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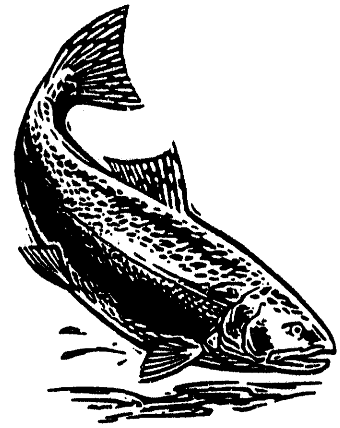

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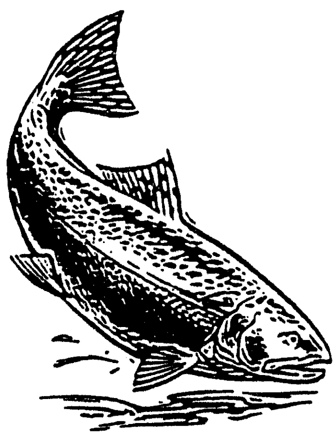

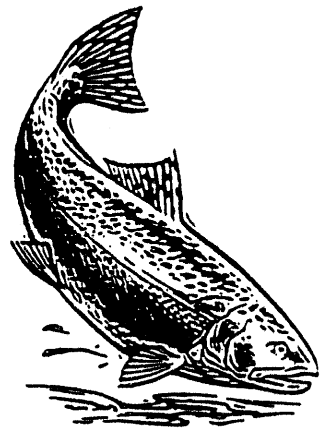

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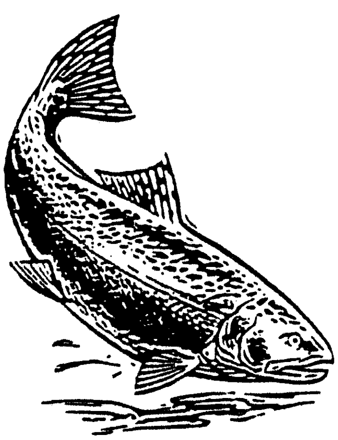

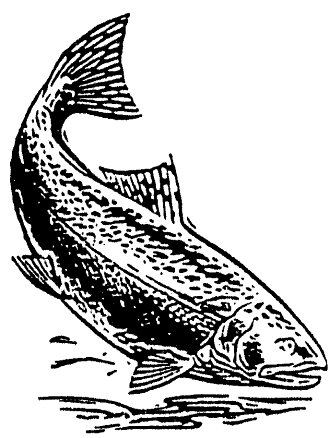

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A Hierarchical Approach to Classifying Stream Habitat Features.

American Society of Civil Engineers (Waterpower' 91)

Improving the Assessment of Instream Flow Needs for Fish Populations.
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A Demonstration of Strobe Lights to Repel Fish.
The use of IFIM for Evaluating Effects of a Flow Alternative on Fish Habitat in a River System with Competing Water Demands.
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Twin Falls Mitigation Plan: Long Term Monitoring of Fish Populations.
Mercury in Fish and Water in New Impoundments, a Review of the Literature.
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Fish Protection at Water Intakes using a New Signal Development Process and Sound System.
Atlantic Salmon Smolt Movement and Behavior at Vernon Hydroelectric Station.

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Twin Falls Mitigation Plan: Long-Term Monitoring of Fish Population.

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Assessing Fish Mortality Rates.
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Introducing a 'Modular' Approach to Fish Screen Installation.

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Development of Technology to Treat and Dispose of Fish Farm Waste.
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The Hydropower Industry's Fishway Principles.

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Using Sound Waves to Monitor Fish Entrainment.

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Salmon Passage Notes.

United States Committee On Large Dams

Fish Passage and Hydropower Development at the Dalles Dam.
Evaluation of a Louver Array/Bypass System in Bypassing Atlantic Salmon Smolts from the Holyoke Canal to the Connecticut River.
Two Promising Technologies for Fish Protection at Hydroelectric Projects.
Debris Removal from a Low-Velocity, Inclined Fish Screen.
Use of a Dam to Revitalize Aquatic Environment in an Intermittent River.

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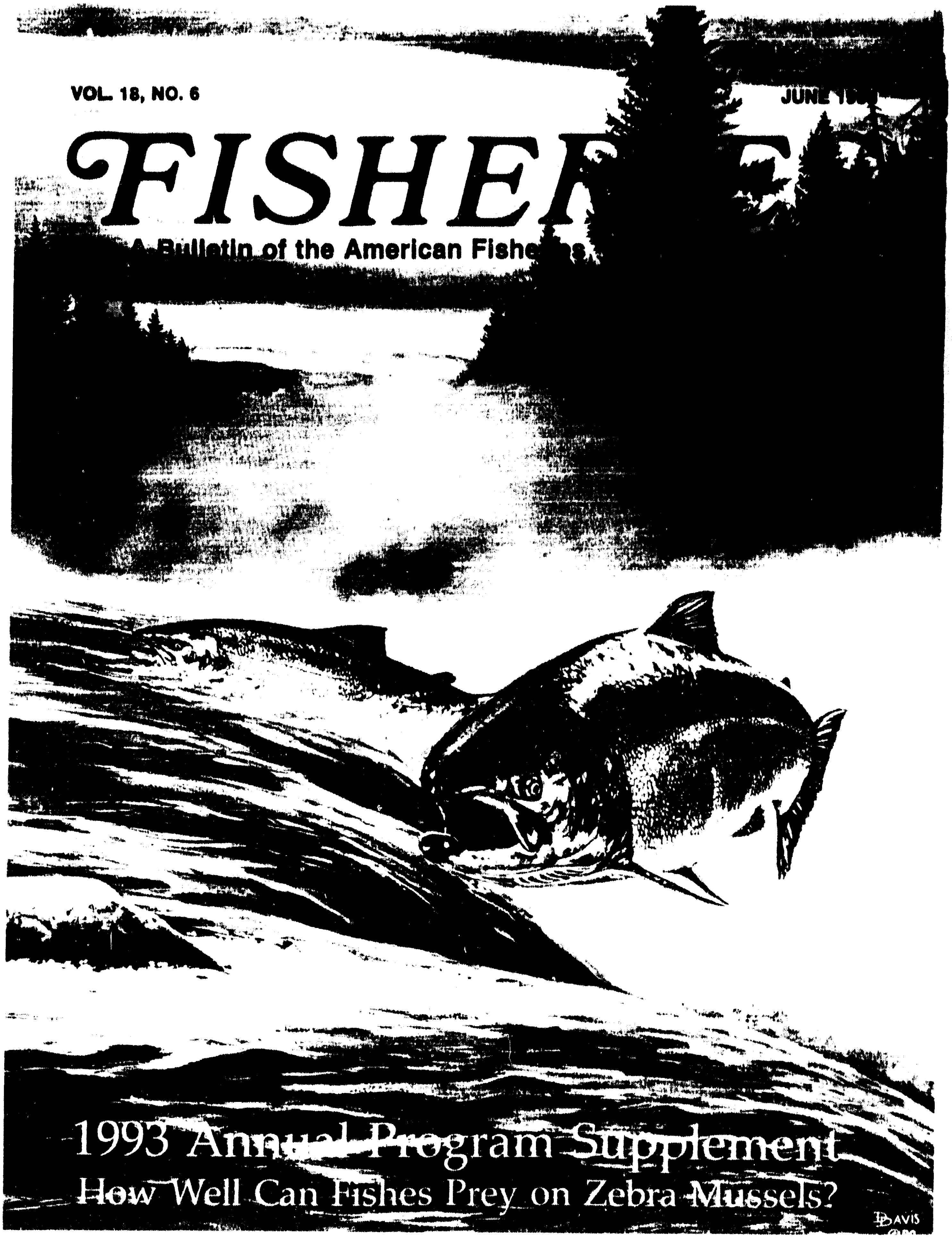

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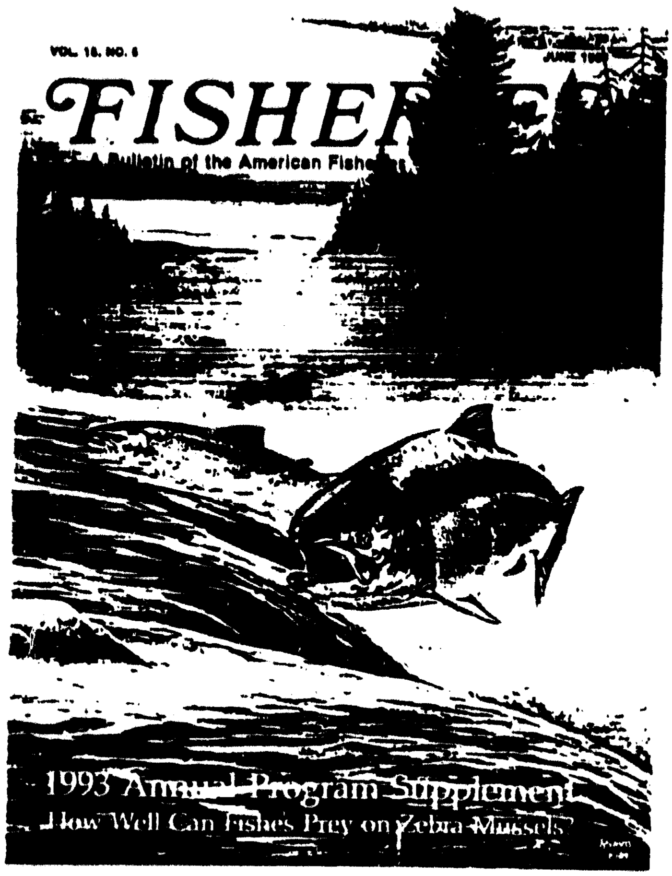

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Status of Fish Passage Facilities at Nonfederal Hydropower Projects

Glenn F. Čada and Michael J. Sale

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- 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.

The regulatory process that controls development of hydroelectric power in the United States has become increasingly complex. The role of natural resource agencies in the regulation of nonfederal hydropower projects has been significantly strengthened in recent years, in part as a result of amendments to the Federal Power Act (FPA) brought about by the Electric Consumers Protection Act of 1986. For example, the Federal Energy Regulatory Commission (FERC), which licenses nonfederal water power projects, must give fish and wildlife resources equal consideration with power production in its licensing decisions, must be satisfied that a project is consistent with comprehensive plans for a waterway (including qualifying fisheries management plans), must include resource agency terms and conditions for the protection of fish and wildlife in any exemption from licensing, and must adopt in a license the mandatory terms and conditions of land management agencies (FERC 1991).

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Section 18 of the FPA authorizes the departments of Commerce and the Interior to prescribe fishways at projects licensed by the FERC.

Hydropower projects can seriously harm fish populations. Natural resource agencies attempt to avoid these impacts by recommending to the FERC appropriate mitigative measures (e.g., to enhance upstream and/or downstream fish passage). The decision whether or not to mandate fish passage facilities and, if so, which types, is often disputed. Although numerous mitigative measures for fish passage are available for hydropower projects, their costs can be high, and their effectiveness may be poorly understood.

In keeping with its mission to promote environmentally sound hydroelectric development, the Hydropower Program of the U.S. Department of Energy (DOE) is conducting a multi-year study of environmental mitigation. The first phase of this study was an examination of mitigation practices associated with three issues: fish passage, instream flow requirements, and dissolved oxygen. The objectives were (a) to identify, compile, and analyze information on the implementation and monitoring of specific, direct mitigation practices; and (b) to determine the degree to which costs, benefits, and effectiveness of these practices have been measured. This paper is a summary of the findings related to fish passage in that report (Sale et al. 1991), which is the first (Volume 1) of a series. Subsequent volumes of the environmental mitigation study will treat these three issues and others individually.

Study Methods

The commission's licensing records were used to identify projects that were required to mitigate environmental impacts related to either upstream or downstream fish passage. The data contained in these records were verified by contacting hydropower developers, and additional information was obtained directly from both developers and state and federal resource agencies responsible for overseeing hydropower development.

Federal Energy Regulatory Commission Data Bases

The hydropower licensing records used in this study came from two sources: (1) the FERC's Hydroelectric Power Resources Assessment (HPRA) data base and (2) the FERC's Hydropower Licensing Compliance Tracking System (HLCTS). The HPRA database system is a comprehensive repository of information on developed and undeveloped hydropower resources in the United States. HPRA was used to obtain descriptive information on existing projects in the study's target population, including such characteristics as licensing and construction status, project location, and developer type (e.g., private, municipality, utility).

The HLCTS data base is used by the FERC's Division of Project Compliance and Administration to track license requirements and compliance actions. HLCTS includes codes for all study and reporting requirements defined in each project's license, license articles, or exemption order. Although these codes do not completely describe all mitigation measures, HLCTS is the only computerized data base available that contains general information on mitigation requirements for recent FERC licenses and exemptions. A copy of the HLCTS data base was obtained from the FERC in July 1990. Our study of fish passage mitigation measures covered nonfederal hydroelectric projects that were licensed or exempted before 1 July 1990. Although most environmental mitigation was required for projects licensed or exempted during the 1980s, mitigative measures at some sites (e.g., fish ladders) have been operating for many years.

Information from Hydropower Developers

Information available from FERC data bases is coded or otherwise abbreviated and is not sufficient to evaluate site-specific mitigation practices or costs and benefits. Therefore, a major effort was made to acquire new information directly from the developers of projects at which fish passage mitigative measures were required. Developers were contacted via mailings and were asked to describe the specific mitigation measures required by their FERC licenses or exemptions, the extent to which the requirements have been implemented, the extent to which data have been collected to determine if mitigation was successful, and the success of mitigation requirements in protecting aquatic resources. We contacted all 707 developers believed to have instream flow, dissolved oxygen and/or fish passage requirements and received 280 responses (40%), most of which indicated that no fish passage requirements had been mandated. Returns were representative of the geographic distribution of fish passage requirements (i.e., most returns came from the Northeast, West Coast, and the Rocky Mountain states). No systematic follow-up mailings or phone calls were made to nonrespondents to assess possible bias in the returns. The assumptions associated with deriving conclusions for the overall target population of FERC-licensed projects from the 280 projects that responded to the information request are discussed in Sale et al. (1991).

Information from Natural Resource Agencies

In an effort to obtain additional information on mitigation policies, effectiveness, and available data and to ensure a balanced view of current practices, those state and federal resource agencies that have responsibilities for recommending environmental mitigation at hydropower projects were also asked for information. Two or more agencies in each of the 50 states, as well as the regional offices of the U.S. Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS), were asked to provide information on fish passage issues. Agencies were asked to list the hydropower projects in their respective states or regions that have fish passage mitigative measures, to describe their mitigation policies and practices, and to identify any studies that could be used to quantify benefits and costs. Agencies from 34 states responded to the fish passage information requests.

Current Mitigation Practices

This section describes the types and frequencies of application of fish passage mitigation measures that have been required at FERC-licensed hydropower projects during the 1980s. Descriptive information about these fish passage measures, including a review of the published literature about effectiveness, is given in Sale et al. (1991). Unless indicated otherwise, the description of current practices in this section is based solely on the new information provided by hydropower developers and agencies for this study.

Analysis of the FERC HLCTS data base indicated that 707 projects have some type of environmental mitigation requirement (i.e., for fish passage, instream flow releases, and/or dissolved oxygen maintenance); fish passage facilities were specifically mentioned in the licenses of 79 of these projects. We asked the developers of all 707 projects about fish passage facilities, even though only a fraction were known to have relevant license requirements. Developers of 280 of the 707 projects (40%) responded to the information request, including 34 projects with upstream fish passage facilities and 85 projects with downstream fish protection measures. More projects with downstream passage measures were found via the information request (85) than expected from the HLCTS data base (no more than 79), indicating that the data base is in need of updating and verification. We considered the 40% overall return rate for information requests good.

