

FINAL REPORT

**UPPER COLORADO RIVER BASIN
RECOVERY IMPLEMENTATION PROGRAM**

**FEASIBILITY EVALUATION OF NON-NATIVE FISH
CONTROL STRUCTURES**

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EXECUTIVE SUMMARY

Non-Native fish have been identified as an impediment to recovery of endangered fish in the upper Colorado basin, the impediment being habitat competition and predation. Control of non-native species has been identified in the recovery action plan as one item that needs to be accomplished to move toward recovery. This report is a feasibility evaluation of installing control structures to eliminate escapement from off-stream reservoirs in the upper Colorado basin. The reservoirs evaluated in this study are Elkhead Reservoir near Craig, Colorado, and Highline Reservoir near Loma, Colorado. This study also serves as a source of reference information and an example of how control structures might be implanted at other similar facilities throughout the upper basin.

Objectives of the report were to examine two different levels of control. The first objective examined full exclusion of egg and larger life stages at Elkhead and Highline Reservoirs. The exclusion facility would handle flows up to the 100 year flood event with as close as possible to 100% efficiency. The second objective was to evaluate installing a control structure that limited escapement to the current industry practice. That practice is approximately 90% effectiveness and screen openings no smaller than 3/32 inch. Also, the facility would handle flows up to the 100 year flood event. For frame of reference, a no action alternative was also looked at to provide a basis for change in fish community and a perspective on effectiveness of the full exclusion and current industry practice alternatives.

Elkhead Reservoir is located on Elkhead Creek which is tributary to the Yampa River. Elkhead Creek has routed flows up to 2,100 cfs and is an unregulated watershed. The reservoir spills annually and is rarely drawn down for release of water for municipal or irrigation use.

Highline Reservoir is located on Mack Wash which is a tributary to the Colorado River. Highline receives all inflow, except for local storm runoff, as administrative spills from the Highline diversion canal. Flows into the reservoir and out of the reservoir generally are less than 100 cfs. The watershed upstream of Highline Reservoir on Mack Wash is small and the high flows would be the result of storm runoff, especially summer thunderstorms.

Target species evaluated for this control structure feasibility study included channel catfish, smallmouth bass and northern pike. These species are present in both reservoirs with the exception of northern pike which is present only in Elkhead Reservoir. Currently, smallmouth bass reproduce in the reservoirs. Channel catfish are suspected of reproducing only in Highline Reservoir. With these species, the life stages of interest include everything from egg size and larger. Other warm water species present in the reservoirs include black crappie and largemouth bass. These species can escape but are not likely to successfully reproduce and recruit to the riverine fish populations. Therefore, these latter species were not the primary focus of the evaluation. Control techniques selected for the target species also should control the non-target species.

Evaluations started with a literature review and personal interviews on various screening and fish passage facilities. The interviews were with experts in the field of fish passage, specifically related to design, construction and operation of mostly downstream migrant facilities. Structures evaluated in the present study did not include a fish bypass. The structural option designs were configured so that there would be no bypass of non-native fish downstream and result in handling of those fish for either disposal or transport back upstream to the reservoir. This is a substantial

variation from the usual downstream passage facilities. Most screening facilities have some sort of safe passage feature for the fish to move safely around the dam or diversion structure and back to the receiving stream downstream of that structure.

This project has several features which make the selection of feasible control options unique. The current technology includes both physical and behavioral techniques to control fish passage. In this case, the behavioral techniques will not stop the passive life stages that may be present and are only marginally effective on controlling active life stages. For these reasons, behavioral techniques were not considered feasible control options at either Elkhead or Highline reservoirs.

Physical control devices include several types of screening devices. Since the objective of this study is to control escapement, the best location for controlling the fish is within the reservoir. Any device placed downstream of the reservoir would require construction of a stream channel and physical screening facility large enough to protect to the maximum flow event. Further, the facility would need to be designed to function at the current industry standard for the full range of flows. The wide range of flows from flood flows to near zero would be very difficult to protect with one facility. This may require one facility designed to work at high flows and another to work at the low flows. Further, any fish that get to the downstream facility are already moving toward habitat occupied by the endangered fish species. Any facility downstream of the reservoirs also would require a fish bypass or collection facility and some type of fish handling or disposal. All of these factors eliminate the downstream location as a feasible option.

Physical facilities designed for in-reservoir control include both high velocity and low velocity screens. Both the high and low velocity screens constructed in the reservoir would have to be designed to operate for the full range of flow conditions.

High velocity screens include Eicher and Modular Inclined Screens. Both of these screen types are intended for use within a reservoir outlet or penstock and both require fish bypass. To meet the criteria set for this study, the reservoir outlets would have to be reconstructed to a size that would pass all flow up to the 100 year event and include the screen. The fish bypass would require a fish collection facility that could retain any bypassed fish for either disposal or transport back to the reservoir. This would require additional operation and maintenance funds for the life of the project. This additional cost in excess of the capitol cost for reconstruction of the outlet works and requirement for fish handling makes these screen types lower priority for selection than types that have no fish bypass or fish handling.

Low velocity screens include traveling and fixed screen types. The traveling screens all require considerable operation and maintenance costs. In addition, there is a possibility that escapement can occur as screen seals wear. The gap between the screen and the seal could exceed the 3/32 inch opening for the criteria for this project. This would not meet the exclusion criteria for the project. The traveling low velocity screens would require a large screen face relative to the flow rate ratio and do not work in a submerged location. The large size would require considerable capitol cost for construction of the civil works associated with these types of screen and high annual operation and maintenance costs. Therefore, traveling screens were not selected for further evaluation in this project.

Fixed screens are generally designed for low approach velocities to eliminate fish impingement. Most fixed low velocity screens have a traveling brush to clean the screen face of debris. Any such mechanical device requires additional maintenance over a non-mechanical system.

Therefore, fixed screens that can be installed in a submerged location without mechanical cleaning were rated as the best potential device for this project.

The two objectives for this project require two different screen alternatives, one that prevents escapement of all life stages and the second that protects to the current industry standard. In this project, impingement was deemed an acceptable consequence of in-reservoir protection. This allowed the evaluation of higher (2 ft./sec.) velocity fixed screens in this project for both objectives. In addition, for the protection to current industry practice option, a secondary protection mechanism was evaluated in each reservoir in addition to the fixed screens to protect at high flow events.

Control structures are feasible at both reservoirs. The best location for the structures is on the primary outlet to the reservoir. To meet the criteria for full exclusion set in this study, the primary outlets for each reservoir would be reconstructed and enlarged to safely discharge flows up to the 100 year event. The best screen type for these reservoirs is a fixed plate screen that functions while submerged. This is a cylindrical screen type with a pneumatic backwash system for cleaning. In addition, the reservoir level would be reduced by 1-3 feet below the spillway crest to prevent spills and escapement. There would be no additional screening protection on the spillway for this alternative.

The control type that meets the criteria for current industry practice is a cylindrical screen on the primary outlet in combination with a barrier net placed in front of the spillway. The primary outlet would require enlargement but would not pass all flows up to the 100 year event. High flows would be released through the service spillway of the reservoir. The escapement protection for these spills would be the barrier net, ¼ inch mesh and suspended from the surface to the bottom of the reservoir. The net bottom is anchored to the reservoir bottom and weighted for its entire length to insure a complete seal at the interface between the net material and reservoir bottom.

The cost for each of the options varied substantially. For full exclusion at Elkhead Reservoir, costs were estimated at approximately \$33 million to exclude all life stages egg size and larger and pass the 100 year event. Capital costs for controlling at Elkhead Reservoir to the current industry practice were approximately \$900,000.00. The main difference in cost being the small screen opening, larger screen area and physical dam modifications needed to control all flows through a screening facility for the full exclusion option.

Control options at Highline Reservoir ranged from approximately \$8 million for the full control option to approximately \$300,000.00 for controlling to the current industry practice.

The selection of an alternative control option at either reservoir should consider collecting additional data that was not available for this analysis. The main data needed includes escapement information of the species present in the reservoirs. Currently there is no escapement data collected at either reservoir or in the receiving streams below to determine the size classes, timing and the population size of the fish leaving the reservoir and resident in the streams downstream of the facilities. Further, there is little information to determine which of these species that leave the reservoir are successful in surviving and recruiting to adult stages and successfully reproducing in the rivers downstream. Annual escapement rates should be monitored to determine which control option would be most cost effective. The size class of fish leaving can greatly impact the cost of the selected facility. If only juvenile and adult sizes are

leaving, larger mesh sizes can be used in the screens thereby reducing the cost substantially over the protection option for smaller, egg and larval life stages.

A further issue that needs to be resolved is the flood hydrology at Highline Reservoir. To date there is insufficient hydrologic information to determine the flow through the reservoir due to storm events and related reservoir attenuation. In the case of both the hydrologic and the biological data, designing a facility to protect for the perceived range of conditions may be more costly than protecting for the known range of conditions. Determining the actual escapement and the hydrologic conditions experienced at each facility would enable the design of an exclusion facility that would work to exclude the problem species through the appropriate range of flows experienced by the facility.

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1. INTRODUCTION

Control of non-native fishes is one element of the endangered fishes recovery program in the upper Colorado River basin. In particular, it is thought that chronic escapement of non-native fishes from off-channel impoundments is associated with mortality or competition that may limit recruitment of endangered fishes. It is believed that fish control structures emphasizing mechanical means can effectively limit this escapement.

This study directly relates to the Recovery Action Plan's (USFWS 1993) following sections for the Colorado mainstem and Yampa/Little Snake Rivers:

- III. Reduce Negative Impacts of non-native fishes and sport fish management activities (non-native and sport fish management)
- III. A. 2. Identify and implement viable control measures
- III. A. (c). Implement and evaluate the effectiveness of viable active control measures
- III. B. Reduce negative impacts to endangered fish from sport fish management activities
- III. B 2. Evaluate control options and implement control non-native fish escapement from Elkhead Reservoir.

1.1 Purpose of Study

The purpose of this study was to examine the feasibility of constructing on-site facilities to control escapement or downstream movement of non-native fishes from large off-channel dams or reservoirs on tributaries to mainstem rivers in the Colorado River basin. The study focused on Elkhead and Highline Reservoirs as physical facilities where escapement control may be particularly beneficial. Both Elkhead and Highline Reservoirs are located on streams which are outside of habitat occupied by the endangered species. However, both streams enter the mainstem rivers, Yampa and Colorado, respectively, upstream of or within critical habitat reaches.

1.2 Objective

Personnel from the Bureau of Reclamation, U.S. Fish and Wildlife, Colorado Division of Wildlife, Colorado Division of Parks, and Colorado Water Conservation District involved with the Upper Colorado River Basin Recovery Program and familiar with the non-native fish issues at the target reservoirs were asked for their input on the nature and magnitude of the escapement problem including life stages and particular species of concern. This ad hoc team identified two main objectives for the evaluation. The first objective was evaluation of an alternative to contain egg size and larger life stages for levels of flow up to the 100 year flow event and at an effectiveness as close to 100% as possible. After a preliminary review of current control technology and the associated costs with 100% control, the team recommended a second objective. The second objective was to evaluate an alternative to reduce escapement from the reservoirs to the current industry standard of practice and at a 90% or higher efficiency up to the 100 year flow event.

1.3 Overview of Existing Control Technology

Fish passage generally consists of three major subject areas: 1) upstream movement, normally by adult fish to spawn or to reach seasonally occupied habitat; 2) downstream movement, normally by young fish to reach habitat occupied during the majority of their life cycle; and 3) movement back

and forth along the river as a part of normal movement of resident river fish. The stated purpose of this study is closest to subject area 2. Subject areas 1 and 3 are not applicable to this study.

The evaluation of the control structure options to restrict downstream movement was conducted using a combination of a review of literature and interviews with key individuals who are currently operating and/or designing fish protection facilities throughout the nation. The literature is summarized in the annotated bibliography in the Appendix. A description of personal contacts is provided in Section 7.

1.3.1 Summary of Information Sources, Geographic Locations, and Target Fish Species

The initial literature search identified over a hundred publications and associated references which were reviewed. This served as the basis for identifying other publications, grey literature sources and initial personal contacts. Professional acquaintances of the primary investigators and additional individuals suggested by the people contacted were also targeted for interviews. This resulted in individuals from a wide range of agencies and organizations being contacted to get input regarding various protection devices and, in particular, on containing warm water species within reservoirs. These entities included: National Marine Fishery Service, Oregon Department of Wildlife, Washington Department of Fisheries, Washington Department of Ecology, California Department of Fish and Game, the Wisconsin Department of Natural Resources, National Biological Service, Turners Falls Anadromous Fish Labs, and Alden Research Lab in Boston, Massachusetts. In addition, key personnel in the Bureau of Reclamation in Denver, Washington and California were contacted concerning both existing and proposed fish protection facilities. A list of persons contacted is in Section 7.

Current fish protection facilities are located mainly in the Pacific Northwest, Northern California and in the northeast. In general, these facilities are used to protect anadromous salmonid species, normally smolts, from mortality at hydroelectric facilities or irrigation diversions during their downstream passage. Facilities also exist to retain game fish, to separate non-game and game fish, and to protect selected valuable (endangered, game or food) fish from mortality. Very few facilities exist to control fry size fish and smaller life forms.

1.3.2 General Characteristics of Exclusion Facilities

The general characteristics of these facilities are to safely bypass downstream migrating fish past a danger point and return them to the receiving stream below. Most such facilities are in use seasonally versus year round as the primary diversion purpose is for irrigation. Each facility consists of some sort of screen or diversion device to direct the fish toward a bypass. A small amount of flow is then directed down the bypass with the fish entrained in the flow and that flow is returned to the stream downstream of the facility. For the evaluation of this study, an alternative concept was investigated. In particular, that concept included no fish bypass facility, and retained the fish within the reservoir without bypassing them downstream. This is a substantial difference from the usual concept of fish bypass or fish screening facility.

1.3.3 Existing Control Types

1.3.3.1 General

Downstream passage facilities are generally described by two groups. Common groups are physical (primarily oriented to fish dimensions or mass, usually cross-sectional size); and behavioral (primarily oriented around how fish act in response to stimuli, although some physical element may also be involved); and other (management, etc.). Physical elements usually consist of trash racks which are followed by fish screens which are further subdivided by screen velocity into categories of low velocities (<0.5 ft/sec), and high velocities (>0.5 ft/sec) which are normally associated with high rates of impingement (i.e., fish are killed or injured) or an integral fish bypass. Flow and velocity directly controls screen size and cost. Since discharge is calculated by area multiplied by velocity, a large screen area is required to pass high discharges at low approach velocities. This results in higher screen costs. Screens are a common primary element of exclusion. They come in a variety of materials and configurations. Generally, screens are metal and consist of a bar rack, holes in metal plate, woven mesh or wedge-wire. A woven net is yet an additional screen type; distinctive by its material and its means of field mounting. All screens are designed with a $40\text{--}60\pm$ open area percentage. Features of these categories of physical screens are summarized in Table 1-1 and are described in more detail in immediately following sections of this narrative.

The screen/net cost varies considerably by its area and materials of construction. Both variables are highly correlated with the approach and passage flow velocity and related head loss. There are a full range of screen/net sizes, opening shapes, materials, % open area, configurations or combinations which are potentially applicable. As such, it is not possible to generalize head loss/velocity relationships in a meaningful way without detailed engineering evaluation and possibly model testing of the specific physical situation for which the screening is intended. Some head loss/velocity relationships for standard manufactured units can be made available separately.

1.3.3.2 Low Velocity

The vast majority of screens are low velocity screens; low velocity meaning less than 0.5 ft/sec and most commonly 0.1 to 0.3 ft/sec. These low velocities are designed to prevent impingement of fish on screens or injury by descaling, starvation, excessive stress, etc. The primary focus of most such screens is the safe exclusion of small anadromous fish about the age of 1 year and approximately 3 inches long. As such, common screen open spaces vary from 3/32- to 1/2-inch (2.38-12.7 mm). Recently, more installations with 3/32 inch openings to pass young of the year salmonids have been constructed. Low velocity screens require specific attention to be directed at both upstream and downstream sediment deposition.

1.3.3.3 High Velocity

All other screens with velocities greater than 0.5 ft/sec up to a practical upper limit of about 10 ft/sec are high velocity screens. These high velocities originate from the criteria associated with required screen strength when clogged with debris and related operations and maintenance considerations. Either increasing mortality is expected and accepted with increasing velocities associated with high velocity screens or a fish bypass system is incorporated to carry fish past or away from the screen. High velocity screens can be much smaller in size and lower in capital cost than low velocity screens. As flow velocities exceed 3 ft/sec, associated components which become necessary (mechanical cleaners, bypasses, etc.) begin to reduce some of the economy of high velocity screens. Screens with velocities up to and including 3 to 5 ft/sec have wide application in water and wastewater treatment facilities where debris collection or exclusion is the primary function. Facilities intended to function with velocities greater than 5 ft/sec are rare and mostly experimental. High velocity screens tend to have the same open spacing as low velocity screens. If fish mortality is an acceptable, albeit

regrettable, consequence of downstream passage restriction in the present study, the relative economy of high velocity screens may make them a particularly interesting alternative.

1.3.3.4 Behavioral

Behavioral devices have been used for protection at dams and diversions for decades (Nolting 1961, Fish Passage Technology 1995). The purpose of behavioral devices is to elicit a response either away from harm or towards a safe fish bypass at each of these facilities. Behavioral methods include a wide range of applications including electrical, lights and sound as well as several other behavioral devices. These three major types are described in more detail in immediately following sections of this narrative. The electrical methods and lights and sound try to elicit a startle response at the facilities although no success has been shown in causing movement to a desired location or in a desired direction in a consistent manner. Behavioral methods may not be able to direct fish to a bypass when the bypass flow is small compared to river flow. These are some of the limitations for behavioral methodologies. In addition, the behavioral methods only work on actively swimming life stages. Passive life stages are not deterred by behavioral devices. Features of these behavioral devices are summarized in Table 1-2.

1.3.3.5 Other Technologies

Other technologies available are generally grouped with the behavioral devices. These include air bubble curtains, hanging chains, water jet curtains, chemicals and visual keys. There have been no recent advances in these techniques and limited success in the use of these techniques at the facilities where they were used. Most of these would be used in conjunction with some other type of screening or passage facility and they would not be the primary technology used to safely bypass fish or deter fish from movement downstream or upstream. None of these technologies had direct application at either of the projects, Elkhead or Highline Reservoir, and therefore, not discussed in detail in this report.

Table 1. Summary of Physical Screen Types (Note: Number and) indicate project and data association in table.)

Control Structure Category	High Velocity Screens			Low Velocity Screens Traveling		Low Velocity Screens Fixed		
Control Type	Modular Incline Screen (MIS)	Eicher	Profile (Coanda)	Rotating Drum	Plate	Cylindrical	Plate	Barrier Nets
Structure Design Life	Unknown	Unknown	30 - 50 Years	30 Years +/-	30 Years +/-	30-50 Years	30-50 Years	< 30 Years 3) 3-7 years
Reliability (Prevention Capability & Backup)	Currently experimental. Studies have not shown exclusion of very small life stages. Fish passage can occur during debris flushing. Close to 100% efficient for bluegill, channel catfish, walleye.	Currently experimental. Very high fish diversion efficiency (about 99%) for target species and life stages. Not developed for exclusion of very small life stages. Fish passage can occur during debris flushing.	Barrier to all life stages 0.5 mm and larger. Depends on dry reach downstream of screen or fish collection with debris for further handling. Depends on no tailwater.	Very high fish exclusion efficiency for target species and life stages. Not intended to exclude small life stages. Small life forms can pass through seals.	Not intended to exclude small life stages. Small life forms can pass through seals.	Good exclusion efficiency for particles greater than 0.5 mm. Designed for liquid solids separation (not fish exclusion). Works for passive life stages.	Very high fish exclusion efficiency for target species and life stages. Can be configured to exclude small life stages.	Very good exclusion efficiency for target species and life stages. Not developed for life stages less than 0.25 in. 84% exclusion of target species.
Operation, Maintenance & Replacement Considerations	Collects fish only when water is flowing over the screen. Operational changes may be necessary to ensure adequate flow to the screen when filling reservoirs, when not submerged or when not flowing full. Fish handling may be required.	No icing potential. Not dependent on forebay area. Fish handling required.	Debris collection and processing at downstream toe. Operates well under ice conditions. Forebay elevation must be controlled using flashboards to assure sufficient flow depth over crest to flush debris.	Continual operation for cleaning. Requires ongoing costly maintenance of seals. May require dry & underwater inspection of seal tightness. Redundancy required for maintenance. Velocity variability common.	Requires ongoing costly maintenance of seals and gap tolerances between baskets. May require dry & underwater inspection of seal tightness. Operation cost associated with electric drive mechanisms. Redundancy required for maintenance.	Requires pneumatic cleaning system. Very little maintenance of screens. No debris or fish handling required; separate trash racks not needed for submerged application.	Requires a reliable cleaning system. Minimal seal maintenance is required. Velocity variability problem; baffles can help.	Buoyancy/bottom seal problems. Manual brushing/drying and/or coatings required for biofouling (top 0-5 ft). Remove/drop to bottom during winter. Remove/install by divers and/or barge. Possible redundancy if debris and/or biofouling. Impacted by wave action. 3) high pressure water jet cleaned.
Cost Range	None available, assume similar to Eicher	1) \$7M for 2-8 ft. dia., including structural retrofit. 3) \$8,000/cfs capital; \$30/cfs/yr O&M.	\$200/ft² (\$1000/cfs) - Screens only. Superstructure cost is very site dependent.	\$2,000 - \$3,000/cfs including nominal superstructure. O&M, 2%/yr of capital cost; new facilities.	Not available.	\$500/cfs (vertical) - \$1,500/cfs (Horizontal Tee) for screens only. Flushing becomes a significant cost for greater intake depths. 1) \$1,000/cfs capital; \$26/cfs/yr O&M.	3) \$800/cfs capital, \$10/cfs/yr O&M. 4) \$200/cfs capital (screen only), \$3/cfs/yr O&M. 7) \$1,500/cfs capital, \$12/cfs/yr O&M. 8) \$1,700/cfs capital, \$40/cfs/yr O&M.	2) \$4/ft² complete. 3) \$19,400 (1977) and \$15,000/year O&M. 4) \$0.25 - \$0.50/ft² (nylon netting only). 4) & 5) \$200 - \$300/ ft² for superstructure.
Constructibility	Requires no space in the forebay area. Requires retrofit of intake or new intake.	Requires no space in the forebay area. Requires retrofit of pipe or new pipe.	Easily constructed at a remote location. Requires superstructural mount for screen, and access walkway for service of flashboards and weir area.	Relatively difficult construction. Requires concrete piers and floor at proper angle to flow.	Relatively difficult construction. Requires concrete piers and floor.	Attach to intake pipe, tower, or manifold into outlet tower. Requires forebay area.	Relatively difficult construction. Requires concrete piers and floor.	Very simple to construct. May require floating boom type structure and fixed anchors at bottom or a more elaborate bridge system.
Flexibility	Accessible for modification.	Not easily modified (inside penstock).	Not easily modified.	Not easily modified.	Not easily modified.	Modular enlargement possible.	Modular enlargement possible.	Very flexible.
Outlet Types and Configuration	Designed to operate at any type of submerged application. Especially penstocks and pipe inlets.	Inside penstocks or pipes. Submerged applications.	Surface diversion/water intakes. Small dam spillway crests.	Surface diversion/water intakes.	Surface diversion/water intakes, or submerged turbine intakes.	Penstock or pipe inlet. Normally submerged applications.	Surface diversion/water intakes or separate facility.	Surface and subsurface water intakes/diversions.
Engineering Characteristics	Composed of trash rack, stop log slots, an 15-20° inclined wedge-wire screen, and occasionally a fish bypass. Designed to operate at water intake velocities of 2 to 10 fps and capacities up to 1000 cfs.	Elliptical screen fits inside the penstock at an angle that can function in flow velocities up to 8 fps. Requires fish bypass. 3) 2mm opening, 19° to flow, 5 fps, 420 cfs.	Approach velocities 2-4 fps. Self-cleaning, no moving parts or power requirements. Utilized mainly for flows of 0-250 cfs. Head required 4-5 ft. 10-25 year design frequency. 1.5 cfs/ft. capacity. Stainless steel wedgewire screen. 3) 1mm wedgewire screen.	Self cleaning. Algae may require jetting/brushing. Cathodic protection needed (node preferred). Common frame roundness problem. Mechanical/hydraulic powered (flowing water). Flows can go under or over the stainless steel screen. Requires fish bypass. Up to 3000 cfs. Handles high debris loads. Small water surface fluctuation. 4) 3.18mm screen.	More cost effective for deep intake channels. Can accommodate large water surface fluctuations & flows. Most common for diversions from 100 to 500 cfs (or more). Horizontal and vertical motion directions are available. Screen rotation speed is 0.03 fps. 2) 3/8” punched plate; horizontal movement. 4) typically used for pump intake screens. 5) 3 ft/sec velocity, 2.5mm opening. 6) 2.4-2.9 ft/sec approach velocity. 7) 0.5 ft/sec velocity, 1mm screen, 1378 cfs.	Designed to maintain uniform intake velocity from ~ 0.3 to 2 fps. Requires large screen area for small flow rate. Debris flushed away by compressed air. Slot openings from 0.02 in. - 0.5 in. 1) 0.33 fps, 2.38mm screen, 115 cfs capacity.	Can accommodate large water fluctuations and flow rates. Common for diversions up to 2,000 cfs. Minimal debris loading required. Good edge seals can be made. 2) 0.7 fps design flow, 2mm opening. 3) 0.2mm opening. 4) 12mm opening. 7) & 8) 1/2 inch opening	Low approach velocities (below 0.4 fps), minimal wave action, and light debris loads. A 50% clear opening is required. 1/4 - 1/2 inch typical mesh opening. 600-1,200 cfs typical capacity. Skirting at top is necessary. 3) 72” deep, 16 thread knotless dacron net, 83mm mesh.
Compatibility with Other Structural Components of the Reservoir	Can be installed at water intake.	Can be installed in the penstock or outlet pipe.	Special structure needed to hold screen and occasionally special headworks to control flow/build headwater.	Usually requires large area at water intake. Special structure required.	Special structure needed or can be placed in intake channel if sufficient screen area.	Connects directly to existing intake. Can be placed away from debris trapping areas or sensitive fish areas.	Requires special structure.	Could easily be mounted in spillway approach on existing trash rack or log boom.
Time of Use	Whenever water is flowing over the screen. High velocities and enclosed location minimizes icing.	Whenever water is flowing through outlet pipe. High velocities and enclosed location minimizes icing.	Whenever sufficient depth of water is flowing over the screen. All seasons.	Not practical in winter unless enclosed or heated due to icing. Sufficient depth to maintain low velocity.	Not practical in winter unless enclosed, heated or submerged.	No restrictions as long as submerged. Can operate during winter if properly located.	Not practical in winter unless enclosed or heated due to icing	When spillway is flowing. Is not practical in winter due to icing.
Examples Where Used	Lab test on design (EPRI) Niagara Mohawk Green Island, NY	1) Elwha Hydropower Project, Port Angeles, WA. 2) Puntledge Project at B.C. Hydro, Vancouver Is. 3) T.W. Sullivan Plant, OR.	1) Nycklemoe, MN. 2) Crow Creek, MT. 3) Hood River, OR.	1) Jackson Lake, CO. 2) Tehama-Colusa Irr. Canal, CA. 3) Glenn-Colusa Irr. District, CA. 4) Yakima R. (3), WA.	1) Lower Monumental, WA. 2) Multifarious P.P., NY. 3) Bowline Point, NY. 4) Yakima River, WA. 5) Wanapum & Priest Rapids, WA. 6) Hanford, WA. 7) Brayton Pt., MA.	1) Arbuckle Mtn. Hydro Plant, Redding, CA. 2) Eddystone, Delaware River, Philadelphia, PA. 3) Delmarva, DE. 4) Umatilla Pumping Plant, OR.	1) The Dalles Dam, WA. 2) Leaburg Hydro Project, McKenzie River, OR. 3) McClusky Canal. ND. 4) BC Hydro, Salmon River Division. 5) Wadhams, NY. 6) Little Falls, NY. 7) Twin Falls, WA. 8) Jim Boyd, OR.	1) Northfield Pump Storage Project, Connecticut River. 2) Ludington Pumped Storage Plant, Lake Michigan. 3) Banks Lake, Washington. 4) Wisconsin Electric Power Co. (several projects). 5) WPSC, Green Bay, WI. 6) Bauer Locks, WA.
Species Present at Facility	Bluegill, channel catfish, walleye, trout, salmon, alosid species.	1) Chinook, coho, steelhead. 2) Chinook, coho.	1) Carp, bullheads, red horse. 2) Carp. 3) Salmon.	3) Chinook Salmon. 4) Spring and Fall Chinook salmon.	1) Salmon. 3) White perch, striped bass. 6) Yellow perch, Chinook salmon. 7) Winter flounder.	2) Resident and migratory species.	4) Salmon and Steelhead	2) Chinook, Alewives. 3) Kokanee. 4) Trout, Centarkids, Muskie. 5) Perch, Alewives, Walleye, Carp. 6) Salmon have avoidance response to nets.
Life Stages Targeted for Protection	32-68 mm bluegill, 52-118 mm catfish, 74-100 mm walleye, juvenile trout.	1) Fingerling, presmolt, smolt. 2) Smolt.	1) & 2) Eggs and larger. 3) Fry/smolts and larger.	3) Juvenile.			4) Smolts and kelts	2) Adult 3) Adult 4) Larvae and larger - 50mm 5) Fry (1/4 in. opening)

Table 1-2. Summary of Behavioral Control Types

Control Structure Category	Behavioral		
Control Type	Electrical	Light	Acoustical (Sound)
Structure Design Life	30 years		
Reliability (Prevention Capability & Backup)	Currently experimental. Does not work with passive life stages. Effectiveness is very site specific and restricted to areas between electrodes. Effective barrier to target adult species, not eggs, larvae, or fry. May be dangerous to non-target species. Field strength for small fish may be lethal to large fish. Strength for large fish may not deter small fish. Mixed results. Trout most effected, largemouth bass moderately effected.	Currently experimental. Does not work on passive life stages. Only applicable to species with well-developed visual systems. Very dependent on water turbidity, and variable attenuation of different wave-lengths. Depends on contrast between artificial and ambient light. Effectiveness site specific to hydraulic, environmental, design, and operational conditions. Tests show catfish and bluegill avoided strobes. Mercury lights attract fish.	Currently experimental. Does not work with passive life stages. Not affected by turbidity, travels very fast in water, attenuates slowly, is highly directional, and not affected by light. Many species can detect sound. Depends on low ambient noise levels. Response affected by growth stage and time of day for some species. Effectiveness ranged from 55 to 70% deterrence for warmwater fish. Deterred 83-100 % salmonids
Operation Maintenance & Replacement Considerations	Required 240VAC power supply with auxiliary backup. Human safety is a concern.	Requires electrical power source and backup.	Requires electrical power source and backup.
Cost Range	\$100/cfs.	Less than electrical.	Insufficient data.
Constructibility	Not suited for remote applications. Will require auxiliary power and enclosure for pulse generating and monitoring equipment.	Not suited for remote applications.	Not suited for remote applications.
Flexibility	Can be retrofit on spillway.	Can be added to existing structures.	Can be added to existing structures.
Outlet Types and Configuration	Surface diversion/water intakes and outlet pipes.	Surface diversion.	Surface diversion.
Engineering Characteristics	Requires shallow water depth or narrow channel reach. Channel velocities must be uniform and can range from 2 to 10 fps. Static water arrays available.	Mercury and strobes both used - brightness and intensity varied.	Very low frequency and ultrasound (120KHZ).
Compatibility with Other Structural Components of the Reservoir	Can be constructed in spillway. Installation requires special concrete mix. Requires controlled geometric approach section.	Can be installed at spillway or outlet.	Can be installed at spillway or outlet.
Time of Use			
Examples Where Used	1) Puntledge Diversion, Puntledge, BC. 2) Duke Power plastic flume. 3) Rock River, WI. 4) SRP, AZ.	1) York Haven, Susquehanna River; 2) Ludington Pumped storage, Lake Michigan 3) lab studies, U. Iowa	1) Racine hydroelectric, Ohio R 2) Buchanan Hydro, St. Joseph R., Michigan
Species Present at Installed Facility	1) Salmon 2) Trout, largemouth bass 3) Carp.	1) Juvenile American Shad 2) NR 3) channel catfish, bluegill, largemouth bass	1) basses, catfish, shad 2) steelhead, chinook
Life Stages Targeted	1) smolts 2) adults 3) smolts		1) NR 2) smolts

1.3.4 High Velocity Screens

1.3.4.1 Modular Inclined Screen

Characteristics. The Modular Incline Screen or MIS is a developing technology that is similar in many ways to the Eicher screen. It is designed for higher approach velocities than conventional screens, and incorporates an incline screen within a pressure conduit. A marked difference is that the MIS is designed to fit within a rectangular conduit. This configuration develops uniform velocities over the screen surface without the need for baffles or varying porosity which in turn reduces the headloss across the screen. The MIS consists of an entrance with trashrack, dewatering stoplog slots, and inclined (10° to 20° to flow) wedge wire screen, and may have a fish bypass (Figure 1-1). Debris is removed by rotating the screen about a pivotal shaft which allows flow across the reversed screen surface. During debris flushing, fish passage or entrainment may occur. The time required for flushing is short and passage or entrainment is expected to be low. Laboratory tests have shown promising results for velocities ranging from 2 to 10 ft/sec and capacities of 500 to 1,000 cfs .

Typical Existing Applications. Typically intended for submerged application, the MIS is experimental. Laboratory testing is being conducted to evaluate the best hydraulic design configuration for safe fish passage, and the biological effectiveness in diverting selected fish species to a bypass. A prototype has been designed for the spillway sluiceway at Niagara Mohawk's Green Island facility on the Hudson River.

Typical Advantages

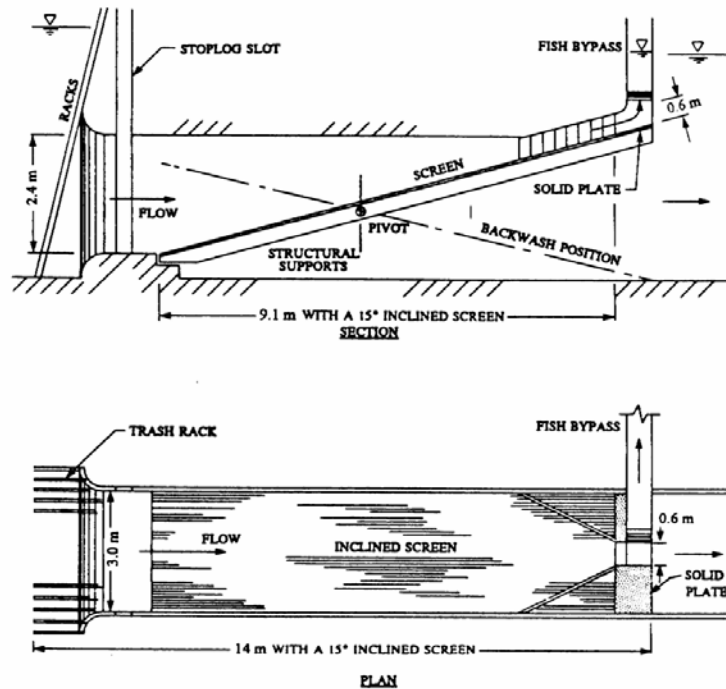
- Requires no space in forebay area
- Can easily be installed at a variety of water intakes
- Not affected by icing
- Unaffected by changes in forebay water surface elevation
- Operation and maintenance costs are small except when fish handling is necessary
- High velocities permit smaller screen area to be used

Typical Disadvantages

- Fish passage or entrainment may occur during debris flushing
- Fish bypass and handling occasionally required
- Not developed for exclusion of passive or very small life stages (2 mm smallest opening)
- Currently developing technology, has not been field tested
- May require operational changes to ensure adequate flow to the screen during reservoir filling, low flows and partly submerged conditions

Application to Limiting Downstream Passage. This screen can be effective for the subject application when installed at a rectangular bell-mouthed entrance at the upstream end of a pipe type intake (Figure 1-1). Its high velocity criteria makes it desirable from a cost/size standpoint especially where it can be positioned to avoid fish handling. Unfortunately, the backwashing cycle which has a brief period of open passage when it rotates around the center pivot, its relatively large screen openings and its lack of field applications reduces its potential application to the objectives of this study.

