, facilities, or devices necessary to maintain all life stages of such fish, and project operations and measures related to such structures, facilities or devices that are necessary to ensure the effectiveness of such structures, facilities, or devices for such fish.

National Invasive Species Act of 1996 – P.L. 104–332 – Reauthorizes and amends the Non-indigenous Aquatic Nuisance prevention Control Act of 1990 (P.L. 101–646). Authorizes the Secretary of Transportation to develop national guidelines to prevent the introduction and spread of non-indigenous species into the United States waters via ballast water of commercial vessels.

A variety of specific and omnibus authorizing statutes provide for fish and wildlife conservation at Reclamation and Corps water resource projects.

In some cases, work is needed to address fish protection and passage issues; however, there may not be legislation to help drive the needed improvements. Such is the case with much of the Restoration program on the Colorado River. In this case, funds are provided for the construction, long-term O&M, and water is reserved in upstream reservoirs for minimum flow needs.

B. Development Process

“The best laid schemes of mice and men
Gang aft a-gley;
And leaves us naught but grief and pain
For promised joy”

Robert Burns

The development process relative to fish protection issues consists of identifying the fishery resource in need of protection and the specific needs for protection, developing alternative plans that address those needs, and selecting from the alternatives one that best satisfies the identified protection needs. Solutions to fish protection problems come from alternatives developed by working with stakeholders and State and Federal fisheries and regulatory agencies that have diverging issues and concerns. The development of alternatives is an iterative process involving the best available science and public input where the most acceptable plan is identified after comparing and selecting from alternatives. The effort should involve an interdisciplinary team representing a wide range of expertise and interests including some or all of the following: the owner/user of the existing facility or site where protection is needed as well as the disciplines of:

- ▶ fishery resource and regulatory agencies
- ▶ economics
- ▶ design
- ▶ research
- ▶ biology
- ▶ recreation
- ▶ hydrology
- ▶ hydraulics
- ▶ engineering
- ▶ sociology

The following sequence of steps can serve as a guide in developing fish protection facilities :

- ▶ Identify the need for fish protection
- ▶ Follow environmental and regulatory processes and develop documentation
- ▶ Develop various alternative designs that will provide the needed protection based on fish species behavior, physiology, consideration of the river and diversion flow requirements, constructability, and O&M issues
- ▶ Evaluate alternative designs for both cost effectiveness and benefits to the fish species of concern
- ▶ Select final design
- ▶ Construct the facility
- ▶ Monitor and evaluate the facility's effectiveness

1. Regulatory Responsibilities

"A policy is a temporary creed liable to be changed, but while it holds good it has got to be pursued with apostolic zeal."

Mahatma Gandhi 1869–1948

Legislation and public concern have fostered a multi-objective approach to all water projects and more serious consideration of the potential environmental consequences of development. This applies as well to projects conceived in an effort to fix previous negative impacts to the natural environment. Environmental aspects must be considered from the initial planning and design of a project through its construction and operation. The NEPA of 1969 adds a component of environmental awareness to all Federal agency decision making. NEPA is the key environmental statute that must be considered within natural resources law. Many, if not all, water resource projects require compliance with NEPA and other pertinent Federal regulations. NEPA is triggered if there is a proposal for "major Federal action" [42 U.S.C. 4332(2)(C)]. This results in three questions centered on the words: "major," "Federal," and "environmental." Certainly, any Federal construction activity that will have a significant environmental impact will likely be considered a "**major**" Federal action. Federal action within the

authority of NEPA includes not only action by the agency itself, but could also include action permitted or approved by a federal agency. In general NEPA does not apply to private projects. There must be a “**Federal**” link. Regarding “**environmental**,” there must be a significant environmental impact for NEPA to apply (Laitos, 1992).

The NEPA process requires various documents to help ensure a thorough, well thought out process. Figure 1 summarizes the NEPA documents and process:

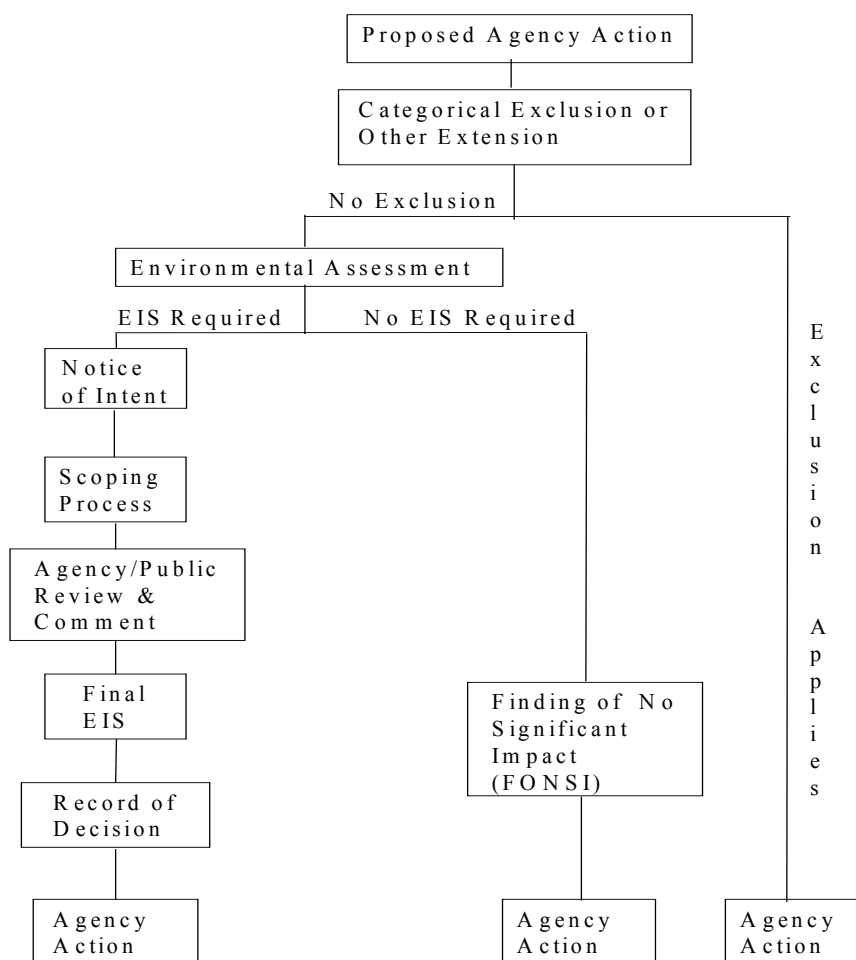


Figure 1.—NEPA documents and process (Laitos, 1992).

A determination of a categorical exclusion is the first step in the process – it is necessary to determine whether or not the action is significant enough to warrant an Environmental Assessment (EA). An EA should include an Introduction, Proposed Action and Alternatives, Affected Environment and Environmental Consequences, Consultations and Coordination, and Cited References. If a categorical exclusion applies, the agency action can proceed to project construction without an EA. If there is no categorical exclusion, the agency must complete an EA. The EA is shorter and less detailed and involved than an EIS, usually no more than 20 pages. The EA process helps determine if an action will have a significant environmental impact. If, based on the EA, all major issues are addressed and it is determined that the proposed action does not significantly affect the environment, a finding of no significant impact (FONSI) can be prepared and agency construction action can proceed.

If an EA indicates that there will be an impact, an EIS is required, which helps decision makers weigh those impacts for a balanced decision. Notices of intent, the scoping processes, and periods for review and comment help to involve the public. Knowledge of environmental integrity and concern for a sustainable environment will enable the project to proceed with responsible decision making. This process will often influence others in the community regarding the principles of sustainable resource management and development.

Scoping is an important component of the process that allows an agency to identify the problem areas relative to a project. It provides the base map, and public involvement puts the roads on it. Public involvement and participation in the decision process is vital. It centers around effective communication among partners, agencies, organizations, the various stakeholders, and the interested public. Public involvement and participation should not be confused with public relations, public information, or public education (Reclamation, 1996)

2. Planning Checklist

“It is our task in our time and in our generation to hand down undiminished to those who come after us, as was handed down to us by those who went before, the natural wealth and beauty which is ours.”

John F. Kennedy 1917–1963

Public involvement initiatives should begin during the draft EA phase. A well written EA will often meet the compliance requirements of the NEPA of 1969 and the ESA of 1973. Often, this provides the opportunity to inform the public about

the project and address some of the local issues before they become serious road blocks in the process. It also provides the opportunity to inform the public about legal requirements of the action agencies under the ESA. Copies of the draft EA should be sent out soliciting comments, and public meetings with interested parties should be held. The following are typical concerns and comments raised in a public involvement meeting with a fish protection proposal:

- ▶ It's a waste of taxpayer's money
- ▶ Water rights and supplies should be protected
- ▶ O&M issues need to be addressed
- ▶ Non-native fish management needs to be addressed
- ▶ "Incidental take" of a listed species needs to be addressed more clearly

These issues can usually be successfully resolved during the public involvement phase of the draft EA process eliminating the need for an EIS. If FONSI is the determination, the agency may proceed toward construction. It is important to note that each fish exclusion project will generate its own list of public concerns.

In the planning phase for fish exclusion facilities, there are many issues that need to be identified and addressed in a professional and timely fashion. The ability to adequately address all these issues is paramount to a successful fish exclusion project. These issues include not only environmental considerations but cultural resource issues; water rights (adjudication); right-of-way, permitting by Federal, State and local governmental entities; funding; issues of ownership, operation, and maintenance; and construction considerations. The following checklist can be very helpful in the predesign phase for a fish exclusion facility. The list is given in a chronological order that is typical for a predesign, as currently used in the Pacific Northwest Region of Reclamation.

Checklist for Predesign of Fish Screens

1. Fish Protection required

What are the fish species of concern?

What are the biological requirements of the species; e.g., spawning, rearing, or foraging habitats that require protection?

2. Type of Screen

To exclude fish from the diversion or to allow the diversion and then screen and provide bypass back to the river?

3. **Socio-economic and Political Concerns**

Acceptability of the fish facility concept to the technical work group team?

4. **Biological Concerns**

If used, will the bypass pipe cause false attraction to fish?

What is the migration season of the fish species of concern?

Is telemetry needed to determine fish movement; is other monitoring of fish movement required; what equipment is required?

5. **Site Features**

Do headworks exist; if so, is modification necessary?

Location of river thalweg; e.g., is it suitable for a bypass pipe?

Site geometry for screen layout?

Space constraints for the selection of screen type?

Adaptability of site to a standard screen or other various style screens?

6. **Operational Aspects**

What is the duration of the irrigation season?

Is there floating debris in the canal or the river?

Will cleaning of the screens be a problem?

7. **Non-structural Changes**

What are possibilities of consolidating several diversions into one?

8. **Structural Changes**

What type of bypass is appropriate for the site; e.g., submerged, ramped, perched?

Are screens required to operate at optimum submergence for all flows?

Possibility of retrofit for existing screens?

Expandability of screen design or application should canal flow increase?

9. **Survey Needs**

Complexity, accuracy, and availability of survey information?

10. **Geology**

Existence of rock in foundations and general geology of area?

11. **Cultural Considerations**
 - Cultural resources constraints at site?

12. **Ambient Conditions**
 - Adverse climatic condition at site; e.g., icing, extreme weather changes?

13. **Hydrology of Canal and River**
 - Quantity and velocity of canal flow?
 - River velocities?
 - Availability of hydrological data on river and canal?

14. **Hydraulics of Concepts Considered**
 - Available bypass flow, closed pipe or open channel, and ability to incorporate a bypass pipe into the design?
 - Type of tailwater control for fish screen?

15. **Constructability**
 - Difficulty in diverting stream and maintaining stream integrity during construction?
 - Difficulty in dewatering construction site?
 - Difficulty in constructing screens?

16. **Right-of-Way Needs**
 - Existing rights of way or easements and ability to obtain additional rights of way?
 - Temporary construction easement?

17. **O&M Concerns**
 - General O&M?
 - How will screens be removed for maintenance; e.g., gantry, jib crane, boom truck, etc?
 - Power availability (paddle wheel or solar drive feasible)?
 - Ability and experience of O&M personnel to maintain proposed screen?
 - O&M access?
 - Will cleaning of screens be problematic?
 - Frequency of O&M?

18. **Cost of Screen Design**

Both capital and O&M costs?
Cost effectiveness?

19. **Scheduling and Permits**

Construction window to complete all work?
Difficulty in obtaining State, Federal, and local permits?

Consideration of Adverse Effects During Fish Exclusion Project Construction

Although fish screen projects built and operated to meet fishery resource agency design criteria have a long-term beneficial effect on fish species, adverse effects to listed fish species may occur during in-river construction activities from water quality degradation, habitat destruction, physical injury, or entrapment. If fish screens are not 100 percent effective in preventing entrainment and impingement of juvenile fish, adverse effects may occur during the long-term operation of the screen.

Figure 2 shows a typical *informal* consultation process recommended by the Service, Sacramento, California.

If a proposed Federal action has any adverse effects on listed species or habitat, formal consultation is required. Formal consultation will be needed to authorize *incidental take* of the listed species during the construction and operation phases of such a project.

Regarding *environmental considerations* at fish exclusion structures, construction activities normally have only minor, short-term, and localized negative environmental effects. Most construction for fish exclusion at small diversions is conducted during the non-irrigation season and in dewatered canals. The effects of the construction will normally be limited to primarily six environmental parameters: air quality, water quality, noise, vegetation, wetland resources, and fish and wildlife. Often, a FONSI is the result of the EA process. Regarding *permits and clearances*, construction will typically involve placement or excavation of materials within a stream or river. This will require permits, clearances, or approval from various Federal, State, and local agencies. These permits and clearances may include:

Section 404 permit from the Corps
Water quality certifications from involved States
County Shoreline Management Act exemption

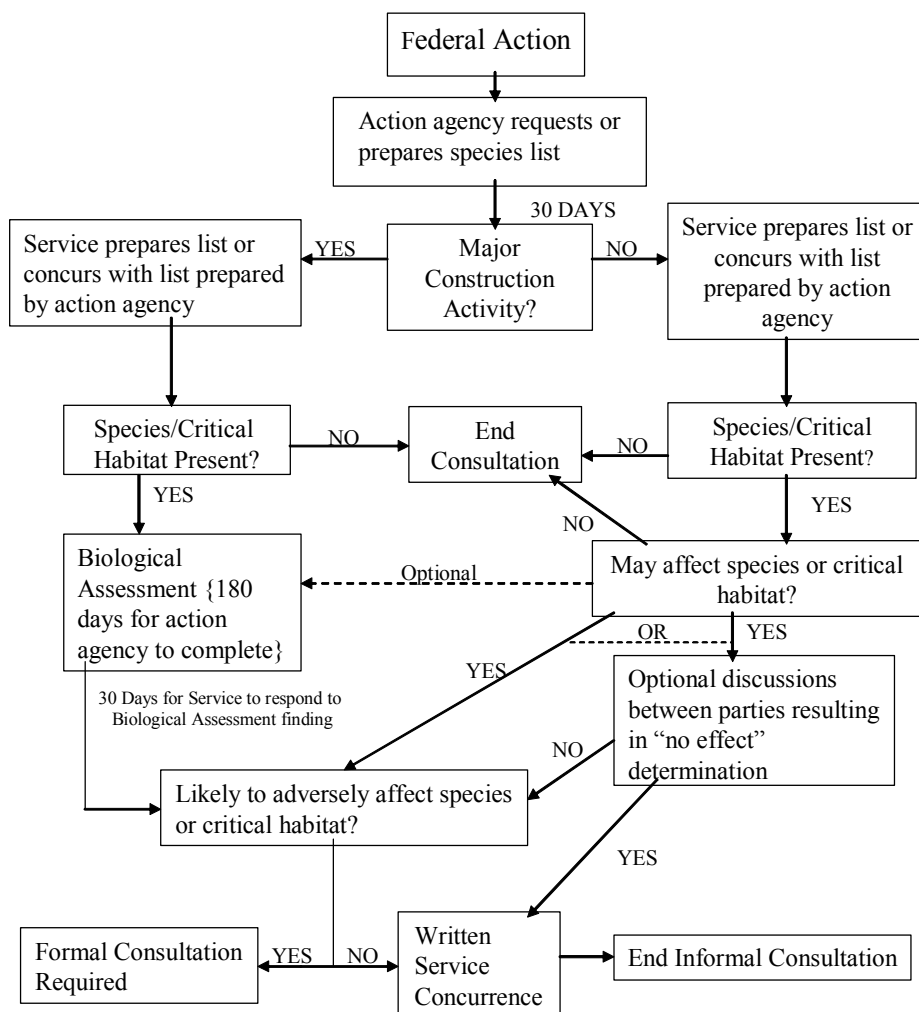


Figure 2.—Informal consultation process (Service, 2000).

- Hydraulic project approvals from involved States
- Water standards and modifications from involved States
- Right-of-way and construction access approval from facility owners and private landowners
- Railroad crossing agreements where appropriate

Regarding *O&M*, responsibility for *O&M* costs will have to be determined before fishery exclusion facilities can be designed and constructed.

Operation costs include:

- ▶ adjustment of flow distribution on screens and bypass operation
- ▶ evaluation of facility during initial years of operation

Maintenance costs include:

- ▶ routine maintenance of trashracks, screens, and gates
- ▶ periodic cleaning, repair, and painting
- ▶ removal of debris and silt accumulation at screens
- ▶ removal of sediments from screen forebay areas

Replacement costs include:

- ▶ replacement of screen mesh, seals, gates, motor and drive mechanisms, cleaning equipment, and structural metalwork

Power costs include:

- ▶ power to operate trashrack and screen cleaning
- ▶ power to operate screen mechanisms
- ▶ backup power needs

A realistic estimate of annual operation, maintenance, replacement, and power costs needs to be determined, followed by an agreement, signed before construction proceeds, defining the responsibilities of the affected entities.

From a fish and wildlife perspective (Service, 2000), as soon as a proposed fish exclusion project is identified, a species list should be requested from the Service. An agency can also develop its own species list and confer with the Service or NMFS (NOAA Fisheries) as appropriate. This starts an informal consultation process. The Service and the NMFS (NOAA Fisheries) for anadromous species, will provide a list of threatened and endangered species that may occur in the project area or may be potentially affected by the proposed project. The list could take up to 30 days to prepare and, eventually, should be included in the appendix of any EA. Although an EA and a biological assessment (BA) have different content, an EA that adequately addresses impacts to listed and proposed species may serve as the BA pursuant to the ESA.

The BA should make one of the following determinations regarding effects:

No effect – the appropriate conclusion when the Federal lead agency determines its proposed action will not affect a listed species or critical habitat.

Is not likely to adversely affect – the appropriate conclusion when effects on the species or critical habitat are expected to be beneficial, discountable, or insignificant. Beneficial effects have current positive effects without any adverse effects to the species or habitat. Insignificant effects relate to the size of the impact and should never reach the scale where *take* of the fish species occurs. (“...to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt to engage in any such conduct”). Discountable effects are those extremely unlikely to occur. Based on best judgement, a person would not: (1) be able to meaningfully measure, detect, or evaluate insignificant effects; or (2) expect discountable effects to occur.

Is likely to adversely affect – the appropriate conclusion if any adverse effect to listed species or critical habitat may occur as a direct or indirect result of the proposed action or its interrelated or interdependent action. In the event the overall effect of the proposed action is beneficial to the listed species or the critical habitat, but also is likely to cause some adverse effects, the proposed action “*is likely to adversely affect*” the listed species or critical habitat. An “*is likely to adversely affect*” determination requires formal consultation pursuant to Section 7 of the ESA.

When the BA indicates no effect or not likely to adversely affect, the Service provides a letter of concurrence, which completes informal consultation.” (Service, 2000)

The time period required to comply with the ESA, NEPA, FWCA, and Clean Water Act will depend on the complexity of the project, level of environmental impacts, document preparation, review and revision, and agency workloads. Figure 3 is an example of the typical time periods that may be required to meet compliance criterion.

If the biological opinion from the Service or NMFS (NOAA Fisheries) is a “jeopardy opinion” (project adversely affects a listed species), it contains a *reasonable* and *prudent* alternative that consists of few to many action items that the action agency is required to address. If the biological opinion shows a project is “likely to adversely affect” (short of jeopardy opinion), it contains *reasonable* and *prudent* measures that include terms and conditions that have a different suite of action items. They may both contain conservation recommendations. Biological opinions are issued to the Federal Government for Federal actions that may have potentially negative impact on a listed species.

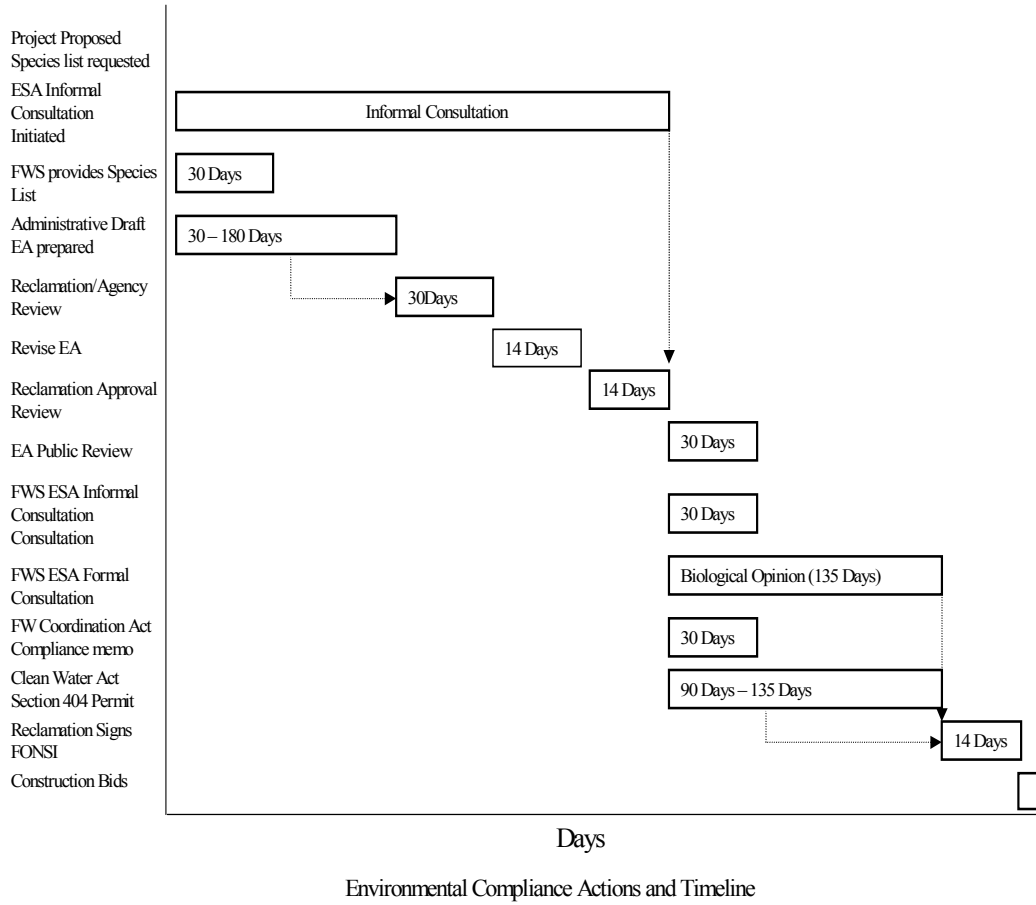


Figure 3.—Typical environmental compliance actions and timetable (Service, 2000).

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.

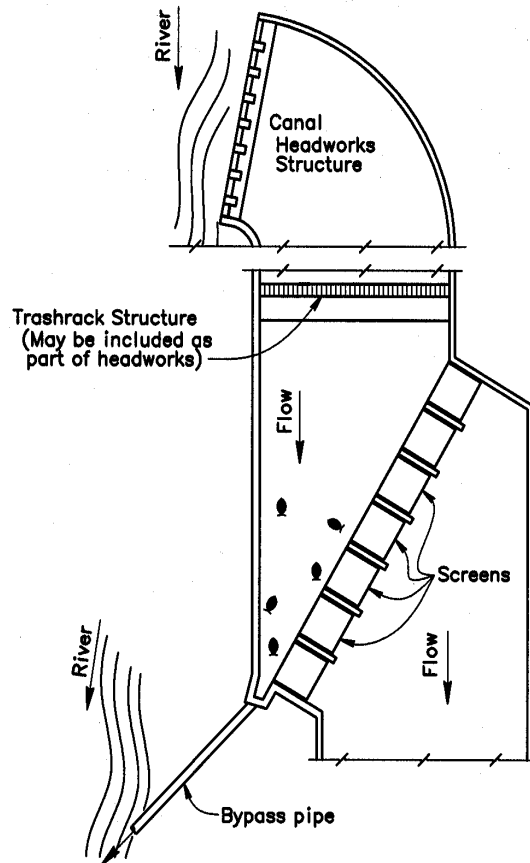


Figure 4.—In-canal fish exclusion structure.

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.

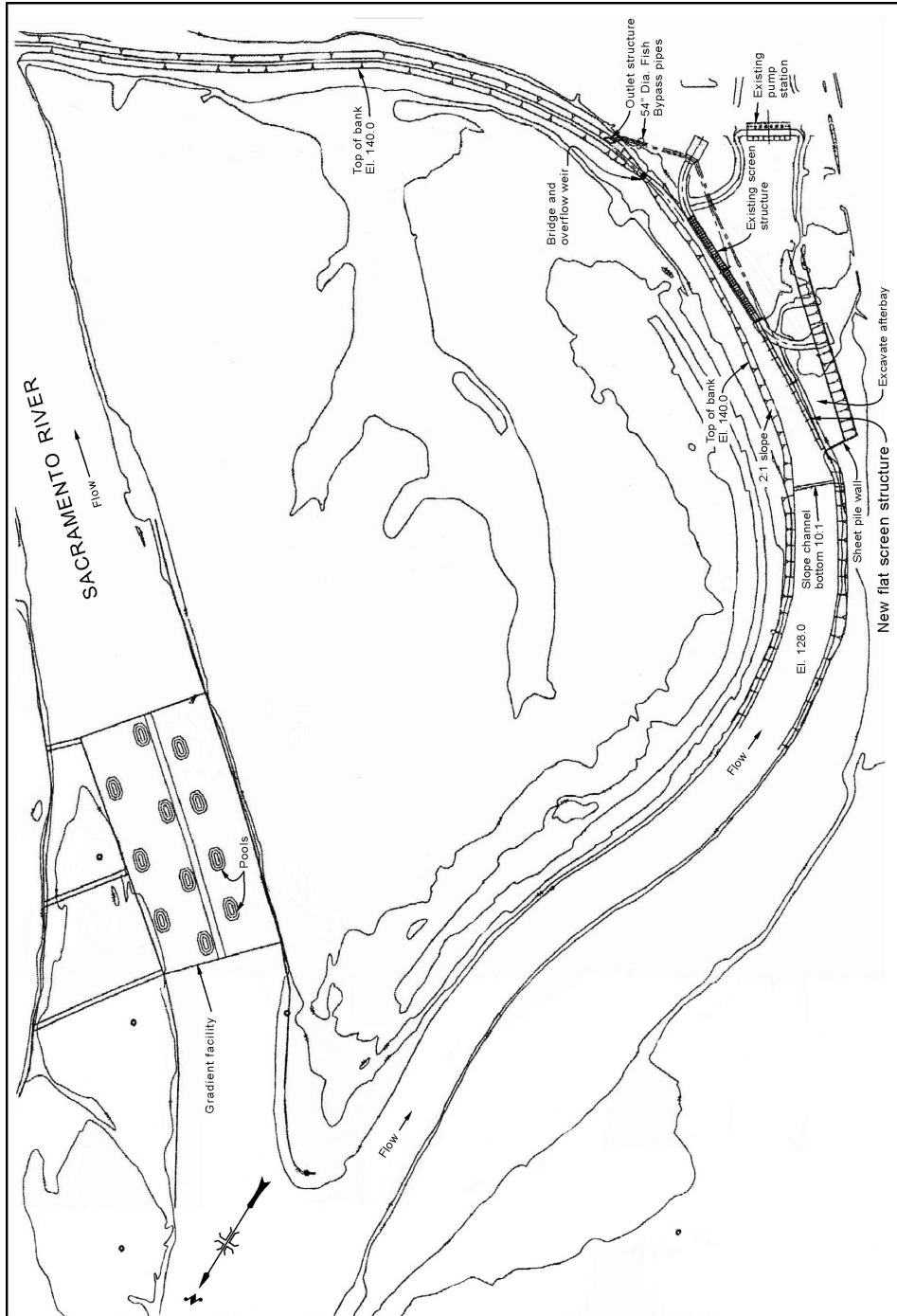


Figure 5.—In-river fish exclusion structure – Glenn Colusa Irrigation District (GCID) on the Sacramento River, California.



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).

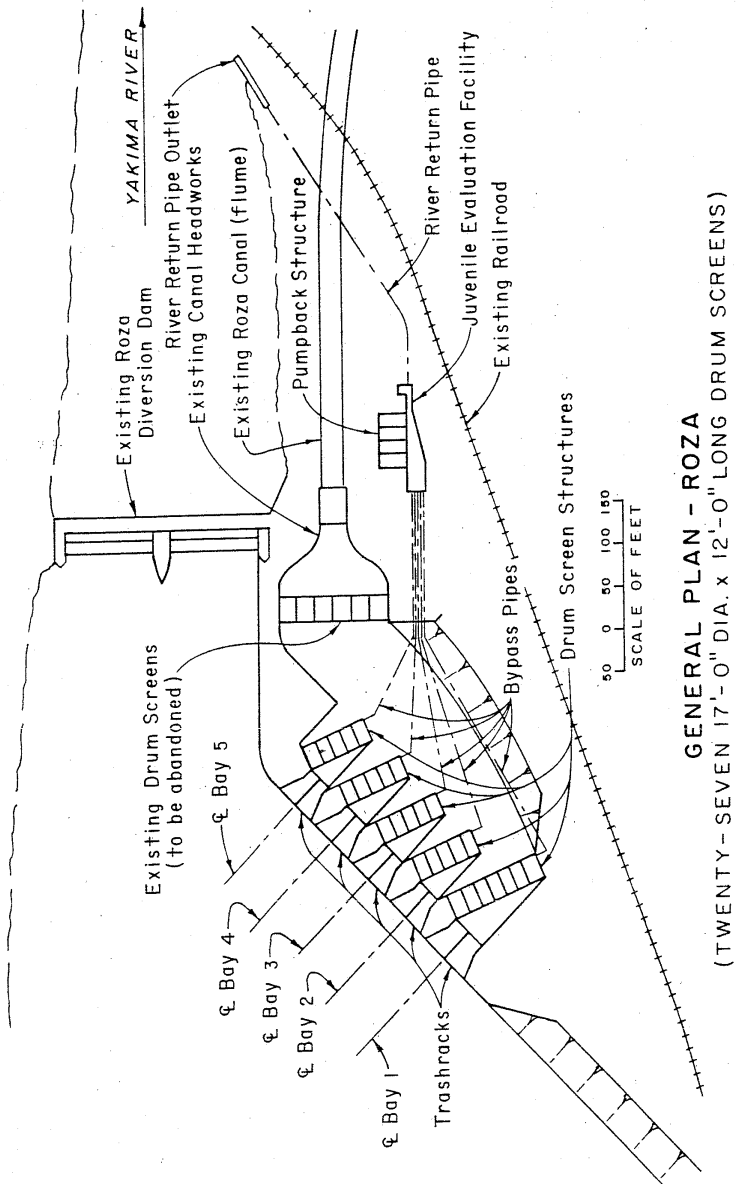


Figure 7.—In-diversion pool fish exclusion structure – Roza Diversion Dam, Washington.

- ▶ 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.

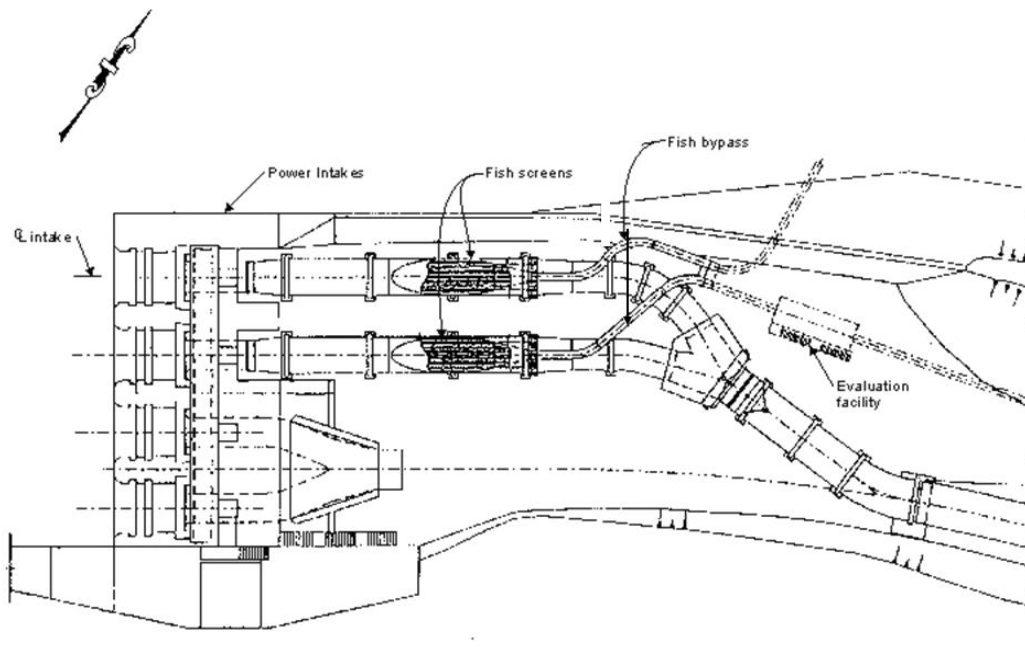


Figure 8.—Plan view of Puntledge screens, British Columbia (Rainey, 1985).

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.

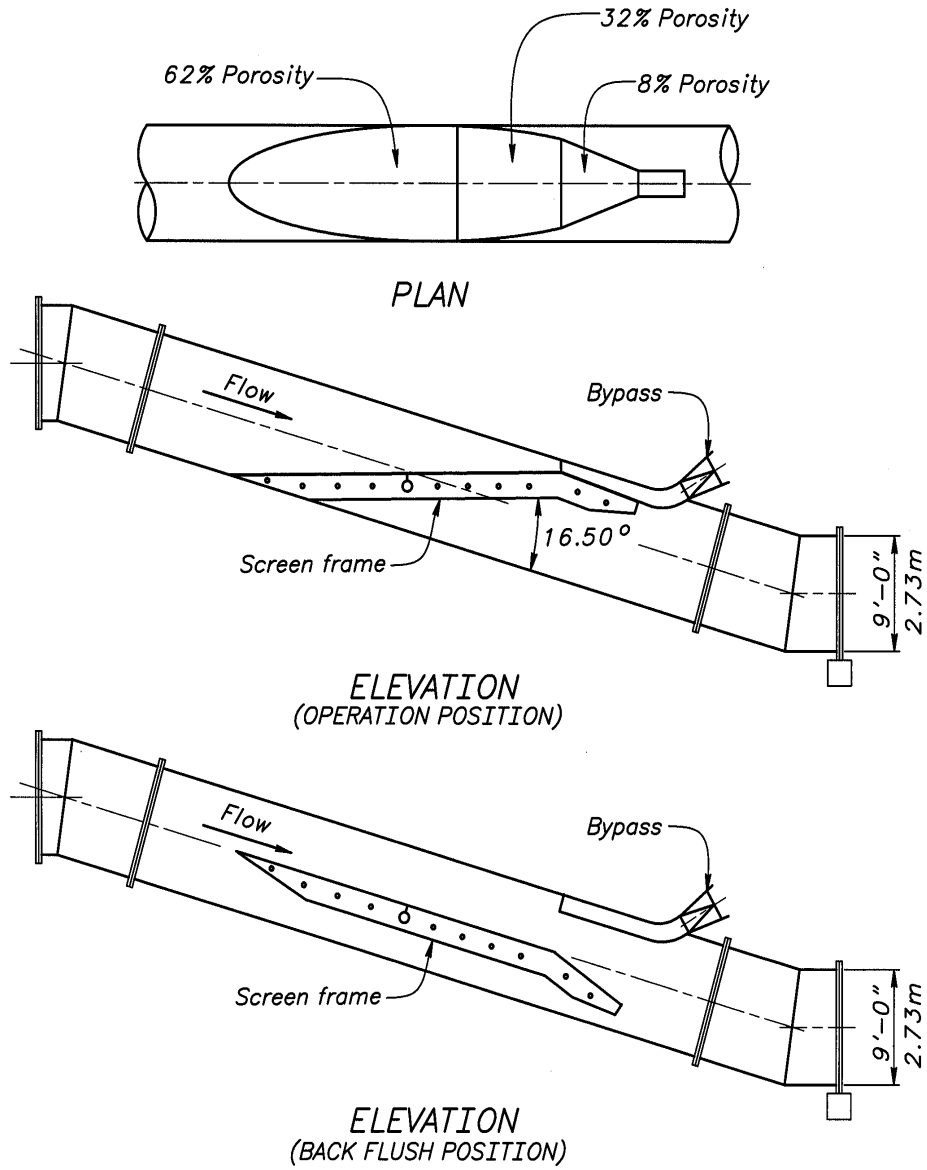


Figure 9.—Fish exclusion structure in a closed conduit (Electric Power Research Institute – EPRI, 1994).

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.

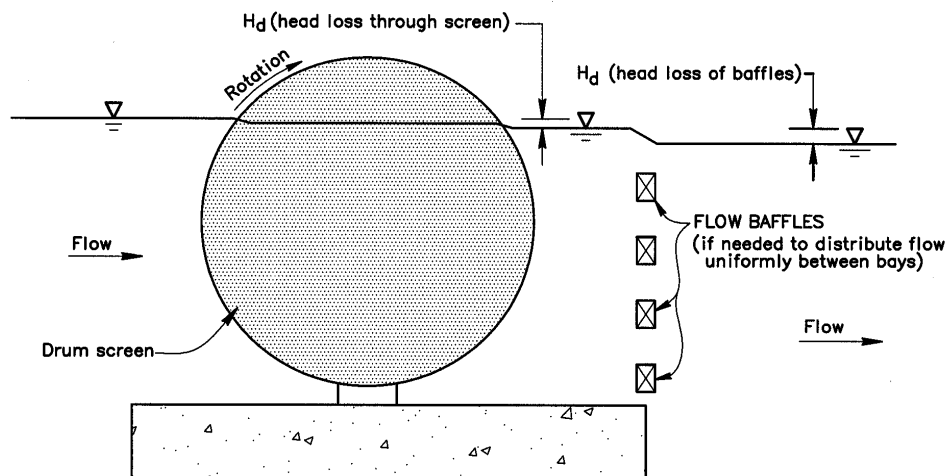
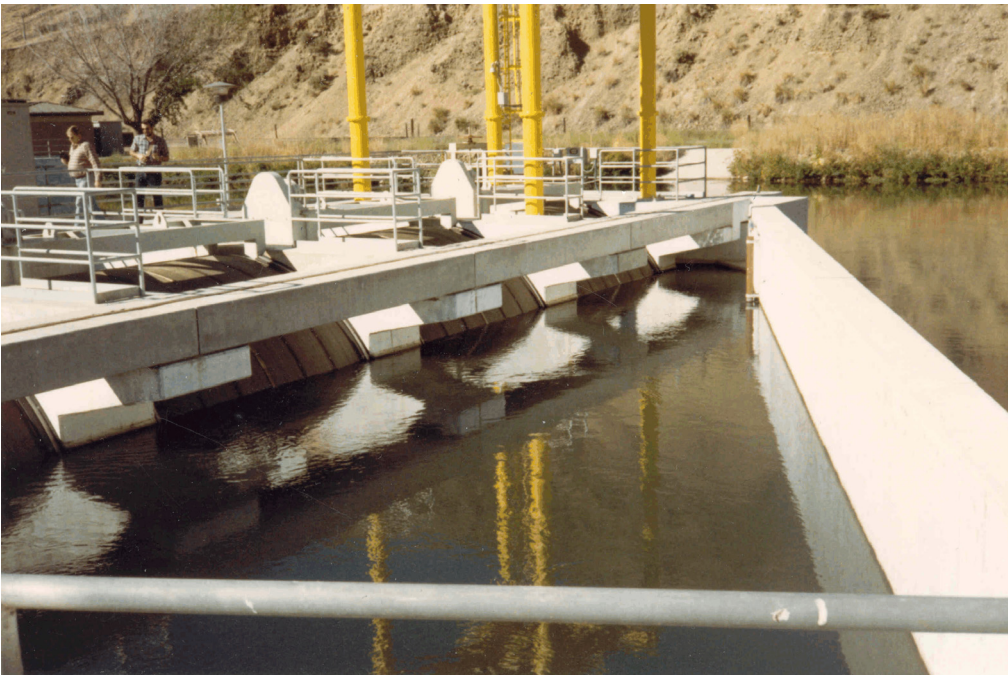


Figure 11.—Sectional view of drum screens (Pearce and Lee, 1991).



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.

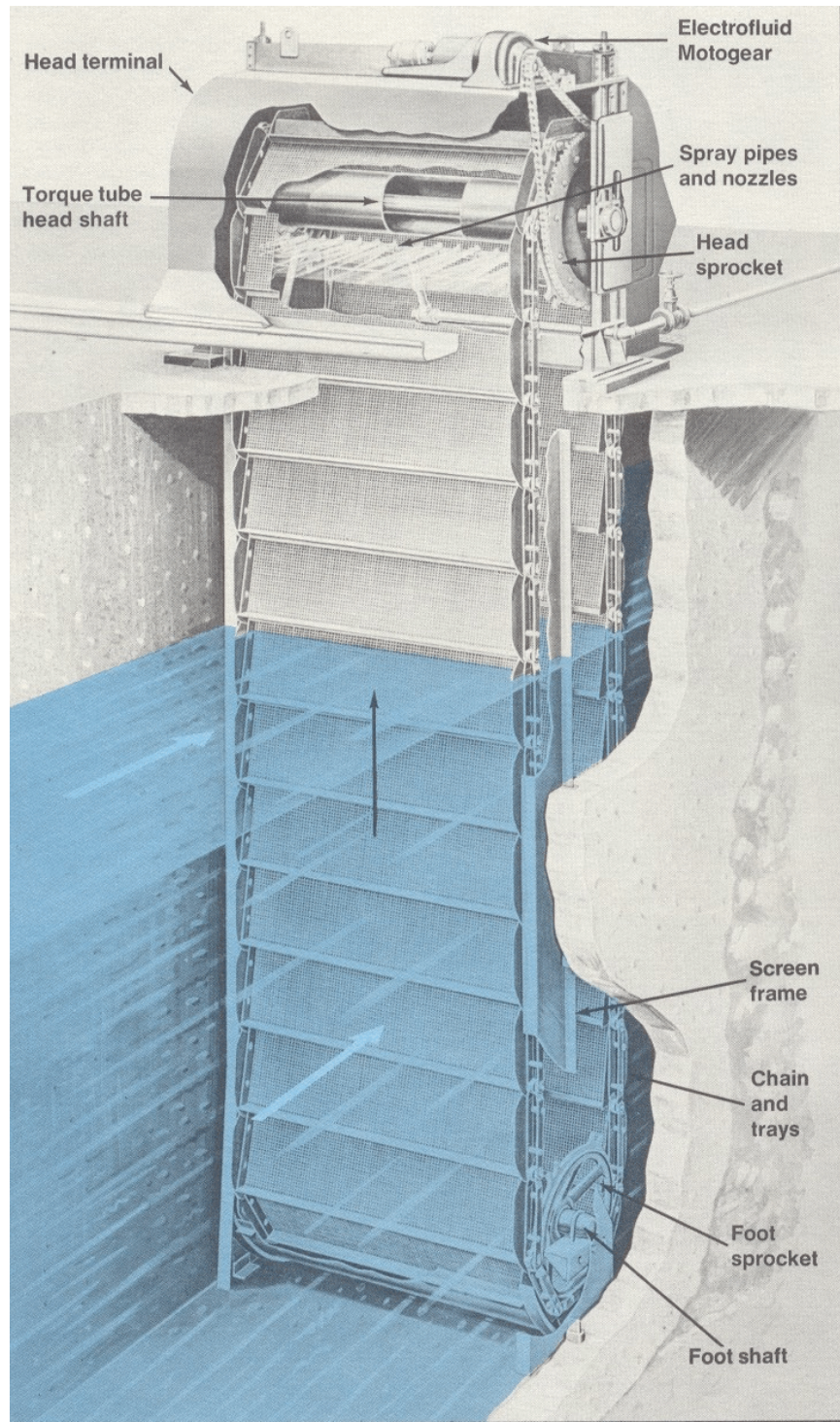


Figure 13.—Traveling screen.
(Courtesy of USFilter, A Siemens Business.)

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.

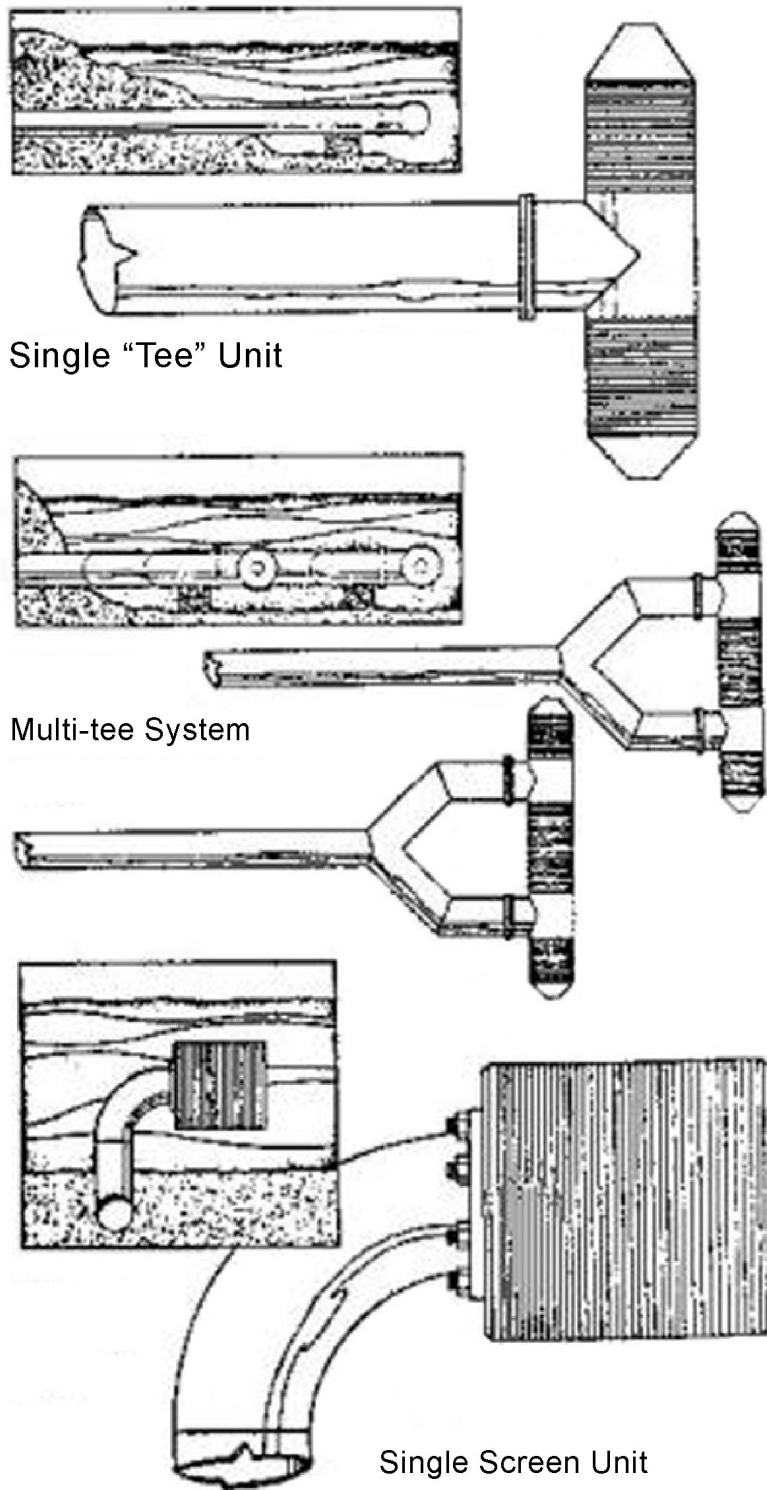


Figure 14.—Fixed cylindrical screens (Johnson screens).



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

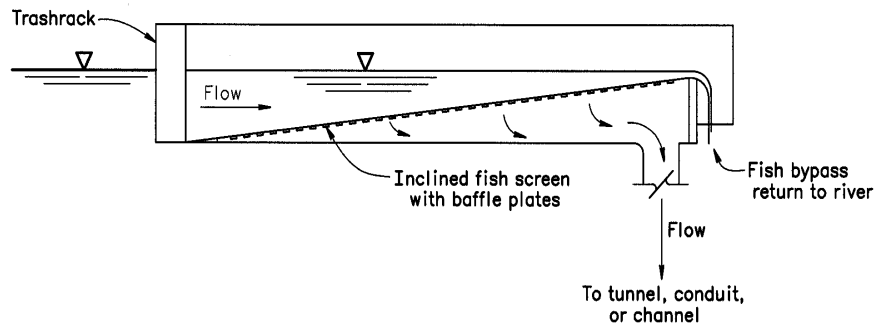


Figure 18.—Fixed inclined screens.

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

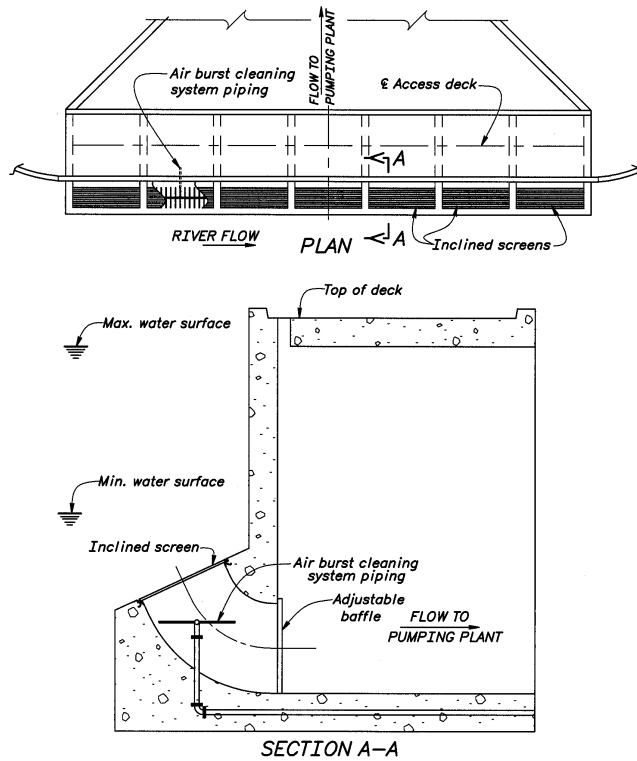


Figure 19.—Inclined screen along river bank.

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.

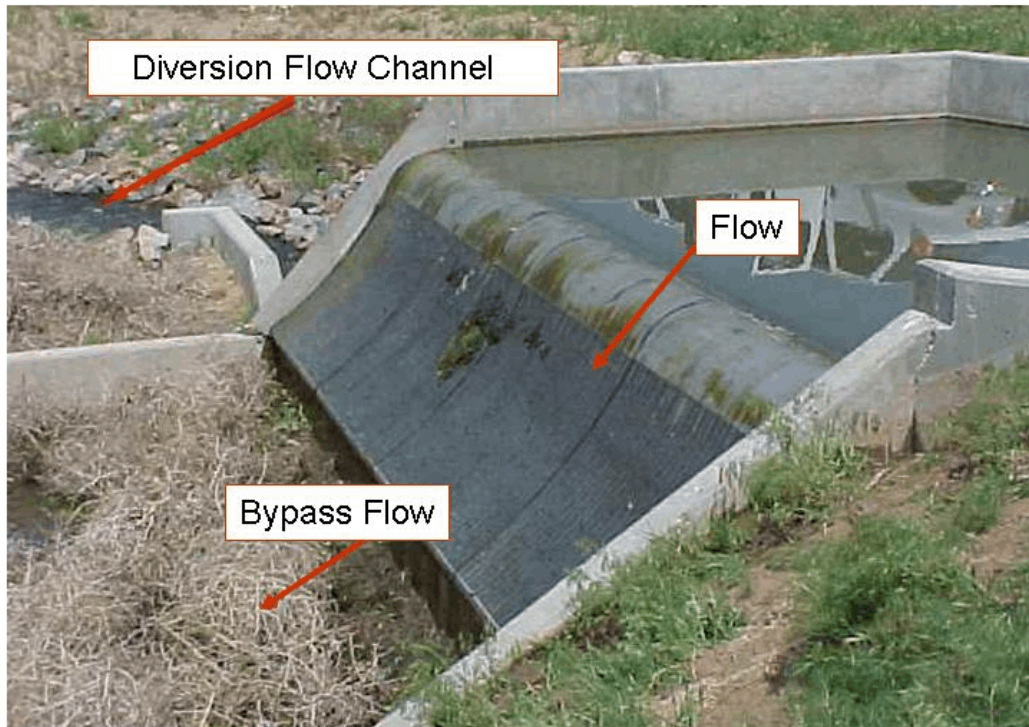


Figure 21.—Field site Coanda screen, Rocky Mountain Arsenal, Denver, Colorado.

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.

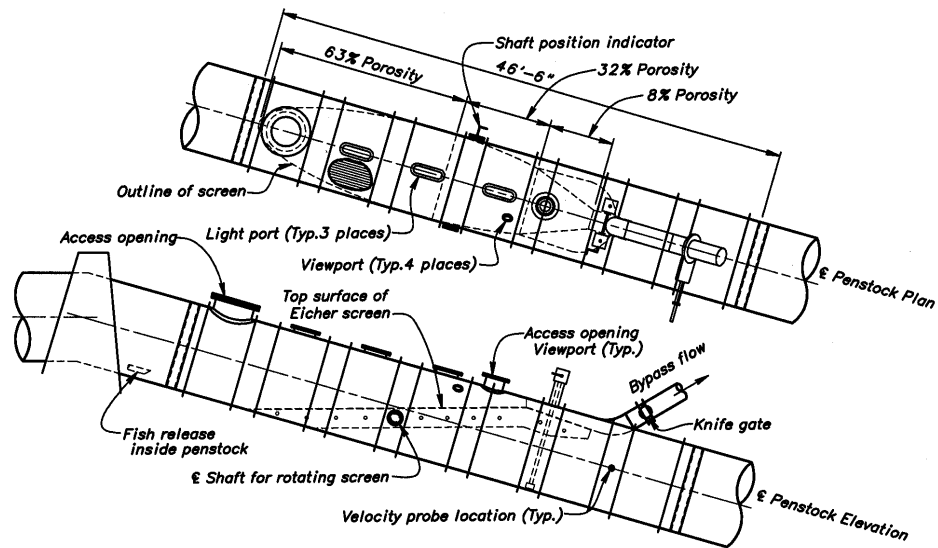


Figure 22.—Eicher screen (EPRI, 1994).

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.

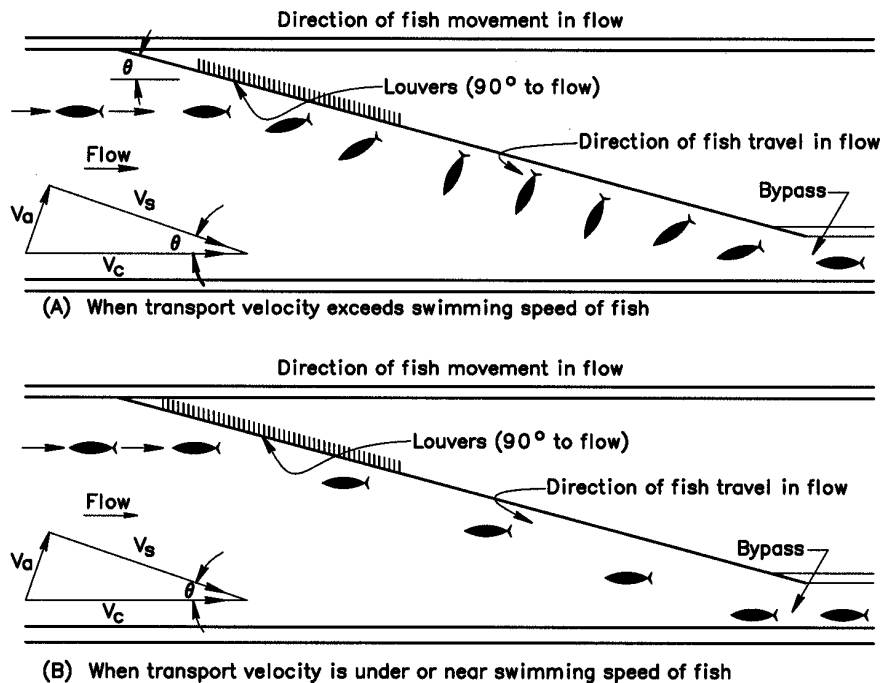


DIAGRAM ILLUSTRATING REACTION OF FISH TO LOUVERS

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.