The distribution of nonfederal hydroelectric projects with environmental mitigation requirements is shown in Figure 1. The percentage of newly issued licenses with upstream fish passage requirements did not change significantly during the period between 1980 and 1990, averaging around 11% (Sale et al. 1991). However, the percentage of new licenses that have downstream fish passage requirements increased from 22% in 1980–83 to 35% in 1984–90.

Upstream Fish Passage

The blockage of upstream fish movements by hydroelectric dams may have serious impacts on species whose life histories include spawning migrations. Anadromous fish (e.g., salmon, American shad, blueback herring, striped bass), catadromous fish (e.g., eels), and some resident fish (e.g., trout, white bass, sauger) could all have spawning migrations halted by barriers such as hydroelectric dams. Maintenance, restoration, or enhancement of these species' populations may require construction of facilities to allow for upstream fish passage (Mattice 1990). Most upstream passage measures can be placed into three general categories: trapping and hauling, fishways (Fig. 2), and fish lifts or elevators (Fig. 3). Descriptions of the basic types of upstream fish passage measures are provided in earlier reviews (Clay 1961; Hildebrand 1980; Orsborn 1987).

Information on 34 projects that have upstream fish passage facilities was obtained from hydropower developers. Thirty-one of these facilities (91%) were either in operation or completed. Fish

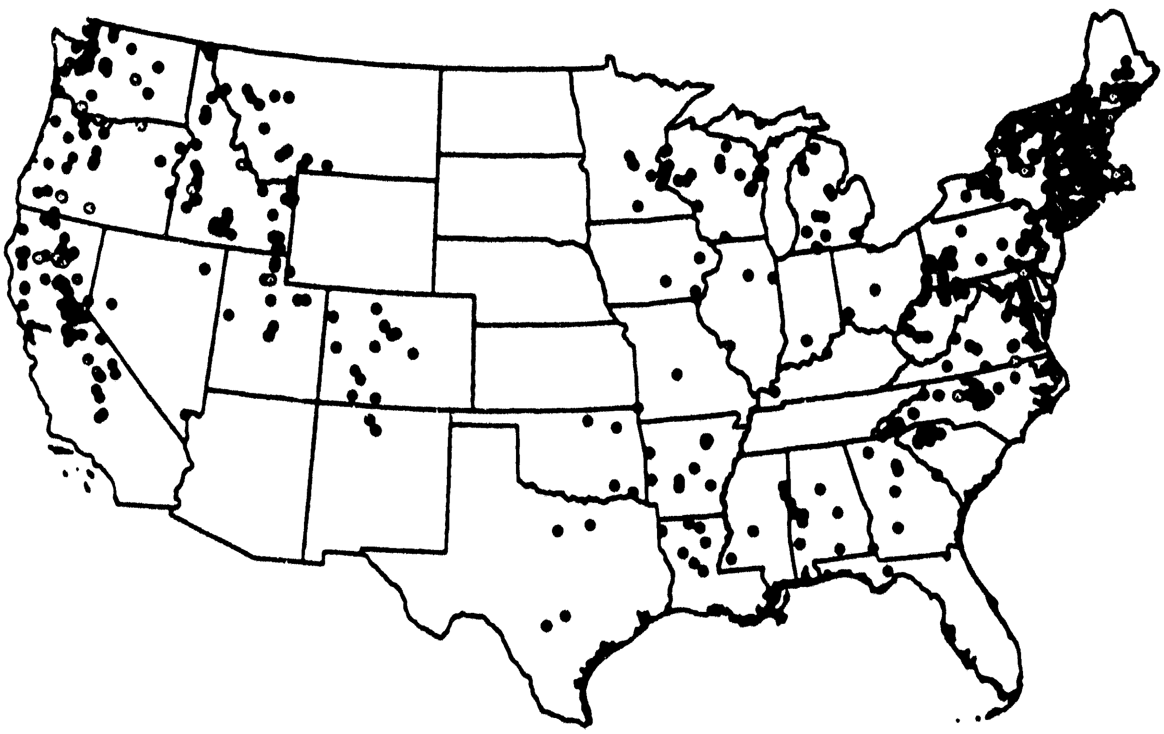

Figure 1. Distribution of nonfederal hydroelectric projects in the continental United States with mitigation requirements related to fish passage, instream flow, or dissolved oxygen.

ladders were the most common mitigative measure, accounting for 24 of the 34 (71%) upstream passage devices reported (Fig. 4). Fish ladders are employed throughout the United States, and some are quite old, dating back to the turn of the century. Fish elevators are a less common (4 out of 34 or 12%) mitigative measure. The trapping and hauling (by trucks) of fish to upstream spawning locations is used at some older dams or in conjunction with fish lifts, but in two of the projects, fish ladders or elevators are being constructed to replace this labor-intensive mitigative measure. Some upstream passage measures that are used at few sites and fit none of the three categories include berms (to keep upstream migrating fish away from the powerhouse discharge area or to guide fish toward ladders) and the use of navigation locks.

Among the 29 respondents that have operating upstream fish passage facilities, 12 (41%) reported that the facilities are in operation at all times. Another 10 of the 29 projects (35%) reported that passage facilities are operated only during specified seasons, whereas 4 (14%) are required to operate only during certain hours (e.g., nighttime) during specified seasons. Three of the developers (10%) didn't respond to this question.

Twenty-three of the 34 projects (68%) that responded to our information request reported that the upstream passage mitigation was designed for anadromous fish. On the other hand, some hydroelectric projects are required to maintain upstream movements of resident (nonanadromous) fish as well. Thirteen of the projects (38%) reported resident fish passage requirements, and 4 (12%) reported only resident fish passage requirements. Not all of these facilities currently transport the fish they were designed to protect; a few upstream passage facilities were installed with the expectation that future fish restoration efforts would necessitate their use.

According to the developers who provided information to the study, professional judgment by the agencies was the most common basis for incorporation of an upstream fish passage requirement; 17 of 34 (50%) reported that professional judgment contributed to the requirement, and 12 (35%) reported that this was the sole basis for the requirement. Licensee-conducted and agency-conducted studies contributed to the development of fish passage requirements in 7 and 6, respectively, of the 34 projects. Eight of the project operators (24%) were not aware of any studies conducted to determine a need for upstream fish passage at their sites. Regarding the role of professional judgment in setting fish passage requirements, it should be noted that in many cases the agency position may reflect knowledge or studies unknown to the developer. For example, the need to pass anadromous fish upstream of an existing dam may have been identified

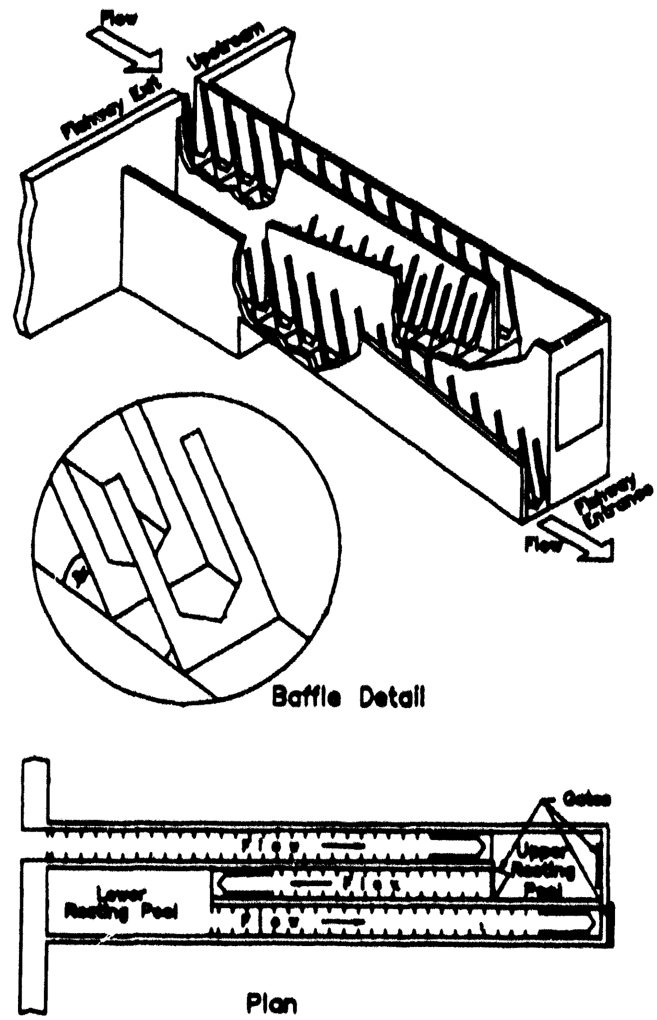

Figure 2. Example of a Denil fishway for upstream fish passage. Modified from Katopodis et al. (1991).

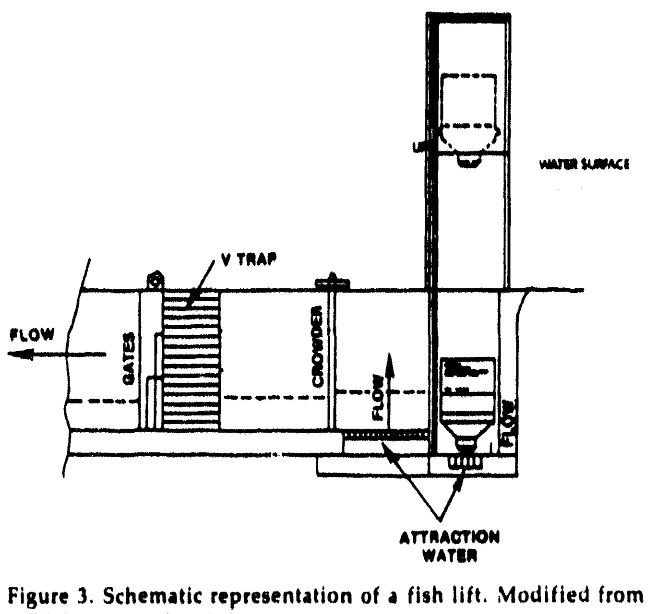

Figure 3. Schematic representation of a fish lift. Modified from Hildebrand et al. (1980).

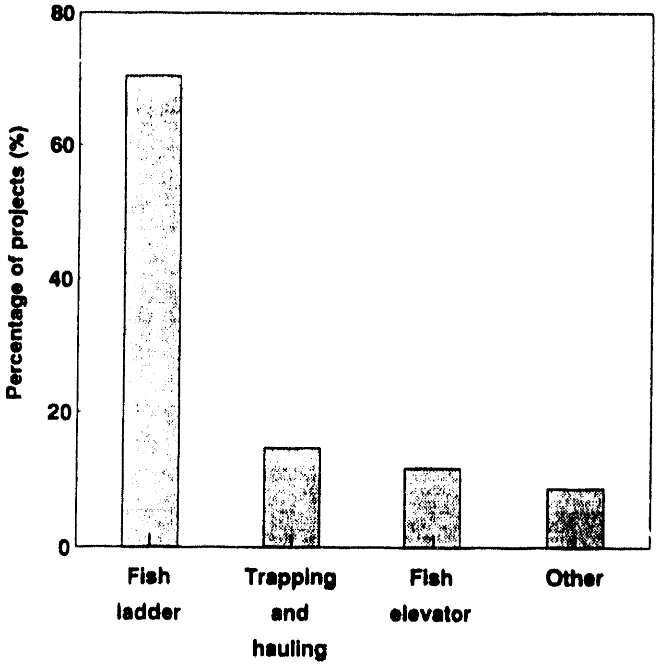

Figure 4. Relative frequency of upstream fish passage measures at nonfederal hydropower projects, based on information provided by developers.

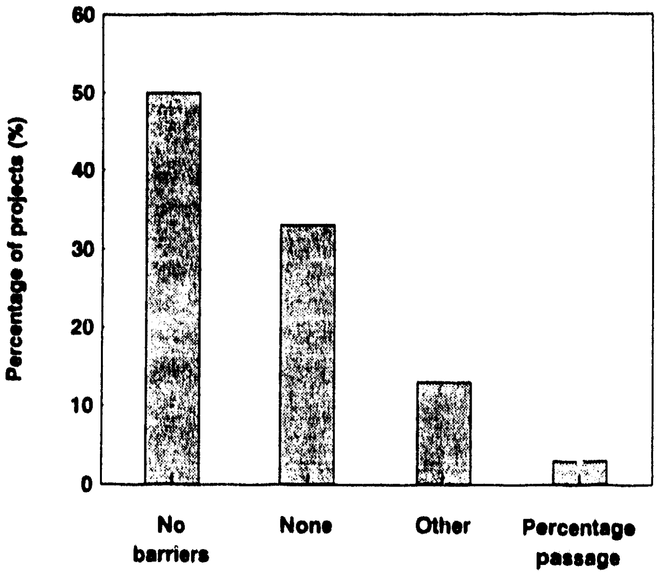

Figure 5. Performance objectives for upstream fish passage measures at nonfederal hydropower projects, based on information provided by developers.

by the agency via management objectives or restoration plans before the developer prepared the FERC license application.

Performance objectives are an important part of assessing the benefits of a fish passage facility. Seventeen of the 30 developers (57%) who responded to a question about written performance objectives indicated that "no obvious barriers to upstream movement" was one of the criteria used to judge effectiveness (Fig. 5); 15 (50%) reported that this was the sole criterion. One facility was required to pass a specified percentage of migratory adults; another was required to pass a specified number. Four projects (13%) had some other performance criteria that generally were consistent with goals of a larger fishery restoration program. Operators of 10 of the projects (33%) were unaware of any performance objectives for the upstream fish passage measures at their sites. Responses of the resource agencies to this question also indicated that specific, quantified performance objectives were rare.

In addition to developing specific, verifiable objectives, monitoring the operational performance of fish passage facilities is important. Without performance monitoring, neither an objective evaluation of site-specific mitigation effectiveness nor the transfer of knowledge gained at that site to other sites is possible. Based on the responses of licensees contacted for this study, performance monitoring at nonfederal hydroelectric projects has been largely neglected.

Many of the projects that operate under upstream fish passage monitoring requirements have been recently licensed or constructed, and results of monitoring studies are not yet available. Performance monitoring of upstream fish passage measures is not being conducted at 17 of the 30 operating projects (57%) that provided information. Those projects for which either the developer or a resource agency has monitored the success of upstream passage generally quantify passage rates or, less commonly, fish populations. Twelve of the operating facilities (40%) monitor fish passage rates; these are generally fishway counts that are conducted by either the licensee or a fishery resource agency. Although monitoring studies determine the number of fish that passed through the facility, they rarely provide information about the numbers of fish unable to successfully negotiate the facility and therefore are not useful for comparing effectiveness of different devices or of the same device at different sites.

Seven of the operating projects (23%) monitor the specific fish populations protected by the mitigation measure. Population monitoring studies provide a longer-term view of the success of a mitigative measure because they can estimate whether fish populations have been maintained or enhanced during the facility's operation. Because other factors may influence fish numbers or standing crops, however, fish population monitoring by itself may not yield widely transferable information about the effectiveness of a device.

Downstream Fish Passage

A variety of downstream fish passage screening devices have been employed to prevent fish from becoming entrained in the turbine intake flows. The simplest measure, spill flows, can transport fish over the hydropower dam rather than through the turbines. At the other end of the scale, sophisticated physical screening and light- or sound-based guidance measures are being studied. Unlike spill flows, physical and behavioral screening make possible bypassing downstream migrating fish with a minimal loss of water that can be used for power generation. Extensive reviews of downstream fish passage mitigation measures are available (Taft 1986; EPRI 1988; Bell 1991). No single fish protection system or device has yet been demonstrated to be biologically effective, practical to install and operate, and acceptable to regulatory agencies under a wide variety of site conditions.