Figure 1-1. Example Modified Inclined Screen



(Source: Taft et al. 1995)

1.3.4.2 Eicher

Characteristics. The Eicher screen is a developing technology that is intended to divert fish at significantly higher approach velocities than conventional screen designs. It is named after biologist George Eicher who first developed the idea in the late 1970's as a better means of safely bypassing fish around a turbine. The basic Eicher screen is elliptical in shape and designed to fit inside the pressure penstock at an incline to flow (Figure 1-2). Non-penstock designs are also being developed. Fish are diverted up to the penstock roof where a bypass conduit is located. Rather than being designed to guide all target fish to a bypass without contact with the screen, the screen is constructed of very smooth stainless steel profile wire to minimize injury to fish that contact the screen. Debris is removed by rotating the screen about a pivotal shaft which allows flow across the reversed screen surface. During debris flushing, fish escapement may occur. This screen has been shown to operate successfully under a range of velocities up to a maximum of about 8 ft/sec. It is relatively less expensive and has smaller space requirements than most current barrier screen designs. Since it is installed in the penstock, forebay area is not required, nor is icing a problem. In addition, since the screen operates at much higher velocities, predation of bypassed species is reduced. Head loss may be significant (up to 2 feet) due to high velocities and baffling needed to obtain uniform flow. During backflushing, the flow distribution into a turbine may be affected.

Typical Existing Applications. This screen was designed with the assumption that the swimming ability and stamina of the target fish were inconsequential to the proper functioning of the screen.

Laboratory and field testing have provided data that support this assumption. In 1990-91, prototype testing was conducted at the Elwha Hydropower Project located on the Elwha River near Port Angeles, Washington. Very high fish diversion efficiency was realized for target species and life stages. Injury and mortality rates for some target species and life stages were comparable to those expected from current state-of-the-art screening facilities that have much lower approach velocities. Injury rates were increased when debris was present on the screen. Two installations that are currently in full operation are the Portland General Electric's Sullivan Plant on the Willamette River near Portland, Oregon, and the other at British Columbia Hydro's Puntledge Hydro Project on the Puntledge River located on Vancouver Island. Both installations show promising results similar to the Elwha project. Additional Eicher screen facilities are being designed for hydro power installations in the United States and Canada.

Typical Advantages

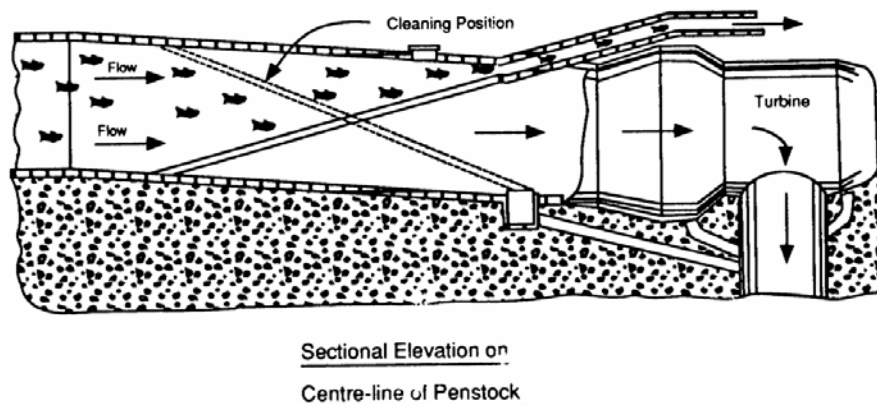
- Requires no space in forebay area
- Can be easily installed in a new penstock
- Not affected by icing
- Biologically effective for target species and life stages
- Total cost of installation can be competitive depending on site specifics
- Unaffected by changes in the forebay water surface elevation
- Operation and maintenance costs are small except when fish handling is necessary
- The relatively high velocities (2-10 fps) at which it can operate make it adaptable to some penstock applications

Typical Disadvantages

- Not applicable to most penstocks as penstock velocity normally exceeds 10 fps
- Fish entrainment possible during debris flushing
- Requires penstock structural modification at existing facilities
- Fish bypass and handling required
- Not developed for exclusion of passive or very small life stages
- Head loss may be significant (up to 2 feet) across the screen
- During backflushing, the flow distribution may be affected
- Currently developing technology, not widely accepted

Application to Limiting Downstream Passage. Its high velocity criteria makes it desirable from a cost/size standpoint. Unfortunately, the backwashing cycle which has a brief period of open passage, the requirement for a fish bypass and therefore handle fish, its relatively large screen openings, and its lack of field applications, reduces its potential application to the objectives of this study.

Figure 1-2. Example Eicher Screen



(Source: Clay 1995)

1.3.4.3 Coanda

Characteristics. The Coanda or profile screen is a sloped fixed screen consisting of a wedge-wire type mesh which allows water to be sheared off and through the mesh as it passes over its downstream ogee or “profile” face (Figure 1-3). All dewatered debris is collected at the toe of the screen or occasionally flushed downstream by flows exceeding its design capacity. Its name is taken from the phenomenon of fluids following a solid surface. It operates under an approach velocity of in excess of 3 ft/sec.

Typical Existing Applications. The profile screen’s most common application is to achieve direct diversion of debris free water from a waterway to a hydroelectric facility. It has also been used as both an upstream (drop type) and downstream (dewatering type) fish barrier, and on irrigation water diversions. It has been typically utilized on facilities with flows of 0-250 cfs. Most of the 20 plus project applications are in California.

Typical Advantages

- Self cleaning
- No electrical or mechanical parts
- Available with openings down to 0.5 mm to exclude organic material as small as eggs and larvae
- Operates well under ice conditions

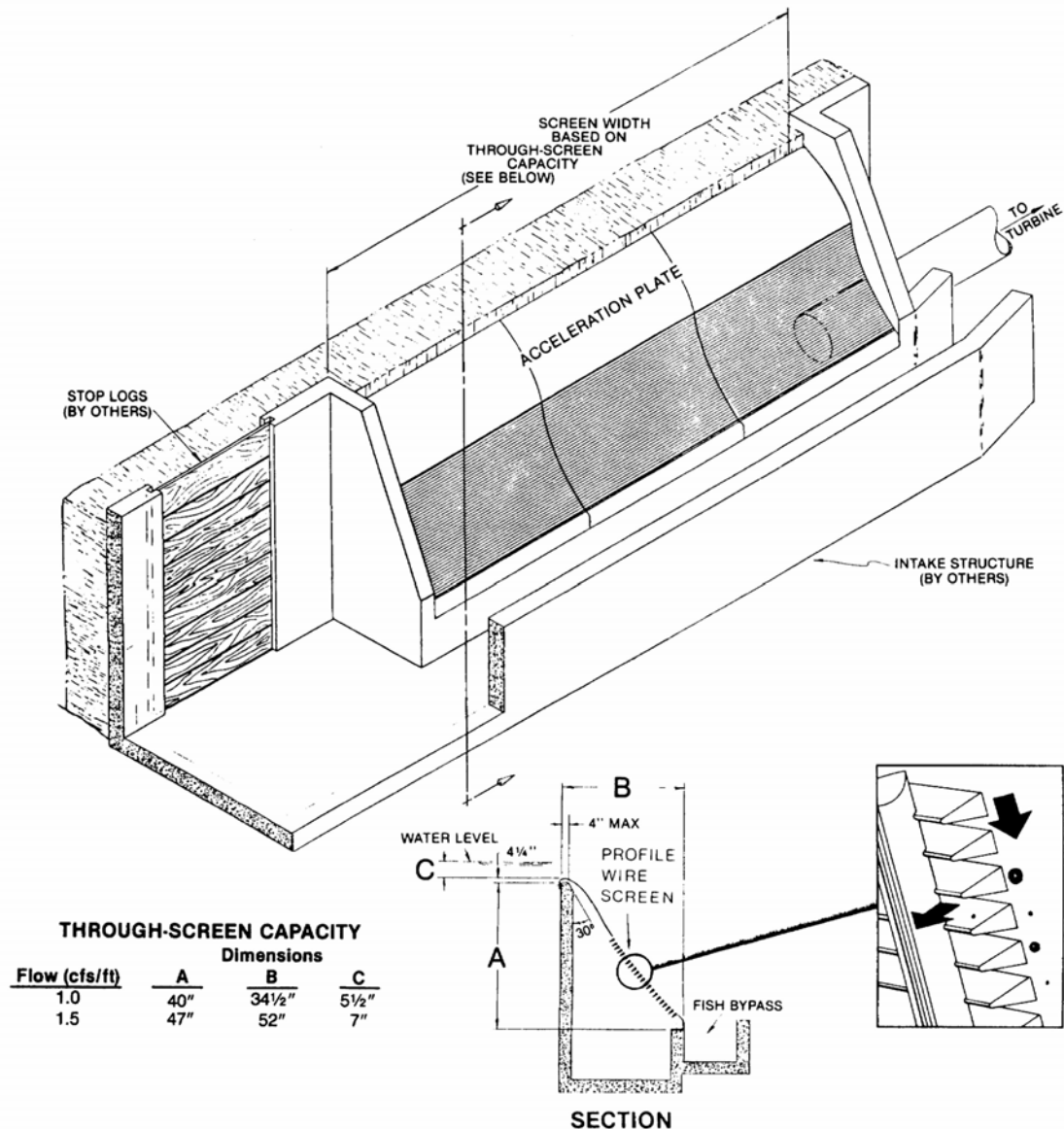
Typical Disadvantages

- The standard design is for less than 1 foot of head on the crest
- Downstream debris collection and processing required
- Requires approximately 5 feet of head below crest (i.e., requires a low dam superstructure)
- Downstream barrier is a short dewatered stream reach
- At small mesh openings, may require specific edge seals (pneumatic) to have edge space as small as mesh openings

- Not fish friendly
- May require a structural headworks for flow control

Application to Limiting Downstream Passage. The Coanda Screen is probably best used in circumstances where the flow is small and fairly constant. Due to its self cleaning, simple configuration it is also well suited to steeper streams at remote locations.

Figure 1-3. Example Coanda Screen



(Source: Aquadyne, Inc., Healdsburg, CA)

1.3.5 Low Velocity Screens - Traveling

1.3.5.1 Rotating Drum

Characteristics. This screen design is very popular and in common use on diversions up to 3,000 cfs, particularly in the Pacific Northwest. The screen consists of a horizontal drum with a screen mounted around its circumference that rotates within a metal frame (Figure 1-4). The frame is lowered into slots constructed in support piers at each end. Larger installations are usually equipped with an electric motor mounted on the frame to rotate the drum. Power to rotate the drum has been successfully produced from a paddle wheel located immediately downstream for installations where electric power is unavailable or unreliable. Smaller screens can be driven by internal turbines or paddle wheels that rely on the differential head between the upstream and downstream water surface and/or the flow velocity of the canal.

Drum screens work well at sites with high debris loads and small water surface fluctuations. The screen must operate continuously for debris cleaning. Debris is either carried over the screen and passed downstream or, for installations where the screen is oriented at an angle to flow, is diverted into the fish bypass where handling is required. Some applications require mechanical brushing or water jetting to clean algae from the screen surface.

Drum sizes range from 18 inches in diameter by 3 feet long, up to 19 feet in diameter by 12 feet long, and 15 feet in diameter by 24 feet long. Seals require good design, installation and ongoing maintenance to assure reliability. Neoprene seals are most common and may last 1 to 5 years depending on sediment loading. They are required between the drum and frame, and between the frame and the concrete support piers and floor. Large screens are difficult to manufacture and meet opening tolerances on the perimeter. Maintenance on large screens can be a significant dollar and personnel commitment.

Typical Existing Applications. Horizontal drum screens are mainly applicable to canal intakes, rather than deep water inlets, due to the limited depth of water screened. They have proven to be reliable in California and the Pacific Northwest. Drum screens have been proven to demonstrate nearly 100 percent overall efficiency and survival from comprehensive testing conducted at various large installations. Recent installations in the Yakima River basin in Washington and the Umatilla River basin in Oregon have been biologically evaluated and shown to pass juvenile salmonids with 0 to 2 percent of the bypassed fish killed or descaled.

Typical Advantages

- High fish exclusion efficiency for target species and life stages when facility is in optimal condition
- Fish friendly

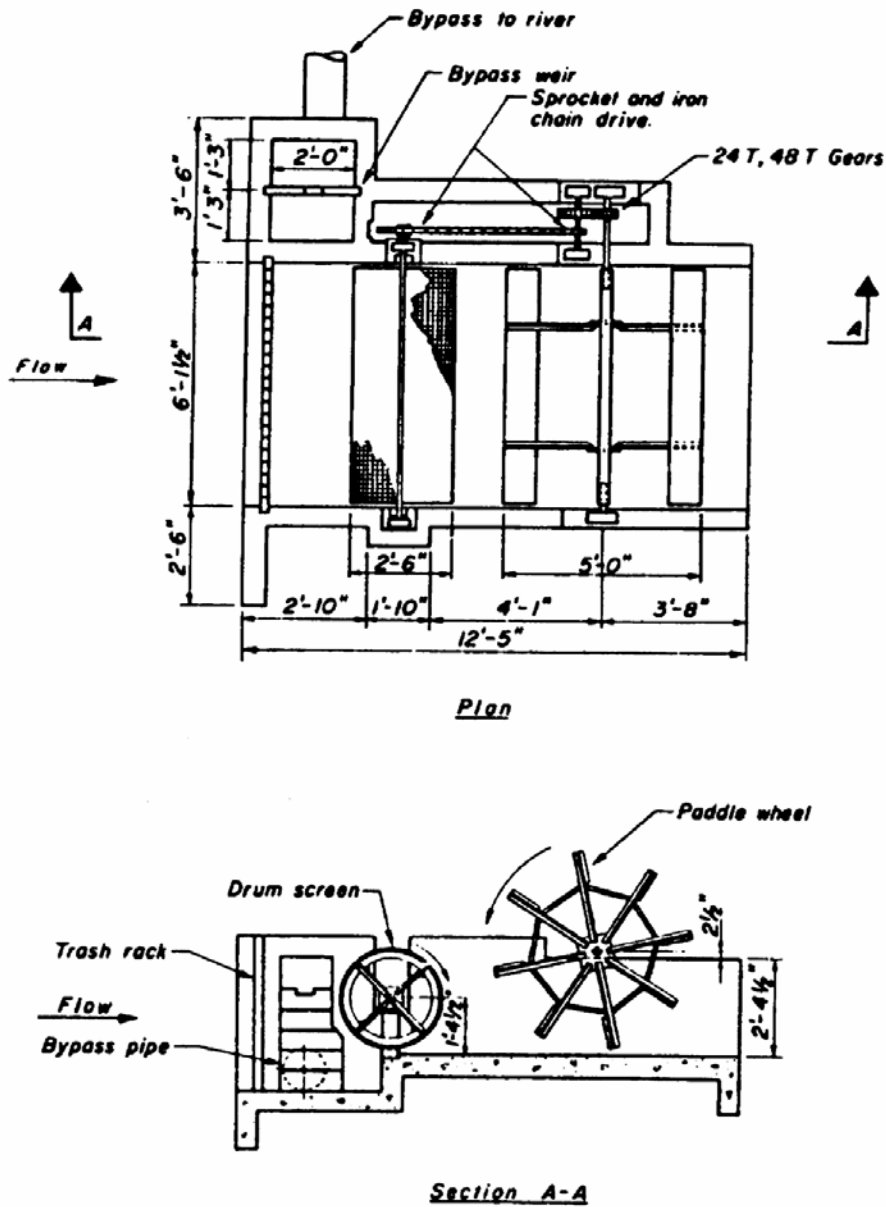
Typical Disadvantages

- Out of roundness or structural sag
- Large drum screens require considerable expenditure of time and money for maintenance
- May require costly and problematic maintenance of seals
- Contains mechanical and/or electrical parts which requires a high level of maintenance

- Fish passage may occur through faulty or worn seals or areas out of roundness where seals do not fit well
- Not designed to screen out small life stages
- Does not work well under ice conditions unless enclosed or heated
- Redundancy, fixed screen inserts, or blockouts are required for maintenance
- Small life forms can pass seals
- Sediment accumulation upstream or downstream

Application to Limiting Downstream Passage. The typically large mesh openings (>2 mm) and gaps at the rotating element seals eliminates this type of exclusion device from serious consideration for project objectives that include smaller life stages. In cold climates, the screens must be fully enclosed, again reducing this features applicability. In addition, the typical use in shallow water reduces their applicability to reservoirs or spillway approaches.

Figure 1-4. Example Drum Screen



(Source: Clay 1995)

1.3.5.2 Plate

Characteristics. This type of plate screen consists of a horizontal or vertical traveling screen. The vertical traveling screen contains a continuous belt of flexible screen mesh or separate small framed screen panels (baskets) connected to a continuous sprocket-drive chains on each side of the main screen frame (Figure 1-5). They were first designed to exclude debris from water intakes but were found to be effective in fish passage around turbine intakes. Most applications are electric powered. This type of screen can accommodate large forebay water surface fluctuations while maintaining desired hydraulic conditions for fish guidance. The basket can be used to guide fish to a bypass or for exclusion. The guidance design requires specific modifications to facilitate fish salvage.

Typical Existing Applications. The vertical traveling screen is most commonly used for applications where the intake channel is relatively deep. These screens are commonly used for diversions of approximately 100 to 500 cfs or more. Traveling screens have been used in the hydroelectric penstock intakes (Lower Monumental Dam) to screen only the top portion of the intake where juvenile salmon movement occurs.

Typical Advantages

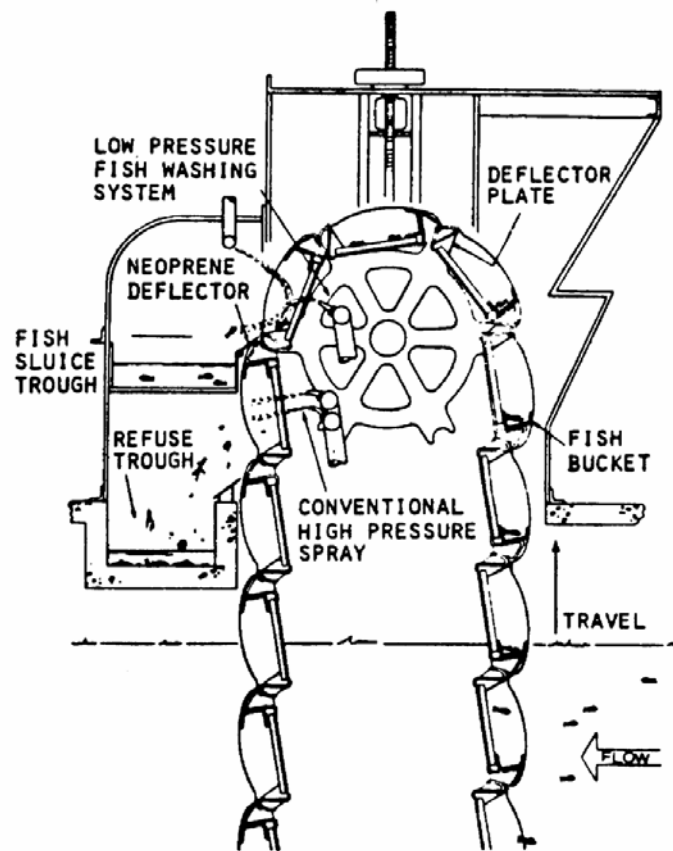
- Applicable to deep water submerged use
- Generally fish friendly
- High fish exclusion efficiency for target species and life stages

Typical Disadvantages

- Not recommended for fish that are easily injured
- Expensive to construct, install, operate, and maintain due to the many moving parts; especially when submerged
- Metal components wear under use and require high maintenance, newer materials (plastics) may reduce this cost but are untested in the field
- Requires costly ongoing maintenance of seals and gap tolerances between baskets
- Does not work well under ice conditions unless submerged, enclosed, or heated
- Fish passage may occur through faulty or worn seals or areas not screened
- Redundancy, fixed screen inserts or blockouts required for maintenance
- Not designed to screen out small life stages
- Small life forms can pass seals

Application to Limiting Downstream Passage. Has many of the same limitations as drum screens for downstream passage use, but with the advantage of use in a completely submerged condition.

Figure 1-5. Example Traveling Plate Screen



(Source: Clay 1995)

1.3.6 Low Velocity Screens - Fixed

1.3.6.1 Cylindrical

Characteristics. The cylindrical screen is a fixed screen consisting typically of a wedge-wire type mesh which was initially designed for liquid/solid separation, not fish exclusion. The screen can be attached directly to a pipe or multiple screens can be attached to a manifold or tower (Figure 1-6). Debris is flushed from the screen surface by a compressed air backwash system. Design screen approach velocities range from approximately 0.3 to 2 ft/sec and are distributed uniformly across the screen surface.

Typical Existing Applications. The cylindrical screen is most applicable to submerged pipe inlets for water supply systems. It has also been used successfully to exclude fish from entering the penstock at the Arbuckle Mountain Hydro Facility, near Redding, California.

Typical Advantages

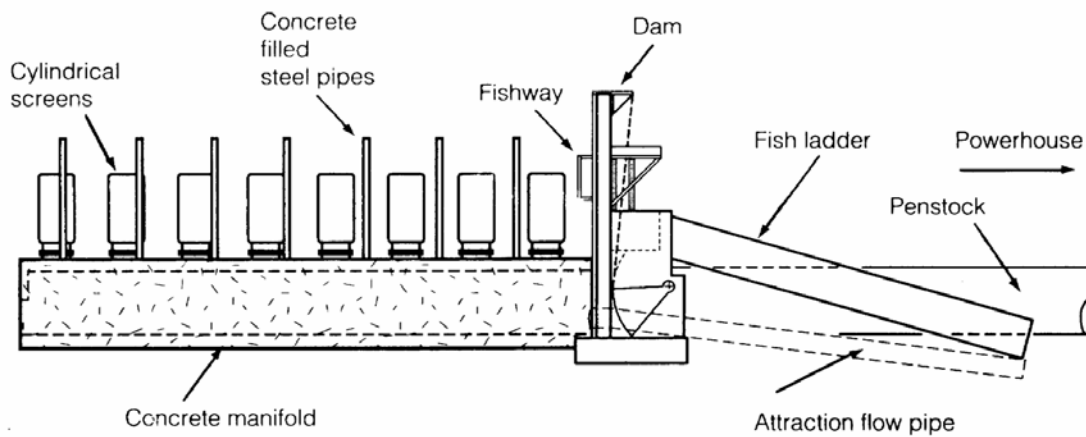
- Operates well under ice conditions
- No electrical or mechanical parts (except for the ancillary pneumatic cleaning system)
- Available with openings down to 0.5 mm to exclude organic materials as small as eggs and larvae
- Virtually no maintenance of screen required
- No debris handling is required
- Can operate at velocities up to 2 ft/sec and flows up to 500 cfs ±

Typical Disadvantages

- Not applicable to spillways
- Requires large screen area to flow ratio
- Not normally designed for flow rates >500 cfs
- Compressed air debris backwashing required
- Does have some depth limitations

Application to Limiting Downstream Passage. Excellent for low to medium flows through primary outlet pipes in submerged applications where flow can approach from almost any direction.

Figure 1-6. Example Fixed Cylindrical Screen



(Source: Francfort et al. 1994)

1.3.6.2 Plate

Characteristics. Fixed plate screens are very commonly used in a variety of applications. A fixed plate screen consists of a standard large size screen panel that may be mounted in several different configurations (Figure 1-7). Fixed plate screens can be either a vertical or near vertical wall of mesh in a straight line or a “V” plan configuration, or set at an incline (i.e., inclined screen) to direct fish upward or downward in the water column to a bypass. This category also includes conventional bar racks used for velocities up to 5 feet per second at waste or/water screening facilities. The inclined screen must have adequate control of the water surface elevation on the screen to assure that the downstream end does not become dewatered, which may in turn dewater the fish and debris bypass. The inclined screen also has problems establishing a uniform flow distribution over the length of the screen. In contrast, the vertical and “V” screen configuration can accommodate a range of flows and forebay water surface elevations with uniform flow over the screen surface (sometimes requiring baffles or vanes on either side of the screen) as long as debris is removed promptly. Mechanical brushing or backwashing is required for removing debris from all fixed plate screen configurations.

Typical Existing Applications. The fixed plate screen is commonly used to provide fish screening against turbine entrainment at hydro-power projects. They are especially prevalent in the northeastern and northwestern United States from the smallest flows up to 2,000 cfs. Most applications consist of a single bank of racks placed in front of the turbine intake or intake forebay at a 45 degree angle to flow. Many have been installed for debris exclusion at small hydro-power, water and wastewater projects, and have not been used as extensively for fish diversion. Notable examples were fixed plate screens that have been installed are the North Wasco Public Utility District Hydro Project at The Dalles Dam on the Columbia River, the Eugene Water and Electric Board’s Leaburg Hydro Project on the McKenzie River in Oregon, and the proposed large flow, small screen size (0.2 mm) facility at the McCluskey canal diversion in South Dakota.

Typical Advantages

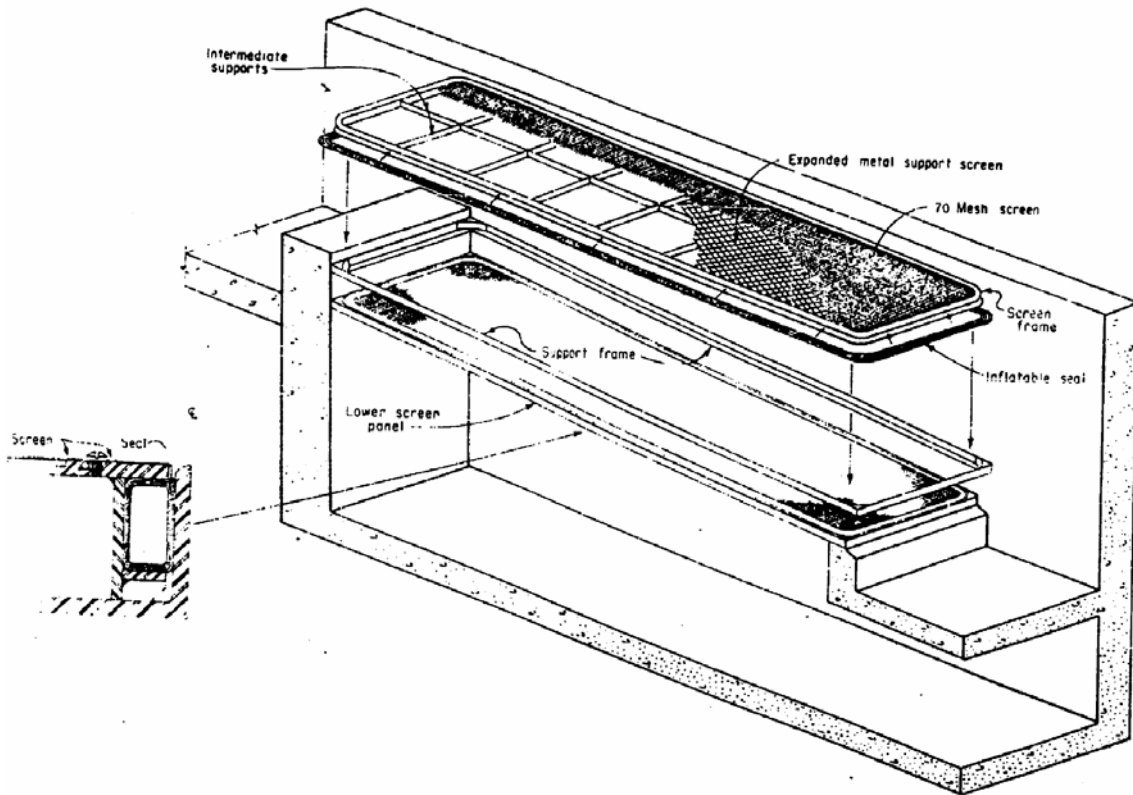
- Positive seals are easier to make with fixed or pneumatic seals
- Minimal seal maintenance is required
- Vertical plate screens can handle a large range of flows and fluctuations in forebay elevation
- The only demonstrated technique to screen down to egg size life forms at high flow rates

Typical Disadvantages

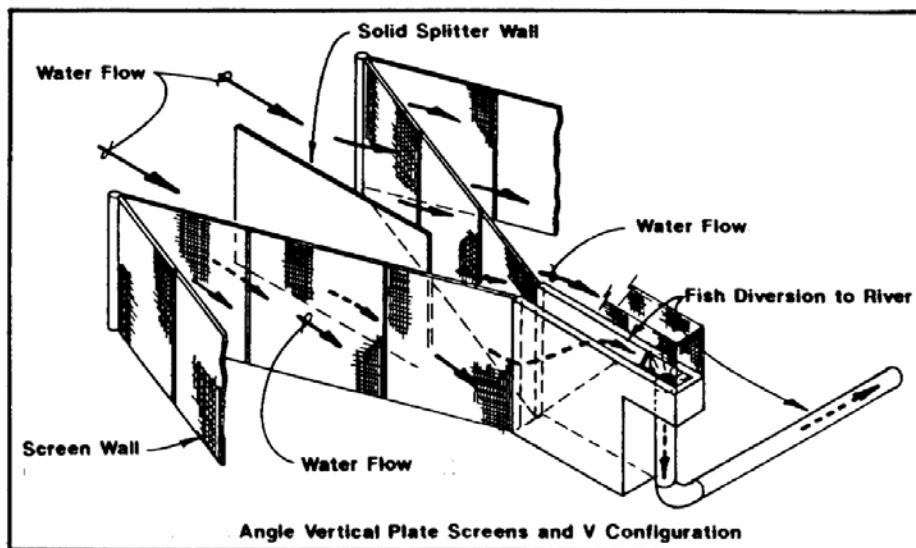
- Velocity variability across the screen as flow spatially varies
- Debris accumulation must be removed mechanically, except for the flat plate screen where debris is flushed off the end of the screen and must be handled for disposal
- Velocity hot spots may develop requiring the use of guide vanes
- Protection from icing needed in cold climates

Application to Limiting Downstream Passage. Fixed plate screens are not particularly applicable to limiting downstream passage from reservoirs. Normally reservoirs have a greater than 10-foot water depth approaching the dam, and shallower forebay areas tend to be limited in area and have high velocities. Outdoor screens in colder climates are subject to icing and frequent clogging by small debris.

Figure 1-7. Example Fixed Plate Screen



(Source: U.S. Bureau of Reclamation 1982)



(Source: Ott and Stansbury 1993)

1.3.6.3 Barrier Nets

Characteristics. A barrier net is composed of rope or synthetic twine that is woven into a mesh. The smallest mesh opening is 0.25 inches. The net must be installed far enough away from the intake to insure that velocities through the mesh are maintained well below 0.4 ft/sec. It is important that the percent open area be above 50 percent of the total area of the screen. This will improve the velocity and head loss through the screen significantly. The mesh size and material must be adapted to the fish species to be excluded, and the conditions of the lake or river such as temperature and current. Barrier nets can be mounted on existing trash racks or log booms at a water intake or can have their own structure. They usually must have floatation buoys at the top and heavy chains and anchors at the bottom (Figure 1-8). Fish may pass underneath the net since obtaining a positive seal between the lake bottom and net is difficult. Some applications have reduced fish passage by adding skirting to the bottom and/or top of the net. High wind, wave action, and submergence are a typical problem with barrier nets. In climates where ice develops the net must be removed or dropped to the bottom during the winter.

Typical Existing Applications. Barrier nets have been successful in excluding adult Chinook and Alewives from pump intakes at the Ludington Pumped Storage Plant located on Lake Michigan. They have been applied to hydroelectric intakes and on the approach to diversion canals in Wisconsin. They have also been used to exclude other creatures (turtles) from drowning at intake structures.

Typical Advantages

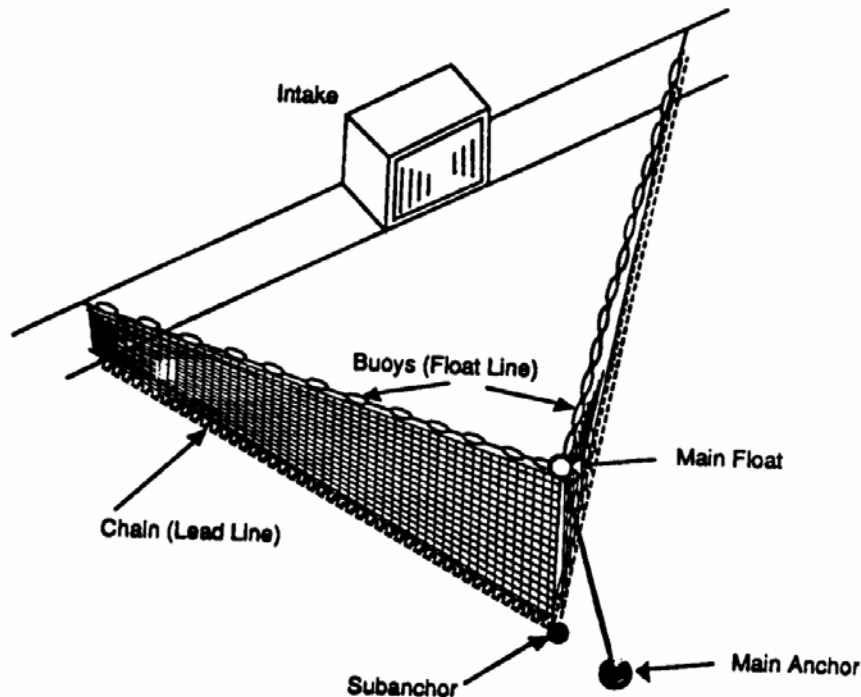
- Flexible to a variety of physical configurations
- Inexpensive to purchase and install
- No mechanical or electrical parts
- Flexibility to varying water surface level

Typical Disadvantages

- Difficult to maintain seal with lake bottom
- Cannot be used during winter due to icing
- High winds can damage the net
- Submergence can be a problem
- Required mechanical brushing and special coatings to prevent biofouling
- Smallest opening mesh typically available is 1/4-inch

Application to Limiting Downstream Passage. Flexibility and cost for the benefit gained are the primary attractive characteristics applied to downstream passage. It is the only barrier which is effective for depths greater than 20 feet. Nets are nicely applied to spillways as they can be out of service in the winter or whenever water is not going through a service spillway.

Figure 1-8. Example Barrier Net



(Source: Clay 1995)

1.3.7 Behavioral Barriers

1.3.7.1 Electrical

Characteristics. Electrical barriers require an electrical array either suspended in water or embedded in a concrete apron for functioning. These require high voltage AC current for operation and generally a back-up electrical source is used to have continuous operation. Electrical barriers are designed to elicit avoidance response from the species targeted. They require shallow water depth for successful deterrence and are species specific and life stage specific.

Typical Existing Applications. Electrical barriers have been used successfully to prevent upstream migration in the Pacific northwest, in the northeast, and in the upper Great Lakes region for deterrence of lampreys. Downstream facilities have been installed to prevent entrance into penstocks or sluice gates. The electric field used to direct fish to a bypass has resulted in mixed results in directing fish. The field has shown that it will fatigue fish under constant swimming and that those fish are entrained in the flow and then go downstream over the area desired to be prevented from movement. Electrical barriers, like all other behavioral devices, are considered experimental at this time and are not a standard application at downstream protection facilities.

Typical Advantages

- Successful in stopping upstream migrants
- Lower cost for construction than standard physical screen
- Useful in shallow canals or inlets
- Used at locations with lower flow volumes

Typical Disadvantages

- Response to electrical field is species and life stage specific
- Electrical barriers are not useful with passive life stages
- Electrical field fatigues fish which then become entrained in the flow
- Require multiple fields and multiple field strengths to deter a wide variety of size classes at one location
- Main disadvantage: In the current application, there is a danger to humans and large animals that would fall into the field and be subject to electrocution.

Application to Limiting Downstream Passage. Prevention of downstream passage has shown mixed results. The installation requires a shallow water depth and that it also is used usually in conjunction with other technology. They have been most successful in preventing upstream migration, not downstream migration. It also would require a secondary bypass once the fish are moved away from the spillway or outlet works. In previous applications, a DC electrical field has been used to stun the fish and move them into the bypass because of either stress or the inability of the fish to locate the bypass once they have been subject to the AC field for deterrence. This system could be used in conjunction with some other technology under the current projects but it is not as successful at preventing downstream migration as standard technologies.

1.3.7.2 Sound

Characteristics. Recent work on sound systems has focused on both high and low frequency systems. Sound systems consist of speaker arrays to distribute sound through the water and speakers generally are mounted in underwater locations. Speakers are usually located underwater to deploy either sound such as natural predators or pure tones. Frequencies vary at each application. Sounds customized to each specie's hearing abilities are shown to be the most effective. This requires considerable research and experimentation for each specie to be deterred at the installed location.