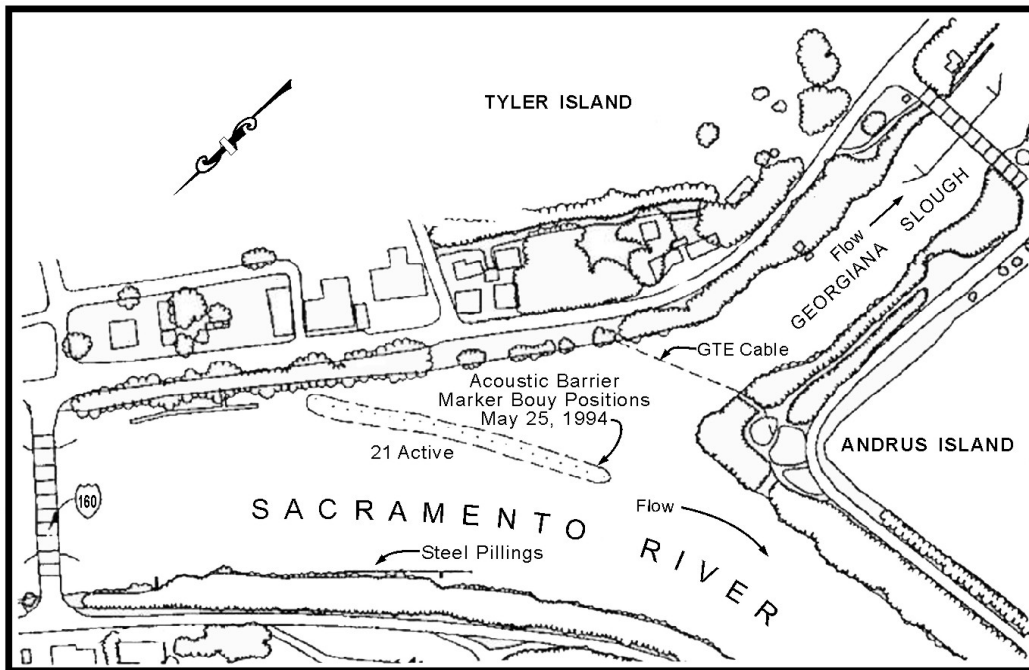


Figure 24.—Georgiana slough facility, California.

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	\$ Low	Q < 200 cfs
○ Fair	↓	QQ < 1000 cfs
● Poor	High	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).

Chapter IV. Positive Barrier Screens

“The significant problems we face cannot be solved at the same level of thinking we were at when we created them.”

Albert Einstein

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

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

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

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

A. Facility Design

A good scientist is a person with original ideas. A good engineer is a person who makes a design that works with as few original ideas as possible. There are no prima donnas in engineering

Freeman Dyson, 1923-, British-born American Physicist, Author

1. Site Selection

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

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

Site selection considerations will need to address:

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

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

a. In-canal siting

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

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

- ▶ Fish screens should be located as close to the upstream end of the canal as possible, based on canal hydraulics and site constraints. This placement allows fish to return to the river as soon as possible and reduces potential predation.
- ▶ Sediment deposition must be addressed. (See chapter IV.A.14 for sediment considerations.)
- ▶ The fish exclusion facility should be well aligned with the canal and preferably located in a straight reach of canal where uniform flow velocity distributions are provided and good sweeping flow can be achieved (figure 4).
- ▶ Bypass hydraulics, available head (between the canal and bypass outfall location in the river), and the river location for the fish bypass outfall will need to be evaluated.
- ▶ Sufficient flow depth must be maintained at the fish screens to ensure that adequate active screen area is provided and that the maximum screen approach velocity is not exceeded.
- ▶ Scheduling for construction of the fish exclusion structure and bypass will need to be carefully considered, especially if water deliveries will need to be continued during construction.
- ▶ Debris should be captured at the canal headworks.

An example of an in-canal positive barrier fish exclusion facility:

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

The Chandler Canal Fish Facility (Prosser Diversion Dam), Yakima River, Washington, is an example of a moderate to large capacity facility where the fish exclusion screen (drum screen facility) is located well downstream from the headworks at a site that provides both suitable space for facility installation and a well aligned straight canal reach. Immediately downstream from the headworks, the canal passes through a highly developed area (homes and roads). Space for the fish exclusion facility was limited and the canal alignment within the upstream reach included numerous bends. The fish screen structure was located in a straight reach of canal 4,300 ft downstream from the headworks. The site had sufficient space for the screens and for auxiliary fish evaluation and holding facilities. An approximately 500-ft-long straight canal reach leading to the screens was available, establishing a uniform channel approach flow distribution to the fish screens. (A hydraulic model study was used to develop and refine hydraulic features of the screen design, including approach and exit channel configurations). At the screen location, the checked water level in the canal is approximately 10 to 15 ft above typical river water surface elevations. Figures 26 and 27 show plan and section drawings of the constructed fish screen. The maximum diversion discharge capacity at the site is 1,500 cubic feet per second (ft³/s).

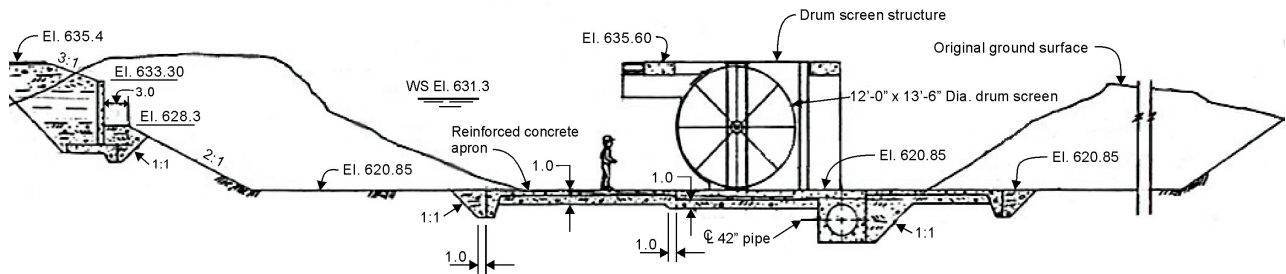


Figure 26.—Elevation view of Chandler Canal Fish Screen, Washington.

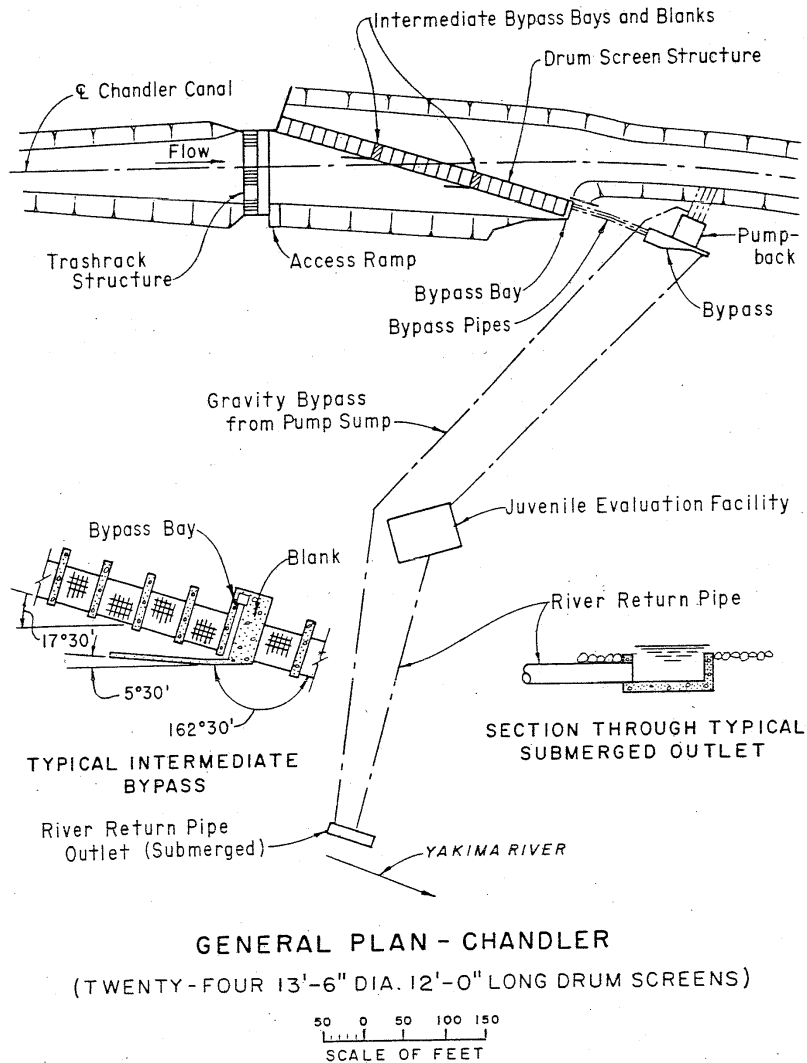


Figure 27.—Plan view of Chandler Canal Fish Screen Structure.

Flow is diverted into the existing canal by a diversion dam. Sediment deposition has occurred within the diversion pool to the point that significant quantities of sediment are diverted into the canal. Sediment sluicing capabilities were not included in the original design for the diversion dam. As a result, sediment

accumulates in the low velocity reaches of the canal. The existing canal headworks include submerged vertical slide gates that provide flow control and exclude most floating debris. Trashracks were not included as part of the existing headworks.

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

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

b. In-river siting

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

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

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

- ▶ The screen structure should be positioned and oriented with careful consideration of the in-river velocity field for a range of river stage and diversion conditions. This positioning will require evaluation of river flow patterns that will occur at the site at various river stages. The facility must then be oriented to yield a sweeping flow capable of moving fish and debris along and past the facility for all flow conditions.
- ▶ Sediment deposition and scour must be evaluated. (See chapter IV.A.14 for sediment considerations.)

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

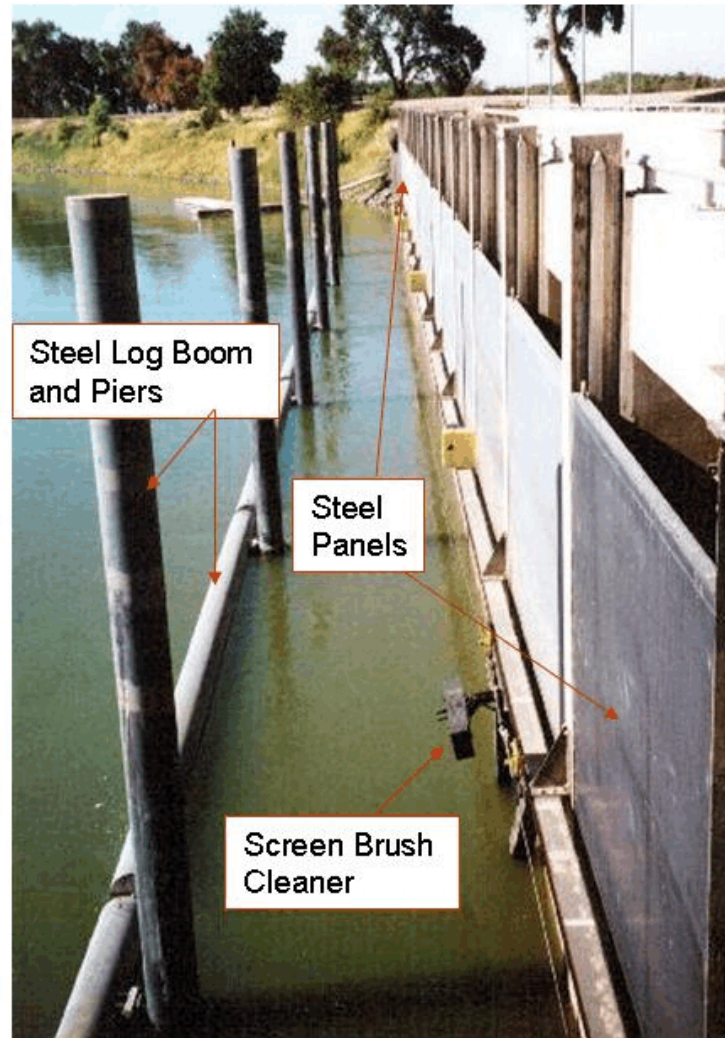


Figure 28.—Debris boom in front of the Wilkins Slough Fish Screen Structure, California (RD-108).

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

Examples of an in-river positive barrier fish exclusion facilities:

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

The Wilkins Slough Fish Screen Facility, Bureau of Reclamation (Reclamation) District 108 (RD-108) Wilkins Slough, Sacramento River, California, demonstrates a moderate flow capacity facility with a *flat plate* fish screen sited in the river. The maximum diversion discharge capacity at the site is 830 ft³/s. The fish screen is a positive fish barrier for the diversion. A hydraulic model was used to develop the screen configuration and flow distribution control features of the design (Vermeyen, 1996). Figure 29 shows an aerial photo of the facility. Figure 30 shows a plan layout of the river, screen, and pumping plant.



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

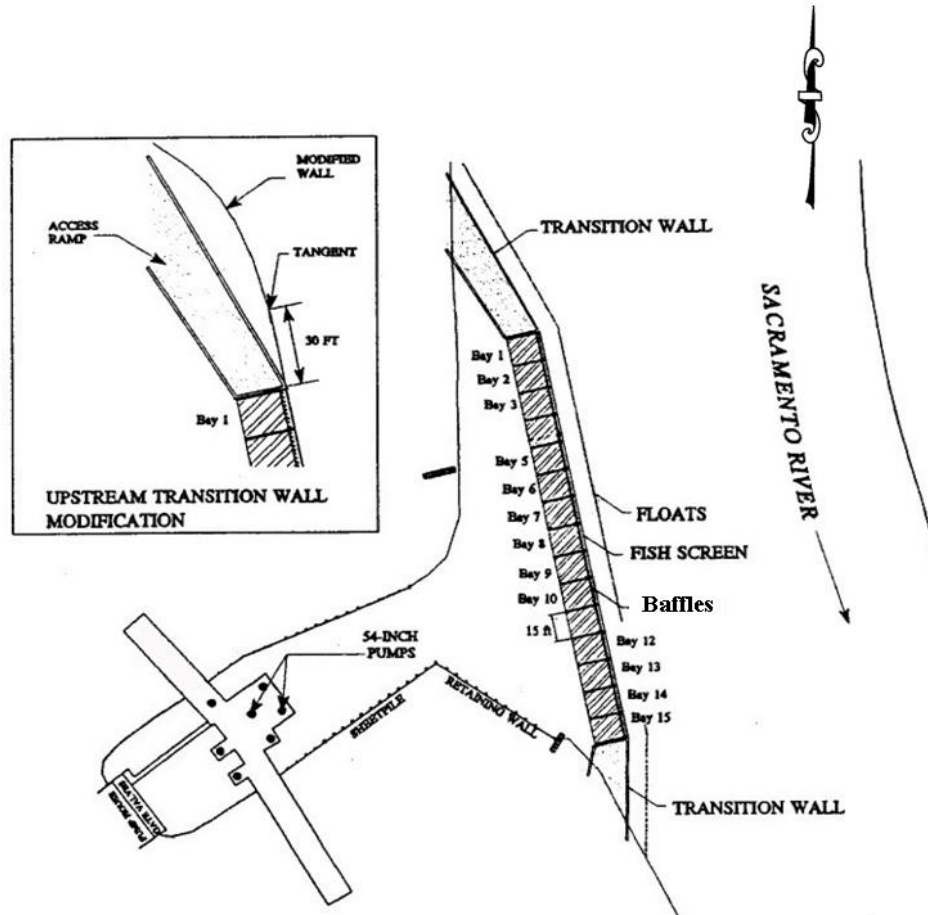


Figure 30.—Plan view of Wilkins Slough positive barrier fish screen (RD-108).

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

During the diversion season (April – December) the normal river flows range from 4,000 to approximately 17,500 ft³/s. Corresponding, river stages range from elevation 26.0 to 40.2 ft. The river bottom at the site is at approximately elevation 15.0 ft. Thus, riverflow depths at the screen facility during the diversion season range from approximately 11.0 to approximately 25.2 ft. Flow depths are substantial, which allows use of a screen with a significant screen height (a 12.0 ft vertical screen height with a 3/32-inch slot size was used). Based on the

established fishery resource agency maximum allowable approach velocities and the vertical submerged screen height, a screen length of 225 ft was chosen to pass the 700 ft³/s design diversion (maximum diversion capability is 830 ft³/s).

Maximum river flows at the site during flood events exceed 100,000 ft³/s. Corresponding river stages approach elevation 46 ft. The river transports significant sediment and debris loads during these high flow events. The screen was designed and constructed with the top of the screen fabric set at elevation 27.0 ft, which permits a submergence of at least 10.0 ft below the river water surface for moderate and high flow events. Trashracks, which would protect the screen face, were not included in the design because of concerns with sediment buildup between the trashrack and the screens. Above the screens, from elevation 27.0 to 51.0 ft, the structure face is made up of two solid steel plate panels, each 12.0 ft high. (See figure 28.) A large floating log boom is installed on piles approximately 8.0 ft in front of the screen facility along its length (figures 28 and 29). Thus, large floating debris encounters the boom and steel plate panels and not the screen, which is positioned deep in the water column. The submerged screen panels are pulled and replaced with solid plates containing pressure relief panels to equalize water levels on both sides of the panels from December to March (high flow season), thus further reducing screen damage potential. The design has proven effective. The screen that was installed in 1997 has experienced only limited debris-caused damage. The automated brush cleaning system, which sweeps the entire screen surface every 5 minutes, has proven effective and requires only limited maintenance. Brushes last for the whole diversion season.

Although the screen was installed in the sediment scour zone on the outside of a river bend, the screen is still exposed to significant sediment load. Agency mandated screen approach velocities yield low velocity zones behind the screens. As the model study predicted (Vermeyen, 1996), sediment deposition has occurred at these locations. An air jetting system has been developed by project personnel to keep sediments in suspension immediately behind the screens (further described in chapter IV.A.14 and figure 60). The currents then transport the sediment to the pumping plant forebay area where a drag line and trucks are used to remove sediment at the end of each pumping season (approximately 600 yd³, figure 30).

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

The plant is part of the Chief Joseph Dam Project, Greater Wenatchee Division and was built in 1960 by Reclamation. There are four pumping units at the river

pumping plant, which pumps to a booster plant. The combined pumping units have a total capacity of approximately 75 ft³/s. The pump bays are located about 50 ft from the bank of the river channel.

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

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

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

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

The submerged cylindrical Tee-screens with 36-inch diameter manifolds were chosen to replace the original screens in order to place the screens close to the path of strongest river velocities and to use this velocity for sweeping flows at the face of the screens. The facility includes four Tee-screens with diameters of 48 inches and assembled lengths of 136 inches. The maximum flow through each screen is 8,500 gallons per minute (gal/min) (18.9 ft³/s). The screens have a conical shroud on the upstream end and are located with the longitudinal axis parallel to the river flow. Sweeping velocity is about 1.3 ft/s at elevation 599.0. The screens use profile bars with 1.75 mm slot openings. Maximum screen approach velocities are calculated at 0.20 ft/s.

Other examples of in-river positive barrier screens:

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



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

c. In-diversion pool siting

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

Low velocities occurring in the diversion pool may stabilize or eliminate sediment loading at the facility. Icing issues will be less influenced by ice floes and frazil ice loading and more associated with loading from surface ice cover. Without auxiliary structures to influence the flow pattern at the screens, the

generated current resulting from diverted through-screen flow in a low or stagnant velocity field will tend to be normal to the screen face and will not produce a sweeping influence.

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

- ▶ Although hydraulic and loading conditions are moderated by the diversion pool, the facility design must allow for operation under a wide range of conditions and the design must be secure under seasonally occurring and storm event loading.
- ▶ The in-diversion pool facility may require a special configuration or use of supplemental flow guidance features to generate effective approach and sweeping velocities at the screen face. This may lead to requiring a fish bypass structure.
- ▶ Sediment deposition and scour must be evaluated (see chapter IV.A.14) for sediment considerations). Sediment deposits at the structure location may negatively impact the performance and operation.
- ▶ Construction may require use of a cofferdam with site dewatering.

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

Example of in-diversion pool positive barrier fish exclusion facilities:

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

The Roza Fish Screen Facility, Roza Diversion Dam, Yakima River, Washington, demonstrates a large capacity facility where fish exclusion occurs in the diversion pool upstream from the canal headworks. The *drum* screens were placed in the diversion pool instead of in the downstream canal because the canal, immediately below the dam, enters a steep walled canyon that greatly limits space available for in-canal structures. Figure 32 shows an aerial photo of the facility and figures 7, 33, and 34 show plan and section drawings of the fish screen facility. The maximum diversion discharge capacity at the site is 2,200 ft³/s.

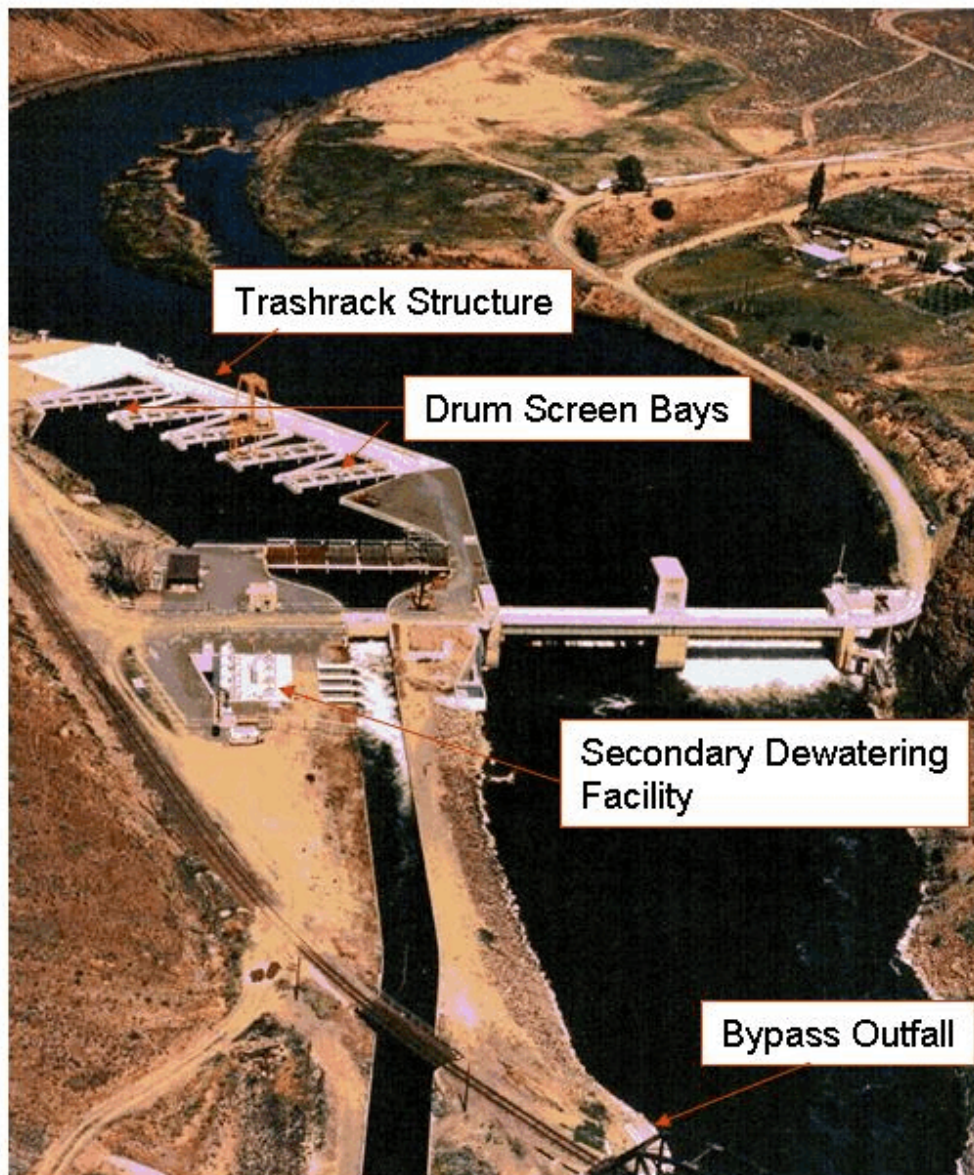


Figure 32.—Aerial view of Roza Diversion Dam and Fish Screen Facility.

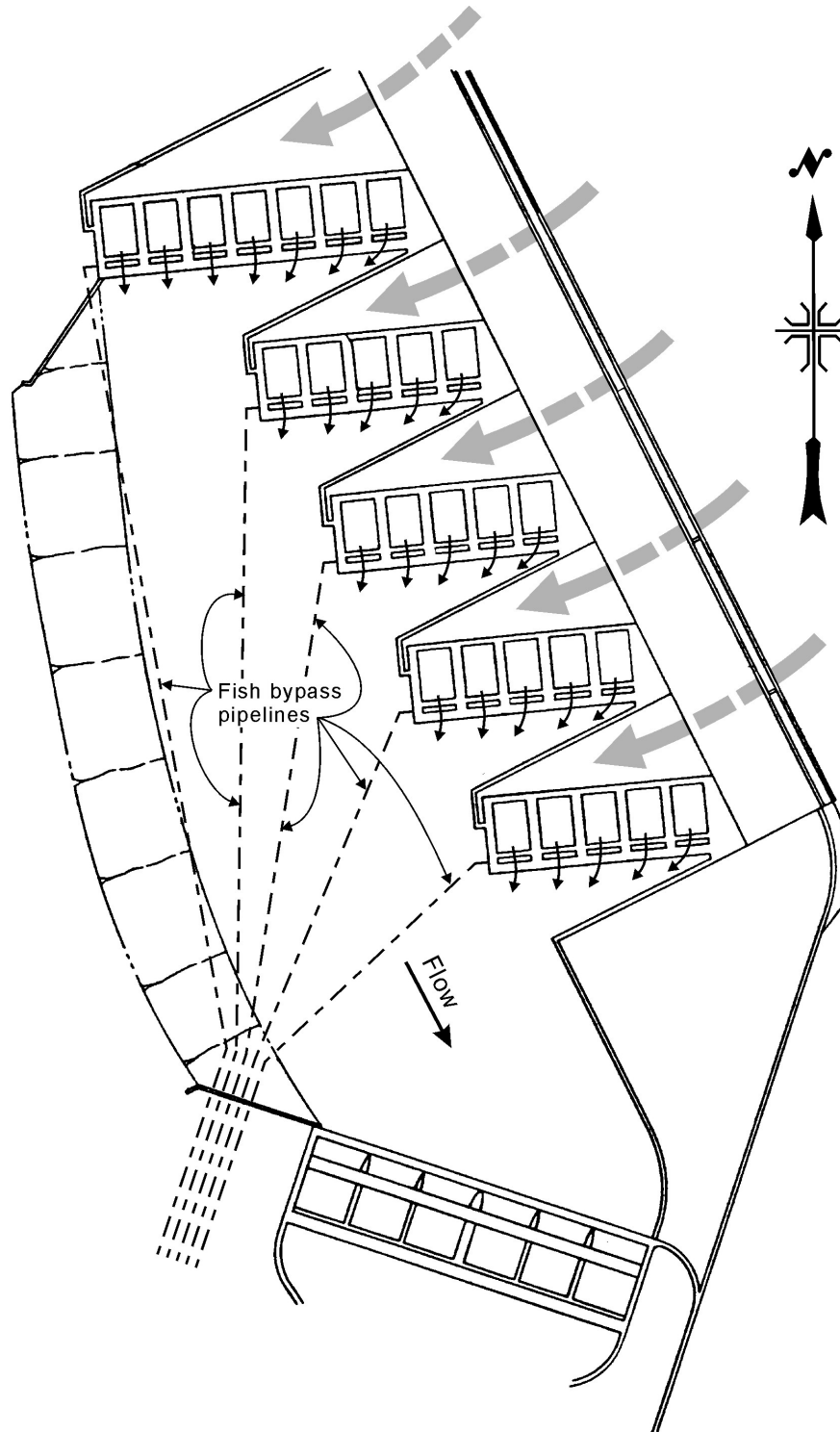


Figure 33.—Plan view of Roza Fish Screen Facility.

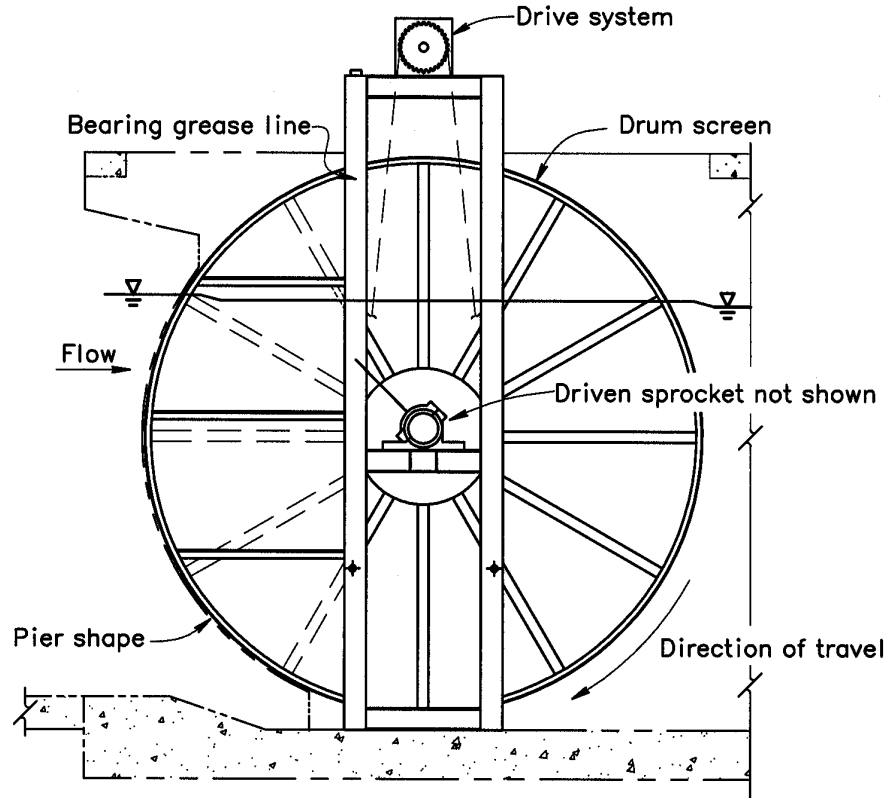


Figure 34.—Sectional view of Roza Fish Facility Drum Screen Structure.

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

Of particular concern with the design was development of a screen configuration that would generate uniform through-screen flow distributions and produce sweeping flows that guide fish by the screens and into fish bypasses. Generation of effective screen hydraulics is a common concern for in-pool screen facilities because velocities through the pool are low. Placement of an operating screen in a low velocity pool without proper consideration for screen hydraulics will generate flows normal to the screen and will not provide the necessary sweeping

flow for effective fish movement and debris removal. As a consequence, a poorly configured design may yield “dead-end” hydraulics that will tend to exaggerate fish delay and impingement and debris accumulation on the screen.

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

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

Other examples of in-diversion pool positive barrier screens:

Diversion pools:

Lilly Pumping Plant – traveling screens

Potter Valley – inclined screens

Reservoirs:

Osoyoos Pumping Plant – cylindrical screens

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

Clear Lake Dam – flat plate screens

d. In-closed conduit siting

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

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

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

- ▶ The screen should be positioned in the conduit at a location where well directed and uniform approach flow distributions can be achieved across the screen surface. Positioning requires consideration of the influence of entrance and conduit transitions and bends.
- ▶ Bypass hydraulics, available head, the on-river location of the bypass outfall, and the resulting configuration of the bypass conduit need to be evaluated.
- ▶ Screen cleaning operations (typically rotation of the screen panel to a back-flushing position), procedures for initiating cleaning (periodic intervals, pressure differential), and cleaning influences on fish exclusion need to be evaluated.
- ▶ Screen head loss influences on system operation and conduit loading need to be evaluated (including debris fouling influences).
- ▶ Access for maintenance and inspection should be identified.
- ▶ The time required for construction of the screen and the resulting influence on water deliveries and operation, in particular if the screen is being installed in an existing conduit needs to be considered.
- ▶ The risk of installation and testing requirements because the concept may be considered experimental by fishery resource agencies.

Example of a closed conduit positive barrier fish exclusion facility:

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

To date, a very limited number of closed conduit fish exclusion facilities have been developed. Most installations are associated with hydropower development. Many were developed as prototype facilities that were thoroughly field evaluated

but not operated for extended periods (years). As a consequence, extended operation and maintenance experience, as well as fish exclusion performance with closed conduit facilities, is limited.

British Columbia Hydro's Puntledge Facility, Puntledge Hydroelectric Project, Puntledge River, British Columbia, is a production facility that has been operational since 1993 (figure 8). The fish screen facility is located on Vancouver Island in a Pacific marine environment. It includes screens installed in two parallel 10.5-ft-diameter power penstocks. The maximum discharge capacity of each penstock is 520 ft³/s. Penstock flow velocities at the maximum discharge are approximately 6.0 ft/s.

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

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

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

complete plugging without structural failure. Venting downstream from the screens is provided to prevent penstock failure.

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

Other examples:

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

2. Site Isolation and Dewatering for Construction

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

a. In-canal

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

- (1) The headworks gate can be closed and the canal taken out of service for an adequate length of time for construction.
- (2) A temporary flow bypass can be constructed. A bypass typically requires cofferdams upstream and downstream from the construction site and an open channel bypass or a pipe bypass around the construction site. If an open channel bypass is constructed, the groundwater seepage between the bypass flow channel and the construction site must be evaluated and the seepage may have to be protected from piping embankment material that could cause failure of the embankment between the channels.

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



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

b. In-river and in-diversion pool

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

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

Some small screen installations may be constructed by divers.

3. Foundation Design

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

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

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

Another foundation consideration is the degree of seepage under the fish screen structure. Typically, fish screens and associated baffles will operate with a small differential in water surface (usually 0.1 ft to 0.5 ft). Water surface differentials will also be increased by upstream trashracks and the use of baffles, weirs, or gates downstream from screens, such as in figures 11 and 67. However, if the

trashracks, screens, and cleaning systems malfunction or cannot keep up with the debris load, the water surface differential may increase significantly. Structures have been designed for differential water levels of 2 to 5 ft or more to provide a design capable of withstanding screens plugged with debris. At these higher water level differentials, seepage could occur under the structure.

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

- a. A free exit. This is to say that a seepage exit is free to expel soil particles. A geotechnical engineer should be consulted to select a filter material that would be suitable.
- b. Sufficient gradient to facilitate particle movement. If the gradient is sufficient, any particle can be transported. Steep gradients should be reviewed as to foundation particle size and the potential for particle movement.

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

- a. Cutoffs on the upstream and downstream sides of the structure (also good for preventing scour from undermining the structure foundation).
- b. A graded filter (riprap on top of sand filter layer(s)) on the downstream side of the structure. Geotextiles may be substituted for one or more layers of the sand gravel bedding.

4. Location of Screen Structures

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

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

- ▶ Suitable flow conditions:

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

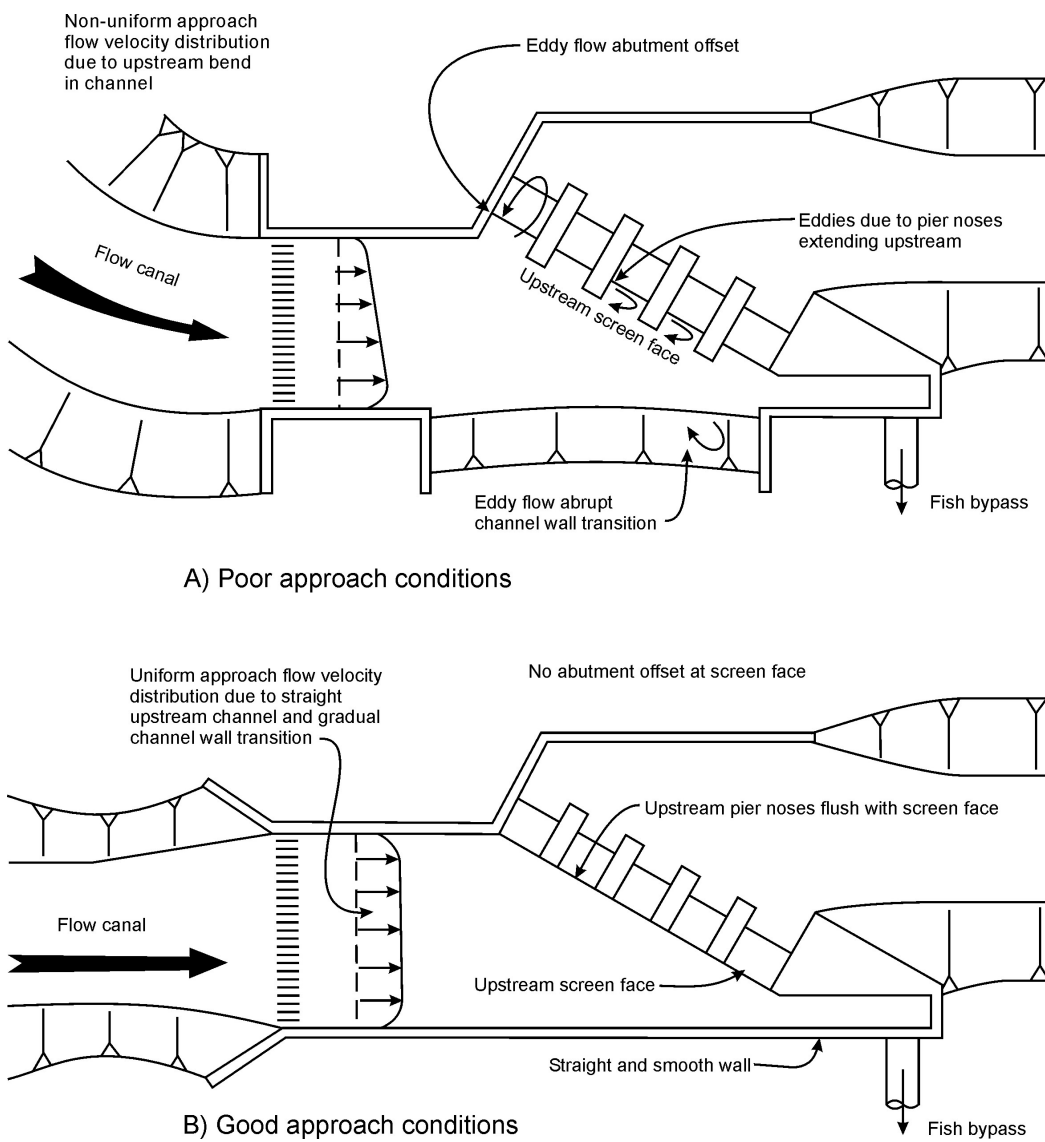


Figure 36.—Effect of approach channel on screen flow distribution (Pearce and Lee, 1991).

- ▶ Screen area: Fish screen size must be based on the minimum operating water level at the highest diversion flows. The highest flows will generate the maximum approach velocities. (For required fish screen area, see chapter IV.A.5).
- ▶ Screen approach velocity: The fish screen structure should be large enough to provide a screen approach velocity that will not exceed the criteria for the fish size specified over the expected range of diversion flows.
- ▶ Screen sweeping velocity: Sweeping velocities must be greater than the screen approach velocity (some agencies require at least twice the screen approach velocity) and some agencies prefer that this velocity be at least 2 ft/s.

a. In-canal

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

- ▶ Water level control: A downstream water level control structure (check structure) may be required to ensure adequate water depth on the fish screens. This is critical for drum screens where the water depth should be maintained between 65 and 85 percent of the drum diameter to ensure that debris can pass over the drum screen while fish are swept to a bypass.
- ▶ Fish bypass: A fish bypass structure will be required for fish screens located in canals. An effective bypass requires flow that guides fish back to the river. This flow should be free of eddy and slack-water.
- ▶ Screen should be located at least 40 times the canal depth downstream from bends in the canal.

b. In-river

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

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

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

c. *In-diversion pool*

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

- ▶ Screen approach and sweeping velocities: Screen approach and sweeping velocities in the diversion pool will likely be low. Therefore, supplemental structures are used to confine and guide the flow past the screen face
- ▶ Fish bypass: Conventional bypass structures may be required for fish screens located in diversion pools.

d. *In-closed conduit*

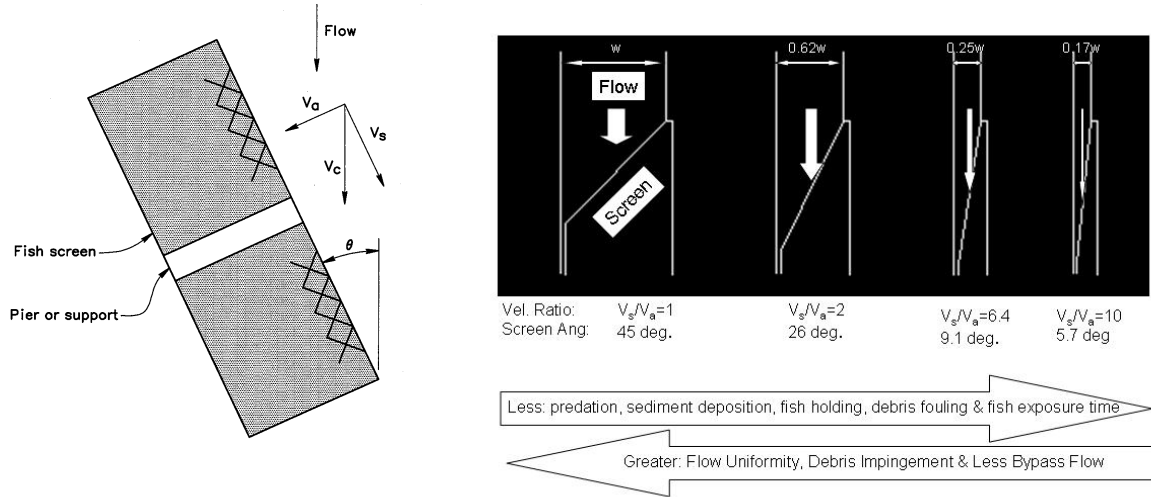
A fish screen structure located in a closed diversion conduit (penstock, pump suction tube) typically requires that the screen converge with the upper conduit surface, thus leading to the bypass entrance.

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

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

a. *Sizing screen area*

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



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

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

Figure 37.—Screen hydraulics.

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

$$\text{Approach velocity, } V_a = V_c (\sin \theta)$$

$$\text{Sweeping Velocity, } V_s = V_c (\cos \theta)$$

Where: V_c = channel resultant velocity and,

θ = Angle between screen face and channel flow line

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

$$A = Q/V_a$$

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

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

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

b. Screen approach velocity

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

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

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

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

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

c. Sweeping velocities

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

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

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

d. Sweeping/approach velocity ratio

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

$V_s/V_a < 5$, High debris impingement on the screen.

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

$V_s/V_a > 15$, Very low debris impingement on the screen.

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

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

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

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

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

6. Uniform Flow Distribution on Screen Surface

Flow passes through the screen because of head (water level differentials) across the screen. These differentials are typically not uniform over an entire screen

surface. Local variations in velocities and flow patterns, as influenced by localized approach and exit flow concentrations, structure and channel geometries, and head losses in the system, will yield localized variations in differentials across the screen. Therefore, achieving uniform approach velocities requires either refinement of flow patterns, restriction of flow paths to modify water level differentials, adjustment of actual open areas in or just downstream from the screen to modify local through-screen flow rates, or some combination of the above.

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

a. Criteria

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

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

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

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

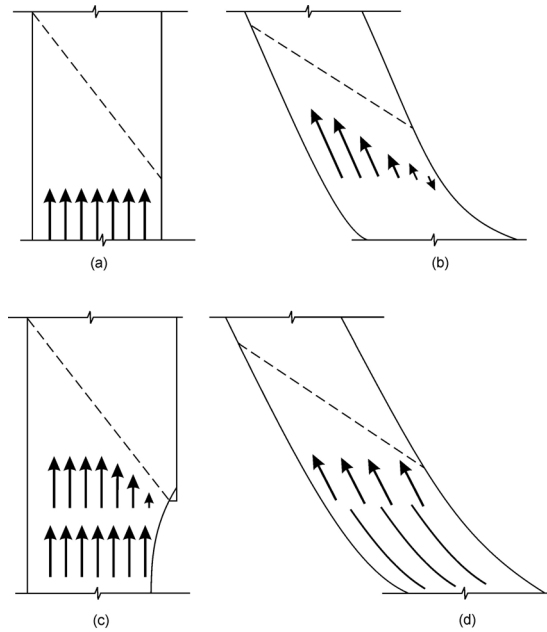
b. Methods of generating uniform distributions

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

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

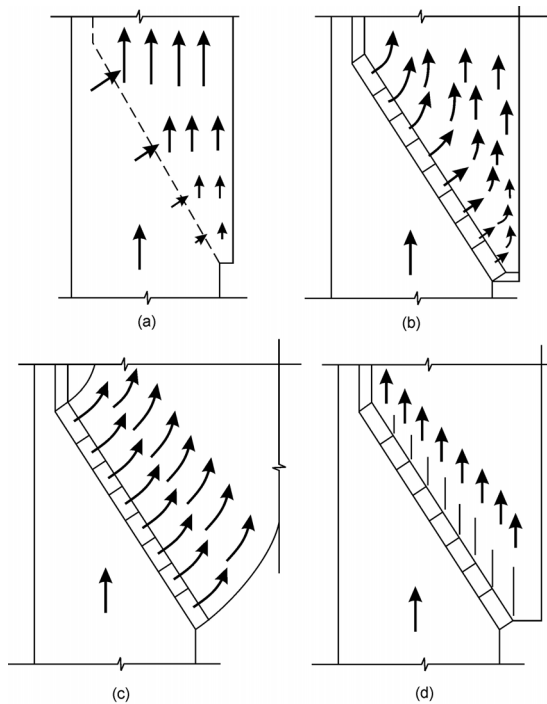
If a screen structure must be placed a short distance downstream from a bend in the approach channel, turning walls could be used to sustain uniform velocity distributions through the bend and on to the screen (figure 38d). This treatment was effectively applied at the Three Mile Falls Left Bank Fish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

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



Approach Channel Geometry Influence on Approach Velocity Distributions

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

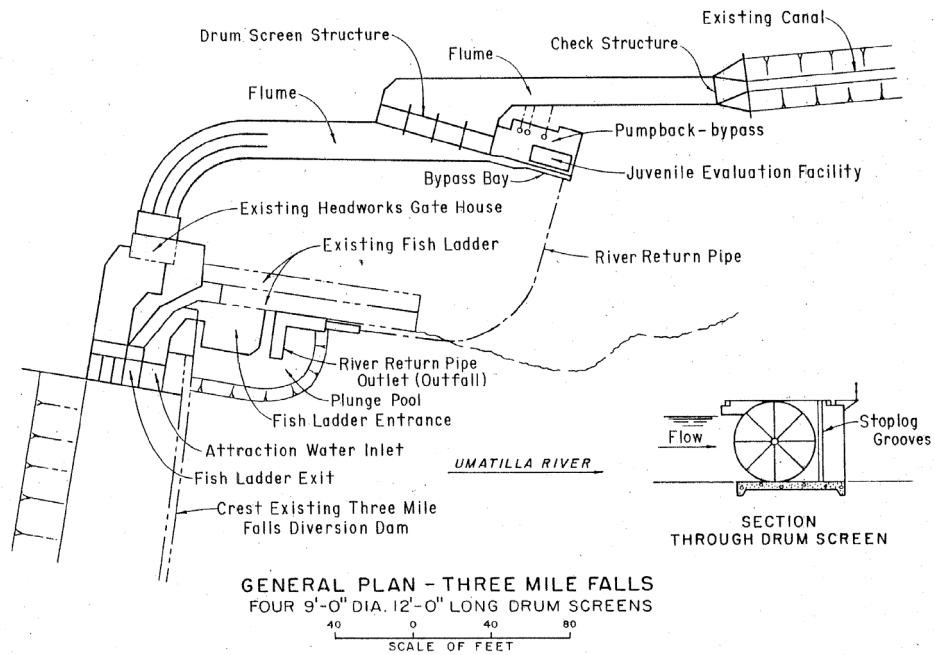


Exit Channel Geometry Influence on Approach Velocity Distributions

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



a. Photo.



b. Schematic of site.

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

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

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

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

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

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

- ▶ Perforated plate bolted to a supporting framework or placed in guides behind the screens (figure 41)
- ▶ Vertically adjustable (individually controlled or ganged) baffle vanes that can be rotated to open and close much like a vertical window blind (figure 42)
- ▶ Baffles fabricated with an upstream perforated plate capable of being adjusted up or down to vary the open areas and a back support frame fabricated with matching fixed perforated plate holes or horizontal slots similar to figure 41
- ▶ Other screen or flow restriction/resistance elements that are placed locally behind the screen

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

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

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

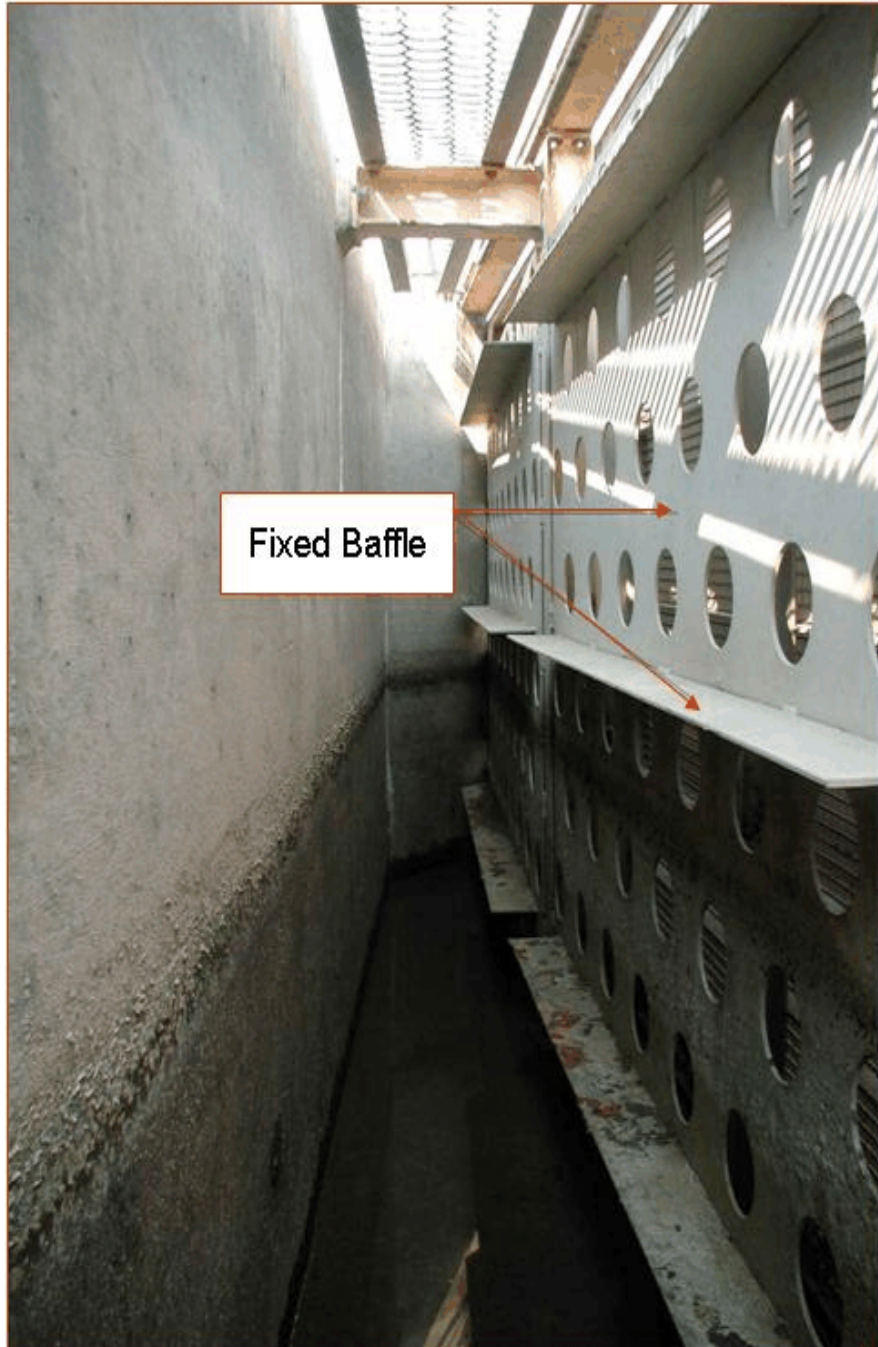


Figure 41.—Fixed perforated plate baffle behind Red Bluff flat plate screen.



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

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

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

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

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

c. Other downstream controls

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

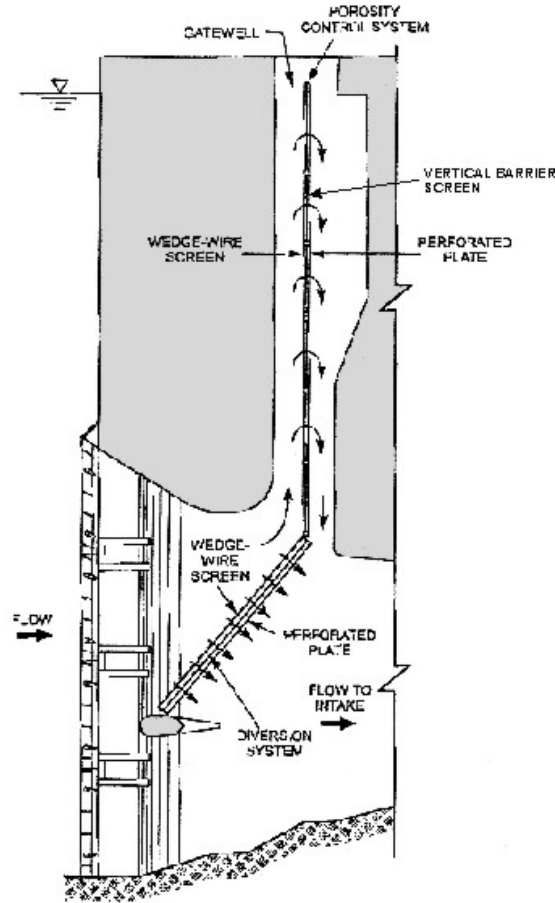


Figure 43.—High flow resistance perforated plated element as used in turbine intake screens, Columbia River (Weber, 2001).

d. Maintenance/operations considerations

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

backside by either a high pressure spray wash system or an air burst backwash system, adequate room for the piping between the screens and the baffles is required.

7. Design flow

Fish screen facilities are commonly designed to pass 90 percent to full design flow of the diversion, plus the bypass flow. If the design flow of a canal is 1,000 ft³/s, the fish screen structure flow plus bypass flow (which may be 50 ft³/s) would be 1,050 ft³/s. Much of the 50 ft³/s bypass flow is needed to attract the fish to the bypass entrance. A smaller flow can actually guide the fish back to the river through the bypass. In many cases, especially where there are multiple bypasses, some of the bypass flow can be returned to the canal using secondary fish screens and pumps as shown in figure 56. Figures 7 & 27 show secondary screening facilities for Roza Diversion Dam and Chandler Canal fish facilities. The remaining bypass flow with fish goes back to the river.

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

8. Head Loss Estimates

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

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

a. Head loss through trashracks

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

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

The head loss, H can be calculated by;

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

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

T = Thickness of trashrack bar in inches (mm)

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

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

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

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

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

Example 1

T = 0.5 inch
V = 2.0 ft/s
A = 75.96 degrees (1:4)
B = 0
D = 6 inches

Example 2

1.0 inch
3.0 ft/s
80 degrees
45 degrees
6 inches

Example 1

$$H = 7.07 * (.5/6)^2 * (\sin 75.9 / (\cos 0)^{1.875}) * (2)^2 / (2 * 32.2)$$
$$H = 0.00296 \text{ ft (0.035 inch)}$$

Example 2

$$H = 7.07 * (1/6)^2 * (\sin 80 / (\cos 45)^{1.875}) * (3)^2 / (2 * 32.2)$$
$$H = 0.0518 \text{ ft (0.62 inch)}$$

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

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

Based on velocity through the trashracks:

V=1.0 ft/s, H=0.1 ft

V=1.5 ft/s, H=0.3 ft

V=2.0 ft/s, H=0.5 ft

b. Head loss through the screen

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

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

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

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

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

The literature includes evaluations of the head loss characteristics of commonly used screen and baffle materials (woven wire screen, perforated plate, and profile bar (wedge-wire)). These losses have typically been evaluated either for site specific applications or as a general evaluation of the loss characteristics of various materials. The site-specific evaluations determine the loss characteristics

of a screen with a specific configuration and specific design features operating in a specific flow field (specific flow distributions and flow convergence angles). The general evaluations have nearly all focused on loss characteristics of screen materials oriented normal to the approach flow.