Information was obtained from 85 hydroelectric projects that have downstream fish passage requirements. The required measures are in operation at 58 of the 85 projects (68%). Figure 6 lists the most common measures employed to reduce turbine entrainment of fish; some of these measures are used in combination, e.g., fixed screens with velocity limits. The most frequently required downstream fish passage device is the angled bar rack (Fig. 7). This mitigative measure, in which a trash rack that has closely spaced bars (ca 2 cm) is set at an angle to the intake flow, is commonly required in the Northeast. Angled bar racks are used by 32 of the 85 projects (38%) that responded to the information request. Other types of fixed fish screens (34% of the projects) range from variations of conventional trash racks oriented perpendicular to flow to more novel designs employing cylindrical, wedge-wire intake screens. Traveling screens are used at three of the projects (4%); these screens are installed in the gatewells of large hydroelectric projects.

Intake screens of all kinds may have a maximum approach velocity requirement and a sluiceway or some other type of bypass to transport the fish below the dam (Fig. 6). In some cases a properly designed trash sluiceway may serve to transport screened fish safely downstream. Twenty of the 85 projects (24%) have a maximum velocity limit on the intake flows (ranging from 0.1 to 1.2 m/s), and 22% have a sluiceway or some other form of bypass. Only three of the projects (4%) have a maximum approach velocity requirement as the sole measure to reduce turbine entrainment. Eight of the projects (9%) have a sluiceway or bypass as the only mitigative measure to enhance downstream fish passage.

The other types of downstream fish passage measures reported were barrier nets, blockage of the top portion of the trash rack to guide surface-oriented fish to a sluiceway, modification of the operating sequence of multiple-unit projects, and experimental use of strobe lights or underwater sound to drive fish away from the turbine intake area.

As with upstream fish passage facilities, a significant percentage (57%) of the downstream fish passage measures are in operation at all times. Eighteen of the 85 projects (21%) operate the mitigative measure only during specified seasons, whereas 3 (4%) are operated only during certain hours of specified seasons. Seventeen percent of projects did not report when the downstream fish passage measures are used, perhaps because many are still under construction, and specific requirements have not been determined.

Downstream fish passage facilities were most frequently designed to protect adult resident fish (55% of projects with such facilities). Juvenile resident fish (41%) and juvenile anadromous fish (25%) were also important targets for these mitigative measures. Downstream fish passage facilities are intended to protect fish eggs and larvae at only 8% of the projects.

In the views of developers providing information to this study, professional judgment by the agencies was the most common basis for incorporation of a downstream fish passage requirement; 43 of the 85 projects (51%) reported that professional judgment contributed to the requirement, and 38% reported that this was the sole basis for the requirement. As with upstream fish passage requirements,

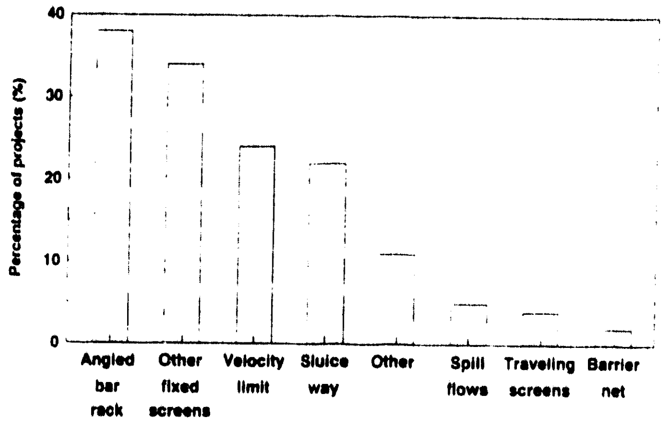

Figure 6. Relative frequency of downstream fish passage measures at nonfederal hydropower projects, based on information provided by developers.

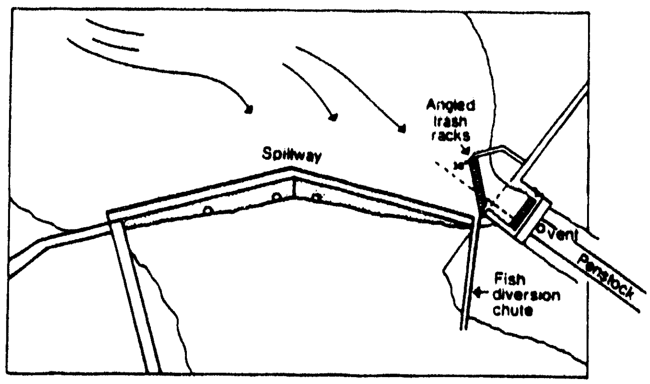

Figure 7. Diagram of an angled bar rack installation. Modified from Nettles and Gloss (1987).

the agency position on the need for downstream fish passage facilities may have been based on knowledge or studies unknown to the developer. Further, professional judgment in selecting a type or design of a needed downstream fish passage system may have been necessitated by lack of data on the effectiveness of most protection systems. Licensee-conducted and agency-conducted studies contributed to the development of the fish passage requirements in 22% and 9% of the projects, respectively. Twenty-six percent of the projects reported being unaware of any studies related to downstream fish passage at their sites.

Developers were asked about what performance objectives had been specified by the FERC or fisheries agencies (Fig. 8). Fifty of the 71 projects (70%) providing this information reported that no performance objectives had been specified. Four facilities (6%) were required to exclude a specified percentage of fish from entrainment, and three facilities (4%) were required to limit mortality of downstream migratory fish to a specified level. Twenty percent had some other performance objective, usually a qualitative goal such as "effective operation."

The degree of performance monitoring for operating downstream fish passage facilities at the nonfederal projects examined in this study is relatively low. No performance monitoring was reported at 52 of the 66 projects (79%) that have operating downstream fish passage measures. Among the 14 projects that have conducted operational monitoring, 11 monitored passage rates, 10 estimated mortality rates, and one monitored fish populations.

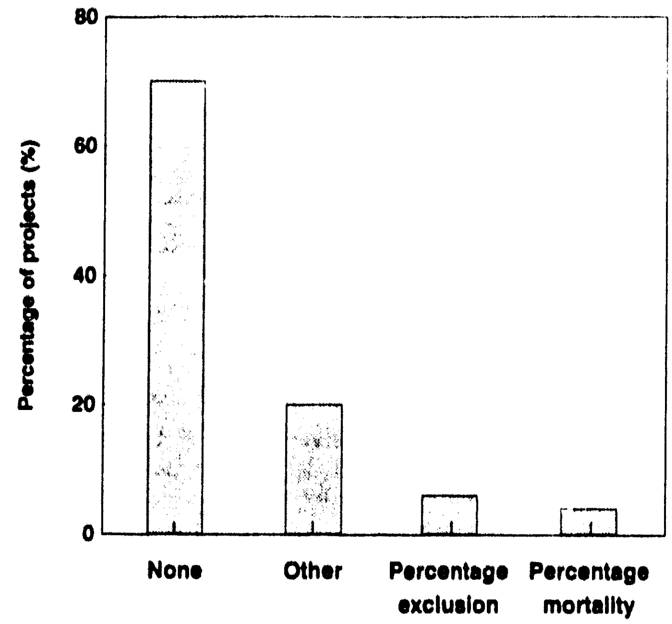

Figure 8. Performance objectives for downstream fish passage measures at nonfederal hydropower projects, based on information provided by developers.

Agency Positions on Fish Passage Mitigation

Agencies from 34 states responded to our request for information about fish passage mitigation; many of those states that failed to respond have little or no nonfederal hydropower development. Relatively few states require mitigation of fish passage impacts for nonfederal hydroelectric projects; where mitigation has occurred, it has most often been associated with runs of anadromous fish. Nine of the state agencies providing information to this study have a written policy regarding mitigation of fish passage impacts of hydropower (Appendix B, Sale et al. 1991). These policies range in stringency from advisory recommendations to requirements by state law that every dam or other obstruction across a stream be provided with fish passage measures. States that have policies relating to fish passage (Alaska, California, Colorado, Idaho, Maine, Michigan, New Jersey, Pennsylvania, and Washington) also tend to be those with the greatest number of hydropower projects. Five agencies reported setting quantifiable performance objectives for fish passage mitigation measures (e.g., a defined number or percentage passage), and an equal number are aware of, or participate in, operational performance monitoring.

None of the federal resource agencies contacted for this study has a specific written policy regarding mitigation of fish passage impacts at hydroelectric projects. The FWS has two policies related to the hydropower licensing and exemption processes. The first (USFWS 1981) covers impacts of all types of development projects, including hydropower. This policy does not specifically address fish passage requirements, but rather identifies a procedure that the FWS uses to determine all types of mitigation. The FWS also has a hydropower policy, issued in 1988. Although the hydropower policy is in effect, it is under review because of numerous public comments on the need, scope, and content that suggest the policy is not needed.

Discussion

In its draft policy statement on hydropower development, the American Fisheries Society supports the implementation of proven technologies to mitigate adverse impacts to fisheries and stresses that monitoring and follow-up studies in demonstration projects are absolute prerequisites for the use of unproven methodologies (Tyus and Winter 1992). Our study found that despite increasing efforts in recent years to install a variety of fish passage and protection measures at hydroelectric power plants, few comprehensive field studies have been carried out either to assess the site-specific effectiveness of these mitigative measures or to evaluate their use in other settings. Experience with biological effects of thermal electric generating stations underscores the role of field research and monitoring in determining both the significance of impacts and the adequacy of mitigation (Coutant 1992). The lack of information about effectiveness is a particular problem for downstream fish passage measures, where designs are more recent and varied and practical operating experience is less than, for example, at fish ladders. Construction and operation of often costly fish passage measures may be required at sites where need is uncertain (e.g, at sites without clearly migratory fish species) or where the subsequent biological benefits remain unknown.

The burden of proving the effectiveness of these technologies will fall on all three parties to hydropower development: licensees, the FERC, and resource agencies. Licensees must conduct adequate preoperational studies to characterize the fish resource at risk and, if needed, should incorporate appropriate, cost-effective mitigative measures to maintain that resource. Because the costs of a definitive testing program may be excessive for individual nonfederal hydropower developers, research sponsored by industry groups may be the most efficient way to test widely applicable, but unproven, technologies. Given the uncertainties associated with both the prediction of impacts and the effect of mitigation, developers should also realize that long-term monitoring and provisions for project modification during the license period may need to be incorporated into project design (Coutant 1992; Tyus and Winter 1992). Similarly, the FERC must exhibit flexibility in licensing requirements (e.g., by increasing use of testing programs and inserting reopener clauses in cases in which mitigation recommendations have been made on the basis of incomplete information). Ideally, elements of the testing programs would provide information of general applicability to other licensing actions. Natural resource agencies must bear in mind that their recommendations for mitigation should be technically defensible, implementable, and consistent with clearly established policies and plans (Railsback et al. 1990). Fish passage measures at particular hydropower projects should be implemented in light of clear agency goals for the resource and of performance objectives for the measure.

All parties to hydropower development must have an accurate understanding of both the costs and benefits of fish passage mitigative measures. Wherever possible, the value of fish transported around the dam should be estimated and compared with construction and operation costs of mitigative measures to ensure that costs do not greatly outweigh benefits. These values should consider indirect values associated with recreational use, use by other species, and nonuse values (Čada and Jones, in press). Obviously such comparisons must be made with caution because there may not be an easily quantified economic value for species being protected from extinction or species undergoing restoration. The DOE Hydropower Program is examining this issue in Volume 2 of the series. This study will attempt to quantify for particular case studies the costs of fish passage mitigation and both market and nonmarket values of fish protected by the mitigation.

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Beyond Dollars and Sense: Debating the Value of Nongame Fish

What can AFS do to promote the benefits of nongame fishes?

By Tom Cain

Aldo Leopold must have anticipated the debate about fisheries priorities in the 20th century when he wrote in *A Sand County Almanac*, "In each field one group (A) regards the land as soil, and its function as commodity-production; another group (B) regards the land as biota, and its function as something broader."

Traditionally, fisheries management has operated largely under the (A) philosophy, with protection of the recreational and commercial values of fish as the sacred cows. Only a fool would argue fish are not an economically valuable resource. Where differences occur is with the idea that economics is the most important value of fish. Some people think biodiversity is not beneficial, or at least does not compare to the economic benefits of fish. If we decide that economics are indeed the overriding value of fish, and the American Fisheries Society (AFS) wants to identify with the (A) group, then we have put the existence of a number of nongame species in doubt. After all, what value would they have? Before people deny this would happen, they should know it already has.

Remember the cover of *Fisheries* (Vol. 14, No. 6), which read "Challenge for the New Decade: Reversing the Decline of our North American Fish Fauna"? Inherent in this challenge is the need to recognize that our traditional management emphasis has not been able to prevent the decline of our North American fish fauna. In our efforts to maximize fish production for the angler, we often unintentionally harm other species or stocks of fish.

A classic example of this can be found in Arizona. With a native fish fauna comprised primarily of nongame species, Arizona has relied heavily on the stocking of exotic game fish to provide sportfishing opportunities. Anglers in Arizona can now pursue a number of exotic game fish ranging from striped bass to arctic grayling. But, while the fishing opportunities are improving, the state has been unable to check the decline of its native fish fauna.

This year the Desert Fishes Recovery Team recommended that the U.S. Fish and Wildlife Service consider four of Arizona's native fishes as candidates for listing under the Endangered Species Act. If the recommendation is accepted, the status of Arizona's 33 native species will read: nine candidates for listing, 18 federally listed, one extinct, and five presently with no special status. I am not implying that stocking of exotic game fish is the only factor causing the decline of our native fish fauna. In fact, habitat degradation is probably the primary factor. The concern with exotic species, aside from the direct impacts these species have had on native fauna, is that their presence has overshadowed that of native species. Consequently, few people are aware of native nongame fish or the trouble they are in, so very little pressure is put on management agencies to improve those species' situations.

What needs to be done about the decline of native species, not just in Arizona, but throughout North America? An important first step is for the AFS to clearly articulate its position on the

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Sometimes, activities to help game fish production to please anglers result in declining nongame species. East Clear Creek on the Coconino National Forest, Arizona, is identified by the U.S. Fish and Wildlife Service as a wild trout management area and as critical habitat for the Little Colorado spinedace, a threatened species (*inset*).

value of biodiversity. With the Clinton administration using the words "biodiversity" and "ecosystems" more in its first 100 days than we heard in the previous 12 years, AFS can make great gains for fisheries management if we are ready to take advantage of the situation. We need to move beyond the debate and identify where we are going as a Society. Once this is done, we can stop talking to ourselves and start talking to others.

The role AFS should assume is one in which all fish are created equal...

If we are serious about reversing the decline of fish fauna, we need to be aggressive in going to the public with our message and not limit ourselves by talking only to the one in four Americans who go fishing each year. Granted, anglers are a powerful group, but think what we can do if we get the support of the three out of four Americans who do not fish. Sounds crazy, but a recent survey by the Arizona Game and Fish Department showed that 65% of the residents who responded believe "we should do everything we can to preserve (native Arizona fish), even if it means restricting activities like stocking sport fish such as trout and bass" (Arizona Game and Fish Department, 1992, "Responsible Management Trend Survey, Volume 1: Summary Analysis"). This shows anglers aren't the only folks who appreciate fish. We should begin to tap into this group that fundamentally values the diversity of life, and public education is one way to do it.

AFS should also encourage land management agencies to broaden the scope of their fisheries programs, which tend to emphasize sportfishing opportunities on public lands. To develop appreciation by, as well as possible new partnerships with, the nonangling community, the message coming from land management agencies should show fishing as a byproduct of good fisheries management and not the sole reason for fisheries management. For example, the motto for the fisheries program in the U.S. Forest Service, "Rise to the Future—Fish Your National Forests" is fairly limited in scope and does not embrace the concept of biodiversity. A motto like "Fish Are Rising to the Future on Your National Forests" seems more inclusive and may instill a sense of ownership in the angler and nonangler alike.