Typical Existing Applications. Sound systems have been experimentally evaluated in the northeast and midwest. Generally they consist of underwater speakers used at sluice gates such as the application that was investigated at Allegheny Reservoir, Pennsylvania. In this application, percussion type sounds were used at sluiceways. No change in fish passage through the sluices was noted during the experimentation. The target species at this location was walleye. Installation of a system at Racine Hydroelectric Plant on the Ohio River showed deterrence of 70% of the basses and catfish present at the intakes area of the hydroelectric plant. This system was a low frequency, high amplitude sound produced by a submerged generator.

Typical Advantages

- Generally inexpensive
- Can be retrofitted to a wide range of applications

Typical Disadvantages

- Results are mixed; many locations and sounds are generally not effective
- Species specific response has been noted in experimentation
- Species become habituated to the sound source and are no longer deterred

Application to Limiting Downstream Passage. Sound systems are generally shown not to be effective in deterring 100% of the fish or high percentages of the fish at the installed locations. The criteria for this study is a high deterrence of downstream migrating fish, 90% or higher. None of the installed locations or previous experimental sound systems were shown to be that high. This system would not be applicable alone as a deterrent at either of the facilities under investigation.

1.3.7.3 Lights

Characteristics. Lights are generally used to deter fish from entering intakes or attract them to bypass areas. Strobe lights are generally used as deterrents and mercury vapor lights are used to attract fish. Strobe lights are mounted in front of the facility facing upstream and are turned on to deter fish from those areas used in conjunction with mercury vapor lamps that are set near the bypass opening to attract fish to that opening area. Tests show that deterrence was successful for extended periods of time with strobe lights on American Shad, although they were unsuccessful in daylight at some locations tested. These mixed results, like other behavioral devices, still keep lights in the experimental category.

Typical Existing Applications. Strobe lights or mercury vapor lights have mainly been installed and tested at facilities in the northeast and used for outmigrating American Shad. Strobes are installed generally on float systems upstream of the dams or canal intakes and mercury vapor lights have been installed at either the bypass systems which include a standard bypass or the sluice gates at the installed facilities. Results have been mixed at these installations. At the Susquehanna River, the strobe light and mercury light combination successfully guided fish away from the trash racks at the spillway and over to the sluice gate area where the fish were moved around the dam. At the Hadley Falls application in the northeast, the fish were not deterred from the canal area that they were trying to be directed away from. In that test, the fish were observed swimming just a few inches away from the strobe lights that were continually functioning. Laboratory studies at the University of Washington have shown that other salmonid species, particularly chinook, coho and Atlantic salmon, did avoid the strobe lights. Steelhead trout, however, did not avoid strobes.

Typical Advantages

- Light systems are relatively inexpensive
- Light systems have been demonstrated effective for warm water species
- Light systems can be easily retrofitted
- Light systems have potential for enhancing other fish protection systems

Typical Disadvantages

- Effectiveness for repelling salmonids is unknown; data is needed for those species
- There have been design and operational problems with experimental underwater strobe systems
- The field testing to date has been limited so that success is unknown

Application to Limiting Downstream Passage. Light systems are generally used to either deter fish from a spillway or intake area or direct them toward a bypass area. In both applications on this project, that would require fish handling if the fish are directed to a fish bypass area. In addition, several species have been shown not to be affected by the light systems and the light systems currently have limited application in daylight hours. This would effectively not deter fish at all times as the criteria for this project are designed.

1.3.7.4 Louvers

Characteristics. Louvers consist of a series of vertical parallel bars spaced from 1 to 12 inches apart and the entire structure angled to flow across the entire channel. This physical device relies on the fish's behavioral response to flow turbulence. The fish approach the louver system tail first, sense the turbulence created by the louvers and move laterally away from the device. This movement directs them to the bypass area.

Typical Existing Application. Louvers have been installed on both the east and west coast rivers. Installed facilities include canals with widths up to 145 feet and maximum capacity of 7,000 cfs. Guidance efficiency ranged up to 87% of downstream migrants in some applications for actively swimming life stages. In general, guidance efficiency was less than 80%. Louvers did not effectively guide smaller life stages and are not effective on passive life stages.

Typical Advantages

- Louvers are adequately tested
- Louvers can be retrofitted in many designs

Typical Disadvantages

- Diversion efficiency lower than agency standards in some applications
- Louvers are size and species specific as far as guidance efficiency
- Potential problems due to clogging arise at some locations
- Louvers are relatively expensive
- Louvers require diversion of the fish and fish handling
- Large openings do not exclude fish

Application to Limiting Downstream Passage. Louvers are designed to guide actively swimming life stages. The current project includes potential escapement of passive life stages exiting the reservoirs. The effectiveness of louvers on passive life stages and the relatively low efficiency (less than 80%) preclude the use of this control option at the subject reservoirs.

1.3.8 Other Control Techniques

1.3.8.1 Management Options

Management of reservoir levels can be an effective technique for escapement control. In most western states and most water storage projects in those states, water is a valuable commodity and proposed changes in water level manipulation may have an impact on water supply and/or water cost which must be considered as an escapement prevention cost. For instance, a restructured winter water level which reduces storage may not adversely impact water for agriculture as long as it can be restored by spring runoff, but may impact water needed for municipal/industrial consumption, the monetary values of which may differ.

Management techniques which have potential application are highly dependent on the individual dam/reservoir purpose and physical facilities. A variety of physical management techniques have been used with different levels of success, including:

1. Low level, cold water release from the part of a reservoir where target fish are least likely to be present; this may involve building larger primary outlet works.
2. Restrict maximum normal operating level to below the lip of the service spillway, passing all routine flow through the more controlled primary outlet; this reduces spillway screening requirements; this may involve building larger primary outlet works.
3. Establish and implement outlet release operating rules (versus unselected default flow releases) which minimize spills.
4. Completely dry up stream below dam; divert all released flow off stream for fish handling flow, screening infiltration, etc. before returning to stream, causing splash and minor flow passage to fall into a non-viable aquatic environment; this is probably not a suitable ecologic alternative for the subject applications.
5. Periodic drawdowns of water surface to route maximum flow volume through primary outlet and to control fish (concentrate them for inventory, sorting, and/or removal); leave spawning areas dry (keep spawning areas inaccessible, etc.); and establish controlled ecologic conditions (temperature, dissolved oxygen, and thermocline).

Fishery management in the reservoir and stream can also be effective, including:

1. Manage for non-competing warm water fish. Non-competing fish, in terms of endangered species in the system, would be fish species that prefer lakes and reservoirs rather than riverine environments. This list of species includes largemouth bass, bluegills and some crappie. Species that would compete and are known to exist in the rivers are smallmouth bass and channel catfish. Fish management should avoid the latter two species to avoid competition if there is escapement. Largemouth bass can provide an alternative to smallmouth bass for sport fishing and will not do well in the river systems. Adults may persist but there is little evidence of any reproduction and recruitment for largemouth bass in the rivers. Similarly, bluegill seem to do well in the lakes but do not persist in the downstream environments once they leave the lakes.
2. In conjunction with reservoir operations, timing of draw downs to reduce spawning success of competitive species may also be an option. This could include dewatering spawning areas immediately after nests are built and eggs are deposited to reduce the spawning success and habitat availability. These fluctuations can lower spawning success and lower the amount of recruitment to the in reservoir population. However, timing drawdowns to be effective can be difficult.
3. Management of non-natives by harvest could be used in the stream and the reservoir for removal of non-natives. This option, though, would not result in 100% removal and there would still be non-native fish that persist. Mechanical removal has been used in several areas but there is not enough data to show what impact removal of non-natives has on those populations.

1.3.8.2 Other Structures Found But Not Directly Applicable

In the process of the literature review and interviews, a number of passage exclusion structures were identified which were either too experimental, non-applicable, impractical, or for which too little information exists. They deserve some mention herein for comprehensiveness and for reference.

1. Granular filters: Filtering through granular berms or beds; similar to rapid sand filters of water and wastewater filtering systems.
2. Resistance board weir: A downstream sloping weir fixed at the bottom, angling up and held up by the resistance of a surface resistance board; primarily used to prevent adult fish (salmon) from moving upstream, but could be applied similarly to a net in a spillway approach area.
3. Hanging fingers: Rods hung from above into a fixed, partly submerged bar rack keeps adult fish from passing up- and downstream, but allows debris to occasionally flush through by pushing fingers downstream, with the fingers falling back to their original position.
4. Hanging chains: Similar to hanging fingers, but hung from a surface superstructure to the waterway bottom or a pre-selected depth.

1.3.8.3 Other Behavioral Techniques Found But Not Directly Applicable

Other behavioral barriers exist which can restrict (repel), attract away, or direct movement away. These are mostly experimental, highly or variably selective or most effective in combination with other behavioral or physical barriers. Some include:

1. Temperature curtains: Impermeable geotextile material suspended from surface flotation devices to block the flow of warm water to outlet structures, thereby excluding warm water fish. A natural variation of a temperature curtain is to simply place the outlet very deep (>100 feet deep).
2. Vibration: Indirect or secondary (trash rack vibration induced by flow) or intentional, artificially generated pressure waves sensed by a fishes inner ear or lateral line can trigger an avoidance reaction.
3. Entrained and bubble curtains: Natural (turbulent flow air entrainment) or artificial (diffused air bubbles) creates a visual barrier. Some fish are attracted to bubble areas, but don't pass. Possible need to keep open, still water on both sides of curtain.
4. Turbidity/optical dispersion curtain: A visual barrier of refracted light (light noise).
5. Turbulence: Water jets directed up from the bottom by pumps to create water shear boundary layer avoided by fish.
6. Combinations: Combinations of physical and behavioral barriers can provide very effective movement restrictions; for example, it was discovered somewhat by accident that high velocities through a bar rack screen can cause screen vibrations and turbulence that acts as a behavioral barrier and results in higher fish exclusion than can be achieved by the bar rack alone.

1.3.9 Examples of Other Downstream Passage Limitation Projects

1.3.9.1 Introduction

Surprisingly little information exists on the subject of intentionally restricting or prohibiting fish movement from within a waterway or from one waterway to another in order to limit species conflicts. Most of the information which exists addresses maximizing the efficiency and effectiveness of passage and minimizing the mortality. While much of the information from the later objective can be applied to restricting downstream movement (e.g., excluding fish from diversions

and hydroelectric power intakes) there is a basic difference which makes restricting fish movement inherently more difficult. Minimizing mortality is directed at adult and juvenile fish of economic or sport value and a survival or passage rate of greater than 80 percent is considered acceptable. However, fish passage restriction to separate species must be essentially 100% and cover all life forms because only a small escapement could enable potential reproduction downstream to population levels which would perpetuate the species conflicts. For this reason, it is important to consider those projects where an effort has been made to benevolently keep species separate with 100 percent success and/or cause 100 percent mortality of passed fish. There are no projects we are aware of where species separation via downstream movement restriction has been attempted within a naturally connected drainageway. However, there are two good examples of projects which involve restrictions of fish movement between historically separated drainage courses.

Naturally, disconnected drainages normally require an anthropogenic act to connect them; therefore, the focus of any effort to keep species separate is simply whatever means (canal, pumping station, etc.) is employed to connect the drainages. Such is the situation with the following two examples.

1.3.9.2 McCluskey Canal

The McCluskey Canal is one component of the Garrison Diversion Unit (GDU) located in North Dakota. GDU is one of the developments in the Pick-Sloan Missouri Basin Program authorized by the Flood Control Act of 1944. Benefits of GDU include irrigation development, fish and wildlife conservation and enhancement, recreation development, water supply for municipal and industrial purposes, and flood control. GDU is comprised of the Snake Creek Pumping Plant, Audubon Lake, the McCluskey Canal, and Lonetree Reservoir. The system operates by pumping Missouri River water from Lake Sakakawea (formed by Garrison Dam) by the Snake Creek Pumping Plant into Audubon Lake which is a subimpoundment of Lake Sakakawea. Audubon Lake is the supply reservoir for the 74-mile long McCluskey Canal, which flows by gravity into Lonetree Reservoir. As initially proposed, water from Lonetree Reservoir would be diverted into project areas in several basins. A few of these basins drain into the Hudson Bay drainage. The Missouri River Basin and Hudson Bay drainage are separate systems; therefore, construction of GDU would allow Missouri River water to eventually flow into Canada via the Hudson Bay drainage. During planning and early construction phases, several government and private agencies in Manitoba, Canada were concerned that the diversion of Missouri River water would transfer undesirable fish species, fish disease, and fish parasites into the Hudson Bay drainage. It was believed that this would have adverse impacts on sport and commercial fisheries in Manitoba, including (1) direct competition with native fish, (2) population eruptions of the introduced fish, (3) reduction in populations of native fish in Lake Winnipeg and other waters, and (4) predation by the introduced species on native fish. The U.S. Bureau of Reclamation (USBR) decided to develop a fish control system that would prevent any (100 percent efficiency) downstream migration of adult fish, fish larvae, and fish eggs, because all life stages of undesirable fish species would be present during some part of the project operating season and they could not be controlled discriminately. The basic criteria were that the fish control system must be capable of handling the maximum canal discharge of 1,950 cfs and not be cost prohibitive.

A fixed horizontal screen sloping slightly downward was chosen as the best available technology. Prior to this application, fixed horizontal screens had not been used to filter fish larvae or eggs. Most applications were used to filter weed seeds from irrigation water, collect water biological samples from a small stream, and filter industrial intake water. Most systems were small with capacities of less than 100 cfs. Because of the uniqueness of the McCluskey Canal screening concept in both design capacity and efficiency, a long-term costly testing program was implemented. Both laboratory

and field testing were conducted on all aspects of the concept, from design to operation and maintenance.

The proposed McCluskey Canal fish screen facility was designed to handle 1,000 cfs with a modular design which was divided into 6 bays of which 4 would be operational, while 2 remained available for standby. Each bay would be subdivided into 14 subbays that could be operated independently. One subbay would contain 4 upper and 4 lower screen panels. The total facility would contain 84 subbays with a total of 672 screen panels. The proposed indoor facility, including shop and personnel areas, would cover more than 2.5 acres. Following is a discussion of the major components of the facilities in the order that they are encountered in the system.

Coarse debris would be removed by trash racks placed at the entrance to the screening facility that would have a 1-1/2 inch bar space opening. Debris would be removed from the upstream face of the trashracks by a mechanical trash rake. A conveyor would transfer the debris to a disposal bin for temporary storage. Flow into each bay of the facility would be controlled by a rapid-closing, top sealing radial gate. Adjustable blade weirs would be used to control flow into each subbay, while stop logs would be used to shut off the flow completely. Screened water follows the outlet channels located underneath the screen panels back to the main McCluskey canal. Each subbay would contain four upper and four lower 3- by 12-foot, 70-mesh (0.198 mm), screen panels. The lower panels provided a backup system in case the top screens or seals are damaged. The screens were set at a 5° downslope in the field test facility based on laboratory tests which indicated this slope would be optimum for both self cleaning and hydraulic efficiency. In the laboratory, as the screen slope was increased, self cleaning action improved as a result of the water velocities increasing across the screen surface. This is desirable for self cleaning, but requires a much longer screen to pass the design flow. Water-activated cleaning methods would be needed rather than mechanical which could damage the screen. During field testing, other slopes and design flow rates were evaluated. Increasing the flow from the design flow of 6 cfs per lineal foot of weir for the test facility to 20 cfs per lineal foot and decreasing the slope from 5° to 2°, resulted in a reduction of backwashing frequency by one-half. The design flow rate for the screening facility would be 1.5 cfs per lineal foot of weir as opposed to 6 cfs per lineal foot for the test facility.

A traveling screen was installed at the test facility to determine if prescreening would remove the plankton load that in turn would allow a higher flow rate through the sloping screens. It was not found to be beneficial during testing, but provisions were recommended in the facility design to install a traveling prescreen if the situation was justified.

All screened material and water that would flow off the end of the screen would be collected in a sump. Water and the screened material would be pumped to vibrating screens that would remove excess water from the screened material. The vibrating screen proved to be an effective relatively maintenance free, device to remove excess water from the screened material. The screened material would then be pumped to a lagoon system. The lagoon system would need to contain enough cells to allow drying and sludge removal. Total lagoon area would be approximately 30 to 40 acres to handle the design flow. The facility would need to be heated and ventilated, and equipped within engine generator to provide emergency standby power.

The total construction cost for the screening facility was estimated to be \$40,000,000 in 1981 dollars. As many as thirty full-time employees could possibly be needed to operate the facility with a total yearly operating budget of \$1,300,000.

1.3.9.3 Havasu Pump Plant

The Havasu Pumping Plant (HPP) is located adjacent to Lake Havasu approximately 20 miles northeast of Parker, Arizona in Yuma County. HPP delivers water from Lake Havasu into the 335 mile canal system of the Central Arizona Project (CAP). The CAP was authorized in 1968 to deliver water from the Colorado River, via Lake Havasu, to central and southern Arizona for agricultural, municipal, and industrial purposes. HPP is designed to pump a maximum of 3,000 cfs. Water deliveries consistently increased from approximately 108,000 to 900,000 acre-feet during 1986 through 1990 with most of the water being pumped from March through September. Lake Pleasant is an off-canal storage reservoir on the Agua Fria River approximately 150 miles downstream of HPP. Lake Pleasant was enlarged in 1993 allowing for more storage of canal waters delivered through HPP for the CAP.. The majority of water diverted at HPP is now during the winter months. This water is stored in Lake Pleasant and released to CAP during the summer months.

The potential introduction and colonization of non-native fish species into the CAP, and subsequently into natural Arizona water, have been a concern since the initiation of pumping at HPP. Non-native fish species are considered a threat to native species in several of the Arizona river systems that are part of the CAP. Even though fish mortalities will occur at HPP, some fish will survive and be transported to the lower portions of the Salt and Verde Rivers. Studies have determined that approximately 17 species of non-native fish have colonized extensively in the CAP. Large non-native fish have been found in the canal directly downstream of HPP which would indicate that all life stages could be entrained. Several studies were conducted to estimate the number of eggs and larvae that might be entrained at HPP. These studies estimated entrainment rates of approximately 3 million larvae per 10 pumping hours and 0.08 eggs per cubic meter.

Several screening options were studied to limit the introduction of non-native fish species into the CAP system. Five fish screening/barrier alternatives were developed at a conceptual level for the HPP. The five alternatives are as follows:

- Fish Screens Upstream of HPP with Fish Bypass.
- Fish Screens Mounted to Existing Trashracks Located Upstream of HPP with no Fish Bypass.
- Fish Screens Downstream of HPP with Fish Destruction.
- Electrical Barrier Downstream of HPP with Fish Destruction.
- Combination of Fish Screen Upstream of HPP with Electrical Barrier Downstream of HPP.

The first option provides screening of fish before they enter the HPP and bypasses them as safely as possible back to Lake Havasu. This would reduce the mortality of fish now being experienced by entrainment in the pumps. Screening options consisted of, (1) vertical wedgewire screens in either a linear or "V" configuration (or multiple "V"), (2) horizontal rotating drum screens, or (3) modular incline screens. The cost estimate and design criteria were based on the vertical wedgewire screen option using a 2.4 mm slot width, which is not intended to remove small or passive life forms. Smaller slots could be installed depending on the efficiency of the cleaning system. The screens would be installed in the HPP intake channel or in the inlet transition channel. Archimedes Screw or Internal Helical Pumps would bypass the fish back to Lake Havasu. This option would require trashracks, wedgewire screens, baffles, screen cleaning machinery, structures and supports, bypass pipes and/or channels, and the bypass pumps. The major cost items and assumptions are included in Table 1-3.

Table 1-3. Cost of Screening HPP at the Inlet

Item	Cost (\$)
Mobilization (5%)	1,050,000
Fish Screen Structure (Civil)	9,000,000
Pump-bypass Structure (Civil)	1,500,000
Fish Bypass Pipeline & Outfall	2,000,000
Cofferdams, Dewatering	3,000,000
Trashracks	500,000
Fish Screens	2,500,000
Baffles	2,000,000
Screen Cleaners	350,000
Bypass Pumps	1,100,000
Subtotal	23,000,000
Unlisted Items (10%)	2,000,000
Contract Cost	25,000,000
Contingency (25%)	6,000,000
Field Cost	31,000,000

The second option would restrict fish from entering the HPP by mounting screens directly on the existing trashracks. This option would require installing the wedgewire screens on the trashracks and providing a trash rake and conveyor system to handle debris accumulation. Debris would need to be elevated and dumped into a debris pit or hauled off site. The slot opening size recommended was 2.4 mm. This would not eliminate entrainment of small life forms. A fish bypass would not be required. The major cost items and assumptions are listed in Table 1-4.

Table 1-4. Cost of Screens Installed on HPP Trashracks

Item	Cost (\$)
Mobilization (5%)	40,000
Fish Screens	420,000
Trash Rake	210,000
Conveyor	120,000
Subtotal	790,000
Unlisted Items (10%)	80,000
Contract Cost	870,000
Contingency (25%)	230,000
Field Cost	1,100,000

The third option would place the fish screens on the discharge side of HPP just downstream of the Buckskin Mountains Tunnel. The fish screens would create a barrier to live fish that have passed HPP and concentrate them into a bypass channel where they will be killed or separated from the flow. Fish will either be comminuted, electrocuted, or pumped with the debris to the desert or to a separator structure. The water from the separator structure would be pumped back into the canal. The separated fish and debris would need to be handled. Screens that could be used at this location in the canal include, (1) vertical wedgewire screens in either a linear or “V” configuration (or multiple “V”), (2) horizontal rotating drum screens, (3) traveling screens, or (4) modular incline screens. Screen opening size has not been determined, but the intent is not to exclude small or passive life forms. Assuming that vertical wedgewire screens were chosen, this option would require installing the screens, baffles, screen cleaners, comminutors or electric barriers, structures to support the screens and comminutors, and a bypass pipe and/or channel. The major cost items and assumptions are included in Table 1-5.

Table 1-5. Cost of Screens on the Discharge Side of HPP

Item	Cost (\$)
Mobilization (5%)	400,000
Fish Screen Structure (Civil)	6,000,000
Fish Screens	800,000
Baffles	700,000
Screen Cleaners	150,000
Grinders	150,000
Subtotal	8,200,000
Unlisted Items (10%)	800,000
Contract Cost	9,000,000
Contingency (25%)	2,000,000
Field Cost	11,000,000

The fourth option would destroy by electrocution all species, sizes, and life stages (including eggs and larvae) that have bypassed the HPP. The electric barrier would be installed somewhere in the discharge pipe. Experience dictates that it would require approximately 500 microwatts/cm³ to assure destruction of all life forms. Total electric power required is calculated based on the distance over which the power would need to be applied given the 3,000 cfs design flow. For this application, the total power needed would be approximately 13 kW. Electrocuted fish would wash down the canal with debris and would be allowed to decompose in the canal system. There were no costs estimated for this option.

The final option is a combination of a fish screen facility and an electric barrier. This option would save the larger life forms from destruction but would destroy all life forms that bypass HPP. A larger screen opening would be used to exclude large fish from entrainment. The screen could be installed in the intake channel or on the trashracks. No fish bypass would be necessary.

Several other options were studied, but not recommended for consideration. These included barrier nets, underwater sound and/or lights, hanging chains, induced gas bubble disease in the Buckskin Tunnel, predator enhancement in the first reach of the Hayden-Rhodes Aqueduct, and placing fish screens/barriers in the aqueduct at an alternate location.

The two alternatives, of the five that were considered, that could possibly exclude all life stages from the CAP, was the electric barrier placed in the discharge pipe, or the combination of the electric barrier and the placement of a screen upstream of HPP.

1.4 Conclusion

It can be concluded from the two preceding example projects which have close control over water flow rates that species separation with 100 percent certainty is not possible and that even at the very high rates of exclusion achieved, the costs involved are prohibitive. This is demonstrated by the fact that neither of these very restrictive fish passage limitation projects have been implemented. The feasibility of restructuring downstream passage within a natural drainage basin where flow rates are not easily controlled and where a natural connection exists or existed, is even less achievable.

This project has several features which make the selection of feasible control options unique. The current technology includes both physical and behavioral techniques to control fish passage. In this case, the behavioral techniques will not stop the passive life stages that may be present and are only marginally effective on controlling active life stages. For these reasons, behavioral techniques were not considered feasible control options at either Elkhead or Highline reservoirs.

Physical control devices include several types of screening devices. Since the objective of this study is to control escapement, the best location for controlling the fish is within the reservoir. Any device placed downstream of the reservoir would require construction of a stream channel and physical screening facility large enough to protect to the maximum flow event. Further, the facility would need to be designed to function at the current industry standard for the full range of flows. The wide range of flows from flood flows to near zero would be very difficult to protect with one facility. This may require one facility designed to work at high flows and another to work at the low flows. Further, any fish that get to the downstream facility are already moving toward habitat occupied by the endangered fish species. Any facility downstream of the reservoirs also would require a fish bypass or collection facility and some type of fish handling or disposal. All of these factors eliminate the downstream location as a feasible option.

Physical facilities designed for in-reservoir control include both high velocity and low velocity screens. Both the high and low velocity screens constructed in the reservoir would have to be designed to operate for the full range of flow conditions.

High velocity screens include Eicher and Modular Inclined Screens. Both of these screen types are intended for use within a reservoir outlet or penstock and both require fish bypass. To meet the criteria set for this study, the reservoir outlets would have to be reconstructed to a size that would pass all flow up to the 100 year event and include the screen. The fish bypass would require a fish collection facility that could retain any bypassed fish for either disposal or transport back to the reservoir. This would require additional operation and maintenance funds for the life of the project. This additional cost in excess of the capital cost for reconstruction of the outlet works and requirement for fish handling makes these screen types lower priority for selection than types that have no fish bypass or fish handling.

Low velocity screens include traveling and fixed screen types. The traveling screens all require considerable operation and maintenance costs. In addition, there is a possibility that escapement can occur as screen seals wear. The gap between the screen and the seal could exceed the 3/32 inch opening for the criteria for this project. This would not meet the exclusion criteria for the project. The traveling low velocity screens would require a large screen face relative to the flow rate ratio and do not work in a submerged location. The large size would require considerable capital cost for construction of the civil works associated with these types of screen and high annual operation and maintenance costs. Therefore, traveling screens were not selected for further evaluation in this project.

Fixed screens are generally designed for low approach velocities to eliminate fish impingement. Most fixed low velocity screens have a traveling brush to clean the screen face of debris. Any such mechanical device requires additional maintenance over a non-mechanical system. Therefore, fixed screens that can be installed in a submerged location without mechanical cleaning were rated as the best potential device for this project.

The two objectives for this project require two different screen evaluations, one that prevents escapement of all life stages and the second that protects to the current industry standard. In this project, impingement was deemed an acceptable consequence of in-reservoir protection. This allowed the evaluation of higher velocity (2 feet/second) fixed screens in this project for both objectives. In addition, for the protection to current industry standards option, a secondary protection mechanism was evaluated in each reservoir in addition to the fixed screens to protect at high flow events.

2. PROJECT DESCRIPTIONS

2.1 Elkhead

2.1.1 Physical Configuration of Reservoir and Outlet

Elkhead Dam and Reservoir is located approximately 10 miles northeast of the City of Craig, Colorado, and straddles the Moffat/Routt County Line as shown on the basin map in Figure 2-1. The dam is located in Section 16, Township 7 North, Range 89 West of the 6th Principal Meridian on Elkhead Creek, a tributary of the Yampa River, and three miles upstream of the confluence. The 205 square mile drainage basin consists of approximately 50 percent rural farming/ranching lands and 50 percent undeveloped public lands. The headwaters are located in a National Forest at elevations exceeding 10,000 feet. Its major tributaries are Dry Fork Elkhead Creek and North Fork Elkhead Creek and there are no transbasin connections.

Originally, Elkhead Dam and Reservoir were conceived around 1970 as the primary features of a recreation and wildlife area and the project was scheduled for construction in 1972. At about the same time, the Craig generating station was in the development stage and the need for a backup cooling water supply had been identified. On the basis of these common interests, the originally proposed 5,000 acre-foot reservoir was enlarged to 13,700 acre-feet. The dam and reservoir were subsequently designed and constructed to this larger size in 1974.

Ownership of all facilities and land, and operational responsibility was with the Colorado Division of Wildlife (CDOW). Basic physical characteristics of the dam/reservoir as originally constructed are presented in Table 2-1 and shown on Figure 2-2. Interim sedimentation has reduced this 13,700 acre-foot original storage volume to an estimated 13,000 acre-feet. Otherwise the dam/reservoir remains in the condition as originally designed/constructed.



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Figure 2-1

ELKHEAD DAM/RESERVOIR GENERAL LOCATION

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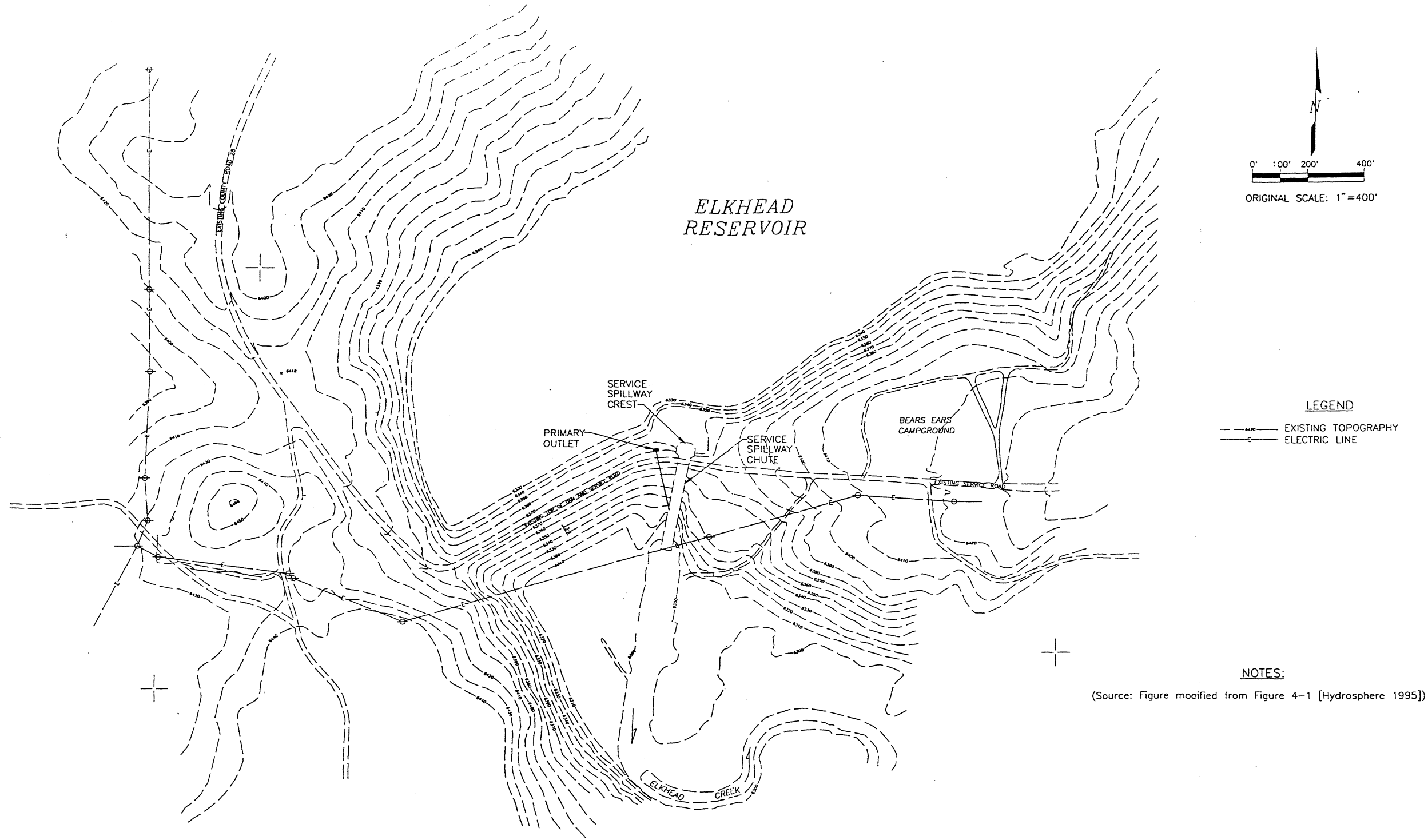


Figure 2-2

GENERAL PLAN OF ELKHEAD DAM AREA

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Table 2-1. Existing Elkhead Dam/Reservoir Characteristics

Inventory of Dams I.D. Number	CO 00976
State of Colorado I.D. Number	C-1339A
Elevations/Capacities	
Crest	6,375 feet
Service Spillway Crest/Normal Maximum W.S.	6,365 feet
Primary Outlet, Intake Invert	6,333 feet
Primary Outlet, Outlet Invert	6,316 feet
Channel at Downstream End of Stilling Basin	6,295 feet
Reservoir Capacity at Normal Maximum W.S.	13,700 acre-feet
Service Spillway Capacity at Crest of Dam	17,000 cfs
Primary Outlet Capacity at Crest of Dam	180 cfs
Primary Features/Dimensions	
<ul style="list-style-type: none"> • 1,160-foot long homogeneous earthfill embankment with chimney drain • 315-foot long 36-inch RCP primary outlet pipe; operated by a hydraulically controlled sluice gate • 135-foot ogee “duckbill or bathtub” shaped service spillway crest with a 40-foot wide spillway chute • 40-foot wide USBR Type III Stilling Basin • 20-foot wide county road on crest 	

2.1.2 Hydrology

The operational and flood hydrology of Elkhead Creek drainage area upstream has been extensively studied as part of the dam/reservoir original construction (ECI 1974); dam safety evaluations (USACOE 1980), (CDOW 1984), (HARZA 1991), and (Ayres 1996a and b); and enlargement and modification studies (MK 1985 a and b), (MK 1986), (MK 1987), (Hydrosphere 1993), and (Hydrosphere 1995).

Annual operational hydrology is dominated by snowmelt runoff during April through June when approximately 90 percent of the annual 20,000-100,000 acre-feet of water occurs as inflow to the reservoir. Part of that annual yield is allocated to storage at Elkhead Reservoir including; 8,310 acre-feet to the Craig Power Plant for standby cooling water and 5,390 acre-feet (including 3,722 acre-feet of dead storage) to CDOW and the City of Craig for recreation and water supply. Rainfall also occurs during this period giving the hydrology a mixed event characteristic. Rainfall is potentially more dominant during the mid-summer through early fall in the form of rare, short duration intense thunderstorms. The theoretically greatest flood [probable maximum flood (PMF)] is projected to be associated with this late summer period. The original dam safety evaluation (USACOE 1980) identified several minor safety issues which needed to be addressed and a hydraulically inadequate spillway as a safety issue. Resolution of these safety issues has been considered integrally with the several dam/reservoir enlargement proposals previously referenced and that activity continues to the present time (Ayres 1996a and b). The PMF is not further addressed herein because of its non-applicability to the current subject. Nor will the focus be on mean annual or more frequent events as these represent flows lower than the desired protection level.

Flood hydrology, or the occurrence of larger (in volume and rate of flow) flows more infrequently than occurs during an average year, up to and including the 100-year flood, is the hydrologic characteristic of most interest. These more frequent yet reasonably possible events have been recently and comprehensively studied (Ayres 1996a and b).

Hydrologic computations were completed for this site utilizing both streamflow statistical information and rainfall-runoff modeling. The 205 square mile drainage basin was divided into five sub-basins representing consistent physical/meteorologic/biologic characteristics and studied in detail. The result is that snowmelt dominated streamflow characterizes the hydrology up to approximately the 100-year event as illustrated by the following table of peak flow rates.

Table 2-2. Rainfall and Snowmelt Peak Rates for Elkhead Reservoir

Rainfall and Snowmelt Peak Runoff Rates Elkhead Reservoir Inflow		
Frequency	Rainfall Peak Runoff Rate (cfs)	Snowmelt Peak Runoff Rate (cfs)
2-year	21	1,300
10-year	425	1,800
100-year	2,850	2,500

In fact, there are no obvious rainfall only or rainfall dominated annual peak flows in the relatively short period of record, yet rare, significant rainfall/runoff events remain as a theoretical possibility.