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

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

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

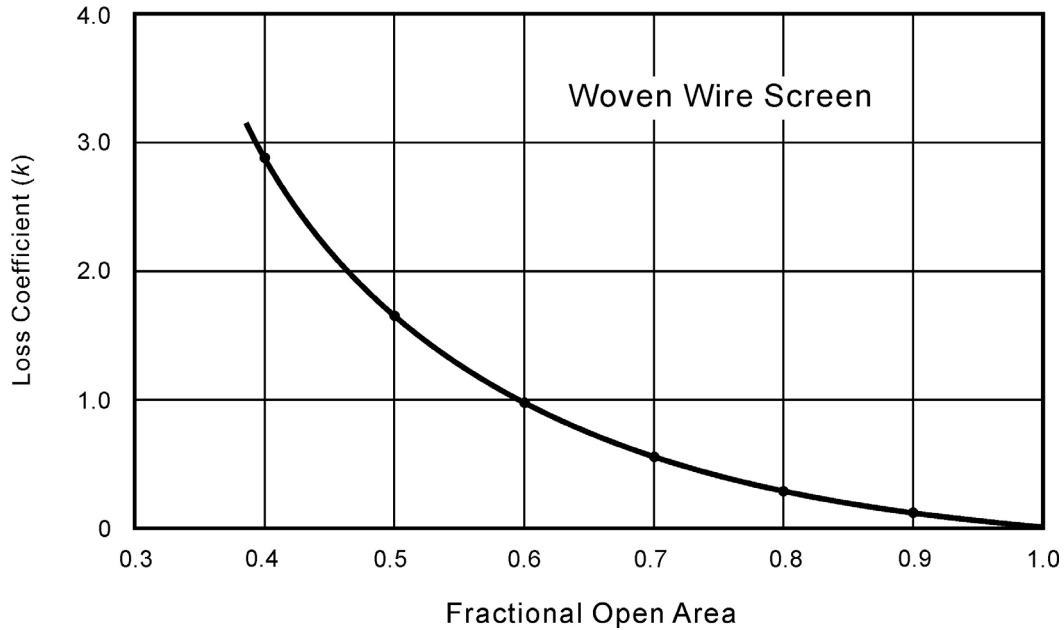


Figure 44.—Head loss coefficient as a function of fractional open area for woven wire screen (Padmanadhan, 1976).

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

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

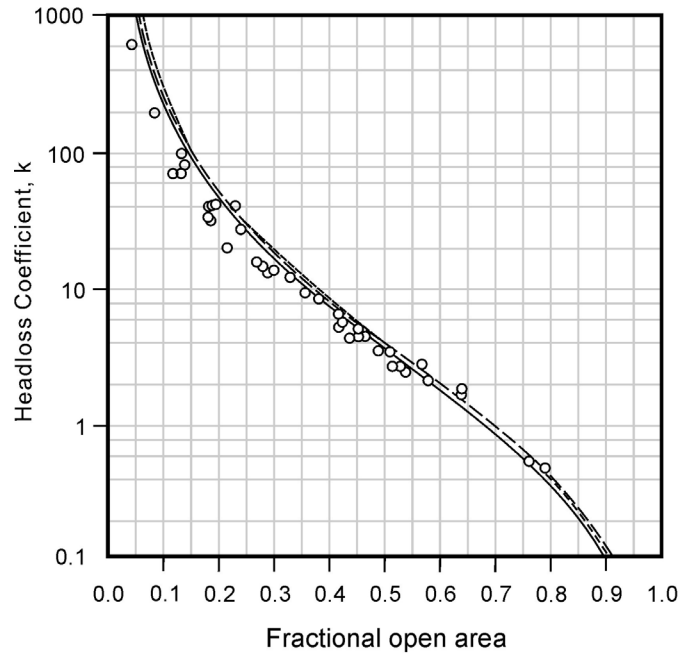


Figure 45.—Head loss coefficient as function of fractional open area for thin perforated plate (Weber, 2001).

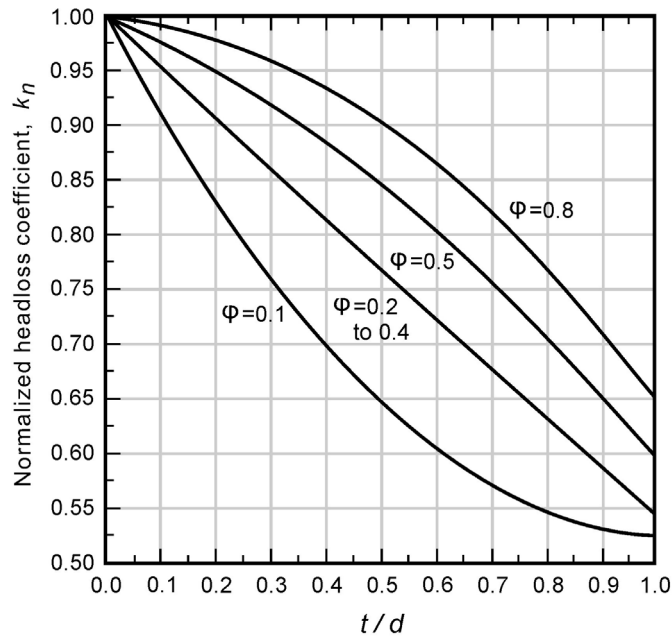


Figure 46.—Normalized head loss coefficient as a functional of fractional open area (Miller, 1990).

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

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

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

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

Profile bar (Wedgewire) – Site specific evaluations of head losses across profile bar screen indicate that loss characteristics vary with screen manufacturer. This is because manufacturers use wire with different cross-sectional shapes and manufacturers also use alternative wire retention and support member design. Generalized evaluations (comparable to those described above for woven wire screens and perforated plate) of the loss characteristics of profile bar screens have not been located. Site specific and single application evaluations indicate that the loss coefficient for profile bar screen (again evaluated with the screen face

oriented normal to the approach flow) is approximately 0.7 times the loss coefficient used for thin perforated plate. An evaluation conducted by Yeh and Shrestha (1989) also shows that loss coefficients for profile bar screens are independent of viscous effects for Reynolds numbers greater than 700 (based on the channel velocity applied to the slot width through the profile bar). Consequently, for a slot width of 0.069 inch (criteria for fry-sized salmonid), the corresponding channel velocities would have to be 1.2 ft/s or greater for the presented coefficients to be valid. The head loss coefficient for profile bar (Wedgewire) screens shown in figure 47 is generated by applying the 0.7 adjustment to the thin perforated plate loss coefficient from figure 45.

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

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

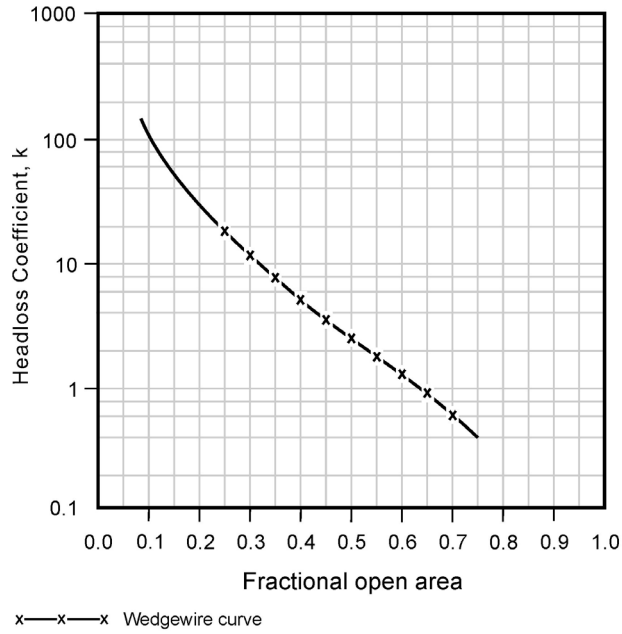


Figure 47.—Head loss coefficient as a function of fractional open area for profile bar (Wedgewire) Screen (based on a coefficient ratio adjustment applied to figure 45) (Weber, 2001).

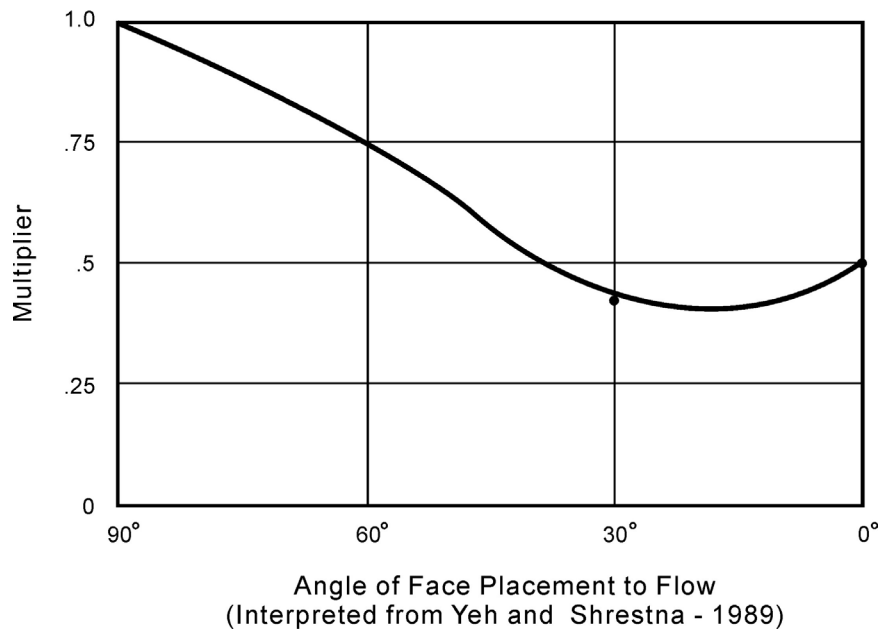


Figure 48.—Multiplier for adjustment of loss coefficients resulting from the angled placement of profile bar (Wedgewire) screen with slots oriented with the flow (Yeh and Shrestna, 1989).

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

c. Head loss through baffles

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

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

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

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

Front plate (fish screen):

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

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

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

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

Baffle plate:

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

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

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

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

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

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

Front plate:

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

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

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

Baffle plate:

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

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

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

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

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

d. Head loss through the bypass

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

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

9. Hydraulic Laboratory Model Studies

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

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

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

10. Screen Design

a. Screen material and fabric

Consider the size of fish to be excluded, marine and aquatic growth, screen durability and corrosion resistance, debris type, debris loading, and water quality when selecting screen material and fabric. Failures in any one of these areas can

substantially increase system and operation costs and reduce the effectiveness of the screen's operation. A wide range of screen materials has been effectively applied in fish exclusion facility applications. Commonly used screen materials include:

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

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

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

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

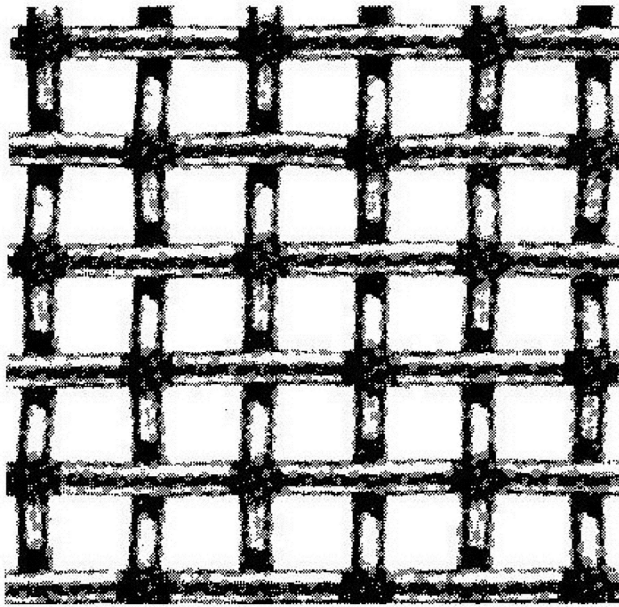


Figure 49.—Woven wire screen.

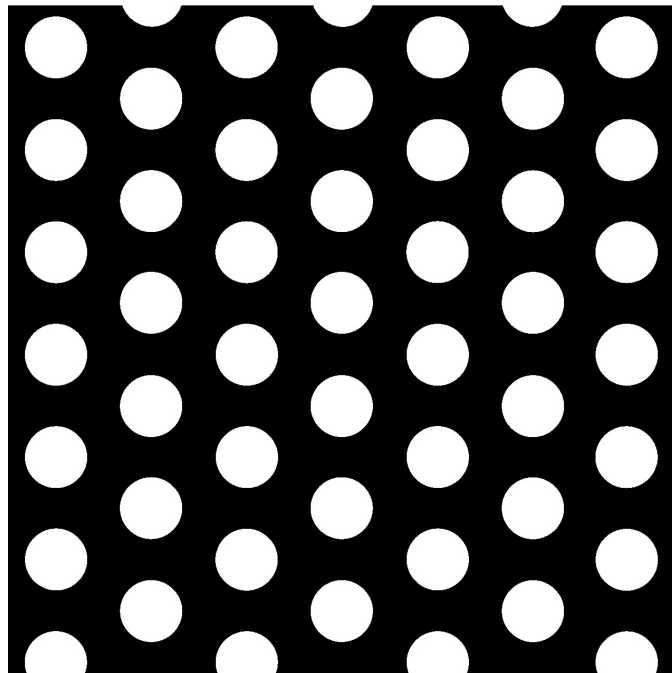


Figure 50.—Perforated plate screen.

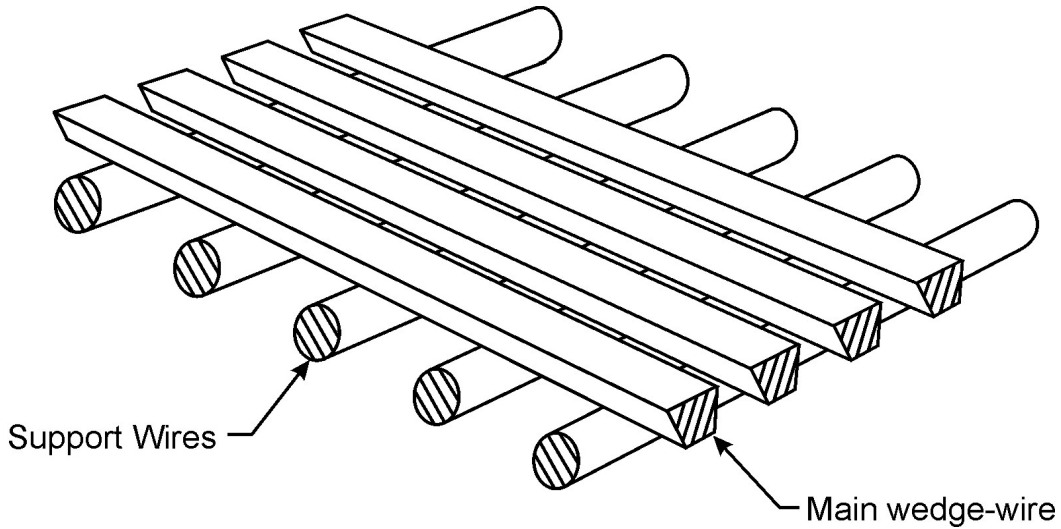


Figure 51.—Profile bar screen.

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

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

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

Table 2.—Screen fabrics and materials

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

b. Screen connectors, seals, support backing

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

Screens may be installed within guides (flat plate screens, drum screens, or traveling screens); may be bolted directly to the structure or the structural supports (flat plate screens, submerged screens, or coanda screens); may be bolted directly to the intake piping, conduit, or intake tower (flat plate screens and submerged screens); may be bolted to a movable support frame (submerged screens, closed conduit Eicher screens, or MIS screens); may be bolted to intake conduit piping for cylindrical screen; or the screen may be supported between the

floor and a support member (inclined screens). Guides allow the screen panels to be more easily removed for inspection, maintenance, and additional cleaning and to be raised if necessary because of ice conditions.

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

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

11. Fish Bypass System

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

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

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

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

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

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

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

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

a. Bypass entrance

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

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

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

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

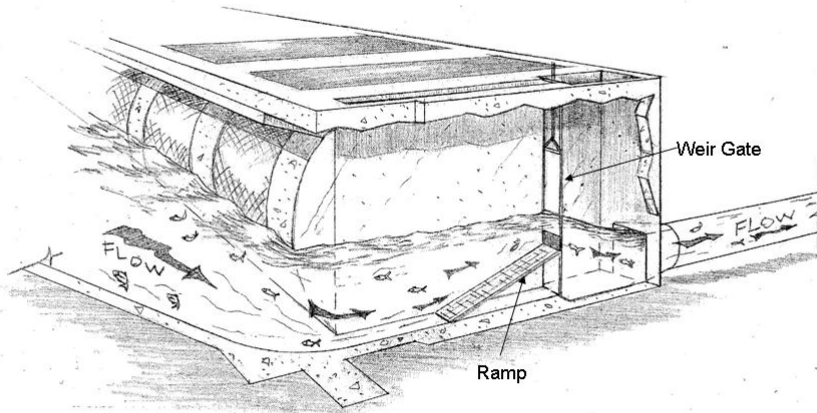


Figure 52.—Bypass entrance design for drum screen concept.

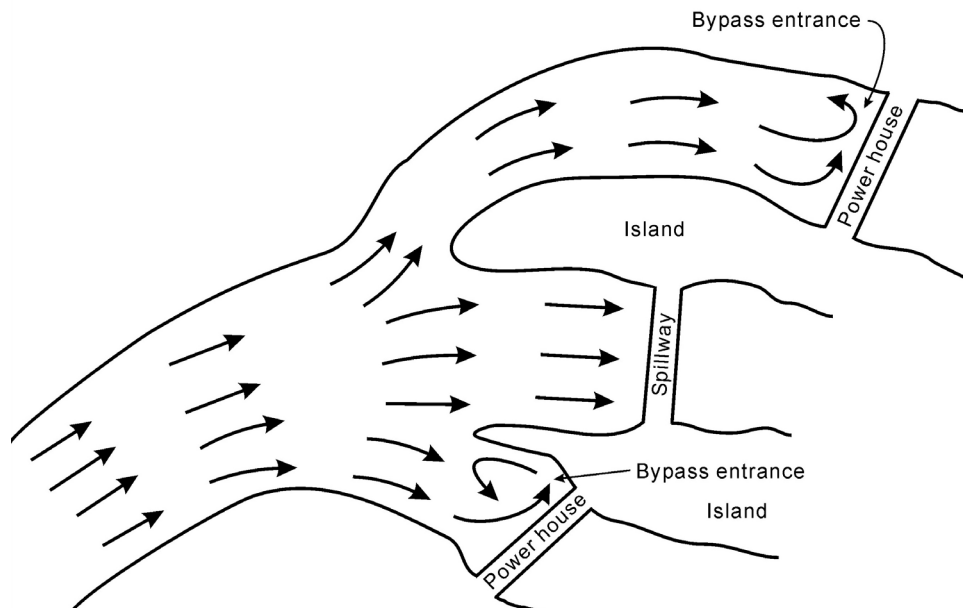


Figure 53.—Bypass placement with a complex geometry and approach flow – Bonneville Dam Forebay (Corps, 1999).

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

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

Note that when the screen operates with diversion flow rates that are smaller than design capacity, the exposure duration criterion can be exceeded. Longer exposure duration may also be acceptable if screen approach velocities are

reduced. Ultimately, bypass entrance locations should be developed based on the design flow rates and velocities.

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

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

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

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

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

the channel velocity, V_c . This relationship between bypass entrance velocity, V_b , and channel velocity, V_c , is defined as the bypass ratio where:

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

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

Table 3.—Fish screen bypass ratios

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

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

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

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

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

$$Q_b = (b)(d)(V_c)r$$

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

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

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

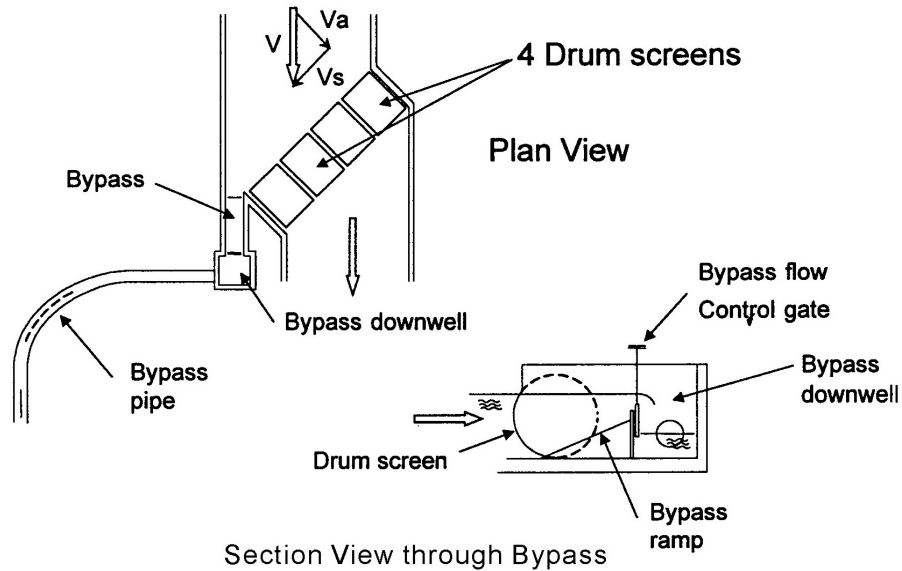


Figure 54.—By pass entrance and conveyance system with downwell (Rainey, 1985).

b. Bypass conduit

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

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

Published criteria (attachment A) do not permit negative pressure zones in the bypass and require that pressure in bypass pipes be equal to or above atmospheric pressure. Fishery resource agency criteria allow for use of both pressurized closed conduit bypasses and open conduit bypasses. The appropriate use of open or closed fish bypasses will depend largely on site characteristics and what

constitutes a workable design. The Washington Department of Fish and Wildlife (2000) in its screen design guidelines (which go beyond published criteria) states a preference for conduits with free surface flow that do not expose fish to changing pressures. This would require that the conduit be placed above the maximum river tailwater elevation to eliminate tailwater effects on flow depths, velocities, and pressurization of the conduit. This preference may not provide an effective and workable design at many sites.

Published criteria (NMFS, 1995; Washington Department of Fish and Wildlife, 2000) require minimum flow depths in open channel bypass conduits to be at least 0.75 ft (9.0 inches). The pipe or conduit gradient should be selected to sustain these flow depths over the full possible range of bypass discharges. Diversions of less than 25 ft³/s capacity (NMFS, 1993 and 1997), with screens, where bypass flow depths can be as small as 1.8 inches at the minimum flow rate are excepted. A drawback of shallow bypass flow depths is that fish in the flow will always be near the conduit boundary. Being near the conduit boundary increases the potential for fish injury.

Debris fouling that would reduce hydraulic capacity and thus limit bypass entrance operations should be prevented. Accumulated debris also places materials in the conduit that could cause fish injury. Access for inspection, maintenance, and debris removal must be provided. To reduce debris clogging, pipe bypasses should have a diameter of 24 inches or greater (attachment A.1). Diversions with screens passing 25 ft³/s or less are excepted (attachments A.1.K. and A.3.K). For these small installations, fishery resource agency criteria allow minimum bypass pipe diameters as small as 10 inches. It should be recognized that smaller diameter conduits are more susceptible to debris fouling and may pose a significant maintenance problem, particularly if access is difficult.

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

Flow through most bypasses and bypass conduits is gravity driven. Typically, screen structures are placed in diversion structures and canals at locations that are physically higher than the water surface at the bypass outfall. Consequently, drop or head is available to move the flow through the bypass system. Velocities through the conduit are often controlled by placing the outfall conduit at a grade

that generates the desired velocities. Again, the full range of bypass discharges should be considered in design development.

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

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

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

1. Use of supercritical chutes (as long as minimum depth can be maintained) in which there is no chance for fish holding up in rollers and little possibility of debris blockage (figure 124). Reaches of higher gradient chute coupled with flatter gradient sections can be used to manage energy and velocities in the bypass. This option largely eliminates tumbling and turbulence that can lead to fish injury.
2. Use of transitions from the bypass flow control weir (figures 57 and 108) to the bypass conduit that eliminates the plunge pool with roller. As noted above, the drop from the bypass flow control weir may vary with changes in tailwater elevation. By using a downwell geometry that includes confining the flow in the transition to the bypass conduit, development of a roller can be excluded.
3. Drop the flow from the bypass flow control weir into a downwell pool where energy dissipation occurs (figures 52 and 54). Flow then exits the downwell typically into a closed conduit that may operate either with free surface or pressurized flow.

Drop structures with an associated energy dissipation pool should be designed to prevent fish injury and disorientation. High energy dissipation rates and direct flow impingements on structure surfaces should be avoided. The Washington Department of Fish and Wildlife (2000) observes that drop structures are often needed to quickly reduce the water surface elevation from the screen structure to

the ultimate discharge location, particularly at sites where space is limited. A pipe designed to comply with smoothness, flow, and depth criteria will be at a very low slope and, therefore, very long. Drop structures can be much more compact. They have the added risk, however, of causing injury due to turbulence or clogging with debris.

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

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

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

Energy dissipation factor (EDF) rates (dissipated energy in ft pounds (lbs)/s per pool volume in ft³) occurring in downwell pools have been evaluated by both Reclamation and the Washington Department of Fish and Wildlife (2000). It has been suggested that a guide for sizing the downwell or dissipation pool based on these field observations indicates that the maximum energy dissipation factor should be no larger than 60 ft lbs/s/ft³. If fragile fish such as button-up fry are present, development of the design based on a more conservative EDF of 25 ft-lbs/s/ft³ is recommended. Typically, the pool volume is its smallest at minimum tailwater. For typical designs (EDF of 60) the required pool volume is thus computed as:

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

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

where V_{pool} is the required effective energy dissipation volume of the pool in cubic ft at minimum tailwater, Q_b is the flow rate entering the pool in ft³/s, and h is the total energy head of the flow entering the pool in ft (velocity head plus free drop).

Non-gravity driven bypass – At some sites, insufficient drop or head is available to generate a gravity driven bypass flow. These tend to be sites in flat terrain where the river gradient is low. In such cases, the use of a fish-friendly lift/pumped bypass may be considered. The use of pump driven bypasses is in

conflict with currently published criteria (NMFS, 1995; Washington Department of Fish and Wildlife, 2000) that say “There should be no pumping of fish within a bypass system.” Use of pumps, however, allows use of bypasses where, otherwise, bypass operation would not be possible. Pumps selected for fish bypass should be proven to pass the species and life stages of fish that are present with minimal injury or mortality. The Archimedes and helical (centrifugal screw) pumps show promise as pumps capable of pumping fish. Research has been conducted in recent years at the Red Bluff Fish Evaluation Facility to develop and validate such pump designs (McNabb et al., 2003). This work may lead to future fishery resource agency acceptance of pumped bypasses. Figure 83 shows the use of a helical pump in the fish bypass at Potter Valley diversion.

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

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

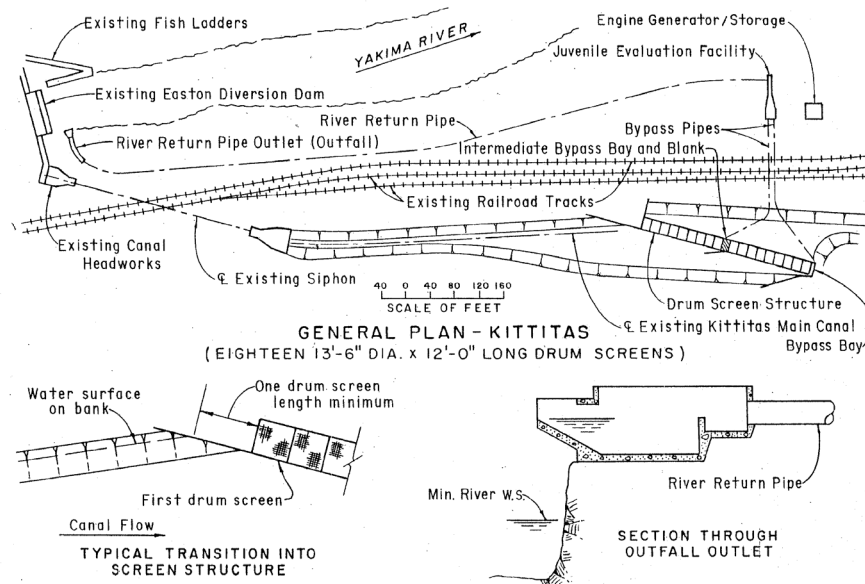
c. *Bypass outfall*

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



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

b. Roza Diversion Dam Fish Bypass Right Bank outfall.



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

Figure 55.—Bypass outfalls to natural water.

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

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

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

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

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

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

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

present even with lower flows. Optimum outfall receiving pool flow conditions may be difficult to achieve in smaller streams and rivers where flow sections are shallow.

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

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

d. Bypass supplemental features

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

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

e. Secondary screening

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

Design options for a secondary screening facility include:

- ▶ An independent secondary screening facility can be included as part of the bypass system. The secondary facility is usually separate from the primary main screening facility. When multiple bypasses are included in the primary screening structure, the bypass conduits typically run to the common secondary screening structure where the flow from the multiple bypasses are merged (figures 7 and 27). Screening with a pump-back operation is used to return a portion of the bypass discharge to the canal or diversion, thus, reducing flow rates through the remainder of the bypass conduit and outfall (figure 32). With this concept, a single bypass conduit and outfall is used beyond the secondary screening facility. The Chandler Canal (figure 27) secondary dewatering facility is a typical example of this concept. Traveling screens are often used in these facilities (figure 76). A typical layout of a pump-back secondary screening facility is shown in figure 56.
- ▶ A recently developed concept includes the secondary screening facility in the bypass channel immediately downstream from the main bypass entrance. In this case, secondary screening occurs upstream from the flow control and velocity trapping section of the fish bypass conduit. Because very little head loss occurs in the bypass before the secondary screening, it is possible that flow can be returned to the diversion by gravity (resulting from the drop between the bypass conduit and the diverted flow channel behind the primary screen). A conceptual design of this type of secondary facility is shown in figure 57.

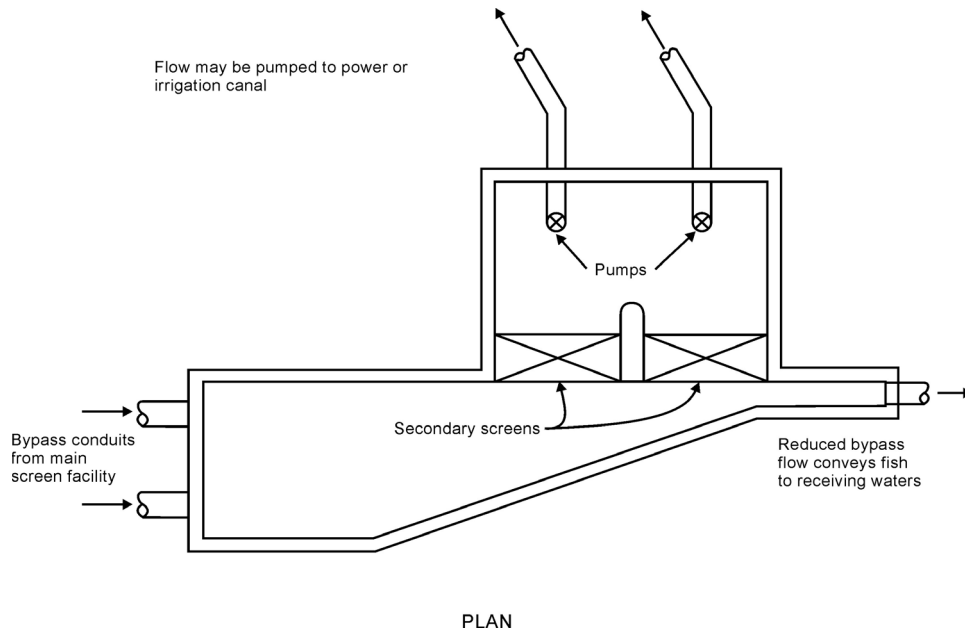


Figure 56.—Secondary screening layout with skewed wall.

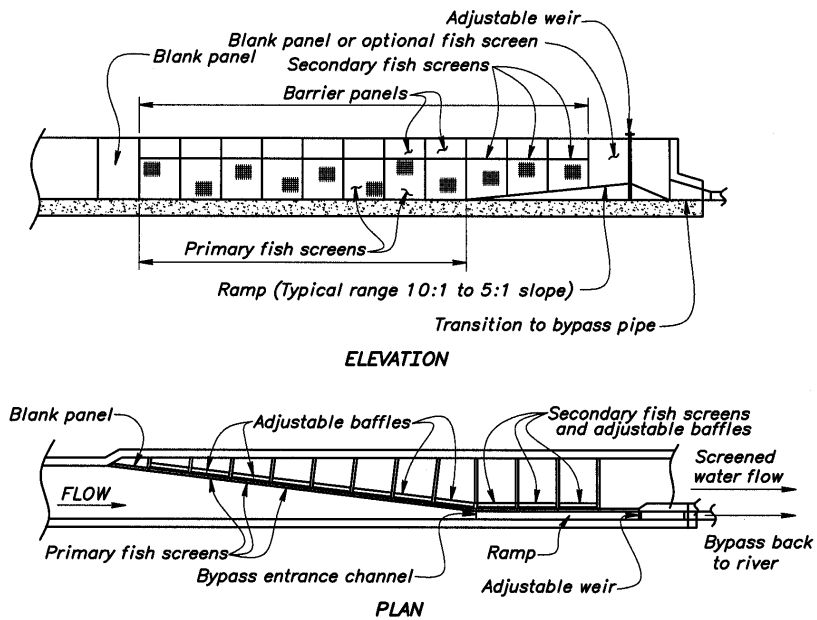


Figure 57.—Secondary screening without pumping.

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

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

12. Cleaning and Maintenance

a. Fish screens

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

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

Debris fouling and cleaning characteristics of fish exclusion facilities depend both on specific characteristics of the facility and on debris types and quantities. Some screen fabrics are susceptible to severe fouling from particular debris types that might embed or intertwine in the screen fabric. Screens located in diversion pools or that receive water directly from biologically productive water bodies may be exposed to heavy debris concentrations. On the other hand, screens that are

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

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

b. Trashracks

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

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

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

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



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

c. Backup power

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

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

d. Maintenance

A reliable, on-going preventative maintenance, inspection, and repair program is necessary to ensure that the facilities are operating effectively, that the log boom, trashracks, positive barrier screens, and bypasses are being kept free of debris, and that the screen mesh, seals, drive units, cleaning systems, level or

pressure sensors, and other components and controls are functioning correctly and have not been damaged. Debris cleaned from the trashracks and the screens (if vertically cleaned) will need to be properly disposed of, which may include transporting the debris to a disposal site.

13. Gantry/Lifting Equipment

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



a. Red Bluff gantry crane.

b. Cascade Canal fish screen monorail hoist.

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

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

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

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

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

14. Sediment Management

Sediment deposits are a concern whether the fish screen is located in a river, in a canal, or a diversion pool. Sediment can move along the bottom of the water column (bed load) or be dispersed throughout the water column (suspended sediment). Bed load is usually a coarser grained material such as sand and gravel. Suspended sediment is fine-grained material such as silts, clay, and fine sand. When water velocities are lower, deposition can be expected if sediment

(especially bed load) is present. An evaluation of potential sediment concerns (quantity and particle sizes) can be made by: (1) reviewing historic records of the river and canal, and (2) sedimentation mathematical model studies.

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

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

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

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

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

- ▶ The invert of the fish screens should be at least 6-inches above the channel invert.
- ▶ Channel and/or sweeping velocities should be maintained to keep the sediment moving and prevent the sediment from settling out. The baffle behind the drum screen in figure 11 can be used to effectively keep sediments in suspension at the screen by causing increased velocities near the channel invert.
- ▶ A sediment sluice may be constructed upstream from the fish screens and at other locations as required.
- ▶ Some projects in the Pacific Northwest are experimenting with “ecology blocks” placed a few ft upstream from the drum screens to control sediment deposition in the forebays. These blocks are similar to 2 ft by 2ft by 4ft long gabions placed in the forebay approximately 3 ft in front of and parallel to the Sunnyside Diversion Dam fish facility drum screens. They are stacked two high and provide excellent sediment transport in front of the screens.
- ▶ An air nozzle may be installed on the bottom of the horizontal cleaner brush to help move sediment and debris from in front of the screens (figure 66).
- ▶ Air bursts or water jets may be installed in the base of the screen panel.
- ▶ A bubble curtain may be created around fixed cylindrical screens.
- ▶ A water spray system may be used downstream from the screens and baffles to keep sediment suspended.

Operation and maintenance personnel at RD 108 (Wilkins Slough) have developed an air burst system (figure 60) that keeps in suspension sediments that normally deposit immediately behind the screens. The sediments eventually reach a zone downstream from the screen but upstream from the pumping plant where the material can be easily removed. During low river flows, project personnel will enter the area between the screen structure and pumping plant with earth moving equipment and annually remove (dredge) 600 yd³ (figure 29). Hydraulic laboratory studies identified this sediment deposition problem in the laboratory and it has now been verified in the field, Vermeyen, 1996.



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

15. Predation Control

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

a. Locations of predation

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

- (1) At trashracks where narrow bar spacing generates fish passage delays and holding in front of the racks.
- (2) At and near bypass entrances where changes in lighting, hydraulics, and possibly restrictive passageways may cause fish passage delays and holding.

- (3) In the bypass structures (if predators are present) where fish densities are concentrated and turbulent flow conditions might cause fish disorientation.
- (4) At the bypass outfalls where fish densities are concentrated and hydraulics may cause fish injury and disorientation

b. Alternatives to reduce and control predation

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

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

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

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

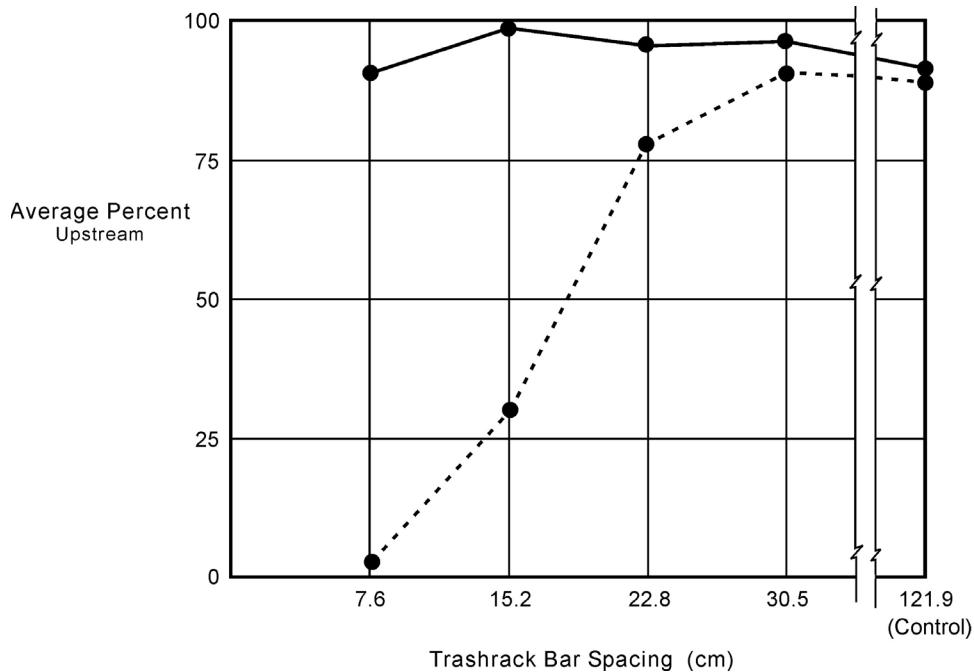


Figure 61.—Average percent of juvenile American shad found upstream from trashracks with various bar spacing – channel velocity of 1.0 ft/s (Reading, 1982).

Fish released upstream from trashrack - - - - -

Fish released downstream from trashrack ———

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

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

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

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

16. Fish Behavioral Influences

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

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

a. Habitat

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

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

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

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

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

As noted, water quality and hydraulic characteristics of a site may also dictate locations where fish are present. In particular with stratified reservoirs, the development of summer temperature stratifications may actually yield water temperatures in portions of the reservoir that are not life sustaining or acceptable for certain fish species. In such cases, the fish will move to locations and depths

in the reservoir where water temperatures and water quality conditions are suitable. Such location shifts may temporarily reflect seasonal changes in water temperature. Fish may return to behaviorally preferred habitat after fall cooling of surface water temperatures.

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

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

b. Turbulence

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

c. Lighting

Light can be used to both attract and repel fish. As discussed in detail in chapter III.B.2.b. and chapter V.C., strobe lights have been used to repel and guide fish. The use of other light sources, including underwater mercury vapor, underwater incandescent, and overhead sodium lights, to attract fish has been

evaluated (EPRI, 1999). Underwater fluorescent and drop lights have been evaluated for repelling fish (EPRI, 1999). Typically, lighting has been used in attempts to supplement the performance of other fish exclusion or protection systems. Lighting, in itself, does not offer a consistently effective fish guidance and/or exclusion option. Successes and benefits associated with the use of lighting are inconsistent and variable, depending in part on fish species, fish-life stage, and other environmental influences. Depending on the specific installation, the effects of lighting are often negated during the day, when the influence of the sun dominates.

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

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

d. Diurnal effects

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

e. Sound

Beyond issues associated with sound generators that are specifically used to repel or disperse fish (chapters V.D. and III.B.2.b), environmental or ambient sound may also affect fish responses. Agencies, at times, will express concern that

equipment (e.g., continuously operating pumps) associated with fish facilities might cause fish avoidance, which could adversely affect fish bypass performance.

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

17. Summary Table

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

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

Design feature	Variations	Criteria
Approach velocity ² (Measured 3 inches from screen face)		Not to exceed 0.4 ft/s for fry or 0.80 ft/s for fingerling
Sweeping velocity		Greater than approach velocity (some State agencies prefer twice approach velocity – greater than 2 ft/s)
Screen material and maximum opening Fry – minimum open area 27% Fingerling – minimum open area 40%	Perforated plate	Fry – 3/32" – 2.38 mm Fingerling – 1/4" – 6.35 mm
	Profile bar	Fry – 0.0689" – 1.75 mm Fingerling – 1/4" – 6.35 mm
	Woven wire	Fry – 3/32" – 2.38 mm Fingerling – 1/4" – 6.35 mm
Structural features		<ul style="list-style-type: none"> * Unimpeded fish movement parallel to screen and into bypass * Oriented at angle up to 45° to the flow * Piers and walls flush with screen face * Screen placed at an angle to flow, and downstream end terminates in bypass entrance
Bypass	Layout	<ul style="list-style-type: none"> * Multiple bypasses are needed when fish exposure time is more than 60 seconds. * Entrance and all components sized to minimize potential for debris blockage * Training walls may be placed at an angle to the screen to aid fish movement toward the bypass and for intermediate bypasses.
	Entrance	<ul style="list-style-type: none"> * Bypass entrance has independent flow control capability * Entrance velocity is greater than or equal to maximum flow velocity vector near screen * Good ambient light * Bypass entrance extends from floor to water surface
	Conduit	<ul style="list-style-type: none"> * No pumps, free fall, valves, or hydraulic jumps within the conduit. * Smooth pipe surfaces * Pipe bends shall have radius/diameter ≥ 5 * Pipe velocity ≥ 2 ft/s * 24" minimum diameter with 9" minimum flow depth
	Outfall	<ul style="list-style-type: none"> * Ambient river velocities of at least 4 ft/s * 25 ft/s maximum outfall impact velocity * Locate to minimize predation
Operation and maintenance		<ul style="list-style-type: none"> * Automatic screen cleaning to prevent accumulation of debris * Head differential on screen of 0.1 ft triggers screen cleaning * Screen and bypass evaluated for biological and hydraulic effectiveness

¹ Varies according to NMFS regions

² Uniform flow required

B. Screen Specific Design Details

“Many things difficult to design prove easy to performance.”

*Samuel Johnson (1709-1784)
Rasselas. Chap. xvi.*

1. Flat Plate Screens

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

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

- ▶ Near vertical and vertical screens allow for easy transition to the fish bypasses.
- ▶ The bypass transition must maintain or accelerate screen sweeping velocity at the bypass entrance to meet fishery resource agencies’ bypass criteria
- ▶ The more the screen angle is off vertical, the greater the bypass entrance area, which results in a larger required bypass flow to achieve the desired entrance velocity.
- ▶ Near vertical screens facilitate easier removal and reinstallation of fish screens and baffles when designed with guides for drop-in capability
- ▶ Automated screen cleaning systems use proven technology for vertically to near-vertically aligned screens.

At locations with shallow water depths, inclining the flat plate screens to increase the wetted screen area while reducing the screen length may be desirable. Check with fishery resource agencies concerning their criteria about inclined screens. Inclining screens at very flat angles (i.e., screens sloped at greater than 45 degrees off vertical) is not recommended when the submerged screen extends to the water surface. Chapter IV.B.4.b presents details for inclined screens. Screens sloped at

shallow angles yield a thin, shallow flow along the edges that can increase fish abrasion and subject fish to increased predation. Other major issues to be addressed are the bypass transition and how to clean the screens.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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



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

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

the metal guides and the screen support frame, but also reduce friction when removing the screens from the guides. The wear strips are fabricated from ultra high molecular weight (UHMW) polyethylene, delrin, brass, etc.

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



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

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

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

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

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

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



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



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

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



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

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

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

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

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

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

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

diverted flow. Winter conditions may also require that the intake system be shutdown because ice can also damage the trashracks, cleaners, pumps, and other equipment.

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

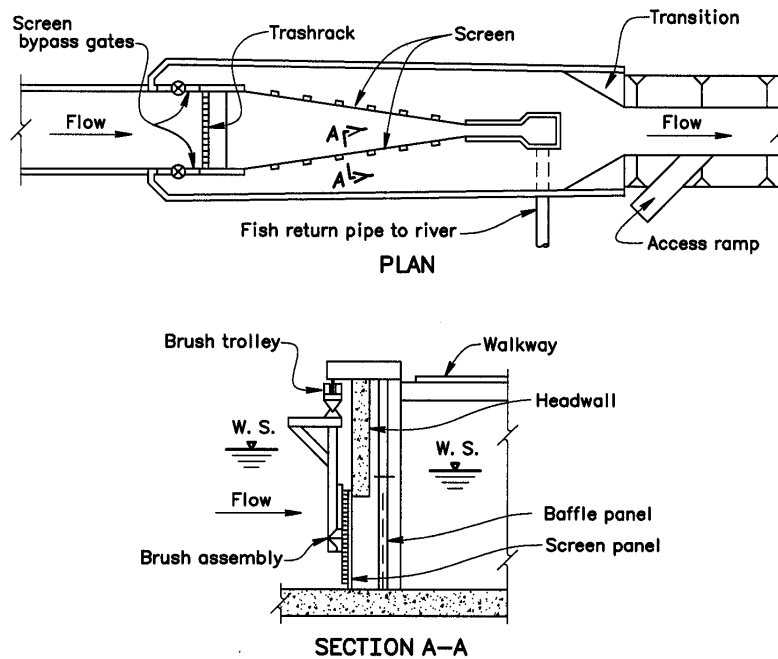


Figure 67.—Intake with concrete head wall – Ice protection at Wapatox (Rainey, 1985).

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

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

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

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

2. Drum Screens

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

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

A screen installation can consist of a single screen at smaller sites. Portable paddle-wheel screens have been installed in numerous locations in Idaho, Washington, and Oregon (figure 68). They are usually a standardized design, fabricated and installed by each State's screen shop, with maximum directed flow of up to 5 ft³/s. They are assembled in sections. Figure 68b shows the drum screen dismantled and elevated out of the canal for winter storage. Reclamation has worked with State screen shops in setting locations and elevations as well as analyzing hydraulics.



a. Operation – in the dry.

b. Dismantled from drive shaft and raised.

Figure 68.—Small paddle-wheel drum screen (2.5 ft³/s) located on Deep Creek near Adel, Oregon.

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

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

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

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

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

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

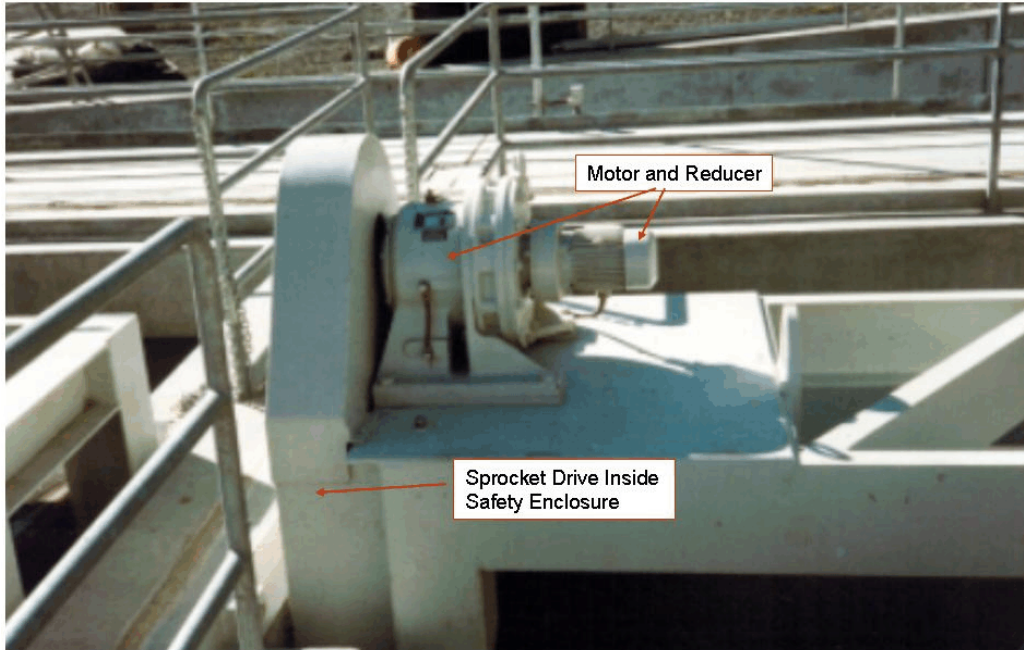


Figure 69.—Drum screen drive system.

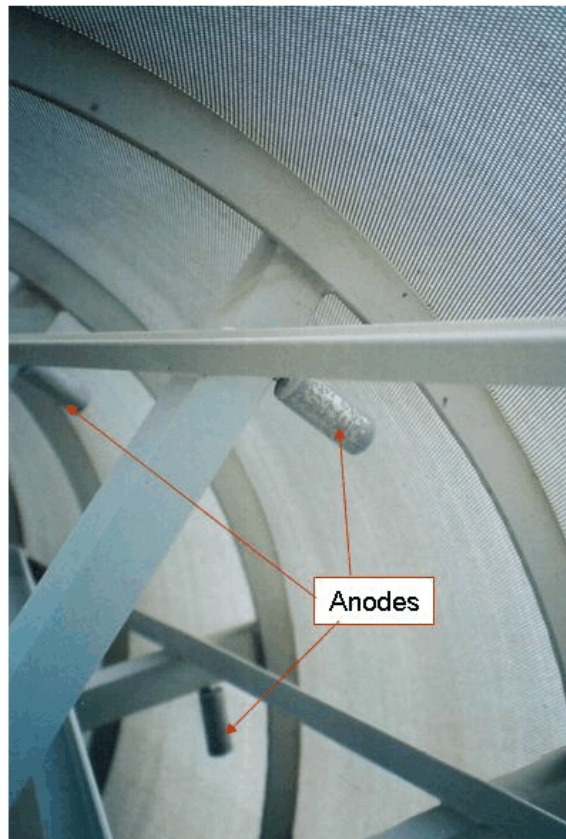


Figure 70.—Sacrificial anodes inside drum screen at Tracy Fish Facility, California.

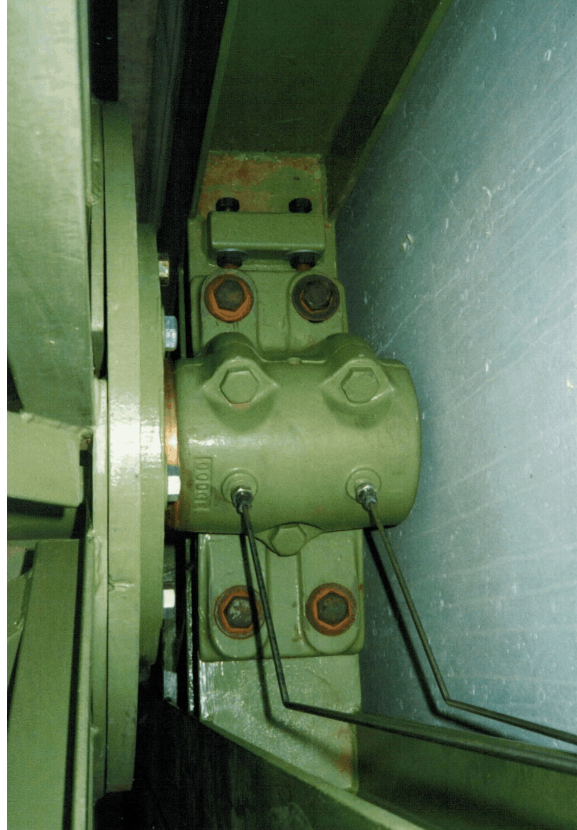


Figure 71.—Looking down on drum screen pillow block bearing with grease tubing.



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

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

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

Drive system – Normally, each drum screen is provided with an electric motor operated drive system designed to continuously rotate the drum (figures 34 and 69). Where power is not available, a water-powered paddlewheel has sometimes been provided directly downstream from each screen and connected to drive the drum (figure 68). Another option may be a solar-powered system to provide electricity. Non-electric power sources are usually applied at sites where there is a small diversion (under 5 ft³/s). The electric operated drive system consists of a motor, a gear reducer, sprockets, drive chain, and chain take-up or tensioning system. The drive system is usually designed to operate the drum screen under a maximum differential water loading, between 2 and 5 ft. The drive system loadings also need to include loadings because of seal forces against the rotating drum. The reducer and sprockets are used to slow the speed from the motor output speed to the desired rotation speed of the drum. The drum screen should be rotated slowly about its axis, usually around 10 ft per minute at the outer screen diameter. Sprockets are keyed to the reducer output shaft and to the shaft on the cylindrical drum. The drive sprocket is usually a shear-pin type sprocket to protect the drive system from damaging overloads. The drive chain may need to be enclosed in an environmentally friendly, food-grade-oil bath. An alternative drive system arrangement uses the outer diameter of the drum as the drive sprocket to turn the drum in lieu of the sprocket on the drum shaft. This may keep the drive chain out of the water; however, the drum shaft bearings are still needed and will be submerged. Gear box sizing is important. Gear boxes have been found to be much more dependable than the old worm-drive design.

Debris cleaning – Drum screen installations usually require an upstream trashrack (figure 4). The continuous rotation of the drum screen creates a self-cleaning feature (figures 11 and 34). Debris that contacts and sticks to the screen

will be lifted out of the water and carried over to the downstream side, where the diverted flow passing through the screen washes the debris off the screen surface and on downstream. Therefore, it is suggested that the drum screen configuration have a lower ratio of sweeping to approach velocity than other screens to ensure debris will attach to the drum screen and be carried out of the water. This is generally the case; however, certain types of the debris may cling to the screen and require additional cleaning. A high pressure spray (spray water pump and piping with connections for spray hoses or spraybars) may be provided to periodically clean the screens. Another cleaning source may be a rotating brush located against the drum at the downstream water surface.

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

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

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

Cold weather operation – Drum screens have been installed in climates where icing may occur. In these cases, additional features or operating controls should be investigated and provided where needed. Since the drum continuously rotates, freezing can occur on the wet screen fabric rotating above the water surface. Ice accumulation at or near the water surface can also damage the structural metal components of the drum and frame. Operation may dictate that the screen be left in place, but turned off to prevent it from rotating and freezing. Other situations where anchor or frazil ice are present may dictate that the screens need to be raised and pinned above the water surface so that they are not damaged. This may also require that the canal system be shutdown because these types of ice can also damage the trashracks, cleaners, and other equipment. The screen guides can also be constructed with heat cables to keep ice off the guides, thus allowing the screens to be pulled if necessary. At some sites, a dedicated gantry crane is provided to automatically pull a screen in the event of an excessive water level differential caused by ice or debris loads. This protects the screen structure from

possible failure and damage; however, it opens a fish passage. Other solutions may use a sluice gate or relief system built within the structure to prevent overloading and damage of the structure. Some installations may be able to incorporate a bubbler or propeller system that raises or circulates the warmer, deeper water to keep ice from forming on the surface. At Roza Diversion Dam, small propellers are used to circulate diversion pool water as a means of preventing ice from building up against the screens.