Finally, AFS should recognize its strength is in its objectivity. As we assume the role of fisheries advocates, it is important that our positions are based on good biology and science and not necessarily on good economics or politics. The role AFS should assume is one in which all fish are created equal. We should be as quick to champion the cause of the little Colorado spinedace as we are the salmon in the Pacific Northwest. Game fish already have their allies in organizations such as Trout Unlimited, Bass Anglers Sportsman Society, and the Sport Fishing Institute. If AFS is not ready to advocate the management of nongame species, who will?

A Hierarchical Approach to Classifying Stream Habitat Features

Charles P. Hawkins, Jeffrey L. Kershner, Peter A. Bisson, Mason D. Bryant, Lynn M. Decker, Stanley V. Gregory, Dale A. McCullough, C. K. Overton, Gordon H. Reeves, Robert J. Steedman and Michael K. Young

ABSTRACT

We propose a hierarchical system of classifying stream habitats based on three increasingly fine descriptions of the morphological and hydraulic properties of channel geomorphic units. We define channel geomorphic units as areas of relatively homogeneous depth and flow that are bounded by sharp gradients in both depth and flow. Differences among these units provide a natural basis for habitat classification that is independent of spatial scale. At the most general level of resolution, we divide channel units into fast- and slow-water categories that approximately correspond to the commonly used terms "riffle" and "pool." Within the fast-water category, we identify two subcategories of habitats, those that are highly turbulent (falls, cascades, chutes, rapids and riffles) and those with low turbulence (sheets and runs). Slow-water habitats include pools formed by channel scour (eddy pools, trench pools, mid-channel pools, convergence pools, lateral scour pools and plunge pools) and those formed behind dams. Dammed pools include those obstructed by debris dams, beaver dams, landslides and abandoned channels. We consider backwaters as a type of dammed pool. Fishes and other stream organisms distinguish among these habitats at one or more levels of hierarchy. Habitats defined in this way represent an important habitat templet on which patterns of biological diversity and production form. We believe that a hierarchical system of classification will facilitate understanding of biotic-habitat relationships in streams and lead to more effective methods of evaluating the effects of environmental change on stream ecosystems. Refining the criteria by which habitats are distinguished, quantifying how different species use different habitats, and integrating the ways biota respond to habitat variation should facilitate the emergence of a theory of stream habitat organization.

"It is not the nomenclature that matters but the clear definitions of the contents given to terms, a truism most frequently misunderstood." E. Balon (1982).

Development of a logical and consistent system of stream habitat classification has challenged both stream researchers and fisheries managers for many years (e.g., Platts 1980; Bisson et al. 1982; review by Mosley 1987). Although there is a clear need for classification, no single approach has been generally accepted. A general system of habitat classification has been hindered because

1. stream environments consist of so many independent and interacting factors known to influence biota that distinguishing habitats based on a single criterion is impractical;
2. environmental heterogeneity varies considerably both within and among streams, which makes the number of habitat classes required for adequate description of a given stream unclear;
3. environmental variation is often gradual rather than discrete at several different spatial and temporal scales, further confounding identification of habitat classes; and
4. the type and resolution of classification needed may vary with specific research or management objectives.

A general classification system of stream habitats should serve several purposes (Pennak 1979; Warren 1979; Platts 1980). The system should provide a standard frame of reference that facilitates communication among researchers and managers. Habitat classes should be defined in an ecologically meaningful way that can be easily recognized by both researchers and managers. These classes should be based on measurable variation in environmental attributes at spatial scales important to the activities of stream biota. It should also be possible to extrapolate biotic-habitat relationships from one stream to another. Furthermore, the system should be flexible

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enough that it can be used to address a variety of research and management objectives.

The need for a general, workable classification is especially acute for small streams (< 4th order), which exhibit considerable heterogeneity in both morphological and hydraulic features (Beschta and Platts 1986; Sullivan et al. 1987; Robinson and Beschta 1990). Environmental variation in small streams is conspicuous at the spatial scale of channel geomorphic units, hereafter referred to as "channel units." Channel units are quasi-discrete areas of relatively homogeneous depth and flow

It seems especially important that hypotheses regarding the effects of individual habitat features (e.g., food or cover) be tested while controlling for the effects of other habitat factors.

that are bounded by sharp physical gradients (e.g., riffles and pools). Individual units are formed by interactions among discharge, sediment load and channel resistance to flow (e.g., Leopold et al. 1964; Richards 1982). Different types of units are usually in close enough proximity to one another that mobile stream organisms can select the type of unit that provides the most suitable habitat.

Variation in the structure and dynamics of the physical environment are primary factors affecting production and diversity of stream biota (e.g., Hynes 1970; Vannote et al. 1980; Minshall 1988). This spatial and temporal heterogeneity represents an important habitat templet (e.g., Southwood 1977) for stream biota. Although important environmental variation exists at all levels of spatial resolution, many research and management objectives are best addressed at the spatial scale of channel units (e.g., Sullivan et al. 1987). At the channel unit of resolution, both abundance of biota and rates of ecosystem processes often exhibit marked patchiness, presumably as a consequence of high variation in habitat suitability or quality. Differences in habitat quality among channel units are often associated with differences in morphology (e.g., depth, width, shape), current velocity (hydraulics) and bed roughness (substrate size). For example, nutrient uptake (Aumen et al. 1990), algal abundance (Tett et al. 1978), invertebrate production (Huryn and Wallace 1987) and diversity (Hawkins 1984), and fish abundance (Bisson et al. 1988) are all known to exhibit significant variation at this spatial scale.

Bisson et al. (1982) based a system of salmonid habitat classification on naturally occurring channel

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The Upper Smith River near Mount St. Helens, Washington, illustrates the heterogeneous nature of physical habitats in many small stream ecosystems. A standardized classification system for habitats at the channel unit spatial scale should lead to better defined habitat relationships for stream biota.

units and the hydraulic processes that formed them. They suggested that several distinct channel units occur at summer, base-flow conditions that could be easily recognized and had ecological relevance to salmonids. The American Fisheries Society has since adopted much of their habitat nomenclature (Helm 1985), and this classification system has been successfully applied to both research and management purposes. For example, by classifying habitats in this manner, Bisson et al. (1982, 1988) and Sullivan (1986) discovered important ecological associations among habitat characteristics, species abundance and body form for the juvenile stages of three species of salmonids. Coho salmon (*Oncorhynchus kisutch*), steelhead trout (*Oncorhynchus mykiss*), and cutthroat trout (*Oncorhynchus clarkii*) segregated within stream segments by using different types of channel units. In these studies, fish distinguished between riffles and pools as well as subclasses of pools defined by channel unit position, forming constraint and flow. Benthic invertebrates also appear to use different types of channel units (e.g., Hawkins 1984; Statzner and Higler 1986). In these cases, the basis for differential use of units appears to be related to differences in either substrate size or hydraulic characteristics. Kershner and Snider (1992) refined the predictions of instream flow models by weighting output by channel unit type thereby more accurately predicting changes in habitat availability with changing flow.

After nearly 10 years of use, we are now aware of several obstacles that limit the original version of the Bisson et al. (1982) system as a general classification tool. First, aquatic ecologists have often assigned habitats into different numbers of habitat classes based on a real or perceived need for more, and sometimes fewer, habitat classes than originally described. As a consequence, there has been a tendency for "habitat-type proliferation" to occur (e.g., McCain et al. 1989). Although such modifications often may be needed to address specific objectives, use of different sets of habitat classes can potentially confound comparisons among streams, if the basis for discriminating habitat units in each case is not clear. Second, we have sometimes used similar terms to describe dissimilar habitats, thereby further confounding among-stream comparisons. Third, we are aware of several instances in which the system has been used without clear consideration of either research or management objectives. In the following section, we suggest that a hierarchical classification scheme can provide both a logical and ecologically relevant foundation on which to base classification of channel units and a means of standardizing descriptions of channel units.

Needs for Consistent Systems of Classification

Stream management depends on a solid understanding of biota-habitat relationships and, as such, refinement of ecologically sound ways to describe and classify habitats is a critical component of stream science and management. For example, managers often rely on empirical descriptions of habitat use to make inferences about factors that limit a species' growth or abundance. Habitat classification can therefore aid in determining the factors that may limit populations, if habitat classes are based on differences in factors known to influence biota, and habitat classification is used in a consistent manner.

Quantification of habitat use provides a basis for predicting biotic response to changes in habitat availability. If the availability of different habitat types and habitat-specific abundances is known, selectivity indices can be calculated. These calculations assume that different habitat types are discrete, are equally accessible, and recognizable by the organism(s) of interest. Where these assumptions are valid, such analyses provide the type of data fundamental to understanding patterns of habitat use by different species and form a basis for predicting biotic response to changes in habitat availability.

Much of our understanding of habitat relationships in streams has emerged from comparative studies that describe statistical relationships between habitat variables and abundance. These studies have yielded important insights regarding the factors that influence abundance, but general quantitative models with high predictive power have not yet emerged (see Fausch et al. 1988; Marcus et al. 1990 for reviews). In fact, some habitat-based models produce conflicting results (see Binns and Eiserman 1979 and Bowlby and Roff 1986). In hindsight, the present status of habitat modelling may not be surprising. The perceived relative importance of different environmental factors may depend strongly on the spatial scale of observation (e.g., Lanka et al. 1987; Crowl and Schnell 1990). Furthermore, comparison of studies conducted at the same spatial scale may be confounded if the relative importance of different micro-spatial factors varies with habitat type. It seems especially important that hypotheses regarding the effects of individual habitat features (e.g., food or cover) be tested while controlling for the effects of other habitat factors. Ideally such analyses would be conducted within a single habitat type in which only the habitat component of interest varied and other habitat variables were constant or nearly so. Truly general models must ultimately integrate responses biota exhibit to environmental variation at several spatial and temporal scales, and we have not progressed far in this respect.

Habitat classification also provides a means to minimize effort and maximize the statistical reliability of population estimates, especially if estimates are required for large spatial scales. We have often based population estimates on samples taken from single, arbitrarily selected sections of stream and have assumed that these estimates are representative of the entire stream within a drainage basin. Although such sampling can sometimes yield valuable information regarding the factors potentially limiting populations (e.g., Hawkins et al. 1983), it is not valid to use a single sample estimate to extrapolate population abundances beyond the boundaries of the area sampled (e.g., abundances within an entire basin).

If habitats can be classified and enumerated, statistically sound estimates of population abundance at several spatial scales can be made by censusing the amount of different habitat types within a stream and then sampling a subset of each habitat type for biota. This approach yields habitat-specific estimates of abundance that can be combined to generate an estimate of population abundance in the stream segment as a whole (e.g., Hankin 1986, Hankin and Reeves 1988). However, accurate, whole-stream estimates require that habitat types be consistently classified. If field personnel do not consistently identify different habitat types, habitat-specific estimates of abundance will be in error and among-basin comparisons will be compromised.

This type of watershed-level survey can also be used as a method of monitoring at different scales. In the Willamette River basin, Sedell and Luchessa (1982) have reconstructed the historic habitat descriptions and fish distributions to compare conditions in the basin from the 1930s to current conditions. If basin-level habitat surveys are repeatable and accurate, they can be used as a long-term monitoring tool to compare current conditions with changes in management over time. By resurveying streams, changes in habitat frequency can be compared with desired objectives.

Restoration of degraded stream ecosystems may sometimes require that we restore habitat features that are damaged or lost by channel alteration. If sampling reveals that certain channel elements may be limiting recovery of a population or community, stream managers may want to manipulate the abundance of specific types of channel units toward a more desired set of conditions. Fisheries managers have frequently attempted to increase the production of fish by this type of channel manipulation (see Everest and Sedell 1983; Wesche 1985), although evaluations of the effectiveness of such practices are sorely lacking. We believe a consistent method of channel unit classification would facilitate our abilities to set realistic restoration objectives and to develop efficient ways of evaluating the effectiveness of specific restoration practices.

Recommendations

We believe a hierarchical classification of channel units may alleviate problems that some users have with Bisson's (Bisson et al. 1982) original classification scheme. Hierarchical systems allow choice of the level of habitat resolution that is required for specific objectives (Frissell et. al. 1986; O'Neill et al. 1986) and provide a consistent means for either collapsing or splitting data sets if comparisons across studies are desired. Such a system is valuable if data on community-wide and ecosystem-wide, as well as species-specific, responses are needed.

Figure 1 illustrates our perception of the hierarchical relationships among different types of channel units. In constructing this hierarchy, we first identified which physical characteristics were needed to describe specific channel units. We then ranked the importance of these factors as descriptive features useful in defining and discriminating among different types of channel units. Rankings used in this scheme were based on consensus derived from our combined experience classifying stream habitats. Although too few empirical studies exist at this time on which to base an objective

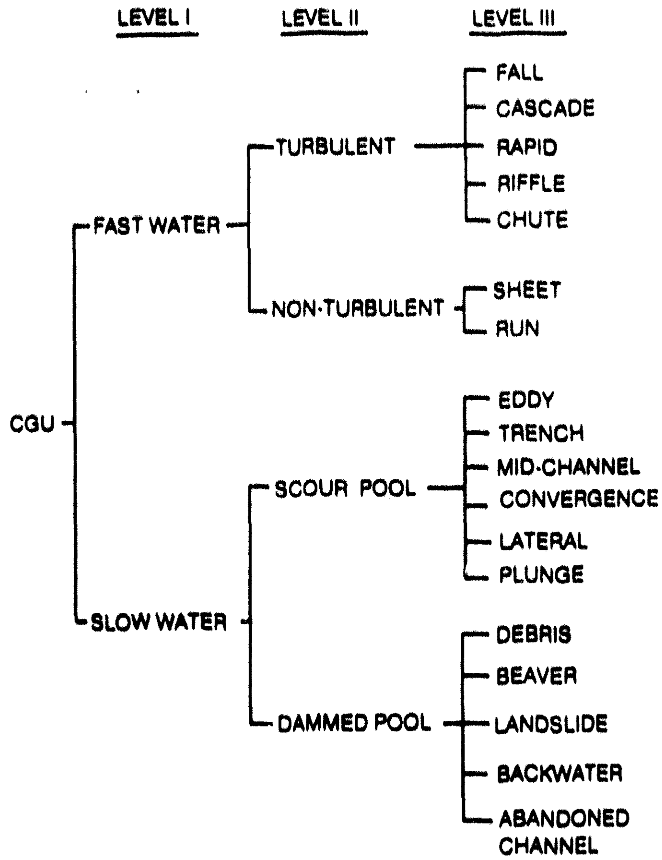

Figure 1. Similarity dendrogram illustrating how channel geomorphic units (CGU) can be classified with increasing levels of resolution. Three levels of classification are shown that can be used to distinguish classes.

analysis, a few studies provide data supporting the idea that these habitat classes differ significantly in the manner we suggest (Sullivan 1986; Bisson et al. 1988).

A three-level hierarchy should provide the level of resolution needed for most research and management purposes (Fig. 1). At the coarsest level of resolution, fluvial geomorphologists recognize riffles and pools as two primary channel unit types (Yang 1971; Keller and Melhorn 1978; O'Neill and Abrahams 1987). Riffles are topographic high points in the bed profile and are composed of coarser sediments, whereas pools are low points with finer substrates (Richards 1982). At base flows, riffles have rapid, shallow flow with steep water-surface gradient, whereas pools are generally deep, slow-flowing and have a gentle surface slope (Richards 1978). Although riffles and pools do not always have sharp boundaries, they appear to represent distinctly different ecological habitats. The biota inhabiting them are markedly different in both taxonomic composition and the morphological, physiological, and behavioral traits they possess.

For many biota, however, important differences in habitat use occur at finer levels of resolution than recognized by geomorphologists (e.g., Minshall 1984; Bisson et al. 1988). Stream ecologists recognize subcategories of riffle and pool that further refine the physical and biological functions of these units. Both Bisson et al. (1982) and Helm (1985) refer to specific types of riffles and pools, which may cause some confusion in terminology. To avoid further confusion, we refer to the broad categories of riffle and pool as fast-water and slow-water channel units, respectively.