2.1.3 Current Reservoir Operation and Fishery Management

Elkhead Reservoir does not have a defined operating plan. As previously described, controlled releases are made from the reservoir for water supply purposes via the primary outlet structure to Elkhead Creek for augmentation or diversion further downstream and from the “Starr Ditch Intake” directly to the Starr Ditch. Both outlet structures are gated and positioned on the dam. All other flow passes over the service spillway at the dam. Records of historical reservoir operations are not available and the reservoir has actually not been regularly operated for water supply purposes since its construction. Reservoir drawdowns have occurred periodically for maintenance, but otherwise the reservoir level stays very stable within one foot of the service spillway crest during an average year. As a result, the historical outflow hydrograph is very similar to the inflow hydrograph, less evaporation, with minor attenuation of peak flows during rainfall events and during spring months when some reservoir filling occurs. It is important to note that several studies have proposed significant physical changes to the reservoir and dam which could result in corresponding operational changes. Since those changes are not immediate, the current operational characteristics will be the focus of this study.

The combination of the hydrology and the dam/reservoir operations results in water regulation for typical year consisting of snowmelt runoff beginning in mid-April with water going over the service spillway and continuing until about mid-July; the remainder of the year the water level remains at the service spillway crest. The primary outlet can pass up to its capacity of 180 cfs during the spring snowmelt months and releases flow continuously down to less than 10 cfs minimum flow from late summer until the next spring. In summary, the dam/reservoir functions primarily in response to the natural hydrologic cycle. The primary outlet releases flow continuously, the service spillway releases flow for approximately two to three months in the spring and water is released to the Starr Ditch

during April through September. Periodic rainstorms, outside of the snowmelt runoff period; (rarely during March and April and occasionally July through September) can cause the spillway to function.

Elkhead Reservoir is not actively managed for sport fishing by Colorado Division of Wildlife. Over the years, numerous fish species have been stocked including northern pike, channel catfish, smallmouth bass, bluegill, crappie, largemouth bass and several trout species. No warm water fish have been stocked since 1986. Pike, smallmouth bass, largemouth bass, crappie and bluegill still persist through natural reproduction. There is no creel survey data or angler use data available for Elkhead Reservoir. Trout stocked in the fall for put and take fishing carry over through the winter but do not persist over the summer season (W. Elmlad, CDOW, personal communication).

2.2 Highline

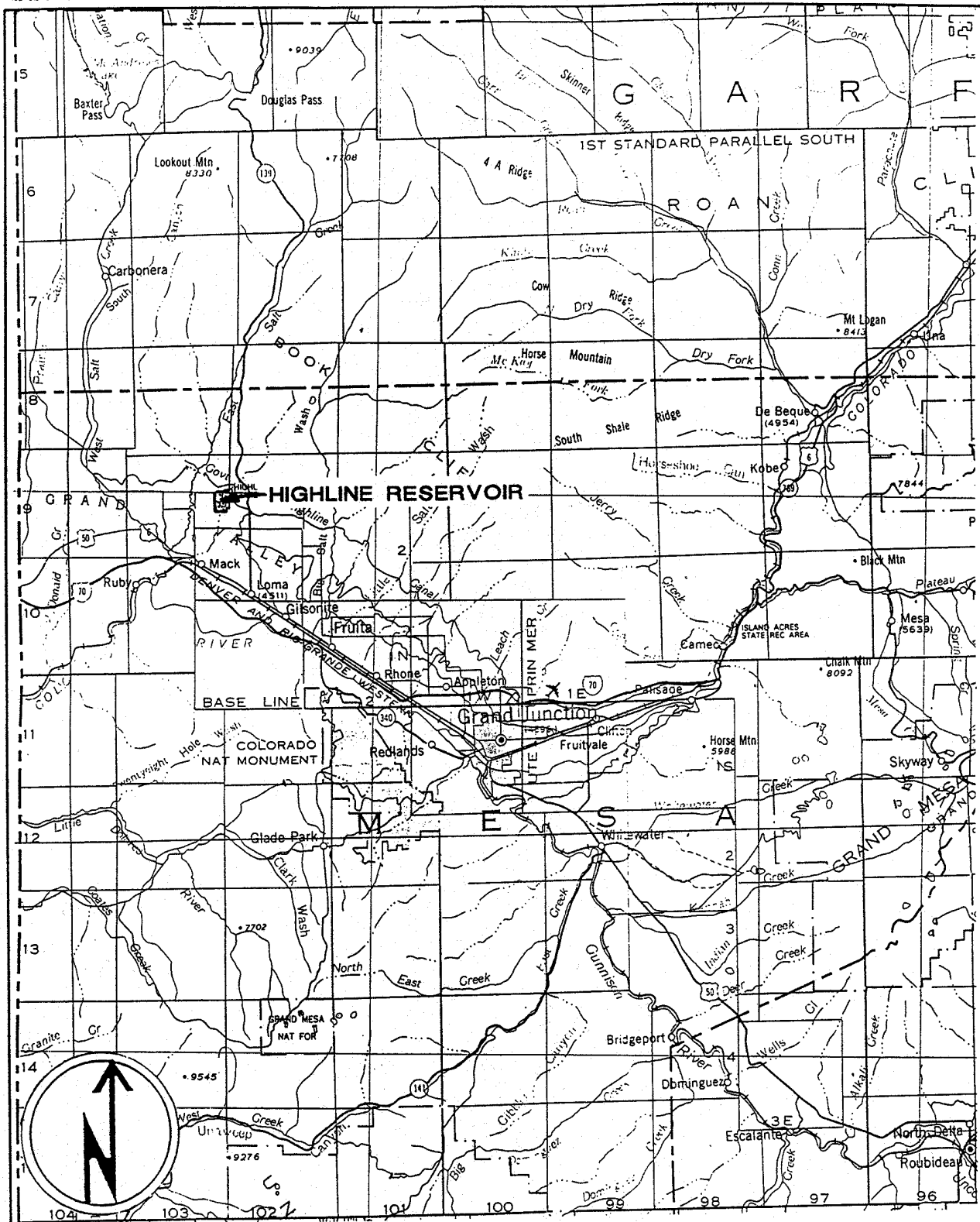
2.2.1 Physical Configuration of Reservoir and Outlet

Highline Dam and Reservoir is located approximately 5 miles north of Mack, Colorado as shown on Figure 2-3. The dam is located in the south 1/2 of Section 5, Township 2 North, Range 3 West of the Ute Principle Meridian, and is situated on Mack Wash, a tributary to Salt Creek which is a tributary to the Colorado River. The 15.26 square mile drainage basin consists of sparsely covered (less than 20 percent) natural and agricultural lands and the climate is semi-arid. Natural base flow is negligible and the majority of water used to fill the reservoir is non-contract spills from the adjacent Government Highline Canal. The Government Highline Canal receives its water from the Colorado River.

The CDOW has ownership of the dam and the facilities associated with the dam, while the reservoir is operated by the Colorado State Parks. Fishery habitat and recreation are the exclusive uses for the reservoir and therefore the impoundment remains essentially full at all times. The embankment is a homogeneous earthfill structure and is classified as an intermediate size Class I dam by the Colorado Office of the State Engineer. It is approximately 80 feet high and 1,350 feet long at the crest. Water is released from the reservoir through a primary outlet structure which is composed of a 30 inch steel pipe with an energy dissipation structure at the outlet. Flow into the primary outlet structure is controlled by a hydraulically operated sluice gate. A service spillway is located at the west end of the embankment and a spillway chute diverts overflow to the channel downstream of the dam (Figure 2-4). Upgrading of the dam is currently underway consisting of raising the crest elevation by approximately 8 to 10 feet, installing toe drains, adding an orifice plate and other enhancements to the existing service spillway and spillway chute and outfall, and other minor features. The final constructed configuration is reflected in this text.

Table 2-3. Highline Reservoir Dam and Spillway Characteristics

Elevations/Capacities	
Crest	4719.0 feet
Service Spillway Crest	4700.6 feet
Normal Maximum W.S.	4698.0 feet
Reservoir Capacity at Spillway Crest	3,400 acre-feet



(Base Map Source: USGS 1:500,000 1980)

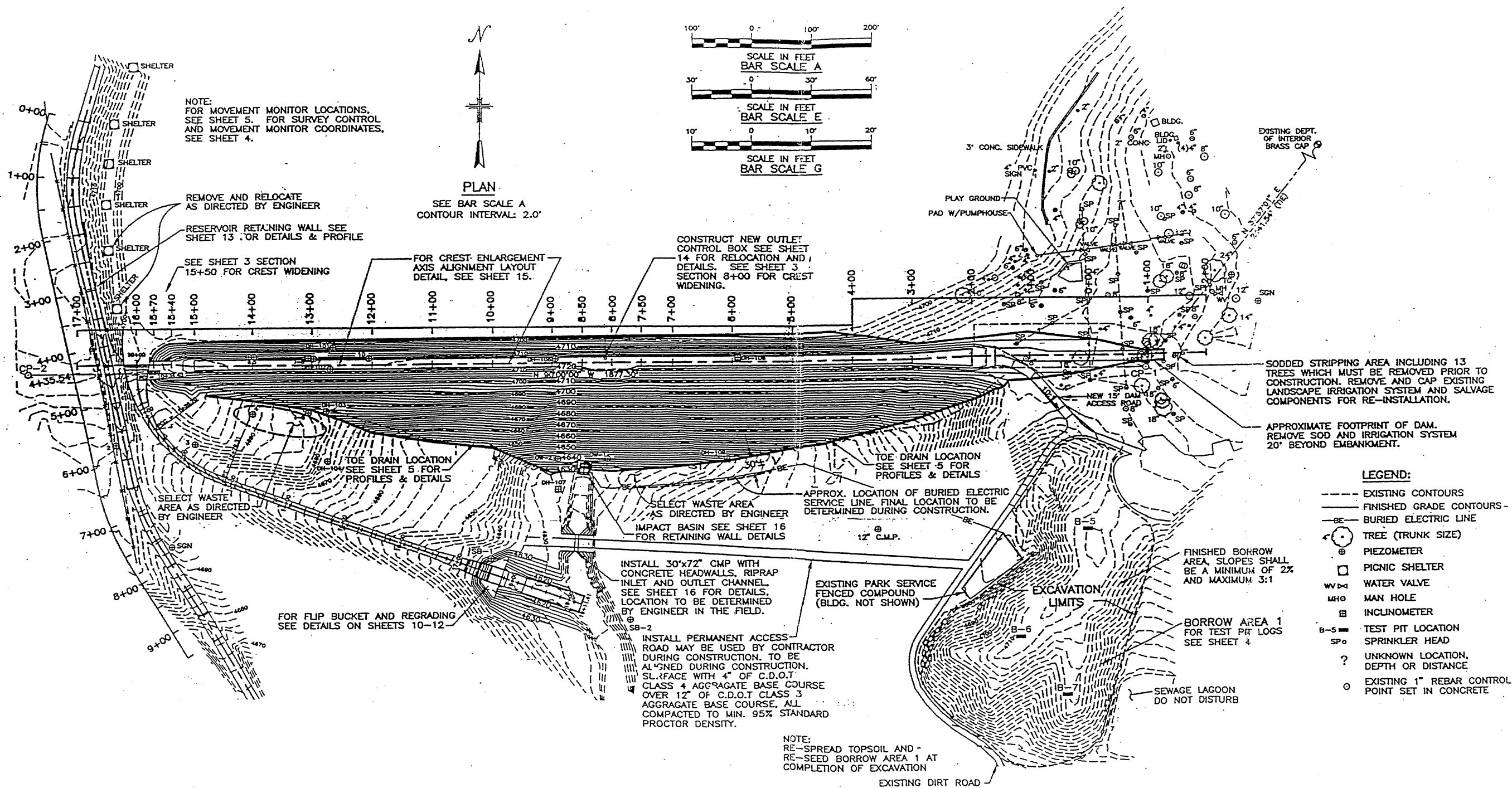
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Figure 2-3 HIGHLINE DAM/RESERVOIR GENERAL LOCATION

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(Base Map Source: CDOW Highline Rehabilitation Design Drawings Sheet 2, 8/94)

Figure 2-4

GENERAL PLAN OF HIGHLINE DAM AREA

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2.2.2 Hydrology

Operational and flood hydrology for the basin has not been extensively studied. Operational hydrology is controlled largely by administrative spills from the Government Highline Canal. Flood hydrology for the 10- and 100-year events was estimated using Technical Manual No. 1 and compared to hydrology supplied by the USBR, which was based on a regression analysis (personal communication R. Norman, USBR). The composite inflow hydrology for the 10- and 100-year events used for the purpose of this report is 750 and 1,700 cfs respectively. It is estimated that the 100-year inflow is attenuated to approximately 500 cfs by the reservoir surcharge storage. A PMF study was conducted but is not applicable to the current subject and will not be addressed further. Snowmelt provides no significant water to the reservoir and therefore need not be considered further.

2.2.3 Current Reservoir Operation and Fishery Management

Annual operational flows largely consist of administrative spills from Government Highline Canal. Flow records for the diversion canal were obtained from 1992 through 1995 (R. Norman, personal communication). Yearly total volumes ranged from 14,959 acre-feet (1993) to 28,426 acre-feet (1995) with a mean of 21,000 acre-feet for the 4 years of record. Most of the water is spilled between April and October, except for 1992 when spill wasn't initiated until June. Since the climate is very dry, snowmelt and rainfall induced base flows are not an issue. Controlled releases are made from the reservoir via the primary outlet structure to Mack Wash. All other flow passes over the service spillway at the dam. The only regulation of the dam is to maintain an adequate level for recreation activities and to provide a "freshening" circulation of the water during the summer water contact period. Any rainfall runoff passes through the reservoir with natural attenuation of peaks by the reservoir surcharge storage.

Highline Reservoir is not actively managed for sport fishing by Colorado Division of Wildlife. Species in the reservoir include channel catfish, smallmouth bass, bluegill, crappie, largemouth bass. Also rainbow trout have been stocked in the past and in 1996. Highline State Park has Highline Reservoir and Mack Mesa Reservoir in its boundaries. Mack Mesa Reservoir is a separate small lake adjacent to Highline Reservoir with a control valve connecting the two. Flow goes from Mack Mesa to Highline when the valve is opened.

In 1996, Mack Mesa Lake received a stocking of six inch channel catfish stocking and also rainbow trout. The channel catfish were stocked with the agreement that no water would be transferred from Mack Mesa to Highline Reservoir. Highline Reservoir received a stocking of whirling disease positive trout but no warm water species. Largemouth bass, channel catfish, bluegill and crappie all reproduce within Highline Reservoir. No angler data or creel survey information is available for Highline Reservoir.

2.3 Fish Species Life History at Elkhead and Highline Reservoirs.

The following section describes life histories of smallmouth bass, channel catfish, northern pike, bluegill and green sunfish. These species, except northern pike, are present at both Elkhead and Highline Reservoirs. Northern pike is present only at Elkhead Reservoir. The descriptions given provide general information on times of spawning, water temperatures required, successive spawning and general habitat requirements in reservoirs.

Smallmouth bass. Life history of the smallmouth bass is similar to other members of the family Centrarchidae, although spawning usually occurs earlier than other members of this family (Carlander 1977). Spawning of smallmouth bass typically occurs between late spring and early summer in pools where minimum velocity is required for nest building and spawning (Beckman 1974; Cross and Collins 1975; Carlander 1977). In lakes smallmouth bass nests are usually in water 0.6 to 1.2 meters in depth and from 0.3 to 2.4 meters from the shore. Nests have been reported in waters as deep as 3.5 meters and up to 10 meters from shore (Carlander 1977).

Environmental requirements include water temperatures that are rising and exceed a minimum daily temperature of 13° C (Carlander 1977). Nests appear as depressions in sand, gravel, or rocks (Stroud 1967; Beckman 1974) with dimensions that are usually between 30.5 and 183.0 centimeters in diameter (Cross and Collins 1975). One female may utilize several nest sites (spawning with different males at each site) and lay as many as 2000 to 14,000 eggs (Beckman 1974). Smallmouth bass eggs, after fertilization, range in size from 1.8 to 3.5 millimeters. Smallmouth bass leaving the nests are approximately 8 millimeters in length and there are reports of a 12 millimeter length bass already eating fish fry. The eggs and nest are guarded by the male until hatching which usually occurs in two to ten days depending on water temperature (Hubbs and Bailey 1938; Cross and Collins 1975). The male smallmouth bass will often continue to guard the fry for up to ten days after hatching (Carlander 1977). Sex ratio among fry is about 1:1 (Hubbs and Bailey 1938). Carlander (1977) suggests that optimum temperature for growth of juvenile smallmouth bass ranges between 26° and 29° C however, over crowding of juveniles may have a negative affect on growth rate. Survival from egg to fall fingerling has been estimated at 0.3% to 0.6% (Carlander 1977). Smallmouth bass of all life stages are sight dependent carnivores. At an early age they feed on plankton and aquatic invertebrates, but will eventually switch to small fish (sometimes other small bass) and crayfish (Carlander 1977). Females become sexually mature between the age of 4 to 6 at which time they are usually able to produce one brood per year. Males become sexually mature at age 3 to 5 (Cross and Collins 1975; Pflieger 1975). Carlander (1977) suggests that the maximum life span for smallmouth bass is about 18 years.

Smallmouth bass of all ages tend to prefer rocky habitat in clear non-turbid water. They avoid water with a pH less than 6.0, and require dissolved oxygen concentrations of greater than 0.96ppm at a water temperature of 21° C (Carlander 1977). Smallmouth bass often benefit from the stability in temperature and discharge created by dams in rivers (Beckman 1974; Cross and Collins 1975). Smallmouth tend to be inactive during the winter when water temperatures are less than 10° C (Carlander 1977).

Channel catfish. Like most fish the life history of channel catfish is highly influenced by environmental conditions and suitable habitat. Nesting occurs in shallow water and requires some form of overhead cover (Pflieger 1975; Memahon and Terrell 1982). In rivers, areas of minimal flow or standing water are preferred for spawning (Bestgen (no date); Scott and Crossman 1973). Substrate in the nest may vary in size from soft sediment to gravel-cobble, and spawning activity begins when water temperatures reach 20° - 22° C (Koster 1957; Cross and Collins 1975; Pflieger 1975). Channel catfish eggs require water temperatures greater than 15.5° C. The male guards the eggs and nest and will continue to guard the fry for a short period after hatching (Scott and Crossman 1973; Cross and Collins 1975). After leaving parental care, juveniles rely heavily on some form of cover type to avoid predation. Juvenile channel catfish will usually feed on plankton and small aquatic insects. As adults they become omnivores, but often feed on small fish and crayfish. The optimal temperature for growth of juvenile channel catfish is between 27° - 29° C (Memahon and Terrell 1982), however growth rate may be slowed as a result of overcrowding (Carlander 1969).

Most channel catfish will reach sexual maturity by the age of 4 to 5. A typical life span for channel catfish is 8-14 years (Scott and Crossman 1973; Cross and Collins 1975; Pflieger 1975).

Channel catfish can withstand large fluctuations in dissolved oxygen, pH, turbidity and organic pollution. Some channel catfish eggs can survive salinity levels up to 16ppt, however spawning success begins to decline at levels greater than 2ppt. Stress caused by oxygen levels of less than 3ppm will decrease growth rate (Carlander 1969).

Northern pike. Northern pike are present in Elkhead Reservoir. The spawning success of northern pike is highly dependent on water temperature and habitat that is created by high flows in rivers or vegetated shore lines in lakes. A “nest” is not used by this species, however eggs are laid over vegetation in shallow areas of flooded streams or lakes. Spawning usually takes place in the spring as water temperatures rise to 7° - 11° C. Carlander (1969) reports that eggs will hatch in about 12 to 14 days at the optimal incubation temperatures of 9°-11° C. Eggs for northern pike range in size from 2.5 to 3 millimeters in diameter and the fry at hatching are 6.5 to 8 millimeters in length. Pike start feeding at a size range of approximately 13 to 15 millimeters in length and 11.5°C temperature. Carbine (1944) suggests that in nature only 0.07% to 0.44% of the eggs survive to the fingerling stage. Young northern pike become piscivores at a very early age and remain that way throughout their life. Because they feed by sight, growth rate of pike may be hindered by high turbidity. Male northern pike become sexually mature around the age two or three, and most females reach maturity by age three (Carlander 1969).

Northern pike have a high tolerance for adverse environmental conditions when they have been gradually acclimated to them. Northern pike have been reported to survive in water with a pH of 9.5 or 1.6% salinity. However, an increase in salinity from 0.8% to 1.5% over a short period of time was responsible for the elimination of all pike in a North Dakota lake (Carlander 1969).

Bluegill and green sunfish. Bluegill and green sunfish are two closely related species in the genus *Lepomis* that are generally referred to as “sunfish”. Life histories of the two species is similar and hybridization is not uncommon. Spawning of “sunfish” occurs between spring and early fall in water temperatures that range from 19° - 31° C (Scott and Crossman 1973; Stuber et. al 1982). The nest site is usually a depression that can be constructed in a variety of substrate sizes or aquatic vegetation (Beckman 1974; Scott and Crossman 1973). Nests and eggs are guarded by the male and may occur in standing water or slow flowing streams (Stuber et. al 1982). Females lay from 2000 to 10,000 eggs (Beckman 1974), which usually hatch in 3 to 5 days (Scott and Crossman 1973). Eggs are approximately 1 to 1.4 millimeters in diameter. Eggs hatched in approximately 50 hours and the larvae are free-swimming at 4.2 to 4.7 millimeters two days after hatching. Sunfish have the capability to spawn more than once a year depending on water temperature. Juveniles consume primarily zooplankton (Siewert 1973), and switch to a diet consisting of a variety of aquatic invertebrates and fish as they grow older. Under good environmental conditions juvenile sunfish grow quickly and can reach sexual maturity in 1 to 3 years (Stuber et. al 1982).

2.4 Overview of Specific Control Alternatives

Neither the Elkhead nor the Highline projects have any type of up- or downstream fish passage features, facilities or operations specifically oriented to controlling fish movement. This absence of fish movement facilities, the fact that dam rehabilitation or enlargement proposals were actively underway at both locations and their physical characteristic as reservoirs managed for sport fishing off stream of rivers occupied by endangered species are reasons why they were selected as prototypes for consideration of fish exclusion facilities. The two facilities are distinctive in their location,

hydrology, and management, but similar in the general physical characteristics of the dam outlet works making them good representatives of the size and type of off stream reservoir of concern.

The initial exclusion objective and related criteria established early in the study as described in Section I of this report was known to be quite aggressive; however, it was accepted as a beginning point. This opinion was confirmed as the literature research and interviews proceeded. The McCluskey and Havasu projects, previously cited as having similar performance criteria, were utilized to estimate the conceptual technical feasibility and cost of exclusion facilities at Elkhead Dam/Reservoir. Using this criteria results in facilities at the cutting edge of current technology (as to size of screen openings and unit sizes) and as such, is apparently technologically feasible. However, the updated exclusion facilities costs exceed \$100 million, or approximately 3 times the total 1995 enlargement cost, making the technology economically unfeasible. At the September 23, 1996, project meeting, it was decided to do three things to resolve this situation and provide as meaningful a study as possible.

1. Use the original criteria with the interpretation that over 90 percent exclusion meets the intent of complete exclusion (it was agreed that 100 percent was unrealistically absolute).
2. An alternative of screening to a 3/32-inch opening size for screens reflecting technology which is currently applied (i.e., the state of industry practice) would be presented.
3. A no-action alternative would be presented as a perspective to judge the value associated with any exclusion facilities.

In addition, it was acknowledged that since protection of reservoir fishes was not a project objective, design screening velocities limited by the structural integrity of the screens could be used with the expectation that some reservoir fish mortality would result. As a result, screen velocities of 2 ft/sec were adopted as a conservative screen velocity. Likewise, no diversion, bypass, or fish handling/sorting facilities are provided.

Therefore, the alternatives for evaluation are (1) full exclusion, (2) exclusion to current industry practice, and (3) no action.

3. DESCRIPTION OF CONTROL ALTERNATIVE TECHNOLOGY AT ELKHEAD RESERVOIR

3.1 Selected Alternative for Full Exclusion at Elkhead Reservoir

3.1.1 Biological Characteristics

Target species at Elkhead Reservoir include northern pike, channel catfish and smallmouth bass. Northern pike and smallmouth bass are able to reproduce in the water temperatures present at Elkhead Reservoir. Summer water temperatures get high enough in June for smallmouth bass reproduction. Those young of the year would be free swimming in several days after hatch and could be moving and mobile around the reservoir perimeter. Northern pike spawn at approximately the same time and those young fish, as well as adults, would also be active during the summer in June, July and August.

There is no known escapement data for Elkhead Reservoir on number and size of the target species that leave the reservoir. Data collected in Elkhead Creek downstream of the reservoir show that smallmouth bass, bluegill and crappie all are found downstream of the reservoir (Miller and Rees 1996). Stream habitat in Elkhead Creek downstream of the reservoir consists of pools, riffles and glides. Flows during the summer go down to about 1-2 cfs with very warm water and very little flow during the summer period other than what's released from the reservoir. Pool depths are as deep as 2-3 feet with pools on most of the outside bends of the meanders. The stream meanders extensively through the lower six miles from Elkhead Reservoir to the Yampa River. Water quality and temperature conditions are suitable for both native and non-native species downstream of the reservoir. Data does not exist to show if reproduction occurs by non-native species in Elkhead Creek downstream of the reservoir.

Control structures that have potential include all screen types that actively screen both passive and actively swimming life stages. This includes most screen designs. Behavioral control techniques will not work for the full exclusion alternative because they do not effectively prevent escapement of passive life stages, which include egg and young of the year life stages.

3.1.2 Engineering Characteristics

This alternative explores the features which can be implemented at the existing dam to limit downstream passage of reservoir fishes in accordance with the project objective described in the first section of this report including: (1) exclusion of all life forms egg size and larger (0.5 mm), (2) exclusion for all flows more frequent than once in 100 years, and (3) exclusion success of 90-100 percent; without significant changes to basin water use and by using techniques recognized as being theoretically technically feasible. This portion of the narrative covers water volume, flow management and physical restrictions at the Starr Ditch outlet, primary outlet and the service spillway.

Inflow Management. The watershed acts almost exclusively in response to natural stimuli, as such no opportunity exists to reasonably alter the temporal and spatial supply of water to the reservoir.

Outflow Management. The primary outlet passes flow continuously either by leakage or intentional releases. Since the mean annual peak flow at the dam (1,250 cfs) is greater than the primary outlet capacity (180 cfs) by a factor of approximately 7, the service spillway is expected to carry flow past

the dam in all but the very driest years. The Starr Ditch outlet is also utilized almost every year to deliver irrigation water downstream. As such, all three water outlet structures function almost every year; therefore, each will be required to have fish exclusion devices. Essentially nothing can be done to minimize the frequency and volume of water discharged through the Starr Ditch outlet as it is operated to deliver irrigation water downstream consistent with established water rights. Purchase of the water rights or arranging an alternate point of diversion (physically and legally) to eliminate this outlet is an option which is not further evaluated herein. The primary outlet is an indispensable component of reservoir operation and must be retained. The need for screening the service spillway could be avoided if its frequency of use could be reduced to less than once in one hundred years. It is possible to reconstruct the primary outlet to increase its capacity to reduce use of the service spillway. This idea will be discussed further in a following section. Several management techniques which could be utilized to minimize flow through the existing service spillway include:

1. Use the primary outlet to release all flow from the reservoir up to its capacity.
2. Operate the normal maximum reservoir level at 1 to 3 feet below the service spillway crest to eliminate spillway flow due to wind tide and waves and to provide flood routing capability. The value of attenuation would be very minor as complete storage of even the mean annual snowmelt volume could not occur.
3. Draw down reservoir more than 1-3 feet during the late summer through early spring period to make use of outlet capacity when it would be flowing at less than maximum capacity (180 cfs) and to allow storing some spring runoff in reservoir that otherwise would flow over the spillway.
4. Operate to the maximum extent possible using the primary outlet in order to release cold water from deep in the reservoir where fish species of concern are least likely to be located and to minimize debris fouling.

None of these measures are expected to have a significant impact on the frequency and amount of flow through the service spillway without major physical changes to outlet structures. Management measures one and four can be accomplished essentially for only the cost of refurbishing the primary outlet to a fully functional condition. Items two and three potentially involve a cost to the water rights owner reflecting loss of water availability. This must be considered a project cost depending upon the details of how this operation occurs. In addition, greater operator attention or automatic operation would be needed to operate the reservoir in this manner.

Starr Ditch Outlet. The most effective technique for excluding fish from this submerged, controlled release point is the use of cylindrical screens at the intake. This would mean reconstruction of the intake structure, gate replacement and screens construction. A maximum flow capacity of 10 cfs is assumed. A single vertical cylindrical screen would be provided with room left to add another. The 0.5 mm (1/50 inch) screen opening size is available although seldom manufactured or used. The screen is cleaned using pneumatic backwash. Construction is possible using conventional techniques. The modification is well suited to the site and fully compatible with other dam components and operation. It is easily modified to a different screen size or more screens if needed. Its exclusion reliability should be excellent. The concrete should have over a fifty-year design life and the screens thirty years effective life. Operation and maintenance is minimal and should be less than \$500 annually.

Table 3-1. Capital Construction Cost for Full Exclusion Protection at Starr Ditch Outlet at Elkhead Reservoir

Item	(\$)
Structural Modification	4,000

Screens and Pneumatic Backwash System	6,000
Gate Replacement	3,000
Unlisted Items	2,000
Contingency	4,000
TOTAL	19,000

Primary Outlet. The most effective technique for excluding fish from this submerged, controlled release point is, as with the Starr Ditch outlet, the use of cylindrical screens at the intake. This would mean reconstruction of the intake structures, gate replacement, and screens construction. A maximum flow capacity of 180 cfs is assumed. Four 50 cfs vertical cylindrical screens would be provided with room left to add two additional. The 1/50-inch (0.5 mm) screen opening size would again be used. The screen is cleaned using pneumatic backwash. The modification is well suited to the site and fully compatible with other dam components and operation; it is easily modified to a different screen size or more screens if needed.

Further outlet modification is required to meet the full exclusion objective. Ideally, the primary outlet could be removed and replaced with a new structure with a hydraulic capacity adequate to handle the 100-year snowmelt peak flow of 2,100 cfs and to screen its intake using a battery of cylindrical screens located on the spillway approach floor. This would be a very large scale use of cylindrical screens consisting of sixteen 125 cfs vertical cylindrical screens manifolded to the new outlet tower with room left to add four additional (Figure 3-1). The construction cost of this enlarged primary outlet and cylindrical screen system is presented for this option (Table 3-2).

Table 3-2. Capital Construction Cost for Full Exclusion Protection at the Primary Outlet at Elkhead Reservoir

Item	(\\$)
Intake Manifold Apron	500,000
Reconstruct Primary Outlet	8,000,000
Screens and Pneumatic Backwash System	3,000,000
Intake Manifold	4,000,000
Demolition/Excavation	1,000,000
Embankment Replacement	2,000,000
Restoration of Existing Facilities	1,000,000
Automatic Level Control	100,000
Lost Water Rights Value (2,000 af) or Replacement Water	4,000,000
Unlisted Items	2,500,000
Contingency	6,500,000
TOTAL	32,600,000

The construction effort associated with this option is extensive requiring reservoir drawdown and complete reconstruction of the primary outlet, a major dam component. The construction itself would be accomplished using conventional techniques. Its exclusion reliability should be excellent. The concrete should have over a 50-year design life and the screens, thirty years effective life. Operation and maintenance costs should be approximately \$50,000 annually.

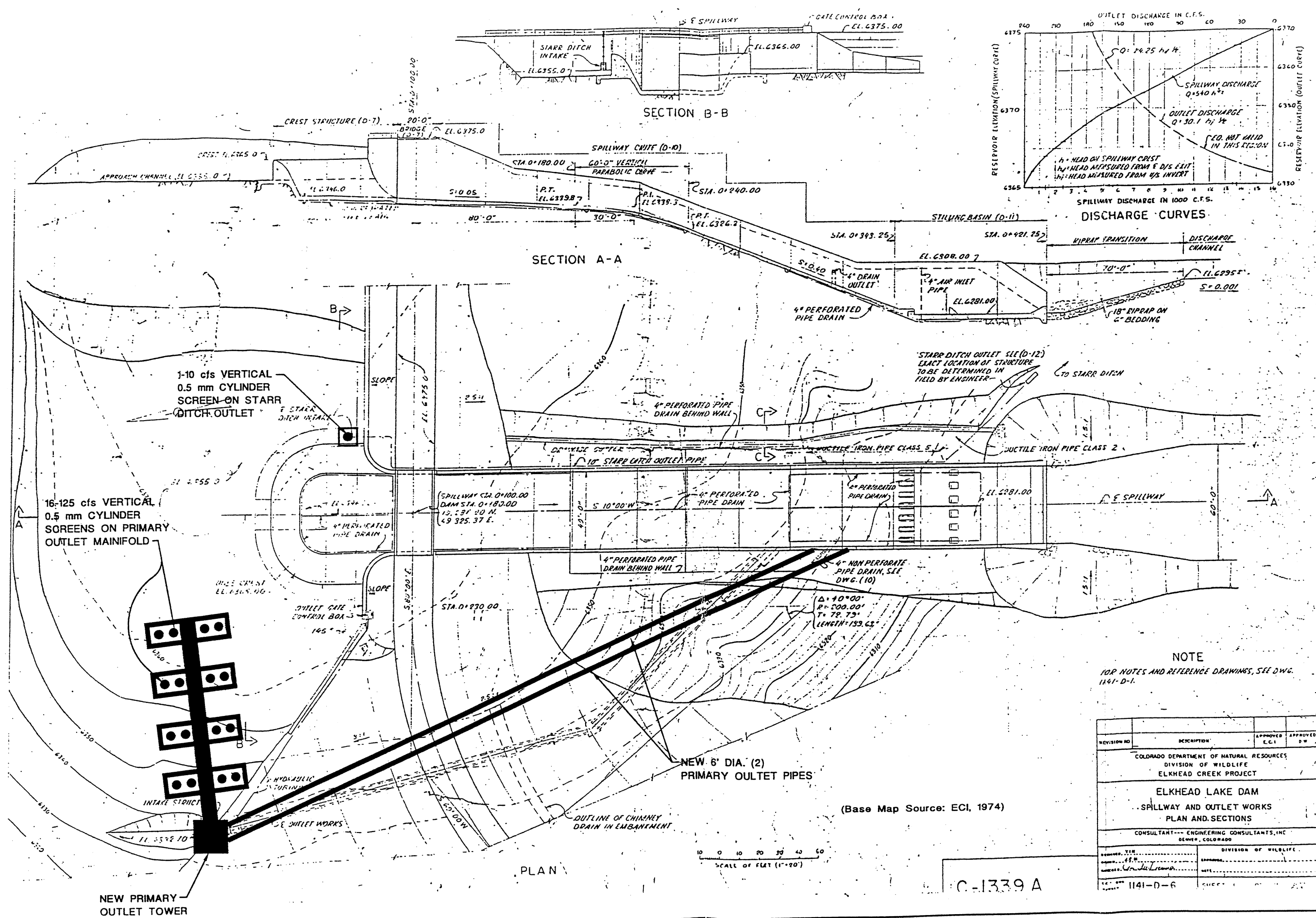


Figure 3-1

COLORADO RIVER WATER CONSERVATION DISTRICT ELKHEAD FULL EXCLUSION SCHEMATIC

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DECEMBER 1996

REVISION NO.	DESCRIPTION	APPROVED E.C.I.	APPROVED D.W.
	COLORADO DEPARTMENT OF NATURAL RESOURCES DIVISION OF WILDLIFE ELKHEAD CREEK PROJECT		
	ELKHEAD LAKE DAM SPILLWAY AND OUTLET WORKS PLAN AND SECTIONS		
	CONSULTANT---ENGINEERING CONSULTANTS, INC. DENVER, COLORADO		
	DIVISION OF WILDLIFE		
DESIGNED BY	DATE		
CHECKED BY	DATE		
1141-D-6			

Service Spillway. Spillways are typically not screened except to retain sport fish within a reservoir. Prevention of downstream migrant diversion entrainment is the typical concern and passage via a spillway is often actually an efficient means of providing downstream passage, consequently spillways are not screened. Prohibiting downstream fish passage via spillway screening is also expensive and potentially obstructs flood conveyance. Using the concept described herein of increasing the capacity of the primary outlet, the service spillway would be used less frequently than once every 100 years and therefore would not require a barrier. In addition, the water level will be maintained 1-3 feet below the crest to prevent wind tide or wave splash over the spillway from occurring. Water level control and water rights costs have been added to the costs in Table 3-2 accordingly.