3. Traveling Screens

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

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

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

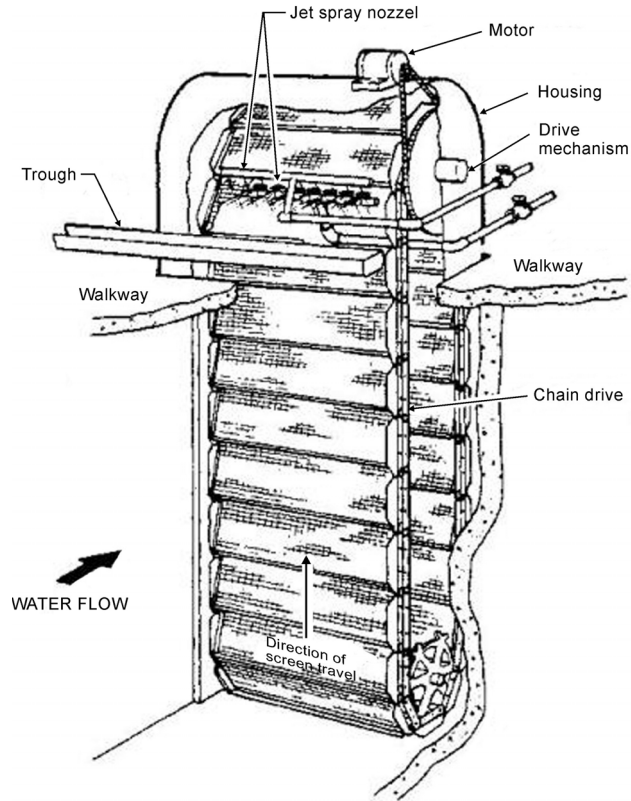


Figure 73.—Vertical traveling screen (EPRI, 1986)

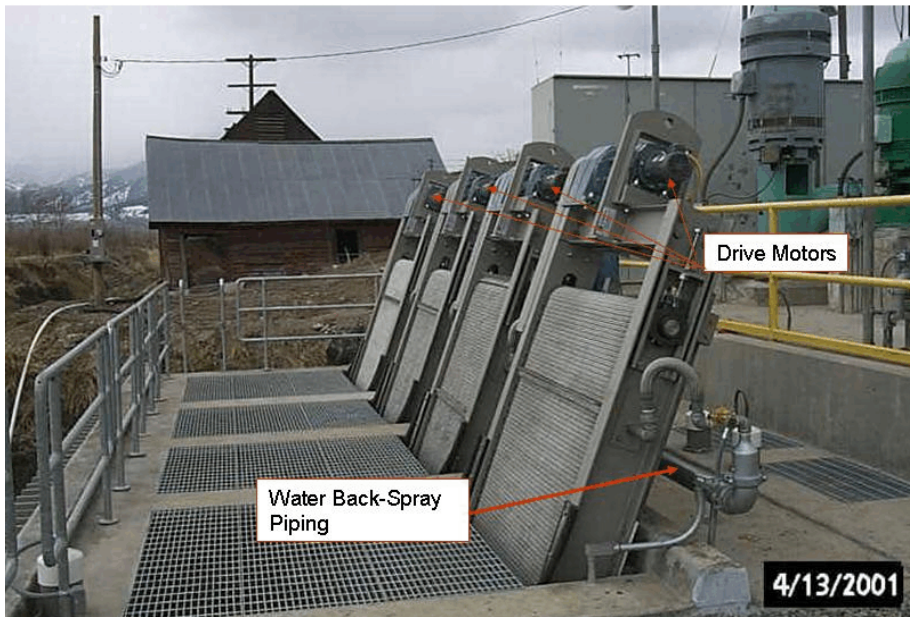


Figure 74.—Inclined traveling screen with continuous belt – Lilly Pumping Plant, Oregon.

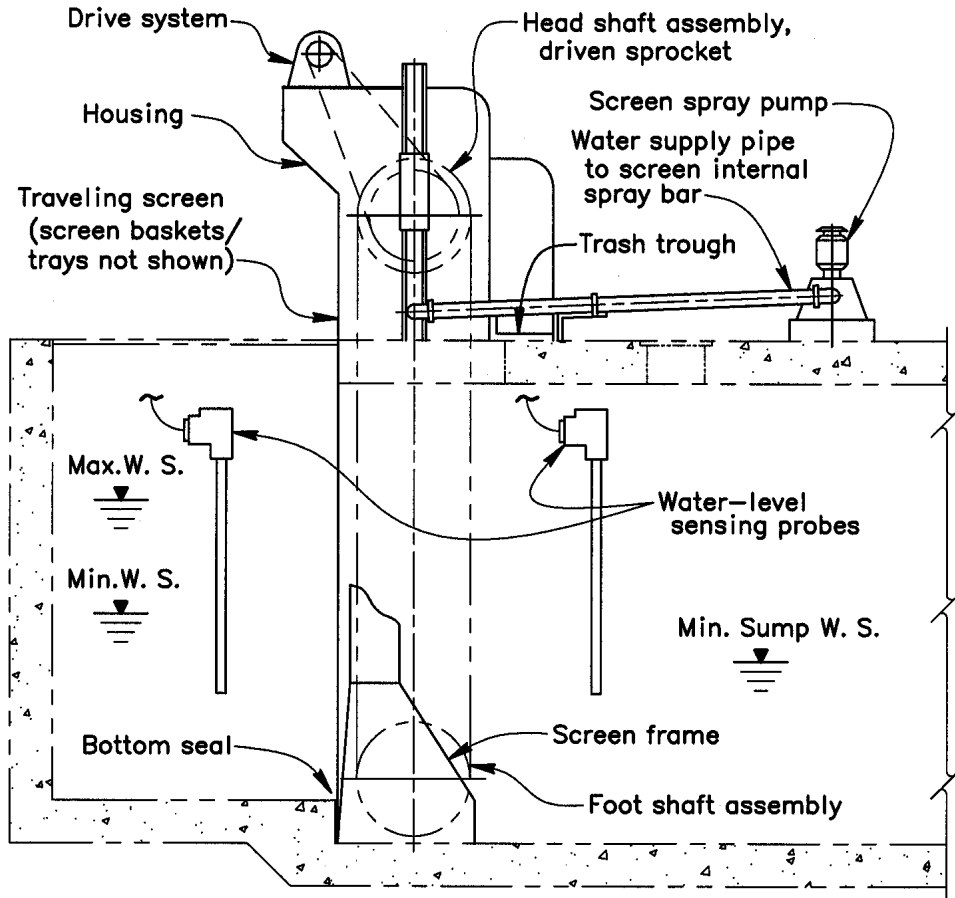


Figure 75.—Vertical traveling screen with increased effective screen height.

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

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



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

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

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

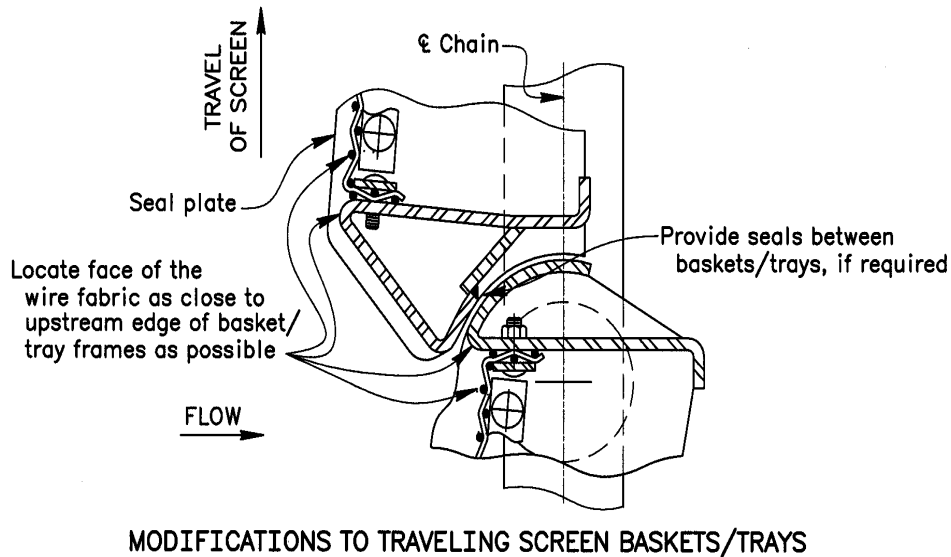


Figure 77.—Location of vertical traveling screen basket frame relative to screen material.

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

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

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

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

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

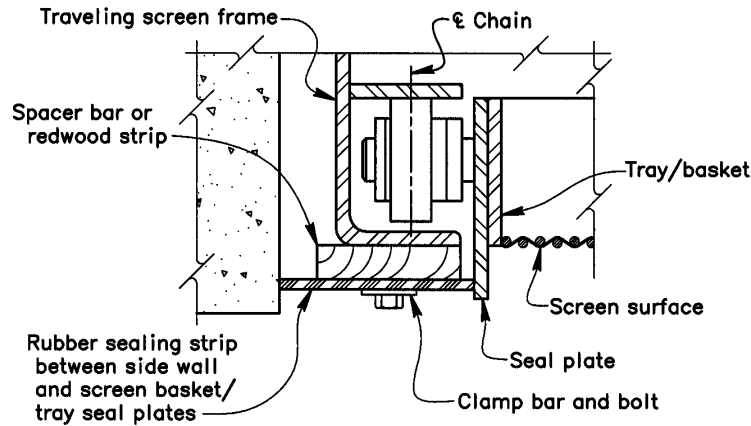


Figure 78.—Vertical traveling screen seals (basket or tray type).

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

Debris cleaning – Traveling screen installations usually require an upstream trashrack. For details of trashrack and cleaners, see chapter IV.A.12.b. The traveling screen removes debris that contacts and sticks to the screen by lifting the debris out of the water with the upward travel of the screen or baskets. Water jets flush the debris from the screen either back into the upstream water to be carried away or into a trash trough where it is sluiced or conveyed away for disposal (figures 13, 73, 74, and 75). A high pressure water source needs to be provided. This source can be a separate deck mounted vertical pump, a submersible pump, or an inline booster pump that uses available water and pressure head from a downstream pumping plant if the pumping plant discharge line has sufficient line pressure and flow. The required water flow and pressure varies between screen

manufacturers, and pressures range between 40 and 100 pounds per square inch (psi). Flow is up to 30 gallons per minute per ft (gal/min/ft) of screen width. Multiple spraybars may be used. For multiple screens, a common trash trough may be desired. For inclined traveling screens, the cleaning process sprays the debris into a trash trough mounted on the downstream side of the screen. The trash trough may be fabricated metalwork mounted on top of the deck or a concrete trench built within the deck. The cleaning system may include a debris conveyance (conveyor) type system to transport the debris flushed from the trash trough to a desired deposit location. This conveyor may also require a spray water cleaning system.

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

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

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

Cold weather operation – Traveling screens have been installed in climates where icing may occur. In these cases, additional features and/or operating controls should be investigated and provided where needed. Freezing can occur on the wet screen fabric rotating in the cold air above the water surface. Ice accumulation on or near the water surface can also damage the structural metal

components of the screen and frame. Ice may also damage the seals. Operation may dictate that the screen be left in place, but turned off, so that it won't rotate and freeze. Other situations where anchor or frazil ice are present may dictate that the screens be removed so that they are not damaged. Removal of screens will require that the canal or pumping system be shutdown since these types of ice conditions can also damage the trashracks, cleaners, and other equipment. Because spray water cleaning is used, the system piping may need to be wrapped with heating cable and insulated or turned off and drained to prevent the spray water pump and piping from freezing. The screen guides may also be constructed with heat cables to keep ice off the guides, thus allowing the screens to be pulled if necessary. Some installations may incorporate a bubbler or propeller system to raise or circulate the warmer deeper water to keep ice from forming.

4. Submerged Screens

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

a. Cylindrical screens

Fixed and retrievable cylinder screens can be used for fish exclusion as part of an intake structure in a river, lake, or reservoir. Other screen intakes may use removable cylinder screens. By controlling the quantity of diverted flow and, therefore, approach velocity, V_a , impingement and entrainment of debris and aquatic life are minimized. Cylinder screens are commercially available and are used in low-flow screening applications, usually for diversion flows ranging from 0.5 to 400 ft³/s, where multiple screens are required at the higher flows. The screens are normally installed in rivers or streams where the flow can be used to assist with fish sweeping velocity and cleaning properties of the screen. In reservoirs and lakes, cylinder screens may be used as part of an intake tower that allows withdrawal from selected levels, thus allowing water quality and/or temperature selection. Cylinder screen installations should be avoided in backwater areas, dead ends, and the ends of canals because debris tends to accumulate in these areas and there are no means of removing debris from screen surfaces. These areas are also common breeding areas for fish and other aquatic organisms.

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

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

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

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

The cylinder screen manufacturers recommend that the outer screen surface be at least a distance of one-half the screen diameter away from any river or reservoir boundary (whether a bottom or a side wall) and at least one-half the screen diameter below the minimum water surface. The latest NOAA Fisheries criteria call for a minimum of one screen diameter clearance completely around the screen centerline. The screen manufacturers also require a minimum of one screen diameter between multiple screens, when screens are installed side by side. Therefore, the distance between screen centerlines should not be less than 2 times the screen diameter. Multiple screens will be required if the calculated single-screen diameter is greater than one-half the minimum water depth. Multiple screens will usually be placed end to end (in line) to improve not only the

hydraulics, but to produce a smaller target for the debris and fish to encounter. Other items that need to be evaluated because they can affect the size of the screen and the intake location are sedimentation, icing, and navigational clearance requirements.

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

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

The hydraulic design of the screen should provide for uniform flow distribution over the surface of the screen. An internal baffling system is usually provided by the screen manufacturer as part of the screen. The system is used to try to create uniform withdrawal over the length of the screen. A physical hydraulic model, bathymetry and hydro-acoustics studies, a sedimentation study, or mathematical model study may be required to ensure good flow conditions and depths at the site, specifically in the channel leading to and past the screens. These studies can

identify and provide solutions for high-velocity areas that could damage the screen if not properly protected and for low-velocity areas that could bring sediment to the screen.

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

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

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

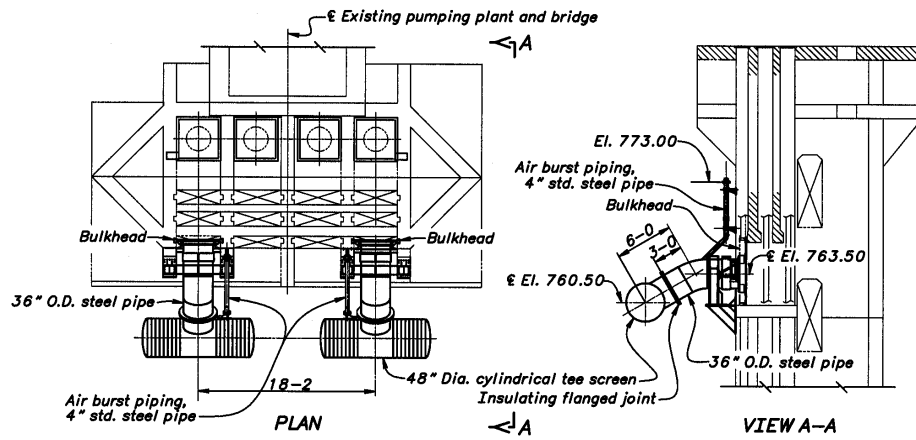


Figure 79.—Intake retrofit using fixed cylinder screen with air burst cleaning at Brewster Flat River Pumping Plant, Washington.

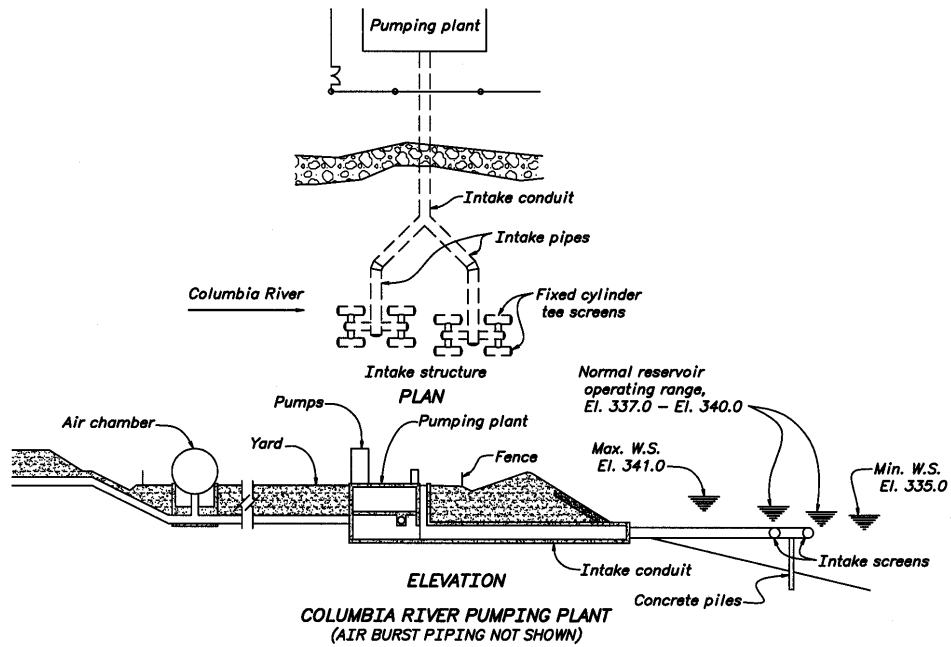


Figure 80.—Plan and elevation of Columbia River Pumping Plant.



a. Internal brush projecting through the screen.

b. External brush.

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

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

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

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

As water is diverted through the cylinder screen, debris will gradually build up onto the screen surface. The most common method of cleaning the fixed cylindrical screen is an air burst cleaning system (figures 31, 79, and 80). This

system requires a high pressure air receiver tank, air compressor, concrete slab, piping between the screen and the air receiver tank, valves, and controls. The system may be designed for outdoor service, but it may be installed within the pumping plant building or its own shelter. A less common cleaning method uses either a high volume of water or high pressure water to back flush the screen. In either cleaning method, once the debris is lifted off the screen by the river flow, it is carried on downstream.

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

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

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

$$P_1 * V_1 = R_f * N * P_2 * V_2, \text{ where:}$$

P_1 = Air receiver tank pressure, psi

V_1 = Air receiver tank size, ft³

$$P_2 = \text{Ambient screen pressure, psi, } (14.7 + d * 0.4334), \text{ where } d =$$

Maximum depth of water above the screen (ft)

V_2 = Volume of screen + volume of air burst pipe, ft³

N = Number of screens to be cleaned simultaneously

R_f = Screen volume ratio factor

Another type of commercially available cylinder screen uses a self-propelled rotating screen and an internal backwash cleaning system (internal spraybar with nozzles). A pump and piping will be needed to provide cleaning water to the

backwash spraybar. The required backwash pressure from the pump will usually range between 50 to 100 psi, depending on the size of the screen. The spray water is used to not only clean the drum shaped screen but also to power the rotation of the screen by pushing against internal propelling vanes.

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

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

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

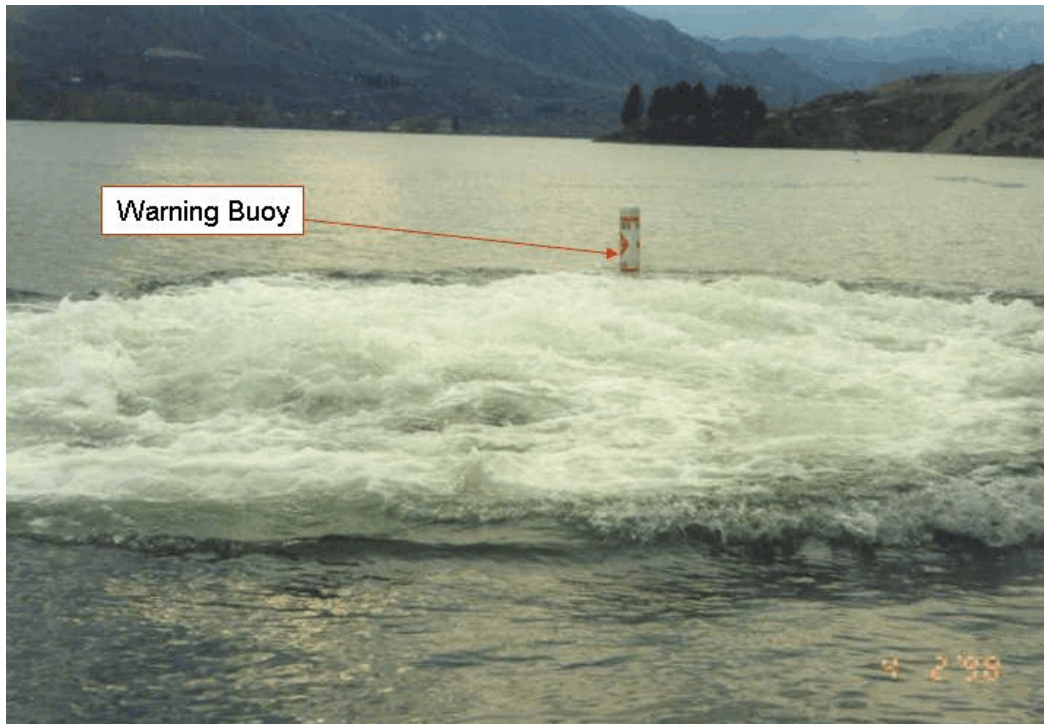


Figure 82.—Surface disturbance resulting from the air burst cleaning of fixed cylindrical screens.

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

Cold weather operation – Fixed cylinder screens have been installed in cold weather climates where icing may occur. The screens should be set as deep as practical and located below any possible ice scour to prevent damage during breakup of an ice cover. Also, cylindrical screens should not be installed directly downstream from rapids because of the possibility of frazil ice forming within the rapids and adhering to the screens. The screen manufacturer should be contacted to provide any additional features, site options, or operating controls that may need to be investigated and applied. Most deep screen installations should not be

affected by cold weather operation, but it may be desirable to incorporate a bubbler system which raises the warmer deeper water to the surface to keep ice from forming near or on the screens. Retrievable screen systems do not have a history, yet, of operating in cold weather. However, if the irrigation season does not extend into the winter season, the winch can raise the screen and store it above flooding events. If cold weather operation is necessary, heaters and a recycling system for the hydraulic fluid (for cleaning) may be required. For self-propelled, rotating cylinder screens, the backwash piping and pump should be protected from freezing.

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

b. Inclined screens

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

One configuration includes a fully submerged screen that is placed on an adverse slope to the flow. The flow passes from the toe or deep end of the screen to the high end of the screen as water is drawn through. Since the screen remains fully submerged, a portion of the flow passes over the downstream (high) end of the screen providing a fish bypass flow. The adverse slope screen may be fully fixed or it may be hinged allowing the screen to be raised or lowered at the downstream end to follow changing water surface elevations (figure 83) (Potter Valley Project). Fish must pass over the full length of the screen to reach the bypass (figure 18). Constant sweeping flow can be sustained across the length of the screen because the flow discharge passing over the screen decreases as the flow

depth and flow cross-section decrease toward the downstream end. The closed conduit Eicher and MIS screens are special types of inclined screens that are addressed in chapter IV.B.6.

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

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

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

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

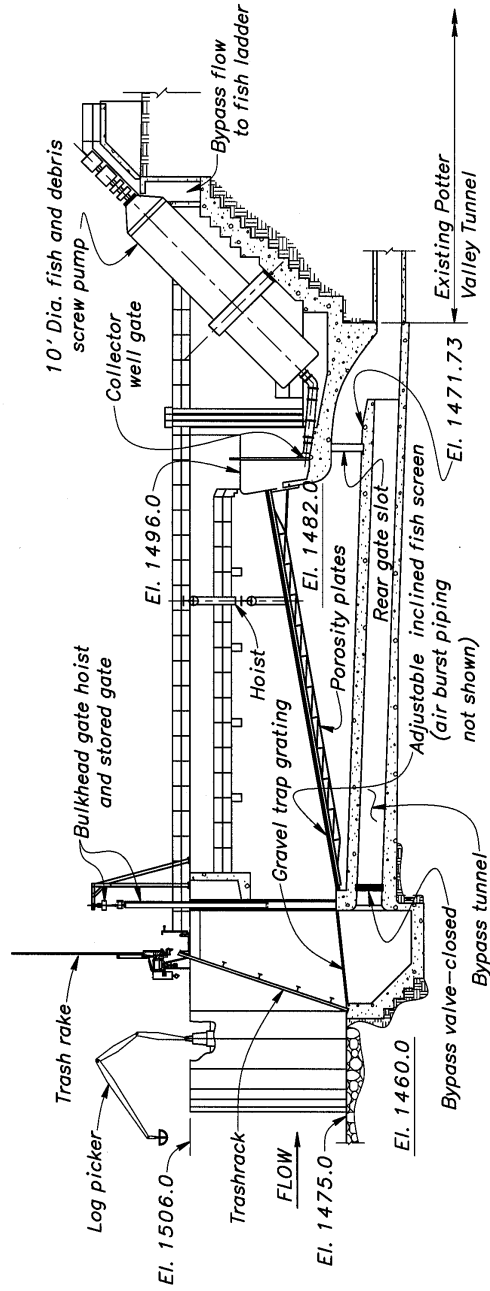


Figure 83.—Potter Valley inclined screen, California (Pacific Gas & Electric).

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

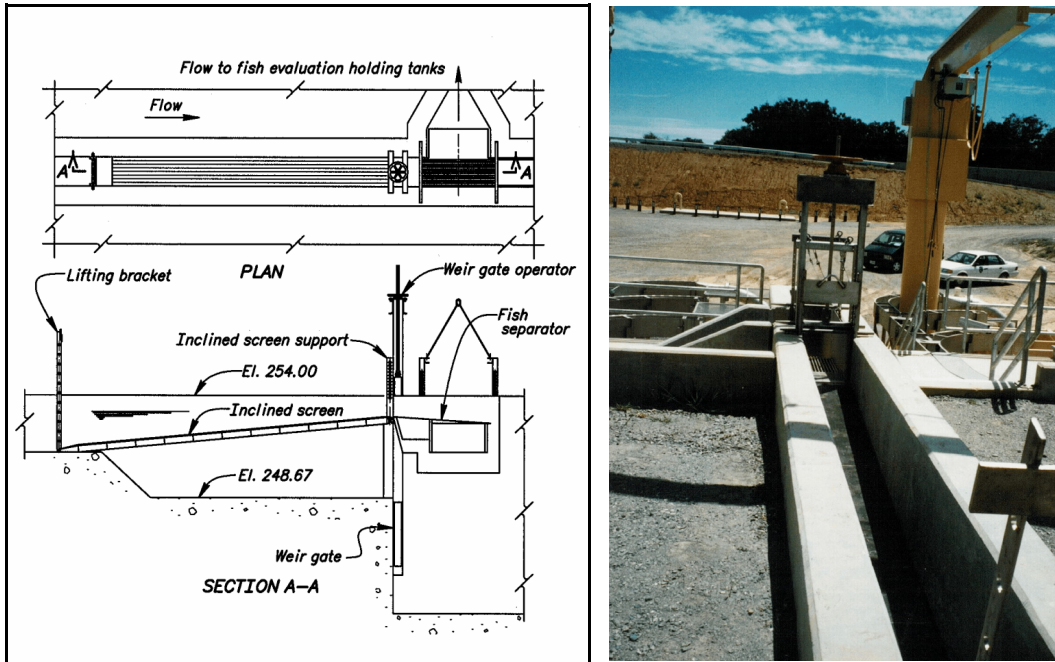
A screen installation can consist of a single screen panel at smaller sites, a series of screen panels placed end to end on a support structure or frame, or multiple screens. The screen facility design must provide for uniform approach flow distribution over the surface of the screen. This usually requires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

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

- ▶ Evaluate and provide good flow conditions in the channel leading to and passing over the screens (particularly where more complex channel and screen configurations are applied)
- ▶ Identify and possibly avoid localized high and low approach velocity zones
- ▶ Ensure adequate bypass approach conditions

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

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



a. Schematic of screen structure.

b. Photo of inclined screen.

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

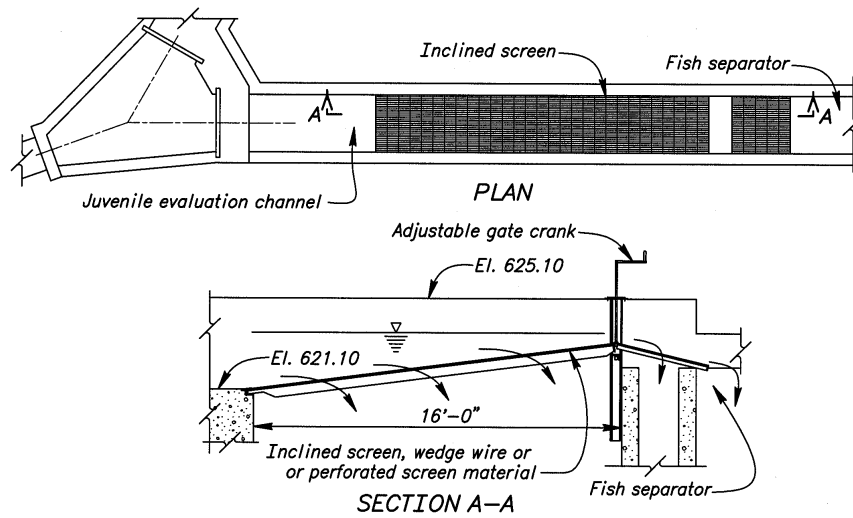


Figure 85.—Chandler inclined screen in juvenile fish bypass facility with downstream adjustment capability.

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

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

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

supporting metalwork to reduce the friction when adjusting the screen. Common types of wear strips are fabricated from UHMW polyethylene, nylon, delrin, Teflon, and brass.

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

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

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

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

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

A crane (jib, gantry, or mobile) or monorail hoist system may be provided as part of the screen structure to allow installing, adjusting, or removing the inclined screen and associated metalwork for maintenance or repair. (See chapter IV.A.7.)

The mobile crane alternative for installing and removing the screens may be more economical for smaller screen structures, but may also be more inconvenient.

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

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

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

c. Horizontal flat plate screens

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

The Horizontal flat plate screen concept has been patented by the Farmers Irrigation District of Hood River, Oregon. NOAA Fisheries has accepted the horizontal flat plate screen concept as a proven technology for fish exclusion and

does not consider the concept experimental. However, it would be wise to check with the local fishery resource agency for acceptance and criteria related to installation of this screen.

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

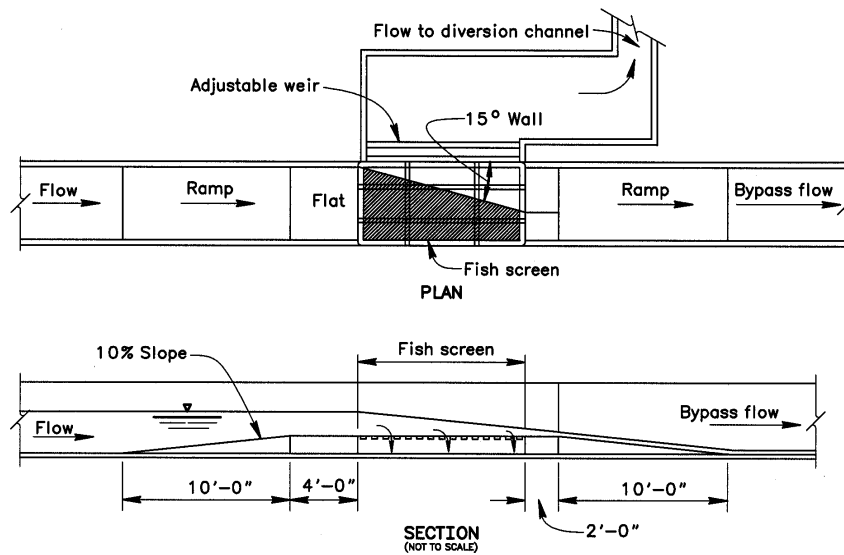


Figure 86.—Horizontal flat plate screen schematic-Reclamation laboratory model.

Desired flow characteristics along the screen surface include uniform flow velocities through the screen and uniform sweeping velocities with no eddy or slack water zones. Hydraulic jumps (flow transitions from supercritical to subcritical flow) should not occur on the screen face. Higher sweeping velocities of 2 to 6 ft/s improve fish guidance across the screen and screen cleaning characteristics. Physical hydraulic model investigations (Frizell and Mefford, 2001) indicated that maintaining high sweeping velocities across the screen may

improve fish passage and cleaning characteristics. An invert drop should be included at the downstream end of the screen. The drop will generate critical flow conditions at the exit (bypass) end of the screen. This critical flow prevents slumps in the sweeping velocity over a wide range of operating conditions (figure 87). The screen should be designed to provide approach velocities (flow normal to the screen, V_a) that comply with fish species and fish size specific criteria (table 4).

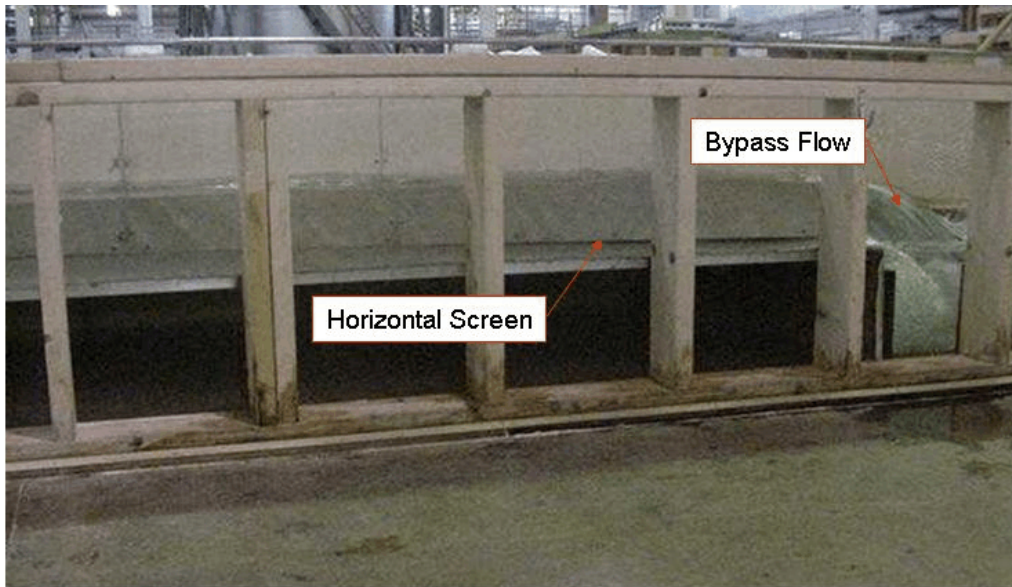


Figure 87.—Side view of horizontal screen in laboratory model showing good flow depth over screen.

Uniform sweeping velocities can best be generated by:

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

Laboratory modeling results indicate that improved self cleaning conditions may be maintained if approach velocities, V_a , are held at or below 0.2 ft/s. Designing an approach velocity, V_a , of 0.2 ft/s may be appropriate where no supplemental screen cleaning is included; fishery resource agency criteria may require a smaller approach velocity depending on how they define this type of screen (self-cleaning

or not self-cleaning). The required screen area should be considered when designing the approach velocity and the active screen area (screen area less area blocked by structural members).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Application experience – Field experience with Horizontal Screens is currently limited to screens on a few irrigation deliveries in Oregon and Idaho. Two state-of-the-art installations were cited by Farmers Irrigation District personnel. An 80 ft³/s screen was installed at Davenport Stream, Oregon, in spring 2002. A second screen was installed at East Fork Ditch, Idaho (16 ft³/s), in summer 2004. To date, sediment and debris handling characteristics of these screens has proven

good. Laboratory evaluations and design refinement studies are limited to the referenced Frizell and Mefford (2001) hydraulic investigation and the Beyers and Bestgen (2001) fisheries investigation. Debris and sediment handling and removal have not been thoroughly investigated and refined.

5. Coanda Screens

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

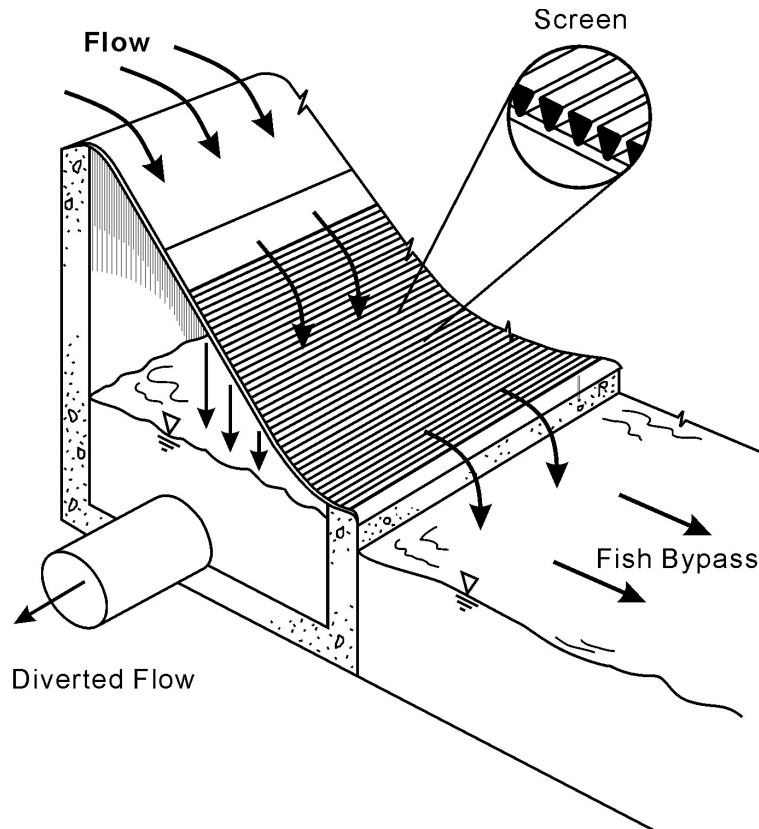


Figure 88.—Coanda screen.

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

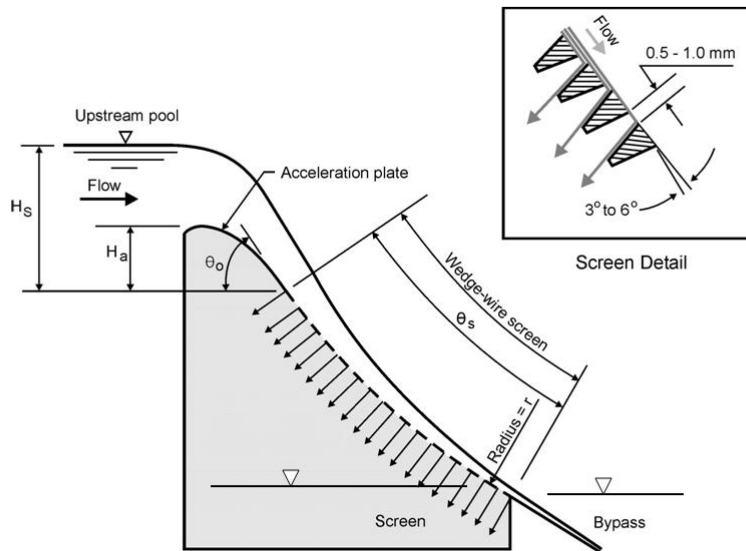


Figure 89.—Features of Coanda screen – Typical arrangement and design elements.

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

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

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

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

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

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

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

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

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



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

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

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

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

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

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

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

Screen panel including screen seats, seals, and supports – The design of the screen panel (that spans the diversion collection trough) and its associated structural support and seats is typically developed by the screen manufacturer. These screen panels include heavy duty backing frames that provide durable screen surfaces that can pass large flows and large debris with minimal damage to the screen. Such performance has been thoroughly documented at several small

hydropower sites in California (Ott et al., 1988). The accelerator plate, backing frame, and screen face are typically fabricated from 304 stainless steel. The accelerator plate is welded to the backing frame so that it is flush with the screen surface at the leading edge of the screen. By its nature, only profile bar screen fabric is used. Copper-nickel plated metalwork and screens are sometimes used at sites where the potential for biological growth on the screen is high, but this practice is not widespread and is of questionable economy.

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

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

while others are properties of the screen material:

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

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

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

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

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

screen length (in the flow direction) or increasing the weir length (the structure length or screen width perpendicular to the flow direction).

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

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

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

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

The Wahl (2003) study evaluated the hydraulic performance of a wide range of Coanda screen structures. Wahl considered variations in screen configuration and slope, slot width, wire size, and wire tilt. Both concave and planar screen configurations were evaluated. The study used a numerical model to generate relationships between unit discharge passing over the weir crest, wetted screen length, unit discharge passing through the screen, and unit bypass discharge. These relationships define the rating curve of a screen structure. Figure 91 shows rating curves for a concave screen with a 0.25 ft accelerator drop (this is representative of commercially available Coanda screens), and figure 92 shows

the rating curves for a 3 ft-long planar screen placed on a 15° slope (this is typical of a screen that might be applied in a small irrigation canal where head losses would have to be limited).

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

For example, for the commercially available screen shown in figure 91, if a diversion discharge of 50 ft³/s with a unit bypass flow rate of 1.0 ft³/s/ft is required, then:

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

Diversion discharge = $(5.55 - 1.0) (11 \text{ ft}) = 50.05 \text{ ft}^3/\text{s}$

As a consequence, an 11 ft wide screen with a minimum unit approach discharge of 5.55 ft³/s/ft will supply the required diversion discharge (50 ft³/s) and required unit bypass flow rate of 1.0 ft³/s/ft for this example. The minimum pool elevations necessary to generate 5.55 ft³/s/ft minimum unit approach discharge must be considered when setting the crest elevation that will supply the screen. Note that when the diversion pool is at higher elevations and greater unit approach flows are generated, both the bypass flow rate and the flow rate through the screen (diverted flow) will increase (figure 91). The conveyance channel receiving the screened flow will then have to be regulated to limit the diversion to the 50 ft³/s maximum. (See the paragraph below.)

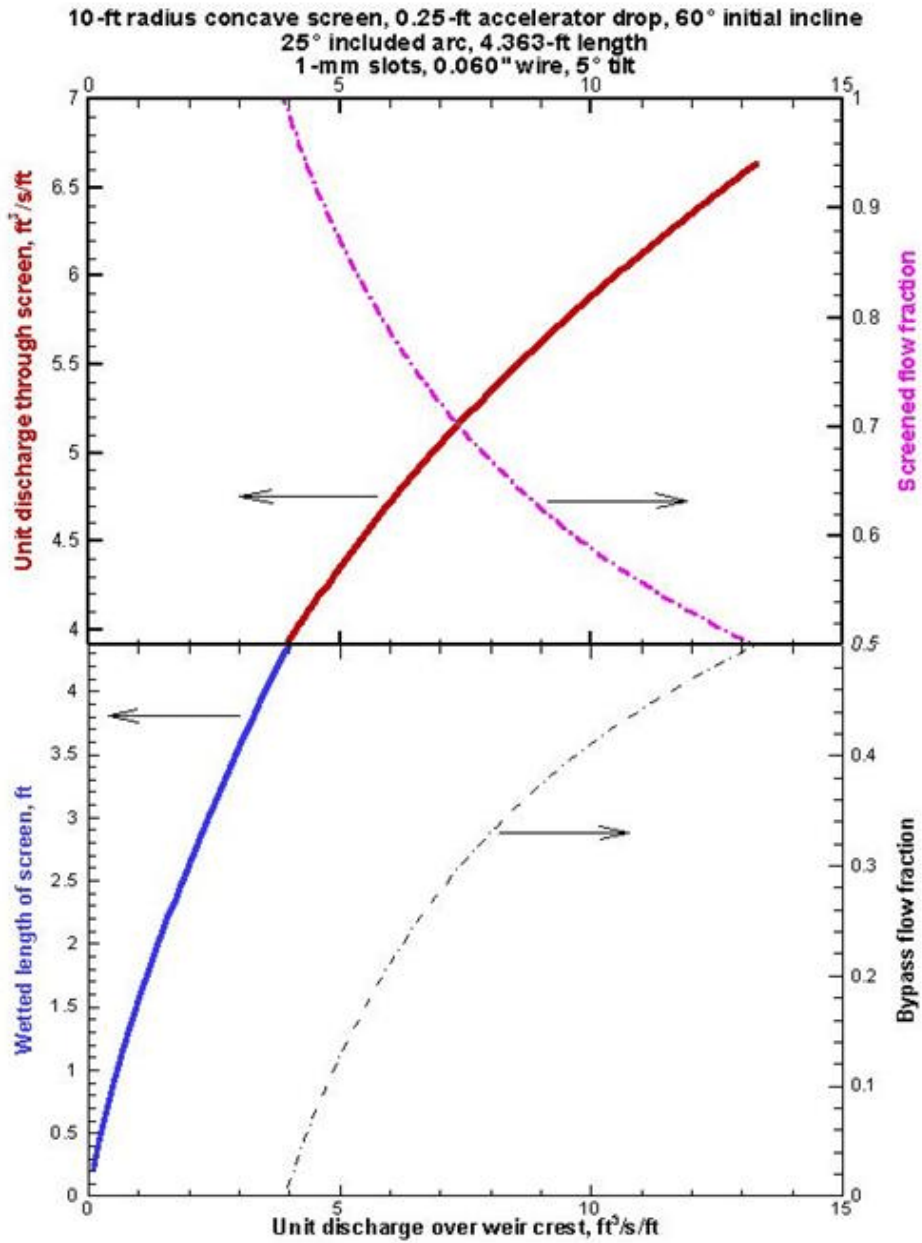


Figure 91.—Concave Coanda screen (commercially available) (Wahl, 2001).

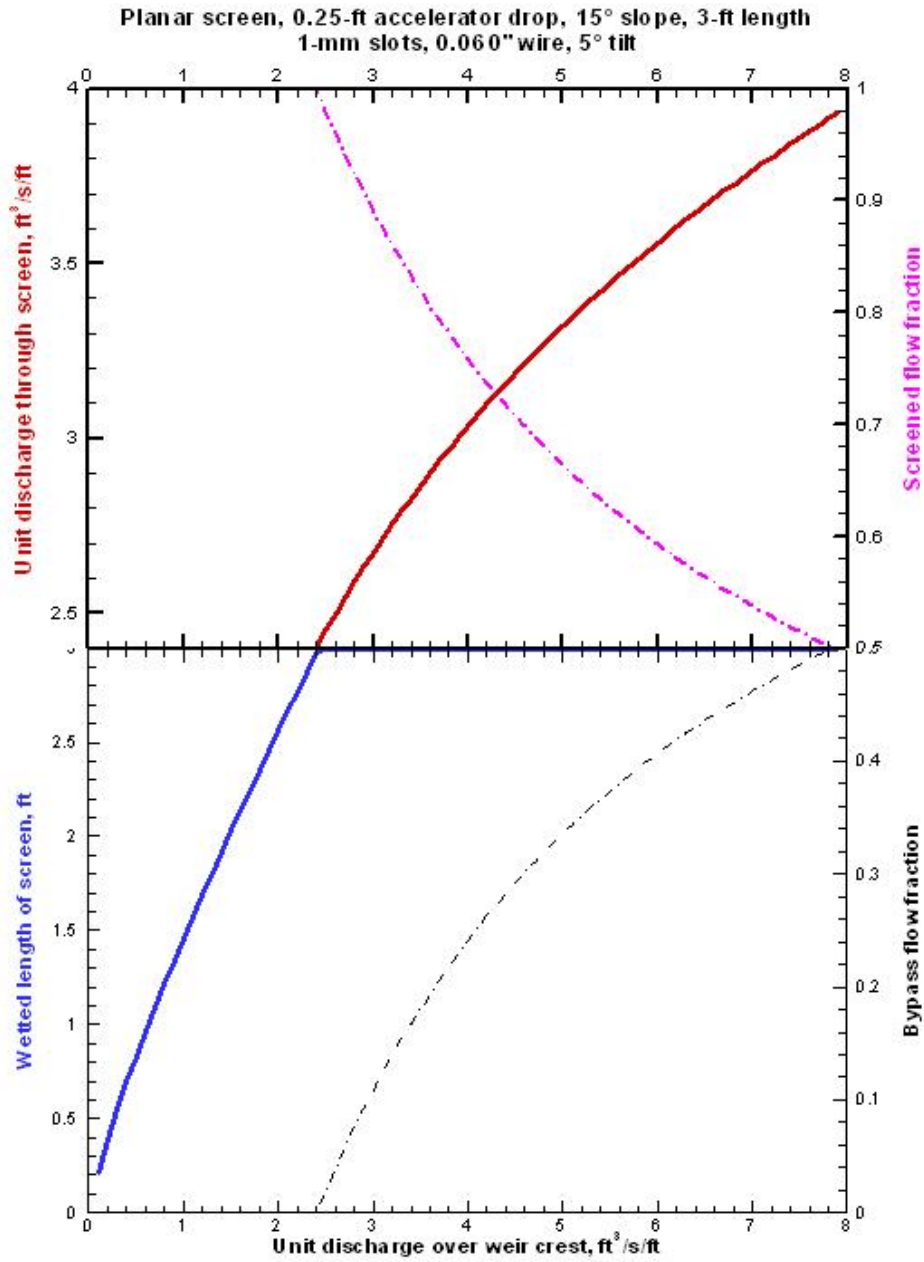


Figure 92.—Planar reference screen on 15 degree slope, 3-ft long with 1-mm slots (Wahl, 2001).

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

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

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

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

become lodged in the slots and are often resilient enough that the flow does not easily break them off.

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

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

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

Screening of heavily sediment-laden flows is a strength of these screens, as one would expect from their mining heritage, but also creates special maintenance concerns. An example is a pair of screens installed on powerplant diversions at Kanaka Creek and Kekawaka Creek in northern California. These projects are operated by STS Hydropower, Ltd., a subsidiary of Northbrook Energy. The screens were installed during initial construction of the powerplants in 1988 and 1989 for the purpose of excluding fish (rainbow trout) and debris. The screens divert 35 and 70 ft³/s, respectively, from streams carrying heavy bed loads and organic debris consisting of leaves and alder buds. The screens are truly self-cleaning and require no manual cleaning, but the bed load traveling over the screens gradually wears down the leading edge of the wires, reducing the flow capacity of the screens. The operators regularly replace screen panels because of this and estimate the average life span of a panel to be about 3 years.

6. Closed Conduit Eicher and MIS Screens

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

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

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

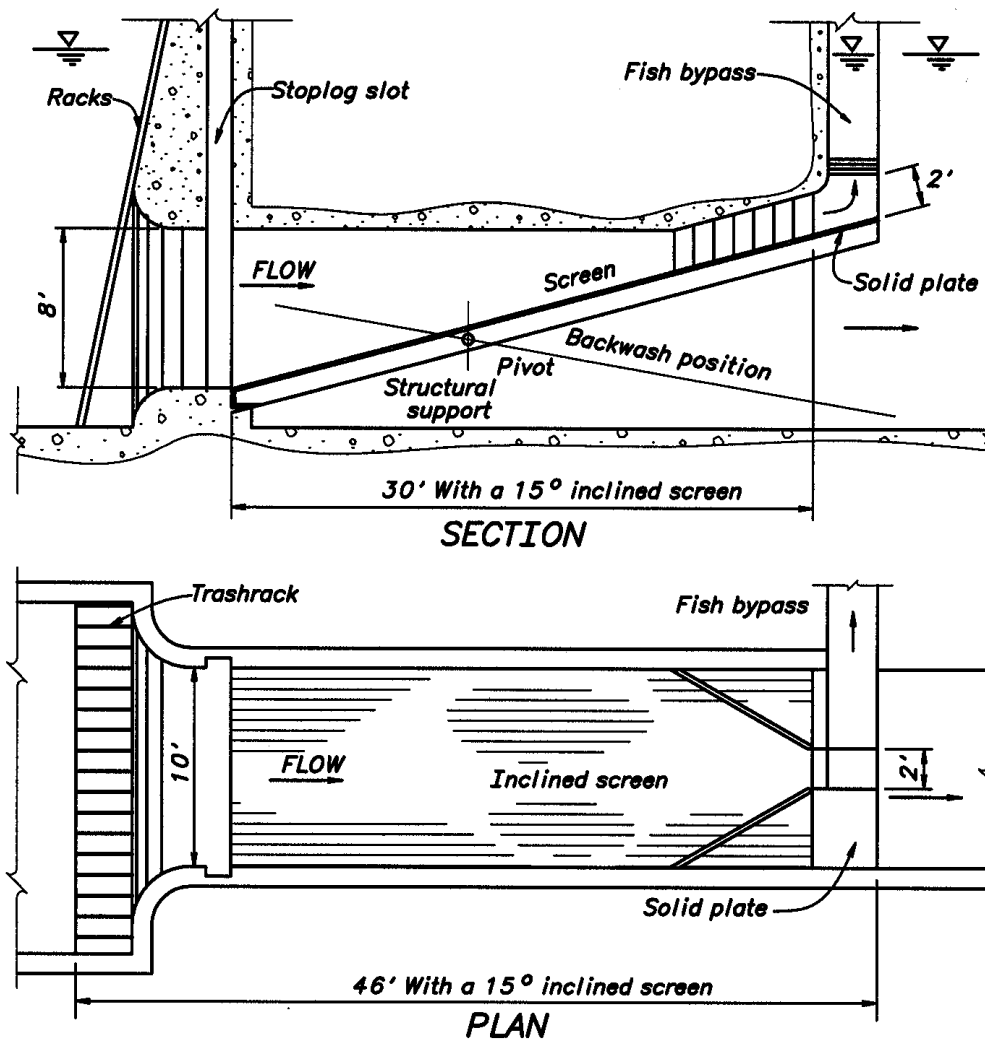


Figure 93.—Features and typical arrangement for a rectangular conduit MIS screen (EPRI, 1996).

modules were developed to be included in the intake structure positioned immediately downstream from the intake trashracks. The configuration of the module with included transitions was developed for this specific application configuration and the specific hydraulic flow patterns generated. The MIS module concept was not developed for application within extended lengths of delivery pipe or conduit, although site specific studies could be used to develop MIS screens for such applications. The MIS concept is patented in the United States by EPRI. The screen concept was developed through use of laboratory studies that refined and evaluated hydraulic and fish passage characteristics of the design. Field application experience is limited to a pilot facility evaluation that

was conducted at Niagara Mohawk Power Corporation's Green Island Hydroelectric Project, New York, in 1996. As a consequence, the field experience base with MIS screens is marginal.

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

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

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

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

Laboratory screens have been tested that effectively exclude fish with minimal injury or mortality. These laboratory installations were applied in conduits with diameters ranging from 2.0 ft to approximately 3.2 ft. Corresponding flow rates with a flow velocity of 6.0 ft/s range from 19 to 48 ft³/s. Effective fish handling performance was also observed in these models when operating with reduced velocities and correspondingly reduced discharges. These laboratory studies indicate that smaller size closed conduit screens are potentially feasible for field application. The hydropower installations that have been field validated were installed in conduits with diameters ranging from 9.0 to 10.5 ft. At a velocity of 6.0 ft/s, corresponding discharges ranged from 380 to 520 ft³/s. These larger facilities have proven fully functional in field applications.

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

Fish passage – From a fish protection and exclusion perspective, the design objective and concerns for closed conduit screens are much different from those for traditional screens. Traditional screens are primarily a physical barrier in a

flow that gently guides the fish to the bypass. The screens are designed so that fish can avoid or maintain a distance off of the screen surface as they swim along the screen and into the fish bypass. Traditional screens are sized such that approach velocities magnitudes, V_a , will not cause fish impingement on the screen that could yield fish injury. Traditional screens are sized by considering the sweeping velocity that will limit the time fish are exposed to the screen. Intermediate bypasses are included if screen length, sweeping velocity, and estimated time of passage from the upstream to downstream end of the screen (exposure time) exceeds criteria.

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

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

rates for the aliased juveniles ranged from 10 to 20 percent (the aliased juveniles tested were stressed and had experienced scale loss associated with collection, transportation, and handling).

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

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

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

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

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

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

Of particular concern in sizing the bypass conduit is conduit fouling. The closed conduit screen bypasses are not readily accessible and, thus, not easily cleaned. Debris removal would likely require shutdown and dewatering of the conduit and screen. NOAA Fisheries criteria (NMFS, 1995) typically requires a minimum 24-inch-diameter bypass conduit specifically to minimize debris fouling potential. This large diameter bypass conduit will, however, yield large bypass flow rates that may be excessive and unacceptable for smaller screen installations. For instance, a 24-inch bypass requires a minimum of 19 ft³/s to achieve a 6 ft/s velocity.

Bypass conduit diameters and configurations for the Eicher and MIS field installations typically were designed to comply with National Marine Fisheries Service (NOAA Fisheries) criteria (NMFS, 1995) and, thus, are sized with a minimum 2.0 ft diameter. These, however, are large-diameter conduits screens. Bypass flow rates at these hydropower sites are less than 5 percent of the total screened flow rate. For screens with conduit capacities of less than 25 ft³/s, NOAA Fisheries criteria allows bypass conduit diameters as small as 10 inches. It may be appropriate to consider smaller diameter bypasses for irrigation screen applications. Hydraulic model studies may have to be conducted to develop and refine such a hybrid design. In such studies, fouling potential should be carefully evaluated. Details on the standard NOAA Fisheries bypass conduit criteria are presented in chapter IV.A.11 of this manual and attachment A.

Screen Capacity – Closed conduit screen capacity (diversion capacity) is a function of conduit diameter, conduit velocity, and the volume of flow diverted into the screen bypass conduit. With 6.0 ft/s as the current maximum design velocity for the Eicher and MIS screens, total discharge is only a function of conduit diameter. A 2-ft-diameter conduit would yield a conduit discharge of 18.8 ft³/s; a 4-ft-diameter conduit would yield a conduit discharge of 75.4 ft³/s.

Flow rates passed through the bypass must be subtracted from these values to determine delivered flow rates. A 1-ft-diameter bypass, operating with a velocity of 6 ft/s, would pass a discharge of 4.7 ft³/s. For the above examples, the 2-ft- and 4-ft-diameter conduit screens operating with a 1-ft-diameter bypass (4.7 ft³/s) would deliver discharges of 14.1 and 70.7 ft³/s, respectively.

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

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

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

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

configuration and flow patterns, include a corner effect that may trap fish or increase impingement potential. (This is particularly a concern where the sealed intersection is converging on the flow.)