Both fast-water units and slow-water units can be divided into two subclasses. Fast-water units can be divided into either high-turbulent or low-turbulent classes based on differences in gradient, bed roughness and step development (Table 1). We use the term "step development" in reference to the distinct breaks in bed slope that may occur within a channel unit. Two types of pools can be distinguished based on whether they are formed by scour or damming (Table 2). Both subdivisions appear to be ecologically relevant. The types and abundances of riffle-dwelling benthos are strongly affected by the amount of turbulence (Statzner et al. 1988). Dammed pools tend to accumulate and retain sediment and organic debris to a greater extent than scour pools. The retentiveness of stream habitats in terms of nutrients, sediment or organic debris is an important factor affecting stream ecosystem energetics (Benke et al. 1988; Meyer et al. 1988). The presence and abundance of cover, and hence fish (Devore and White 1978; Shirvell 1990), also appear to be associated with type of pool. Dammed pools often have greater amounts of cover than scour pools, because they are usually formed behind wood, debris or large substrates.

The fast- and slow-water classes can be further divided based on other criteria. Most of these subclasses correspond to the names and definitions of stream habitat types provided by the Habitat Inventory Committee of the Western Division, American Fisheries Society (Helm 1985). For this reason, we have attempted to preserve the nomenclature used by Bisson et al. (1982) and Helm (1985). In some cases, we have either collapsed or added categories based on how well original definitions fit within our hierarchical framework. For example, we used ranked differences in gradient, percent super critical flow, bed roughness, mean velocity and step development to identify subclasses of both turbulent (falls, cascades, rapids, riffles, chutes) and non-turbulent (sheets and runs) units. The subclass of sheet was not identified by either Bisson et al. (1982) or Helm (1985). This subclass refers to units with shallow water flowing over smooth bedrock, a common habitat type in some geographic regions. Individual pool types within scour and dammed groups differ in terms of their location within the flood or active channel (i.e., main channel or off channel), longitudinal and cross-sectional depth profiles, characteristics of surficial substrates, and the constraining feature that helps form them. This is the finest level of resolution that we believe can be visually distinguished.

We have not included some habitat types identified in Bisson et al. (1982) and Helm (1985); e.g., pocket water, alcove, slackwater pool, underscour pool. In general, these habitats were collapsed within broader categories. For example, we considered alcoves to be a form of eddy, and pocket water pools were small-scale habitat features that exist within fast-water channel units.

We had trouble placing some commonly cited "habitats" within this framework. Whereas, we agreed on the names for and characteristics of most habitat types, glides were more difficult to define. Some of us, in fact, had markedly different ideas of

Table 1. Classes of fast-water channel units and variables used to distinguish them. Differences among classes are ranked for each variable. In all rankings, 1 indicates highest magnitude. Supercritical (SC) flow is a measure of turbulence and is ranked by amount of broken surface water within the channel unit. Step development is ranked by the number and size of energy dissipation features within a habitat unit.

Class	Gradient	SC flow	Bed roughness	Mean velocity	Step development
Turbulent:					
Fall	1	NA	NA	1	1
Cascade	2	1	1	2	2
Chute	3	2	4	3	5
Rapid	4	3	2	4	3
Riffle	5	4	3	5	4
Nonturbulent:					
Sheet	Var	6	6	6	5
Run	6	5	5	7	5

NA = Not Applicable
Var = Variable

Table 2. Classes of slow-water channel units. Channel location refers to whether the unit occurs in the main flow of the stream or near a bank. Shape of the units are indexed by location of the deepest point along both longitudinal and cross-sectional (L and X) depth profiles. Substrate character refers to the degree of sorting, erosional resistance and/or size of particles. The forming constraint describes the feature causing water to pool.

Class	Channel location	L-section profile	X-section profile	Substrate character	Forming constraint
Scour					
Eddy	bank	mid	mid	surface fines	lateral obstruction
Trench	main	uniform	uniform	uniform, resistant	bilateral resistance
Mid-channel	main	mid	mid	uniform, resistant	constriction at head
Convergence	main	mid	mid	sorted, fine at head	convergence of streams
Lateral	main	up or mid	side	sorted, resistant	deflector at head
Plunge	main	up	variable	sorted	obstruction at head
Dammed					
Debris	main	tail	variable	sorted, fine	debris
Beaver	main	tail	variable	uniform, fine	beaver dam
Landslide	main	irreg	irreg	variable	colluvium
Backwater	bank	tail	variable	uniform, fine	obstruction
Abandoned channel	bank	tail	mid	uniform, fine	headward deposits by active channel

what makes up a glide. One reason for the lack of consensus may be that glides are often the low-flow remnants of high-flow scour pools (c.f. Keller 1971; Lisle 1979) and are thus extended transitional areas between fast- and slow-water habitats. For these reasons, we deleted glides from our classification.

We recognize that not all types of channel units may exist in any one stream at any specific time. For example, during higher (floods) or lower (drought) flows, some units may change in physical character (e.g., a run may change to a riffle). Although most ecological and management studies are conducted during base flow conditions, we doubt if any fundamentally different types of units would be needed to characterize habitats available to and used by stream biota under other flow regimes.

Discussion

The classification system we describe here is meant to be a foundation for describing stream habitats at the scale of channel geomorphic units. In principle, this approach should be easily integrated into the spatial hierarchical classification systems proposed by Platts (1980), Frissell et al. (1986) and Gregory et al. (1991). Doing so should ultimately provide a more sound understanding of the structural and functional properties of stream ecosystems that occur at different scales.

Determining how well the proposed classification approach works will depend, in part, on eventually quantifying the amount of variance in physical attributes that exists both within and between channel unit classes. The proposed approach to classifying channel units will certainly require refinement and validation. Perhaps the most important immediate task is to objectively verify that these or similar classes actually comprise a useful set of different habitat types. The most straightforward way of doing this is to collect a sufficiently large set of habitat data in several streams and use cluster or ordination techniques to reveal if our groupings have an objective basis. Special attention may have to be paid to how different habitat variables are weighted. For those habitat classes that have an objective physical basis, it will then be necessary to determine to what extent the different channel units are biologically different and for what taxa.

A particularly vexing problem with this scheme is that it is not clear to what extent the nature of channel units is dependent on stream size. For example, as streams get larger, the size of channel units increases, and the boundaries between them may become less distinct. It is likely that channel units in large streams comprise several smaller scale habitat patches that are physically and biologically equivalent to entire stream channel units in small streams. Additional research is clearly needed to explore how well classifications designed for small streams can be used to describe river habitats.

One of the most important advantages of this type of classification system is that individual habitats can be rapidly assigned to classes based on visual appearances. However, valid comparisons either across streams or through time assume that all observers will assign habitats to the correct classes. No studies have been published that quantify the magnitude of subjective bias that exists among observers, although results from unpublished data show that bias can be a problem if field crews are inadequately trained and supervised (unpublished independent data sets of L. M. Decker, C. P. Hawkins, J. L. Kershner, C. K. Overton and G. H. Reeves). It is important that the accuracy of visual assignments be evaluated before the adequacy of such approaches are taken for granted. One way of doing this would be to measure the relevant physical variables for a subset of habitat units after they have been visually assigned to classes. Comparing visually with empirically determined assignments would serve two purposes. First, it would generate statistics regarding precision and accuracy of visual estimates. Second, such checks would serve to identify and limit bias among individual observers.

We expect that with testing and use, this system will be modified and improved to increasingly reflect the physical and biological reality of stream habitats. With improvement, the main advantages of this approach should become increasingly evident, i.e., the flexibility that hierarchical classifications provide in addressing different objectives, the ability to rapidly classify habitats through visual observations, and the ability to conduct statistically sound, large-scale surveys at a reasonable cost.

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A New View of Hydro Resources

ABSTRACT

This proceedings, Waterpower '91: a *New View of Hydro Resources*, consists of papers presented at WATERPOWER '91 conference held in Denver, Colorado, July 24-26, 1991. It is the seventh biennial edition of the series begun in 1979. It is a conference directed toward resolving issues concerning generating electricity by using the renewable resource water as the prime mover of the generation system. The broad coverage of this topic is suggested by some of the subject areas discussed in the various sessions: 1) Civil works; 2) computer applications; 3) construction; 4) finance; 5) environmental issues; 6) hydraulics; 7) maintenance; 8) project planning; 9) reservoir regulation; and 10) risk analysis. This proceedings presents the Hydroelectric power experts and managers from around the world will find this proceedings to provide the latest information on this method of generating electricity.

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IMPROVING THE ASSESSMENT OF INSTREAM FLOW NEEDS FOR FISH POPULATIONS [1]

Michael J. Sale[2] and Robert G. Otto[3]

Abstract

Instream flow requirements are one of the most frequent and most costly environmental issues that must be addressed in developing hydroelectric projects. Existing assessment methods for determining instream flow requirements have been criticized for not including all the biological response mechanisms that regulate fishery resources. A new project has been initiated to study the biological responses of fish populations to altered stream flows and to develop improved ways of managing instream flows.

Introduction

Water development projects, including hydroelectric facilities, can affect the quantity and quality of water in streams and rivers and consequently influence the well-being of downstream fish populations. State and federal regulatory policies and recent legislative changes, such as the Electric Consumers Protection Act of 1986, have firmly established the fact that the environmental effects must be addressed in the licensing and development of hydroelectric projects (Clark 1989). Instream flow needs (IFN), defined as the

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flow of water required below a dam to avoid adverse impacts on downstream fish and other aquatic resources, may be the most universal and costly environmental issue for the hydroelectric industry (e.g., Railsback et al. 1991, these proceedings). The determination of instream flow requirements to protect riverine fisheries continues to be a controversial issue for these projects, in part because biological processes that regulate fish populations (e.g., density-dependent growth and survival, competition for food and habitat, winter starvation, and dependence of growth rates on temperature and flow regime) are not included in existing habitat-based assessment methods.

Standardized methods for assessing instream flow requirements of fishes are available and are widely used (e.g., Stalnaker 1982; Reiser et al. 1989). Physical habitat evaluation models, such as the U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM) and its PHABSIM models (Bovee 1982, Stalnaker 1982), are perceived as the most sophisticated and acceptable tool for determining minimum flow requirements (Loar and Sale 1981, Orth 1987, Gore and Nestler 1988, Reiser et al. 1989). The PHABSIM approach involves two major steps: (1) determining the physical habitat requirements of each life stage of the fish being evaluated, and (2) calculating the quantity of habitat available for each life stage under different instream flow regimes. The method uses extensive field survey data and computer models to predict incremental changes in physical habitat indices with changes in stream flow. In practice, instream flow assessment is limited to estimation of the amount of physical habitat available for individual life stages of a fish species. There is little or no consideration of population-level cumulative effects of flow alterations on different life stages, primarily because the methods for doing this do not exist.

Although existing IFN assessment methods have survived more than a decade of controversy (Mathur et al. 1985, Morhardt 1986, Scott and Shirvell 1987, Lamb 1989), even the proponents of habitat evaluation methods admit that physical habitat is not the only factor limiting fish (Bovee 1982, Sale 1985). The habitat-based assessment methods do not represent the biological mechanisms (e.g., survivorship, fecundity, or growth rates) that link flow alteration to important fish population characteristics (e.g., abundance and size/age composition). The ability of habitat indices to predict fish abundance is therefore questionable in many situations, especially in coolwater and warmwater streams (Morhardt 1986, Orth 1987). Calls for additional research to correct this problem have been made repeatedly over the last ten years (Patten et al. 1979, Hildebrand and Gross 1981, Reiser et al. 1989).

In recognition of the IFN problem, the Electric Power Research Institute (EPRI) has focused considerable research effort on the issue. The major portion of this work has been organized under EPRI's Steam/Hydroelectric Aquatic Population Effects (SHAPE) program that is intended to develop methods to predict both direct effects (e.g., individual fish mortality) of electricity generation and the long-term consequences of these direct effects on fish population structure and stability. A review of existing methods for predicting instream flow needs (Morhardt 1986) was completed. Other research efforts included: (1) an evaluation of the use of existing data for developing empirical instream flow models for use in the Sierra Nevada Mountains, (2) an evaluation of an instantaneous index of fish population size in streams, and (3) a field evaluation of the applicability of habitat simulation models for predicting instream flow requirements of salmonids. With the exception of the general review of methods, previous EPRI-funded research on the instream flow issue has focused on fish resources in coldwater streams in California. The EPRI has now initiated a long-term research project to develop improved models of stream fish populations for use in determining instream flow needs.

Project Design

This new Stream Systems Project has as its objective the identification and improved understanding of biological mechanisms by which size and structure of fish populations respond to stream flow. A basic premise is that instream flow assessment methods cannot be improved significantly without first developing a better understanding of how fish interact with their physical, chemical, and biological environment in streams. The assessment methods developed in this research will be applicable to evaluating a range of cumulative impacts derived from hydroelectric project operation, including flow alteration, changes in water quality, and direct mortality from impingement and entrainment of fish during passage through turbines. Field studies and modeling will focus primarily on smallmouth bass (*Micropterus dolomieu*) populations, but other fish species that coexist with smallmouth bass will also be studied. Smallmouth bass was selected as an important target species because it is a top predator in coolwater systems and it has centrarchid reproductive strategies that are likely to be sensitive to stream flow.

The Stream Systems Flow Project is being incorporated into EPRI's ongoing COMPMECH Program which has very similar goals, approach, and organization. The project is a cooperative effort managed through Oak Ridge National Laboratory (ORNL) and the Sport Fishing Institute, with participation from university researchers, utilities, and natural resource management agencies (Figure 1). The project was initiated in April, 1990, and is planned to continue through 1994. Field research, which is the key to the project, will be coordinated through academic institutions and their faculty. Utilities are co-sponsoring the field research along with EPRI. Participation in field research will also be solicited from state and Federal resource agencies. Model development and integration will be conducted by ORNL staff.

The overall objective of the COMPMECH Program is to develop improved methods for predicting the dynamics of fish populations that are

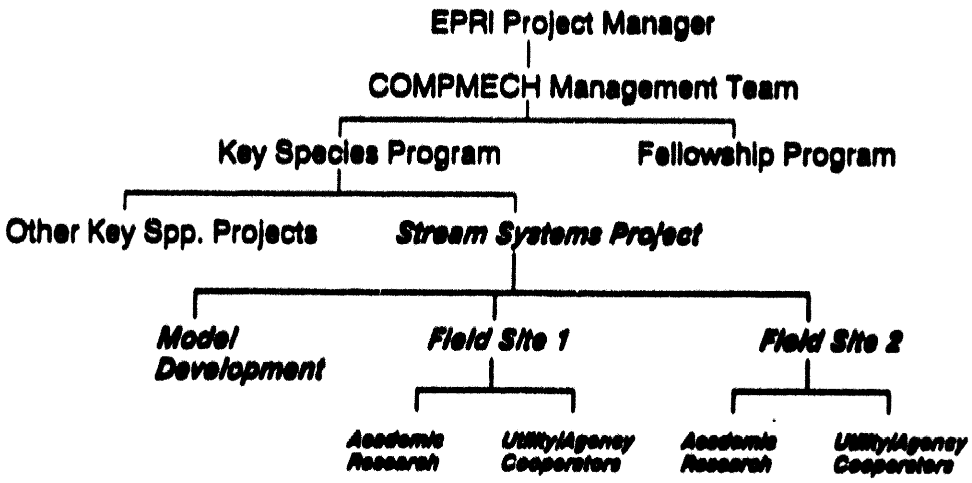

Figure 1. Organization chart for the EPRI Stream Systems Project.

exposed to various forms of anthropogenic exploitation (e.g., incremental mortality due to entrainment/impingement or habitat modification due to altered stream flows). The approach adopted to developing these methods involves: (1) description of critical events in the life history of individual fish; (2) quantification of the scope (magnitude and direction) of fish responses to physical, chemical, and biological features of the environment; and (3) integration of a range of individual responses into fish population models. The ability to predict long-term consequences of direct effects at a population level is essential to rational regulatory decisions, because fish populations have the capability to potentially 'self-mitigate' intermediate levels of mortality or harm due to man-made or natural impacts. Better understanding of the density-dependent and density-independent response mechanisms will improve IFN decision-making by improving predictions of the tradeoffs among fish resources (i.e., populations), flow alterations, and power generation.