Should the primary outlet remain at its 180 cfs capacity, the service spillway must be screened. This would require a minimum screen size approximately 300 feet long by 10 feet high with 50 percent open area and an elaborate structural support system including cold weather protection and automatic debris removal. Such a screen system could possibly be located in the spillway approach area. No precedent exists for screening spillways in this manner for this purpose. The elaborate structure required would constitute an obstruction to flood flows and would unlikely be approved by dam safety regulators. An alternative could be an intake structure located along the shore with a diversion back to the spillway chute, however, this would require very significant water diversion facilities in addition to the screen structure. Neither of these two options are reasonably feasible.

3.2 Selected Alternative for Exclusion to Current Industry Practice

3.2.1 Biological Characteristics

Biological characteristics for protection at the current industry practice are the same as those listed under Section 3.1.1. for the full exclusion alternative.

3.2.2 Engineering Characteristics

This alternative explores the options which can be implemented at the existing dam to limit downstream passage of reservoir fishes without major alterations to the primary components of the existing facility, without significant changes to basin water use and by using techniques in common industry practice. This covers water volume/flow management and physical restrictions at the Starr Ditch outlet, primary outlet and service spillway. It does not cover behavioral techniques as behavioral techniques are known to have an unacceptable escapement rate for target life stages.

Inflow Management. The watershed acts almost exclusively in response to natural stimuli, as such no opportunity exists to reasonably alter the temporal and spatial supply of water to the reservoir.

Outflow Management. The primary outlet passes flow continuously either by leakage or intentional releases. Since the mean annual peak flow at the dam (1250 cfs) is greater than the primary outlet capacity (180 cfs) by a factor of approximately 7, the service spillway is expected to carry flow past the dam in all but the very driest of years. The Starr Ditch outlet is also utilized almost every year to deliver irrigation water downstream. As such, all three water outlet structures function almost every year and each will be required to have fish exclusion devices. Essentially nothing can be done to minimize the frequency and volume of water discharged through the Starr Ditch as it is operated to deliver irrigation water downstream consistent with established water rights. Purchase of the water rights or arranging an alternate point of diversion (physically and legally) to eliminate this outlet is an option which is not further evaluated herein. The primary outlet is an indispensable component of

reservoir operation and must be retained. Several management techniques which could be utilized to minimize flow through the service spillway include:

1. Use the primary outlet to release all flow from the reservoir up to its capacity.
2. Operate the normal maximum reservoir level at 1 to 3 feet below the service spillway crest to eliminate spillway flow due to wind tide and waves and to provide flood routing capability. The value of attenuation would be very minor as complete storage of even the mean annual snowmelt volume could not occur.
3. Draw down reservoir more than 1-3 feet during the late summer through early spring period to make use of outlet capacity when it would be flowing at less than maximum capacity (180 cfs) and to allow storing some spring runoff in reservoir that otherwise would flow over the spillway.
4. Operate to the maximum extent possible using the primary outlet in order to release cold water from deep in the reservoir where fish species of concern are least likely to be located and to minimize debris fouling.

None of these measures are expected to have a significant impact on the frequency and amount of flow through the service spillway. Management measures one and four can be accomplished essentially for only the cost of refurbishing the primary outlet to a fully functional condition. Items two and three potentially involve a cost to the water rights owner reflecting loss of water availability. This must be considered a project cost depending upon the details of how this operation occurs. In addition, greater operator attention or automatic operation would be needed to operate the reservoir in this manner.

Starr Ditch Outlet. The most effective technique for excluding fish from this submerged, controlled release point is the use of an MIS or cylindrical screens at the intake. This would mean reconstruction of the intake structure, gate replacement and screens construction. A cylindrical screen is preferred as it pneumatically backwashes into the reservoir rather than downstream. A single vertical cylindrical screen would be provided with room left to add another. A maximum flow capacity of 10 cfs is assumed. The 3/32-inch (2.38 mm) screen opening size and the 10 cfs flow rate are commonly supplied sizes and the construction is possible using conventional techniques. The modification is well suited to the site and fully compatible with other dam components and operation. It is easily modified to a different screen size or more screens if needed. Its exclusion reliability should be excellent and it would be positioned behind the screening of the service spillway for backup protection. The concrete should have over a fifty-year design life and the screens thirty years effective life. Operation and maintenance is minimal and should be less than \$500 annually.

Table 3-3. Capital Construction Cost for Exclusion to Current Industry Practice at Starr Ditch Outlet at Elkhead Reservoir

Item	(\$)
Structural Modification	4,000
Screens and Pneumatic Backwash System	6,000
Gate Replacement	3,000
Unlisted Items	2,000
Contingency	4,000
TOTAL	19,000

Primary Outlet. The most effective technique for excluding fish from this submerged, controlled release point is, as with the Starr Ditch outlet, the use of an MIS or cylindrical screens at the intake.

This would mean reconstruction of the intake structures, gate replacement, and screens construction. A cylindrical screen is preferred as it pneumatically backwashes debris into the reservoir rather than downstream and requires no fish bypass. A maximum flow capacity of 180 cfs is assumed. Four 50 cfs cylindrical screens would be provided with room left to add two additional. The 3/32-inch (2.38 mm) screen opening size and the 180 cfs flow rate are commonly supplied sizes and the construction is possible using conventional techniques (Figure 3-1).

Table 3-4. Capital Construction Cost for Exclusion to Current Industry Practice at the Primary Outlet at Elkhead Reservoir

Item	(\$)
Approach Apron Modifications	10,000
Structural Modification	50,000
Screens and Pneumatic Backwash System	100,000
Gate Replacement	25,000
Unlisted Items	20,000
Contingency	50,000
TOTAL	255,000

The modification is well suited to the site and fully compatible with other dam components and operation; it is easily modified to a different screen size or more screens if needed. Its exclusion reliability should be excellent and it would be positioned behind the screening of the service spillway for backup protection. The concrete should have over a 50-year design life and the screens, thirty years effective life. Operation and maintenance is minimal and costs should be less than \$10,000 annually.

Service Spillway. Spillways are typically not screened except to retain sport fish within a reservoir. Prevention of downstream migrant diversion entrainment is the typical concern and passage via a spillway is often actually an efficient means of providing downstream passage consequently spillways are not screened. Prohibiting downstream fish passage via spillway screening is also expensive and potentially obstructs flood conveyance. Since the head on the spillway will vary, a floating screen system or a rigid screen extending above the water surface is needed. In addition, to achieve velocities less than 2 ft/sec for a 100-year flow of 2,100 cfs through the screen, the screen must be located approximately 100 feet into the reservoir from the spillway crest. A flexible net screen anchored to the spillway apron and to floats at the surface is one way to provide this screening, however, the typical minimum opening size is 1/4-inch (6.35 mm). To achieve the 3/32-inch screen size of the current industry practice requires a fixed plate or traveling plate metal screen (angled or vertical) permanently anchored to the spillway apron floor at approximately 7 times the cost of the flexible net screen. A rigid screen in the service spillway approach area has the same inherent limitations as described under the full exclusion narrative. An on shore screening option is again possible but not reasonably feasible. The cost of a barrier net is presented for this option (Table 3-5). Since this concept allows water to be conveyed regularly through the service spillway, the water level will not be maintained 1-3 feet below the crest to prevent wind tide or wave splash over the spillway from occurring. Therefore, no water level control and water rights costs have been added to the costs in Table 3-4.

Table 3-5. Capital Construction Cost for Exclusion to Current Industry Practice at the Spillway at Elkhead Reservoir

Item	(\$)
Approach Apron Preparation	20,000
Net and Skirt (2)	100,000
Superstructure, Anchors, and Floats	50,000
Access Platform	100,000
Unlisted Items	50,000
Contingency	130,000
TOTAL	650,000

Construction is almost completely separate from the dam itself and is possible using conventional techniques. It is very easily modified to a different configuration if needed. It would typically be dropped to the bottom when not in use and raised in place for May and June during spring snowmelt and through the late summer thunderstorm season. With the net use, exposure to escapement exists both for periods of ice cover when the net is not in place and the water level rises causing spillway overflow and for periods of wind tide and wave splash causing flow over the spillway if a freeboard buffer is not provided. A winter only drawdown of 1-3 feet may provide some mitigation of this impact with little impact on water use, however, a year round restricted water level is not economically justified. The screen (net) is very inexpensive and can be replaced completely if needed without complete replacement of the screen system. Its exclusion reliability is only moderate at 60 percent. The superstructure and net design life is less than 30 years. The operation and maintenance cost is unknown, but expected to be very small with most of the cost associated with the effort to place the net in its proper seasonal position.

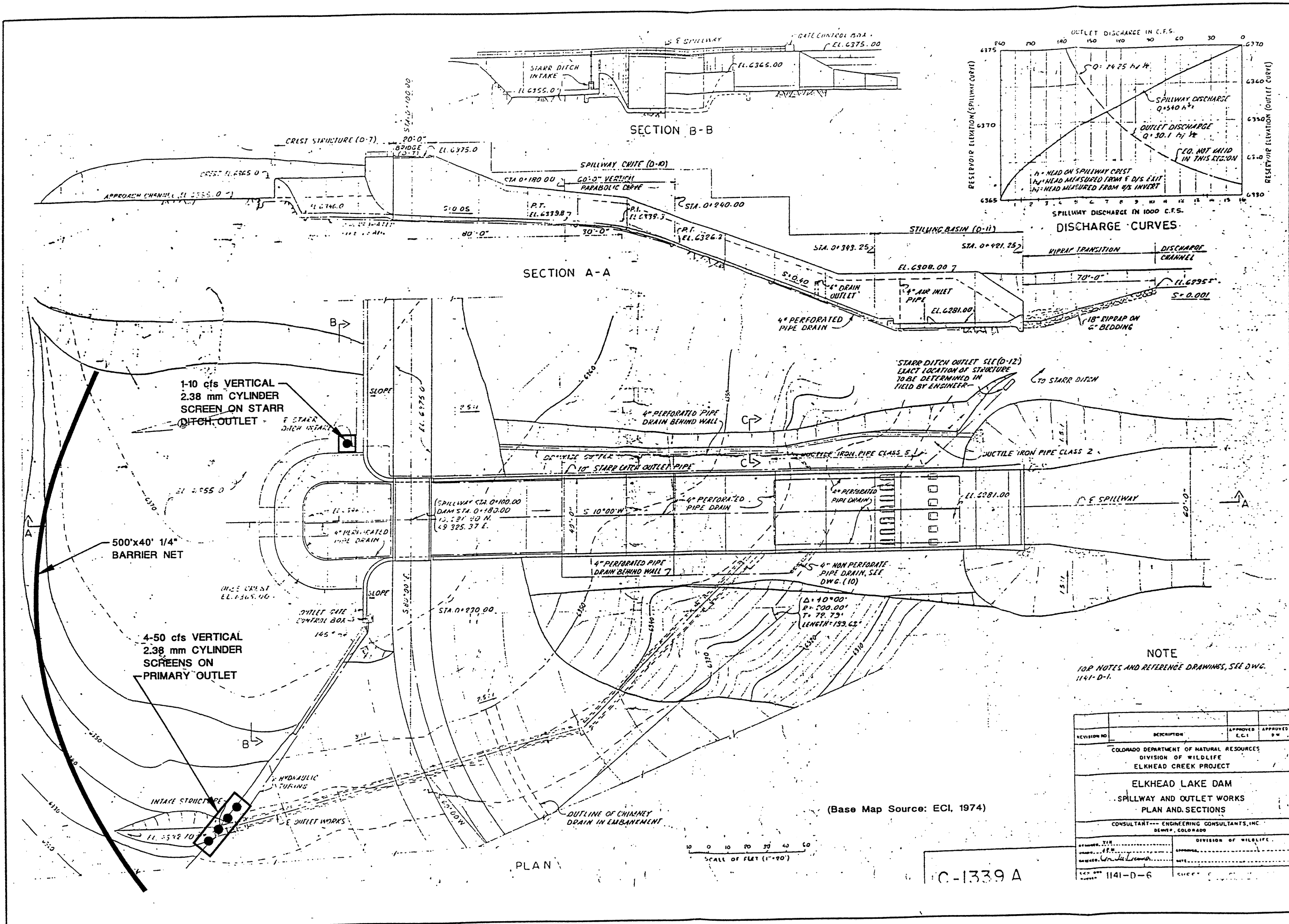


Figure 3-2

ELKHEAD EXCLUSION TO CURRENT INDUSTRY PRACTICE SCHEMATIC

DECEMBER 1996

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DISTRICT

3.3 No Action Alternative

The No Action Alternative would result in continued escapement of non-native fish from the reservoir at the current levels. The magnitude, size of fish or species and timing of escapement is unknown. Sampling in Elkhead Creek downstream of the reservoir in fall of 1995 suggests that young of the year smallmouth bass escape from the reservoir into Elkhead Creek. No sampling has been conducted to specifically quantify escapement.

Species currently in the reservoir include smallmouth bass, northern pike, black crappie, channel catfish and bluegill. None of these species are actively managed by the Division of Wildlife for sport fishing. The fish that currently inhabit the reservoir persist from natural reproduction from fish stocked in the early to late 1980s. No Action would result in no new management or stocking of warm water non-native fish that could survive and recruit in the downstream waters. Management alternatives would be limited to stocking of fish that are known not to survive in downstream waters.

All of the fish listed above have been captured in surveys in Elkhead Creek or the Yampa River. With No Action, the potential for these fish to escape from Elkhead Reservoir would continue. Since the escapement has not been quantified, the total contribution and recruitment to Elkhead Creek and the Yampa River is unknown. It would be expected to continue at the current level and any negative impacts to the listed fish species would continue.

4. DESCRIPTION OF CONTROL ALTERNATIVE TECHNOLOGY AT HIGHLINE RESERVOIR

The following section describes the control alternatives at Highline Reservoir. Coincidentally, Highline Reservoir and Elkhead Reservoir have many characteristics in common and the narratives associated with each are similar. Similarities include the size, condition and configuration of the primary outlets; the configuration of the service spillways; the normally full operation; and others. The narrative is kept consistent so that the differentiating items can be more clearly identified and for ease in comprehension.

4.1 Selected Alternative for Full Exclusion at Highline Reservoir

4.1.1 Biological Characteristics

Target species at Highline Reservoir include channel catfish, smallmouth bass and potentially bluegill and sunfish. Reservoir conditions at Highline Reservoir allow reproduction of channel catfish, bass, bluegill and crappie. All of these species reproduce during early summer, June and July time period, and the young of the year would be actively swimming in the reservoir several days after incubation and hatch. Water temperatures for the reservoir are not available but generally water would become warm enough in June into July for spawning of all the warm water species.

There is no escapement history available for Highline Reservoir and no information on species immediately downstream of the reservoir. The Department of Interior Fish and Wildlife Service drainwater study starting at about 1993 did collect information in Salt Creek at the I-70 bridge location which receives water from Highline Reservoir via Mack Wash. At this location, both native and non-native species were observed and collected. Water chemistry data was also collected. Water chemistry shows that there is very high salinity and conductivity levels as well as selenium. The presence of both native and non-native species show that the water is not acutely toxic to the life forms at this location during sampling. Sampling occurred in early spring, before irrigation. Flows were noted at approximately 1-2 cfs.

Historic records for Mack Wash also show this same information. Conditions in the creek, therefore, are not acutely toxic to the fish and any fish escaping the reservoir do have a chance to make it to the Colorado River, especially during irrigation season when flows are at the highest levels. Therefore, any type of control structure should be at the reservoir and not downstream of the reservoir. Fish escaping from the reservoir have a good chance of successful survival and the ability to move to the Colorado River and interact with the endangered species there. Control structure options for Highline Reservoir are the same as those listed for Elkhead Reservoir. All active screening types are viable options. Behavioral types are not suitable due to their lower efficiency and ability to handle passive life stages.

4.1.2 Engineering Characteristics

This alternative explores the features which can be implemented at the existing dam to limit downstream passage of reservoir fishes in accordance with the project objective described in the first section of this report including: (1) exclusion of all life forms egg size and larger (0.5 mm), (2) exclusion for all flows more frequent than once in 100 years, and (3) exclusion success of 90-100 percent; without significant changes to basin water use and by using techniques recognized as being

theoretically technically feasible. This portion of the narrative covers water volume/flow management and physical restrictions at the service spillway and primary outlet.

Inflow Management. The tributary watershed is small and arid and has negligible contribution to reservoir inflow. The baseflow water supply to the reservoir itself is transbasin administrative spills received via Government Highline Canal from the Colorado River. This has a significant impact on temporal and spatial supply of water to the reservoir. As such, there is significant control over most of the annual inflow volume and the resulting annual water level fluctuation. Inflow seems to currently be managed well and consistent with outflow capability. No significant inflow management alterations are suggested at this time.

Outflow Management. The ability to control the inflow to the reservoir, together with outflow management can be used to exercise relatively close control over reservoir releases downstream. The primary outlet is an indispensable component of reservoir operation and must be retained. Since it passes flow continuously either by leakage or by intentional releases, it must be screened. The reservoir does remain impacted by natural flood events from its watershed which are not controlled and these peak flows are the values of greater concern with respect to escapement. Since the average daily flows received by the reservoir are less than the primary outlet capacity of 200 cfs and routed flood flows up approximately to the 10-year event can also be handled by the primary outlet without the use of the service spillway, most of the outflow regulation can occur through use of only the primary outlet. However, to obtain full exclusion up to the 100-year event will require screening of both outlets or major modification of the primary outlet to pass all flow through the primary outlet up to and including the 100-year event. This later concept will be discussed in a following section. Several management techniques which could be utilized to minimize flow through the existing service spillway include:

1. Use the primary outlet to release all flow from the reservoir up to its capacity.
2. Operate the normal maximum reservoir level at 1 to 3 feet below the service spillway crest to eliminate spillway flow due to wind tide and waves and to provide flood routing capability. The specific amount of attenuation is currently unknown because the flood hydrology for the reservoir has not been studied.
3. Operate to the maximum extent possible using the primary outlet in order to release cold water from deep in the reservoir where fish species of concern are least likely to be located and to minimize debris fouling.

These measures can have a significant impact on the frequency and amount of flow through the service spillway, but not sufficient to meet the project objectives without significant changes to outlet structures. Management measures one and three can be accomplished essentially for only the cost of refurbishing the primary outlet to a fully functional condition. Item 2 involves a loss of storage volume, however, the water supply source which is from administrative spills may not have a monetary value which is appropriate to include as a project cost.

It is important to note that the current means of operating is to use the service spillway to continuously discharge water from the reservoir for reservoir water quality reasons (water contact activity), therefore, these suggested operations measures may be inconsistent with the current operation. This issue remains to be resolved separately.

Primary Outlet. The most effective technique for excluding fish from this submerged, controlled release point is the use of cylindrical screens at the intake. This would mean reconstruction of the intake structures, gate replacement, and screens construction. A maximum flow capacity of 200 cfs is

assumed. Four 50 cfs vertical cylindrical screens would be provided with room left to add two additional. The 1/50-inch (0.5 mm) screen opening size would be used. The screen is cleaned using pneumatic backwash. The modification is well suited to the site and fully compatible with other dam components and operation; it is easily modified to a different screen size or more screens if needed. Further modification is required to meet the full exclusion objective. Ideally, the primary outlet could be removed and replaced with a new structure with a hydraulic capacity adequate to handle the 100-year routed rainfall peak flow of 500 cfs and to screen its intake using a battery of cylindrical screens located on the spillway approach floor. This would be a very large scale use of cylindrical screens consisting of four 125 cfs vertical cylindrical screens manifolded to the new outlet tower with room left to add two additional (Figure 4-1). The construction cost of this enlarged primary outlet and cylindrical screen system is presented for this option (Table 4-1).



Table 4-1. Capital Construction Cost for Full Exclusion Protection at Highline Reservoir

Item	(%)
Intake Manifold Apron	100,000
Reconstruct Primary Outlet	2,000,000
Screens and Pneumatic Backwash System	1,000,000
Intake Manifold	1,000,000
Demolition/Excavation	500,000
Embankment Replacement	1,000,000
Restoration of Existing Facilities	500,000
Automatic Level Control	100,000
Unlisted Items	600,000
Contingency	1,700,000
TOTAL	8,500,000

The construction effort associated with this option is extensive requiring reservoir drawdown and complete reconstruction of the primary outlet, a major dam component. The construction itself would be accomplished using conventional techniques. Its exclusion reliability should be excellent. The concrete should have over a 50-year design life and the screens, thirty years effective life. Operation and maintenance costs should be approximately \$15,000 annually.

Service Spillway. Spillways are typically not screened except to retain sport fish within a reservoir. Prevention of downstream migrant diversion entrainment is the typical concern and passage via a spillway is often actually an efficient means of providing downstream passage, consequently spillways are not screened. Prohibiting downstream fish passage via spillway screening is also expensive and potentially obstructs flood conveyance. Using the concept described herein of increasing the capacity of the primary outlet, the service spillway would be used less frequently than once every 100 years and therefore would not require a barrier. In addition, the water level will be maintained 1-3 feet below the crest to prevent wind tide or wave splash over the spillway from occurring. Water level control cost has been included in Table 4-1. There is no definitive monetary value associated with the lost storage due to its source from an administrative spill.

Should the primary outlet remain at its 200 cfs capacity, the service spillway would have to be screened. This would require a minimum screen size approximately 200 feet long by 5 feet high with 50 percent open area and an elaborate structural support system including cold weather protection and automatic debris removal. Such a screen system could possibly be located in the spillway approach area. No precedent exists for screening spillways in this manner for this purpose. The elaborate structure required would constitute an obstruction to flood flows and would unlikely be approved by dam safety regulators. An alternative could be an intake structure located along the shore with a diversion back to the spillway chute, however, this would require very significant water diversion facilities and land area in addition to the screen structure. Neither of these two options are reasonably feasible.

4.2 Selected Alternative for Exclusion to Current Industry Practice

4.2.1 Biological Characteristics

Biological characteristics for exclusion to the current industry practice at Highline Reservoir are the same as those for the full exclusion alternative.

4.2.2 Engineering Characteristics

This alternative explores the options which can be implemented at the existing dam to limit downstream passage of reservoir fishes without major alterations to the primary components of the existing facility, without significant changes to basin water use and by using techniques in common industry practice. This covers water volume/flow management and physical restrictions at the service spillway and primary outlet. It does not cover behavioral techniques as behavioral techniques are known to have an unacceptable escapement rate for target life stages.

Inflow Management. The tributary watershed is small and arid and has negligible contribution to reservoir inflow. The baseflow water supply to the reservoir itself is transbasin administrative spills received via Government Highline Canal from the Colorado River. This has a significant impact on temporal and spatial supply of water to the reservoir. As such, there is significant control over most of the annual inflow volume and the resulting annual water level fluctuation. Inflow seems to currently be managed well and consistent with outflow capability. No significant inflow management alterations are suggested at this time.

Outflow Management. The ability to control the inflow to the reservoir, together with outflow management can be used to exercise relatively close control over reservoir releases downstream. The primary outlet is an indispensable component of reservoir operation and must be retained. Since it passes flow continuously either by leakage or by intentional releases, it must be screened. The reservoir does remain impacted by natural flood events from its watershed which are not controlled and these peak flows are the values of greater concern with respect to escapement. Since the average daily flows received by the reservoir are less than the primary outlet capacity of 200 cfs and routed flood flows up approximately to the 10-year event can also be handled by the primary outlet without the use of the service spillway, most of the outflow regulation can occur through use of only the primary outlet. However, to obtain full exclusion up to the 100-year event will require screening of both outlets. Several management techniques which could be utilized to minimize flow through the existing service spillway include:

1. Use the primary outlet to release all flow from the reservoir up to its capacity.
2. Operate the normal maximum reservoir level at 1 to 3 feet below the service spillway crest to eliminate spillway flow due to wind tide and waves and to provide flood routing capability. The specific amount of attenuation is currently unknown because the flood hydrology for the reservoir has not been studied.
3. Operate to the maximum extent possible using the primary outlet in order to release cold water from deep in the reservoir where fish species of concern are least likely to be located and to minimize debris fouling.

These measures can have a significant impact on the frequency and amount of flow through the service spillway but not sufficient to meet the project objectives. Management measures one and three can be accomplished essentially for only the cost of refurbishing the primary outlet to a fully

functional condition. Item 2 involves a loss of storage volume, however, the water supply source which is from administrative spills may not have a monetary value which is appropriate to include as a project cost.

It is important to note that the current means of operation is to use the service spillway to discharge water from the reservoir for reservoir water quality reasons (water contact activity), therefore these suggested operations measures may be inconsistent with the current operations. This issue remains to be resolved separately.

Primary Outlet. The most effective technique for excluding fish from this submerged, controlled release point is, outlet, the use of an MIS or cylindrical screens at the intake. This would mean reconstruction of the intake structures, gate replacement, and screens construction. A cylindrical screen is preferred as it backwashes debris into the reservoir rather than downstream. A maximum flow capacity of 200 cfs is assumed. Four 50 cfs cylindrical screens would be provided with room left to add two additional (Figure 4-2). The 3/32-inch (2.38 mm) screen opening size and the 200 cfs flow rate are commonly supplied sizes and the construction is possible using conventional techniques. The screen is cleaned using a pneumatic backwash.

Table 4-2. Capital Construction Cost for Exclusion to Current Industry Practice at the Primary Outlet at Highline Reservoir

Item	(\$)
Approach Apron Modifications	20,000
Structural Modification	60,000
Screens and Pneumatic Backwash System	100,000
Gate Replacement	20,000
Automatic Level Control	100,000
Unlisted Items	30,000
Contingency	85,000
TOTAL	415,000

The modification is well suited to the site and fully compatible with other dam components and operation; it is easily modified to a different screen size or more screens if needed. Its exclusion reliability should be excellent. The concrete should have over a 50-year design life and the screens, thirty years effective life. Operation and maintenance is minimal and costs should be less than \$10,000 annually.

Service Spillway. Spillways are typically not screened except to retain sport fish within a reservoir. Prevention of downstream migrant diversion entrainment is the typical concern and passage via a spillway is often actually an efficient means of providing downstream passage, consequently spillways are not screened. Prohibiting downstream fish passage via spillway screening is also expensive and potentially obstructs flood conveyance. Since the head on the spillway will vary, a floating screen system or a rigid screen extending above the water surface is needed. In addition, to achieve velocities less than 2 ft/sec for a 100-year flow of 500 cfs through the screen, the screen must be located approximately 50 feet into the reservoir from the spillway crest. A 200-foot long by 5-foot high flexible net screen anchored to the spillway apron and to floats at the surface is one way to provide this screening, however, the typical minimum opening size is 1/4-inch (6.35 mm). To achieve the 3/32-inch screen size of the current industry practice requires a fixed plate or traveling plate metal screen (angled or vertical) permanently anchored to the spillway apron floor at over 10

times the cost of the flexible net screen. A rigid screen in the service spillway approach area has the same inherent limitations as described under the full exclusion narrative. An on shore screening option is again possible but not reasonably feasible. The cost of a barrier net is presented for this option (Table 4-3). In addition, the water level will be maintained 1-3 feet below the crest to prevent wind tide or wave splash over the spillway from occurring. Water level control cost has been included in Table 4-2. There is no definitive monetary value associated with the lost storage due to its source from the administrative spill.

Table 4-3. Capital Construction Cost for Exclusion to Current Industry Practice at the Spillway at Highline Reservoir

Item	(\$)
Approach Apron Preparation	5,000
Net and Skirt	5,000
Superstructure, Anchors, and Floats	10,000
Unlisted Items	2,000
Contingency	6,000
TOTAL	28,000

Construction is almost completely separate from the dam itself and is possible using conventional techniques. It is very easily modified to a different configuration if needed. It would typically be dropped to the bottom or removed when not in use and raised in place for spring snowmelt and through the late summer thunderstorm season. With the net use, exposure to escapement exists both for periods of ice cover when the net is not in place and the water level rises causing spillway overflow and for periods of wind tide and wave splash causing flow over the spillway if a freeboard buffer is not provided. The screen (net) is very inexpensive and can be replaced completely if needed without complete replacement of the screen system. Its exclusion reliability is only moderate at 60 percent. The superstructure and net design life is less than 30 years. The operation and maintenance cost is unknown, but expected to be very small with most of the cost associated with the effort to place the net in its proper seasonal position.

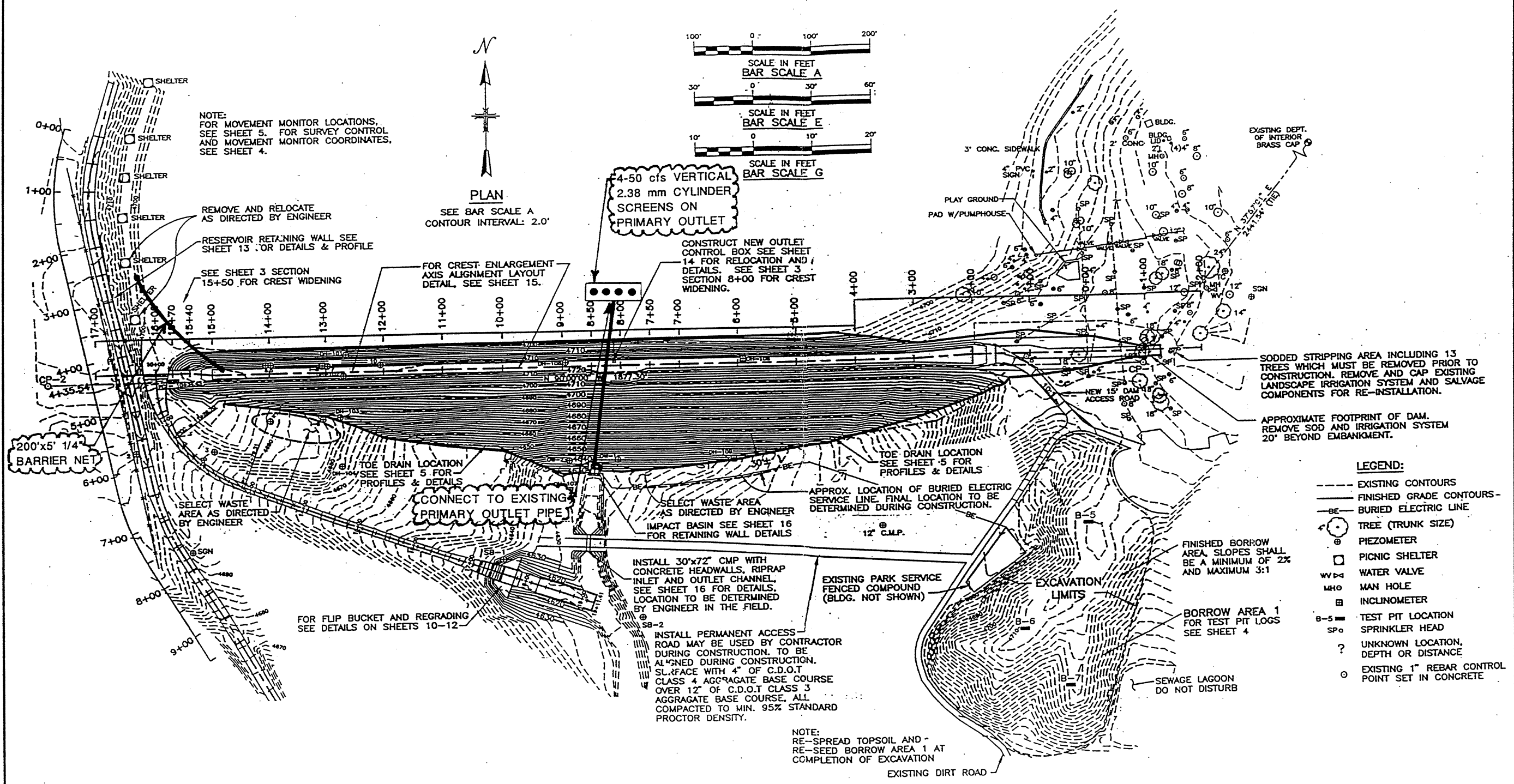


Figure 4-2

HIGHLINE EXCLUSION TO CURRENT INDUSTRY PRACTICE SCHEMATIC

DECEMBER 1996

MILLER ECOLOGICAL CONSULTANTS

Engineers/Scientists/Surveyors
AYRES
ASSOCIATES

COLORADO RIVER
WATER CONSERVATION
DISTRICT

4.3 No Action Alternative

The No Action Alternative would result in continued escapement of non-native fish from Highline reservoir at the current levels. No sampling has been conducted to specifically quantify escapement. The magnitude, size of fish or species and timing of escapement is unknown. Sampling in Salt Wash downstream of the reservoir in the early 1990s suggests that largemouth bass, bluegill and crappie escape from the reservoir.

Species currently in the reservoir include largemouth bass, black crappie, channel catfish and bluegill. None of these species are stocked in Highline Reservoir by the Division of Wildlife for sport fishing. The fish that currently inhabit the reservoir persist from naturally reproduction from fish stocked in the early to late 1980s. No Action would result in no new management or stocking of warm water non-native fish that could successfully reproduce and recruit in the downstream waters. Management alternatives would be limited to stocking of cold water fish that are not likely to survive in downstream waters.

All of the fish listed above have been captured in surveys in Salt Wash and the Colorado River. With No Action, the potential for these fish to escape from Highline Reservoir would continue. Since the escapement has not been quantified, the total contribution and recruitment to Salt Wash and the Colorado River is unknown. It would be expected to continue at the current level and any negative impacts to the listed fish species would continue.

5. SUMMARY OF IMPLEMENTATION ISSUES RELATED TO NON-NATIVE CONTROL STRUCTURES

5.1 General Applicability of Control Structures at Reservoirs

Structures to control escapement of fish species at reservoirs depend on several factors to determine applicability. These factors include species size classes, volume of water to be screened or controlled, type of outlet facility at the reservoir and desired effectiveness of the screening facility. Most existing screening facilities at other reservoirs in Colorado are in place to keep adult game fish in the reservoirs and to prevent escapement downstream and loss of those fish from the fishery. Screens are not designed, in general, to preclude escapement of very small life stages. Current technology, where protection of the smaller life stages is desired, usually includes a bypass to safely pass those fish downstream of the reservoir or diversion.

The current technology can protect down to free-swimming life stages with a standard minimum opening of the screen material of 3/32 inch. The technology exists to protect even smaller size classes but there is an appreciable cost increase to construct facilities of this type.

Reservoir facilities generally screen an outlet rather than the spillway. Spillways in most applications are unprotected and allowed to spill during high flow events. This feature arises from the fact that the usual application for screens is to safely pass migrant fish, not to preclude downstream escapement.

There are many types of screening facilities installed throughout the nation to date. From these applications, it can be concluded that a control structure can be selected to work at Elkhead, Highline and other reservoirs in the upper Colorado basin. Selection of an appropriate option requires several steps.

5.1.1 General Processes for Selection of Criteria and Control Technique for Effective Control of Escapement

Criteria to control escapement can be set in a number of ways. Absent adequate biological, hydrology and engineering information from each reservoir, the assumptions are made that any and all life stages of the non-native species can and do escape from the reservoirs. To protect against these escapements, the control option selected should be one that involves a small screen size to protect against escapement of small life stages and a large screen area to deal with high flow volumes, both of which would be considered a maximum release, minimum life stage criteria. The control options to protect for these conditions are rarely economical and may provide insufficient measurable benefits. It is important to identify, characterize and understand the scope of the problem rather than propose a solution that is effective for controlling escapement that may not exist. Establishing objective criteria for limiting downstream passage includes determining the timing and number of individual fish that leave, which species are escaping, and what size classes. In addition, physical factors at the reservoirs are important. This includes the timing and magnitude of flows either released or passed through the reservoirs. Physical releases and size of those releases can greatly affect cost of the protection facilities.

The general process used to set criteria for effectiveness and the selection of a feasible alternative can take two analytical sequences. The first sequence is conducted without detailed site specific

biological and hydrologic information. The second sequence is conducted with detailed site specific biological and hydrologic information. Each sequence can result in selection of a feasible alternative although as shown in this report, there can be a significant difference in cost of the selected alternative for each sequence.