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

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

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

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

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

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

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

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

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

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

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

It is noted in EPRI (1994) that:

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

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

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

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

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

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

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

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

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

Finally, Smith (1997) observes:

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

Power availability and need for backup power – Power is required to operate the backwash system. With closed conduit screens, it is critical that effective cleaning be maintained both to prevent fish injury and descaling and to

ensure that flow blockage resulting in negative pressures downstream from the screen does not occur. As a consequence, power and backup power are typically required at closed conduit screen sites. An option might be to develop a screen design that would open (go to the neutral or back-flush position) with loss of power.

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

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

Chapter V. Behavioral Barriers

“No human being, however great, or powerful, was ever so free as a fish.”

John Ruskin 1819-1900, British Critic, Social Theorist

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

A. Louver Design

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

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

Disadvantages of louvers over flat plate screens include the following:

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

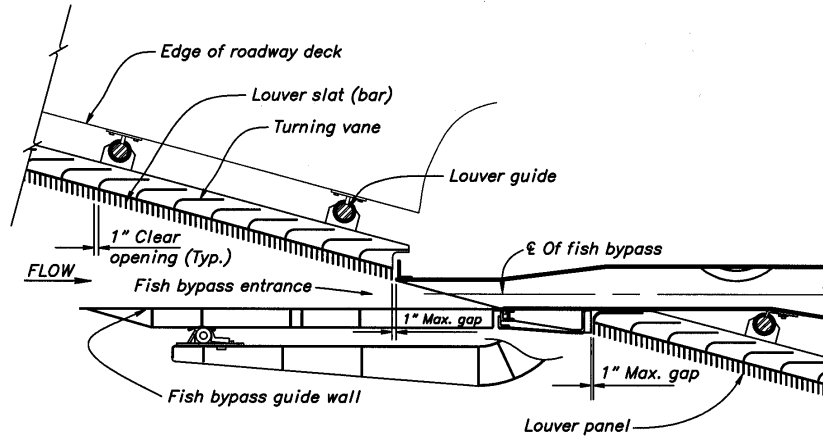


Figure 94.—Louver and bypass entrance design – Tracy Fish Collection Facility.

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

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

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

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

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

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

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

Table 6.—Summary of existing louver evaluations

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

Table 6.—Summary of existing louver evaluations

Species	Size/life stage	Site	Exclusion efficiency (%)	Site features
Chinook salmon	35 mm fork length 40 mm fork length 50 mm fork length 60 mm fork length	Tehama Colusa Canal headworks ⁵	35 75 97 98	<ul style="list-style-type: none"> * Louver lines set at 15 degrees to the canal centerline * "V" configured louvers with center wall * A section width expansion was included immediately upstream from the louvers that generated less than optimum flow alignment and distribution approaching the louver lines * 25 mm clear slat spacing * Slats oriented normal to approach channel * Evaluated operating conditions could not be located (probable channel velocities 3 to 5 ft/s)
Chinook salmon	85 to 150 mm (fall) 140 to 295 mm (spring)	T.W. Sullivan Hydroelectric Plant ⁶	94 90	<ul style="list-style-type: none"> * Forebay louver system in front of hydro intakes * Portions of louver line set at 17 degrees to and portions set parallel to approach channel * 25 and 38 mm clear slat spacing * Slats oriented normal to louver line * Channel velocities are variable depending on forebay elevation and position on louver line * The bypass is a terminal turbine intake
Steelhead	159 to 290 mm	T.W. Sullivan Hydroelectric Plant ⁶	82	Same as above
Chinook salmon	71 mm average length smolt	Tracy research facility ³	94 (90 mm) 97 (25 mm)	<ul style="list-style-type: none"> * Louver line set at 16 degrees to flow * 90 and 25 mm clear slat spacing * Slats oriented normal to approach channel * 1.9 to 2.5 ft/s (90 mm) and 2.4 to 4.5 ft/s (25 mm) channel velocity * 6.0-inch- and 4.0-inch-wide bypass * Bypass ratio not defined

Table 6.—Summary of existing louver evaluations

Species	Size/life stage	Site	Exclusion efficiency (%)	Site features
Atlantic salmon	Out-migrating smolt (length not defined)	Holyoke Canal ⁷	92 (3-inch spacing) 80 (12-inch spacing)	<ul style="list-style-type: none"> * Power canal * Floating, partial depth louver line (extended to a depth of 8 ft) * Louver line set at 15 degrees to the flow * 3-inch and 12-inch clear slat spacing * Slats oriented normal to approach channel * Approaching channel velocities were variable with discharge and position (approx. 1.0 to 3.0 ft/s max.) * Large diameter bypasses ranging from 6 to 15 ft
American shad and blueback herring	Out-migrating juveniles (length not defined)	Holyoke Canal ⁷	28 indications were that many fish passed under the louver 83 max velocity 60 half velocity	<p>Same as above</p> <p>Full-depth louver with 2.375-inch slat spacing</p>
White catfish	20 mm 30 mm 40 mm 60 mm 90 mm	Skinner Fish Facility ⁴	7 17 25 30 60	<ul style="list-style-type: none"> * “V” configured louver without center wall * Louver faces set at 15 degrees to the flow * 25 mm clear slat spacing * Slats oriented normal to approach channel * 1.5 to 3.5 ft/s channel velocities * 12.0-inch-wide bypass * 1.2 to 1.6 bypass ratios
White catfish	20 mm 30 mm 40 mm 60 mm 90 mm	Skinner Fish Facility ⁴	13 30 44 58 77	Same as above but with “V” configured louver with center wall

¹ Alden Research Laboratory, 2000.

² Heubach and Skinner, 1978.

³ Bates and Vinsonhaler, 1956.

⁴ Skinner, 1974.

⁵ Vogal et al., 1990.

⁶ Cramer, 1997.

⁷ Stira and Robinson, 1997.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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



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



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

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

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

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

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

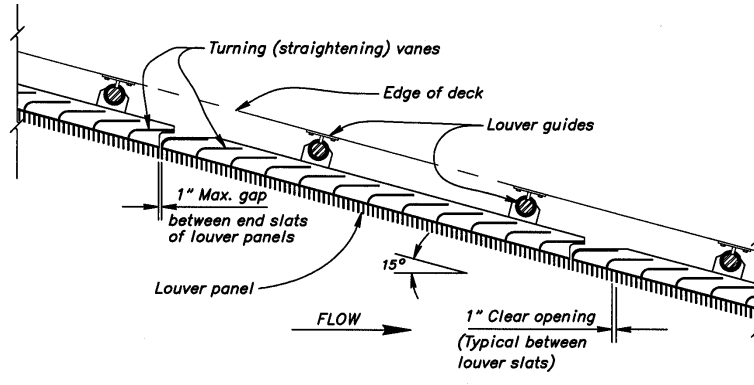
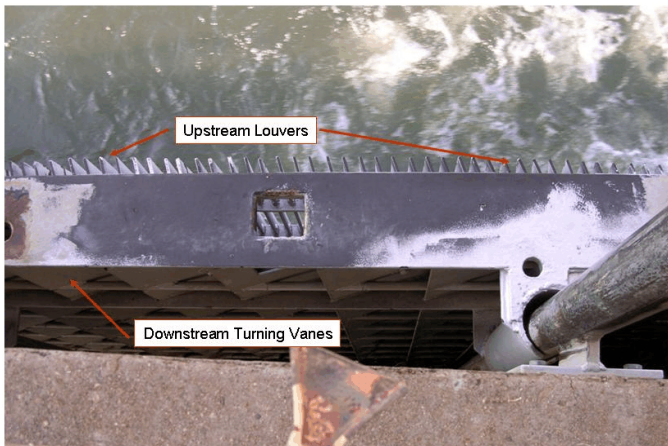
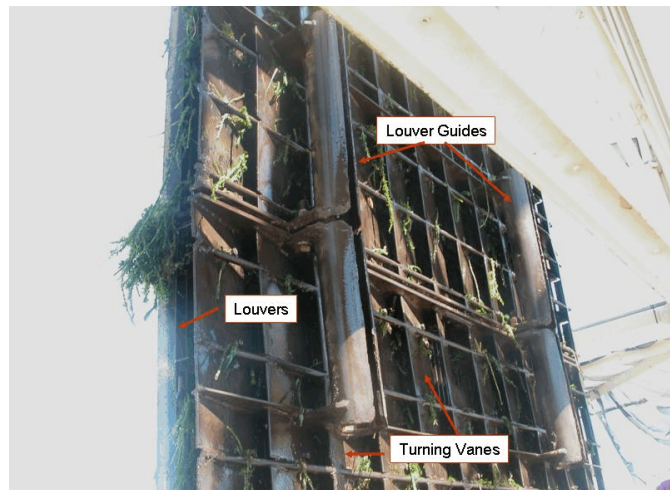


Figure 97.—Detailed louver layout.



a. Louver in louver guides.



b. Looking at downstream side of removed louver.

Figure 98.—Tracy louver panel.

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

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

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

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

Angle of louver line placement – Louvers are placed at an angle across the flow to generate a sweeping flow that provides fish guidance across the louver face and to the bypass entrances (figure 23). The objectives are similar to guidance objectives pursued with an angled screen placement (chapter IV.A.5). Generating effective fish guidance and maintaining fish passage across the louver face is

likely more critical for achieving effective fish exclusion performance with louvers than with screens in that louvers depend on fish avoidance. Indications are that if fish hold position in front of the louver, the louvers tend to lose effectiveness (field observations indicate that in zones where fish do not sweep across the louver face there is an increased tendency for the fish to pass through the louver).

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

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

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

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

would still allow sediment and debris passage while generating flow rate controlling back pressure.

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

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

B. Electrical Fields

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

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

Wilkins Slough Pumping Plant personnel and Reclamation staff worked with various behavioral suppliers in testing experimental acoustical and electrical fish fields for over 4 years to try to evaluate and develop a more cost-effective barrier than the positive barrier screens. Although there was considerable and valuable

data gathered, these experimental devices did not prove as effective as positive barrier screens and, in most cases, are not acceptable as proven fish barriers by fishery resource agencies.

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

C. Strobes and Lighting

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

Lighting systems may be found more useful for improving the performance of conventional fish exclusion devices, for example, by using lighting to attract fish to the fish bypass entrances and away from the diversion intakes and screen

structures. Lighting of bypass entrances may also encourage fish entrance into bypasses, thus expediting fish passage.

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

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

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

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

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

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

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

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

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

Example installation: Wapatox Canal, Washington – Supplemental mercury vapor lighting was added to the bypass entrances on an aging drum screen structure in an attempt to improve the screen structure's fish guidance and bypass capabilities (primarily for Chinook salmon and kokanee). The Wapatox Canal delivers flows ranging from 300 to 500 ft³/s for irrigation and hydropower production. The canal had an aging drum screen (the screen has since been replaced) that included six 6.6-ft-diameter drums placed normal to the channel flow. The fish bypass entrances located on each abutment of the structure were relatively small. The combined effect of the normal screen placement (with no angled configuration that would supply fish guidance to the bypass entrances) and the small bypass entrances lead to poor fish guidance to the bypasses and, thus, delayed fish passage.

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

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

Support structure – Strobe and lighting systems require minimal support structure. Most commonly, lights are attached directly to the intake structure or associated wing walls. Deployment may require a large framework to support the lights, and to provide a sufficient array of lights. On occasion they are also

deployed from bridge piers, safety cables, debris booms, and from buoy lines. Protection of lights from debris loading is a concern and should be considered.

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

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

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

D. Sound

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

Optional devices – Devices that have been used include low-frequency mechanical sound generators (hammers, poppers, fish drones) and sonic transducer systems that generate a wide range of frequencies (EPRI, 1994; EPRI, 1999). Mechanical devices that have been used include the hammer (or fishpulser), which is an impact device that uses a spring-driven mass to excite the resonant modes of a submerged structure. It produces a high-energy, low-frequency sound with a duration of approximately 200 milliseconds that is repetitively generated. Poppers are pneumatic devices that produce low-

frequency (20 to 100 Hz,) high-amplitude sound through the valve controlled release of air from a pressurized chamber. Poppers produce an acoustic signal that has a rapid peak (2 milliseconds in duration) followed by a low ringing that lasts for about 150 milliseconds. The fishdrone is a device that uses sonic vibrations to excite metallic structures. Frequencies ranging from 20 to 1,000 Hz can be generated either continuously or intermittently, producing regular or irregular pulses. These mechanical sound systems have not been consistently effective in repelling fish species. Their application and evaluation were actively pursued in the 1980s. Currently, little activity and interest exists with mechanical sound systems.

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

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

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

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

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

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

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

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

Both the river and the slough are low gradient channels (slow moving water). The site experiences tidal influences that cause variations in flow velocities and may, on occasion, cause flow reversals. Maximum flood events typically occur in the winter and spring with storm events that may be influenced by snow melt runoff. Debris loading may be substantial and may include trees and other large components. In addition, both recreational and commercial navigation occurs at the site. The range of river flows during testing was from 1,600 ft³/s to 15,000 ft³/s.

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

(quite inefficient) during flood events. On occasion, damage occurred to the sound barrier facility during flood events. Generally, however, O&M costs were low.

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

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

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

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

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

Chapter VI. Fish Manual Case Studies

“By far the best proof is experience.”

Sir Francis Bacon

A. Design Examples

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

Yogi Berra, American Baseball Player

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

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

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

The diversion dam and canal are existing facilities without provision for fish exclusion. The canal diverts a maximum of 850 cubic feet per second (ft³/s) from the river (figure 99). The diversion dam consists of an overflow weir, a sluiceway, and the canal headworks. The diversion season is from mid-March through mid-October.

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

a. Fishery

Salmon

Size – fry, fingerlings, adults

Move downstream – early spring

Move upstream to spawn – early spring

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

and

Bull trout

Size – fry, fingerlings, adults

Move downstream – late spring

Spawning – late summer to early fall and emerge in spring

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

b. River design data

- ▶ The river flow is significantly affected by snow melt and reservoir releases. The peak river flows occur from May through July.
- ▶ The canal can divert 850 ft³/s when the river flow is as low as 5,000 ft³/s.

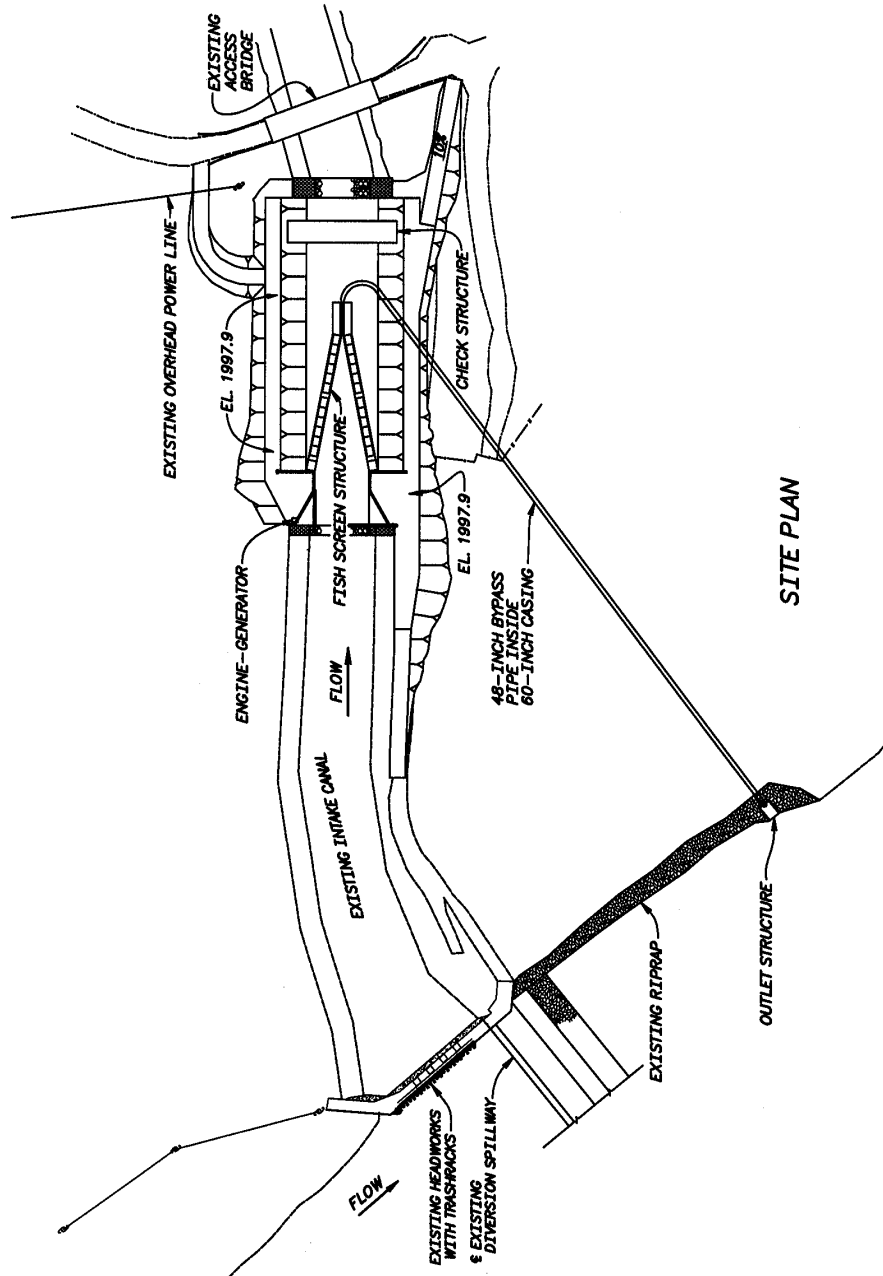


Figure 99.—Site plan – Example 1.

- ▶ River water surface elevations at headworks intake (based on 850 ft³/s in canal):
 - ▶ Water surface is adequate to provide 10 ft water depth in the canal at the fish screens
 - ▶ Water surface at fish bypass outlet structure:
 - ◇ Low flow (5,000 ft³/s) – 3.0 ft less than water level in canal.
 - ◇ High flow (38,000 ft³/s) – 1.5 ft less than water level in canal.

c. Design data

The canal data and section properties are:

Bottom width = 50 ft
Side slopes = 2 (horizontal): 1 (vertical)
Maximum flow = 850 ft³/s
Depth at 850 ft³/s = 10 ft
Bank height = 13 ft
Lining – none
Water surface is controlled by a downstream check structure and does not vary significantly with flow.
Velocity in canal = 1.21 feet per second (ft/s)
Operating season – Mid-March through mid-October

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

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

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

d. Fish screen structure design criteria

- ▶ Fish species – Salmon, bull trout.
- ▶ Fish size – The screens should be able to safely exclude fish as small as fry (25–60 mm).
- ▶ The design flow through the fish screens is 850 ft³/s. The operators can divert 850 ft³/s when the river flow is as low as 5,000 ft³/s.

- ▶ The fish screens must also be able to operate satisfactorily when fish are migrating downstream and the river flow is as high as 38,000 ft³/s (90 percent of the maximum river flow).
- ▶ Maximum fish screen approach velocity is 0.4 ft/s (based on National Ocean and Atmospheric Administration Department of Fisheries [NOAA Fisheries] – Northwest criteria for salmon fry).
- ▶ Uniform approach velocity required along fish screens.
- ▶ Channel velocity is 2 ft/s or greater; sweeping velocity is 2 times the screen approach velocity or greater. The ratio of sweeping velocity to approach velocity should be between 5 and 10 to facilitate cleaning the fish screens.
- ▶ The invert of the screen structure will be located 0.5 ft above the canal invert to prevent sediment deposits from interfering with the operation of the fish screens and cleaning devices. Water depth on fish screens is 9.5 ft.
- ▶ Exposure time – The maximum exposure time of fish to the screen structure is 60 seconds.
- ▶ Bypass to river:
 - ▷ Entrance width is 2 ft or greater
 - ▷ Entrance velocity is channel velocity or greater
 - ▷ Minimum pipe diameter is 24 inches
 - ▷ Bypass pipe velocity is 3 to 10 ft/s
 - ▷ Minimum pipe bend radius is at least 5 times the bypass pipe diameter
- ▶ Fish screens
 - ▷ Maximum opening (NOAA Fisheries – Northwest Region)
 - I. Perforations – Rectangles and circles maximum openings – 3/32 inch in narrowest dimension.
 - ii. Slots – 1.75 mm (0.0689 inches)
 - iii. Minimum open area percentage is 27 percent (table 4)
 - ▷ Maximum design cleaning cycle time is 5 minutes
- ▶ Assumed head loss across fish screen and baffle is 0.5 ft

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

e. Location of fish screen structure

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

- ▶ The screens would be adjacent to the sluiceway, which is not continuously operated. Thus, there would not always be a good sweeping flow past the fish screens.
- ▶ Ice conditions would require removing the fish screens. If fish screens remain in the canal, there will be no flow in the winter and the canal can be unwatered to prevent damage to the fish screens and to allow maintenance.
- ▶ Constructing the fish screens upstream from the headworks would require a cofferdam in the river. This would increase the construction cost and possibly have environmental impacts.

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

The downstream distance from the curve is:

$$\text{Distance} = 40 * 10 = 400 \text{ ft.}$$

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

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

The fish screen facility will consist of the following:

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

g. Fish screen structure (figure 101)

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

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

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

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

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

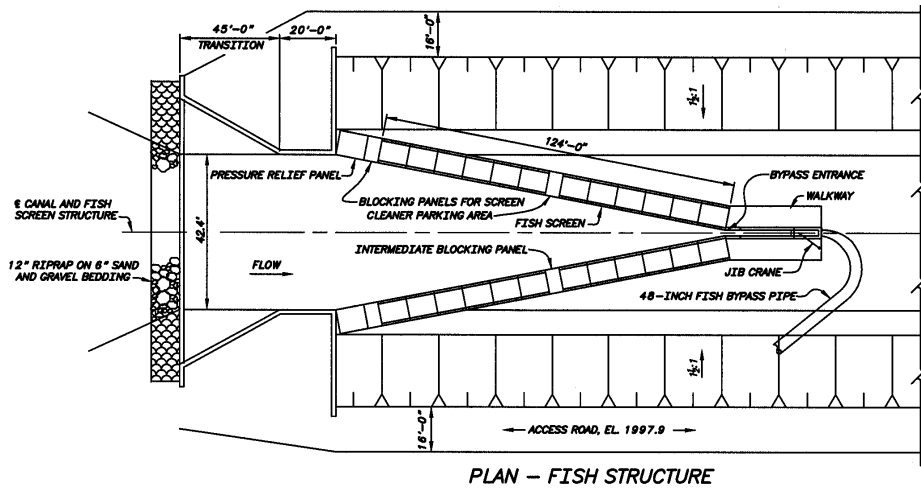


Figure 100.—V-Configured fish screen – Example 1.

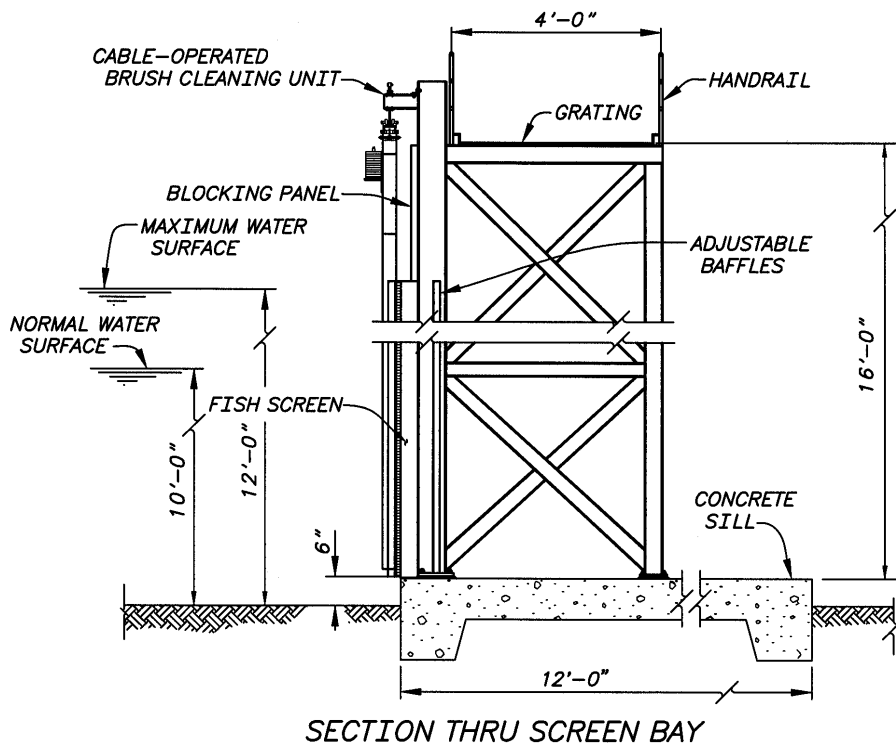


Figure 101.—Steel support structure – Example 1.

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

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

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

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

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

There are two potential configurations for the fish screen structure:

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

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

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

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

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

- ▶ The “V” configuration requires only one bypass with a flow of 40 ft³/s.
- ▶ The straight-line configuration requires two bypasses with a total flow of 80 ft³/s (40 ft³/s for each bypass). If two bypasses were used, a secondary screened return flow facility might be required. The return flow facility would return flow from the bypasses to the canal and allow a reduced bypass flow with fish. The return flow structure would contain traveling water screens and pumps.
- ▶ The straight reach of the canal where the facility is to be located is not long enough to contain a straight-line structure and have enough upstream straight reach for acceptable flow conditions.

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

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

The fish screen structure will be located in a trapezoidal canal section with a transition from 2:1 canal side slopes to vertical concrete walls at the upstream end of the screens. The channel bottom width at the upstream end of the fish screen structure is determined by the area needed for a velocity of 2.0 ft/s. In calculating the required area, the bypass flow of 40 ft³/s is added to the screen flow of 850 ft³/s for a total flow of 890 ft³/s. The required area to produce a 2.0 ft/s velocity is the flow divided by the velocity (890 ft³/s/2.0 ft/s) = 445 ft². Since the depth is 10 ft, upstream bottom width is calculated to be 44.5 ft.

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

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

h. Upstream transitions

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

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

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

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

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

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

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

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

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

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

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

Operators may select the option that best suits their conditions.

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

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

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

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

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

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

$$\text{Head loss} = 0.3 * (0.062 - 0.025) = 0.011 \text{ ft}$$

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

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

I. Fish bypass description

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

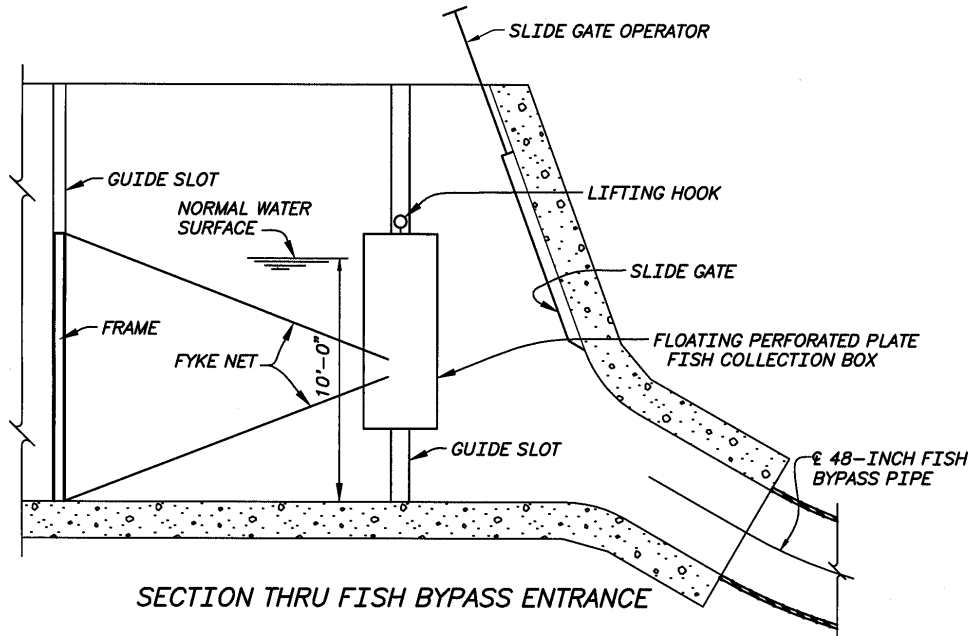


Figure 102.—Bypass entrance – Example – 1.

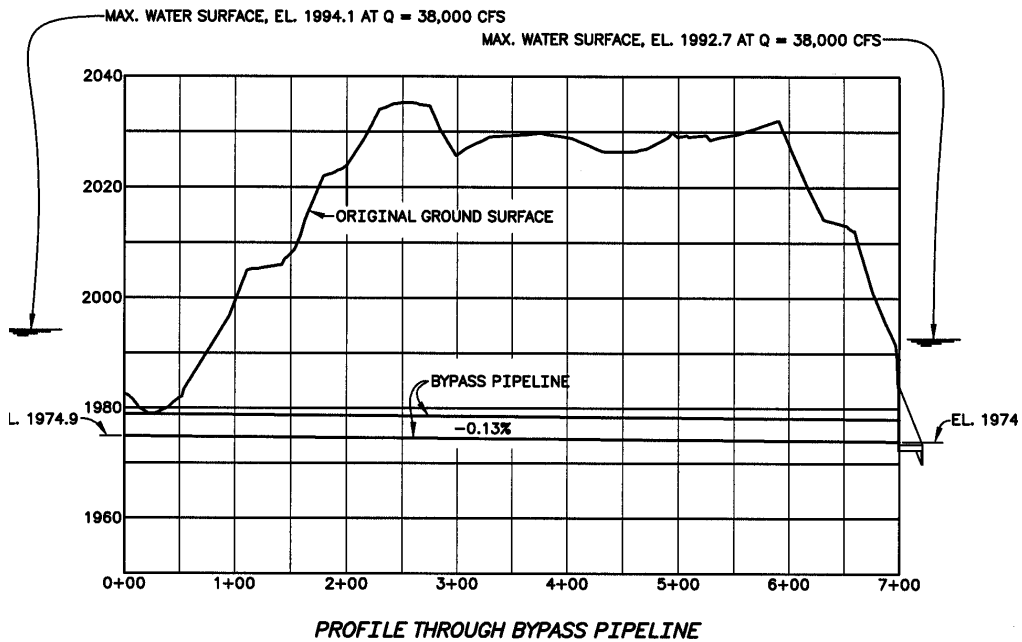


Figure 103.—Profile of bypass pipe – Example 1.

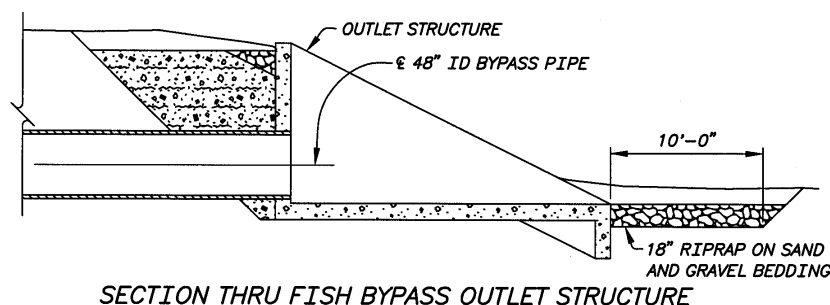


Figure 104.—Bypass outlet structure – Example 1.

Entrance – The entrance (figures 100 and 102) is 2.0 ft wide, which is adequate to pass trash and fish, and meets criteria. The channel upstream from the gate should be open topped to allow light in and not elicit an avoidance response from the fish. As previously estimated, the minimum bypass flow is 40 ft³/s. Options for controlling the flow through the bypass are: (1) using an adjustable weir with an upstream ramp or (2) using a slanted type gate. A slanted slide gate at the entrance will be used to control the flow in the bypass channel and isolate the facility from the river. The slanted gate can be used to control the flow if it is not required to close more than half way to accomplish this. An alternative to the slanted gate would be an adjustable weir with ramp (similar to figures 52, 54, and 108). For this example, the slanted gate is selected because there is minimal head loss available to drive the bypass flow. A drop well is sometimes required just downstream from the gate or weir to accommodate excess available head. However, in this example, a drop well is not required.

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

Bypass return flow channel – The difference in water level between the bypass entrance and the river is 3 ft during low river flow (5,000 ft³/s) and 1.5 ft during high river flow (38,000 ft³/s). A canal check structure is required to ensure adequate head for the bypass flow during high river flows. Buried pipe will be used for the bypass flow to the river (figure 103). The flow must have a velocity between 3 and 10 ft/s, and the bypass pipe must be smooth, with no protrusions that might injure fish. To meet velocity criteria, the pipe diameter may be between 2.26 ft (10 ft/s) and 4.12 ft (3 ft/s). For economy and to keep fish moving, it is desirable to make the diameter as small as possible while not

exceeding head loss requirements. Head loss through the bypass system must be estimated and must not exceed available head. The pipe diameter from the bypass entrance to the river is 48 inches. With a flow of 40 ft³/s, the velocity is 3.2 ft/s (within criteria of 3 to 10 ft/s). Reinforced concrete, steel, and high density polyethylene (HDPE) pipes were considered for the bypass. The joints in the reinforced concrete pipe would be mortar filled to make them smooth, and the joints in the HDPE would be butt welded.

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

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

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

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

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

Where:

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

The Colebrook-White equation is:

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

Where:

- C₃ = 2
- C₄ = 2.51
- C₅ = 3.7
- The roughness, e = 0.0002 for smooth pipe and 0.001 for rough pipe

R is the Reynolds number = $4*(A/W_p)*V/v$, where
 A is the pipe area = 12.57 ft²
 W_p is the wetted perimeter
 D is the pipe diameter = 4 ft
 V is the flow velocity = 3.2 ft/s
 v is the kinematic viscosity = 0.0000141

Solving the equation, $f = 0.01527$

Friction loss/ft = $f * (V^2/2g)/D = 0.0006$

The friction loss is therefore pipe length * head loss/ft:

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

The bend loss¹ is estimated: $0.0035 * (3.2)^2/2g * \text{bend angle} =$
 $0.0035 * 0.159 * 140 = 0.078 \text{ ft}$.

The exit loss is estimated to be one velocity head: $1.0 * (3.2)^2/2g = 0.16 \text{ ft}$.

The entrance loss is estimate to be $0.5 * \text{velocity head} = 0.080 \text{ ft}$.

The total head loss in the bypass system is then $0.072 + 0.078 + 0.16 + 0.080 =$
 0.390 ft .

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

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

j. Operation and maintenance

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

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

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

Cleaning criteria requires that the screens should be kept clean enough to prevent the head loss, across the fish screens only, from exceeding 0.1 ft. Therefore, the fish screens should be kept as clean as possible at all times. With the baffles located immediately behind the fish screens, it will be feasible to measure only a

combined head loss of the fish screens plus baffles. Normally, the head loss through clean fish screens is relatively minor, while the head loss through the baffles is relatively large. An alarm system is installed that will sound if the differential head across the fish screens and baffles reaches a predetermined level (usually set between 6 and 12 inches). The screens may have to be thoroughly cleaned with a high-pressure water system once or twice a year. This cleaning can be accomplished with the screens in place with the canal unwatered. A backup power generator is included with the facilities that will power the screen cleaning system, area lights, sensors, and alarm systems.

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

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

The Water District diverts (pumps) up to 3,000 ft³/s from the river. The diversion site is located on an oxbow of the river (figures 5 and 6). Originally, the pumping plant was unscreened. There have been two previous efforts to screen fish from the diversion. The first effort consisted of installing drum screens. The drum screens were 17 ft in diameter and could operate successfully for a river depth range of 11.1 to 14.5 ft on the screens (0.65 to 0.85 times the screen diameter). There were two problems with the drum screen installation: (1) failed seals and (2) limited operating range because of fluctuating water levels. It was decided to retrofit the structure with flat plate fish screens with a horizontal brush cleaning system. The flat plate screens were installed at a 5-degree angle to vertical.

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

Planning of the fish screen structure involved the following organizations:

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

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

- ▶ Glenn Colusa Irrigation District

The technical support and final design groups consisted of:

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

a. Fishery

Species – salmon and steelhead

Size – fry through adults

Move downstream – throughout the year

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

b. River design data

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

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

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

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

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

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

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

c. Design Data and fish screen structure design criteria

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

Fish screens – Design flow for fish screens is 3,000 ft³/s at a river flow of 7,000 ft³/s and an associated water surface at El. 137.0. Historic diversion records were reviewed, and it was found that in only 1 in 20 years is the pump demand of 3,000 ft³/s required when the river flow was less than 7,000 ft³/s. Maintaining this water level requires a grade control structure (gradient facility) in the main river channel and an adjustable flow control structure (overflow weir) in the oxbow channel figures 5 and 6. Additional pumping criteria are set for river flows less than 7,000 ft³/s and for river flows during times of the year when downstream fish migration is most likely. The water district and the environmental and fishery resource agencies agreed to these criteria.

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

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

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

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

Bypass system – The bypass system will consist of the open channel bypass at the end of the fish screens and intermediate (intermediate) bypasses (with bypass pipes which extend downstream past the fish screens). Fish migrating upstream should be able to swim up the oxbow and past the fish screens. Intermediate bypasses must be located to limit the exposure time to 60 seconds (this was subsequently revised with a variance from the fish agencies). The minimum oxbow bypass flow should be 500 ft³/s at 7,000 ft³/s river flow, and the minimum pipe diameter is 24 inches.

The intermediate bypass entrance, figure 108, should:

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

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

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

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

The extended fish screen structure deck El. is 154.8, to match the existing deck. The deck will be overtopped during high river flood flows. The existing fish structure deck is overtopped when the river flow exceeds approximately 120,000 ft³/s, and this will continue to be acceptable criteria.

The barrier panels can be placed above the fish screens to prevent them from being overtopped by flows of less than 120,000 ft³/s.

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

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

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

Electrical power is available at the site.

d. Location of fish screen structure

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

- (1) The upstream end of the oxbow is used as a settling basin for sediment. Dredging operations are required in the upstream end of the oxbow every 1 to 3 years. Dredge volumes have been as high as 60,000 yd³. Sediment will continue to collect when the new facilities are constructed, and dredging would be very difficult if the structure is located at the upstream site.
- (2) Sediment deposition is not a problem at the existing downstream fish screen site.

- (3) The straight-line configuration may allow fish to stay in the river (oxbow bypass open channel) without being guided into a pipe bypass system.
- (4) Trash will be kept in the river and not have to be removed and trucked away.
- (5) Construction at the existing site will allow use of the existing fish screen structure as part of the facilities. The existing fish screen structure does, however, require some modifications.

e. Design of fish screen structure

The design of the fish screen structure includes the following:

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

f. Fish Screen structure

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

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

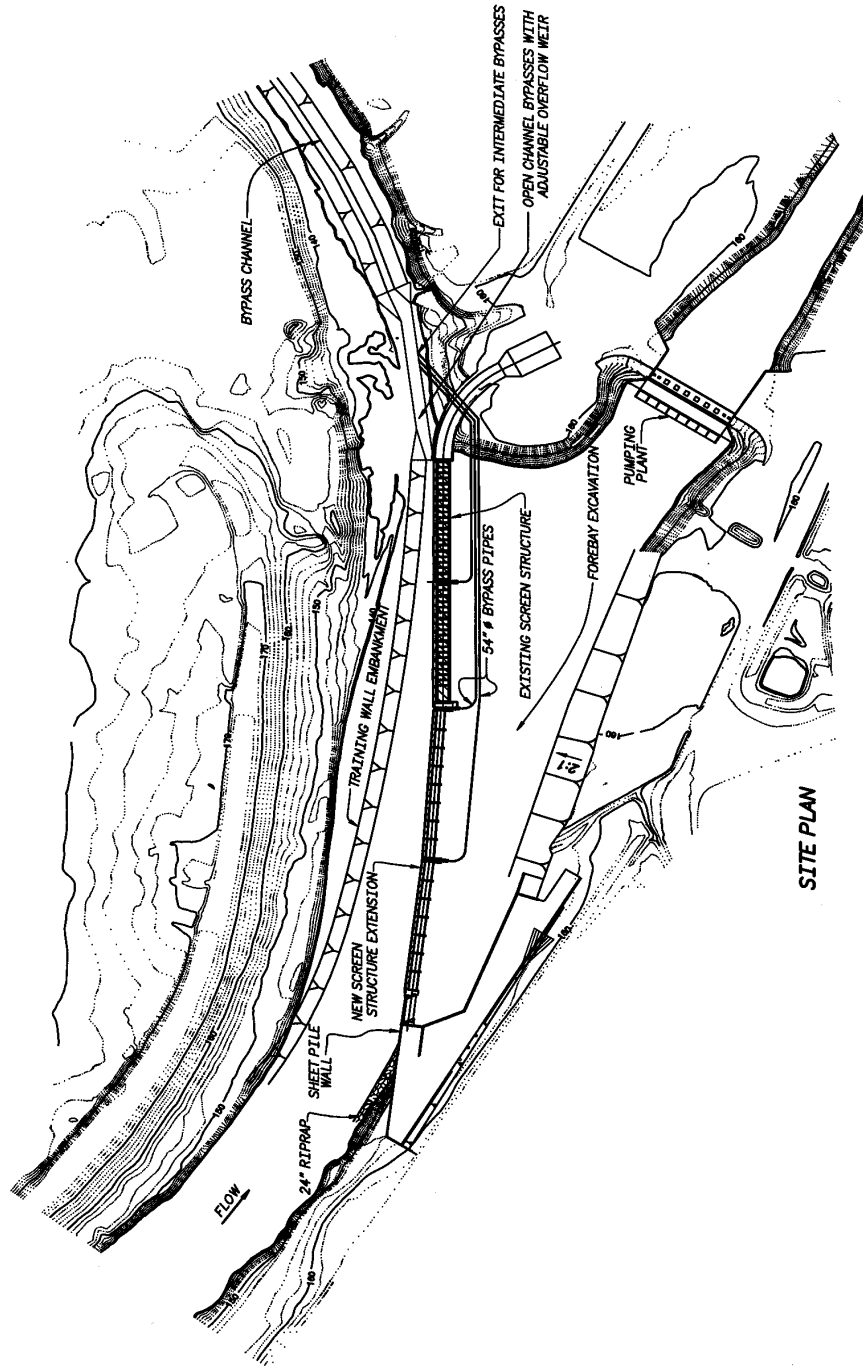
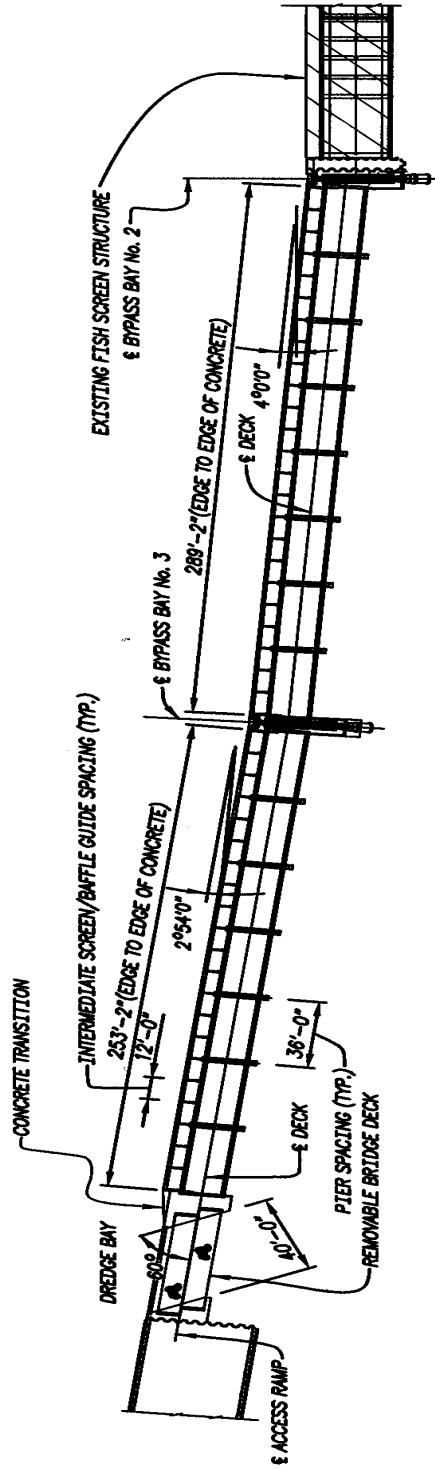


Figure 105.—Site plan —Example 2.



PLAN - NEW SCREEN STRUCTURE EXTENSION

Figure 106.—New screen structure — Example 2.

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

The length of the total fish screen structure is based on the river at a flow of 7,000 ft³/s and the maximum design pumping flow. The existing fish screen structure is 478 ft long, including existing bypasses, or 470 ft not including the bypasses. The capacity of the existing structure at an approach velocity of 0.33 ft/s and a depth of 10 ft (El. 137 – El. 127) is the gross screen area multiplied by the reduction for structural members and the approach velocity:

$$\begin{aligned} \text{Allowable flow through existing fish screens} &= 470 \text{ ft (length of fish} \\ &\text{screen)} * 10 \text{ ft (depth)} * 0.9 \text{ (correction for structural members)} * \\ &0.33 \text{ ft/s (approach velocity)} = 1,395 \text{ ft}^3/\text{s} \end{aligned}$$

The required flow through the extended fish screen structure is:

$$\begin{aligned} \text{Required flow through fish extension screens} &= 3,000 \text{ ft}^3/\text{s} - \\ &1,395 \text{ ft}^3/\text{s} = 1,605 \text{ ft}^3/\text{s}. \end{aligned}$$

The required length of the extension is therefore:

$$\begin{aligned} \text{Gross length of extension screens} &= 1,605 \text{ ft}^3/\text{s} / (0.33 \text{ ft/s} * 10.5 \text{ ft} * \\ &0.90) = 515 \text{ ft}. \end{aligned}$$

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

g. Modifications to Existing structure

The existing structure will be modified by constructing the following:

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

h. Modifications to the oxbow channel

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

The oxbow channel was narrowed across from the fish screen structure to maintain a minimum velocity of 2.0 ft/s in the channel. The hydraulic model

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

The adjustable overflow weir, just downstream from the fish screens, controls flow in the open channel bypass. The adjustable overflow weir has precast concrete planks and is ramped upstream and downstream. Planks can be inserted or removed to set the crest elevation of the ramped weir, thus setting the flow desired for the river flow and elevation. The drop over the adjustable overflow weir is approximately 2.0 ft for a river flow of 7,000 ft³/s. The drop across the adjustable overflow weir decreases as the river flow increases.

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

I. Fish screens and baffles

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

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

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

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

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

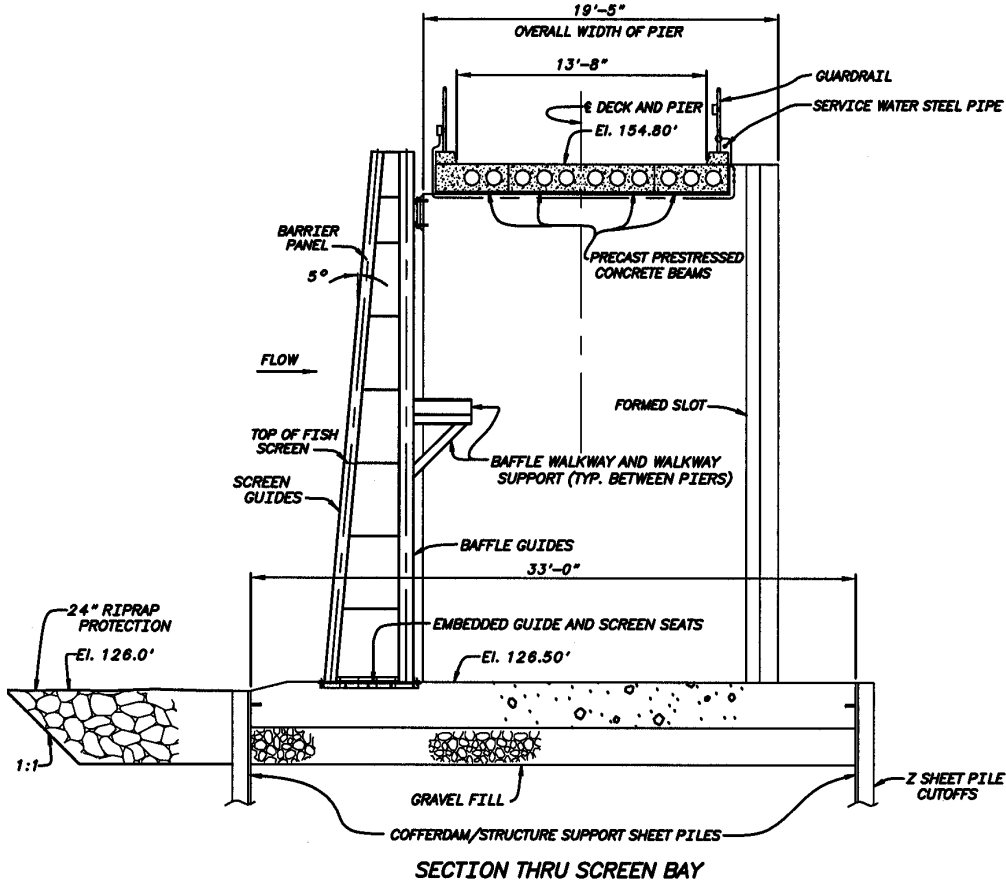


Figure 107.—Cross section of screen bay – Example 2.

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

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

j. Fish screen cleaning

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

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

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

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

k. Fish bypasses (intermediate)

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

The minimum total bypass flow is 500 ft³/s. The bypass flow will be a combination of open channel flow and the flow from the intermediate bypasses. Flow for an intermediate bypass is based on the flow entering the bypass at a minimum velocity of 2.0 ft/s, a 10.5-ft depth, and a minimum bypass entrance width of 2.0 ft.

Minimum flow for the intermediate bypass = 10.5-ft depth x 2.0-ft width x 2.0 ft/s velocity = 42 ft³/s

Each intermediate bypass flow was rounded up to 50 ft³/s to ensure the 2 ft/s approach velocity at higher river flows.

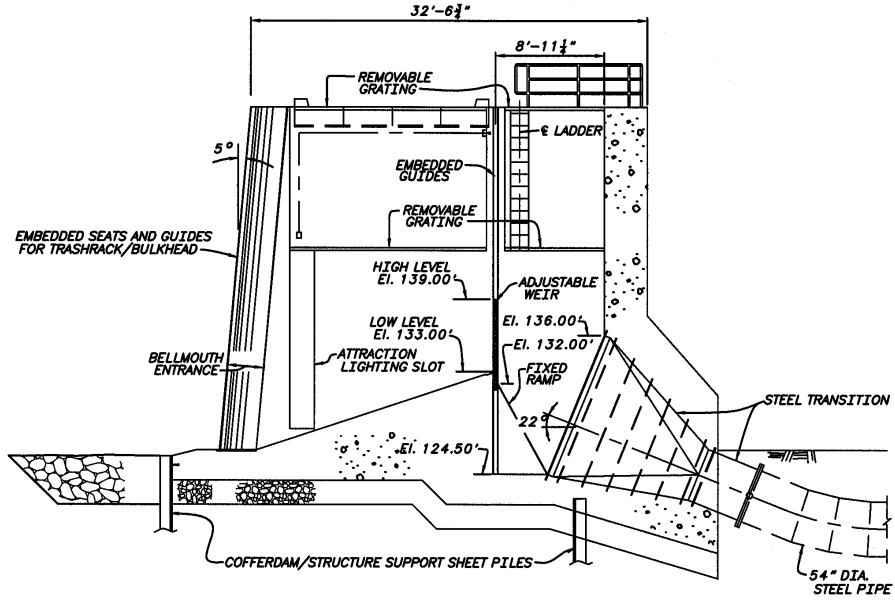
If eight intermediate bypasses are constructed and used, the total flow from the intermediate bypasses will be 400 ft³/s and only 100 ft³/s would be available in the open channel bypass at the downstream end of the screens.

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

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

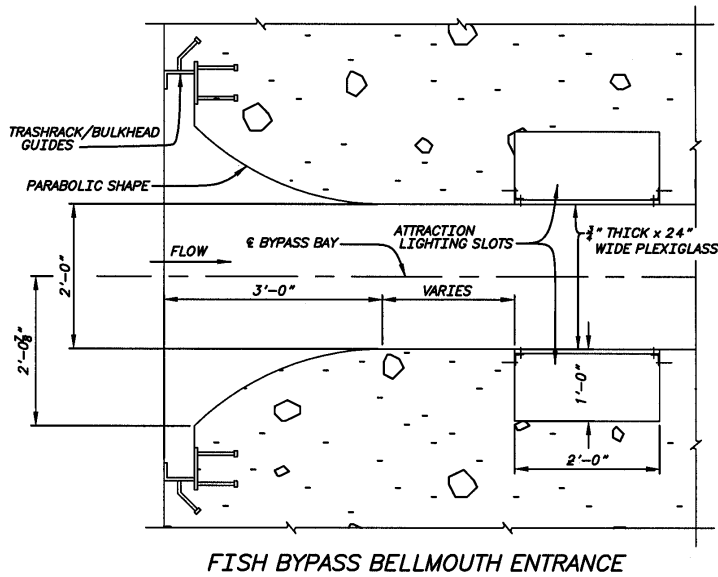
The bypass entrance trashrack prevents large trash from entering and plugging the bypass. The center-to-center spacing of the trash bars is 9 inches to allow passage of fish but not trash.

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



SECTION THRU FISH BYPASS ENTRANCE

Figure 108.—Bypass entrance – Example 2.



FISH BYPASS BELLMOUTH ENTRANCE

Figure 109.—Bypass Bellmouth entrance – Example 2.

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

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

The intermediate bypass pipes are sized to meet velocity requirements (3.0 ft/s to 10 ft/s) and to operate under available head. The available head is 2.0 ft. The bypass pipe diameter selected was 54-inches, and the velocity for 50 ft³/s is 3.14 ft/s. The farthest upstream intermediate bypass has the longest pipe, which is 1,100 ft long. Head loss was estimated for this upstream bypass from the entrance to the exit. (See table 10).

Table 10.—Head loss in the intermediate bypass

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

I. Evaluation and O&M after construction

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

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

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

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

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

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

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

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

This example presents improvements to a diversion on the Lemhi River in Idaho (Pacific Northwest, 1993). The improvements are part of a project that will improve several diversion facilities. The improvements are required to prevent stranding fish in canals, provide upstream fish passage, and increase river flows. A smaller than desired population of spring and summer Chinook salmon and steelhead exists. The gravel berm diversion dams, when in place, prevent

upstream fish migration. The diversion for this example is referred to as Site L-6 on the Lemhi River. Site L-6 is an existing diversion with a maximum diversion capacity of 50 ft³/s. The water is diverted for irrigation of pasture and hay crops. At certain times of year, excess water is diverted in an attempt to buildup the groundwater table. The groundwater then helps maintain river flows late in the season.

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

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

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

a. Fishery

Species – spring Chinook salmon and steelhead

Size – fry through adults

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

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

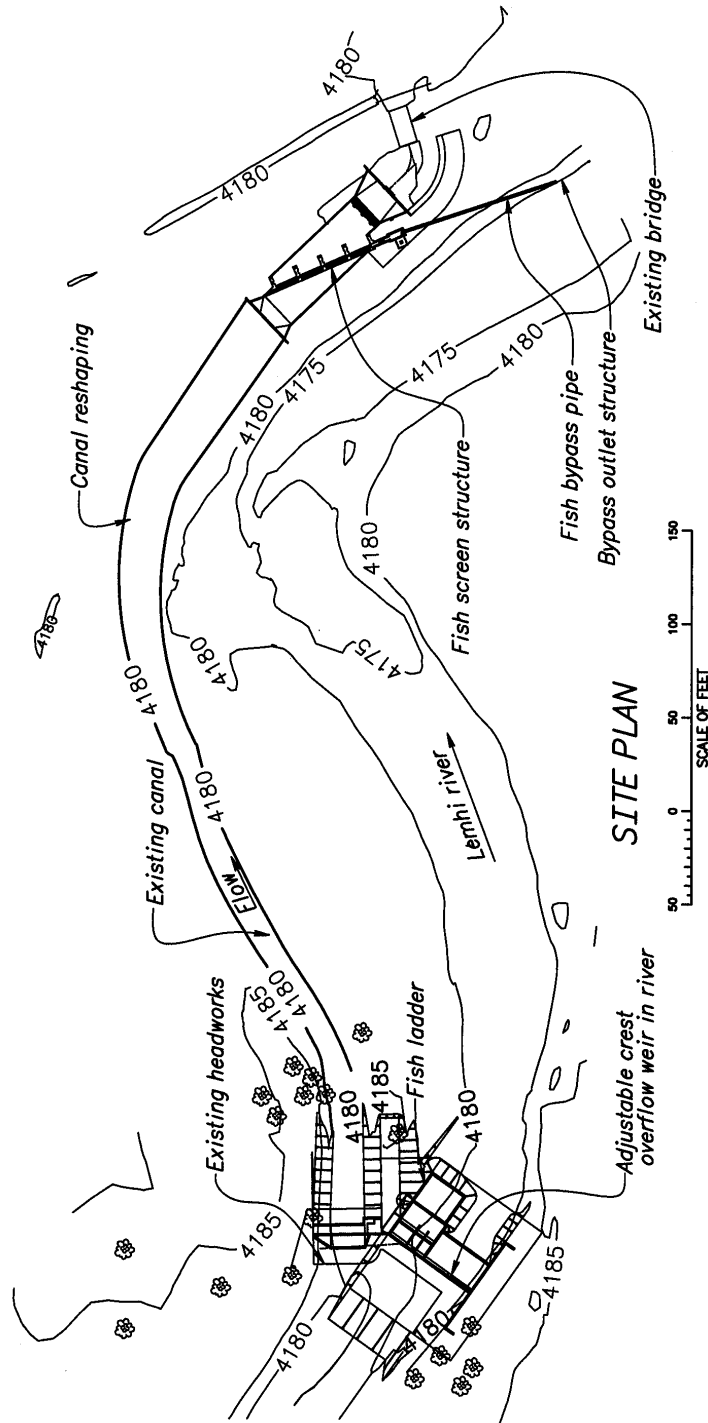


Figure 110.—Site plan – Example 3.