Modeling Approach

The COMPMECH modeling approach that will be adopted by this project involves (1) determining the response of individual fish and specific life stages to physical and biological stresses and then (2) using "individual-oriented" population models to accumulate the responses of many individuals (e.g., Huston et al. 1988). Other types of fish population models have been proposed for use in instream flow assessment (Williams 1984, Cheslak and Jacobson 1990). However, these age-structured life cycle models represent population dynamics with aggregated parameters that mask the variability inherent in individual fish. The individual-oriented approach has important advantages over aggregated life-cycle models because they can fully represent the response mechanisms at the extremes of individual variability (e.g., larger individuals that contribute disproportionately to annual recruitment or smaller/weaker individuals that have a low probability of survival) (DeAngelis et al. 1990). The individual-based approach is also a better tool for synthesizing field data, such as will be generated by this project.

The starting point for model development for the Stream Systems Project is an existing individual-oriented model for smallmouth bass populations in lakes (DeAngelis et al. 1991). Results to date with this model demonstrate that the individual-oriented models are capable of quantifying the biological control processes that are absent from existing methods. PHABSIM and individual-oriented models require similar physicochemical data, although the ways in which these data are incorporated into the individually-oriented models will be much more explicit to life-cycle processes of fish. One of the major challenges in developing these models for stream populations is to incorporate microhabitat concepts, including habitat selection and bioenergetic costs and benefits of different environmental conditions. Rules of spatial movement of fish within streams will be an important part of new individual-oriented models that can be used for instream flow assessment.

Field Research

Two primary sites have been selected for detailed field studies (Figure 3): the North Anna River in Virginia, and the Saint Louis River in Minnesota.

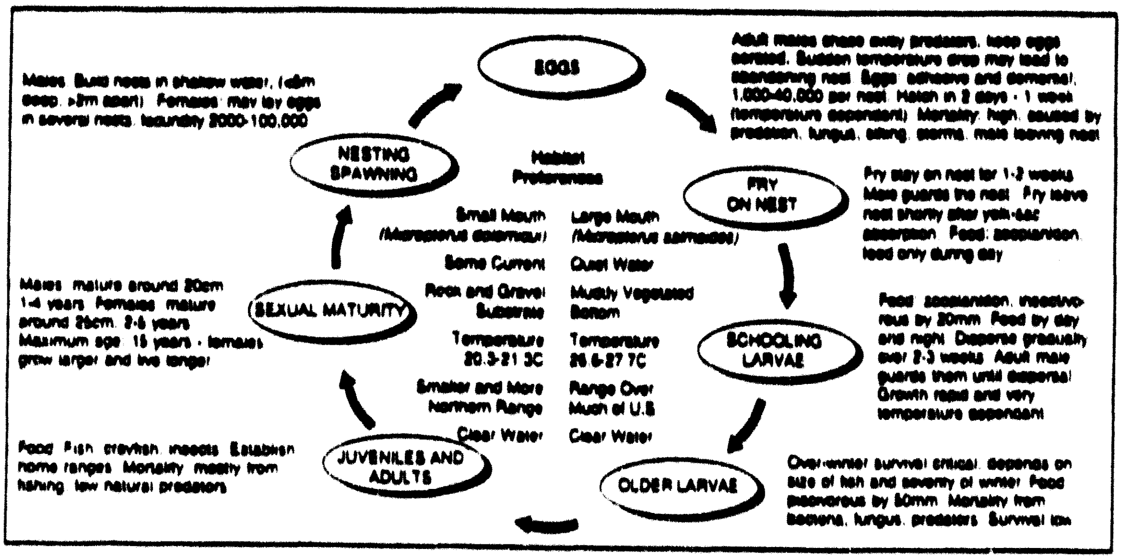

Figure 2. Life-cycle processes that will be specifically included in the individual-oriented fish population models.

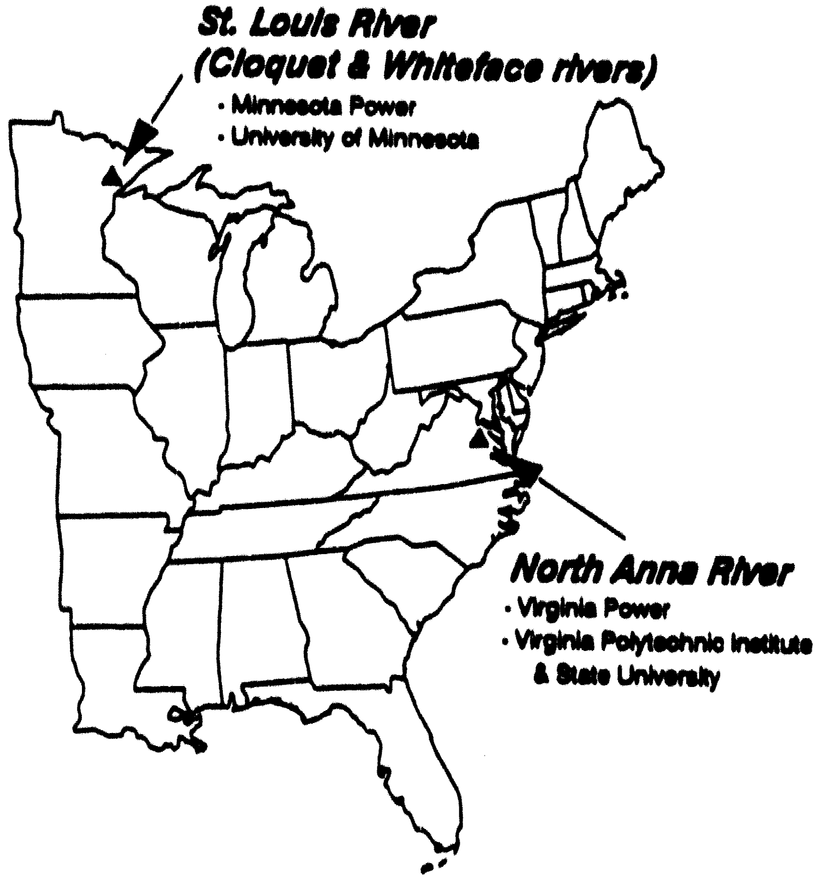

Figure 3. Field sites selected for the Instream Flow Project.

At both field study sites, physical habitat and water quality characteristics are being described using traditional IFIM procedures and continuous monitoring of stream flow and water temperatures. Aerial photography is also planned to provide a more detailed description of habitat characteristics than can be obtained from transect-oriented measurements.

Biological data collections will be generated by a series of graduate student research projects at each of the sites. In Virginia, the field studies are being coordinated through Virginia Polytechnic Institute & State University by Donald Orth and are cosponsored by Virginia Power Company. In Minnesota, field studies are being coordinated by Ray Newman from the University of Minnesota and are cosponsored by Minnesota Power Company.

The first year of field research on the North Anna River has been completed with studies focusing on the early life history of smallmouth bass. In the second year of research, additional effort will be directed at examining interspecies interactions. Both largemouth bass and redbreast sunfish populations were evaluated this year to decide which species is interacting more strongly with smallmouth bass at this site; from this analysis it was decided to concentrate on redbreast sunfish.

Field research in the Saint Louis River basin will begin in 1991 with a generalized sampling program to characterize fish communities and to provide information that will be used to select target species and future, more detailed studies.

Anticipated Results

A number of different types of products are anticipated from this project. The first, and most important, is a body of new scientific understanding about fish population dynamics in streams, especially with respect to the affects of stream flow variability. The graduate-level research that will be supported will produce new professionals who have interests and capabilities to contribute well beyond the time-frame of this project. Secondly, the model development work that will be conducted should lead to improvements in existing assessment methods, both by providing new quantitative tools and by defining the applicability of existing methods. Last, but not least, the project should generate cooperation and communication among research, developer, and regulatory groups that hopefully will help minimize the controversial nature of instream flow assessment that is such a problem to the hydropower industry (e.g., Mattice 1991).

In summary, this research project should improve the applicability of habitat-based assessment methods by developing a better understanding of the role of abiotic factors, such as physical habitat, in regulating riverine fish resources. It is our hope that the individual-oriented assessment models developed under this EPRI project will provide a more realistic way of examining the tradeoffs between flow regulation and fish resources below hydroelectric projects.

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Evaluation of an Eicher Fish Diversion Screen at Elwha Dam

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Abstract

In the spring of 1990, the Electric Power Research Institute (EPRI) initiated testing of an inclined fish screen installed in a 9-foot diameter penstock at the Elwha Hydroelectric Project in Washington State. In tests performed with coho salmon smolts, over 99 percent of the fish were diverted without mortality. At penstock velocities from 4 to 6 fps, less than 0.1 percent of the fish had scale loss exceeding 16 percent on either side (considered "descaled" in criteria used on the Columbia River), and less than 5 percent showed any type of injury. Slightly more descaling was observed at higher penstock velocities. At the maximum velocity tested (7.8 fps), 3.6 percent of the fish had scale loss of over 16 percent, and 18.1 percent of the fish had scale loss between 3 percent and 16 percent. Mortality after a 3 to 10-day holding period averaged 0.21 percent for test fish and 0.14 percent for controls.

Introduction

The concept of installing a fish screen inside of a penstock at a shallow angle to the flow was first applied by George Eicher at the T.W. Sullivan hydro plant in Oregon. This type of screen is now commonly referred to as an "Eicher Screen." Its basic principle is to sweep fish rapidly towards a bypass at high velocities, as opposed to other types of screens which are designed to maintain velocities lower than the swimming speed of the target fish species.

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Advantages of Eicher's design include low capital and maintenance costs, minimal space requirements, minimal icing potential and insensitivity to forebay level fluctuations. However, a demonstration of the screen's ability to safely pass fish is necessary before it can gain widespread acceptance.

This paper describes the evolution of the Eicher Screen design from its initial installation at the Sullivan hydro plant to the refined prototype recently installed at the Elwha Hydroelectric Project in Washington state. The results of passage tests performed in 1990 with coho salmon smolts are presented. Passage tests for coho salmon and other species will be continued in 1991 and in following years.

Background

The original "Eicher Screen" was installed in 1980 at Portland General Electric's T.W. Sullivan hydro plant at Willamette Falls, and is still in operation. It consists of a 21-foot long stainless steel wedgewire screen with 0.08-inch (2 mm) bars and 0.08-inch openings between bars. The screen is located inside an 11-foot diameter penstock, and is inclined at a slope of 19 degrees to the flow, leading to a surface bypass. The average water velocity through the penstock is approximately 5 fps.

The screen at the Sullivan plant has been relatively free of operational problems. Despite non-uniform flow conditions caused by the layout of the intake and penstock, testing has shown that the screen can divert several species of smolts at high rates. However, an accurate evaluation of fish injury has been precluded by the lack of adequate fish collection facilities. New test facilities planned by Portland General Electric should provide more information on the effectiveness of this screen in the near future.

Without conclusive data on fish injury rates, the Eicher screen has been slow to gain agency acceptance. In order to test and demonstrate the concept's potential, the Electric Power Research Institute (EPRI) initiated a research and development effort in 1984. This program started with laboratory studies conducted at the University of Washington and has culminated in the current test program of the Elwha prototype.

The University of Washington laboratory studies were conducted in a plexiglass flume, with a screen mounted in a test section 8-feet in length and 6-inches in width. The effects of bypass and flume velocities, screen angle, lighting, and various screen materials on the passage of several species of salmonid juveniles and smolts were examined. Fish were effectively diverted under a wide range of velocity conditions. Impingement did not occur at conditions where a high sweeping velocity was maintained along the full length of the screen. At most conditions where impingement did occur, it was limited to the area approaching the bypass entrance. Impingement was reduced or eliminated when the spacing between bars was reduced from 2 mm to 1 mm in the 18-inches of screen closest to the bypass entrance.

Soon after beginning the laboratory tests, EPRI started a search for a suitable site to test a prototype installation. The Elwha Hydroelectric Project, located on the Elwha River near Port Angeles, Washington was selected. With four 3.2 MW units and a total project flow capacity of 2,000 cfs, the site offers a high degree of operational flexibility for testing. The exposed section of the Elwha penstocks provided good access to several possible installation sites. Unlike the Sullivan plant, good alignment of the intakes and penstocks indicated that relatively uniform flow fields could be expected.

In 1989, EPRI entered into an agreement with the project's owners, James River II Inc., to evaluate the Eicher screen in one of the 9-foot diameter penstocks at the Elwha plant. James River II Inc. funded design and installation of the Eicher screen, including a hydraulic model study which was used to refine the initial design. EPRI funded design and installation of evaluation facilities and is also funding the ongoing biological and hydraulic evaluation of the screen.

Prototype Design

James River II Inc. contracted with Hosey and Associates Engineering Company to design the prototype screen and oversee hydraulic model testing. Hosey, in turn, contracted with Engineering Hydraulics, Inc., to build the model and conduct the laboratory tests.

A model of the intake, penstock and screen was constructed on a scale of 1 to 4.7 to develop detailed information on the flow field immediately upstream of the Eicher Screen and in the fish bypass. The initial design used profile bar screen with uniform bar spacing. The screen angle was set at 16 degrees to the penstock for all tests, except for a short section of screen in the bypass transition which was roughly parallel with the penstock.

Two major refinements were made to the screen design during the hydraulic model studies. The design of the support structure was streamlined in order to reduce headloss, and the porosity (percent open area) of the screen was reduced in the downstream end of the screen to provide a more uniform flow field over its entire length.

The prototype using the refined design was installed in the spring of 1990 as part of a 46.5-ft long, prefabricated penstock section. Plan and section views of the screen are shown in Figure 1. The inclined portion of the screen is comprised of two sections with uniform bar width (0.073-inch or 1.9 mm) but different bar spacing. The upstream section is 20-feet in length, has a porosity of 63 percent with an opening between bars of 0.125-inches (3.2 mm). The downstream section is 7.5-feet in length and has a screen porosity of 32 percent with an opening between bars of 0.035-inches (0.9 mm). The section of screen in the bypass transition is 7 feet in length and has a porosity of 8 percent, with an 0.093-inch (2.4 mm) bar width and an 0.008-inch (0.2 mm) opening between bars. The entire screen including the transition section is designed to pivot so that it can be cleaned by backflushing or put into a position parallel to the penstock when not in use.