The first analytical sequence and result is as follows:

1. Assume all life stages of the species of concern are escaping from the reservoir under study.
Result: Requires smallest screen size available for protection.
2. Assume that escapement occurs year round, which requires a protection technology that functions at all times.
Result: Requires protection that functions in all weather conditions.
3. Assume that escapement occurs at all flow levels, which requires facility to be designed to effectively function at the highest flow experienced at the reservoir (e.g. 2100 cfs for 1 in 100 year snowmelt event at Elkhead Dam).
Result: Requires protection on most reservoir outlets - all primary outlets and most service spillways.
4. Define the level of protection desired (e.g. 90 % effective for all life stages at all times).
Result: Sets criteria for screen size and type.
5. Select screen size opening that provides protection for size classes in Step 4.
Result: Based on unknown biological data, screen size selected is based on smallest life form size that has potential to escape. This would be egg diameter or smaller (approximately 0.5 mm).
6. Select screen type that will work at the reservoir (e.g. cylindrical screens, rotary drum screens, fixed screen, barrier nets).
Result: Determined by physical outlet characteristics. Could result in redesign of primary outlet works to release all flow events up to maximum criteria and/or screening on spillway.
7. Design facility to function at the flow rate described in Step 3.
Result: Redesign and reconstruction of outlet works and possible spillway to release all flows and prevent escapement.
8. Develop cost estimate for the design in Step 7.
Result: Costs reflect maximum possible due to wide range of flows and small size of screen material.
9. Develop operation and maintenance costs for facility.
Result: Cost added to estimate in Step 8.

The facility selected and the resulting cost estimate from this sequence will most likely be the maximum needed for protection of a potential escapement rather than actual escapement. It is possible that the maximum and actual escapement could be the same for some reservoirs. However, since the cost to construct a control facility that works for the maximum possible range

of conditions can be extremely high, the second sequence provides a means to incorporate site specific data in the analysis to refine the selection and design of a control facility.

The second analytical sequence is as follows:

1. Collect biological data in the reservoir and the downstream receiving water to determine the number, species, size and timing of escapement from the reservoir.
Result: Known escapement timing, magnitude, species and life stage sizes.
2. Develop the hydrologic data needed to determine the range and timing of flows that occur when fish escape from the reservoir.
Result: Determines range of flows to be used in design of facility.
3. Define the level of protection desired (e.g. 90 % effective for smallest life stages now escaping) and the facilities that require protection.
Result: Design can be set to exclude only those life stages escaping from those facilities that allow escapement, not all that could exist in the reservoir.
4. Select screen size opening and configuration that provides protection for size classes in Step 4.
Result: Screen size would be smallest needed for escaping life stages, not all life stages that exist.
5. Select screen type that will work at the reservoir (e.g. cylindrical screens, rotary drum screens, fixed plate screen, barrier nets) for each element needing screening.
Result: Selection is based on known escapement not perceived escapement. Protection only required where escapement occurs.
6. Design facility to function at the flow rate described in Step 2.
Result: Facility designed for known escapement flows, not all flows possible.
7. Develop cost estimate for the design in Step 7.
Result: Cost based on known biological and hydrologic characteristics, not potential range of conditions. Cost most likely will be lower than in first analytical sequence.
8. Develop operation and maintenance costs for facility.
Result: Cost added to estimate in Step 7.

The first sequence requires assumptions regarding the level and timing of escapement from the reservoir that may be more than are actually required to prevent escapement. This will result in considerably higher costs for the facility than one based on the second analytical sequence. The second sequence will allow the selection and design of a facility that prevents escapement to the desired level but does not overbuild for that objective.

Understanding the above sequences can lead to realistic criteria that allow the design to protect against the scope of the problem as it exists. Without this problem definition, providing protection for a full range of flows that exist and also for all life stages can increase the facility size and cost dramatically. For example, changing the frequency of the peak flow protection from a 100 year event to a 10 year event can have a great effect on the amount of flow that the facility is required to pass. With knowledge of what time of year the species tend to escape or tend to migrate from the reservoir, designing for that flow regime allows the best protection at the

facility. Further, by changing certain criteria, such as approach velocities to screens by an order of magnitude from 0.2 feet to 2.0 fps, can have a dramatic effect in the cost of designing the facility. This has an impact to the reservoir fishery by impinging fish on the screen face but may provide the same benefit of precluding escapement downstream, with little additional loss of fish from the reservoir fishery than under a “no action” alternative.

An appropriate starting point for setting criteria is at the current industry standard. That standard on most facilities is to provide an opening no less than 3/32 inch and to obtain effectiveness of safely bypassing fish around the facility at approximately 90%. Criteria outside of that range with smaller openings and higher efficiencies is possible but the cost to build those facilities increases dramatically.

5.1.2 Knowledge of Escapement Potential and Effect to Downstream Receiving Water

Selection of an appropriate control technology should include knowledge of the escapement potential and the effect of the fish that escape on the downstream receiving water and the stream populations. There is very limited information on escapement from either of the reservoirs involved available to this study.. Biological data has not been collected in a manner or with enough detail that would allow the determination of which size classes, timing, and population size that is escaping from the reservoirs. In addition, there is no information on the magnitude of the affect of those fish that leave the reservoir on the downstream fishery or native fishes. It is believed that the waters receiving non-native species from the reservoirs do maintain those populations, in particular, channel catfish, smallmouth bass, and in the case of Elkhead Reservoir, northern pike. Further, those fish reproduce in the downstream waters and the offspring survive and recruit to the populations downstream.

It is unknown what time of year or what size classes of fish are leaving the reservoir. With the current populations that exist in both those reservoirs, life stages of young of the year through adult could be leaving either of the impoundments. The water quality and water temperature conditions and habitat within the reservoir is suitable for spawning of smallmouth bass and in the case of Highline, also channel catfish. Northern pike could be reproducing in Elkhead but there was no indication of small northern pike downstream of the reservoir in recent surveys.

The aquatic surveys conducted on either receiving stream are limited. There was a brief survey on Elkhead Creek downstream of Elkhead Reservoir in 1995 for gathering information on environmental impacts of an enlarged Elkhead Reservoir. Highline Reservoir has little fish population information on downstream areas with some limited sampling by the Department of Interior, U.S. Fish and Wildlife Service for their national drainwater study. These were spring samples that were collected two years previous to the onset of this study and only at one location. Northern pike, channel catfish and smallmouth bass have been collected in the Yampa River. Channel catfish and smallmouth bass have been collected in the Colorado River.

Detailed information of the size classes and timing of escapement would provide basic biological data to make a sound decision on selection of the appropriate control type at each reservoir. Absent of this information and to protect against escapement of all non-natives, the assumption must be made that all life stages are and can escape from the reservoir and are detrimental to the native species in the receiving water. Therefore, protection criteria would be set to protect for all of those life stages. As has been shown in this report, this is or can be a costly decision.

5.1.3 Management Options

In addition to or in place of building physical control structures, management options may be feasible at some reservoirs. These management options include alternate stocking policies, reservoir operations and harvest regulations.

Fisheries management options include stocking non-competitive species in the reservoirs. This could include stocking of warm water species that are not suited to riverine environments and therefore have little chance of survival and reproduction if they escape from the reservoir. Examples of these species are largemouth bass and bluegill. Stocking cold water species that would not survive in the downstream warm water environments is also an option. Detailed evaluations of either of those options is beyond the scope of this review. Potential species for both of those are listed in the stocking policies for the upper basin and the list of species that would be allowed are listed in that document.

Reservoir management options include attenuation of reservoir inflow and releasing through an alternate outlet works that is either “deep water” to have a cold water release and therefore very little potential of releasing warm water fish downstream or by managing reservoir levels so that spawning does not persist in the reservoirs and that the warm water fish that are stocked are stocked at a larger size. The control options that would be applied in this situation could be a larger mesh net or screen facility that is a lower overall size and cost than the small mesh while still controlling the escapement of larger adults of the species. Inadequate reservoir depth probably eliminates this option at Highline or Elkhead Reservoirs. Also, to pursue water management issues requires detailed hydrologic information which does not exist at this time for Highline Reservoir. Impacts to water rights and water supplies due to Elkhead reservoir operation would also require further investigation before implementing this option.

5.1.4 Engineering Evaluation and Model Testing

With the implementation of any control structure in a new situation such as this, a detailed engineering evaluation and prototype or model testing should be conducted. Screen orientation and the details of screen hydraulic efficiency and structural integrity are specific areas of interest. Both facilities in this study, Highline and Elkhead Reservoirs, have the unique situation of spillways that must be protected given the frequency of spill at both reservoirs due to hydrologic conditions and current reservoir operation. The design of spillway exclusion features must be preceded by an engineering evaluation that addresses dam safety issues and also how the spillway will function in combination with fish exclusion. Sweeping velocities to carry debris away from the outlet and spillway protection measures must also be addressed for this unique in-reservoir application. In addition, the size and configuration of some of the suggested facilities differ from more conventional applications, therefore, design criteria should be carefully confirmed including specifically the velocity criteria (2 ft/sec) and its impact on all structural elements.

5.1.5 Implementation of Control Option

The next phase of this study would be selection by decision makers of the appropriate control option of those listed above. Part of that implementation process is to go from a conceptual phase of this report to an evaluation of the problem, preliminary design, then final design and construction.

That design phase should include engineering evaluation and model testing, refinement of the escapement behavior of the species of concern at the facilities, refinement of screen design criteria and structural and hydraulic design. Other issues that should be factored into this implementation are the decision of what the benefit cost criteria will be for the facility, what agency or group of agencies will cover cost of design and installation of the facility, and also performance monitoring and maintenance after the facility has been installed.

Any option that is selected should have a monitoring phase involved with it since this is a new application of screening controls. That monitoring phase includes both biological and engineering monitoring. Biological monitoring includes escapement evaluation prior to installation and then after installation of the feature. Biological evaluations which include species numbers, identification of timing of movement of species and the flows at which the species leave the reservoirs. Engineering evaluations after construction include routine operation of the control structure, maintenance issues, and hydraulic/structural design confirmation. These would be used to revise operations to be more effective and to establish revised design criteria for other applications. The three options addressed here included a no action alternative that leaves the reservoirs as is with no physical control at either reservoir; a full exclusion alternative which keep all life stages in the reservoir; and a exclusion to current industry practice alternative. Issues are involved with each one of those alternatives are identified.

5.2 No Action

The no action alternative would keep the status quo at each reservoir. In the case of both Elkhead and Highline reservoirs that means no additional stocking of any warm water fish and occasionally stocking salmonids requiring no protection for escapement. Flows at Elkhead would continue to fluctuate and spill annually up to 3,000 cfs in the highest water years. Highline would have spillway releases annually. Both reservoirs have spill patterns that result in probable loss of fish to downstream receiving waters.

Downstream receiving waters for both Elkhead Reservoir and Highline Reservoir have water quality conditions that allow survival of non-native fish that escape. Water quality at Elkhead Reservoir is good with the exception of high turbidity. Water quality in Mack Wash downstream of Highline Reservoir has high salinity and conductivity and high selenium levels. However, sampling in Salt Creek downstream from Highline Reservoir shows that both native and non-native fish persist and survive in the stream year round and that the conditions are not acutely toxic, even with the elevated parameters for water quality conditions.

5.2.1 Escapement Potential

The escapement potential is unknown at either reservoir. It is believed that fish do escape annually from both reservoirs and probably contribute to recruitment in the downstream receiving waters. In the case of Elkhead, the species of concern are channel catfish, smallmouth bass and northern pike. For Highline Reservoir, the species of concern in this evaluation are smallmouth bass and channel catfish. Additionally at Highline, bluegill, crappie, and largemouth bass can escape from the reservoir but probably do not recruit in the riverine environment downstream but could have a continual short term impact. The number and size of individuals escaping from the reservoir is unknown.

At Elkhead Reservoir, recent fish collection data downstream of the reservoir in late fall shows that there were numerous small smallmouth bass downstream of the reservoir. It is probable that those fish escaped from Elkhead Reservoir after spawning. Studies are not detailed enough to show if those fish actually came from Elkhead Reservoir or were spawned in the stream. If no action on either reservoir is taken, this escapement potential would continue as it is today.

5.2.2 Potential Downstream Effects

With continued escapement from the reservoirs, there are potential fish that would escape and survive in the downstream receiving waters. These fish could survive and recruit to the populations. Magnitude of this impact cannot be quantified due to lack of biological data at either receiving stream or mainstem downstream of the tributaries on which those reservoirs exist. It is possible that, if escapement is unchecked, these fish could increase non-native populations in the downstream receiving waters and impacts to listed fish would continue.

5.3 Full Exclusion

The full exclusion option is designed to exclude all life stages from escaping the subject reservoirs at an efficiency of greater than 90% exclusion. No bypass facility was included in this option.

5.3.1 Control Structure Type

Control structures at Elkhead Reservoir and Highline Reservoir would consist of a screening facility with 0.5 mm mesh sizes to preclude escapement of all life stages from the reservoirs and approach velocities would be allowed to reach 2 fps.

Control structures would be a series of cylindrical screens placed on the primary outlet. All releases from the reservoir, up to the 100 year event, would pass through these screens. This would require construction of a new low level outlet works at increased flow capacity and an intake manifold for installation of the cylinders in the reservoir. There would be no additional protection needed for the spillway during events of less frequent flow. This control type would be used on both Elkhead and Highline Reservoirs. The normal water surface of the reservoir would be regulated 1-3 feet below the service spillway crest to provide flow attenuation and, more importantly, wind tide or wave splash overtopping of the spillway.

5.3.2 Effectiveness on Various Life Stages

Both control structure types would work at 90% or higher efficiency on all egg and larger (0.5 mm) life stages. Small life stages that are non-free swimming, either egg or larvae, would be controlled by this structure type. The smaller passive life stages could be impinged because of high velocities and would then be removed by the cleaning mechanism from the screen.

5.3.3 Effect on Reservoir Fishery

At both reservoirs under the full exclusion option, there is a potential to lose some reservoir fish to the screening mechanism. This would include impingement or possible injury to the fish from contact with the screen itself. Fish that are impinged would be cleaned and moved off with the debris as the screen is cleaned. This in turn could have a negative effect on the reservoir fishery and decrease population size of warm water fish within the reservoirs. The level of impact is unknown because of the lack of biological data on fish population structure within the reservoirs themselves, the level of escapement from the reservoirs and operational experience with such facilities. Loss of fish from the reservoir would be lower than the current escapement due to no screening. Full exclusion, with the very restricted escapement, would allow more aggressive reservoir sport fisheries management.

5.3.4 Potential Downstream Effects

At both Highline and Elkhead Reservoirs, the effect of the current escapement on the downstream receiving waters has not been quantified. It is believed that some of these fish do survive and recruit to the populations downstream and, therefore, increase conflicts with the downstream endangered species. Under the full exclusion alternative, with less escapement from the reservoirs, this potential effect could be decreased. Level of decrease cannot be quantified because of the lack of biological data on the escapement from the reservoirs and the survival rates in the receiving waters downstream. A proportion of all flow rates greater than the 100 year event would pass the reservoir unscreened via the surface service spillway and potentially carry with it some portion of the fish population.

5.3.5 Estimated Costs

Estimated costs for full exclusion at Elkhead Reservoir are approximately \$33 million for capital construction. Estimated cost for capital construction at Highline Reservoir is approximately \$8 million. In addition, there would be ongoing operation and maintenance costs at both facilities. Elkhead Reservoir operation and maintenance is estimated at \$50,000.00 annually. Highline Reservoir operation and maintenance is estimated at \$15,000.00 annually.

5.4 Exclusion to Current Industry Practice

Current industry practice includes protection to a mesh size of 3/32 inch and at an effectiveness of approximately 90% diversion of fish around the screen face and safely bypass downstream. In the current application, there would be no fish bypass associated with the facility and the fish would be allowed to move away from the screen under their own swimming ability or they would be impinged on the screen and removed with the cleaning facilities. Smaller life forms then would pass through the screen.

5.4.1 Control Structure Type

Control structures at both Elkhead and Highline Reservoirs would be fixed cylindrical screens with cleaning mechanisms mounted to the primary outlet works via a new intake manifold. Screen wire mesh size would be a 3/32 inch minimum and velocities would be allowed to reach 2

fps. In addition, there would be a ¼ inch barrier net placed in front of each spillway to preclude escapement of larger fish from the reservoir.

5.4.2 Effectiveness on Various Life Stages

This control option at both Elkhead and Highline Reservoirs would be most effective on the larger life stages of all species. These life stages include juvenile up through adult. Effectiveness is based on the size of the fish and this will vary by individual species but in general the minimum size of these fish would be entering the fall of the year as juvenile fish and at a size that they would be able to survive over winter. In addition, all larger juvenile and adult life stages would be effectively screened by this facility. The facility should operate at approximately 90% or higher prevention of escapement on the life stages juvenile and larger. Smaller life stages would be able to pass the dam to the downstream receiving waters. Fish of larger sizes would not be able to pass through the barrier net during periods of flow occurring through the service spillway.

5.4.3 Effect on Reservoir Fishery

This control option would have less retention of fish in the reservoir than the full exclusion. Fish that contact the screen could be impinged or, if smaller, would pass through and be lost to the reservoir fishery. There would be some impact because of impingement and loss of fish from the reservoir fishery, however, the loss to the reservoir fishery should be less than the current no action alternative. Under the exclusion to current industry practice, fish of small size would still be able to leave; the larger adult sizes should be retained and therefore, have a positive effect on the reservoir fishery by retaining adult size classes.

5.4.4 Potential Downstream Effects

There is no existing biological data to determine the current biological impact under the no action alternative, therefore, to determine impacts to exclusion to the current industry practice, one could assume that reduction in escapement may cause reduction in recruitment to downstream populations. Magnitude of this decrease is unknown. It would be expected that if a higher percentage of fish are retained in the reservoir, that there would be less recruitment in the downstream reaches particularly those species that can survive in the receiving waters.

5.4.5 Estimated Costs

Estimated costs for these facilities range from approximately \$900,000.00 at Elkhead Reservoir to \$300,000.00 at Highline Reservoir. Associated with this construction cost would be an operation and maintenance cost, estimated at less than \$10,000.00 annually.

5.5 Conclusions

Control structures to reduce or possibly eliminate escapement at Elkhead and Highline Reservoirs are feasible. Costs based on the desired level of protection range from \$33 million to \$900,000 at

Elkhead Reservoir and \$8 million to \$300,000 at Highline Reservoir. Costs are relative to the life stages effectively prevented from escaping and effective flow frequency range. Little data exists to make an informed decision regarding the benefit to the endangered species downstream by elimination of non-native escapement from either reservoir.

The control structures selected for both the full exclusion and the current industry practice are cylindrical screens on the primary outlet. There are no biological data on escapement from either reservoir to justify selection of one alternative over the other. If actual escapement data existed or was collected at each reservoir, those data could be used as the basis for selecting a particular alternative.

Escapement data could determine what “full exclusion” means in terms of current escapement. For example, if only larger size classes are escaping the alternative that protects to the current industry practice should be selected and would in effect become a “full exclusion” level of protection. If small size classes (i.e. larval stages) are escaping, then the full exclusion alternative should be selected.

Other options for control of escapement, such as reservoir operation and alternate stocking are potential means to control escapement but cannot be recommended independent of installing a structural alternative. The reason for this is the absence of known escapement data and the unknown relationship between the fish that escape and the survival and recruitment of those fish in the downstream waters. Therefore, neither of these options meet the criteria set by either of the objectives in this study.

The selection of either the full exclusion alternative or the current industry practice alternative will be the responsibility of the decision makers for the resource or private agencies funding the exclusion alternative.

5.6 Recommendations

The final decision on an escapement control option at each facility should include further data gathering and analysis of the escapement problem. The following steps, listed in sequence of action, are recommended:

1. Design and initiate multiple year biological studies to ascertain the nature and extent of the escapement at both reservoirs.
2. Undertake biological studies in the downstream receiving waters, tributary and mainstem, to determine species composition, size classes, and relative abundance of non-native portion of the fish community.
3. Initiate and maintain continuous outflow and water level monitoring at both reservoirs.
4. After completion of baseline biological studies, a first step aimed at stopping escapement could be to construct ¼ inch net type barriers at the inlet of all primary outlets and spillways. Construction could occur before completion of biologic studies if deemed necessary but may affect the study results.
5. Rehabilitate the primary outlet structure gates at both dams to a fully functional condition.
6. Establish a no or minimal cost management plan unique to reach reservoir which has minimization of escapement as an objective.
7. Operate each reservoir in accordance with the new reservoir management plan.
8. Determine impacts to water rights and supplies from proposed reservoir management changes.

9. Conduct detailed hydrologic study at Highline Reservoir to determine flow frequency.
10. Re-evaluate and revise (based on biological monitoring) escapement criteria based upon the relative potential impact each reservoir has on the magnitude of the entire escapement problem.
11. Conduct a prototype cylindrical screen facility evaluation. This could be constructed on the Starr Ditch outlet with interchangeable screen elements and monitor its performance.
12. Initiate engineering studies, model testing and related fieldwork needed to implement the revised site specific escapement control structure.

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American Society of Civil Engineers. GUIDELINES FOR DESIGN OF INTAKES FOR HYDROELECTRIC PLANTS. 1995.

ABSTRACT: Today, the designer of a hydroelectric facility has to take a variety of issues into consideration including the protection of and mitigation for fish and wildlife, the protection of recreational opportunities, and the general preservation of environmental quality. This results in the need for accurate, continuously regulated bypass flows, fish entrainment prevention, and other environmental mitigation. These can reduce the amount of head and flows available for power generation. Therefore, power plants have to operate at maximum efficiency to make the most of the available head and flows in order to be economically viable. Under the Energy Division of the American Society of Civil Engineers, a multidiscipline task committee was formed to develop a state-of-the-art guidelines document for the sound environmental design of hydropower intakes. This document, Guidelines for Design of Intakes for Hydroelectric Plants, includes over 400 pages, many of which are graphics and photos, that provide information on intake types and features, hydraulic design considerations, forebay, trashrack and gate design, structural design, fisheries considerations, ice, sedimentation, environmental factors, hydraulic models, and evaluation of existing intakes. These guidelines factor in years of experience of specialists from the engineering and biological communities and is intended for use by new planners and designers of intake structures for hydroelectric plants as well as provide specialized information on a variety of topics related to intake design.

Anderson, M.R.; J.A. DiVito, and Y.G. Mussalli DESIGN AND OPERATION OF ANGLED-SCREEN INTAKE. J. Hydraulic Engr., 114(6):598-615. June 1988.

ABSTRACT: A new angled-screen intake was constructed in 1984 at the Brayton Point Generating Station Unit 4 to protect fish and larvae and to allow the use of a once-through cooling system. The intake features low approach velocity, 1-mm fine-mesh screens, flush angled screens with fish buckets, and low-pressure sprays. The installation of the angled-screen structure has proven to be an economical option for operation of Unit 4 at Brayton Point Station in an open-cycle mode, while providing maximum protection for marine organisms. This protection has been accomplished by modifying standard intake traveling screen and arranging them to suit fish swimming patterns while adding fish pumps for the bypassing of fish and provisions for impingement release of nonguiding species.

Barnthouse, L. W.; W. Van Winkle and D. S. Vaughan IMPINGEMENT LOSSES OF WHITE PERCH AT HUDSON RIVER POWER PLANTS: MAGNITUDE AND BIOLOGICAL SIGNIFICANCE. Environ. Manage., 7(4):355-364. July 1983. SFA 29(3)

ABSTRACT: We performed a quantitative assessment of the impact of impingement at power plants on the Hudson River white perch population. We estimated that impingement reduces the abundance of each white perch year class by at least 10% and probably by 15-20% or more after 203 years of vulnerability to power plants. We attempted to detect effects of impingement on average year-class abundance of white perch from a time series of abundance indices derived from impingement data. We found, however, that neither impingement collection rates observed

at Hudson River power plants nor beach seine data provide a reliable index of year-class strength in white perch. Even if a reliable index were developed, natural fluctuations in year-class strength are great enough that a short-term monitoring program would be inadequate for detecting even a large reduction in average year-class strength. We performed a multipopulation analysis using simple food chain and food web models. The results suggest that any long-term decline in white perch abundance caused by impingement should be accompanied by an increase in the abundance of one or more competing fish species and by an increase in the biomass of adult white perch relative to young-of-the year. We conclude that 1) at present, assessments of population-level impact of impingement should focus on short-term effects, 2) research is needed to develop a reliable index of year-class strength for use in long-term monitoring programs, 3) identification and quantification of natural environmental factors influencing year-class strength are needed to improve our ability to predict and detect changes in abundance, and 4) it would be useful in designing monitoring programs to focus on detecting patterns of change among populations and age groups rather than solely on declines in abundance of individual populations.

Beach, M. H. FISH PASS DESIGN--CRITERIA FOR THE DESIGN AND APPROVAL OF FISH PASSES AND OTHER STRUCTURES TO FACILITATE THE PASSAGE OF MIGRATORY FISH IN RIVERS. Fish. Res. Tech. Rep. (Lowestoft), No. 78. 46p. 1984. SFA 30(3)

ABSTRACT: A salmon or sea-trout's river passage to spawning gravel is often restricted by the structures and practices associated with water resource management for water supply and flood prevention: the attitudes of the biologist and the water engineer to river management are consequently somewhat different. This report explains in simple terms how the fish and water control requirements can be reconciled and proposes design criteria to enable fish to negotiate structures such as sluice gates, weirs and fish passes. It also explains the Ministry's legal position with regard to obstructions in migratory fish rivers and gives examples of the procedures necessary to obtain approval for satisfactory structures. The information on fish swimming speeds and endurance and the relation of these parameters to water control structures and fish passes is essential to the effective management of migratory fish in our rivers.

Bomford, Jim A. and Maurice G. Lirette DESIGN, OPERATION, AND EVALUATION OF AN INVERTED, INCLINED, OUTMIGRANT FISH SCREEN. Am. Fish. Soc. Symp., No. 10. p. 228-236. 1991. FR 38(2)

ABSTRACT: A unique screening device for juvenile fish has been built on, and is operating in, a hydroelectric canal on Vancouver Island, British Columbia. The canal diverts up to 42.5 m³/s, and the screen is designed to remove outmigrant smolts of steelhead *Oncorhynchus mykiss* and coho salmon *O. kisutch* from the canal inflow and return them to the Salmon River. The 25-m-long by 6.7-m-wide screen is supported on a removable steel truss suspended in a rectangular section of the canal flowing at a depth of 2.9 m. It incorporates 170 m² of slotted woven-wire-mesh screen, and when in service, it inclines downward in the downstream direction, forcing fish into a collector resting on the canal floor at its lower end. The collector diverts the fish laterally out of the canal and into the bypass works. Although the screen provides less than 100% protection, because of compromises required by budgetary constraints, it is a practical, cost-effective alternative to more conventional designs.

Brege, Dean A., Richard C. Johnsen, Richard W. Frazier and Winston E. Farr BOX NET FOR COLLECTION OF JUVENILE SALMONIDS FROM TURBINE INTAKE GATEWELLS AT JOHN DAY DAM. N. Am. J. Fish. Manage., 7(3):446-448. 1987. FR 33(1)

ABSTRACT: A large box net was constructed to capture migrating juvenile salmonids from turbine intake gatewells at hydroelectric dams. This net, operated at John Day Dam on the Columbia River, caught an average of 97.3% of the fall chinook salmon *Oncorhynchus tshawytscha* smolts present in the gatewells. The net is presently being used at other hydroelectric dams on the Columbia River system.

Cada, Glenn F. and Michael J. Sale STATUS OF FISH PASSAGE FACILITIES AT NONFEDERAL HYDROPOWER PROJECTS. Fisheries (Bethesda), 18(7):4-12. 1993. FR 38(3)

ABSTRACT: The status of direct mitigation practices for fish passage was assessed as part of an ongoing, multi-year study of the costs and benefits of environmental mitigation measures at nonfederal hydroelectric power plants. Information was obtained from the Federal Energy Regulatory Commission, hydropower developers and state and federal resource agencies involved in hydropower regulation. Fish ladders were found to be the most common means of passing fish upstream; elevators/lifts were less common, but their use appears to be increasing. A wide variety of mitigative measures, including spill flows, narrow-mesh intake screens, angled bar racks and light-based or sound-based guidance measures, is employed to prevent fish from being drawn into turbine intakes. Performance monitoring and detailed, quantifiable performance criteria were frequently lacking. Fifty-two of the 66 projects (82%) with operating downstream fish passage measures had no performance monitoring requirements; 50 of 71 project operators (70%) indicated that no performance objectives had been specified for the mitigative measures. We found that comprehensive field studies needed to evaluate the effectiveness of fish passage devices have been rare.

Cannon, J.B., G.F. Cada, K.K. Campbell, D.W. Lee, and A.T. Szluha FISH PROTECTION AT STEAM-ELECTRIC POWER PLANTS: ALTERNATIVE SCREENING DEVICES. Report ORNL/TM-6472. July 1979.

ABSTRACT: This study examines engineering feasibility, biological effectiveness and costs of alternative screening devices to be utilized for fish protection at power plant cooling-water intakes. Physical screening barriers which are considered include: conventional vertical traveling screens (VTS) with modifications, center-flow traveling screens, flush-mounted horizontal traveling screens (HTS), cylindrical wedge-wire screens, and radial well intakes. Behavioral screening devices considered are the angled HTS and louver and angled screen diversion systems. Radial well intakes and cylindrical wedge-wire screens function as exclusion devices. Exclusion devices conceptually provide the most effective means of minimizing impingement and entrainment mortality. The extent to which physical screening devices can reduce impingement and entrainment mortality is site and species specific. It was concluded that alternative devices are available to potentially reduce impingement and entrainment but that these are site specific.

Clark, Robert D. and James J. Strong FACTORS AFFECTING PERFORMANCE OF THE GLENN-COLUSA FISH SCREEN. Am. Fish. Soc. Symp., No. 10.p. 249-255. 1991. FR 38(2)

ABSTRACT: The Glenn-Colusa Irrigation District fish screen consists of 40 screen drums, each 17-ft. in diameter and 8 ft. wide, arranged in a linear configuration along a dredged side channel of the Sacramento River, and having a total capacity of 3,000 ft. ³/s. The original purpose of the Glenn-Colusa fish screen was to protect migrating juvenile chinook salmon *Oncorhynchus tshawytscha* as they moved downstream. The screens have proven troublesome because of changes in water surface elevation and profile brought about by erosion and siltation in the channel during heavy winter storms. Effective screen area and bypass flows have been substantially reduced. Currently, a single 17-ft. prototype drum is being tested. It has been retrofitted with profile-wire screen with 3/32-in. slots versus wire mesh of 4-by-4 (wires per inch) stainless steel.

Crook, Peter H. DESIGN OF LOW-COST FISHWAYS. Am. Fish. Soc. Symp., No. 10. p. 256-263. 1991. FR 38(2)

ABSTRACT: Fishways have traditionally consisted of concrete flumes built on the side of a dam. This paper presents two alternative constructions that have recently been built in southwestern Ontario for the passage of rainbow trout *Oncorhynchus mykiss* and other salmonid species around mill dam structures. The first structure is fishlock; after fish enter a lower chamber, water fills a transport pipe, allowing fish to swim above the dam. Concrete sewer pipe was used for the transport and ancillary water supply pipes.. The second structure is an earthen bypass channel equipped with concrete baffle blocks. Both bypass methods resulted in considerable cost savings compared with concrete flume construction.

Davies, J. K. A REVIEW OF INFORMATION RELATING TO FISH PASSAGE THROUGH TURBINES: IMPLICATIONS TO TIDAL POWER SCHEMES. J. Fish Biol., 33(Supp. A):111-126. 1988. FR 34(1)

ABSTRACT: Field and laboratory studies on the passage of adult and juvenile fish through hydroelectric turbines are reviewed, with special emphasis on tidal schemes in operation. Although the types of injury which fish incur and their frequency are well documented, little appears to be known about the specific hydraulic conditions within the turbine structure which actually cause the injury, despite the fact that the four main causes of fish loss (abrupt changes in pressure, water turbulence, shearing currents, and mechanical contact with turbine blades) have been identified. Factors causing fish mortality fall into two main categories: (1) hydraulic conditions of pressure change, cavitation, shearing, and turbulence, producing direct, characteristic injuries; (2) conditions influencing the likelihood of actual fish collision with turbine components. These factors can be enhanced or reduced by alterations in turbine operation and, possibly, design. The significance of fish behavior and ecology with respect to prediction of numbers of fish passing through installations, plus criteria which govern actual mortality rates, have yet to be elucidated.

DuBois, R.B. and S.P. Gloss MORTALITY OF JUVENILE AMERICAN SHAD AND STRIPED BASS PASSED THROUGH OSSBERGER CROSSFLOW TURBINES AT A SMALL-SCALE HYDROELECTRIC SITE. No. Am. J. Fish. Mgmt., 13(1):178-185. 1993.

ABSTRACT: A full-recovery technique was used in mortality experiments conducted with juveniles of American shad *Alosa sapidissima* and striped bass *Morone saxatilis* passed through

Ossberger crossflow turbines to obtain antecedent information about their fish passage characteristics. Immediate turbine-induced mortality was 66% for 85-mm-long (total length) American shad. Turbine-induced mortality of striped bass was significantly related to the total length of the fish and ranged from 16% for 67-83-mm-long fish to 39% for 136-mm-long fish immediately after passage; after 24 h, turbine-induced mortalities of these two size-groups were 61 and 72%, respectively. The mortality of striped bass was not affected by power output (320-600 kW) of the turbine or by turbine size (650 versus 850 kW). Because of high mortality of control fish, the full-recovery technique was not fully adequate for obtaining reliable delayed-mortality estimates for these fragile fish species.

DuBois, Robert B., John E. Miller and Scott D. Plaster AN INCLINED-SCREEN SMOLT TRAP WITH ADJUSTABLE SCREEN FOR HIGHLY VARIABLE FLOWS. N. Am. J. Fish. Manage., 11(2):155-159. 1991. FR 36(3)

ABSTRACT: An inexpensive inclined-screen smolt trap was designed and constructed for use in rivers having highly variable flow regimes. The trap included a pontoon-supported floating catch barge and an adjustable inclined screen made of parallel aluminum rods that effectively strained large volumes of water, transported smolts without injury, and was highly resistant to debris buildup and easily cleaned. The inclined screen was supported by a movable carriage within a stationary frame that permitted the screen to be deployed at a wide range of depths and angles depending on flow conditions and amount of water-borne debris. The trap was operated for three field seasons in the Bois Brule River, a large Wisconsin tributary to western Lake Superior, to capture and retain parr and smolts of steelhead *Oncorhynchus mykiss*, coho salmon *O. kisutch*, chinook salmon *O. tshawytscha*, and brown trout *Salmo trutta*, ranging from 45 to 300 mm in total length. The trap remained operational in flows ranging from 2.1 to 17.3 m³/s and through large variations in debris content without sustaining damage or requiring excessive maintenance. The design could be adapted to most locations where a low-head dam exists or can be established.

Ebel, W. J. REVIEW OF EFFECTS OF ENVIRONMENTAL DEGRADATION ON THE FRESHWATER STAGES OF ANADROMOUS FISH. Habitat Modification and Freshwater Fisheries. John S. Alabaster, editor., p. 62-79. 1985. In English with French summary. FR 34(3)

ABSTRACT: Early research efforts begun in the 1950s and continued to the present to address the problems of environmental degradation on anadromous fish were centered mainly on fish behavioral work designed to provide solutions to fish passage problems. Information leading to solutions to passage problems for both adult and juvenile salmonids caused by dams and impoundments in the Columbia River was the highest priority of this research. Research on various fisheries enhancement measures was also begun in the late 1960s to increase production of Columbia River salmon. Some conclusions drawn from the study are: (1) Velocities in adult fish passage facilities should fall within the range of 2.4-4.0 m/s for optimum passage of salmonids; (2) Use of electrical guidance systems to divert fish from turbines or into bypass flumes or traps in rivers was effective under controlled conditions, but was impractical for operational field applications; (3) Use of water and air jets, sound, and lights to guide juvenile migrants were effective only under limited and controlled environmental conditions; (4) Traveling screens, suspended at an angle to the stream flow, were effective in flumes or irrigation canals for guiding juvenile migrants, but costs and engineering problems preclude their use at dams or large streams; (5) Adult passage of anadromous salmonids through both large and small reservoirs was not a serious problem in reservoirs studied on the Columbia River, except during

periods of high water temperature; (6) Juvenile migrants were adversely affected by the impoundments on the Columbia River, which caused substantial delays in migration. These delays, coupled with changed environmental conditions in the river, caused substantial mortality to juvenile migrants which was as high as 95% in the Columbia River during low flow periods; and (7) Studies of the effect of water temperatures and supersaturation of atmospheric gas on salmonids led to the establishment of water temperature and atmospheric gas standards for the Columbia River. Any increase in temperature above 17-20 C or increase in atmospheric gas above 110% of the air-saturation value was considered detrimental to fish in the Columbia River.

Ebel, W.J. MAJOR PASSAGE PROBLEMS. Proc. Of a Symposium, Vancouver, WA. Amer. Fish. Soc., Bethesda, MD. 33-39. 1977.