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

b. River design data

The river flow is significantly affected by snow melt and reservoir releases. The peak river flows occur from May through July. The fish protection facilities must be able to operate satisfactorily for river flows up to 500 ft³/s. Ninety-five percent of the time, the river flow will not exceed the 500 ft³/s. A minimum water surface of El. 4181.5 is required in the diversion pool to provide the maximum diversion flow of 50 ft³/s.

c. Design data

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

Table. 11 – Canal flow versus water surface elevation

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

Notes:

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

The canal section properties are:

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

River water surface profiles have been evaluated for a range of flows to ensure that the fish screen facilities will operate for a range of river flows up to 500 ft³/s.

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

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

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

Electrical power – Electrical power is locally available.

d. Fish screen structure design criteria

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

Irrigation district requirements:

- ▶ Base the screen design flow on existing canal capacity. It should be 45.6 ft³/s (table 11).
- ▶ Design the fish screen facility so that it is easy to operate and maintain.
- ▶ Don't allow construction to interfere with canal operations. Construction in the canal can occur from mid-October through mid-March (5 months), which is the non-operating period.
- ▶ Locate the screens in the canal so that they will provide good access for O&M.
- ▶ Use drum screens because of the anticipated ease of O&M. The drum screens will be 3 ft 6 inches in diameter and 12 ft long. These are standard dimension screens that are available in the area. The drum screens are self-cleaning, and, because of the small screen size, maintenance on the seals is not anticipated to be difficult.

e. NOAA Fisheries and State criteria

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

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

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

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

Bypass to river – The bypass will operate satisfactorily up to a 500 ft³/s river flow and at the minimum allowable channel depth (0.65 x screen height).

The bypass entrance shall meet the following requirements:

- ▶ The bypass entrance shall have independent flow control.
- ▶ The minimum bypass flow shall be 0.8 ft³/s.
- ▶ The velocity at the entrance to the bypass shall be equal to or greater than 1.1 times the upstream channel velocity or greater if possible.
- ▶ The entrance shall have ambient lighting.
- ▶ The invert of the entrance shall be at the same elevation as the upstream channel.
- ▶ Construction in the river can occur from late August to the beginning of March.

The bypass conduit shall meet the following requirements:

- ▶ The pipe shall be smooth.

- ▶ A 10-inch minimum pipe diameter is acceptable for a small diversion (attachment A.1.K).
- ▶ Bends shall be avoided, if possible.
- ▶ The pipe velocity shall be between a minimum 2.0 ft/s to a maximum 10.0 ft/s.

Monitoring shall meet the following requirements:

- ▶ The Positive Integrated Transponder (PIT) tag detectors shall monitor juvenile fish passage.
- ▶ A more extensive juvenile monitoring facility will be constructed at another diversion site. The monitoring facility will provide for PIT tag installation and detection, and juvenile sorting and counting.
- ▶ An adult monitoring facility will be constructed at a fish ladder at another location. The fish ladder will include a viewing window, which will allow video monitoring.

f. Location of fish screen structure

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

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

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

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

g. Design of fish screen structure

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

- ▶ Fish screen structure and associated guide walls
- ▶ Transitions from the upstream canal and downstream trapezoidal canal section to the rectangular fish screen structure channel

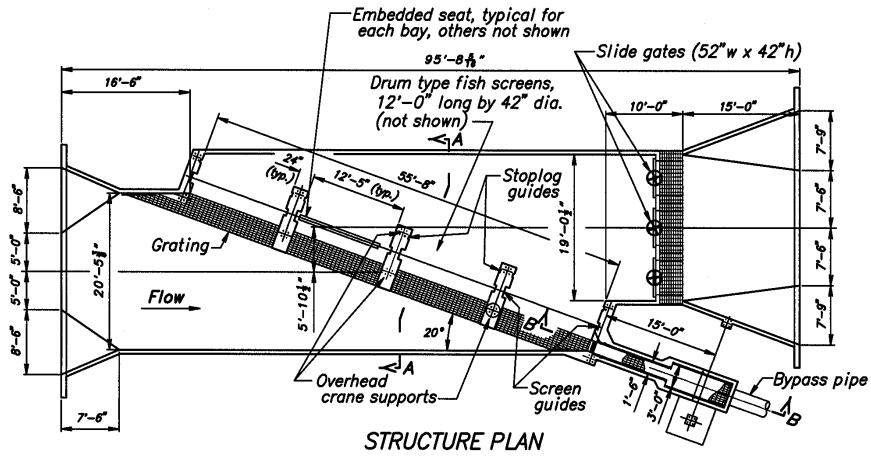


Figure 111.—Structure plan – Example 3.

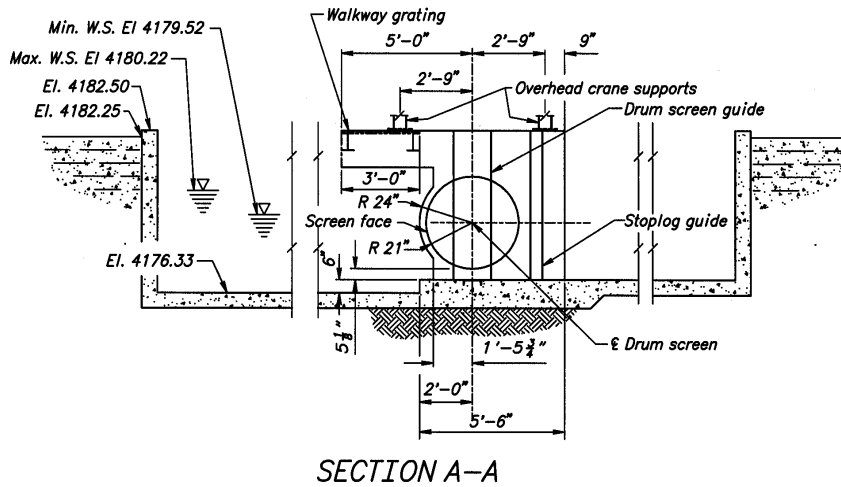


Figure 112.—Section through drum screen structure – Example 3.

- ▶ Fish screens – drum screens
- ▶ Overhead monorail to remove and replace the drum screens, etc.
- ▶ Grooves for installing adjustable stoplogs or baffles behind the fish screens
- ▶ Fish bypass to the river including: the bypass entrance, the bypass pipe, and the outlet structure
- ▶ Three downstream slide gates for controlling the water level at the fish screens

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

- ▶ Foundation slab
- ▶ Drum screens
- ▶ Intermediate piers
- ▶ Guide walls
- ▶ Metal grating walkway
- ▶ Monorail

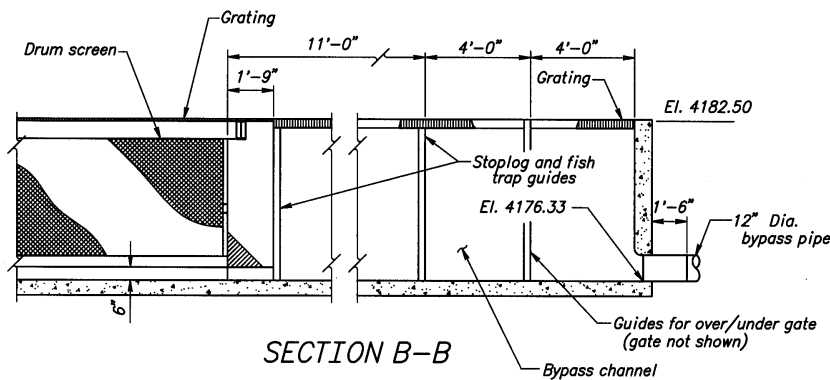


Figure 113.—Section through bypass entrance – Example 3.

The concrete slab under the fish screens is elevated 0.5 ft above the invert of the approach channel to allow for sediment deposits.

The required net area of fish screens is the design flow divided by the maximum allowable approach velocity:

$$\text{Net area} = (45.6/0.4) = 114 \text{ ft}^2$$

The required area does not include structural support members. Structural support members normally occupy 5 to 10 percent of the fish screen area. For this example, we will use 10 percent. Thus, the required gross area will be:

$$A_g = 126.7 \text{ ft}^2$$

The minimum length of the fish screens is obtained by dividing the required area by the submerged screen depth. The depth on the fish screens at the design water level is $0.75 * 3.5 = 2.625$ ft. The required length of the fish screens is:

$$L = 126.7/2.625 = 48.3 \text{ ft}$$

Four 12-ft-long drum screens were selected. During low flows, two of the screens can be shutdown by placing stoplogs behind them.

An upstream channel width of 20.45 ft results in the hydraulic properties shown in table 11.

$V_s/V_a = 0.65/0.4 = 1.65$, which is satisfactory because any impinged debris will be carried over the drum screens and washed downstream.

With a sweeping velocity = 0.65 ft/s and a 55.72 ft length, the exposure time is:

$$\text{Exposure time} = 55.7/(0.65) = 86 \text{ seconds.}$$

This is greater than the 60 seconds allowed by the criteria, and a variance will be sought from the fishery resource agencies.

The walkway deck (steel grating) was set 3 inches above the canal bank elevation. The deck must be wide enough for access by maintenance personnel and is typically 3 to 4 ft wide. A deck width of 3 ft was selected (figure 112).

The deck is designed for dead loads and live loads.

Upstream and downstream transitions – At the upstream and downstream ends of the fish screen structure, there are transitions from the canal (trapezoidal channel) to the rectangular fish screen structure channel. The transitions must be

sized and shaped to provide a non-turbulent transition of flow, without eddies. To accomplish this, the transition wall angle, at the flow line, should be 25 degrees or less. The upstream transition is 7.5 ft long, and the downstream transition is 15 ft long and the water surface angles are 0 and 22 degrees, respectively, thus meeting criteria. Cutoffs are provided to prevent undermining by scour and reduce seepage and piping of foundation materials. Riprap should be provided upstream and downstream from the structure, as required, for scour protection.

Fish screens – The screen material will be woven wire with a maximum 3/32-inch opening. The screens will be fabricated from 6 mesh (6 wires/inch) – 14-gage (0.08") wires with 27.2 percent open area. For durability, stainless steel wire will be used. The fish screen frames can be structural steel. Anodes may be required for corrosion protection. Electric drive motors will be provided to continuously rotate the drums. Shear pins will be provided to protect the drive system. Seals will be provided on the bottom and sides of the fish screens. Lifting lugs will be welded to the frames.

Flow control – Three slide gates are provided in the canal downstream from the fish screens to control the water surface elevation at the fish screens at .65 – .85 percent of drum screen diameter. The slide gates can also be adjusted to affect the flow distribution through the fish screens.

If necessary, baffles can be installed in the guides that are provided immediately downstream from the fish screens to obtain a uniform flow distribution along the screens. The baffles will consist of stop logs similar to those shown in figure 11. The stop logs can be located off the bottom and spaced apart from each other to achieve the desired effect while allowing debris passage.

h. Fish bypass

The bypass consists of the entrance, the return flow channel, and the outlet structure.

Entrance – The bypass entrance is at the downstream end of the fish screens (figure 111). The entrance is initially 1.5 ft wide, which is adequate to pass trash and fish. At the downstream end, it widens to 3.0 ft for the over/under gate. The bypass entrance velocity is 0.8 ft/s (greater than 1.1 x the upstream channel velocity) and the bypass flow will range from 3.8 to 4.6 ft³/s, depending on the channel depth (table 11). An over/under gate, installed in the downstream guides, will be used to control the bypass flow. The gate can be set to pass flow over the top and flow and sediment underneath. The gate also acts as a drop structure for excess head. The bypass channel is designed to allow a fish trap to be installed and allow PIT tags to be detected (figure 113). This is accomplished by embedding guides in the sidewalls so that a removable net and trap box (or other equipment) can be inserted and removed.

Bypass return flow channel – The bypass must be able to operate during the most limiting conditions, which occur during the high river flow (500 ft³/s) and a diversion flow (screen flow) of 45.6 ft³/s . Buried pipe will be used for the bypass to the river (figure 114). For economy and to keep fish moving, it is desirable to make the diameter as small as possible. Head loss through the bypass system must be estimated and must not exceed available head. The selected pipe diameter from the bypass entrance to the river is 12-inches. With a flow of 3.8 to 4.6 ft³/s, the velocity will be 4.8 to 5.8 ft/s (which is within criteria). Polyvinyl chloride (PVC) pipe is used for the bypass. The joints in the PVC pipe will have rubber gaskets.

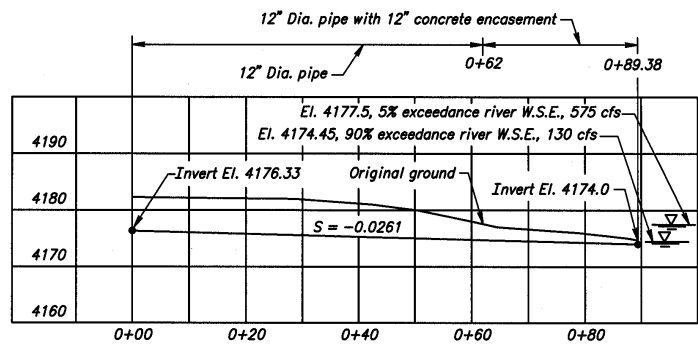


Figure 114.—Fish bypass pipe profile – Example 3.

Bypass outlet structure – The outlet structure is a concrete transition (figure 115). The following items must be considered in locating the outlet structure: the river flow velocity and depths, the possibility of future river changes such as degradation and changes in alignment, and sedimentation. The outlet structure is in a straight reach of the river that has a good river velocity. Also, the site is not subject to significant scour or sediment deposits. Riprap on a sand and gravel bedding is placed about the structure to protect against scour.

I. Screen facility head loss estimate

Head loss through the fish screen facility must be considered when designing the diversion dam and canal section:

For this example, the total head loss estimate will be assumed to be 0.3 ft. This will account for baffling and minor screen plugging by debris.

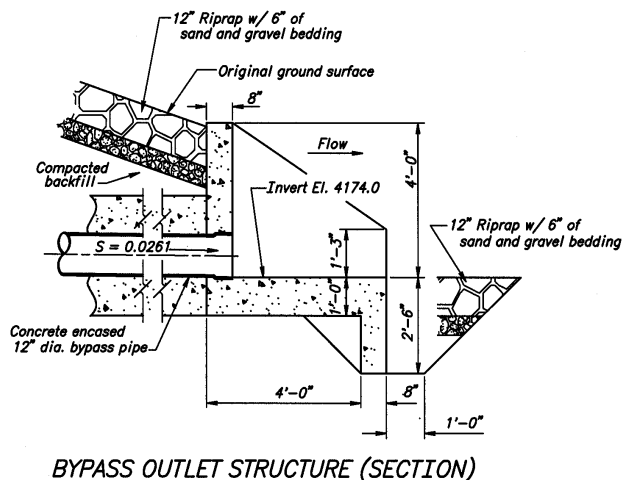


Figure 115.—Paypass outlet structure section – Example 3.

j. Operation and maintenance

For an overview of Operation and Maintenance issues, see Chapter VII, Post Construction Evaluation and O&M Plans.

The fish facilities are designed to be as flexible as possible to maximize successful fish exclusion and protection.

Flow in the canal is controlled and measured at the new headworks.

The fish screens are self-cleaning, because of the rotation of the drum screens and require maintaining the upstream water level between .65 and .85 of the diameter of the drum screen. The drum screen motors and seals will require maintenance. The screen drive system will have to be maintained (oiled and greased).

The monorail used to lift screens and the stoplogs used for baffling will be maintained.

Flow to the bypass can be adjusted with the over/under gate. The over/under gate can also be used to sluice sediment from the bypass entrance. The gate also acts as a drop for excess head.

The water surface elevation at the fish screens is maintained with the three downstream slide gates.

At initial startup, velocity measurements should be made along the fish screens. Baffles can be installed to obtain a uniform flow distribution along the fish screens.

Sediment deposits can be removed during the non-irrigation season when the canal is unwatered.

PIT tags can be detected in the bypass entrance

4. Example 4 – Louver in Canal (Based on T&Y Canal and Diversion)

The diversion dam and canal are existing facilities. The T&Y Canal and 12 Mile Diversion Dam are located on the Tongue River, Montana, approximately 20 miles upstream from the confluence of the Tongue River with the Yellowstone River. A 10 ft-high concrete capped timber crib dam diverts up to a maximum discharge of 237 ft³/s from the river into the canal. The dam and diversion include an overflow ogee weir and the canal headworks. A sediment sluice structure was included to bypass sediments that will accumulate at the entrance to the headworks, which include vertical slide gates. The headworks are positioned such that floating debris is largely sluiced over the dam ogee spillway. The dam and diversion are owned and operated by the T&Y Irrigation District. Liston et al., 1995, and Mefford et al., 1997, document, in detail, the fish exclusion and concept selection and design process.

The irrigation district has limited financial and labor assets. The district recognized that fish entrainment occurred at the diversion and, as a consequence, desired to add a fish exclusion structure to the diversion that would reduce impacts on the Tongue River fishery. The diversion season extends from April to October.

a. Fishery

The fishery issues at the T&Y Diversion include both the impact of the diversion on the migration and habitat range of native fish in the Tongue River and the loss of fish to entrainment to the diversion canal. The dam is a barrier to upstream passage of migratory Yellowstone River fish. These include the endangered pallid sturgeon. The addition of a fishway that would allow upstream passage at the dam might be considered at a later date.

As established in fishery surveys conducted by the Montana Department of Fish, Wildlife, and Parks and by the Montana Department of Natural resources and Conservation (Backes, 1993; Clancy, 1980; and Elser, et al, 1977), approximately 16 species of fish are present in the river reach above the diversion. These are the species that could be entrained in the diversion canal. None of these species is

listed as threatened or endangered. Present are sport fish species including rock bass, smallmouth bass, white crappie, channel catfish, and sauger. Supplemental stocking of juvenile (possibly 2.0-inch long) smallmouth bass and channel catfish has been explored. Seasonal variations in fish species and fish sizes present at the diversion are not well documented. If, in the future, fish passage was added to the dam, the species of concern would be expanded. Adding passage would likely increase the need to exclude smaller juvenile fish from the canal because fish migrations would occur during spawning.

In coordination with the Montana Department of Fish, Wildlife & Parks and with recognition of the lack of endangered species, it was concluded that total exclusion of all fish from the T&Y Canal was not required. It was decided that a reasonable design should exclude a relatively high percentage (preferably a 70 percent exclusion efficiency or higher) of fish that are 2 inches long or longer. It was also recognized that, if fish passage were added to the dam, high (approaching 100 percent) exclusion would be required for all fish 1 inch long or longer. Since additional passage is possible, concepts that allow future retrofit modifications to improve fish exclusion efficiencies should be considered.

No salmonid species were identified either above or below the diversion dam. Salmonids are the species for which most design criteria are available. Only limited criteria are available for non-salmonids that are the target species for this design application. Existing non-salmonid data would have to be reviewed to select criteria that would be applicable for this design.

b. Selection of preferred exclusion concept

The primary screen options considered in the selection process were linear flat plate, drum, inclined screens, and louvers.

Linear flat plate, drum, and inclined screens meet the stated fish exclusion objectives. However, their performance is sensitive to debris, sediment, and ice fouling which could be a major factor at this site. Consequently, the maintenance demands and the capital cost of a screen that complies with fishery resource agency criteria would be greater than preferred. These screen concepts exceed proposed fish exclusion performance objectives for this site at this time.

Although not a positive barrier, louvers meet the current stated fish protection objectives except for a limited potential that debris and ice fouling will generate moderate maintenance demands (maintenance demands will likely be less than that required for screen concepts). Where threatened and endangered species are present, louvers are not considered an acceptable means of fish protection by fishery resource agencies. However, the lower capital costs are in line with the district's capabilities.

The flat plate screen and louver concepts were selected and conceptual designs were developed for the T&Y site. Cost estimates indicated that the louver structure could be constructed for approximately \$240,000 (1997 costs). Comparable cost estimates for the linear flat plate screen were approximately \$340,000.

Noting that the louver concept is less affected by debris, sediment, and ice fouling and has reduced operations and maintenance demands as compared to the alternative flat plate screen concept and that a louver structure can be constructed for a substantially reduced capital cost, the louver concept was selected for development. It was anticipated that a louver facility design could be developed that would meet the stated fish exclusion objectives (70 percent exclusion efficiency or greater for fish that are 2 inches long or longer). A linear flat plate screen could be used as a retrofit (in place of the louvers) as a future upgrade, if upstream fish passage is proposed at some future date for the dam.

c. *River design data (diversion flows and associated water surface elevation data)*

Data establishing the hydraulic characteristics of the site were collected and developed through analysis and on site documentation. Hydraulic characteristics of the site include:

- ▶ The Tongue River flow is significantly affected by snow melt, storm events, and reservoir releases. The peak river flows occur in the spring (up to 1600 ft³/s) while river flows in the late summer and fall are typically low (fall minimum flow can be as low as 190 ft³/s).
- ▶ Pool water surface elevations just upstream from the dam are:
 - 2448.4 with 200 ft³/s over the dam weir
 - 2448.75 with 600 ft³/s over the dam weir
 - 2449.0 with 1,000 ft³/s over the dam weir
- ▶ Diversion discharges range from 100 ft³/s to the design discharge of 237 ft³/s.
- ▶ Water surface elevations in the first reach of canal (based on checking the existing canal):
 - 2447.0 with canal flow of 250 ft³/s
 - 2446.8 with canal flow of 235 ft³/s
 - 2446.0 with canal flow of 150 ft³/s
 - 2445.4 with canal flow of 100 ft³/s

- ▶ Tailwater elevations below the dam vary between 2443.0 and 2439.0 during most diversion periods.

The maximum allowable diversion is 237 ft³/s. The bypass operation will reduce delivered discharge accordingly. Thus, the fish facility operation will reduce deliverable discharge by up to 8.0 ft³/s.

d. Design of fish louver facilities/structure

The new fish louver facility consists of:

- ▶ Modification to the existing headworks
- ▶ A transition from the headworks section to the louver section
- ▶ Lined louver approach and exit channels that ensure consistent velocity fields on both sides of the louvers, thus helping to maintain a constant differential across the louver
- ▶ A diagonally placed louver with support structure
- ▶ Turning (straightening) vanes placed behind the louvers that prevent exit velocity concentrations that could yield variations in differential across the louvers (figure 122)
- ▶ Open chute fish bypass to the river, including embedded guides that allow placement of stoplogs for bypass flow rate control

e. Fish louver structure design criteria

- ▶ The fish species present are rock bass, smallmouth bass, white crappie, green sunfish, channel catfish, sauger, suckers, carp, shorted redhorse, and forage species.
- ▶ The louvers should exclude fish longer than 2.0 inches.
- ▶ The design flow through the louvers is 237 ft³/s; this flow may be diverted with an upstream river flow as small as 427 ft³/s (190 ft³/s is the fall minimum streamflow below the diversion dam).
- ▶ During low river flow periods, the facility is operated without bypass flow (which maximizes the diversion). Periodically, in such water periods, fish have to be removed by netting from the zone ahead of the louvers and returned to the river.
- ▶ The diversion and louvers must operate effectively with river flows up to 1,600 ft³/s, which is the spring maximum flow.

- ▶ The differential water level between the canal and the river, immediately downstream from the dam, varies as a function of river flow and diversion discharge. With minimum streamflows below the dam, differentials will range from 6.4 to 7.8 ft, while with high streamflows, differentials will range from 2.4 to 3.8 ft.
- ▶ Maximum louver approach velocity criteria are poorly defined for the fish species present at the T&Y diversion dam. Interpretation of table 6, chapter V.A. of this report indicates that a maximum louver approach velocity of 1.3 ft/s for bass and 0.9 ft/s for catfish may be appropriate. Lower approach velocities would be appropriate for other weaker swimming species. Use 1.0 ft/s.
- ▶ Uniform approach velocities are required across the louver face.
- ▶ Sweeping velocity criteria are poorly defined for the fish species present at the T&Y diversion. Interpretation of table 6 in chapter V.A. of this report indicates that sweeping velocities of up to 5.0 ft/s are appropriate for bass and 3.0 ft/s are appropriate for catfish. At Reclamation's Tracy Fish Collection Facility, which also excludes many non-salmonid species, 3.0 ft/s is the operating criterion maximum.
- ▶ The invert of the louvers was positioned 1.0 ft above the canal invert to improve sediment sluicing and to generate a sill that would function to guide bottom oriented fish directly to the bypass. Water depth on the louvers ranges from 1.4 to 2.8 ft, varying with diversion discharge.
- ▶ Fish should be exposed to the louvers for no more than 60 seconds.
- ▶ The criteria for the bypass to river are:
 - ▷ Entrance width – 2.0 ft
 - ▷ Entrance velocity – Sweeping velocity or greater (up to 1.4 times sweeping velocity)
 - ▷ Constructed as an open chute to allow easy access for maintenance
 - ▷ Bypass channel (chute) velocities – 3 to 10 ft/s

- ▶ The criteria for the louvers are:
 - ▷ Clear spacing between louver slats – 1.0 inch, figure 122 (based on experience summarized in table 6, chapter V.A.)
 - ▷ Slat size 2.5 inch by 3/16 inch, based on previous experience
 - ▷ Slat orientation to flow – slats placed normal to approach channel flow
 - ▷ The louver line should be oriented at angles ranging from parallel to 17 degrees to the channel flow (chapter V.A.). The louver face was placed at a converging angle of 15 degrees to the flow.
 - ▷ Turning vanes were used behind the louvers to generate uniform approach velocity distributions (chapter V.A.) and improve hydraulics through and past the louvers.

Although debris fouling will affect fish exclusion effectiveness, the woody material does not greatly reduce louver open area and does not greatly increase head loss. As a result, there is little need for emergency shutdown or louver bypass facilities. If flow is diverted from a highly biologically productive water body, fouling with aquatic plants could produce excessive head loss that could require emergency shutdown or louver bypass operation. A trashrack will be included to prevent large debris from entering the headworks.

f. Location of louver structure

There are a number of reasons why the in-canal placement was selected. The gravity diversion is made from an existing diversion dam and pool; therefore, in-river placement of exclusion facilities was not an option. Heavy sediment deposition within the diversion pool yields shallow depths within the pool that would require an extended fish exclusion facility if placed in the diversion pool. This would also require an extended flow guidance structure to generate sweeping flows across the fish exclusion facility. This structure would be costly. In addition, placement of the facility within the diversion pool would expose the facility to severe sediment, debris, ice, and water loading. As a consequence, placement in the diversion pool was also eliminated as an option.

The canal, land surrounding the canal for several hundred feet below the headworks, and access to the site are owned or controlled by the T&Y Irrigation Company. As a result, property did not have to be acquired for fish facility construction, fish bypass construction, construction staging, or access.

The alignment of the existing canal with respect to the headworks was well suited to generate uniform, well directed approach flow for the angled louver facility. A short distance downstream from the headworks, the canal turns approximately 6 degrees away from the river. By using this 6 degrees with a 5-degree convergence of the louver into the flow, the required louver length could be placed on a diagonal across the canal (figure 121).

An additional advantage of placing the louver structure immediately downstream from the headworks is that this placement reduces the potential for predation. The placement also minimizes the required length of the fish bypass chute because the canal is close to the river.

g. Design and construction of headworks and canal reach

Design – The canal headworks and initial reaches of the canal were in disrepair. As a consequence, rebuilding the headworks and canal reach with specific consideration of installation of the in-canal louver facility was necessary (figures 116 and 117). The developed headworks include three 3-ft-high by 5-ft-wide, manually operated slide gates. These gates can supply the maximum diversion discharge of 237 ft³/s with approximately 0.5 ft of head differential between the diversion pool and the canal. The headworks gates were also positioned across the full width of the canal to generate uniform channel flow conditions leading to the louver.



Figure 116.—Overview of T&Y Diversion with fish louver structure – Example 4 (T&Y Irrigation District).

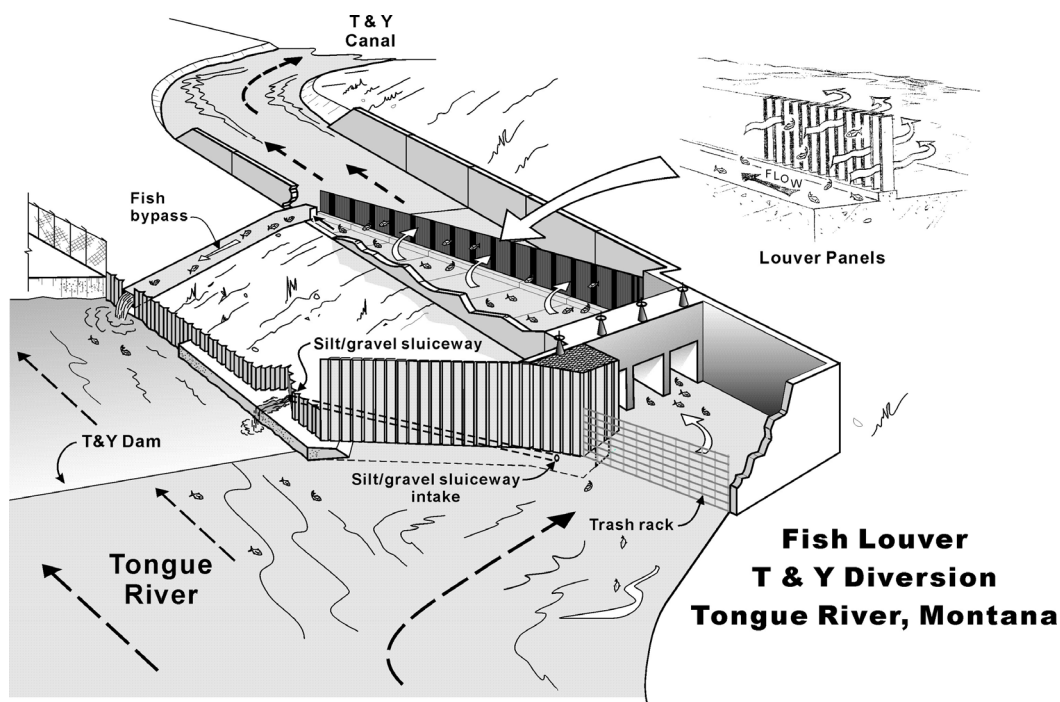


Figure 117.—Layout of T&Y Diversion Project – fish louver structure – Example 4 (T&Y Irrigation District).

Approximately 150 ft of canal immediately downstream from the headworks was lined with a concrete invert and vertical concrete walls (figures 116 and 118). This section of canal was configured to accept the louver fish exclusion structure. The canal data and section properties follow:

- ▶ Bottom width = 20 ft (downstream from the headworks to the louver structure) 24 ft (downstream from the louver structure)
- ▶ Side slopes = vertical
- ▶ Maximum flow = 237 ft³/s
- ▶ Depth at 237 ft³/s (at louvers) = 3.8 ft
- ▶ Bank height = 7.0 ft
- ▶ Lining = reinforced concrete from the headworks past the louver
- ▶ Bottom slope = horizontal through louver structure



Figure 118.—T&Y Diversion Dam trashrack structure – Example 4 (T&Y Irrigation District).

- ▶ Velocity in canal at maximum diversion (at louvers) = 2.6 ft/s
- ▶ Operating season = April to October

The water surface is controlled by a downstream check structure and varies as previously noted.

Construction – The existing headworks structure was replaced with a new headworks, flume, and fish exclusion facilities. The construction work was accomplished during non-operating periods from October to April. Therefore, a canal bypass to deliver diversion during construction was not required.

The concrete foundation for the replacement headworks includes upstream and downstream cutoffs to prevent undermining of the headworks by scour and to reduce problems caused by seepage. In that a continuous wall and invert lining was used in the reach of canal that includes the louver, cutoffs were not required in the foundation of the louver.

A sheetpile wall was placed across the intake channel to provide for dewatering the headgate structure during construction. The sheetpile was initially installed to an elevation of 2454.0 (figures 117 and 118). When construction was completed, a 35-ft notch was cut to elevation 2446 in front of headworks entrance. Because

the sheetpile is 2 ft above the headgate invert, it will serve as a weir across the intake channel. This should reduce sediment entrainment at the headworks. A 24-inch low-level sluice has been placed adjacent to the headgate structure in front of the trashracks (figures 117 and 121).

Louver support structure – The louver support structure consists of a steel support frame placed on the concrete slab canal invert lining (figures 119, 120, 121, and 123). The louver face is vertical and retained by bolting louver panels to the support frame. The louver panels form a continuous louver face that is not broken by structural members that could collect debris, injure fish, or disrupt fish guidance along the louver. A foot bridge is included with the support structure to allow access to the full length of the louver face for maintenance and inspection. The invert of the louvers was positioned 1.0 ft above the canal invert to improve sediment sluicing and to generate a sill that would function to guide bottom oriented fish directly to the bypass (figures 117 and 121).

Louvers – As summarized in the presentation on criteria, the 90-ft-long louver line was installed in a section in which the maximum occurring sweeping velocity would be 2.6 ft/s. Based on the maximum diversion discharge and the corresponding active louver face area, the maximum approach velocity to the louver is approximately 1.0 ft/s. This velocity complies with the experience-based criteria.

This sweeping velocity yields a 35 second exposure time for fish passing along the 90-ft-long louver face.

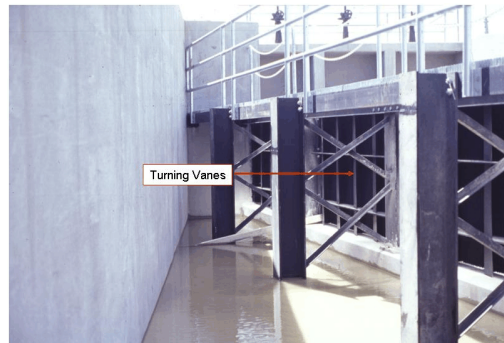
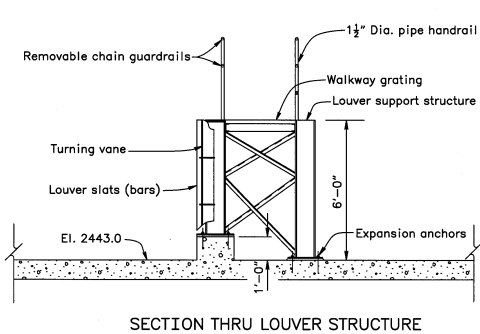
Again, relying on experience-based criteria, the 2.5-inch by 3/16-inch louver slats were set with a 1.0-inch clear spacing between slats. The slats were oriented normal to the approach flow (figure 122).

To minimize costs, the louvers were fabricated from coated steel. Each louver panel is 5 ft high by 10 ft long (figures 120 and 122). This positions the top of the louvers approximately 2 ft 2 inches above the maximum water surface elevation and at the same elevation as the walkway deck. This height allows the louvers to be manually raked to the walkway.

The louvers could have been either bolted to the support frame or placed in guides. Placing the louvers in guides facilitates removal and replacement; however, it also increases facility cost. For this facility, the louver panels were bolted to the support structure (figure 120). Removal of panels would be accomplished using a mobile crane. The louver structure is unwatered from mid-fall to mid-spring. Unwatering allows convenient access for maintenance, including debris and sediment removal.



Figure 119.—View looking upstream at the T&Y louver placed at an angle to the canal flow – Example 4 (T&Y Irrigation District).



- a. Flow is from left to right through the louver.
- b. View through support structure on backside of louvers.

Figure 120.—Louver structure setting on 1-foot curb – Example 4 (T&Y Irrigation District).

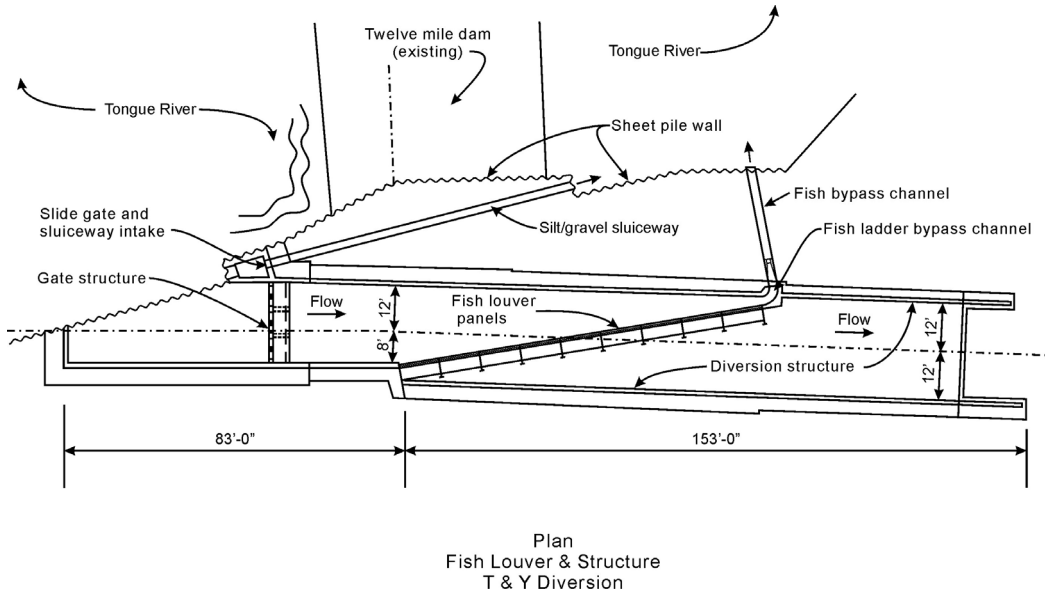


Figure 121.—Schematic layout of T&Y Diversion Project – Example 4 (T&Y Irrigation District).

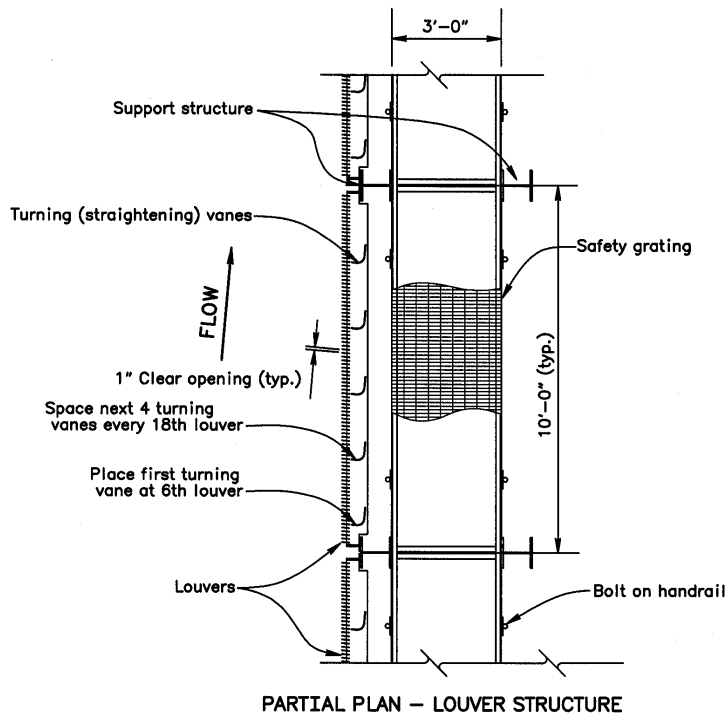


Figure 122.—Louver structure detail – partial plan – Example 4 (T&Y Irrigation District).



Figure 123.—Louver and walkway. Note river on the left and canal downstream beyond the louver – Example 4 (T&Y Irrigation District).

Turning vanes – Turning vanes were placed directly behind the louver array to turn the flow that has passed through the louvers and direct it down the canal (figure 122). This treatment maintains a uniform velocity field on the back side of the louvers. The turning vanes assist in generating uniform approach velocities across the louvers without the need for refined analysis and development of hydraulic flow distributions in the approach and exit channels (figure 97) (chapters IV.A.6. and V.A.).

Louver facility head loss estimate – Assumed louver head losses range from 2 to 4 times the channel velocity head (chapter IV.A.5. and 8.) which yields estimated losses of 0.3 to 0.6 ft of water at the maximum diversion. These head losses result from the effect of both the louvers and the turning vanes.

h. Fish bypass channel

A 2-ft-wide bypass channel is placed at the downstream end of the louver structure. The open chute bypass allows natural light and allows convenient access for cleaning. The 2-ft-wide channel will produce excessive bypass flow as well as excessive exit velocities if not restricted. Control is achieved using stop logs placed in a guide placed immediately downstream from the fish bypass entrance (figure 124). Stoplogs have to be adjusted with changing diversion flows and flow depth to supply adequate control and allow continued bypass flow

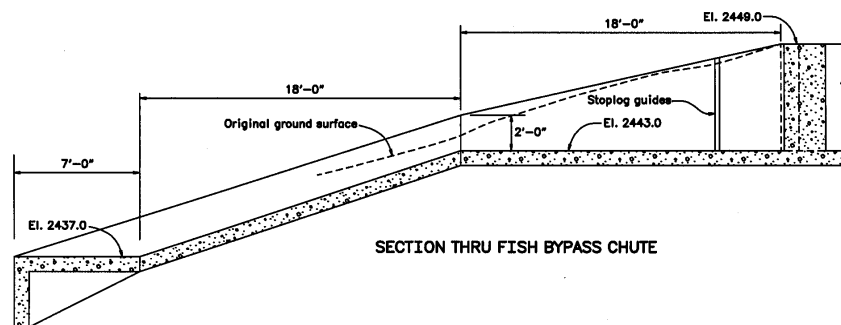


Figure 124.—Section through bypass outlet – Example 4.

for various river conditions. The bypass channel produces exit flow velocities in the range of 3 to 10 ft/s. The bypass flow, normally less than 8.0 ft³/s, returns to the river in a distance of approximately 30 ft.

Debris and cleaning – Debris loading varies seasonally and includes heavy loading of floating debris during the high-river-flow events (the headworks design tends to exclude most floating debris), loading with water logged woody materials, and limited loading with aquatic plants and leaves (in the fall). A trashrack is included upstream from the gate structure when the replacement headworks structure was built (figures 116, 117, and 118). The trashrack combined with sluicing action generated by the overflow weir effectively sluices most floating debris away from the headworks and over the ogee weir. This sluicing is optimized by the close placement of the headworks to the weir and the tangential orientation of the trashrack to the weir approach flow. The primary debris management problem at the site is associated with the smaller, water-logged, woody materials that are embedded in the deposited sediment upstream from the dam. In the mid to late summer, streamflows decrease and, thus, the sluicing action generated by the overflow weir is reduced. However, irrigation diversion demands during this time are high. Headcutting occurs in the sediment in the diversion pool, and as a result, sediment and water logged materials are transported into the canal. The water-logged materials may become wedged between the louver slats and making cleaning difficult. Manual removal (raking) of this debris has been required.

Facilities for Emergency operation due to potential louver plugging – Although woody debris accumulation on the louver has proven to be a problem that may adversely influence fish exclusion performance, the louver maintains diversion capacity even when fouled with woody debris. Consequently, emergency operations have not been required at the site.

Sediment management – Heavy bedload sediment is transported in the river, particularly during high flow events (primarily in the spring). As a result, sediment deposition in the diversion pool is near the elevation of the overflow weir crest. A sediment sluice was included with the replacement headworks (figures 117 and 121). Operating this sluice during high river flow events will help reduce sediment deposition at the headworks. Because of limited river flow, the sluice cannot be routinely used during late summer. Consequently, sediment will be diverted into the canal as sediment head cutting occurs in the diversion pool. The louver structure was constructed with the louvers placed on a 1.0 ft high concrete sill (figure 120). This sill elevates the bottom of the louver above the floor of the approach channel and functions to direct bedload sediment along the louver and to the fish bypass, which also functions as a sediment sluice. Louvers can also effectively pass suspended sediment and are less sensitive to sediment influences than positive barrier screens.

Ice loading – Icing can occur in both the spring and fall, particularly near the start and end of the irrigation season. Although severe icing conditions are typically not anticipated, icing might be sufficient to yield fouling of fine mesh screens. Snow and ice will accumulate in the canal during the winter. Because of potential ice damage, winter screen removal is likely.

I. Post construction adjustments and testing

Post construction evaluations of the louver facility performance were conducted. Operation of the facility has proven generally effective. Debris is manually removed from the louvers. Evaluation of fish exclusion performance by the Montana Department of Fish, Wildlife and Parks has shown approximately 90 percent effectiveness in keeping fish out of the canal.

Options available for modification of hydraulic operation of the T&Y louver structure were limited to adjustment of louver approach flow distribution between the three slide gates of the headworks and placement of stop logs in the bypass structure to modify bypass flow rates and bypass velocities. The turning vanes (positioned behind the louvers) are not adjustable, and experience has shown that adjustment of the turning vanes will not be required. Figure 119 shows a view looking upstream at the louver structure and walkway.

5. Example 5 – Cylindrical Screening Facility (Based on Columbia River Pumping Plant, Oregon)

This example presents a cylindrical screening facility located in a river/diversion pool with an on shore pumping plant. The screening and pumping plant facilities are a key feature in a project to restore salmon runs and enhance steelhead fishing in the Umatilla River (Reclamation, 1994). The Columbia River Pumping Plant, part of the Umatilla Basin Project, delivers water from Lake Wallula to the

Columbia-Cold Springs Canal, which then transports the water to Cold Springs Reservoir. The pumping plant will pump approximately 40,800 acre ft of water annually (240 ft³/s plant design capacity) from the Columbia River. This water will replace water previously diverted by two irrigation districts from the Umatilla River. These previous diversions from the Umatilla River will be eliminated to meet target flows for fish passage.

a. Fishery

Species – Salmon and steelhead

Size – Fry, fingerlings, and larger

Move downstream – Critical time for screening is from late April through mid-July

Swimming – The fry generally drift with the current and have little strength and endurance to swim against the current. Fry occur throughout the water column.

b. Reservoir/river design data

The water surface of Lake Wallula is controlled by McNary Dam and the upstream dams in the Columbia River system. The fish exclusion facilities for this pumping plant must be able to operate satisfactorily at the following water surface elevations and conditions of Lake Wallula:

- ▶ Maximum water surface: El. 341.0 (all elevations in ft mean sea level)
- ▶ Normal reservoir operating range: El. 337.0 to El. 340.0
- ▶ Minimum water surface: El. 335.0
- ▶ Daily fluctuations could be as large as 2 ft
- ▶ Severe wind and boat wave action can be expected (up to 6 ft high)

c. Design data

Construction – No in-river work including operation of equipment can be performed in the active flowing stream between April 1 and November 30, unless otherwise coordinated with the Division of State Lands and Oregon Department of Fish and Wildlife.

Sediment – Sediment deposition is expected to be minor.

Debris – During the months of April and May, tumbleweeds are blown into the river, become saturated, and sink and move along the lake bottom. The tumbleweeds are not expected to be a problem with blocking the screens. In June and July, increasing amounts of Eurasian water millfoil (yew plant) have been found in small clumps floating down the river toward McNary Dam.

Pumping plant design capacity – The pumping capacity for the Columbia River Pumping Plant was based on an operations study conducted in Reclamation’s Pacific Northwest Region. The studies determined that the canal needs to be able to deliver an average of 220 ft³/s in any given month. The design pumping plant capacity was then increased to 240 ft³/s to account for allowances of minor seepage losses and for operational flexibility to permit down time for power outages, routine maintenance, and emergency repairs.

Site layout – The visual and audio impacts on the surrounding area need to be considered in the site design, both on river and off river. Extensive landscaping is required to help reduce the impact of the plant on the surrounding area. Electrical power is available in the general area and can be extended to the fish screen facilities. The electrical equipment for the switchyard will be provided by Umatilla Electric. A short access road to the site will be required off an existing highway. Five different geologic reports on sites close to or at the pumping plant site were provided for use in preparing the designs and specifications for the Columbia River Pumping Plant.

d. Fish screen structure design criteria

The criteria were agreed to by a group consisting of State and Federal agencies, the water districts, and the designers. Design criteria for the fish screen structure are based on juvenile fish screening criteria of the NOAA Fisheries northwest division. Note that the plant was designed in 1991 and 1992; at that time, NOAA Fisheries screen criteria for juvenile salmonids were slightly different from their current criteria. (See the current criteria in attachment A.)

Fishery

- ▶ Fish species – The fish species are salmon and steelhead.
- ▶ Fish size – The screens should be able to safely exclude fish as small as fry (25–60 mm).

Screen structure

- ▶ Positive barrier screens are required.
- ▶ The preferred screen location is in the river.
- ▶ Generally, the screen face should be parallel to the river flow.
- ▶ The screened intakes should be offshore to minimize fish contact with the facility.

- ▶ The screened intakes should be in areas with sufficient sweeping velocity to minimize sediment accumulation in or around the screen and to facilitate debris removal and fish movement away from the screen face.
- ▶ The screens should be sized for a screen approach velocity not to exceed 0.40 ft/s.
- ▶ The screen approach velocity should be uniform across screens.

Fish screens

- ▶ The screen material should be corrosion resistant and sufficiently durable to maintain a smooth uniform surface with long term use.
- ▶ For profile bar (wedge or “Vee” wire) screen, the narrowest dimension in the screen openings (slot opening) should not exceed 0.125 inch in the narrow direction (old criteria).
- ▶ Screen material to provide a minimum of 27 percent open area.
- ▶ Fish screens should be cleaned as frequently as necessary to prevent accumulation of debris. The cleaning system and protocol must be effective, reliable, and satisfactory to NOAA Fisheries. Proven cleaning technologies are preferred.

e. *Location of Fish screens and pumping plant*

An in-river location of the fish screen structure with fixed cylindrical screens and an off-site pumping plant were chosen (Reclamation, 1995). Some of the reasons for this selection were:

- ▶ This screen allows the fish to stay in the river.
- ▶ With this in-river structure, fish bypasses would not be required.
- ▶ Sediment deposition is not a problem.
- ▶ Trash will remain in the river and will not have to be removed and trucked away.
- ▶ Since the screens are always submerged, icing and visual impacts are reduced.
- ▶ Air burst cleaning systems are a proven technology for cleaning cylindrical screens.

- ▶ It was determined that the screen and intake piping could be installed in the wet, on piles, thus reducing the cofferdam and dewatering requirements.
- ▶ An off site pumping plant reduces concerns with visual and sound issues.
- ▶ With the intake conduit extending to the pumping plant sump, entrapped air can be vented before the flows reach the pumps.

f. Design of Fish screen structures (figure 80)

The fish screen facility will consist of:

- ▶ Intake screens (cylindrical tee screens)
- ▶ Concrete piles
- ▶ Intake pipes
- ▶ Intake conduit (concrete box culvert)
- ▶ Air burst cleaning equipment
- ▶ Pumping plant, discharge piping and valves, flowmeter, and spherical air chamber

Fish screen intake – Cylindrical fixed screens were chosen to allow mounting the screened intake offshore, in the river, and below the water surface. This type of screen is a positive barrier screen. The screens prevent entrainment of fish and aquatic organisms in three ways. First, the 0.125 inch wide screen slots prevent the entry of small fish. Second, the surface area and net-through-the-screen openings are designed so the screen approach velocity does not exceed 0.40 ft/s. And finally, the cylindrical design creates a small cross-sectional target, thus, reducing the time (or the likelihood) that fish may be exposed to the cylindrical screens.

The cylindrical screen manufacturers recommend that the through-slot velocity be not greater than 0.5 ft/s. For this case, the through-slot velocity requirement will govern the sizing of the screens because it will give a smaller screen approach velocity than the maximum allowed by the fish resource agency's criteria.

$$V_{\text{approach}} = V_{\text{through slot}} \times \text{Screen percent open area}$$

Assuming: $V_{\text{through slot}} = 0.5 \text{ ft/s}$ and the maximum screen slot openings = 0.125 inch.

From the screen manufacturers products data sheets: The screen percent open area is approximately 64 percent for 0.125" slot openings and their standard (wedge or "Vee") wire. Therefore, the maximum screen approach velocity used for sizing the screen is:

$$V_{\text{approach}} = 0.5 \text{ ft/s} \times 0.64 = 0.32 \text{ ft/s} \text{ (this is less than the fish resource agencies allowed maximum approach velocity of 0.40 ft/s)}$$

The required screen area (A_{required}) is equal to the flow (Q) divided by the screen approach velocity (V_{approach}). So the required screen area is:

$$A_{\text{required}} = Q/V_{\text{approach}} = (240 \text{ ft}^3/\text{s})/(0.32 \text{ ft/s}) = 750 \text{ ft}^2$$

The manufacturers of fixed cylindrical screens recommend that the bottom of the screen be at least half a screen diameter above the lake or river bottom and that the top of the screen be at least half a screen diameter below the minimum water surface. (They also recommend checking navigational requirements.) At this site, the centerline of the cylindrical screens was set at El. 328.17 to be above sediment deposition and the potential for bottom submerged tumbleweeds, and to be as high as possible to limit excavation requirements to the pumping plant. This placed the centerline of the screens approximately 18 ft above the lake/river bottom (silt) and 6.83 ft below the minimum water surface.

Eight 60-inch diameter cylindrical tee screens, each sized for 30 ft³/s flow, were chosen after looking at the screen manufacturers' product data sizing charts and sheets (recommended screen size based on percent open area and flow in gallons per minute). This size of screen provided at least 52 inches of submergence above the top of the screen at the minimum water surface. Larger diameter cylindrical tee screens were available in the catalogs (up to 84 inch), but were not selected since they are fabricated in a less streamlined assembly. Each screen contains a 42-inch diameter flanged outlet connection, a 6-inch diameter flanged connection for the air supply piping for the air burst cleaning system, and an air burst distribution pipe within the screen (figure 31). (Note that the construction specifications need to clearly indicate the installed position of the screens so that the screen manufacturer can properly position the internal air distribution piping and nozzles within the screens.) The screens will be fabricated from 304 stainless steel and will use profile bar (wedge wire or "Vee" wire) with 0.125 inch slot openings. (See figure 51.) The screens were specified to withstand a differential hydrostatic collapse load of 18 ft of head without damage to the screen.

The configuration and spacing of the screens and intake piping are designed to balance the flow of the intake water and to allow silt and debris to flow away from the screens during the air burst cleaning operation. Each cylindrical screen is bolted to a 42-inch-diameter pipe. These pipes tee into 54-inch-diameter header pipes, which tee into two 72-inch-diameter steel intake pipes. These larger

pipes will convey the intake flows to a single, rectangularly shaped concrete box culvert (10-ft-wide by 7-ft-high conduit). (See figure 80.) The screens are installed so that their centerlines are parallel with the river flow. The two branches of screens are offset from each other so the centerlines of the installed screens are not directly in line with the centerlines of the other branch of screens. This reduces the potential for fish to be exposed to the full line of screens. The box culvert conveys the flow to the pumping plant sumps and allows venting of entrapped air before the flows reach the pump bowls. The differential pressure that drives the flows through the screens is caused by the difference between the lake elevation and the sump elevation of the pumps. The minimum operating water surface at the pumping plant sumps is El. 333.0.

The submerged cylindrical tee screens and the intake steel piping will be supported on concrete piles, thus, allowing installation in the wet without a cofferdam. (See figures 31 and 80.) Saturated alluvium overlaying basaltic bedrock will be encountered during drilling operations of the offshore piles. Braces on the intake support structures will be installed underwater and may require some excavation. The intake steel pipes will be designed to span the distances between the piles and the box culvert. The intake pipes and the air-burst supply piping will be assembled underwater. Insulating gaskets, sleeves, and washers are installed between the mating flanges and bolt surfaces of both the 42-inch flanges and the 6-inch air burst flanges to prevent galvanic corrosion caused by contact of dissimilar metals.

Pumping plant – A cofferdam and dewatering system will be required to allow construction in the dry of the intake concrete box culvert and the pumping plant. The groundwater table in the pumping plant area closely reflects the level of Lake Wallula. The concrete box culvert was chosen to reduce costs over extending the intake steel pipes all the way to the pumping plant (recommended proposal during the value engineering study). The pumping plant is an outdoor plant. The space requirements of the pumps controlled the layout of the pumping plant. The depth of the plant was set by the submergence requirements of the pumps. The pumps are situated to equalize the size of the sumps to the maximum extent possible. Most of the pumping plant and the discharge valves are located below the service yard elevation to reduce the overall visual impact of the plant. Berms were provided around the plant to visually screen the pumping plant and to simultaneously screen pumping plant sounds from adjacent properties. An air chamber was required to prevent water column separation in the discharge line. Stoplog guides were also included at the pumping plant entrance to allow isolation of the pumping plant from the river, if required.