The Elwha Testing Program

EPRI initiated its testing program at Elwha in the spring of 1990 with

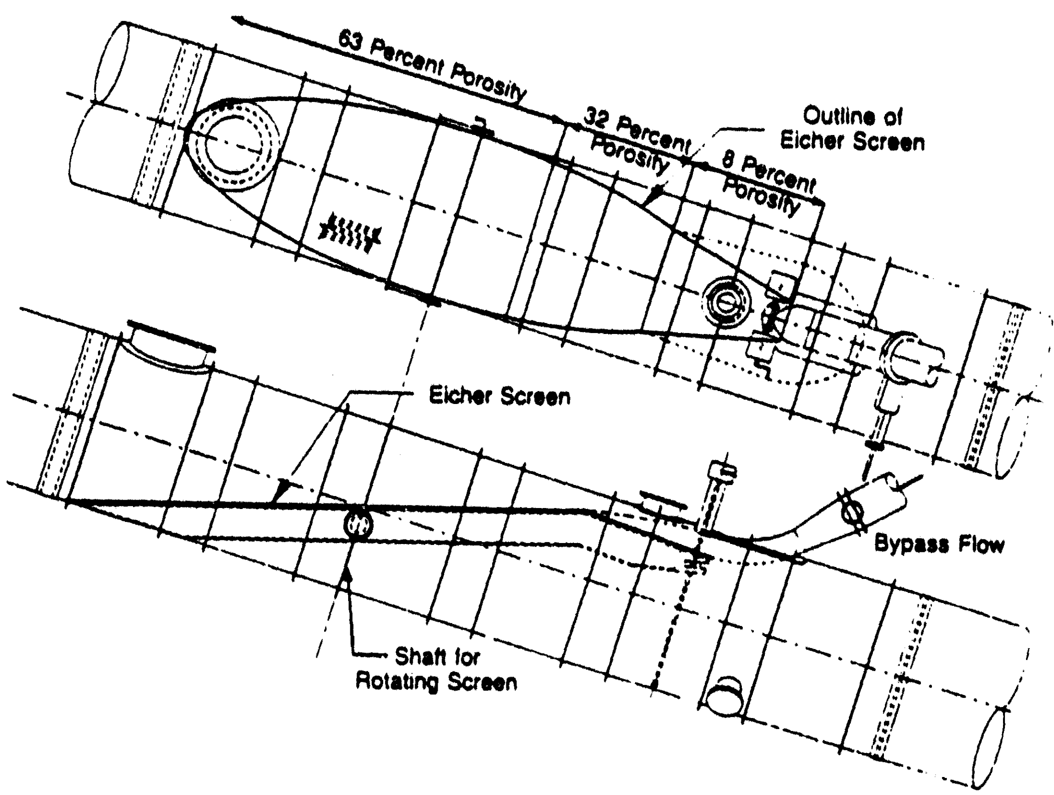

Figure 1. Plan and Section Views of the Elwha Eicher Screen (courtesy Harza Northwest and Hydro Review).

construction of evaluation facilities and completion of the first series of tests with coho salmon smolts. Stone & Webster Environmental Services was retained by EPRI to review hydraulic modelling efforts and design the evaluation facilities. The testing program was developed in a cooperative effort by Stone & Webster and Hosey & Associates with extensive input from state and federal fishery agencies and the Lower Elwha Tribe. A detailed report on the tests performed in the spring of 1990 is presented in EPRI Report No. GS-7036, "Evaluation of an Inclined Penstock Screen at Elwha Dam, Spring 1990 Test Results" (in press). Testing will be continued in 1991 with smolts of steelhead trout, chinook salmon and additional coho salmon.

Evaluation Facility Design

The evaluation facilities installed at Elwha are shown in Figure 2. A pressurized system is used to release test fish into the penstock upstream of the screen. this system is composed of a 60-gallon fish release tank connected to an 8-inch diameter release pipe. The fish are released into the penstock by gradually displacing the water from the release tank and pipe with compressed air. The system releases the fish into the base of the

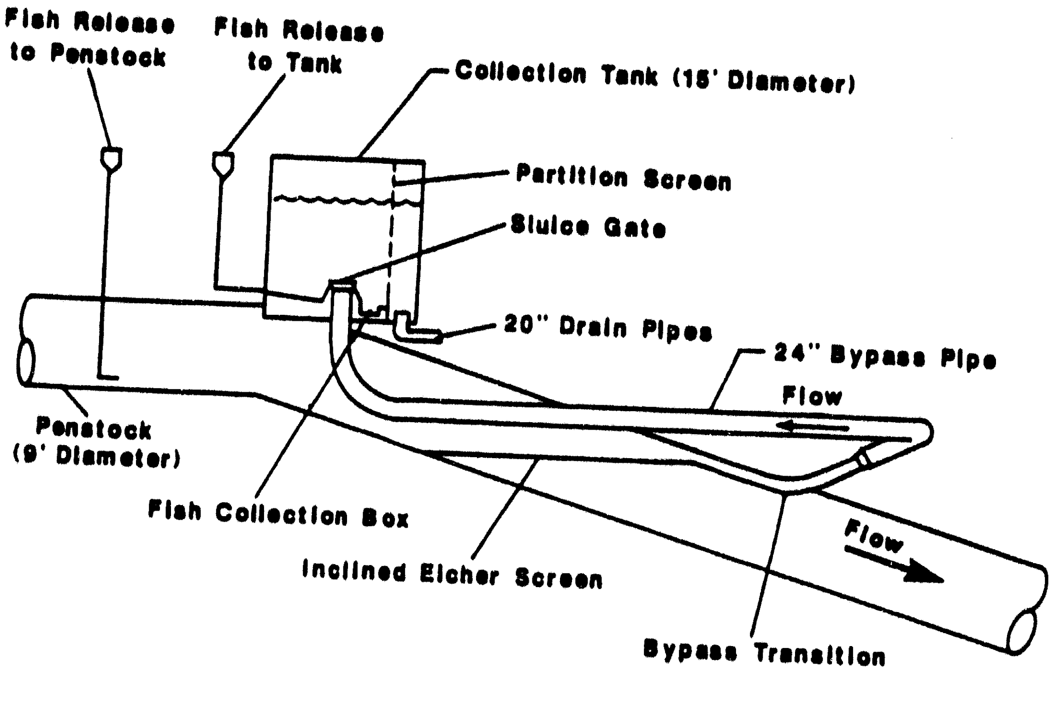

Figure 2. Section View of the Elwha Evaluation Facilities.

penstock approximately 15 feet upstream of the leading edge of the screen. An identical system releases the control fish into the collection tank.

Bypassed fish are delivered into the collection tank through a 24-inch pipe, which discharges the bypass flow and fish upward vertically through an open sluice gate at the floor of the tank. Bypass flows are regulated by adjusting the elevation of the water in the tank, with depths ranging from 7 to 10 ft for the range of bypass flows evaluated (4 to 7.8 fps). The water level in the tank is controlled by adjusting two 20-inch valves which drain flow from the tank behind a screen partition designed to retain collected fish in the tank.

When a test is completed, the tank is drained and the fish are guided by the sloped floor into a 60-gallon collection box. The box is lifted to the uppermost of three work decks surrounding the collection tank. Tanks are provided on the middle and upper decks to hold groups of fish prior to release and following recovery.

Test Parameters

Six combinations of penstock and bypass velocities were evaluated, as shown in Table 1. Penstock velocities were selected to cover the normal operating range of the turbine. Based on results of the University of Washington laboratory studies, the velocity at the bypass entrance was set equal to or greater than the average velocity in the penstock to minimize the potential for fish impingement. The condition with 7 fps in the penstock and bypass was added after a slight increase in injury rate was noted between the 6 fps and 7.8 fps (full gate) penstock conditions.

A study schedule was developed which replicated each test condition twelve times over a fifteen day period. Since the 7 fps condition was added later in the tests, it was only replicated five times. In order to examine time of day as a variable that could affect passage success, each of the five primary conditions were replicated six times during daylight hours and six times during hours of darkness.

Test Methods

The coho smolts used in the spring 1990 testing program were obtained from the Lower Elwha Tribal Hatchery. They were reared for five months to an average size of 135 mm in a net pen located in the forebay of the Elwha project. The fish were monitored to assure that they were in peak migratory (smolted) condition at the time of the tests. At this time, they are

Table 1. Test Conditions Evaluated in the Spring of 1990.

Penstock Velocity (fps)	Bypass Velocity[1] (fps)	Turbine Flow (cfs)	Bypass Flow (cfs)	Wicket Gate Position (%)	Test Replicates Day	Test Replicates Night
4	4	240	11.8	48	6	6
4	6	240	17.7	48	6	6
6	6	360	17.7	70	6	6
6	7.8	360	23.0	70	6	6
7[2]	7	425	20.6	88	2	3
7.8	7.8[3]	475	23.0	100	6	6

[1] Average velocity at the downstream terminus of the bypass transition.

[2] The 7/7 condition was added after a slight increase in injury was noted at the 7.8 fps penstock condition.

[3] 7.8 fps was the highest bypass velocity that could be maintined for extended periods due to wave action in the collection tank.

most prone to scale loss injury. The 15-day test program was initiated on May 19, 1990, and covered the period of peak smoltification.

Before testing, fish were marked with one of four colors of dye pneumatically injected at one of seven locations, producing a total of 28 distinct marks. Marked groups of 100 fish each were held in square, 100-gallon fiberglass tanks situated on the middle deck of the evaluation facility. Each fish was later examined to assure that its mark was visible, to cull out any fish with significant scale loss or other injuries, and to obtain an accurate count of the fish remaining in each mark group.

At the initiation of testing each day, the Eicher Screen was moved from the neutral position (with the screen parallel to the penstock flow) to the fishing position (with the screen at a 16 degree angle to the penstock). Penstock and bypass flows were then set to the first scheduled test condition. A final count was then made as the fish were transferred into buckets. Next, the fish were poured into the appropriate release tanks and the covers were closed and sealed. The fish were then gradually purged from the release systems.

The bypass flow specified for the test condition was maintained for five to ten minutes after fish were released. When the bypass velocity was 7 fps or less, a run time of 10 minutes was used. At a 7.8 fps bypass velocity, the run time was reduced to 5 minutes. These durations were found to be sufficient to allow the fish to pass through the system into the collection tank.

After a test was completed, the inlet sluice gate was closed and the collection tank was gradually drained. Most of the fish moved readily into the collection box as the water depth dropped. The collection box was then hoisted to the upper deck of the evaluation facility.

Fish were evaluated immediately after recovery, directly from the collection box. Each fish was anesthetized and its dye mark, fork length and condition was recorded. A classification system developed by the National Marine Fisheries Service for studies on the Columbia River was used to categorize injuries. The major categories used were:

- o "partial descaling" (scattered or patchy loss 3 to 16% per side);
- o "descaled" (over 16% scale loss on one side); and
- o "other injuries" (bruises and eye injuries).

Fish recovered during the first half of the study were held for three days following recovery to assess delayed mortality. In the last half of the study, the loading density in each tank was increased to enable fish to be held for six to ten days.

Test Results

Results from over 5,000 fish passed through the Eicher Screen prototype indicate that the screen safely diverts coho salmon smolts under a wide range of operating conditions (Table 2). The recapture rate for test and control fish averaged over 98% for each of the test conditions evaluated. Recapture rates increased with time as release and recovery techniques were improved upon. During the last ten days of testing, only 5 fish out of the 3,365 fish released into the penstock were unaccounted for. Four of these fish were lost at test conditions with a penstock velocity of 4 fps, which appears to be too low a velocity to prevent some coho smolts from escaping upstream.

Little or no injury was observed during tests conducted at penstock velocities of 4 or 6 fps. Slightly more injury occurred at higher velocities, but even at the highest velocity condition tested (7.8 fps) only 3.6 percent of the test fish had over 16% scale loss on either side.

Table 2. Summary of Evaluation Results with Coho Salmon.

Penstock/Bypass Velocities (fps)	Replicates		Fish Recovered	Injury Class >16% Descaled	3-16% Descaled	Other Injuries	Delayed Mortality
4/4	Test	12	99.6%	0.0%	0.8%	1.0%	0.3%
	Control	12	100.0%	0.0%	1.2%	0.7%	0.0%
4/6	Test	12	99.2%	0.0%	1.4%	0.7%	0.2%
	Control	12	100.1%	0.1%	0.5%	0.9%	0.2%
6/6	Test	12	99.7%	0.1%	3.3%	0.5%	0.0%
	Control	12	99.9%	0.0%	0.5%	0.9%	0.1%
6/7.8	Test	12	99.9%	0.0%	4.1%	1.1%	0.3%
	Control	12	100.0%	0.0%	1.0%	0.8%	0.2%
7/7	Test	5	99.8%	1.3%	10.4%	1.4%	0.0%
	Control	5	99.7%	0.0%	0.8%	1.0%	0.3%
7.8/7.8	Test	12	98.8%	3.6%	18.1%	0.9%	0.3%
	Control	12	100.4%	0.0%	1.4%	0.7%	0.2%
All Conditions	Test	65	99.5%	0.8%	6.3%	1.0%	0.2%
	Control	65	100.0%	0.0%	0.9%	0.8%	0.2%

Of over 10,000 fish recovered during testing (5,000 test fish and 5,000 controls), only 12 test fish and 8 controls died during the three- to ten-day holding period. The mortality rate was quite low even for the few fish that showed substantial levels of descaling (Table 3).

The salmon smolts used in the tests ranged from 101 to 165 mm in length. No relationship was found between fish length and injury rates. Small numbers of hatchery steelhead (188-282 mm in length), resident rainbow trout (53-122 mm) and sticklebacks (32-60 mm) were also recovered in good condition.

No operational problems were evident during the testing period. Headloss measured across the screen ranged from 0.5 ft at a penstock velocity of 4 fps to 2.0 ft at 7.8 fps. The screen appears to be largely self-cleaning, and backflushing has effectively removed any debris pinned on the screen.

EPRI studies at Elwha are continuing, and are planned to include chinook salmon and steelhead smolts in 1991.

Table 3. Mortality by Injury Class After 6-10 Days Holding.

Injury Class	Total Observed	No. of Mortalities	Mortality Rate
Descaled (>16% loss on one side)	46	4	8.7%
Scattered Scale Loss (3-16% per side)	202	0	0.0%
Patchy Scale Loss (3-16% per side)	184	2	1.1%
Other Injury	93	4	4.3%
OK (<3% scale loss)	10,611	10	0.1%
Total	11,136	20	0.2%

Conclusions

Results of the May-June 1990 tests at Elwha indicate that the Eicher Screen prototype has excellent potential for protecting downstream migrating fish. If the Eicher Screen can safely bypass other species and sizes of fish, the device may see widespread application at hydroelectric projects with penstocks. The screen's modest space requirements, low initial cost and low O&M costs constitute significant advantages over other screening systems.

A DEMONSTRATION OF STROBE LIGHTS TO REPEL FISH

Paul Martin[1], John Downing[1], Ned Taft[2], Charles Sullivan[3]

ABSTRACT

An EPRI review (EPRI, 1986) of fish protection systems for hydroelectric facilities identified strobe lights as a potential behavioral system to minimize fish entrainment. In 1988, EPRI initiated an evaluation of juvenile American shad response to strobe lights at Metropolitan Edison's York Haven Power Station on the Susquehanna River.

During their fall migration, juvenile shad accumulate in the forebay. In 1988, using a raft mounted with four strobe lights, it was clearly demonstrated that shad could be excluded from the area in front of the trash racks, and bypassed through a sluiceway into the tailrace. Hydroacoustics were used to monitor the effectiveness of the strobe lights. In 1989, six rafts supporting 22 strobe lights were moored in front of the trash racks. Unit outages and river flooding limited a full evaluation of the strobe system. Under limited test conditions, it was possible to confirm shad avoidance of strobe lights similar to that observed in 1988. In 1990, testing was performed with a fully operational strobe system under normal flow conditions and hydraulics. Testing showed that shad could be effectively passed around the York Haven Station. The results of the 1990 studies were more extensive than those of 1989, however, flood waters again limited complete testing of the system.

INTRODUCTION

In 1988, the Electric Power Research Institute (EPRI), Metropolitan Edison

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Company (Met-Ed), and the Susquehanna River Anadromous Fish Restoration Committee (SRAFRC) co-funded a study of strobe and mercury lights for diverting outmi grating juvenile American shad (Alosa sapidissima) at Met-Ed's York Haven Hydroelectric Project on the Susquehanna River (Figure 1). The objective of this study was to determine whether these devices could be used to divert shad away from the plant turbines and through an existing trash sluiceway near the downstream-most unit. The results of the 1988 study demonstrated that strobe lights effectively and consistently repelled the juvenile shad and directed them through the sluiceway.

On the basis of excellent results obtained with strobe lights in 1988, a large-scale study was attempted in 1989 and 1990 in which strobe lights were placed in front of Units 1 through 6. These units were most likely to be operated during the shad outmigration period. The purpose of the study was to provide a full-scale demonstration of the effectiveness of a strobe light system in guiding downstream migrating juvenile American shad past the turbine intakes to a trash sluice bypass at York Haven. The primary means of demonstrating the effectiveness of the system was through underwater sonar sampling near the trash racks and sluiceway. In addition, during 1990 periodic netting was used to determine the passage of fish through the turbine intake relative to the sluiceway.