ABSTRACT: This paper discusses the problems of survival of steelhead trout and chinook salmon stocks in the upper Snake River and the effect which the construction of dams along the Snake and Columbia Rivers has on this survival. Since 1969 adult return percentages of both species have declined at an alarming rate. This drop reflects losses of juveniles due to fish passage problems. The majority of these losses are attributed to turbines, supersaturation of water with nitrogen, delay in migration caused by impoundments, and an increase in predation. The average turbine mortality among migrating smolts is between 10 and 15%. Diversion screens have been developed and refined to the point where they are workable and can be used to divert fish from turbines adequately but future research will be centered on obtaining an optimum system. A collection and transport system is being investigated to determine the effects of transportation on homing and survival of juveniles. The data indicate that this system has been helpful in increasing the survival of both chinook and steelhead.

Edwards, S.J., J. Dembeck, T.E. Pease, M.J. Skelly and D. Rengert EFFECTIVENESS OF ANGLED-SCREEN INTAKE SYSTEM. J. Hydraulic Engr, 114(6): 626-640. June 1988.

ABSTRACT: The Unit 6 intake system at Niagara Mohawk Power Corporation's Oswego Steam Station Unit 6 is designed to mitigate periodic losses of lake Ontario fish by bypassing and returning to the lake those fish that enter the offshore intake. Fish are diverted along four traveling water screens installed in a chevron arrangement angled with respect to the flow. Jet pumps provide bypass flow necessary for fish return to the lake. Three years of information on the operational and biological effectiveness of the angled-screen fish diversion system are presented and discussed. System components are discussed in terms of maintenance requirements and operation relative to an adjacent conventional intake system (Unit 5). Hydraulic measurements are also presented. Biological effectiveness of this system is compared with that of a once-through system with conventional vertical traveling screens. Evaluation of fish survival up to 96 hr after diversion indicates seasonal and species-specific survival.

Fiuzat, A. A., C. E. Sweeney and C. W. Long ASSESSING AND IMPROVING FISH GUIDING EFFICIENCY OF SUBMERSIBLE TRAVELING SCREENS. Proceedings of the Symposium on Small Hydropower and Fisheries. Forrest W. Olson, Robert G. White, and R. H. Hamre, editors., p. 279-285. 1985. FR 32(4)

ABSTRACT: Migrating fish travel several hundred miles into the rivers in Northwestern United States for their reproduction needs. The same return distance has to be traveled by the young fish to complete their life cycle in sea water.. Construction of numerous dams and hydropower plants

along these rivers has caused the loss of a portion of the fish traveling past each dam. The net result is a drastic reduction of game fish population. The most effective method of screening the anadromous fish out of the river water has been to guide fish with a submersible traveling screen (STS) into the gatewell of each dam and subsequently transport them to a location downstream of all the dams. However, the efficiency of the presently operating STS's at Lower Granite dam in capturing the fish can be improved by modifications to their original design and incorporating the modifications in the future installations of the STS's. Since STS's are designed to be installed in the gatewells of existing intake structures, they are an obvious choice for retrofit to upgrade facilities. Such upgrade fits well with low head hydro applications as many are retrofits. This study was initiated to improve the fish guiding efficiencies of STS's installed in the Lower Granite Dam and to be installed in the John Day Dam. The tests were carried out in 3 series. The number, sequence, and specific modifications to be tested were specified by the National Marine Fisheries Service (NMFS), Northwest and Alaska Fisheries Center and by the U.S. Army Corps of Engineers, Walla Walla District. In the first series of tests attention was focused on the hydraulics of flow through the intake structure and the effect of the STS and related variables on the overall flow pattern. In the second series the discharge quantities and flow patterns through the gatewell and across the vertical barrier screens (VBS) were determined. However, the overall flow data through the intake structure were also collected. As a result of the first two series, a third set of tests was conducted testing additional modifications and alternatives while still collecting overall velocity data.

Fletcher, R.I. FLOW DYNAMICS AND FISH RECOVERY EXPERIMENTS: WATER INTAKE SYSTEMS. Trans. Am. Fish. Soc., 119(3):393-415. May 1990.

ABSTRACT: Large water-use facilities are often equipped with vertically traveling debris barriers known as Ristroph screens. The imposed fish mortalities associated with these machines are commonly attributed to the consequences of impingements, but laboratory and field experiments indicate that in those circumstances where the screens travel continuously and where water speeds are moderate, the major underwater injuries are attributable instead to buffeting of captured fish within the fish troughs proper. Captured fish often escaped an ascending trough just before its leading edge broke the water surface, and their repeated encounters with the fish recovery apparatus increased the risk of mortality. From flow analyses of reshaped trough and screen profiles, a flow spoiler was devised that eliminates the trough vortex and buffeting of captive fish. The escape of fish at the water surface was eliminated by means of an auxiliary screen affixed to the leading edge of each fish trough. Field experiments revealed other sources of mortality, chief of which was the entanglement of fish in captured debris. As a countermeasure, the order of removing fish and debris was reversed. A reconfigured machine, including the redesigned fish-catching apparatus, was installed and tested at a nuclear generating station on the Hudson River estuary. In tests similar to those on the unimproved machine, injuries and deaths were reduced from 53 to 9% for striped bass *Morone saxatilis*, from 64 to 14% for white perch *Morone americana*, from 80 to 17% for Atlantic tomcod *Microgadus tomcod*, and from 47 to 7% for pumpkinseed *Lepomis gibbosus*. Striped bass losses to the debris removal system were reduced from 23% of recoveries to zero, white perch losses from 33% to 1.3%, and Atlantic tomcod losses from 20% to 0.3%. Release-recovery experiments with juvenile striped bass and white perch revealed probabilities of capture characteristic of weak and strong swimmers. Fletcher, R. Ian THE FAILURE AND REHABILITATION OF A FISH-CONSERVING DEVICE. Trans. Am. Fish. Soc., 121(5):678-679. 1992. FR 38(2)

ABSTRACT: A flow spoiler designed for attachment to the fish-catching rails of large water-intake screens was previously reported as being successful in reducing injuries to fish during the capture process. That spoiler and rail configuration failed to function as intended when applied to screens equipped with superfine screencloth. The desired fluid dynamical properties of the spoiler were restored by a change in the spoiler's geometry.

Foster, J. R. and T. J. Wheaton LOSSES OF JUVENILE AND ADULT FISHES AT THE NANTICOKE THERMAL GENERATING STATION DUE TO ENTRAPMENT, IMPINGEMENT, AND ENTRAINMENT. J. Great Lakes Res., 7(2):162-170. 1981. SFA 26(4)

ABSTRACT: From April 1976 to June 1977, juvenile and adult fish mortality at the Nanticoke Thermal Generating Station (TGS) was determined by examining the numbers, sizes, species, and health of fish entrapped by the western intake, impinged on the traveling screens, and entrained through the tempering pumps. These data indicate that the cooling water system of Nanticoke TGS entraps many valuable commercial and sport species, virtually all of which are subsequently killed. Mortality of entrapped fish was primarily due to entrainment through the tempering pumps, with only a small fraction due to impingement on the traveling screens. Mortality was highest among transient schooling species. The contribution of the eastern and western intakes to fish entrapment and mortality appeared to differ significantly.

Francfort, J.E., B.N. Rinehart, G.L. Sommers, ed. W.D. Hall FISH PASSAGE/PROTECTION COSTS AT HYDROELECTRIC PROJECTS. Amer. Soc. Civil Engr., Proc. Of Intl. Conf. On Hydropower: 129-138. 1993.

ABSTRACT: The U.S. Department of Energy's Hydropower Program is engaged in a multi-year study of the costs and benefits of environmental mitigation measures at hydroelectric power plants. The initial report (Volume I. Current Practices for Instream Flow Needs, Dissolved Oxygen, and Fish Passage - December 1991) reviewed and surveyed the status of mitigation methods for fish passage, instream flows, and water quality. Information on mitigation practices at non-federal hydroelectric projects was obtained from Federal Energy Regulatory Commission databases, provided by hydroelectric developers, and provided by state resource agencies involved in hydroelectric regulation. The types of mitigation costs incurred by the hydroelectric developers and examined include: capital, study, operations and maintenance, annual reporting, and lost generation costs. The costs are reported by capacity categories. While Volume I was a "broad brush" study, the Volume II report focuses in detail on the costs and benefits of fish passage and protection measures. This involves an in-depth analysis of projects reporting upstream and downstream fish passage and protection mitigation. Case studies and information from developers are utilized to acquire detailed information for all incurred costs. This paper will examine the costs and frequencies of fish passage/protection environmental mitigation.

Fritz, E. S. COOLING WATER INTAKE SCREENING DEVICES USED TO REDUCE ENTRAINMENT AND IMPINGEMENT. U.S. Fish Wildlife Svc., FWS/OBS-76/20.9. 21p. July 1980. SFA 26(1)

ABSTRACT: Cooling water intake screening devices that Fish and Wildlife Service personnel may be expected to assess are identified and described. The devices included are modified vertical traveling screens, single-entrance double-exit screens, horizontal traveling screens,

passive intake screens, radial wells, artificial filter beds, and porous dikes. For each device the location, limitations or restrictions, evidence for reducing entrainment and impingement, and major unresolved problems are also discussed.

Giorgi, Albert E.; George A. Swan; Waldo S. Zaugg; Travis Coley and Theresa Y. Barila
SUSCEPTIBILITY OF CHINOOK SALMON SMOLTS TO BYPASS SYSTEMS AT
HYDROELECTRIC DAMS. N. Am. J. Fish. Manage., 8(1):25-29. 1988. FR 33(3)

ABSTRACT: Several hydroelectric dams in the Snake-Columbia river system are equipped with submersible traveling screens that project into the turbine intakes. The screens are designed to divert juvenile migrant Pacific salmon *Oncorhynchus* spp. and steelhead *Salmo gairdneri* from the intake upward into gatewells and the adjoining central bypass system. Assays of gill Na,K-ATPase were performed on yearling chinook salmon *O. tshawytscha* collected during routine fish guidance efficiency tests in 1985 and 1986. On three of the four sampling dates, Na,K-ATPase levels were significantly higher in fish guided into the gatewell than in those not guided. These data suggest a relationship between the physiological status of smolting yearling chinook salmon and their susceptibility to guidance by traveling screens. Assessments of salmonid out-migrations may be biased if they are based on samples from traveling-screen guidance systems.

Grabowski, S. J., D. L. King and P. L. Johnson DEVELOPMENT OF A FIXED
HORIZONTAL SCREEN TO PREVENT TRANSBASIN FISH TRANSFER. Proc. Annu.
Meet. Colo.-Wyo. Chap. Am. Fish. Soc., 17:170-194. 1982. Available @ \$10.00 from Mary
McAfee, Colo. Div. Wildlife., 711 Independent, Grand Junction, CO 81501. SFA 27(4)

ABSTRACT: An irrigation project is being constructed in North Dakota which will transport water from the Missouri River drainage to the Hudson Bay drainage. To prevent interbasin transport of undesirable fish, a fine mesh, fixed, horizontal screen is being developed. Laboratory tests were conducted to evaluate the filtration efficiency of the design using live or preserved fish eggs and larva; to evaluate hydraulic features of the design, including development of sizing guidelines and optimization of self-cleaning features; and to assist in design and development of hardware features, spray cleaning, seal designs, and screen inspection and repair techniques. Operation- and maintenance-related problems are being evaluated at a field test facility. Items being considered at the field test facility include screen fouling and cleaning, screen wear, corrosion and materials selection, and debris types and quantities. Accessory equipment being evaluated includes traveling water screens, vibrating screens, automation devices, and debris handling systems. Maintenance requirements for the prototype structure are being formulated.

Grotbeck, L.M. and J.L. Bechtold FISH IMPINGEMENT AT MONTICELLO NUCLEAR
PLANT. J. of Power Div., Proc. Amer. Soc. Civil Engr. 101(P01), Paper 11409, 69-83. July
1975.

ABSTRACT: To properly evaluate total impact of power generation facilities on aquatic systems, it is necessary to perform site specific fish impingement studies. Intake and screen approach velocities should not be averaged when considering potential screen impingement problems because of wide vertical and horizontal variation in velocity which tend to trap fish. It was estimated that 2,952 fish were impinged during 4 months of sampling with 90.9% of these comprised of black bullheads (*ictalurus melas*) and black crappies (*pomoxis nigromaculatus*).

Distinct relationships can be found between number of impinging fish and river flow, percentage river diverted through the plant, water temperature, and the time of year. For the months of June, July, August, and September, approximately 55% of all impingement occurs in June.

Hackney, P.A. RESEARCH AND DEVELOPMENT OF FISH PASSAGE TECHNOLOGY. Natl. Tech. Info. Svc., Springfield, VA. 22161. DE87-900618. Report No. TVA/ONRED/WRF--87/4, December 1986. 2 p.

ABSTRACT: Any fish passage provided at TVA's John Sevier Fossil Plant (JSF) would involve only warm water species. Warm water fish passage requirements differ substantially from those of salmon for which such technology has long been available. For instance, adults must be passed both upstream and downstream since they do not die after spawning as do salmon. Also, drifting eggs and larvae, and fingerlings of warm water species must be safely passed downstream, not simply outmigrating smolts as for salmon. Although some anadromous (marine) warm water species (e.g., American shad, blueback herring) are currently passed upstream and downstream through structures deliberately built for that purpose, effectiveness of this technology for passage of adults and young of potential target species (e.g., paddlefish and sauger/walleye) in Cherokee Reservoir is unproven. Upstream passage of the JS target species is known to occur for one or more of the available passage structures, but relative passage efficiencies (i.e., proportion of the migrating population) have not been investigated. Downstream passage is by far the larger and more poorly understood subject of fish migration and should be investigated first. Initial research should center on basic biological responses by various life stages of the target species to flow velocity, turbulence, shear forces, etc., encountered during downstream transport in existing water control structures. Currently, the Electric Power Research Institute is conducting research on downstream fish passage. Although this research presently is directed mainly at salmonids, plans are to expand this effort to include warm water species.

Hanson, C. H., J.R. White and H.W. Li ENTRAPMENT AND IMPINGEMENT OF FISHES BY POWER PLANT COOLING-WATER INTAKES: AN OVERVIEW. Mar. Fish. Rev., 39 (10):7-17. Oct. 1977. SFA 23(2)

ABSTRACT: A discussion is presented on types of biological problems caused by intake structures, strengths and weaknesses of various water intake/fish protection systems, and biological/ecological processes relevant to entrapment and impingement problems. Water velocity, impingement time and physiological stress are considered as they relate to mortality caused by impingement. It was concluded that two major issues need to be addressed in future research: (1) what effect, if any, does entrapment/impingement have on the productivity of the ecosystem or resources; and (2) what criteria determine the best intake-design technologies for minimizing effects on the system. (Chilton-ORNL)

Harmon, J. R. and D. L. Park EVALUATION OF A BYPASS SYSTEM FOR JUVENILE SALMONIDS AT LITTLE GOOSE DAM. Mar. Fish. Rev., 42(6):25-28. June 1980. SFA 26(1)

ABSTRACT: A new system for bypassing juvenile chinook salmon at the Little Goose Dam on the Snake River is proposed, and the existing system at Little Goose is evaluated. The orifice diameter, lighting, and placement in turbine intake slots of the test system were evaluated, along with overall system efficiency during the migration of chinook salmon and steelhead smolts in

April and May of 1978. Existing six inch orifices were blocked off, and 12 inch fingerling transfer pipes with 8 to 10 inch orifices were tested. Marked fish were used to determine the efficiency of the orifices. Two orifices are needed for satisfactory passage due to varying current directions. Also, lighted orifices increase passage rates for salmon. A complete system at Little Goose would include north and south, 12 inch diameter lighted orifices in the downstream walls of the bulkhead slots.

Haymes, G. T. and P. H. Patrick EXCLUSION OF ADULT ALEWIFE, *ALOSA PSEUDOHARENGUS*, USING LOW-FREQUENCY SOUND FOR APPLICATION AT WATER INTAKES. Can. J. Fish. Aquatic Sci., 43(4):855-862. 1986. In English with French summ. FR 31(4)

ABSTRACT: Experiments to test the effectiveness of low-frequency, high-intensity sound in excluding alewife, *Alosa pseudoharengus*, from an experimental net structure were conducted on Lake Ontario near Pickering, Ontario. Sound was generated by modified seismic devices call pneumatic poppers. The number of alewife entering the experimental structure was reduced by 71-99% when the poppers were operating. Sonar evidence from one test suggested that another species which was not caught in the collection nets was less influenced by the acoustic deterrent. The results suggest that low-frequency, high-intensity sound may be effective in reducing losses of adult alewife at water intakes.

Hill, Jeffrey P. and William J. Matter A LOW-COST WEIR FOR SALMON AND STEELHEAD. Prog. Fish-Cult., 53(4):255-258. 1991. FR 37(2)

ABSTRACT: Weirs are an important tool for the management of salmon (*Oncorhynchus spp.*) and steelhead (*O. mykiss*). Weirs have been used to concentrate migrating fish for counting and to direct fish to fish ladders or into traps. They can be especially useful for capturing adult fish to be used as hatchery brood stock. A low-cost movable weir to block migration of salmon and steelhead was designed. Each weir panel had a redwood frame (4 2/3 ft long by 3.5 ft high) with holes lined with metal flanges to hold the pickets. The weir cost \$24/linear foot to build and install. It can be operated in waters up to 44 in deep, and weir pickets can be removed readily if stream waters rise too high. The weir performed well over two winter trapping seasons for coho salmon (*Oncorhynchus kisutch*), chinook salmon (*O. tshawytscha*), and steelhead. Pickets in the weir were spaced 1 3/8 in apart and, even though many fish were under 3 pounds, no gilling or fish passage was observed.

Jernejcic, Frank WALLEYE MIGRATION THROUGH TYGART DAM AND ANGLER UTILIZATION OF THE RESULTING TAILWATER AND LAKE FISHERIES. Reservoir Fisheries Management: Strategies for the 80's. Gordon E. Hall and Michael J. Van Den Avyle, editors., p. 294-300. 1986. FR 33(2)

ABSTRACT: Fish populations in 1,740-acre Tygart Lake and its tailwater were sampled to provide information needed to evaluate impacts associated with the addition of hydropower facilities to the Tygart Lake project. Walleyes (*Stizostedium vitreum vitreum*) dominate the sport fishery of the lake and migrate through the dam, providing a major tailwater fishery. Anglers caught 6,042 walleyes from the lake and 8,724 from the tailwater during a 1-year period. Walleye fishing success (C/f) was higher in the tailwater than in the lake (0.56 vs. 0.32 caught per

hour). C/f was highest during the fall in the lake but during the spring in the tailwater. Tag returns indicated a 6% exploitation rate for lake walleyes during a 15-month period. Tailwater walleyes experienced a 25% exploitation rate during a 7-month period. Nine percent of walleyes tagged in the lake were caught by anglers in the tailwater from December through March. Age-0 and -1 walleyes migrated through the dam more readily than older walleyes. Walleye migration occurred during the winter, December through April, at times when the pool elevation was decreasing at a rate of at least 6-ft. per 24 hours.

Johnson, G. E.; C. M. Sullivan and M. W. Erho HYDROACOUSTIC STUDIES FOR DEVELOPING A SMOLT BYPASS SYSTEM AT WELLS DAM. Fish. Res. (Amst.), 14(2-3):221-237. 1992. FR 37(4)

ABSTRACT: Douglas County Public Utility District No. 1 has developed a bypass system to divert downstream migrant salmonid fishes ('smolts') away from hydroelectric turbine intakes at Wells Dam on the Columbia River. Wells' bypass system uses the dam's hydrocombine design in which the spill bay intakes are located directly above the turbine intakes. In annual studies since 1980, hydroacoustic and fyke net methods were used to help develop the bypass and to demonstrate that it is a viable long-term solution for diverting smolts around turbines at Wells Dam. When baffles were installed in spill bay intakes, the flow velocity increased in the forebay near the baffle openings. We postulated that this increased flow velocity attracts smolts. Once entrained in the attractant flow, smolts enter the bypass and migrate through the dam in bypass flow instead of turbine flow. This bypass uses an average of 7% of total discharge. Baffle configurations with either underflow or vertical slots were the most effective with over 90% efficiency.

Kindschi, Greg A.; Frederic T. Barrows and Bill Kirkpatrick EVALUATION OF AN ELECTRONIC WALLEYE FRY COUNTER AND AN ELECTRIC GRID TO PREVENT FISH ESCAPEMENT. Am. Fish. Soc. West. Div. Annual Meeting, p. 12. 1991. Abstract only. FR 36(3)

ABSTRACT: We evaluated a fry counter (Jensorter, Inc. model FC2) for accuracy, precision, ease of use and effects on survival of walleye fry (*Stizostedion vitreum vitreum*). Also evaluated was a grid utilizing 60 Hz, 220 volt single phase electricity to prevent escapement of walleye into a particular drainage. Overall, the greatest differences between the counter and hand counts averaged only 4.7%. Sample estimates volumetrically differed by 46.9% from hand counts, whereas gravimetric samples differed by 17.2%. Survival of electronically counted walleye fry after 66h (96.9%) did not differ from those counted by hand (97.1%), gravimetrically (97.3%), or volumetrically (98.8%). The counter was easy to use, much faster than hand counting, and more accurate than volumetric or gravimetric methods. The device is potentially useful for counting larvae of other small fish species as well as walleye. Walleye fry were shipped in for research purposes and it was critical that none be allowed to escape. Experimental tests established that most effective results were obtained with an electric contact of .4 second and an electric potential gradient of 100 volts per 2.5 cm. The use of 220 volts along with grounding plates on entry and exit ends of the grid served as safety precautions by maintaining zero net volts to ground in the vicinity surrounding the grid.

Kynard, Boyd and John O'Leary EVALUATION OF A BYPASS SYSTEM FOR SPENT AMERICAN SHAD AT HOLYOKE DAM, MASSACHUSETTS. N. Am. J. Fish. Manage., 13(4):782-789. 1993. FR 39(2)

ABSTRACT: A bypass system for postspawned American shad *Alosa sapidissima* began operation in 1980 on the Connecticut River canal system at Holyoke Dam. The purpose of the bypass was to enable downstream migrants that enter the canal to exit and avoid death due to delay or passage through hydroelectric turbines at water use facilities. The bypass system had the following elements: (1) an underwater AC electrical or acoustic barrier to prevent American shad from leaving the bypass area, (2) an underwater DC electrical field to immobilize fish for collection, and (3) a collection box with transfer pipe to carry fish to the river below the dam. During studies of the bypass system from 1979 to 1983, we found that the fish barriers were ineffective, the collection system was partially effective for American shad but not for anadromous species that passed through trashracks, and American shad could be immobilized and transported at high velocity through a pipe and have only low mortality (4-9%). Radio-tagged American shad, unwilling to pass through trashracks at water exits on the canal, behaved like trapped fish and were delayed an average of two or more days before dying or exiting the canal. An estimated 10 of 47 (21%) of the radio-tagged fish were passed. In 1980, when the greatest number of American shad were passed, an estimated 142,000 (37% of the fish lifted at the dam) survived spawning and used the bypass. After several years of operation, it was evident that, even with major improvements, the bypass could not pass the available American shad, and it was not useful for protecting other anadromous migrants that did not avoid trashracks.

Locher, F.A., P.J. Ryan, V.C. Bird, P. Steiner, ed. W.D. Hall DEBRIS REMOVAL FROM A LOW-VELOCITY, INCLINED FISH SCREEN. Amer. Soc. of Civil Engr., Waterpower '93 Proc. Of Intl. Conf. on Hydropower, Vol. 2:1438-1447. 1993.

ABSTRACT: An air backwash system for the Potter Valley Intake Inclining Horizontal Fish Screen Facility was developed through testing of a prototype section of the screen in a test flume located at the project site. Effects of sparger pipe spacing, sparger hole configuration, duration of air burst, and type of debris were investigated. The test program and development of the final configuration of the sparger system are described in this paper.

Marquette, W. M. and Long, C. W. LABORATORY STUDIES OF SCREENS FOR DIVERTING JUVENILE SALMON AND TROUT FROM TURBINE INTAKES. Trans. Am. Fish Soc., 100(3):439-447. 1971. SFA 16(4)

ABSTRACT: Fish-guiding screens of different porosities were tested with juvenile spring chinook salmon (*Oncorhynchus tshawytscha*) in a laboratory model that simulated a turbine intake and gatewell (a vertical shaft in a dam that extends from the forebay deck to the ceiling of the intake). The study was part of a program to develop methods for preventing mortality of juvenile salmon and steelhead trout (*Salmo gairdneri*) in Kaplan turbines of low-head dams on the Columbia and Snake rivers. If large numbers of juvenile fish could be guided into gatewells, a method of safely bypassing them around turbines might be devised. Three types of screens (wood, and single and double layers of spiral-weave conveyor belt) were attached to the intake ceiling at an angle of 45 degrees to the flow; their lengths were adjusted to intercept 1/3 or 2/3 of the total flow into the intake. The screen with the greatest porosity (constructed of a single layer of belting) gave the highest guiding efficiency; 87% of the test fish were diverted into the

gatewell. It was believed that water deflected under the screen carried fish with it, but tests indicated that some fish swam upwards out of the flow and into the gatewell. Diversion of 3% of the intake flow up through a gatewell with a single opening into the intake increased the guiding efficiency of only the double-layer screen. Diversion of flow through a gatewell with two openings caused a significant percentage of the guided fish to leave the gatewell and reenter the intake.--Copyright 1971, Biological Abstracts, Inc.

Mathur, Dilip; Paul G. Heisey and David A. Robinson TURBINE-PASSAGE MORTALITY OF JUVENILE AMERICAN SHAD AT A LOW-HEAD HYDROELECTRIC DAM. Trans. Am. Fish. Soc., 123(1):108-111. 1994. FR 39(2)

ABSTRACT: The immediate (l-h) turbine-related mortality of juvenile American shad *Alosa sapidissima* at the Hadley Falls Hydroelectric Station on the Connecticut River, Holyoke, Massachusetts, was estimated to be $0\% \pm 14.5\%$ (95% confidence interval) at the 35% wicket gate opening and $2.7\% \pm 16.2\%$ at the 100% opening. We used the HI-Z Turb'N tag-recapture technique, which helped minimize control mortality and maximize recapture rates. Earlier literature estimates of turbine-related mortality (up to 82%) of juvenile alosids in passage through Kaplan turbines, in our view, were substantially overstated due to either low recapture rate, high control mortality, or both.

Matousek, J.A., T.E. Pease, J.G. Holsapple and R.C. Roberts BIOLOGICAL EVALUATION OF ANGLED-SCREEN TEST FACILITY. J. Hydraulic Engr., 114(6): 641-650. June 1988.

ABSTRACT: A three-year study sponsored by the Empire State Electric Energy Research Corporation was conducted to determine the diversion efficiency and survival of adult and larval fish at a full-scale angled screen demonstration facility located on the Hudson River estuary. A total of 59,309 fish were collected during the three-year study, 99.4% from the diversion flow. Initial survival was 90.2%. Extended survival following a 96-hr observation period was 35.3%. The angled-screen system efficiency was 31.6%, increasing to 84.3% when corrected for collection and handling mortality. Ichthyoplankton (yolk-sac, post-yolk-sac, and juvenile stages) diversion efficiency of 16.3% was inversely related to angled screen approach velocity and directly related to the size of the organism. Angled-screen system efficiency for ichthyoplankton was 1.7%. The angled-screen was judged to be successful for mitigating fish impingement. Ichthyoplankton study results indicate low diversion and high mortality, suggesting that angled screens are not effective for mitigating entrainment.

Matthews, G. M., G.A. Swan and J.R. Smith IMPROVED BYPASS AND COLLECTION SYSTEM FOR PROTECTION OF JUVENILE SALMON AND STEELHEAD TROUT AT LOWER GRANITE DAM. Mar. Fish. Rev., 39 (7):10-14. July 1977. SFA 23(1)

ABSTRACT: A new and improved system for diverting, bypassing, and collecting juvenile salmon, *Oncorhynchus* sp., and steelhead trout, *Salmo gairdneri*, at Lower Granite Dam on the lower Snake River was described. Major changes from previous systems of this type included a special fish screen slot for placement of the improved traveling screen, an open gallery bypass system for routing fish around the turbines, and a collection and holding area totally supplied by gravity-flow. (Katz)

McKay, Edward H. PORTABLE, SELF-CLEANING FISH SCREEN FOR LOW-FLOW WATER DIVERSIONS. N. Am. J. Fish. Manage., 7(4):603-605. 1987. FR 33(2)

ABSTRACT: A portable, self-cleaning fish screen for diverting migrating salmonids in irrigation ditches is described. The entire device weighs 540 pounds and is designed to operate at flows less than 5 ft super(3)/s. It can be easily moved from site to site during the migration period, and it is as efficient as a permanent screen.

McLean, R. B., J. J. Beauchamp, V. E. Kane and P. T. Singley IMPINGEMENT OF THREADFIN SHAD: EFFECTS OF TEMPERATURE AND HYDROGRAPHY. Environ. Manage., 6(5):431-439. Sept. 1982. SFA 29(3)

ABSTRACT: A model is presented that allows testing of hypotheses concerning the effects of temperature and change in temperature on impingement. The model is evaluated using data from the Tennessee Valley Authority's Kingston Steam Plant, Watts Bar Reservoir, Tennessee, USA for two fish species impinged in large numbers in the United States: threadfin and gizzard shad, *Dorosoma petenense* and *D. cepedianum*. Hydrographic characteristics near the intake screens were mapped to help explain the possible role of hydrography in distributing fish across the screens. Understanding the role of temperature and hydrography in impingement of fish provides a basis for new intake designs that may reduce impingement and helps in the development of methods to reduce impingement at existing facilities. The temperature modeling approach and conclusions about hydrographic effects might be applied to other systems in which cold-stressed schooling fish are impinged.

Menchen, R. S. PERFORATED PIPE USED TO SCREEN AND TRAP JUVENILE SALMONIDS. Prog. Fish-Cult., 37(2):85-89. Apr. 1975. SFA 20(3).

ABSTRACT: High costs, mechanical and debris problems, and fish impingement have caused problems for fishery workers over the years at fish screens and trapping stations. Developing better methods of by-passing fish at diversions in anadromous fish streams is an unending task. Perforated pipe, buried in stream gravel, has recently been developed in California as a tool to overcome many of these problems. Advantages of the perforated pipe are simplicity of construction, low installation costs, and low operating and maintenance costs. This report describes two ways perforated pipe is used on the Merced River, California, to by-pass juvenile king salmon (*Oncorhynchus tshawytscha*). One is a fish screen and the other is a barrier for algae. Both have been in operation for several seasons with good success. Many other applications of this technique are possible and some are being tried in California now.

Mih, W.C. FISH DIVERSION EFFICIENCY OF A TRAVELING SCREEN AT HYDRAULIC TURBINES. Proc. Conf. on Frontiers in Hydr. Engr. p. 165-169. 1983.

ABSTRACT: A 1:20 scale model of a turbine unit at Rock Island Dam was constructed to test a typical traveling screen arrangement for diverting the salmon juveniles away from the turbines into a bypass system. The diversion facility should have minimal adverse effects on the efficiency and mechanical integrity of the turbines. In order to test the efficiency of the screen in the model, neutrally buoyant plastic particles are released in the forebay to simulate the migrating juvenile

salmon. The ratio of diverted particles into the bypass system to the total released is a quantitative measurement of the diversion efficiency.

Mussalli, Y.G., P. Hofmann and E.P. Taft INFLUENCE OF FISH PROTECTION CONSIDERATIONS ON THE DESIGN OF COOLING WATER INTAKES. Joint Sym. on Design and Operation of Fluid Machinery, Vol. 1, p. 413-424. 1978.

ABSTRACT: Stringent regulatory requirements in the USA often require the incorporation of fish protection facilities at power plant intakes. These facilities can be based on three different concepts: fish collection and removal, fish diversion, and fish deterrence. The incorporation of fish protection systems at specific sites can necessitate modifications to conventional intake designs. Such modifications can influence screenwell layouts and selection of screens and pumps, and in certain cases require model studies to develop design criteria which will ensure that proposed fish protection facilities will be biologically effective and will not adversely affect plant operation.

Mussalli, Y.G. and E.P. Taft III FISH RETURN SYSTEMS. Hydraulics in the Coastal Zone, Proc. of 25th Annual Hydr. Div. Spec. Conf. p. 288-295. 1977.

ABSTRACT: As a result of present regulatory requirements for the protection of fish at cooling water intakes, several power plant intakes are being designed to incorporate fish protection facilities and transportation systems to return live fish to their natural environment. Fish protection can be based in principle on three different concepts: fish collection and removal, fish diversion, and fish deterrence. The first two concepts require systems to return collected or diverted fish from circulating water systems to their natural environment. The third concept involves exclusion of fish prior to entering an intake. This paper described, in general, important parameters which should be considered in designing each element of various fish transport systems. These systems included bypasses, pumps, and lift baskets.

Mussalli, Y.G., E.P. Taft and W. Micheletti ASSESSMENT OF DEVELOPMENTAL NEEDS FOR ADVANCED INTAKE TECHNOLOGIES. J. Hydr. Engr. 114(6):675-688. June 1988.

ABSTRACT: Increasing fuel and construction costs of new power plants have emphasized the need to achieve cost-effective, highly reliable circulating water intake designs that can improve power plant availability and performance while meeting environmental requirements. Additional concerns are to reduce maintenance, improve hydraulic conditions, and control fouling, siltation, and ice. The present paper discusses an Electric Power Research Institute (EPRI)-sponsored study to assess the status of available intake technologies for fish protection and to develop a research program to evaluate and compare the operation, performance, cost, and reliability of selected fish protection systems. The initial assessment of the available behavioral barriers, physical barriers, collection and removal systems, and diversion systems identified for further study 11 of the most promising technologies. These 11 technologies were ranked as to the importance of various levels of specific design criteria and the importance among these criteria. The technologies were then matched with potential test sites. Biological and engineering test methodologies were developed, together with design schemes for behavioral barriers at each test site. As a result of the study, EPRI is testing behavioral barriers at several sites. EPRI also is collecting data from several

existing intake facilities where angled screens, modified fish screens, and wedge-wire screens are being evaluated.

Navarro, John E. and Dennis J. McCauley FISH ESCAPEMENT FROM TWO STORAGE RESERVOIRS IN MICHIGAN. Rivers, 4(1):36-47. 1993. FR 38(4)

ABSTRACT: The authors studied fish escapement from two low-head water storage reservoirs in northeast Michigan from April through October 1991 and 1992 to determine the relation between discharge and escapement. Monthly sampling was performed to collect information on acute mortality, species abundance, and size distribution of fish that passed through the dams during a variety of flow releases. No acute mortality due to passage through the dams was observed at either dam. Rock bass (*Ambloplites rupestris*) was the most common fish to pass through the dams. The majority of fish passing through the dams were 10 to 20 cm long and escapement was species selective. Species composition of fish passing through the dams and species composition of fish collected in impoundment surveys was dissimilar. There was no clear relation between the number of fish collected in the escapement surveys and water flow or water temperature.

Neitzel, Duane A., C. Scott Abernethy and E. William Lusty EVALUATION OF ROTATING DRUM SCREEN FACILITIES IN THE YAKIMA RIVER BASIN, SOUTH-CENTRAL WASHINGTON STATE. Am. Fish. Soc. Symp., No. 10. p. 325-334. 1991. FR 38(2)

ABSTRACT: Field-test data from four rotating drum screen facilities indicate that juvenile salmonids are safely returned from the fish screen facility to the river from which the fish were diverted. This conclusion is based on five observations: (1) release-recapture tests with branded salmonids indicated fish that passed through the screening facility were not killed or injured at different rates from control groups; (2) predators were not concentrated within the screen facility; (3) test groups of fish were not delayed within the screen facility; (4) screens with properly maintained seals prevented fish from passing through the screen structure; and (5) altered operating flow conditions did not adversely affect test conclusions. Tests were conducted with smolts of steelhead *Oncorhynchus mykiss* and spring chinook salmon *Oncorhynchus tshawytscha*, and with fall chinook salmon fry. More than 11,000 fish were released during the tests.