Screen cleaning system – The screens are cleaned by bursting air to flush debris and organisms from the screens without removing this material from the water. (See figure 82.) A separate 6-inch air supply line will connect to each screen to

allow cleaning one screen at a time. This also reduces the size of the air burst cleaning equipment required. The air burst cleaning equipment will be at the pumping plant and consists of:

- ▶ one air compressor
- ▶ one horizontally mounted air receiver tank
- ▶ one set of actuator air supply controls
- ▶ eight butterfly valves and actuators

The size of the air receiver tank (V_r) and the pressure (P_r) required for the air burst system were based on the following equation:

$$V_r \times P_r = 3 \times [P_s \times (V_s + V_p)]$$

Where V_r = receiver tank size in ft³
 P_r = receiver tank pressure in lb/ft²
 P_s = pressure above screen centerline
 V_s = volume each screen
 V_p = volume air supply line

Max. water surface = El. 341 ft Centerline fish screen = El. 328.17 ft

Volume each screen, $V_s = 334 \text{ ft}^3$ (cross sectional area of screen times screen length)

Volume air supply line, $V_p = 50 \text{ ft}^3$ (cross sectional area of pipe times pipe length)

Pressure above screen centerline, $P_s = [(341 - 328.17) \times 0.434 \text{ psi/ft}] + 14.7 \text{ psi} = 20.3 \text{ psi}$

Therefore,

$$V_r \times P_r = 3 \times [P_s \times (V_s + V_p)] = 3 \times [(20.3) \times (334 + 50)] = 23,386$$

$$\text{If try } P_r = 150 \text{ psi, then } V_r = 23,386/150 = 156 \text{ ft}^3 = 1167 \text{ gallons}$$

Based on these calculations, an air burst pressure of 150 pounds per square inch and a receiver tank size of 1,200 gallons were selected. The size of the air compressor was then chosen (72 cfm minimum displacement at 150 psi discharge pressure) based on the operating pressure, air receiver tank size, and the desired cleaning cycle time of the screens.

The time required to charge up the air receiver tank can then be determined. First find the required inlet volume (V_1) by using the following equations.

$$V_1 \times P_1 = V_r \times P_r \quad \text{or} \quad V_1 = (V_r \times P_r)/P_1$$

Then divide this calculated inlet volume by the air compressor displacement capacity to get the time (T) required to pressurize the air receiver tank to the desired pressure.

So, given that the receiver tank capacity is: $V_r = 1200$ gallon (160.4 ft^3), the receiver tank is to be pressurized up to $P_r = 150$ psi, the inlet air pressure is $P_1 = 14.7$ psi, and the compressor displacement capacity is $72 \text{ ft}^3/\text{minute}$ (cfm). Therefore, the inlet volume required is:

$$V_1 = (160.4 \times 150)/14.7 = 1636.7 \text{ ft}^3,$$

and the time to charge up the receiver tank is:

$$T = 1636.7/72 = 22.7 \text{ minutes.}$$

So, it will take approximately 23 minutes to pressurize the air receiver tank to clean one screen and approximately 200 minutes to clean all eight screens.

The air burst cleaning system can be manually or semi-automatically operated. Full automation was not desirable at this site, mainly because of boating in the area.

Differential water level controls are provided to monitor the differential water level across the screens. One sensing element will continuously measure the water surface elevation of Lake Wallula and the other sensing element will continuously measure the water level in the pump sump. When the difference in these water levels meets or exceeds a preset point, an alarm will be initiated to indicate that the screens have reached an unsatisfactory level of plugging. This system is designed to allow for future remote monitoring. Additional monitoring of the water surface in the pumping plant intake sump will be provided and will initiate a low water alarm and shutdown of the pumps if the water level in the sump goes below the minimum sump water level.

Chapter VII. Post Construction Evaluation and Operation and Maintenance Plans

“Experience is not what happens to you; it’s what you do with what happens to you.”

– Aldous Huxley

Once construction is completed, a new screen may be required to undergo a series of hydraulic and biological tests. These tests will validate facility construction and operating capability, guide refinement of hydraulic operations, and document facility effectiveness. Hydraulic tests will include velocity measurements (magnitude and direction) along the screen face, bypass entrance velocities, and bypass flow performance. Once the fish screen facility is operating as designed, biological tests can be conducted.

The Central Valley Project Improvement Act’s Anadromous Fish Screen Program Technical Team proposed Guidelines for Developing Post-Construction Evaluation and Assessment Plans, and Operations and Maintenance Plans (Service, 1999). The team included the following:

- ▶ U.S. Fish and Wildlife Service
- ▶ Bureau of Reclamation
- ▶ NOAA Fisheries
- ▶ Natural Resources Conservation Service
- ▶ California Departments of Fish and Game and Water Resources

A. Post Construction Evaluation

Each site will have its own unique physical characteristics. However, all essential components of a fish screen structure should be tested to ensure their functionality. The following is a generalized list of evaluation criteria from USFWS, 1999:

- a. **Mechanical and Electrical equipment** – Testing of mechanical and electrical systems should be performed before initiating operations, whenever possible. The Project Manager should be given adequate notice when testing will be performed. Tests should include

alarm systems including audible alarms, pagers and other warning systems, automated data recording equipment, emergency shut-off systems, cleaning systems, actuators and solenoids, and other mechanical and electrical systems.

b. Automatic cleaning systems evaluations – Cleaning systems and their components should be tested in the dry, when possible, and again when screen facilities are operable prior to initiating normal operations. Using operations and maintenance documentation provided by the designer and/or fabricator of the cleaning systems, all cleaning systems shall be tested and calibrated by applying the design force to each panel. In cases where testing in situ can cause damage to the screen panel, the trip mechanism should be tested under controlled conditions prior to installation in the facility.

c. Fish entrainment evaluations – Fish entrainment evaluations may be required by the Project Manager, or the fishery regulatory agencies represented on the Program’s Technical Team, on a case-by-case basis. If required, tests will be performed by qualified personnel using well established methodologies. Fish entrainment study plans should include equipment and methodologies to be used, duration of testing expected, and frequency of monitoring required.

d. Juvenile fish bypass systems evaluations – Biological and hydraulic testing of juvenile fish bypass systems may be required, where applicable, to ensure the safe return of juvenile fish to the main river channel. When required, the Project Manager, or the above mentioned fishery regulatory representative, will outline an acceptable evaluation process for the specific site. The Guarantee will then use the guidelines provided to prepare a study plan for inclusion in the Evaluation and Assessment Plan. Qualified personnel will use well established methodologies to carry out these evaluations. Expertise from the Program may be available to Grantees for preparing study plans and/or carrying out juvenile fish bypass evaluations.

Study plans may include measuring water velocity profiles at bypass entrances and exits at design bypass flow rates. The study plan should be designed to determine if juvenile fish traveling with the predominant water currents will be guided efficiently into the juvenile bypass system. National Marine Fisheries Service (NMFS) now referred to National Ocean and Atmospheric Administration Department of Fisheries (NOAA Fisheries) fish screen criteria call for bypass entrance velocities to “equal or exceed the maximum velocity vector resultant along the screen, upstream from the entrance.”

Study plans may also include biological tests to evaluate the degree of safety provided to juvenile fish depending on the complexity of the bypass system and the size and number of juvenile fish likely to be present during the diversion season. Such biological evaluation would follow the hydraulic testing. The main points of interest in the biological evaluation are (1. fish passing by the screen and (2. fish passing through the bypass structure. Before any biological testing is performed, a study plan should be developed in cooperation with fishery resource agency staff.

e. Fish screen hydraulic evaluations – Hydraulic evaluations involve measuring water velocity values perpendicular (approach velocity) and parallel (sweeping velocity) to the screen face. The velocity measurements are usually performed some 3-inches off the face of the screen which corresponds to established criteria. Deviations from the 3-inch requirement may be necessary for screen designs where the total screen surface is not readily accessible, such as drum screens. Not all fish screens require hydraulic evaluations. Cylindrical screens with the central axis oriented perpendicular to river flows, and some other designs for small diversions, do not require hydraulic evaluations. This is in particular the case for commercially available, prefabricated screens, where design of the hydraulic and velocity distribution control was developed through generalized studies and laboratory investigations. Screens with flow balancing louvers (baffles) must employ hydraulic testing to properly adjust baffle systems to achieve uniform approach velocities across the screen face. Baffle systems must be properly adjusted prior to initiating normal diversion operations.

f. Post-construction retrofit – In the event the Post-Construction Evaluation determines that structural modifications must be made for the screen facility to operate as designed, a list of possible solutions to rectify these problems shall be submitted to the Project Manager along with a schedule for carrying out the preferred method.”

In appendix A of the Guidelines for Developing Post-Construction Evaluation and Assessment Plans, and Operations and Maintenance Plans (Service, 1999), a guideline for Developing a Study Plan for Hydraulic Evaluations presents a rather complete template for development of a hydraulic evaluation plan.

A long term operations and maintenance plan needs to be developed as part of any fish screen facility design and construction project. The operations and maintenance plan should serve as an owner’s manual for the fish screen facility.

B. Operations and Maintenance Plan

The operations plan should be clearly posted in a highly visible site at any water diversion site where fish screening protection is provided. The list should include instructions for:

- ▶ Specific operating procedures to achieve uniform approach flow velocities on the screen face for various diversion rates
- ▶ Emergency shut down procedures
- ▶ Specific pump use criteria (pumped diversions) and gate use criteria (gravity diversions) needed to achieve uniform approach flow velocities across the screen surface
- ▶ Operating instructions for pressure relief valves, auxiliary equipment, and emergency shut down procedures
- ▶ Operation guidelines for bypass control to ensure acceptable bypass entrance velocities are maintained when there are variations in downstream canal water surface elevations

Maintenance plans should include the following:

- ▶ Recommendations by designers, contractors, and suppliers of equipment used in the fish exclusion facility
- ▶ Intervals at which various procedures should be performed
- ▶ Documentation provided by suppliers for their products, including specifications and maintenance requirements

C. Periodic Inspections

Guidelines for conducting periodic inspections are given below.

1. Audit Maintenance Records

- ▶ Review the operations and maintenance log book for recurring problems
- ▶ Compare the logged records with the O&M plan for compliance and troubleshooting

2. Underwater Inspection or Unwatered Inspection, if Possible

- ▶ Check for gaps at joints, seals, and seams that could compromise screen efficiency.
- ▶ Note accumulation of debris.
- ▶ Inspect screen material for damage and material integrity.
- ▶ Check screens and structure for corrosion, wear, or other deterioration.
- ▶ Check the sacrificial anodes and replace if necessary.
- ▶ Check the screen hold-down plates and other protrusions from the screen face for damage and debris accumulation.
- ▶ View the cleaning system operation. Intentionally foul the screen with locally available materials, if possible, to view cleaning efficiency.
- ▶ Check spray orifices for fouling (water and air spray systems).
- ▶ Check screen face for undulations in the screen material that may reduce cleaning efficiency (travel brush systems).
- ▶ Check brushes for wear and deterioration (traveling brush systems), readjust or replace as needed.
- ▶ Check seals for wear and deterioration.
- ▶ Assess the overall efficiency of cleaning system - suggest solutions in inspection report.
- ▶ Inspect the moving parts below water surface for corrosion and damage.
- ▶ Inspect the channel morphology in the immediate vicinity of the screen for debris, erosion, and sedimentation that may damage screens and their supporting structures or adversely affect the screen operation.

3. Velocity Measurement (if problems warrant)

- ▶ Measure approach and sweeping flow velocities along the screen face using approved methods.

- ▶ Calculate the diversion rates from measured approach velocity values and compare with the measured diversion rates.

4. Test Backup and Alarm Systems

- ▶ Test the pump shutoff.
- ▶ Test the blow-out relief panels.
- ▶ Test the mechanical brush shutoff system.
- ▶ Test the screen cleaning system operating and failure alarms.
- ▶ Test the water level (differential) readouts and alarms.

5. Reporting

- ▶ Document the results of periodic inspections in a report submitted to the Project Manager within 30 days of their completion.
- ▶ Suggest additions and eliminations to the operation and maintenance plan based on inspection results.
- ▶ Recommend corrective actions for ensuring that the diversion will function as designed and as required to satisfy fish screen standards. Corrective actions include repairs to facilities, changes in operation procedures, and changes in setting of baffles and automatic equipment.

Chapter VIII. Exclusion Barriers for Upstream Migrating Fish

“Adapt or perish, now as ever, is nature’s inexorable imperative.”

– H.G. Wells (1866–1946)

Exclusion barriers are designed to block upstream movement of fish. These barriers are used for a variety of purposes. *Instream* barriers are constructed across a river to block upstream movement of invasive species or guide migratory fish to fishways, count stations, or hatcheries. *Return flow* barriers are designed to exclude fish from man made conveyance channels that return flow to the stream. Return flow barriers are often used to prevent fish entry to tailraces of off channel hydropower facilities, water treatment plant outfalls, or irrigation wasteways.

Most barriers to upstream movement of fish are *velocity barriers* or *physical barriers*. Behavioral barriers (chapter V) including acoustic, light, electric and mixed flow systems have been used experimentally but have not proven to be effective in most cases (EPRI, 1999). A barrier must be designed to function over the expected design range of flow conditions for the site. In the case of anadromous fish, their presence may be seasonal and therefore, the barrier may not be required to function when the target species are not present in the river.

A. Velocity Barriers

Velocity barriers create a combination of flow conditions that restrict a fish’s ability to swim and leap into oncoming flow. The advantages and disadvantages of velocity barriers are:

Advantages

- ▶ Low maintenance
- ▶ Debris passes with the flow
- ▶ All species and life stages that are weaker swimmers than the target species are excluded

Disadvantages

- ▶ Barriers require significant head
- ▶ Performance is dependent on maintaining a minimum head differential across the barrier
- ▶ The upstream barrier pool may increase sediment deposits and reduce channel flood flow capacity

The basic requirements of a velocity barrier are:

- ▶ the combination of barrier height and length in the flow direction must be sufficient that the target fish can not leap from the downstream face over the barrier
- ▶ the flow depth and velocity passing down the barrier (non-vertical barriers) exceeds the fish's ability to swim over the barrier and prevent opportunities for sequential leaps

1. Fish Swimming and Leaping Performance

The swimming speed, endurance, and leaping ability of many migratory fish are well documented. The magnitude of these parameters is influenced by many factors, including: size, age, gender, spawning condition, and water temperature. Therefore, a wide range of swimming and leaping ability is encountered between individual fish and as a result of environmental conditions. Velocity barriers designed to exclude 100 percent of the fish are based on the strongest fish swimming under ideal conditions. If less than 100 percent exclusion is acceptable, barrier design parameters may include coefficients applied to the swimming performance that account for fish conditions typically observed in the field.

The swimming performance of fish is described by three ranges; cruising speed, sustained swimming speed and darting or burst speed. Fish can swim at cruising speeds for long periods, maintain sustained swimming speed for several minutes and dart for several seconds. Bell (1991) presents values for these ranges for a number of fish species. For example, the maximum swimming speed in each range for adult Chinook salmon are given as 4 ft/s (cruising speed), 12 ft/s (sustained speed) and 22 ft/s (burst speed) respectively.

Powers (1985) describes the leap trajectory (height and distance) a fish can achieve by applying the theory of particle trajectory under the influence of gravity. The trajectory of a fish leap is a function of the initial velocity (speed

and direction) of the fish as it leaves the water at the initiation of the leap. To estimate the leap trajectory of the strongest fish, the maximum burst speed is used as the initial velocity. Since the main propulsion is created by a fish's tail, the calculated trajectory can be thought of as following the path of the fish's tail with the body of the fish reaching above the estimated trajectory path. The relationship for particle trajectory can be expressed as:

$$y = x \tan \theta - \frac{gx^2}{2V^2 \cos^2 \theta}$$

At its maximum trajectory:

$$y = \frac{V^2 \sin^2 \theta}{2g}$$

where: y = vertical distance
 x = horizontal distance
 θ = angle of initial trajectory measured from horizontal
 g = acceleration of gravity
 V = initial velocity

Flow depth significantly affects the swimming and leaping performance of fish. Swimming performance is reduced if the flow depth is less than the depth of the fish. The movement of a fish's body and tail lying above the water can not produce propulsion. Leaping performance is restricted if the pool depth the fish leaves does not allow it to reach maximum burst speed or achieve the necessary leap trajectory. As a rule of thumb, pool depth should be less than the length of the fish to retard its ability to leap.

2. Velocity Barrier Design

The simplest velocity barrier is a weir that creates a vertical free jet. A barrier relying solely on vertical drop requires sufficient differential head across the barrier for all flow and downstream channel conditions for the barrier to function successfully. Fish will often leap in an attempt to pass barriers created by free falling flow. This behavior has been observed in many fish species including species not considered prone to leaping. An example of the leaping capability of healthy Chinook salmon follows. Applying the previous equation and assuming a burst speed of 22 ft/s and a leap trajectory of 80 degrees, a salmon could leap over 7 ft high $[(22)^2 \sin^2 80^\circ / 2g = 7.3 \text{ ft}]$. To exclude fish during high tailwater conditions requires a weir crest elevation about 8 ft above the design high

tailwater elevation. To reduce the dependency of barrier height on tailwater elevation, a weir with a shallow sloping downstream apron can be used. The apron is elevated above the high tailwater elevation and therefore maintains a length of shallow high velocity flow immediately downstream from the weir. The apron is designed to require a fish to use its burst speed while shallow flow impedes swimming ability and prevents the fish from leaping from the apron to pass over the weir wall (figure 125). Draft design guidelines and criteria for velocity barriers for anadromous salmonids have been adopted by the United States NOAA Fisheries, attachment A.

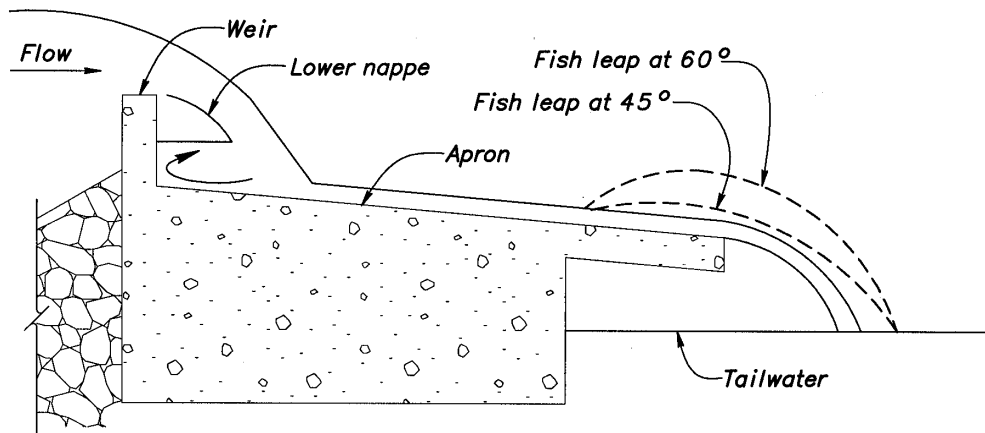


Figure 125.—Schematic of velocity barrier weir.

Consistent with the terminology used throughout the draft document, criteria are specified by the word “shall” and guidelines are specified by the word “should”. Criteria are required design features, unless site specific conditions preclude their use and a site-specific written waiver is provided by NOAA Fisheries. Guidelines are not required, but deviation from a guideline require a written explanation by the project designer. NOAA Fisheries suggests that deviation from a guideline be discussed with them prior to final design.

A summary of the major design criteria follows:

- ▶ The minimum weir height relative to the maximum apron height shall be 3.5 feet
- ▶ The minimum apron length shall be 16 feet
- ▶ The minimum downstream apron slope shall be 16:1 (horizontal: vertical)

- ▶ The maximum head over the weir shall be 2 feet
- ▶ Flow over the weir crest must be fully vented
- ▶ The elevation of the downstream apron shall be above the high design flow water surface

If these guidelines and criteria are varied, physical modeling is recommended to ensure the performance of the barrier.

3. Hydraulic Design

Hydraulic design of the weir includes estimating the flow versus depth on the apron, the nappe profile, the impingement zone flow and the nappe aeration requirements.

a. *Nappe Profile*

The nappe profile for flow over a sharp crested weir was studied by Reclamation for the design of ogee spillways (1987). The lower nappe profile shown on figure 125 can be approximately defined by the equation:

$$\frac{y}{H_0} = -K \left[\frac{x}{H_0} \right]^n$$

where: K and n are constants whose values depend on the slope of the upstream face of the weir and velocity of approach flow,
 x and y are nappe distances measured relative to the nappe trajectory apex
 H₀ = total head on the weir measured relative to the nappe trajectory apex.

For the simplest case of a vertical weir of height greater than 0.5 times the head on the weir, K = 0.5, n = 1.87 and the apex of the nappe lies 0.284 H₀ downstream and 0.127 H₀ above the weir crest. Coefficients for short weirs or inclined weirs can be found in *Reclamation Design of Small Dams* (1987). Other methods to estimate nappe profiles are available. Chow (1959) presents a quadratic form of a sharp crested weir nappe formula based on particle trajectory developed by Blaisdell (1954). Rouse (1950) presents graphical descriptions of nappe profiles for sharp crested weirs, sills, and free overfalls.

b. Nappe Impingement Zone

Downstream from the weir, the nappe impinges on a shallow sloping apron redirecting the flow along the apron. Flow conditions at the impingement zone can be approximated utilizing study results by Moore (1941), White (1942) and Rand (1955) on free overfalls. In figure 126, White (1942) shows a portion of the jet is redirected both upstream and downstream from the impingement. The upstream flow results in an elevated water depth, d_f , between the lower flow nappe and the downstream weir face. Prior to impingement, the jet is shown thickening and slowing as it entrains water passing in front of the backflow pool. The water entrained is equal to the upstream flow dispersed by the impingement. By continuity, the downstream flow must be equal to the flow passing over the upstream weir. Flow moving downstream on the apron transitions toward normal depth based on the apron slope and roughness. White shows the velocity of the downstream jet is given by the equation:

$$V_d = \frac{V}{2}(1 + \cos\theta)$$

- where: V_d = velocity of downstream flow
 V = velocity of flow prior to impingement
 θ = upstream angle between the nappe centerline and the apron surface

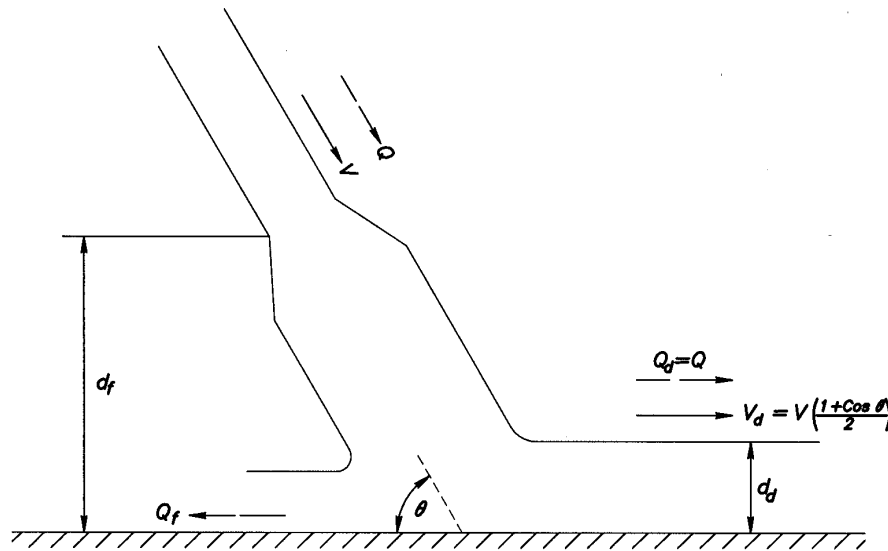


Figure 126.—Inclined jet impinging on a horizontal surface (White, 1942).

The flow velocity prior to impingement is estimated using the total upstream energy as:

$$V = \sqrt{2g(h + h_f)}$$

where: g = acceleration of gravity
 h = head on the weir
 h_f = distance from the weir crest to the apron

The depth of flow downstream from the impingement zone (d_d) is determined by the unit discharge divided by the downstream velocity (q/V_d).

The depth of the backwater pool on an apron of shallow slope behind an aerated jet is estimated using the drop number developed by Rand (1955) for a free jet impinging on a horizontal surface. The drop number (D) is a dimensionless number defined as:

$$D = \frac{q^2}{gh_f^3}$$

The backwater pool depth (d_f) is approximately:

$$d_f = h_f D^{0.22}$$

c. Nappe Aeration

The lower flow nappe downstream from a barrier weir must spring free of the weir crest forming an air cavity between the lower nappe and the downstream weir wall. Stability of the air cavity depends on a continuous supply of air from above the flow to beneath the nappe at a rate equal to the air entrained and transmitted downstream by the flow. If insufficient air is available to the cavity, pressure below the nappe will decrease and suppress the flow nappe toward the weir wall. A sufficiently suppressed nappe increases the opportunity for fish passage over the weir through a reduction in the size of the air cavity and an increase in the strength of the backflow. Boss (1990) presents a relationship for estimating the air demand beneath the nappe per unit length of weir as:

$$\frac{q_{air}}{q_w} = \frac{0.1}{(d_f / h)^{1.5}}$$

where: q_{air} = unit discharge of air, ft³/s/ft
 q_w = unit discharge of water over the weir, ft³/s/ft

Air may be drawn beneath the flow nappe by several paths. Thin flow nappes often breakup quickly as the water falls allowing air to pass through the nappe. Flow nappes that remain coherent over the length of the drop require access points where air is drawn into the air cavity under the flow nappe. Contracted weirs or weirs with the end walls that form a sudden expansion downstream from the weir can provide direct venting from the ends. Access for air across the length of the nappe can be attained downstream from crest piers that extend above the water surface and cause the flow to separate. If the structure geometry does not provide sufficient access for air to reach the lower nappe, venting can be achieved by installing air vent pipes. Vent pipes are commonly run through the structure endwalls and then daylight above the ground surface. Ideally, vent pipes should be sized sufficiently large to provide a fully aerated nappe. A fully aerated nappe was found by Hickox (1944) to occur when the ratio of pressure beneath the nappe (p , ft of water) to head on the weir (p/h) is less than about 0.01. This can result in large air vents for many barrier designs. Until data is available to identify allowable nappe suppression for barriers, it is suggested air vent designs use a p/h ratio of 0.05 to 0.1. The air vent can then be sized following standard hydraulic methods as:

$$p = \frac{1}{830} \left[\sum Losses \right] \frac{V_a^2}{2g}$$

where: p = pressure beneath the nappe, ft of water
 $Losses$ = loss coefficients for vent geometry and friction
 V_a = Vent air velocity, ft/s
 g = acceleration of gravity, ft/s²
 (1/830 = ratio of density of air to density of water)

4. Examples of Velocity Barriers

a. Coleman National Fish Hatchery Barrier

A photograph of the Coleman National Fish Hatchery Barrier located near Redding, California is shown in figure 127. The barrier constructed in 1992 by the U.S. Fish and Wildlife Service blocks salmon from moving upstream and guides them to a bypass where fish are taken for hatchery spawning. The barrier has a 2 ft high weir with a 15:1 downstream sloping apron, 14 ft in length.



Figure 127.—Fish barrier weir at Coleman National Fish Hatchery, Battle Creek, California.

Monitoring of the barrier has revealed approximately 5 to 10 percent of the Chinook salmon that reach the barrier are able to pass when the weir flow depth is between 1 to 1.5 feet. The 5 to 10 percent barrier passage is likely due to intermittent nappe suppression caused by insufficient venting of the flow nappe. Video records clearly show fish using the suppressed nappe condition to pass the barrier weir. The barrier weir is being modified to improve performance by improving air venting and mounting a 2-ft-wide-horizontal plate on the weir crest to form a cantilevered lip extending downstream over the apron (figure 128).

b. *Walterville Tailrace Barrier*

The Walterville tailrace barrier was designed by MWH Engineering for Eugene Water and Electric Board, Eugene, Oregon (2005). The barrier is located about 1,300 ft off the McKenzie River in the Walterville tailrace channel near river mile 21. The velocity barrier replaced an existing rack barrier. A section through the barrier is shown in figure 129. The velocity barrier was first operated in 2003. The barrier has a 3.5 ft high weir with an adjustable crest and a 16-ft-long apron sloping at 16:1. The weir is 250 ft long and is set at a 30 degree angle to the tailrace channel. At the upstream terminus of the barrier a bypass channel leads

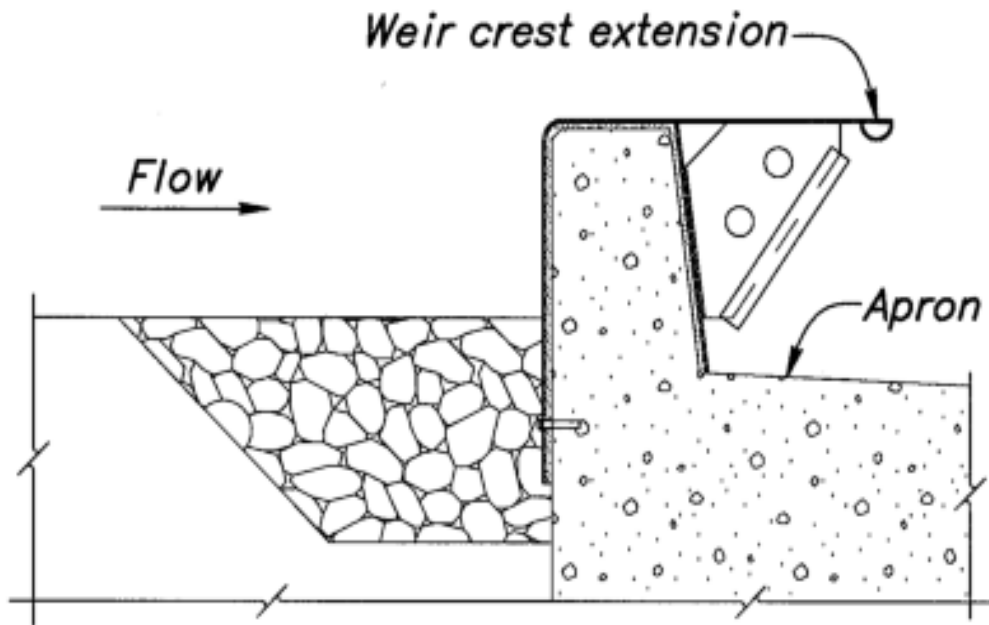


Figure 128.—Weir crest extension applied to the Coleman National Fish Hatchery barrier weir.

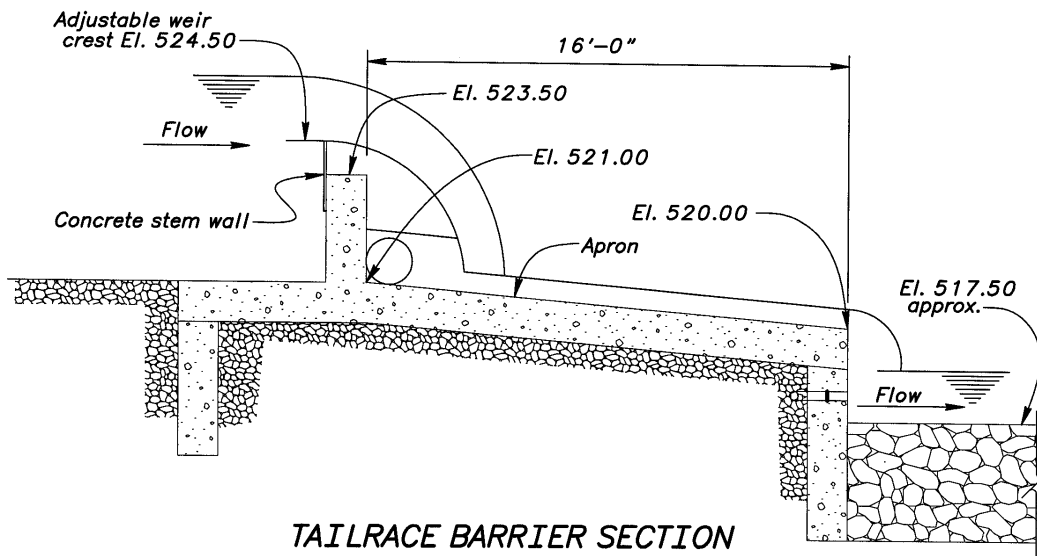


Figure 129.—Walterville tailrace velocity barrier weir, McKenzie River, Oregon. (Eugene Water and Electric Board).

fish back to the river. Some Chinook salmon were observed passing the barrier during the first year of operation. It was determined the weir was not sufficiently vented. Modifications were made to the weir vent system which has improved fish exclusion to nearly 100 percent.

B. Physical Barriers

Physical barriers (picket barriers) to upstream passage are typically flow-through structures designed to exclude fish using closely spaced bars also referred to as pickets. Physical barriers may be permanent structures with cleaning devices, seasonal structures with or without cleaning devices or temporary structures. Where no cleaning device is provided, periodic hand raking and cleaning is typically performed. Temporary physical barriers are used for guiding fish to traps or counting stations and to control fish movement during in-river construction. The advantages and disadvantages of physical barriers are:

Advantages

- ▶ Low head loss under clean and partially plugged conditions.
- ▶ Functions over a wide range of river stage.
- ▶ Barriers can be designed to be installed and removed seasonally, if not required.

Disadvantages

- ▶ Physical barriers only exclude fish larger than the bar spacing.
- ▶ Bar racks require periodic cleaning and are subject to rapid plugging if exposed to high flow events that transport large debris.

1. Physical Barrier Design

Physical barrier bar racks designed to exclude upstream migrating fish are similar in concept to intake trashracks. The main differences are:

- ▶ The bar spacing is designed to prevent adult fish passage.
- ▶ Fish are swimming into the flow downstream from the bar rack.
- ▶ If the barrier is to provide fish guidance, the entire structure is typically aligned at an angle to the main channel flow.

Draft design guidelines and criteria for bar rack barriers for adult anadromous salmonids have been adopted by the United States NOAA Fisheries, attachment A. A summary of the major design criteria follows:

- ▶ The maximum clear opening between the bars (pickets) is 1 inch.
- ▶ Bars shall be flat bars aligned with flow or round tubes aligned in the vertical direction.
- ▶ The rack shall have a minimum of 40 percent open area.
- ▶ The average design velocity passing the rack should not exceed 1 ft/s for all design flows with a maximum local velocity of 1.25 ft/s or half the velocity of the adjacent river flow which ever is less. Velocity is based on the gross submerged area of the bar rack.
- ▶ Bar racks shall be designed to lead fish to a safe passage route by angling the barrier to the safe passage route and providing sufficient attraction flows from the safe passage as to minimize false attraction to the bar rack flow.
- ▶ The maximum headloss across the bar rack should be 0.3 ft during operation. The rack should be cleaned if higher headlosses occur.
- ▶ The rack shall extend at least 2 ft above the maximum design water elevation.
- ▶ A minimum depth of 2 ft shall be maintained at the barrier for at least 10 percent of the river cross section at the barrier.
- ▶ A uniform concrete sill should be provided.
- ▶ Bar racks shall be structurally designed to withstand high stream flows.

For fish species other than adult anadromous salmonids, consideration of fish size and behavior should be reviewed before applying the NOAA criteria for bar rack design.

2. Examples of Bar Racks

a. *Nimbus Dam*

A removable bar rack has been used for many years on the American River, near Sacramento, California to prevent Chinook salmon from reaching Nimbus Dam (figure 130). The bar rack spans the river and guides upstream migrating salmon to the Nimbus Fish Hatchery. The rack has been an effective fish barrier but is now scheduled for replacement due to continued problems with debris accumulation on the rack during high flow events.

b. *Leaburg Tailrace*

The Leaburg tailrace barrier located on the McKenzie River at river mile 33 is an example of an off-river bar rack style tailrace barrier (figure 131). The barrier was designed by MWH Engineering for Eugene Water and Electric Board, Eugene, Oregon (2003). The barrier is designed for 2,500 ft³/s flow from the power station. The structure is 250 ft long and sets at the confluence of the river and the tailrace. The barrier is aligned approximately parallel to the river to provide a strong guidance current along the rack. The rack has 50 panels that can be lowered during the non-migration period.



Figure 130.—Nimbus Dam bar rack barrier, American River, near Sacramento, California. (Nimbus Fish Hatchery).

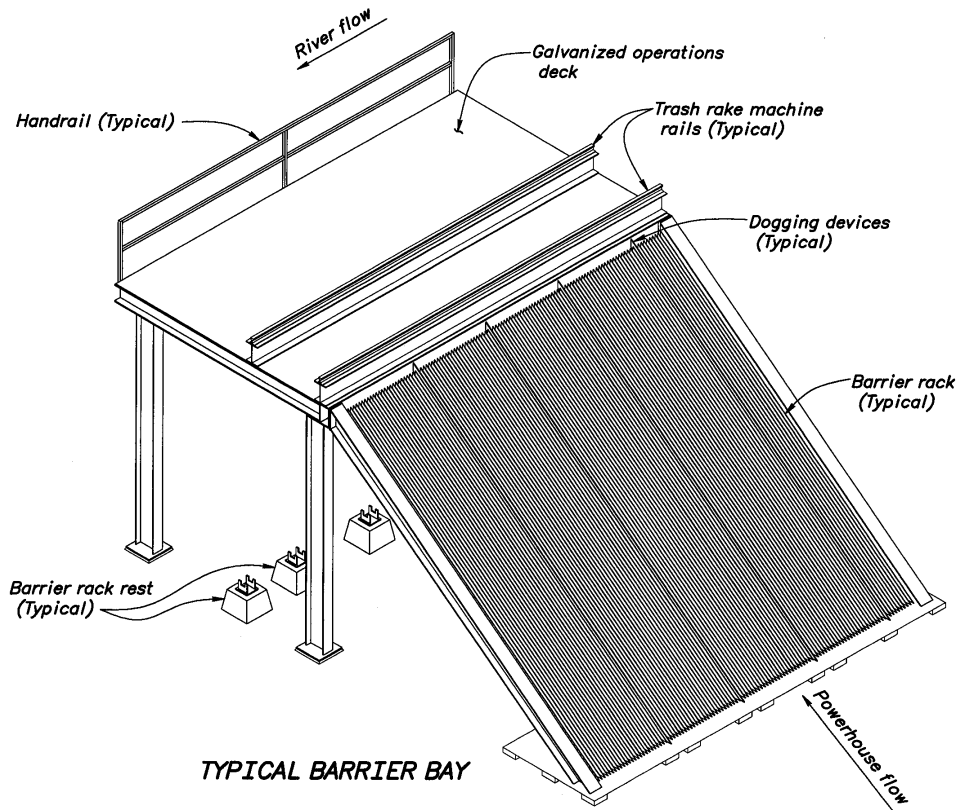


Figure 131.—Leaburg bar rack tailrace barrier McKenzie River Oregon. (Eugene Water and Electric Board).

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Glossary

Active Screens – Juvenile fish screens equipped with a cleaning system with proven capability which are automatically cleaned as frequently as necessary to keep the screens free of any debris that will restrict flow area. An active screen is the required design in most instances.

Affect and effect – To affect (a verb) is to bring about a change (“The proposed action is likely to adversely affect piping plovers nesting on the shoreline”). The effect (usually a noun) is the result (“The proposed highway is likely to have the following effects on the Florida scrub jay”). “Affect” appears throughout the Environmental Species Act, Section 7 regulations and documents in the phrases “may affect” and “likely to adversely affect.” “Effect” appears throughout Section 7 regulations and documents in the phrases “adverse effects,” “beneficial effects,” “effects of the action,” and “no effect.” From ESA Section 7 Consultation Handbook, March 1998

Approach Velocity – The flow velocity perpendicular to and approximately 3 inches in front of the screen face, V_a .

Anadromous Fish – Fish that are born in freshwater streams and lakes and migrate as juveniles to saltwater to grow and mature and return as adults to fresh water to spawn.

Behavioral Devices – Requires a decision, response, or reaction (volitional taxis) on the part of the fish to avoid entrainment.

Benthic Species – Orient themselves based on tactile mechanisms. They concentrate along stream margins or in other suitable velocity zones and exhibit high threshold velocities and low critical velocities.

Biological Assessment – Information prepared by, or under the direction of, a Federal agency to determine whether a proposed action is likely to: (1) adversely affect listed species or designated critical habitat, (2) jeopardize the continued existence of species that are proposed for listing, or (3) adversely modified proposed critical habitat. Biological assessments must be prepared for “major construction activities.” See 50 CFR Par402.02. The outcome of this biological assessment determines whether formal consultation or a conference is necessary. [CFR par 402.02, 50 CFR Par 402.12] from ESA Section 7 Consultation Handbook, March 1998.

Biological Opinion – A document that includes: (1) the opinion of the Fish and Wildlife Service or NOAA Fisheries as to whether or not a Federal action is likely to jeopardize the continued existence of listed species, or result in the destruction or adverse modification of designated critical habitat; (2) a summary of the information on which the opinion is based; and (3) a detailed discussion of the effects of the action on listed species or designated critical habitat. [50 CFR Par 402.02, 50 CFR Par 402.14(h)] from ESA Section 7 Consultation Handbook, March 1998.

Bypass Entrance Velocity, V_b – Flow velocity at the bypass entrance.

Bypass Flow, Q_b – The diverted flow required to effectively attract fish into the bypass entrance(s) and convey fish to the bypass outfall location or other destination.

Bypass Ratio, V_b/V_c – Ratio of the flow velocity at the bypass entrance to the channel velocity.

Candidate Species – Animal taxa considered for possible addition to the List of Endangered and Threatened species.

Channel Velocity, V_c – Flow velocity approaching a fish protection screen or louver. It is made up of the approach velocity vector, V_a , and sweeping velocity vector V_s , (figure 37).

Colorado Squawfish – Now called Colorado Pikeminnow, *Ptychocheilus lucius*.

Critical Habitat – For listed species consists of: (1) the specific areas within the geographical area occupied by the species, at the time it is listed in accordance with the provisions of Section 4 of the Endangered Species Act, on which are found those physical or biological features (constituent elements) (a) essential to the conservation of the species and (b) which may require special management considerations or protection; and (2) specific areas outside the geographical area occupied by the species at the time it is listed in accordance with the provision of Section 4 of the Act, upon a determination by the Secretary that such areas are essential for the conservation of the species. [ESA Par 3 (5)(A)] Designated critical habitats are described in 50 CFR Par 17 and 226. From ESA Section 7 Consultation Handbook, March 1998.

Cruising Speed – A swimming speed that fish can maintain for long periods of time (hours).

- Darting/Burst Speed** – A swimming speed that fish can achieve in a single effort but cannot maintain.
- Delisted** – Removing a fish species from being “listed” as “Threatened” or “Endangered”.
- Diurnal** – Active in the daytime
- Diversion Losses** – Includes power, irrigation, municipal, and other potential fish losses associated with the use of water by man.
- Effective Screen Area** – The total submerged screen area (excluding major structural members). For rotating drum screens, this is the area that projects onto a vertical screen.
- Endangered Fish Species** – Species determined by U.S. Fish and Wildlife Service or NOAA Fisheries, under the Endangered Species Act, to be in imminent danger of extinction throughout all or a significant portion of their range are listed as "endangered."
- Energy Dissipation Factor (EDF)** – The measurement of energy in a bypass downwell to assist in providing enough water volume in the downwell to dissipate the energy entering the downwell and to limit turbulence and circulation patterns that may trap debris and/or fish.
- Entrainment** – The unwanted passage of fish through a water diversion.
- Environmental Assessment** – Addresses impacts of development on listed fish species and species proposed for listing.
- Exclusion Barriers** – Velocity or physical barrier (picket barrier) built to minimize the attraction and stop the migration of upstream migrating fish.
- Exotic fish** – Any species not naturally occurring, either currently or historically, in an ecosystem.
- Fish Habitat** – A place where fish can find the physical, chemical, and biological features needed for life, including suitable water quality, passage routes, spawning grounds, feeding and resting sites, and shelter from predators.
- Fingerling** – Fish greater than 60 mm in length (approximately size of a human finger).

Formal Consultation – A process between the services (resource agencies) and a Federal agency or applicant that: (1) determines whether a proposed Federal action is likely to jeopardize the continued existence of a listed species or destroy or adversely modify designated critical habitat, (2) begins with a Federal agency’s written request and submittal of a complete information package, and (3) concludes with the issuance of a biological opinion and incidental take statement by either of the Services. If a proposed Federal action may affect a listed species or designated critical habitat, formal consultation is required. From ESA Section 7 Consultation Handbook, March 1998.

Fry – Fish generally between 25 and 60 mm in length.

Head Differential – The water pressure difference across the surface of a screen, trashrack, or louver. Usually measured in inches of water.

Incidental Take – Take of listed fish or wildlife species identified under ESA that results from, but is not the purpose of, carrying out an otherwise lawful activity conducted by a Federal agency or applicant.

Informal Consultation – An optional process that includes all discussions and correspondence between the U.S. Fish and Wildlife Service (resource agency) and a Federal agency or designated non-Federal representative to determine whether a proposed Federal action may affect listed species or critical habitat. This process occurs before formal consultation and allows the Federal agency to use the U.S. Fish and Wildlife Services’ expertise to evaluate the agency’s assessment of potential effects or to suggest possible modifications to the proposed action which could avoid potential adverse effects. From ESA Section 7 Consultation Handbook, March 1998.

Impingement – Physical contact of fish with a structure occurs when the fish is not able to avoid contact with a screen surface, trashrack, or debris at the intake.

Jeopardize the Continued Existence of – To engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species. [50 CFR Par 402.02] From ESA Section 7 Consultation Handbook, March 1998.

Larval Stage – Fish less than 25 mm in length.

Listed Fish Species – The authority to list species as threatened or endangered is shared by NOAA Fisheries (formerly National Marine Fisheries Service (NMFS)), which is responsible for listing most marine species, and the U.S. Fish and Wildlife Service (Service), which administers the listing of all other plants and animals. There are two classifications under which a species may be listed: “threatened” or “endangered.”

Native Fish Species – Any species that naturally occurred within a given body of water, as opposed to an introduced species.

Native Fish or Riverine Fish – Freshwater species that use rivers or lakes as residence for their entire life. They cannot tolerate long-term exposure to salt water.

Passive Screens – Juvenile fish screens with no automated cleaning system.

Pelagic Species – Visual mechanism is dominant in determining orientation. Distribute themselves fairly uniformly in the flow and locate themselves in the upper portion of the water column.

Picket Barrier – A flow barrier that diffuses the entire streamflow made up of flat bars or round columns placed such that the clear opening between pickets is not more than 1-inch to provide a physical barrier for upstream migrating fish.

Post Larval – Fish greater than 1.0 inch (25 mm) long.

Predation – Occurs when fish are preyed upon by aquatic or avian animals.

Screen Porosity – The ratio of open area to total area of the screen.

Screen Area – The open slots and perforations in the screen that provide for free flow of water through the screen.

Smolt – Young anadromous fish as their bodies change (physiological) from the fry/fingerling stage and prepare for life in sea water.

Species – Includes any subspecies of fish or wildlife or plants, and any distinct population segment of any species or vertebrate fish or wildlife that interbreeds when mature. [ESA Par 3(16)]

Sustained/Maximum – A fish swimming speed that fish can maintain for minutes.

Sweeping Velocity – The average flow velocity parallel to and adjacent to the screen face, V_s .

Take – The ESA prohibits the taking of any listed species of fish or wildlife by any person, "...to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt to engage in any such conduct"- [ESA Par 3(19)].

Through-slot Velocity, V_t – The flow velocity passing through the screen slot openings (suggested not to exceed 0.5 ft/s for submerged cylindrical screens).

Trapping Velocity – Also referred to as capture velocity. It is the velocity needed to "trap" or "capture" the specific fish species and prevent it from returning up a bypass pipe at a fish screen facility.

Threatened Fish Species – Species determined likely to become endangered in the foreseeable future are listed as "threatened."

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Attachment A – Fish Screen Criteria

The users of this manual should verify the criteria published herein with the latest fish resource agencies draft criteria before advancing into the predesign and final design phases of a fish protection project.

1. Screen Criteria For Juvenile Salmonids (NMFS – Northwest Region 1995)

Juvenile Salmonid Fish Screen Criteria – NMFS
February 16, 1995

NMFS Web site

<<http://www.nwr.noaa.gov/1salmon/salmesa/pubs/nmfscrit.pdf>>

A. Structure Placement

1. Streams and Rivers

- a. Where physically practical and biologically desirable, the screen shall be constructed at the diversion entrance with the screen face generally parallel to river flow. Physical factors that may preclude screen construction at the diversion entrance include excess river gradient, potential for damage by large debris, and potential for heavy sedimentation. For screens constructed at the bankline, the screen face shall be aligned with the adjacent bankline and the bankline shall be shaped to smoothly match the face of the screen structure to prevent eddies in front, upstream, and downstream from the screen. If trash racks are used, sufficient hydraulic gradient is required to route juvenile fish from between the trash rack and screens to safety.
- b. Where installation of fish screens at the diversion entrance is not desirable or impractical, the screens may be installed in the canal downstream from the entrance at a suitable location. All screens installed downstream from the diversion entrance shall be provided with an effective bypass system approved by NMFS, designed to collect juvenile fish and safely transport them back to the river with minimum delay. The angle of the screen to flow should be adequate to effectively guide fish to the bypass (see Section F, Bypass Layout).

2. Lakes, Reservoirs and Tidal areas

- a. Intakes shall be located offshore where feasible to minimize fish contact with the facility. Water velocity from any direction toward the screen shall not exceed allowable approach velocities (see Section B, Approach Velocity). When possible, intakes shall be located in areas with sufficient sweeping velocity to minimize sediment accumulation in or around the screen and to facilitate debris removal and fish movement away from the screen face (see Section C, Sweeping Velocity).

- b. If a screened intake is used to route fish past a dam, the intake shall be designed to withdraw water from the most appropriate elevation based on providing the best juvenile fish attraction and appropriate water temperature control downstream from the project. The entire range of forebay fluctuation shall be accommodated in design, unless otherwise approved by the NMFS.

B. Approach Velocity

Approach velocity is the water velocity component perpendicular to and approximately three inches in front of the screen face.

1. Salmonid fry [less than 2.36 inches {60.0 millimeters (mm)} in length]: The approach velocity shall not exceed 0.40 ft/s {0.12 m/s}.
2. Salmonid fingerling {2.36 inches (60.0 mm) and longer}: The approach velocity shall not exceed 0.80 f/s (0.24 m/s).
3. The total submerged screen area required (excluding area affected by structural components) is calculated by dividing the maximum diverted flow by the allowable approach velocity (also see Section K, Modified Criteria for Small Screens).
4. The screen design must provide for uniform flow distribution over the screen surface, thereby minimizing approach velocity. This may be accomplished by providing adjustable porosity control on the downstream side of screens, unless it can be shown unequivocally (such as with a physical hydraulic model study) that localized areas of high velocity can be avoided at all flows.

C. Sweeping Velocity - Definition

Sweeping velocity is the water velocity component parallel and adjacent to the screen face. Sweeping velocity shall be greater than the approach velocity. This is accomplished by angling the screen face at less than 45 degrees relative to flow (also see Section K, Modified Criteria for Small Screens). This angle may be dictated by site specific canal geometry, hydraulic, and sediment conditions.

D. Screen Material Characteristics

1. Fry criteria - If biological justification can not be provided to demonstrate the absence of fry-sized salmonids (less than 2.36 inches (60.0 mm)) in the vicinity of the diversion intake leading to the screen, fry will be assumed present and the following criteria apply for screen material:
 - a. Perforated plate: Screen openings shall not exceed 3/32 or 0.0938 inches (2.38 mm).
 - b. Profile bar screen: The narrowest dimension in the screen openings shall not exceed 0.0689 Inches (1.75 mm) in the narrow direction.
 - c. Woven wire screen: Screen openings shall not exceed 3/32 or 0.0938 inches (2.38 mm) in the narrow direction (example: 6-14 mesh).
 - d. Screen material shall provide a minimum of 27% open area.
2. Fingerling criteria - If biological justification can be provided to demonstrate the absence of fry-sized salmonids {less than 2.36 inches (60.0 mm)} in the vicinity of the diversion intake leading to the screen, the following criteria apply for screen material:
 - a. Perforated plate: Screen openings shall not exceed 1/4 or 0.25 inches (6.35 mm).
 - b. Profile bar screen: The narrowest dimension in the screen openings shall not exceed 1/4 or 0.25 inches (6.35 mm) in the narrow direction.
 - c. Woven wire screen: Screen openings shall not exceed 1/4 or 0.25 inches (6.35 mm) in the narrow direction.
 - d. Screen material shall provide a minimum of 40% open area.
3. The screen material shall be corrosion resistant and sufficiently durable to maintain a smooth uniform surface with long term use.

E. Civil works and Structural Features

1. The face of all screen surfaces shall be placed flush (to the extent possible) with any adjacent screen bay, pier noses, and walls to allow fish unimpeded movement parallel to the screen face and ready access to bypass routes.

2. Structural features shall be provided to protect the integrity of the fish screens from large debris. Provision of a trash rack, log boom, sediment sluice, and other measures may be needed. A reliable, ongoing preventative maintenance and repair program is necessary to assure facilities are kept free of debris and that screen mesh, seals, drive units, and other components are functioning correctly.
3. Screen surfaces shall be constructed at an angle to the approaching flow, with the downstream end of the screen terminating at the entrance to the bypass system.
4. The civil works shall be designed in a manner that eliminates undesirable hydraulic effects (such as eddies and stagnant flow zones) that may delay or injure fish or provide predator habitat or predator access. Upstream training wall(s), or some acceptable variation thereof, shall be utilized to control hydraulic conditions and define the angle of flow to the screen face. Large facilities may require hydraulic modeling to identify and correct areas of concern.

F. Bypass Layout

1. The screen and bypass shall work in tandem to move out-migrating salmonids (including adults) to the bypass outfall with a minimum of injury or delay. The bypass entrance shall be located so that it can easily be located by out-migrants. Screens placed in diversions shall be constructed with the downstream end of the screen terminating at a bypass entrance. Multiple bypass entrances (intermediate bypasses) shall be employed if the sweeping velocity will not move fish to the bypass within 60 seconds, assuming fish are transported at this velocity.
2. The bypass entrance and all components of the bypass system shall be of sufficient size and hydraulic capacity to minimize the potential for debris blockage.
3. In order to improve bypass collection efficiency for a single bank of vertically-oriented screens, a bypass training wall shall be located at an angle to the screens, with the bypass entrance at the apex and downstream-most point. This will aid fish movement into the bypass by creating hydraulic conditions that conform to observed fish behavior. For single or multiple Vee screen configurations, training walls are not required, unless a intermediate bypass is used (see Section F, Bypass Layout, Part 1).

4. In cases where there is insufficient flow available to satisfy hydraulic requirements at the bypass entrance (entrances) for the main screens, a secondary screen may be required. This is a screen located in the main screen bypass which allows the prescribed bypass flow to be used to effectively attract fish into the bypass entrance(s) and then allow for all but a reduced residual bypass flow to be routed back (by pump or gravity) for the primary diversion use. The residual bypass flow (not passing through the secondary screen) would then convey fish to the bypass outfall location or other destination.
5. Access is required at locations in the bypass system where debris accumulations may occur.
6. The screen civil works floor shall be designed to allow fish to be routed back to the river safely, if the canal is dewatered. This may entail a sumped drain with a small gate and drain pipe, or similar provisions.

G. Bypass Entrance

1. Each bypass entrance shall be provided with independent flow-control capability, acceptable to NMFS.
2. The minimum bypass entrance flow velocity must be greater than or equal to the maximum flow velocity vector resultant upstream from the screens. A gradual and efficient acceleration of flow into the bypass entrance is required to minimize delay by out-migrants.
3. Ambient lighting conditions are required at, and inside of, the bypass entrance and should extend downstream to the bypass flow control.
4. The bypass entrance must extend from the floor to the canal water surface.

H. Bypass Conduit Design

1. Bypass pipes shall have smooth surfaces and be designed to provide conditions that minimize turbulence. Bypass conduits shall have a smooth joint design to minimize turbulence and the potential for fish injury and shall be satisfactory to the NMFS.
2. Fish shall not be pumped within the bypass system.
3. Fish shall not be allowed to free-fall within a confined shaft in a bypass system.

4. Pressures in the bypass pipe shall be equal to or above atmospheric pressures.
5. Bends shall be avoided in the layout of bypass pipes due to the potential for debris clogging. Bypass pipe center-line radius of curvature (R/D) shall be greater than or equal to 5. Greater R/D may be required for super-critical velocities.
6. Bypass pipes or open channels shall be designed to minimize debris clogging and sediment deposition and to facilitate cleaning as necessary. Therefore, the required pipe diameter shall be greater than or equal to 24 inches {0.610 meters (m)}, and pipe velocity shall be greater than 2.0 fps (0.610 mps), unless otherwise approved by the NMFS, for the entire operational range (also see Section K, Modified Criteria for Small Screens, Part 4).
7. Closure valves of any type are not allowed within the bypass pipe, unless approved by NMFS.
8. The minimum depth of open-channel flow in a bypass conduit shall be greater than or equal to 0.75 ft (0.23 m), unless otherwise approved by the NMFS (also see Section K, Modified Criteria for Small Screens, Part 5).
9. Sampling facilities installed in the bypass conduit shall not impair normal operation of the facility.
10. The bypass pipe hydraulics should not produce a hydraulic jump within the pipe.

I. Bypass Outfall

1. Bypass outfalls should be located such that ambient river velocities are greater than 4.0 f/s (1.2 m/s).
2. Bypass outfalls shall be located to minimize avian and aquatic predation in areas free of eddies, reverse flow, or known predator habitat.
3. Bypass outfalls shall be located where the receiving water is of sufficient depth (depending on the impact velocity and quantity of bypass flow) to ensure that fish injuries are avoided at all river and bypass flows.
4. Maximum bypass outfall impact velocity (including vertical and horizontal velocity components) shall be less than 25.0 fps (7.6 mps).

5. The bypass outfall discharge into tailrace shall be designed to avoid adult attraction or jumping injuries

J. Operations and Maintenance Requirements

1. Fish screens shall be automatically cleaned as frequently as necessary to prevent accumulation of debris. The cleaning system and protocol must be effective, reliable, and satisfactory to the NMFS. Proven cleaning technologies are preferred.
2. Open channel intakes shall include a trash rack in the screen facility design which shall be kept free of debris. In certain cases, a satisfactory profile bar screen design can substitute for a trash rack.
3. The head differential to trigger screen cleaning for intermittent type cleaning systems shall be a maximum of 0.1 ft (0.03 m) or as agreed to by the NMFS.
4. The completed screen and bypass facility shall be made available for inspection by NMFS, to verify compliance with the design and operational criteria.
5. Screen and bypass facilities shall be evaluated for biological effectiveness and to verify that hydraulic design objectives are achieved.

K. Modified Criteria for Small Screens (Diversion flow less than 25 CFS)

The following criteria vary from the criteria listed above and apply to smaller screens. Twenty-five CFS is an approximate cutoff; however, some smaller diversions may be required to apply more universal criteria listed above, while some larger diversions may be allowed to use the “small screen criteria. listed below. This will depend on site constraints.

1. The screen area required is shown in Section B, Approach Velocity, Parts 1,2 and 3. Note that “maximum” applies to the greatest flow diverted, not necessarily the water right
2. Screen orientation:
 - a. For screen lengths less than or equal to 4 ft, screen orientation may be angled or perpendicular relative to flow.

- b. For screen lengths greater than 4 ft, screen-to-flow angles must be less than or equal to 45 degrees (see Section C, Sweeping Velocity, Part 1).
 - c. For drum screens, the design submergence shall be 75% of drum diameter. Submergence shall not exceed 85%, nor be less than 65% of drum diameter.
3. The minimum bypass pipe diameter shall be 10 inches, unless otherwise approved by NMFS.
4. The minimum allowable pipe depth is 0.15 ft (1.8 inches or 4.6 cm) and is controlled by designing the pipe gradient for minimum bypass flow.

2. Juvenile Fish Screen Criteria For Pump Intakes (NMFS – Northwest Region – 1996)

Developed by
National Marine Fisheries Service
Environmental & Technical Services Division
Portland, Oregon
May 9, 1996

<http://www.nwr.noaa.gov/1hydro/pumpcrit1.htm>

The following criteria serve as an addendum to current National Marine Fisheries Service gravity intake juvenile fish screen criteria. These criteria apply to new pump intake screens and existing inadequate pump intake screens, as determined by fisheries agencies with project jurisdiction.

Definitions Used in Pump Intake Screen Criteria

Pump intake screens are defined as screening devices attached directly to a pressurized diversion intake pipe. Effective screen area is calculated by subtracting screen area occluded by structural members from the total screen area. Screen mesh opening is the narrowest opening in screen mesh. Approach velocity is the calculated velocity component perpendicular to the screen face. Sweeping velocity is the flow velocity component parallel to the screen face with the pump turned off.

Active pump intake screens are equipped with a cleaning system with proven cleaning capability, and are cleaned as frequently as necessary to keep the screens clean. Passive pump intake screens have no cleaning system and should only be used when the debris load is expected to be low, and

- (1) if a small screen (less than 1 CFS pump) is over-sized to eliminate debris impingement, and
- (2) where sufficient sweeping velocity exists to eliminate debris build-up on the screen surface, and
- (3) if the maximum diverted flow is less than .01% of the total minimum streamflow, or
- (4) the intake is deep in a reservoir, away from the shoreline.

Pump Intake Screen Flow Criteria

The minimum effective screen area in square ft for an active pump intake screen is calculated by dividing the maximum flow rate in cubic ft per second (CFS) by an approach velocity of 0.4 ft per second (FPS). The minimum effective screen area in square ft for a passive pump intake screen is calculated by dividing the maximum flow rate in CFS by an approach velocity of 0.2 FPS. Certain site conditions may allow for a waiver of the 0.2 FPS approach velocity criteria and allow a passive screen to be installed using 0.4 FPS as design criteria. These cases will be considered on a site-by-site basis by the fisheries agencies.

If fry-sized salmonids (i.e. less than 60 millimeter fork length) are not ever present at the site and larger juvenile salmonids are present (as determined by agency biologists), approach velocity shall not exceed 0.8 FPS for active pump intake screens, or 0.4 FPS for passive pump intake screens. The allowable flow should be distributed to achieve uniform approach velocity (plus or minus 10%) over the entire screen area. Additional screen area or flow baffling may be required to account for designs with non-uniform approach velocity.

Pump Intake Screen Mesh Material

Screen mesh openings shall not exceed 3/32 inch (2.38 mm) for woven wire or perforated plate screens, or 0.0689 inch (1.75 mm) for profile wire screens, with a minimum 27% open area. If fry-sized salmonids are never present at the site (by determination of agency biologists) screen mesh openings shall not exceed 1/4 inch (6.35 mm) for woven wire, perforated plate screens, or profile wire screens, with a minimum of 40% open area.

Screen mesh material and support structure shall work in tandem to be sufficiently durable to withstand the rigors of the installation site. No gaps greater than 3/32 inch shall exist in any type screen mesh or at points of mesh attachment. Special mesh materials that inhibit aquatic growth may be required at some sites.

Pump Intake Screen Location

When possible, pump intake screens shall be placed in locations with sufficient sweeping velocity to sweep away debris removed from the screen face. Pump intake screens shall be submerged to a depth of at least one screen radius below the minimum water surface, with a minimum of one screen radius clearance between screen surfaces and adjacent natural or constructed features. A clear escape route should exist for fish that approach the intake volitionally or otherwise. For example, if a pump intake is located off of the river (such as in an intake lagoon), a conventional open channel screen should be considered, placed

in the channel or at the edge of the river. Intakes in reservoirs should be as deep as practical, to reduce the numbers of juvenile salmonids that approach the intake. Adverse alterations to riverine habitat shall be minimized.

Pump Intake Screen Protection

Pump intake screens shall be protected from heavy debris, icing and other conditions that may compromise screen integrity. Protection can be provided by using log booms, trash racks or mechanisms for removing the intake from the river during adverse conditions. An inspection and maintenance plan for the pump intake screen is required, to ensure that the screen is operating as designed per these criteria.

3. National Marine Fisheries Service Southwest Region Fish Screening Criteria (1997) for Anadromous Salmonids

January 1997
Southwest Region

<http://www.nwr.noaa.gov/1salmon/salmesa/pubs/swrscrng.pdf>

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Fish Screening Criteria for Anadromous Salmonids ¹ National Marine Fisheries Service

I. General Considerations

This document provides guidelines and criteria for functional designs of downstream migrant fish passage facilities at hydroelectric, irrigation, and other water withdrawal projects. It is promulgated by the National Marine Fisheries Service (NMFS), Southwest Region as a result of its authority and responsibility for prescribing fishways under the Endangered Species Act (ESA), the Federal Power Act, administered by the Federal Energy Regulatory Commission (FERC), and the Fish and Wildlife Coordination Act (FWCA), administered by the U.S. Fish & Wildlife Service.

The guidelines and criteria are general in nature. There may be cases where site constraints or extenuating circumstances dictate a waiver or modification of one or more of these criteria. Conversely, where there is an opportunity to protect fish, site-specific criteria may be added. Variances from established criteria will be considered on a project-by-project basis. The swimming ability of fish is a primary consideration in designing a fish screen facility. Research shows that swimming ability varies depending on multiple factors relating to fish physiology, biology, and the aquatic environment. These factors include: species, physiological development, duration of swimming time required, behavioral aspects, physical condition, water quality, temperature, lighting conditions, and many others. Since conditions affecting swimming ability are variable and complex, screen criteria must be expressed in general terms and the specifics of any screen design must address on-site conditions.

NMFS may require project sponsors to investigate site-specific variables critical to the fish screen system design. This investigation may include fish behavioral response to hydraulic conditions, weather conditions (ice, wind, flooding, etc.), river stage-discharge relationships, seasonal operations, sediment and debris problems, resident fish populations, potential for creating predation opportunity, and other pertinent information. The size of salmonids present at a potential screen site usually is not known, and can change from year-to-year based on flow and temperature conditions. Thus, adequate data to describe the size-time relationship requires substantial sampling over a number of years. NMFS will normally assume that fry-sized salmonids are present at all sites unless adequate biological investigation proves otherwise. The burden of proof is the responsibility of the owner of the screen facility.

¹ Adapted from NMFS, Northwest Region

New facilities which propose to utilize unproven fish protection technology frequently require:

- (1) development of a biological basis for the concept;
- (2) demonstration of favorable behavioral responses in a laboratory setting;
- (3) an acceptable plan for evaluating the prototype installation;
- (4) an acceptable alternate plan should the prototype not adequately protect fish.

Additional information can be found in Experimental Fish Guidance Devices, position statement of the National Marine Fisheries Service, Southwest Region, January 1994.

Striped Bass, Herring, Shad, Cyprinids, and other anadromous fish species may have eggs and/or very small fry which are moved with any water current (tides, streamflows, etc.). Installations where these species are present may require individual evaluation of the proposed project using more conservative screening requirements. In instances where state or local regulatory agencies require more stringent screen criteria to protect species other than salmonids, NMFS will generally defer to the more conservative criteria.

General screen criteria and procedural guidelines are provided below. Specific exceptions to these criteria occur in the design of small screen systems (less than 40 cubic ft per second) and certain small pump intakes. These exceptions are listed in Section K, Modified Criteria for Small Screens, and in the separate addendum entitled: Juvenile Fish Screen Criteria For Pump Intakes, National Marine Fisheries Service, Portland, Oregon, May 9, 1996.

II. General Procedural Guidelines

For projects where NMFS has jurisdiction, such as FERC license applications and ESA consultations, a functional design must be developed as part of the application or consultation. These designs must reflect NMFS design criteria and be acceptable to NMFS. Acceptable designs typically define type, location, method of operation, and other important characteristics of the fish screen facility. Design drawings should show structural dimensions in plan, elevation, and crosssectional views, along with important component details. Hydraulic information should include: hydraulic capacity, expected water surface elevations, and flows through various areas of the structures. Documentation of

relevant hydrologic information is required. Types of materials must be identified where they will directly affect fish. A plan for operations and maintenance procedures should be included- i.e., preventive and corrective maintenance procedures, inspections and reporting requirements, maintenance logs, etc.- particularly with respect to debris, screen cleaning, and sedimentation issues. The final detailed design shall be based on the functional design, unless changes are agreed to by NMFS.

All juvenile passage facilities shall be designed to function properly through the full range of hydraulic conditions expected at a particular project site during fish migration periods, and shall account for debris and sedimentation conditions which may occur.

III. Screen Criteria for Juvenile Salmonids

A. Structure Placement

1. General:

The screened intake shall be designed to withdraw water from the most appropriate elevation, considering juvenile fish attraction, appropriate water temperature control downstream or a combination thereof. The design must accommodate the expected range of water surface elevations. For on-river screens, it is preferable to keep the fish in the main channel rather than put them through intermediate screen bypasses. NMFS decides whether to require intermediate bypasses for on-river, straight profile screens by considering the biological and hydraulic conditions existing at each individual project site.

2. Streams and Rivers:

Where physically practical, the screen shall be constructed at the diversion entrance. The screen face should be generally parallel to river flow and aligned with the adjacent bankline. A smooth transition between the bankline and the screen structure is important to minimize eddies and undesirable flow patterns in the vicinity of the screen. If trash racks are used, sufficient hydraulic gradient is required to route juvenile fish from between the trashrack and screens to safety. Physical factors that may preclude screen construction at the diversion entrance include excess river gradient, potential for damage by large debris, and potential for heavy sedimentation. Large stream-side installations may require intermediate bypasses along the screen face to prevent excessive exposure time. The need for intermediate bypasses shall be decided on a case-by-case basis.

3. Canals:

Where installation of fish screens at the diversion entrance is undesirable or impractical, the screens may be installed at a suitable location downstream from the canal entrance. All screens downstream from the diversion entrance shall provide an effective juvenile bypass system- designed to collect juvenile fish and safely transport them back to the river with minimum delay. The angle of the screen to flow should be adequate to effectively guide fish to the bypass. Juvenile bypass systems are part of the overall screen system and must be accepted by NMFS.

4. Lakes, Reservoirs, and Tidal Areas:

- a. Where possible, intakes should be located off shore to minimize fish contact with the facility. Water velocity from any direction toward the screen shall not exceed the allowable approach velocity. Where possible, locate intakes where sufficient sweeping velocity exists. This minimizes sediment accumulation in and around the screen, facilitates debris removal, and encourages fish movement away from the screen face.
- b. If a screened intake is used to route fish past a dam, the intake shall be designed to withdraw water from the most appropriate elevation in order to provide the best juvenile fish attraction to the bypass channel as well as to achieve appropriate water temperature control downstream. The entire range of forebay fluctuations shall be accommodated by the design, unless otherwise approved by NMFS.

B. Approach Velocity

Definition: *Approach Velocity* is the water velocity vector component perpendicular to the screen face. Approach velocity shall be measured approximately three inches in front of the screen surface.

1. Fry Criteria - less than 2.36 inches {60 millimeters (mm)} in length.

If a biological justification cannot demonstrate the absence of fry-sized salmonids in the vicinity of the screen, fry will be assumed present and the following criteria apply:

Design approach velocity shall not exceed-

- Streams and Rivers: 0.33 ft per second
- Canals: 0.40 ft per second
- Lakes, Reservoirs, Tidal: 0.33 ft per second (salmonids)²

2. Fingerling Criteria - 2.36 inches {60 mm} and longer

If biological justification can demonstrate the absence of fry-sized salmonids in the vicinity of the screen, the following criteria apply:

Design approach velocity shall not exceed -

- All locations: 0.8 ft per second

3. The *total submerged screen area required* (excluding area of structural components) is calculated by dividing the maximum diverted flow by the allowable approach velocity. (Also see Section K, Modified Criteria for Small Screens, part 1).
4. The screen design must provide for uniform flow distribution over the surface of the screen, thereby minimizing approach velocity. This may be accomplished by providing adjustable porosity control on the downstream side of the screens, unless it can be shown unequivocally (such as with a physical hydraulic model study) that localized areas of high velocity can be avoided at all flows.

C. Sweeping Velocity

Definition: *Sweeping Velocity* is the water velocity vector component parallel and adjacent to the screen face.

1. Sweeping Velocity shall be greater than approach velocity. For canal installations, this is accomplished by angling screen face less than 45 degrees relative to flow (see Section K, Modified Criteria for Small Screens). This angle may be dictated by specific canal geometry, or hydraulic and sediment conditions.

² Other species may require different approach velocity standards, e.g.- in California, the U.S. Fish & Wildlife Service requires 0.2 fps approach velocity where delta smelt are present in the tidal areas of the San Francisco Bay estuary.

D. Screen Face Material

1. Fry criteria

If a biological justification cannot demonstrate the absence of fry-sized salmonids in the vicinity of the screen, fry will be assumed present and the following criteria apply for screen material:

- a. Perforated plate: screen openings shall not exceed 3/32 inches (2.38 mm), measured in diameter.
- b. Profile bar: screen openings shall not exceed 0.0689 inches (1.75 mm) in width.
- c. Woven wire: screen openings shall not exceed 3/32 inches (2.38 mm), measured diagonally. (e.g.: 6-14 mesh)
- d. Screen material shall provide a minimum of 27% open area.

2. Fingerling Criteria

If biological justification can demonstrate the absence of fry-sized salmonids in the vicinity of the screen, the following criteria apply for screen material:

- a. Perforated plate: Screen openings shall not exceed 1/4 inch (6.35 mm) in diameter.
- b. Profile bar: screen openings shall not exceed 1/4 inch (6.35 mm) in width
- c. Woven wire: Screen openings shall not exceed 1/4 inch (6.35 mm) in the narrow direction
- d. Screen material shall provide a minimum of 40% open area.

3. The screen material shall be corrosion resistant and sufficiently durable to maintain a smooth and uniform surface with long term use.

E. Civil Works and Structural Features

1. The face of all screen surfaces shall be placed flush with any adjacent screen bay, pier noses, and walls, allowing fish unimpeded movement parallel to the screen face and ready access to bypass routes.

2. Structural features shall be provided to protect the integrity of the fish screens from large debris. Trash racks, log booms, sediment sluices, or other measures may be needed. A reliable on-going preventive maintenance and repair program is necessary to ensure facilities are kept free of debris and the screen mesh, seals, drive units, and other components are functioning correctly.
3. Screens located in canals - surfaces shall be constructed at an angle to the approaching flow, with the downstream end terminating at the bypass system entrance.
4. The civil works design shall attempt to eliminate undesirable hydraulic effects (e.g.- eddies, stagnant flow zones) that may delay or injure fish, or provide predator opportunities. Upstream training wall(s), or some acceptable variation thereof, shall be utilized to control hydraulic conditions and define the angle of flow to the screen face. Large facilities may require hydraulic monitoring to identify and correct areas of concern.

F. Juvenile Bypass System Layout

Juvenile bypass systems are water channels which transport juvenile fish from the face of a screen to a relatively safe location in the main migratory route of the river or stream. Juvenile bypass systems are necessary for screens located in canals because anadromous fish must be routed back to their main migratory route. For other screen locations and configurations, NMFS accepts the option which, in its judgement, provides the highest degree of fish protection given existing site and project constraints.

1. The screen and bypass shall work in tandem to move out-migrating salmonids (including adults) to the bypass outfall with minimum injury or delay. Bypass entrance(s) shall be designed such that out-migrants can easily locate and enter them. Screens installed in canal diversions shall be constructed with the downstream end of the screen terminating at a bypass entrance. Multiple bypass entrances (intermediate bypasses) shall be employed if the sweeping velocity will not move fish to the bypass within 60 seconds³ assuming the fish are transported at this velocity. Exceptions will be made for sites without satisfactory hydraulic conditions, or for screens built on river banks with satisfactory river conditions.

³ In California, 60 second exposure time applies to screens in canals, using a 0.4 fps approach velocity. Where more conservative approach velocities are used, longer exposure times may be approved on a case-by-case basis, and exceptions to established criteria shall be treated as variances.

2. All components of the bypass system, from entrance to outfall, shall be of sufficient hydraulic capacity to minimize the potential for debris blockage.
3. To improve bypass collection efficiency for a single bank of vertically oriented screens, a bypass training wall may be located at an angle to the screens.
4. In cases where insufficient flow is available to satisfy hydraulic requirements at the main bypass entrance(s), a secondary screen may be required. Located in the main screen's bypass channel, a secondary screen allows the prescribed bypass flow to be used to effectively attract fish into the bypass entrance(s) while allowing all but a reduced residual bypass flow to be routed back (by pump or gravity) for the primary diversion use. The residual bypass flow (not passing through the secondary screen) then conveys fish to the bypass outfall location or other destination.
5. Access is required at locations in the bypass system where debris accumulation may occur.
6. The screen civil works floor shall allow fish to be routed to the river safely in the event the canal is dewatered. This may entail a sumped drain with a small gate and drain pipe, or similar provisions.

G. Bypass Entrance

1. Each bypass entrance shall be provided with independent flow control, acceptable to NMFS.
2. Bypass entrance velocity must equal or exceed the maximum velocity vector resultant along the screen, upstream from the entrance. A gradual and efficient acceleration into the bypass is required to minimize delay of out-migrants.
3. Ambient lighting conditions are required from the bypass entrance to the bypass flow control.
4. The bypass entrance must extend from floor to water surface.

H. Bypass Conduit Design

1. Smooth interior pipe surfaces and conduit joints shall be required to minimize turbulence, debris accumulation, and the risk of injury to juvenile fish. Surface smoothness must be acceptable to the NMFS.

2. Fish shall not free-fall within a confined shaft in a bypass system.
3. Fish shall not be pumped within the bypass system.
4. Pressure in the bypass pipe shall be equal to or above atmospheric pressure.
5. Extreme bends shall be avoided in the pipe layout to avoid excessive physical contact between small fish and hard surfaces and to minimize debris clogging . Bypass pipe centerline radius of curvature (R/D) shall be 5 or greater. Greater R/D may be required for super-critical velocities.
6. Bypass pipes or open channels shall be designed to minimize debris clogging and sediment deposition and to facilitate cleaning. Pipe diameter shall be 24 inches (0.610 m) or greater and pipe velocity shall be 2.0 fps (0.610 mps) or greater, unless otherwise approved by NMFS. (See Modified Criteria for Small Screens) for the entire operational range.
7. No closure valves are allowed within bypass pipes.
8. Depth of flow in a bypass conduit shall be 0.75 ft. (0.23 m) or greater, unless otherwise authorized by NMFS (See *Modified Criteria for Small Screens*).
9. Bypass system sampling stations shall not impair normal operation of the screen facility.
10. No hydraulic jumps should exist within the bypass system.

I. Bypass Outfall

1. Ambient river velocities at bypass outfalls should be greater than 4.0 fps (1.2 mps), or as close as obtainable.
2. Bypass outfalls shall be located and designed to minimize avian and aquatic predation in areas free of eddies, reverse flow, or known predator habitat.
3. Bypass outfalls shall be located where there is sufficient depth (depending on the impact velocity and quantity of bypass flow) to avoid fish injuries at all river and bypass flows.
4. Impact velocity (including vertical and horizontal components) shall not exceed 25.0 fps (7.6 mps).

5. Bypass outfall discharges shall be designed to avoid adult attraction or jumping injuries.

J. Operations and Maintenance

1. Fish Screens shall be automatically cleaned as frequently as necessary to prevent accumulation of debris. The cleaning system and protocol must be effective, reliable, and satisfactory to NMFS. Proven cleaning technologies are preferred.
2. Open channel intakes shall include a trash rack in the screen facility design which shall be kept free of debris. In certain cases, a satisfactory profile bar screen design can substitute for a trash rack.
3. The head differential to trigger screen cleaning for intermittent type systems shall be a maximum of 0.1 ft (.03 m), unless otherwise agreed to by NMFS.
4. The completed screen and bypass facility shall be made available for inspection by NMFS, to verify compliance with design and operational criteria.
5. Screen and bypass facilities shall be evaluated for biological effectiveness and to verify that hydraulic design objectives are achieved.

K. Modified Criteria for Small Screens (Diversion Flow less than 40 cfs)

The following criteria vary from the standard screen criteria listed above. These criteria specifically apply to lower flow, surface-oriented screens (e.g.- small rotating drum screens). Forty cfs is the approximate cut off; however, some smaller diversions may be required to apply the general criteria listed above, while some larger diversions may be allowed to use the “small screen” criteria below. NMFS will decide on a case-by-case basis depending on site constraints.

1. The required screen area is a function of the approach velocity listed in Section B, Approach Velocity, Parts 1, 2, and 3 above. Note that “maximum” refers to the greatest flow diverted, not necessarily the water right.
2. Screen Orientation:
 - a. For screen lengths six ft or less, screen orientation may be angled perpendicular to the flow.

- b. For screen lengths greater than six ft, screen-to-flow angle must be less than 45 degrees. (See Section C Sweeping Velocity, part 1).
- c. For drum screens, design submergence shall be 75% of drum diameter. Submergence shall not exceed 85%, nor be less than 65% of drum diameter.
- d. Minimum bypass pipe diameter shall be 10 in (25.4 cm), unless otherwise approved by NMFS.
- e. Minimum pipe depth is 1.8 in (4.6 cm) and is controlled by designing the pipe gradient for minimum bypass flow.

Questions concerning this document can be directed to NMFS Hydraulic Engineering Staff at:

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777 Sonoma Ave. Room 325
Santa Rosa, CA 95402
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4. National Marine Fisheries Service Southwest Region – Experimental Fish Guidance Devices

Experimental Fish Guidance Devices - 1994
Position Statement of
National Marine Fisheries Service
Southwest Region
January 1994

<http://swr.ucsd.edu/hcd/expert.htm>

NMFS Southwest Region Position Paper on Experimental Technology for
Managing Downstream Salmonid Passage

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Introduction

Numerous stocks of salmon and steelhead trout in California streams are at low levels and many stocks continue to decline. The Sacramento River winter-run chinook salmon is listed as “endangered” under the Federal Endangered Species Act. Petitions for additional listings are pending. It is essential to provide maximum protection for juveniles to halt and reverse these declines.

The injury or death of juvenile fish at water diversion intakes have long been identified as a major source of fish mortality [Spencer 1928, Hatton 1939, Hallock and Woert 1959, Hallock 1987]. Fish diverted into power turbines experience up to 40 percent mortality as well as injury, disorientation, and delay of migration [Bell, 1991], while those entrained into agricultural and municipal water diversions experience 100 percent mortality. Diversion mortality is the major cause of decline in some fish populations.

Positive barrier screens have long been tested and used to prevent or reduce the loss of fish. Recent decades have seen an increase in the use and effectiveness of these screens and bypass systems; they take advantage of carefully designed hydraulic conditions and known fish behavior. These positive systems are successful at moving juvenile salmonids past intakes with a minimum of delay, loss or injury.

The past few decades have also seen much effort in developing “startle” systems to elicit a taxis (response) by the fish with an ultimate goal of reducing entrainment. This Position Statement addresses research designed to prevent fish losses at diversions and presents a tiered process for studying, reviewing, and implementing future fish protection measures.

Juveniles at Intakes

The three main causes of delay, injury, and loss of fish at water intakes are entrainment, impingement, and predation. Entrainment occurs when the fish is pulled into the diversion and passes into a canal or turbine. Impingement is where a fish comes in contact with a screen, a trashrack, or debris at the intake. This causes bruising, descaling, and other injuries. Impingement, if prolonged, repeated, or occurs at high velocities also causes direct mortality. Predation also occurs. Intakes increase predation by stressing or disorienting fish and/or by providing habitat for fish and bird predators.

A. Positive Barriers

Positive barrier screen systems and criteria for their design have been developed, tested, and proved to minimize harm caused at diversions. Positive barriers do not rely on active fish behavior; they prevent physical entrainment with a physical barrier. Screens with small openings and good seals are designed to work with hydraulic conditions at the site, providing low velocities normal to the screen face and sufficient sweeping velocities to move fish past the screen. These screens are very effective at preventing entrainment [Pearce and Lee 1991]. Carefully designed bypass systems minimize fish exposure to screens and provide hydraulic conditions that return fish to the river, preventing both entrainment and impingement [Rainey 1985]. The positive screen and fish bypass systems are designed to minimize predation, and to reduce mortality, stress, and delay from the point of diversion, through the bypass facility, and back the river.

Carefully designed positive barrier screen and bypass systems have been installed and evaluated at numerous facilities [Abernethy et al 1989, 1990, Rainey, 1990, Johnson, 1988]. A variety of screen types (e.g. flat plate, chevron, drum) and screen materials (e.g. woven cloth, perforated plate, profile wire), have proved effective, taking into consideration their appropriateness for each site. Well-designed facilities consistently result in a guidance efficiency of over 95 percent [Hosey, 1990, Neitzel, 1985, 1986, 1990 a,b,c,d, Neitzel, 1991].

The main drawback to positive barrier screens is cost. At diversions of several hundred cubic ft per second or greater, the low velocity requirement and structural complexity can drive the cost for fish protection and the associated civil works over a million dollars. At the headwork, the need to clean the screen, remove trash, and provide regular maintenance (e.g. seasonal installation, replacing seals, etc.) also increase costs.

B. Behavioral Devices

Due to higher costs of positive barrier screens, there has been much experimentation since 1960 to develop behavioral devices as a substitute for barrier screens [EPRI, 1986]. A behavioral device, as opposed to a positive (physical) barrier, requires a volitional taxis on the part of the fish to avoid entrainment. Early efforts were designed to either attract or repel fish. These studies focused on soliciting a behavioral response from the fish, usually noticeable agitation. Using these startle investigations to develop effective fish guidance systems has not been effective.

Experiments show that there is a large response variation between individual fish of the same size and species. Therefore, it cannot be predicted that a fish will always move toward or away from a certain stimulus. Even when such a

movement is desired by a fish, it often cannot discern the source or direction of the signal and choose a safe escape route.

Many behavioral devices do not incorporate and use a controlled set of hydraulic conditions to assure fish guidance, as does the positive screen/bypass system. The devices can actually encourage fish movement that actually contrasts with the expected rheotactic response. Thus, the fish gets mixed signals about what direction to move. Another concern is repeated exposure; a fish may no longer react to a signal that initially was an attractant or repellent. In addition to the vagaries in the response of an individual fish, behavior variations are expected due to size, species, life stage, and water quality conditions.

In strong or accelerating water velocity fields, the swimming ability of a fish may prevent it from responding to a stimulus even if it attempts to do so. Other environmental cues (e.g., pursuing prey, avoiding predators, or attractive habitat) may cause a fish to ignore the signal.

A main motivation for opting to install behavioral devices is cost-savings. However, much of the cost in conventional systems is for the physical structure needed to provide proper hydraulic conditions. Paradoxically, complementing a behavioral device with its own structural requirements may lessen much of its cost advantage.

Present skepticism over behavioral devices is supported by the fact that few are currently being used in the field and those that have been installed and evaluated seldom exhibit consistent guidance efficiencies above 60 percent [Vogel, 1988, EPRI, 1986]. The louver system is an example of a behavioral device with a poor success record. In this case, even with the use of favorable hydraulics, performance is poor especially for smaller fish. Entrainment can be high, particularly when operated over a wide range of hydraulic conditions [Vogel, 1988, Cramer, 1982, Bates, 1961]. Due to their poor performance, some of these systems are already replaced by positive barriers.

Experimentation Process

However, there is potential for developing new positive screens as well as behavioral guidance devices for the future. Nonetheless, experimental technology must achieve, over the foreseeable range of adverse conditions, a consistent level of success that equals or exceeds that of best available technology. It should be a deliberate, logical process. NMFS will not discourage research and development on experimental fish protection devices if the following tiered study process is incorporated:

- (1) Consider earlier research. A thorough review should be performed of past methods similar to that proposed. Reasons for substandard performances of these earlier methods should be clearly identified.
- (2) Study plan. A study plan should be developed and presented to NMFS for review and concurrence. It is essential that tests occur over a full range of possible hydraulic, biological, and ecological conditions that the device is expected to experience.
- (3) Laboratory research. Controlled laboratory experiments should be developed using species, size, and life stages intended to be protected (or acceptable surrogate species). For behavioral devices, special attention must be directed at providing favorable hydraulic conditions and demonstrating that the device clearly causes the planned behavioral response. Studies should be repeated with the same test fish to examine any habituation to the stimulus.
- (4) Prototype units. Once laboratory tests show high potential to equal or exceed success rates of state-of-the-art screening, it is appropriate to further examine the new device as a prototype under real field conditions. Field sites must be fully appropriate to (1) demonstrate all operational and natural variables expected to influence the device performance, (2) evaluate the species, or an acceptable surrogate, that would be exposed to the device under full operation, and (3) avoid unacceptable risk to resources at the prototype locations.
- (5) Study results. Results of both laboratory tests and prototype devices examined in the field must demonstrate a level of performance equal to or exceeding that of conventional, established technology before NMFS will support further installations.

Conclusions

In the course of the past few decades, we have seen increased demand for water diversions. This trend is likely to continue. Accompanying this demand is a corresponding decline of fisheries. Therefore, prudence dictates that fish protection facilities be held to the highest practicable level of performance.

A major effort was made to examine experimental guidance systems over several decades by a variety of funding agencies. The results were generally poor or inconclusive, with low guidance efficiencies attributable to the particular device used. Often results were based on a small sample size or varied with operational

conditions. In addition, unforeseen operational and maintenance problems, including safety hazards, sometimes developed.

Nevertheless, some of these experiments show potential. To further improve fish protection technology, NMFS will not oppose tests that proceed in the tiered process outlined above. Further, to ensure no further detriment to fish, experimental field testing should be done with the simultaneous design of a positive barrier and bypass system for that site. This conventional system should be scheduled for installation immediately, if the experimental guidance system, once again, does not prove to be as effective as a conventional system.

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5. State of Washington Screening Requirements For Water Diversions

<<http://wdfw.wa.gov/hab/engineer/fishscrn.htm>>

Washington State Laws (RCW 77.16.220; RCW 77.55.040 (formerly RCW 75.20.040), RCW (formerly RCW 75.20.061)) require all diversions from waters of the state to be screened to protect fish. These laws and the following design criteria are essential for the protection of fish at surface water diversions. Fish drawn into hydropower, irrigation, water supply, and other diversions are usually lost from the fish resources of the state of Washington.

The following criteria are based on the philosophy of physically excluding fish from being entrained in water diverted without becoming impinged on the diversion screen. The approach velocity and screen mesh opening criteria are based upon the swimming stamina of emergent size fry in low water temperature conditions. It is recognized that there may be locations at which design for these conditions may not be warranted. Unless conclusive data from studies acceptable to Washington Department of Fish and Wildlife indicate otherwise, it is assumed that these extreme conditions exist at some time of the year at all screen sites.

Additional criteria may be required for unique situations, large facilities or intakes within marine waters.

I. Screen Location and Orientation

- a. Fish screens in rivers and streams shall be constructed within the flowing stream at the point of diversion and parallel to the streamflow. The screen face shall be continuous with the adjacent bankline. A smooth transition between the screen and bankline shall be provided to prevent eddies in front, upstream and downstream from the screen.

Where it can be thoroughly demonstrated that flow characteristics or site conditions make construction or operation of fish screens at the diversion entrance impractical, the screens may be installed in the canal downstream from the diversion.

- b. Diversion intakes in lakes and reservoirs shall be located offshore in deep water to minimize the exposure of juvenile fish to the screen. Salmon and trout fry generally inhabit shallow water areas near shore.
- c. Screens constructed in canals and ditches shall be located as close as practical to the diversion. They shall be oriented so the angle between the face of the screen and the approaching flow is no more than 45

degrees. All screens constructed downstream from the diversion shall be provided with an efficient bypass system.

II. Approach Velocity

The approach velocity is defined as the component of the local water velocity vector perpendicular to the face of the screen. Juvenile fish must be able to swim at a speed equal or greater than the approach velocity for an extended length of time to avoid impingement on the screen. The following approach velocity criteria are maximum velocities that shall not be exceeded anywhere on the face of the screen. A maximum approach velocity of 0.4 ft per second is allowed.

The approach velocity is calculated based on the gross screen area not the net open area of the screen mesh.

The intake structure and/or fish screen shall be designed to assure that the diverted flow is uniformly distributed through the screen so the maximum approach velocity is not exceeded.

III. Minimum Screen Area

The minimum required screen area is determined by dividing the maximum diverted flow by the maximum allowable approach velocity. To find the screen area in square ft, divide the diverted flow in cubic ft per second (450 gpm = 1.0 cubic ft per second) by the approach velocity 0.4 ft per second):

$$\text{Minimum Screen Area} = \frac{\text{Diverted Flow (ft}^3\text{/s)}}{\text{Approach Velocity (ft/s)}}$$

The minimum required screen area must be submerged during lowest streamflows and may not include any area that is blocked by screen guides or structural members.

Diversions less than or equal to 180 gallons/minute (0.4 cfs) require a minimum submerged screen area of 1.0 square ft, which is the smallest practical screening device.

IV. Sweeping Velocity

The sweeping velocity is defined as the component of the water velocity vector parallel to and immediately upstream from the screen surface. The sweeping velocity shall equal or exceed the maximum allowable approach velocity. The

sweeping velocity requirement is satisfied by a combination of proper orientation (angle of screen 45 degrees to the approaching flow) of the screen relative to the approaching flow and adequate bypass flow.

Screen bay piers or walls adjacent to the screen face shall be flush with screen surfaces so the sweeping velocity is not impeded.

V. Screen Mesh Size, Shape, and Type of Material

Screen openings may be round, square, rectangular, or any combination thereof, provided structural integrity and cleaning operations are not impaired.

Screen mesh criteria is based on the assumption that steelhead and/or resident trout fry are ubiquitous in the state of Washington and will be present at all diversion sites.

Following are the maximum screen openings allowable for emergent salmonid fry. The maximum opening applies to the entire screen structure including the screen mesh, guides, and seals. The profile bar criteria is applied to the narrow dimension of rectangular slots or mesh.

Woven Wire Mesh	Profile Bar	Perforated Plate
0.087 inch	1.75 mm (0.069 inch)	0.094 inch
(6-14 mesh)		(3/32 inch)

The allowable woven wire mesh openings is the greatest open space distance between mesh wires. An example allowable mesh specifications is provided; there are other standard allowable openings available. The mesh specification gives the number of mesh openings per lineal inch followed by the gauge of the wires. For example, 6-14 mesh has six mesh openings per inch of screen. It is constructed with 6, 14-gauge (0.080 inch diameter) wires per inch.

The profile bar openings are the maximum allowable space between bars. The allowable perforated plate openings are the diameter of circular perforations. Perforated slots are treated as profile bars.

Screens may be constructed of any durable material; woven, welded, or perforated. The screen material must be resistant to corrosion and ultraviolet damage.

For longevity and durability, minimum wire diameter for woven mesh shall be 0.060 inch (18 gauge) on fixed panel screens, where they are not subjected to impact of debris. Minimum wire diameter for woven mesh shall be 0.080 inch

(14 gauge) for rotary drum screens, traveling belt screens, and in areas where there is a potential for damage from floating debris or cleaning operations.

VI. Bypass

All screens constructed downstream from the diversion shall be provided with an efficient bypass system to rapidly collect juvenile fish and safely transport them back to the river. The downstream end of the screen shall terminate at the entrance to the bypass system. It is the water diversion owner's responsibility to obtain necessary water rights to operate the fish bypass; failure to do so may be considered failure to meet state screening law requirements.

VII. Cleaning

Fish screens shall be cleaned as frequently as necessary to prevent obstruction of flow and violation of the approach velocity criterion. Automatic cleaning devices will be required on large screen facilities.

Additional detailed information is available explaining the background and justification of these criteria and showing standard details of flow distributors, acceptable bypass designs, and screen areas required for various flows.

For further information contact:

Wash. Dept. of Fish and Wildlife
3705 W. Washington Ave.
Yakima, WA 98903-1137
(509) 575-2734 Fax: 454-4139

Wash. Dept. of Fish and Wildlife
600 Capitol Way North
Olympia, WA 98501-1091
(360) 902-2545 Fax: 902-2946

6. State of California Department of Fish and Game – Fish Screening Criteria – June 19, 2000

<http://www.dfg.ca.gov/nafwb/fishscreencriteria.html>

1. Structure Placement

A. *Streams And Rivers (flowing water):*

The screen face shall be parallel to the flow and adjacent bankline (water's edge), with the screen face at or streamward of a line defined by the annual low-flow water's edge.

The upstream and downstream transitions to the screen structure shall be designed and constructed to match the back-line, minimizing eddies upstream from, in front of and downstream from, the screen.

Where feasible, this “on-stream” fish screen structure placement is preferred by the California Department of Fish and Game.

B. *In Canals (flowing water):*

The screen structure shall be located as close to the river source as practical, in an effort to minimize the approach channel length and the fish return bypass length. This “in canal” fish screen location shall only be used where an “on-stream” screen design is not feasible. This situation is most common at existing diversion dams with headgate structures.

The National Marine Fisheries Service - Southwest Region “Fish Screening Criteria for Anadromous Salmonids, January 1997” for these types of installations shall be used.

C. *Small Pumped Diversions:*

Small pumped diversions (less than 40 cubic ft per second) which are screened using “manufactured, self-contained” screens shall conform to the National Marine Fisheries Service - Southwest Region “Fish Screening Criteria for Anadromous Salmonids, January 1997”.

D. *Non-Flowing Waters (tidal areas, lakes and reservoirs):*

The preferred location for the diversion intake structure shall be offshore, in deep water, to minimize fish contact with the diversion. Other configurations will be considered as exceptions to the screening criteria as described in Section 5.F. below.

2. Approach Velocity (local velocity component perpendicular to the screen face)

A. Flow Uniformity:

The design of the screen shall distribute the approach velocity uniformly across the face of the screen. Provisions shall be made in the design of the screen to allow for adjustment of flow patterns. The intent is to ensure uniform flow distribution through the entire face of the screen as it is constructed and operated.

B. Self-Cleaning Screens: The design approach velocity shall not exceed:

1. Streams And Rivers (flowing waters) - Either:
 - a. 0.33 ft per second, where exposure to the fish screen shall not exceed fifteen minutes, or
 - b. 0.40 ft per second, for small (less than 40 cubic ft per second) pumped diversions using “manufactured, self-contained” screens.
2. In Canals (flowing waters) - 0.40 ft per second, with a bypass entrance located every one-minute of travel time along the screen face.
3. Non-Flowing Waters (tidal areas, lakes and reservoirs) - The specific screen approach velocity shall be determined for each installation, based on the species and life stage of fish being protected. Velocities which exceed those described above will require a variance to these criteria (see Section 5.F. below).

(Note: At this time, the U.S. Fish and Wildlife Service has selected a 0.2 ft per second approach velocity for use in waters where the Delta smelt is found. Thus, fish screens in the Sacramento-San Joaquin Estuary should use this criterion for design purposes.)

C. Screens Which are not Self-Cleaning:

The screens shall be designed with an approach velocity one-fourth that outlined in Section B. above. The screen shall be cleaned before the approach velocity exceeds the criteria described in Section B.

D. Frequency of Cleaning:

Fish screens shall be cleaned as frequently as necessary to prevent flow impedance and violation of the approach velocity criteria. A cleaning cycle once every 5 minutes is deemed to meet this standard.

E. Screen Area Calculation:

The required wetted screen area (square ft), excluding the area affected by structural components, is calculated by dividing the **maximum** diverted flow (cubic ft per second) by the allowable approach velocity (ft per second). Example:

1.0 cubic ft per second / 0.33 ft per second = 3.0 square ft

Unless otherwise specifically agreed to, this calculation shall be done at the minimum stream stage.

3. Sweeping Velocity (velocity component parallel to screen face)

A. In Streams And Rivers:

The sweeping velocity should be at least two times the allowable approach velocity.

B. In Canals:

The sweeping velocity shall exceed the allowable approach velocity. Experience has shown that sweeping velocities of 2.0 ft per second (or greater) are preferable.

C. Design Considerations:

Screen faces shall be designed flush with any adjacent screen bay piers or walls, to allow an unimpeded flow of water parallel to the screen face.

4. Screen Openings

A. Porosity:

The screen surface shall have a minimum open area of 27 percent. We recommend the maximum possible open area consistent with the availability of appropriate material, and structural design considerations.

The use of open areas less than 40 percent shall include consideration of increasing the screen surface area, to reduce slot velocities, assisting in both fish protection and screen cleaning.

B. Round Openings:

Round openings in the screening shall not exceed 3.96mm (5/32in). In waters where steelhead rainbow trout fry are present, this dimension shall not exceed 2.38mm (3/32in).

C. *Square Openings:*

Square openings in screening shall not exceed 3.96mm (5/32in) measured diagonally. In waters where steelhead rainbow trout fry are present, this dimension shall not exceed 2.38mm (3/32in) measured diagonally.

D. *Slotted Openings:*

Slotted openings shall not exceed 2.38mm (3/32in) in width. In waters where steelhead rainbow trout fry are present, this dimension shall not exceed 1.75mm (0.0689in).

5. *Screen Construction*

A. *Material Selection:*

Screens may be constructed of any rigid material, perforated, woven, or slotted that provides water passage while physically excluding fish. The largest possible screen open area which is consistent with other project requirements should be used. Reducing the screen slot velocity is desirable both to protect fish and to ease cleaning requirements. Care should be taken to avoid the use of materials with sharp edges or projections which could harm fish.

B. *Corrosion And Fouling Protection:*

Stainless steel or other corrosion-resistant material is the screen material recommended to reduce clogging due to corrosion. The use of both active and passive corrosion protection systems should be considered.

Consideration should be given to anti-fouling material choices, to reduce biological fouling problems. Care should be taken not to use materials deemed deleterious to fish and other wildlife.

C. *Project Review And Approval:*

Plans and design calculations, which show that all the applicable screening criteria have been met, shall be provided to the Department before written approval can be granted by the appropriate Regional Manager.

The approval shall be documented in writing to the project sponsor, with copies to both the Deputy Director, Habitat Conservation Division and the Deputy Director, Wildlife and Inland Fisheries Division. Such approval may include a requirement for post-construction evaluation, monitoring and reporting.

D. *Assurances:*

All fish screens constructed after the effective date of these criteria shall be designed and constructed to satisfy the current criteria. Owners of existing

screens, approved by the Department prior to the effective date of these criteria, shall not be required to upgrade their facilities to satisfy the current criteria unless:

1. The controlling screen components deteriorate and require replacement (i.e., change the opening size or opening orientation when the screen panels or rotary drum screen coverings need replacing),
2. Relocation, modification or reconstruction (i.e., a change of screen alignment or an increase in the intake size to satisfy diversion requirements) of the intake facilities, or
3. The owner proposes to increase the rate of diversion which would result in violation of the criteria without additional modifications.

E. Supplemental Criteria:

Supplemental criteria may be issued by the Department for a project, to accommodate new fish screening technology or to address species-specific or site-specific circumstances.

F. Variances:

Written variances to these criteria may be granted with the approval of the appropriate Regional Manager and concurrence from both the Deputy Director, Habitat Conservation Division and the Deputy Director, Wildlife and Inland Fisheries Division. At a minimum, the rationale for the variance must be described and justified in the request.

Evaluation and monitoring may be required as a condition of any variance, to ensure that the requested variance does not result in a reduced level of protection for the aquatic resources.

It is the responsibility of the project sponsor to obtain the appropriate fish screen criteria as provided herein. Project sponsors should contact the Department of Fish and Game, the National Marine Fisheries Service (for projects in marine and anadromous waters) and the U.S. Fish and Wildlife Service (for projects in anadromous and fresh waters) for guidance.

Copies of the criteria are available from the Department of Fish and Game through the appropriate Regional office, which should be the first point of contact for any fish screening project.

Northern California and North Coast Region; 601 Locust Street, Redding, CA 96001 - (530) 225-2300.

Sacramento Valley and Central Sierra Region; 1701 Nimbus Drive, Rancho Cordova, CA 95670 - (916) 358-2900.

Central Coast Region; 7329 Silverado Trail/P.O. Box 46, Yountville, CA 94599 -(707) 944-5500.

San Joaquin Valley-Southern Sierra Region; 1234 E. Shaw Avenue, Fresno, CA 93710 - (209) 243-4005.

South Coast Region; 4649 View Crest Avenue, San Diego, CA 92123 - (619) 467-4201.

Eastern Sierra and Inland Deserts Region; 4775 Bird Farms Road, Chino Hills, CA 91709 - (909) 597-9823.

Marine Region; 20 Lower Ragsdale Drive, #100, Monterey, CA 93940 - (831) 649-2870.

Technical assistance can be obtained directly from the Habitat Conservation Division; 1416 Ninth Street, Sacramento, CA 95814 - (916) 653-1070.

The National Marine Fisheries Service - Southwest Region "Fish Screening Criteria for Anadromous Salmonids, January 1997" are also available from their Southwest Region; 777 Sonoma Avenue, Room 325, Santa Rosa, CA 95402 - (707) 575-6050.

7. Exclusion Barriers

Anadromous Salmonid Passage Facility Guidelines and Criteria
Developed by
National Marine Fisheries Service
Northwest Region
Portland, Oregon
1-31-04 external review draft
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<<http://www.nwr.noaa.gov/1hydro/hydroweb/docs/Passagecriteria.extrevdraft.pdf>>

6.1 Description, purpose and rationale: *Exclusion barriers* are designed to minimize the attraction and stop the migration of upstream migrating fish into an area where there is no upstream egress or suitable spawning area, and to guide fish to an area where upstream migration can continue. *Exclusion Barriers* can also be used to restrict movement of undesirable species into habitat. *Exclusion barriers* are designed to minimize the potential for injury of fish that are attracted to impassable routes.

Some examples of the use of *exclusion barriers* include:

- preventing fish from entering return flow from an irrigation ditch
- preventing fish from entering the *tailrace* of a power plant
- guiding fish to a trap facility for upstream transport, research or broodstock collection
- guiding fish to a counting facility
- preventing fish from entering a channel subject to sudden flow changes
- preventing fish from entering turbine draft tubes
- preventing fish from entering channels with poor spawning gravels, poor water quality or insufficient water quantity.

The two primary categories of *exclusion barriers* are picket barriers and velocity barriers.

Another type of exclusion barrier is a vertical drop structure, which provides a jump height that exceeds the vertical leaping ability of fish. Other types of

barriers, such as electric and acoustic fields, have very limited application because of inconsistent results most often attributed to varying water quality (turbidity, specific conductance).

Consistent with the terminology used throughout this document, criteria are specified by the word “shall” and guidelines are specified by the word “should”. Criteria are required design features, unless site specific conditions preclude their use and a site-specific written waiver is provided by NOAA Fisheries (also see Foreword). Guidelines are not required, but deviation from a guideline require a written explanation by the project designer. It is suggested that deviation from a guideline be discussed with NOAA Fisheries prior to final design. Since these guidelines and criteria are general in nature, there may be cases in which site constraints or extenuating circumstances dictate that certain criteria be waived or modified. Conversely, where there is a need to provide additional protection for fish, including species of fish not directly under NOAA Fisheries jurisdiction, site-specific criteria may be added. These circumstances will be considered by NOAA Fisheries on a project-by-project basis.

6.2 Picket Barrier - Description: Picket barriers diffuse nearly the entire streamflow through pickets extending the entire width of the impassable route, sufficiently spaced to provide a physical barrier to upstream migrant fish. This category of exclusion barrier includes a fixed bar rack and a variety of hinged floating *picket weir* designs. Picket barriers usually require removal for high flow events, increasing the potential to allow passage into undesirable areas.

In general, since the likelihood of impinging fish is very high, these types of barriers can not be used in waters containing species listed under the ESA, unless they are continually monitored by personnel on-site, and have a sufficient operational plan and facility design in place to allow for timely removal of impinged or stranded fish prior to the occurrence of injury. Since debris and downstream migrant fish must pass through the pickets, sites for these types of *exclusion barriers* must be carefully chosen. Picket barriers shall be continually monitored for debris accumulations, and debris shall be removed before it concentrates flow and violates the criteria established below. As debris accumulates, the potential for the impingement of downstream migrants (e.g., juvenile salmonids, kelts, adult salmon that have overshot their destination, or resident fish) increases to unacceptable levels. Debris accumulations will also concentrate flow through the remainder of the open picket area, increasing the attraction of upstream migrants to these areas and thereby increasing the potential for jumping injury or successful passage into areas without egress.

Picket barrier design criteria include the following:

6.2.1 The maximum clear opening between pickets and between pickets and abutments is one inch.

6.2.2 Pickets shall be comprised of flat bars aligned with flow, or round columns of steel, aluminum or durable plastic.

6.2.3 The picket array shall have a minimum 40% open area.

6.2.4 Picket barriers should be sited where there is a relatively constant depth over the entire stream width.

6.2.5 The average design velocity through pickets should be less than 1.0 ft/s for all design flows, with maximum velocity less than 1.25 ft/s, or half the velocity of adjacent river flows whichever is lower. The average design velocity is calculated by dividing the flow by the total submerged picket area over the design range of stream flows. When river velocities exceed these criteria, the picket barrier shall be removed.

6.2.6 The maximum head differential across the pickets should be 0.3 feet. If this differential is exceeded, the pickets shall be cleaned as soon as possible.

6.2.7 A debris and sediment removal plan is required that anticipates the entire range of conditions expected at the site. Debris shall be removed before accumulations develop that violate the criteria specified in 6.2.5 and 6.2.6.

6.2.8 The minimum picket extension above the water surface at high fish passage design flow is two feet.

6.2.9 The minimum submerged depth at the picket barrier at low design discharge shall be two feet for at least 10% of the river cross section at the barrier.

6.2.10 Picket barriers shall be designed to lead fish to a safe passage route. This can be achieved by angling the picket barrier toward a safe passage route, providing nearly uniform velocities through the entire length of pickets, and providing sufficient *attraction flows* from a safe passage route that minimizes the potential for false attraction to the picket barrier flows.

6.2.11 A uniform concrete sill, or an alternative approved by NOAA Fisheries Hydro Program staff, should be provided to ensure that fish do not pass under the picket barrier.

6.2.12 Picket panels should be of sufficient structural integrity to withstand high streamflows.

6.3 Velocity Barrier - Description: A velocity barrier consists of a *weir* and concrete *apron* combination that prevents upstream passage by producing a shallow flow depth and high velocity on the *apron*, followed by an impassable vertical jump over the *weir*. A velocity barrier does not have the fore-mentioned problems of a *picketed weir* barrier, since flow passes freely over a *weir*, allowing the passage of debris and downstream migrant fish. However, since this type of barrier creates an upstream impoundment, the designer must consider backwater effects that may induce loss of power generation or property inundation. Velocity barrier design criteria include the following:

6.3.1 The minimum *weir* height relative to the maximum *apron* elevation is 3.5 feet.

6.3.2 The minimum *apron* length (extending downstream from base of *weir*) is 16 feet.

6.3.3 The minimum *apron* downstream slope is 16:1 (horizontal:vertical).

6.3.4 The maximum head over the *weir* crest is two feet.

6.3.5 The elevation of the downstream end of the *apron* shall be greater than the *tailrace* water surface elevation corresponding to the high design flow.

6.3.6 Other combinations of *weir* height (6.3.1) and *weir* crest head (6.3.4) may be approved by NOAA Fisheries Hydro Program staff on a site-specific basis.

6.3.7 The flow over the weir must be fully and continuously vented along the entire length, to allow a fully aerated nappe to develop between the weir crest and the apron.

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6.4 Vertical Drop Structures - Description: A vertical drop structure can function as an exclusion barrier by providing *total project head* in excess of the leaping ability of the target fish species. These can be a concrete monolith, rubber dam, or approved alternative. Vertical drop structure criteria include the following:

6.4.1 The minimum height for vertical drop structure shall be 10 feet relative to the *tailrace* high design flow elevation.

6.4.2 To minimize the potential for leaping injuries, a minimum of two feet of cantilevered ledge shall be provided.

6.4.3 Provision shall be made to ensure that fish jumping at the drop structure flow will land in a minimum five foot deep pool, without contacting any solid surface.

6.5 Bottom Hinged Leaf Gates - Description: A bottom-hinged leaf gate is a device that can be elevated to provide an exclusion barrier by providing *total project head* in excess of the leaping ability of the target fish species. These can be mounted on a concrete base, where the leaf gate is raised into position by a hydraulic cylinder, pneumatic bladders, or other means. Bottom-hinged leaf gate criteria include the following:

6.5.1 The minimum vertical head drop (*forebay* to tailwater) shall be 10 feet at high design flow.

6.5.2 Provision shall be made to ensure that fish jumping at flow over the structure will land in a minimum five foot deep pool, without contacting any solid surface.

6.6 Horizontal Draft Tube *diffusers* - Description: A horizontal draft tube *diffuser* is a device used below a powerhouse at the turbine draft tube outlet to prevent fish from accessing the turbine runners, where injury is likely. Even if draft tube velocities are sufficiently high to prevent fish access during normal operations, ramping flow rates during turbine shut-down or start-up create velocities low enough to allow fish to swim up the draft tubes and impact turbine runners. Horizontal Draft Tube *diffuser* criteria include the following:

6.6.1 Average velocity of flow exiting the *diffuser* grating shall be less than 1.25 ft/s, and distributed as uniformly as possible. Maximum velocity should not exceed 2 ft/s.

6.6.2 Clear spacing between *diffuser* bars and any other pathway from the *tailrace* to the turbine runner shall be less than one inch.

6.6.3 *Diffusers* shall be submerged a minimum of two feet for all tailwater elevations.

Hydraulic Conversion Factors for Converting English to Metric Units

<u>Multiply</u>	<u>By</u>	<u>To obtain</u>
Length		
Inches	25.4 (exactly)	Millimeters
Feet	30.48 (exactly)	Centimeters
Miles	1.609344 (exactly)	Kilometers
Area		
Square inches	6.4516 (exactly)	Square centimeters
Square feet	0.092903 (exactly)	Square meters
Acres	0.0040469	Square kilometers
Square miles	2.58999	Square kilometers
Volume		
Cubic feet	0.0283168	Cubic meters
	28.3168	Liters
Gallons (U.S.)	3.78543	Liters
Cubic yards	0.7645	Cubic meters
Mass		
Pounds	0.45359237 (exactly)	Kilograms
Tons	907.185	Kilograms
Acceleration		
Feet/sec/sec	0.3048	Meters/sec/sec
Force/unit area		
Pounds/in ²	0.070307	Kilograms/cm ²
Mass/volume (density)		
Pounds/ft ³	16.0185	Kilograms/m ³
Velocity		
Feet/second	30.48 (exactly)	Centimeters/second
Flow		
Feet ³ /second	0.028317	Meters ³ /second
	28.317	Liters/second
Power		
Horsepower (English)	745.700	Watts
	1.014	Horsepower (Metric)
Viscosity		
Kinematic viscosity (feet ² /second)	0.0929	Meters ² /second