Neitzel, D. A., C. S. Abernethy, E. W. Lusty and L. A. Prohammer AN EVALUATION OF FISH PASSAGE AT THE SUNNYSIDE CANAL FISH SCREEN FACILITY. Proc. Annu. Conf. West. Assoc. Fish Wildlife Agencies, 66:143. 1986. Abstract only. FR 32(3)

ABSTRACT: The Sunnyside Canal Fish Screening Facility is in the Sunnyside Canal, about 500m downstream of the Sunnyside Dam on the Yakima River (river kilometer 167). The screening facility diverts fish that have entered the canal back into the Yakima River. We branded and released about 4,000 chinook salmon, *Oncorhynchus tshawytscha*, and 2,000 steelhead, *Salmo gairdneri*, smolts in front of or within the screening facility. We caught 507 of the steelhead and none were descaled or killed. We caught 3,625 of the chinook salmon and less than 2% were descaled or killed. Our data indicate that fish were safely diverted from the Sunnyside Canal into the Yakima River. The fish screening facility is part of a joint project by the Bonneville Power Administration and the Bureau of Reclamation to construct fish passage and protective facilities at existing irrigation and hydroelectric diversions in the Yakima River

Basin. The project is part of the Northwest Power Planning Council's Columbia River Basin Fish and Wildlife Program.

Nettles, D. C. and S. P. Gloss MIGRATION OF LANDLOCKED ATLANTIC SALMON SMOLTS AND EFFECTIVENESS OF A FISH BYPASS STRUCTURE AT A SMALL-SCALE HYDROELECTRIC FACILITY. N. Am. J. Fish. Manage., 7(4):562-568. 1987. FR 33(2)

ABSTRACT: Downstream movements by smolts of Atlantic salmon *Salmo salar* were monitored with radiotelemetry to assess the effectiveness of an angled trash rack and fish bypass structure at a small hydroelectric dam on the Boquet River, New York. Telemetry of 170 Atlantic salmon smolts and visual observations of stocked smolts were used to determine aspects of migration behavior. Smolts began mass migrations after river temperatures reached or exceeded 10°C. Many radio-tagged smolts interrupted movements upon reaching ponded waters or the dam. River flow did not affect the frequency of migratory movements, dam passages, or rate of movement ($P > 0.05$). Migrations lasted approximately 30 d. Passes at the dam occurred primarily at night (61%); diurnal passages (17%) and crepuscular passages (17%) were of secondary importance, and timing of 5% of the passages was undetermined. All passages were through the bypass or over the spillway when angled trash racks were in place. Six passages occurred when trash rack and bypass structure significantly reduced entrainment through the penstock and turbine ($P < 0.05$).

Nolting, D.H. ELECTRIC FISH SCREEN EFFICIENCY, WILLOW CREEK RESERVOIR. Colorado Game, Fish And Parks Dept.; 31P. Ref., Graphs, Illus., 1962

ABSTRACT: Surveys made during 1955 and 1960 showed that trout losses from Willow Creek Reservoir downstream into the pump canal and through the pumps were severe. On the basis of the 1955 surveys, an electrical fish screen was constructed across the mouth of this pump canal in an attempt to repel trout and to force them to remain in the reservoir. A series of tests were conducted during 1958, 1959 and 1960 to evaluate the effectiveness of this screen. A variety of electric current intensities were used to create electric fields of different strengths. The effects of these electric fields on trout varied from distress and irritation to paralysis and death. Although the electric screen functioned well from an operational standpoint, there was no evidence that the screen reduced the numbers of fish normally passing down the canal. The apparent basic reason for the failure of the screen was the reaction of the fish themselves to an electric shock. This response can best be expressed as uncontrolled panic and a trout is apparently unable to detect the source of danger or to respond in such a way as to consistently avoid the field.

Nolting, D.H. and J.W. Janssen SONIC FISH SCREEN STUDY. Job Completion Report for Project Number T-49. Colo. Game, Fish and Parks Dept.; 9P. Ref., 1961.

ABSTRACT: Laboratory studies were conducted to determine if sound producing devices would prevent rainbow trout escapement at Willow Creek Reservoir, Colorado. No sounds produced the desired effect in the laboratory tests. Trout habituated to the sounds and resumed normal behavior. No devices were installed at Willow Creek Reservoir.

Odgaard, A., M.P. Cherian and R.A. Elder FISH DIVERSION IN HYDROPOWER INTAKE.
J. Of Hydr. Engr., Vol. 113 No. 4 Page(s) 505-519, 1987

ABSTRACT: Hydraulic model studies were conducted to develop a fish screening system to be used in the turbine intakes of Wanapum Development and Priest Rapids Development on the Columbia River, Washington. The system studied utilized a mechanical screen, installed through one of the gate wells, to produce a flow pattern that would deflect downstream migrating juvenile fish into the gate well for subsequent removal by a collection system. The simplicity in the design and relative ease in the installation, operation, and maintenance of the passive screens were all factors favorable to the choice of passive screens over traveling screens. By comparing data for passive screens in the two gate wells, it was determined that better results were obtained by placing the screen in the emergency gate well. With the optimum screen-assembly design for the emergency gate well, a gate-well flow of 7.1% of the intake flow was generated with a head loss of about one velocity head ($K_{sub 1} = 1.1$); the loss coefficient for the gate-well flow was $K_{sub 2} = 1.5$.

Odgaard, A.J., R.A. Elder and D. Weitkamp TURBINE-INTAKE FISH DIVERSION
SYSTEM. J. Hydraulic Engr, 116(11):1301-1317. Nov. 1990.

ABSTRACT: A promising method for protecting downstream-migrating juvenile fish from death or injury due to passage through hydroelectric turbines is diversion by screening in the turbine intakes. A fish-diversion system was developed to be used in the turbine intakes of the Wanapum and Priest Rapids developments on the Columbia River, in the state of Washington. The system uses a passive-bar screen, installed through the emergency gate well, to produce a flow pattern that deflects downstream-migrating juvenile salmonids into the gate well for subsequent removal and bypass to below the dam. The system is based on laboratory model studies and field tests. The model studies provide data on the hydraulic performance of the system and result in an understanding of the hydraulic features of the technique, which can be a guide for future designs. The studies also serve as a guide to development of the structural design of the system. The design, field tested in 1986, 1987, and 1988, attains a fish-guidance efficiency of about 68% with a minimal of descaling (removal of fish scales by abrasion).

Office of Technology Assessment. FISH PASSAGE TECHNOLOGIES: PROTECTION AT
HYDROPOWER FACILITIES. OTA-ENV-641 (Washington, DC: U.S. Government Printing
Office, September 1995).

ABSTRACT: The House Committee on Merchant Marine and Fisheries requested that the Office of Technology Assessment (OTA) examine the role of fish passage and protection technologies in addressing the adverse effects of hydropower development on North American fish populations. After the elimination of the requesting committee, the report was continued on behalf of the House Resources Committee, Subcommittee on Fisheries, Wildlife, and Oceans.

Hydropower development may adversely affect fish by blocking or impeding biologically significant movements, and altering the quantity, quality, and accessibility of necessary habitat. Fish moving downstream that pass through hydropower turbines can be injured or killed, and the inability of fish to pass upstream of hydropower projects prohibits them from reaching spawning grounds. Hydropower licenses issued by the Federal Energy Regulatory Commission (FERC) may include requirements for owners/operators to implement fish passage technologies or other

measures to protect, enhance, or mitigate damages to fish and wildlife, as identified by the federal resource agencies. Although FERC is directed to balance developmental and non-developmental values in licensing decisions, many contend that balancing has been inadequate. Thus, fish passage and protection has become a major controversy between the hydropower industry and resource agencies.

This report describes technologies for fish passage, and those for protection against turbine entrainment and mortality, with an emphasis on FERC-licensed hydropower projects. OTA identifies three areas for policy improvements. First, to establish and maintain sustainable fisheries, goals for protection and restoration of fish resources need to be clarified and strengthened through policy shifts and additional research. Secondly, increased coordination is needed among fishway design engineers, fisheries biologists, and hydropower operators, especially during the design and construction phases of fish passage and protection technologies, to improve efficiency. Finally, new initiatives with strong science and evaluation components are needed to advance fish passage technologies, especially for safe downstream passage.

OTA sincerely appreciates the contributions of the advisory panel, workshop participants, contractors, and reviewers. We are especially grateful for the time and effort donated by the federal and state resource agencies and the Federal Energy Regulatory Commission. The information and assistance provided by all of these individuals was invaluable.

Pavlov, D. S. STRUCTURES ASSISTING THE MIGRATIONS OF NON-SALMONID FISH: USSR. FAO Fish. Tech. Pap., 308. 97p. 1989. FR 35(3)

ABSTRACT: This technical paper provides information on provisions, made in the USSR, to facilitate fish migration under conditions of modified river flow resulting from engineering construction and water abstraction. The fish-pass and fish protection structures described utilize a knowledge of the physiology, biology, ecology and behavior of the migrating species. The principles of their design and operation are elaborated in relation to characteristics of the species of fish concerned. Structures described include sluice fish-passes, hydraulic and mechanical fish-lifts and mobile devices for fish collection and transfer, together with protection and guiding devices used to ensure downstream migration of young fish.

Pearce, Robert O. and Randall T. Lee SOME DESIGN CONSIDERATIONS FOR APPROACH VELOCITIES AT JUVENILE SALMONID SCREENING FACILITIES. Am. Fish. Soc. Symp., No. 10. p. 237-248. 1991. FR 38(2)

ABSTRACT: The size, and therefore the cost, of screening facilities required at water diversion sites is primarily determined by the allowable approach velocity of water at the screen mesh. General screening criteria established by fisheries agencies specify maximum approach velocities. Biological factors affect the swimming ability of the fish. In addition to the biological factors, proper attention must be given to engineering factors including uniform velocity distribution at the screen facility. Providing basic screen facility hydraulics necessary for effective fish protection requires careful attention to channel configuration and frequently involves use of baffles and training walls to control direction of flow and magnitude of velocity.

Powell, D. H. and S.L. Spencer PARALLEL-BAR BARRIER PREVENTS FISH LOSS OVER SPILLWAYS. Prog. Fish-Cult., 47(4):174-175. Oct. 1979. SFA 25(1)

ABSTRACT: A parallel bar barrier was designed to prevent loss of harvestable size fish for public fishing lakes in Alabama. A parallel bar design, with the bars running horizontally along the spillway of a dam with bar spacing approximately 1 inch, provided the barrier to out-migrating fish. The design provided for most debris to pass through but retained harvestable size fish in the lake. Notes on installation and construction are contained in the report. The design was on low-flow spillways and consideration should be given to amount of outflow and head loss through the barriers.

Pugh, C.A. INTAKES AND OUTLETS FOR LOW-HEAD HYDROPOWER. J. Hydraulic Division, Proc. Amer. Soc. Civil Engr., 107(HY9): 1029-1045. Sept. 1981.

ABSTRACT: A state of the art survey on design practices for hydropower development in low-head (less than 20 meters) sites is based on the literature and on information from manufacturers and consultants in the field. With rising fossil fuel costs making the low-head sites more attractive economically, it is desirable to determine possible design changes to lower construction costs without producing significant head losses. Flow passages for low-head hydropower development cannot be standardized because of structural and geological differences and fish passages. However, where geological and structural considerations are similar, the same design may be used for a series of installations, reducing engineering and design costs. The possibility of shortening draft tubes (responsible for 30% of civil costs) using boundary layer control is explored. No research in this area has been done on hydraulic turbines. Intakes may probably be reduced in size or simplified in shape without losing efficiency because flow volumes are low. An example is the use of flat surfaces to approximate curved surfaces. Many hydraulic structures were designed with the demands of high flows and pressures experienced in high-head systems. Since low-head systems do not exert these severe demands, it is possible that equipment can be simplified.

Rainey, W. S. CONSIDERATIONS IN THE DESIGN OF JUVENILE BYPASS SYSTEMS. Proceedings of the Symposium on Small Hydropower and Fisheries. Forrest W. Olson, Robert G. White, and R. H. Hamre, editors., p. 261-268. 1985. FR 32(4)

ABSTRACT: This paper emphasizes the importance of the bypass system in protecting juvenile fish at screen facilities. Screen/bypass layouts, juvenile behavior, and hydraulic considerations are addressed, followed by a discussion of key elements of the bypass design. Principles covered in this paper can be employed in the design of screen and bypass facilities of all sizes.

Richards, R.T. COOLING SYSTEMS: CAN ENGINEERS SAVE THE FISH? Consulting Engr. (St. Joseph) 59(5): 58-64. Nov. 1982.

ABSTRACT: The adverse effects of power plant cooling systems on the aquatic environment can be mitigated by several engineering measures. Heated water leaving the cooling system may be recycled, routed to captive ponds or spray ponds for partial cooling prior to discharge, or treated by a combination of systems. Fish may be protected by recovery from the intake screens and return to a safe section of the waterway, by diversion using angled screens and louvers, by

deterrents such as air bubble curtains and noise generators, by exclusion (very fine screens or a radial well system), by choosing an intake site away from areas of the screen faces, by using velocity caps, and by using cylindrical pipe intakes. Some typical discharge methods are low velocity (2 fps) canal discharge, low velocity diffuser discharge, single port low velocity (5-7 fps) discharge, single port high velocity (12-15 fps) discharge, and multiport (sometimes 50 ports) discharge. Discharge temperatures may be reduced by increasing the amount of water passing through the condenser or adding cool water to the hot discharge. Engineers must also consider the potential effects of a powerplant shutdown (which suddenly eliminates heated discharge from an adapted environment), minerals discharged by blowdown, construction of facilities, and dredging.

Richards, R.T. FISH SCREENING-THE STATE OF THE PRACTICAL ART. Hydr. in the Coastal Zone, Proc. Of 25th Annual Hydr. Div. Spec. Conf. p. 296-303. 1977.

ABSTRACT: This paper was a progress report on the investigation of the ASCE Task Committee on Fish-handling Capabilities of Intake Structures into presently available practical devices or systems for protecting fish at water intakes. The emphasis was on the term 'practical', limiting the discussion to technology which consists of readily available and proven components and which has consistently demonstrated the ability to reduce fish mortality. This particular presentation was limited to the primary fish screening, fish guiding, and fish repulsion techniques. The 'practical' device or systems discussed are substantially effective in protecting fish, are available today without further mechanical development, can be operated at reasonable cost, and can be maintained without interfering with the very high availability factor required of power plant cooling water supplies. The technology must be of proven mechanical reliability. We should keep in mind that for power plants the water intake must function at full capacity 24 hours a day, 7 days a week.

Richards, R.T. PRESENT ENGINEERING LIMITATIONS TO THE PROTECTION OF FISH AT WATER INTAKES Fourth Natl. Workshop on Entrainment and Impingement. p.415-424. 1978.

ABSTRACT: This paper discusses the constraints which engineering practicality imposes on the design of fish protection devices. It is suggested that the most practical fish screening approaches include optimization of the location of the point of water withdrawal to avoid concentrations of aquatic organisms; the use of velocity cap horizontal inflow provisions for offshore withdrawals; the use of conventional vertical straight-through traveling screens with limitations on screen approach velocities; angling of the vertical screen arrays to guide fish to escape sluiceways; flush mounting of screens combined with openings in support walls to provide an unobstructed fish passage escape; modification of conventional vertical screens to include fish removal sprays, fish collection lips and a means of bringing the organisms to a recovery system external to the intake itself.

Richards, R.T. and M.J. Hronchich PERFORATED-PIPE WATER INTAKE FOR FISH PROTECTION. J. Hydraulics Div., 201(HY2), Paper 11900. p. 139-149. Feb. 1996.

ABSTRACT: Since a major concern in the design of pumping station water intakes is the possibility of damage by fish drawn into the facility, some kind of screening system must be installed to minimize or eliminate this possibility. The potentially adverse impact of water intakes

is resolved by the implementation of physical screens, which exclude all debris, including fish. The germane difficulties of screens, i.e., the necessity of lowering the approach velocity, poor velocity distribution across the screen, and danger to fish are overcome by the installation of a perforated-pipe inlet with an added internal perforated sleeve. The benefits of such a device, i.e., relative ease of maintenance, uniform approach velocity, uniform inflow, and protection for fish, cannot be equaled by ordinary means of physical screening. For water intakes up to 100,000 gal/min, the inner sleeve type of perforated-pipe intake provides a viable solution to the problem of screening.

Sale, M.J., G.F. Cada, L.H. Chang, S.W. Christensen, S.F. Railsback, J.E. Francfort, B.N. Rinehart, and G.L. Sommers ENVIRONMENTAL MITIGATION AT HYDROELECTRIC PROJECTS, Volumes 1 & 2. Prepared for the U.S. Department of Energy. December 1991.

ABSTRACT: Current environmental mitigation practices at nonfederal hydropower projects were analyzed. Information about instream flows, dissolved oxygen (DO) mitigation, and upstream and downstream fish passage facilities was obtained from project operators, regulatory and resource agencies, and literature reviews. Information provided by the operators includes the specific mitigation requirements imposed on each project, specific objectives or purposes of mitigation, mitigation measures chosen to meet the requirement, the kinds of post-project monitoring conducted, and the costs of mitigation. Costs are examined for each of the four mitigation methods, segmented by capital, study, operations and maintenance, and annual reporting costs. Major findings of the study include: the dominant role of the Instream Flow Incremental Methodology, in conjunction with professional judgment by agency biologists, to set instream flow requirements; reliance on spill flows for DO enhancement; and the widespread use of angled bar racks for downstream fish protection. All of these measures can have high costs and, with few exceptions, there are few data available from nonfederal hydropower projects with which to judge their effectiveness.

Sazaki, M., W. Heubach, and J.E. Skinner DEVELOPMENT OF FISH SCREEN DESIGN CRITERIA: SOME PRELIMINARY RESULTS ON THE SWIMMING ABILITY AND IMPINGEMENT TOLERANCE OF YOUNG-OF-THE-YEAR STEELHEAD TROUT, KING SALMON AND STRIPED BASS. Cal. Dept. Of Fish And Game; 34p. Ref., Graphs., 1972

ABSTRACT: Laboratory tests were conducted to determine the swimming ability and impingement tolerance of the young of selected anadromous fish species. The tests were undertaken to develop biological criteria to design a fish screen for the proposed joint State-Federal Peripheral Canal. This report reflects only that portion of a much larger study program, which involved funding under the Anadromous Fisheries Act. Both king salmon (36-56 mm) and steelhead trout (22-36 mm) withstood impingement on a screen of 16 meshes to the inch, at water velocities of 2.5 fps for up to six minutes. Survival was rarely less than 100 percent. Swimming capability is related directly to size and inversely with velocity. The highest velocity at which 90% of the (47-56 mm) salmon could swim for six minutes was 0.7 fps. Less than 85% of the steelhead under 36 mm were able to swim for six minutes at 0.2 fps. All steelhead were impinged at 1.0 fps and all king salmon at 1.5 fps. The striped bass tested ranged from 10-50 mm in length. The smaller fish were impinged at velocities as low as 0.4 fps. A velocity of 2.5 fps was required to impinge the largest fish. Mortality from impingement also was related to the size of the fish. For fish 10-50 mm long velocities on the order of 0.5 fps or less were required to attain a survival

of 80 percent for the six minute test period. Seventy percent or more of the striped bass eggs impinged survived the 6 minute test period at velocities up to 0.8 fps.

Schill, D. EVALUATING THE ANADROMOUS FISH SCREEN PROGRAM ON THE UPPER SALMON RIVER. Idaho Department of Fish and Game; 26 pp. Ref., Maps, Charts, 1984

ABSTRACT: Existing data concerning the effectiveness of Salmon River fish screening are summarized, and the relationship between screen operation and maintenance costs and benefits from this program is examined. Suggestions and guidelines for future evaluations of the fish screen program are provided. NOTES: Study performed for the Columbia River Program Office of the National Marine Fisheries Service.

Schleiger, S. L. and E. J. Peters DESIGN AND IMPLEMENTATION OF LOW-FLOW FISH BARRIERS FOR USE IN SMALL STREAMS. Proc. Nebr. Acad. Sci. Affil. Soc., 95:30. 1985. Abstract only. SFA 30(3)

ABSTRACT: Competition for food and space is difficult to measure in aquatic habitats. Studies to measure competition often use enclosures. In lotic situations problems with the use of enclosures are compounded by fluctuating water levels and accumulation of trash carried by the current. To study competitive interactions between Cree Chubs (*Semotilus atromaculatus*) and Green Sunfish (*Lepomis cyanellus*) we developed a low-flow fish barrier from PVC pipe and steel rods which successfully blocked movement of test populations of fish during minor fluctuations in water level in small eastern Nebraska streams. Other advantages of these barriers include: ease of maintenance; resistance to high flows during period of heavy runoff; and that they allow the passage of small fish and food organisms through test sections of the stream.

Schneeberger, P. J. and D. J. Jude USE OF FISH LARVA MORPHOMETRY TO PREDICT EXCLUSION CAPABILITIES OF SMALL-MESH SCREENS AT COOLING-WATER INTAKES. Trans. Am. Fish. Soc., 110(2):246-252. Mar. 1981. SFA 26(3)

ABSTRACT: A relationship between total lengths and body depths of certain fish larvae was used to predict the effectiveness of small-mesh screens in limiting entrainment of fish larvae at cooling-water intakes. Total length-body depth regressions were linear for eight species (293 larvae) common to Lake Michigan near the J.H. Campbell Power Plant at Port Sheldon, Michigan. Regressions indicated at 35-100% (depending on species) of the fish larvae that had been entrained by the J.H. Campbell Plant in 1978 would have been excluded if 0.5-mm mesh screening had been employed in the plant's cooling water intake system instead of 9.5-mm bar mesh vertical traveling screens. These calculations do not take into consideration approach velocities of intake water, larva avoidance behavior, or mortality due to impingement on or extrusion through the screens.

Schwalme, K. and W. C. Mackay SUITABILITY OF VERTICAL SLOT AND DENIL FISHWAYS FOR PASSING NORTH-TEMPERATE, NONSALMONID FISH. Can. J. Fish. Aquatic Sci., 42(11):1815-1822. 1985. In English with French summ. FR 31(1)

ABSTRACT: A vertical slot fishway and two Denil fishways (of 20 and 20% slope) built into a weir on the Lesser Slave River (55 18'N, 115 45'W) were studied from May 12 to June 25, 1984, to determine how effectively these designs pass north-temperate, nonsalmonid fishes. Thousands of spottail shiner (*Notropis hudsonius*), substantial number (>100) of northern pike (*Esox lucius*), longnose sucker (*Catostomus catostomus*), white sucker (*Catostomus commersoni*), immature yellow perch (*Perca flavescens*), and lesser numbers of burbot (*Lota lota*), adult yellow perch, lake whitefish (*Coregonus clupeaformis*) and trout-perch (*Percopsis omiscomaycus*) ascended the fishways. Walleye (*Stizostedion vitreum*) and goldeye (*Hiodon alosoides*), although probably moving extensively through the river, did not use the fishways. Although high water levels allowed most fish to surmount the weir, of that that chose the fishway, pike strongly preferred to ascend the Denil fishways and the two sucker species preferred to ascend the vertical slot. Therefore, a combination of several different fishways may be required for the most efficient passage of a wide variety of species. Plasma glucose and lactate measurements on pike revealed that ascending the Denil fishways was only moderately stressful for these fish.

Seelbach, P. W.; R. N. Lockwood and G. R. Alexander A MODIFIED INCLINED-SCREEN TRAP FOR CATCHING SALMONID SMOLTS IN LARGE RIVERS. N. Am. J. Fish. Manage., 5(3B):494-498. 1985. FR 31(1)

ABSTRACT: A modification of the incline-screen trap was constructed to capture and facilitate processing of runs of salmonid smolts in large rivers. Modifications included a hanging inclined screen, a floating catch barge, and a fish sorter. Two such traps operated in the Little Manistee River in northwestern Michigan caught and held up to 2,500 steelhead (*Salmo gairdneri*) smolts per night. By sampling only a portion of the total river flow and using pipe weirs to guide smolts toward the two traps, we successfully sampled the smolt migration during periods of fluctuating water levels and debris content. It was estimated that our trapping scheme caught 42% of the steelhead smolts, 31% of the chinook salmon (*Oncorhynchus tshawytscha*) smolts, and 22% of the coho salmon (*Oncorhynchus kisutch*) smolts migrating downstream.

Smith, E. J. and J. K. Andersen ATTEMPTS TO ALLEVIATE FISH LOSSES FROM ALLEGHENY RESERVOIR, PENNSYLVANIA AND NEW YORK, USING ACOUSTICS. N. Am. J. Fish. Manage., 4(3):300-307. 1984. SFA 29(4)

ABSTRACT: As a consequence of pool drawdown each fall and winter to enhance flood storage, numerous fish are lost through the bottom sluices of Allegheny Reservoir (located on the western border of Pennsylvania and New York). The sudden release of pressure accompanying the passage of these fish from a deep zone of the reservoir into the tailrace can result in a substantial fish kill. The conditions under which fish are lost apparently are enhanced when the pool level is low and discharge is high. In an effort to reduce these losses, underwater broadcasts of recorded sound effects were tested. The sound projector was a low-frequency transducer mounted above the bottom sluices on the upstream face of the dam. While the sound broadcasts were being evaluated, the Corps of Engineers maintained a higher winter pool at the project to test the effect of controlled flow releases on ice formation at downriver locations. Although the underwater sound broadcasts were not effective, maintenance of a higher winter pool resulted in a marked reduction in the fish losses.

Smith, J.R. and W.E. Farr BYPASS AND COLLECTION SYSTEM FOR PROTECTION OF JUVENILE SALMON AND TROUT AT LITTLE GOOSE DAM. Marine Fisheries Review 37 (2), 31-35., 1975

ABSTRACT: Juvenile fish screening, bypass, and collection facilities at Little Goose Dam on the lower Snake River are described. The complex includes traveling screens for diversion of downstream migrants from turbine intakes, a bypass system for routing fish around the turbines, and a fish collection area for grading, enumeration, and examination of the migrants passed to the tailrace area. The system was operated and evaluated in 1971-72 by the National Marine Fisheries Service under contract to the U.S. Army Corps of Engineers.

Steen, A. E. and J. R. Schubel AN APPLICATION OF A STRATEGY TO REDUCE ENTRAINMENT MORTALITY. J. Environ. Manage., 23(3):215-228. 1986. FR 32(2)

ABSTRACT: Regulatory agencies have often required power plants to operate at low excess temperatures because thermal stresses are believed to be the primary cause of mortality to organisms entrained by the once-through cooling systems of electric generating stations. This practice results in the use of large volumes of cooling water to achieve the mandated low excess temperatures. Operation of power plants below upper tolerable temperatures results in entrainment of unnecessarily high numbers of organisms, and may cause a higher total mortality rate than would result from operating the power plant at high temperatures and using a lower volume of cooling water. Variations in cooling water flow resulting from changes in the number or capacity of circulating water pumps in operation alter the number of organisms entrained, the magnitude of the change in temperature, and, as a result, the mortality rate of entrained organisms. It has become accepted scientific practice to calculate safe levels of toxics. Procedures to determine the temperature and cooling water flow characteristics which minimize entrainment mortality were developed and applied. The operating conditions of a power plant on the Potomac River were examined as a case-study to determine whether the plant was operating at, below, or above a maximum tolerable change in temperature. This method may be applied to power plants to determine if entrainment mortality due to thermal effects may occur and what alterations in cooling water flow would minimize entrainment mortality to selected representative important species.

Stefan, H.G., W.Q. Dahlin, T. Winterstein and P. Fournier PASSIVE SCREEN WATER INTAKE DESIGN STUDIES. J. of Energy Engr. 112(2):115-126. 1986.

ABSTRACT: Experimental and analytical studies are conducted to develop a novel water intake design for the prevention of fish impingement and excessive damage to fish larvae. Requirements by the regulatory agency lead to the use of cylindrical screens mounted in pairs on risers connected to four manifolds, which in turn were connected to an 18 ft diameter withdrawal pipe carrying a total flow of 23.2 cu.m/s to a powerplant condenser. Separate model studies conducted on individual screen panels, individual and multiple risers and manifolds are described. The studies conducted at scale ratios ranging from 1:20-1:3 are described. The system built in 1981 continues to work well with only minor damage sustained by ice.

Stober, Q. J.; R. W. Tyler and C. E. Petrosky BARRIER NET TO REDUCE ENTRAINMENT LOSSES OF ADULT KOKANEE FROM BANKS LAKE, WASHINGTON. N. Am. J. Fish. Manage., 3(4):331-354. 1983. SFA 29(1)

ABSTRACT: A barrier net 1,341 m long was developed to reduce the entrainment of mature kokanee (*Oncorhynchus nerka*) into the main irrigation canal intake of Banks Lake in Washington. The dacron net was constructed of 83-mm mesh (stretch measure) and relied on the visual avoidance response exhibited by salmonids. The net was hauled by machine and cleaning was done with high-pressure water jets. The screening efficiency of the barrier was evaluated by numerous methods including sampling the fishes entrained in the irrigation canal with large nets, mark and recapture of adult kokanee in the reservoir, estimates of the number of beach spawners, sonic tracking near the barrier, census of the sport fishery, and mortality of kokanee gilled in the barrier. The annual canal entrainment of kokanee declined from an average of 64% before installation of the net to 10% afterwards, based on 4 years of catch data. An estimated 35,391 adult kokanee, based on mark-and-recapture estimates, were retained in the lake during the fall of 1978 when 96% retention of the population was achieved. Sonic-tracked kokanee were turned back by the barrier and, during October, "homed" to beach spawning sites. From a creel census, it was estimated that anglers caught 46,427 kokanee in 1978. The catch of kokanee per angler-hour remained stable at 0.216 while the catch of all other species declined from 0.372 to 0.042 from 1972 to 1978. The barrier net enhanced the sport fishery and the spawning population in the reservoir. The number of kokanee gilled in the barrier net was small relative to the population retained, and the net provided an economical means of reducing the entrainment loss of adult kokanee through a spillway.

Taft, Edward P., Fred C. Winchell, Thomas C. Cook and Charles W. Sullivan INTRODUCING A 'MODULAR' APPROACH TO FISH SCREEN INSTALLATION. *Hydro Rev.*, 11(7):36, 38, 40. 1992. FR 38(1)

ABSTRACT: A new screen type of modular inclined screen or MIS is introduced in this article. This screen type can be installed where penstocks are not used for water intakes and applies to a wide variety of water intakes on dams. The screen is an inclined screen with a bypass system attached to it. The screen cleans by inverting itself to a backwash position and backwashes with water pressure through the tubes. This screen works at high velocities as opposed to standard screens which are less than 0.5 foot per second velocity. This one works in velocities of 2-10 feet per second. Tests were made on passing rainbow trout, blueback herring, walleye, channel catfish and several additional species including Pacific salmon. This system provides an alternative to standard screening which will be cost effective and applicable to a wide range of conditions.

Taft, E.P.III and Y.G. Mussalli ANGLED SCREENS AND LOUVERS FOR DIVERTING FISH AT POWER PLANTS. *J. Hydraulics Div., Amer. Soc. Civil Engr.*, 104(HY5), Paper 13731: 623-634. May 1978.

ABSTRACT: Angled screens and louvers have been evaluated experimentally and developed for diverting fish to bypass within cooling water intake structures. Louvers have been shown to be greater than 90% effective in diverting a variety of fish species in both laboratory and prototype studies. Recent studies with angled traveling screens have shown them to be 100% effective in guiding fish to bypasses. Angled screen and fish transportation systems are presently under construction at two large power plants on Lake Ontario.

Taft, E.P.III and Y.G. Mussalli BIOLOGICAL AND ENGINEERING INVESTIGATION OF ANGLED FLUSH FISH DIVERSION SCREENS. Hydr. in the Coastal Zone, Proc. Of 25th Annual Hydr. Div. Spec. Conf.:304-312. 1977.

ABSTRACT: This paper discussed the development of angled, flush-mounted, traveling screens which can be used to divert fish to bypasses without power plant intake screenwells. Although angled screens have not been utilized at power plants, they have been shown to be effective at hydroelectric facilities. Laboratory physical model studies with live fish were carried out to develop and optimize the design of the screen within the constraints imposed for power plant application. Utilizing information obtained, design criteria for effective application were established and the angled screen fish diversion system was incorporated into two power plant screenwells. On the basis of the development efforts, it appears that the angled, flush-mounted traveling screen concept may have the potential for diverting fish at other selected power plant intakes.

Tou, S.K.W. A STATISTICAL AND EXPERIMENTAL STUDY ON FISH RESPONSE SUBJECT TO VORTEX RING MOTION. J. Environ. Sci. Health Part A Environ. Sci. Eng., 26(5):755-775. 1991. FR(36)3.

ABSTRACT: Experiments are conducted to study the fish response in a water channel when subjected to vortex ring motion. The fish activity is measured in terms of counts of occurrence at three different locations along the channel using a series of infra-red sensors. Vortex rings are produced intermittently from a vortex ring chamber located at one end of the channel under various water tank pressure settings and vortex ring generation frequencies. Experimental results show that the fish activity follows a normal distribution. Analysis of data indicates that fish response is statistically significant at different locations in the channel. Fish activity is the lowest (23%) at a region adjacent to the vortex ring chamber. Fish activity is negatively related at each pair of locations. Fish response is sensitive to the combined effects of water tank pressure and vortex ring generation frequencies. The study suggests the potential application of vortex rings as an alternative means of distracting fishes from getting near to the generation source.

Turnpenny, A.W.H. AN ANALYSIS OF MESH SIZES REQUIRED FOR SCREENING FISHES AT WATER INTAKES. Estuaries, 4(4):363-368. Dec. 1981. SFA 27(1)

ABSTRACT: Twenty-four species of marine and fresh water fish were measured to determine optimal mesh sizes for fish screens. Samples were collected from cooling water intakes of power stations on the south coast of England, from trawlers, and from a hatchery. Curves relating fish length to mesh size requirements as a function of fish shape and size are given. A model for predicting mesh size requirements as a function of fish shape and size proved more accurate (7.3% mean deviation) than the Bell (1973) model (45% mean deviation). For species not included in the curves, the screen mesh size requirements can be estimated from an equation.

Vaughn, R. and ed: W.D. Hall OPERATIONAL LOAD TESTING OF TRAVELING FISH SCREENS. Source: Geotechnical Engr., Waterpower '93 Proc. of Intl. Conf. on Hydropower, Vol. 2:1448-1456. 1993.

ABSTRACT: New longer fish screens are being developed to improve passage of fish at some hydropower projects in the Northwest. The first prototypes were used at McNary Dam in 1991. Testing was performed on the prototypes by Teledyne Engineering Services. The data will be used in the design of 42 permanent screens which will be used at this project. Additional testing will be performed at The Dalles and Little Goose Dams, where more screens will be installed, because differences in turbine flow and turbine intake geometry can lead to large differences in loading.

Weisberg, Stephen B.; William H. Burton; Fred Jacobs and Eric A. Ross REDUCTIONS IN ICHTHYOPLANKTON ENTRAINMENT WITH FINE-MESH, WEDGE-WIRESCREENS. N. Am. J. Fish. Manage., 7(3):386-393. 1987. FR 33(1)

ABSTRACT: The exclusion efficiency of cylindrical wedge-wire screens was investigated at the Chalk Point Steam Electric Station in Aquasco, Maryland, by measuring entrainment of larval bay anchovies *Anchoa mitchilli* and naked gobies *Gobiosoma boscii* through screens with slot sizes of 1, 2, and 3 mm and through an unscreened intake. The degree of exclusion by the screens increased with fish size. Fish less than 5 mm long were not excluded by any of the screens. In contrast, more than 80% of larger ichthyoplankton were excluded by all screens. Virtually no ichthyoplankton larger than 10 mm were entrained through the 1-mm screen even when fish of this size were abundant and were entrained through the unscreened intake. The 2-mm and 3-mm-slot screens were not as effective at excluding ichthyoplankton as the 1-mm screen, but the effect of slot size on exclusion efficiency was small relative to the effect of fish size. These results suggest that entrainment through water intake structures can be successfully reduced by wedge-wire screens if the larval fish at risk exceed 5 mm in length.

Winchell, F., S. Amaral, N. Taft, C. Sullivan and ed.s W.D. Hall BIOLOGICAL EVALUATION OF A MODULAR FISH SCREEN. Geotechnical Engr., Waterpower '93 Proc. of Intl. Conf. on Hydropower, Vol. 1:328-337. 1993.

ABSTRACT: The Electric Power Research Institute (EPRI) has developed and is presently testing a new type of fish diversion screen known as the Modular Inclined Screen (MIS). The screen is designed to operate at high water velocities (up to 3.0 ms⁻¹) and is, therefore, significantly more compact than conventional low velocity screening systems. A biological evaluation of the MIS was conducted in 1992 with juveniles of six fish species: bluegill, walleye, rainbow trout, channel catfish, and two alosid species that were tested as one group. The results of this laboratory study demonstrate that the MIS has excellent potential for providing effective fish protection at water intakes.