In 1989, the strobe system was installed in the fall and was fully operational when the shad began to arrive in early October. Unfortunately, heavy rains, and unit outages causing fish to pass over the dam, severely limited the ability to evaluate the strobe system. During the first few days of testing, sufficient shad were in the study area to determine that the strobe lights did, in fact, repel the fish. However, the number of fish available for evaluation declined quickly over several days and it was not possible to complete testing.

In order to complete the study begun in 1989, the strobe light system was reinstalled in 1990. The scope of work for this effort was the same as that used in 1989 except for the addition of trammel net sampling, as described in the following discussion.

MATERIALS AND METHODS

Description of Strobe Light System

The strobe light test system is shown in Figure 2. The system consists of six, interconnected floats which were anchored immediately upstream of Units 1 through 6. The strobe lights were attached to steel poles and these

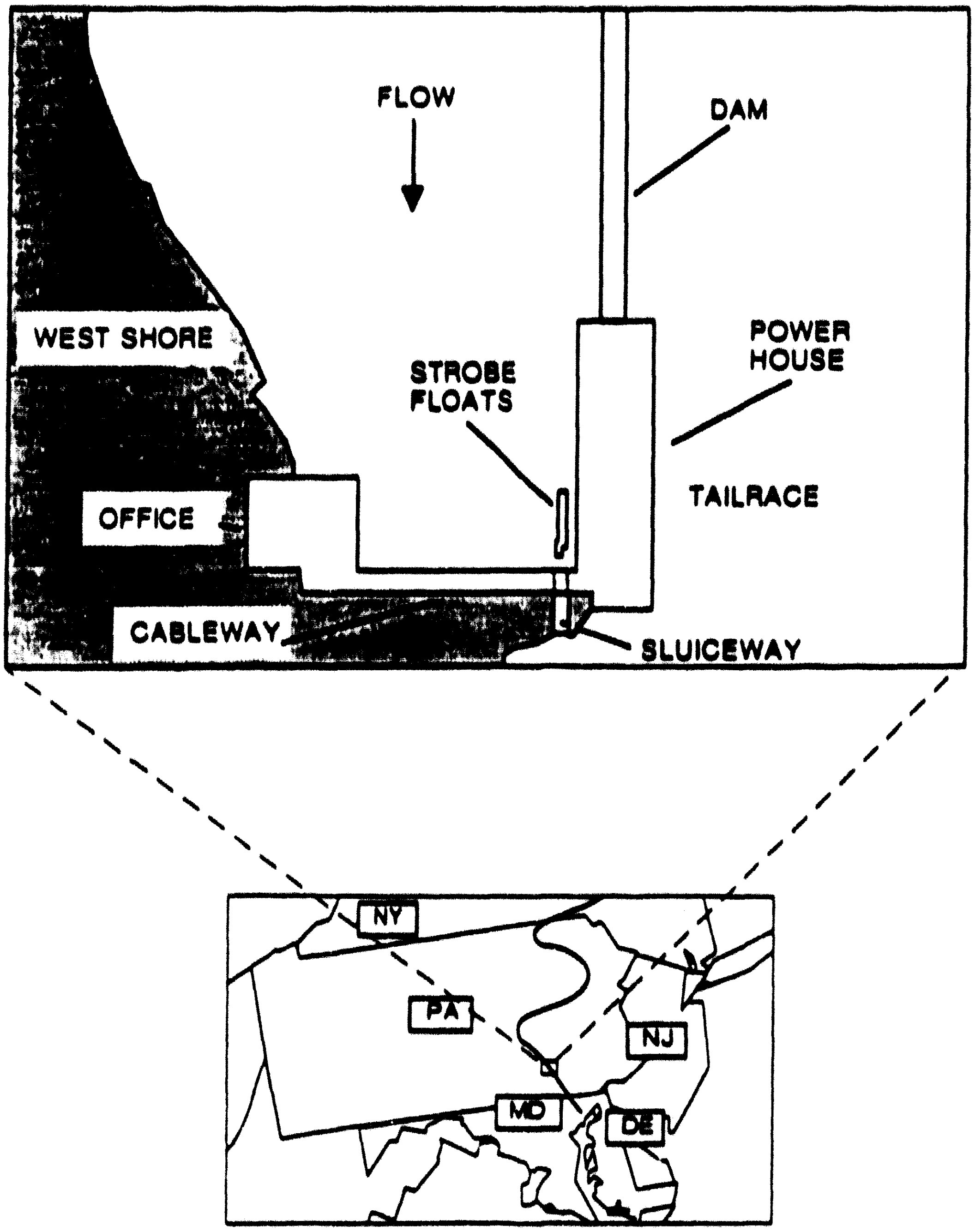

Figure 1 Study Site Location, inset shows York Haven Plant

assemblies were mounted on the floats. Each pole supported two lights; the lights were located 3 ft and 9 ft below the water surface. The poles were spaced at 12 ft intervals. When deployed, the light flashheads on floats 3 through 6 were aimed upstream. The spacing was selected based on the beam spread of the lights and designed to create a continuous "wall" of light across Units 2 through 6.

The floats closest to Unit 1 (floats 1 and 2) were oriented differently (Figure 2). These floats supported strobe lights angled to flash in the direction of the sluiceway. In addition, a small, moveable float supporting a single pole with two lights was located between float 1 and the powerhouse cableway.

The strobe light system was configured as two arrays: the lights on floats 3 through 6 were operated together and sequenced by one controller; the lights on floats 1, 2, and the moveable float operated together on a different controller. This design allowed the strobes on floats 3 through 6 to operate continuously such that shad were repelled from this area and moved downstream to congregate between floats 1 and 2 and the sluiceway. The area in front of the sluiceway was kept dark most of the time to allow fish to accumulate. Periodically, based on the test schedule, the sluiceway gate was opened and the strobes on floats 1 and 2 and the moveable float were activated to repel fish through the sluiceway.

Scanning Sonar

In the 1989 and 1990 testing, two WESMAR Model SS390 scanning sonar systems were used to monitor fish behavior and response to the strobe lights. Each system included a sonar control console, a transducer and preamplifier with connecting cables, a time-lapse video recorder, a color video monitor and a power supply. One unit was deployed from float 1 (range set at 50 ft) to monitor fish in the area of Unit 1 and the sluiceway. The second unit was deployed in front of Unit 4 (set at a range of 150 ft) to monitor fish as they entered the forebay area and approached the strobe light system. The ranges, gains and transducer angles on the units were set to achieve optimal detection and coverage of the fish. The systems were calibrated using fixed targets with known backscattering characteristics.

The two sonar units provided complete coverage of the test area. Data were recorded by the time lapse VCRs in VHS format. The VCRs displayed and recorded date and time information. This approach permitted paired tapes (i.e., one tape from each sonar unit) to be reviewed simultaneously at a later date.

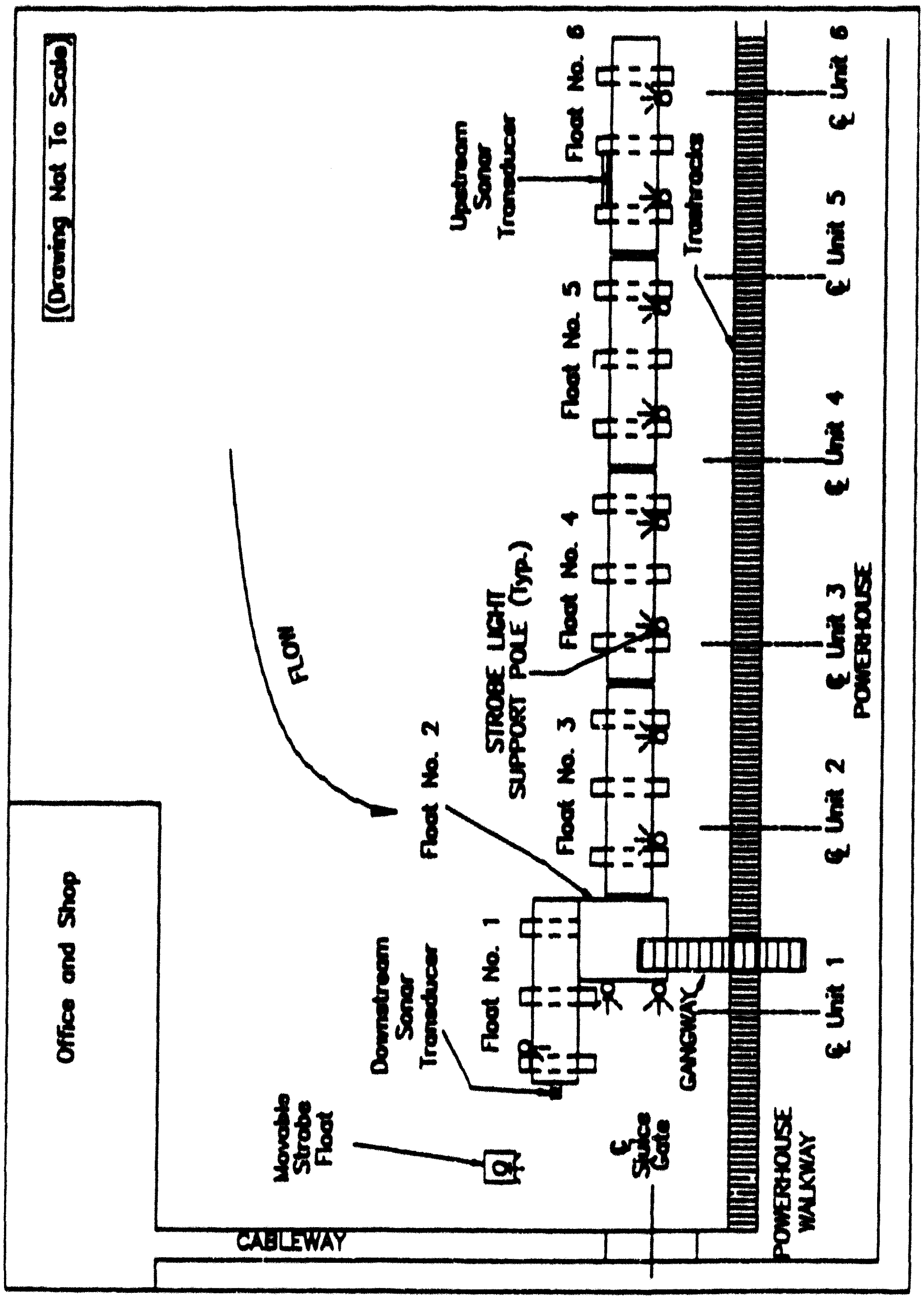

FIGURE 2
York Haven
Forebay and Float Positions

Netting

To quantify the possible passage of fish through the trash racks and turbines at York Haven, a netting program was implemented in 1990. A net frame was constructed of aluminum and steel, measuring 6 ft in height and 10 ft wide. A trammel net was securely fastened within the frame. The frame was supported by adjustable buoys that were set to allow the net to fish at surface, mid-depth and bottom positions. The net was placed into the water for each test and positioned via a series of lines and pulleys. This arrangement permitted the net to be positioned either directly in front of the sluiceway or the Unit 1 trash rack.

The net was used primarily to collect fish that might have been repelled toward the trash racks when the strobe lights near Unit 1 were activated. The net was deployed just before the downstream strobes were activated and retrieved immediately following strobe deactivation. This procedure minimized the potential loss of fish and prevented excessive wear and damage to the net in the relatively high velocity zone near the racks and sluiceway.

The net collection process in front of Unit 1 was repeated numerous times at different test conditions and at different depths so that all depths were sampled repeatedly. A few samples were taken with the net in front of the sluicegate. However, the sluiceway proved to be difficult for sampling due to high flow velocities and debris.

SAMPLING DESIGN

A simple cross-over design blocked within each 24 hour sampling period (testing day) was used to evaluate the effectiveness of the strobe array. Except during the peak outmigration period, daily passage rates can be highly variable. Blocking by date helps to control for this effect. Testing within each sample day consisted of running sequential control and test conditions from around dusk to as late as 3 AM, depending on fish availability. The order of testing varied from night to night but included the following conditions:

- CONTROL: all lights OFF; sluice gate closed
- UPSTREAM LIGHTS ON: strobe lights on floats 3 through 6 activated; downstream lights OFF; sluice gate closed
- UPSTREAM AND DOWNSTREAM LIGHTS ON: net in fishing position and sluice gate open.

For each test, the downstream scanning sonar unit was set at one of several transducer scanning angles. Additionally, an observer was positioned at the downstream side of the sluiceway opening to visually estimate the number and behavior of fish passing out the sluiceway. All fish collected in the trammel net were counted and identified to species. Live fish were returned to the river below the dam.

SUPPLEMENTAL SAMPLING

In order to document the lighting and hydraulic conditions to which fish were exposed, two supplemental sampling efforts were undertaken. First, complete mapping of the light field upstream of the float system and in the sluiceway gate area was performed periodically using a Li-Cor photometer. The frequency of sampling was based on changing turbidity conditions. Turbidity was monitored qualitatively on a daily basis using a Secchi disc and photometric measurements. Water temperature was also monitored daily, since temperature appears to be a key stimulus for the onset of migratory behavior in shad.

Velocity measurements were recorded on a periodic basis using a Swoffer propeller meter. Measurements were taken along the front of the float assembly and at several transects upstream. Velocities in the area of the sluiceway gate were also taken. Measurements were repeated periodically to collect a complete data set at all plant operating conditions that occurred over the duration of the study period.

RESULTS

In 1989, one scanning sonar unit was deployed in mid-September to monitor the forebay area for fish occurrence. Based on the sonar information, strobe system evaluation began October 11 and continued until October 21. Several nights of testing were performed under modified strobe system configuration since the controller for the upstream strobes was initially inoperable. Using the downstream strobes it was possible to repeat tests similar to those performed in 1988. Although limited and qualitative in nature, the 1989 results clearly demonstrated an avoidance response by shad. As evidence of this response, shad were observed passing through the sluiceway following downstream strobe activation. In addition, shad were also observed via the sonar, travelling upstream away from the lights. As mentioned earlier, the altered hydraulic conditions limited the number of shad accumulating upstream of Unit 1 so that the response in 1989 consisted of observations on fewer fish. However, a strong avoidance behavior was still evident.

Increasing water levels and high turbidity greatly reduced both the density of shad in the forebay and the effective range of the strobes. It is presumed that as water began to flow over the crest of the dam most of the outmigrating shad bypassed the forebay and turbines and went over the dam. Testing was ended when water levels dropped without a subsequent increase in the number of shad.

While in 1988 and 1989 the shad arrived during the first week in October, in 1990 they arrived nearly two weeks earlier so that sampling began on September 26. At this time, the water temperature was 17 °C, and the shad did not appear to be actively migrating. Unlike the previous two years, fish were observed in the forebay during the day as well as at night and were deeper in the water column (greater than 6 feet). The scanning sonar observations revealed shad "milling" in the forebay in a wide area upstream of the trash racks. In previous years, the sonar showed the shad in tight, active schools immediately in front of the trash racks. Water temperatures actually rose during the study to 21 °C. The "milling" behavior and therefore lack of downstream movement is probably attributable to a lack of migration stimuli and avoidance of the accelerating flow field in the area of the gate.

Over the 26 days of the 1990 sampling period, 115 tests were run. The trammel net was used in 65 of these tests at surface, mid-depth and bottom locations immediately upstream of Unit 1. Table 1 summarizes the test results, including the sonar scanning angle, the number of tests with the net deployed at the three depths, the average number of shad caught in the net, the average number of shad visually observed going out the sluiceway, and the analysis of shad response to the strobes as revealed on sonar video tapes. Behavioral response to the strobes was determined by reviewing the sonar video recordings and making a determination of the strength of the response based on changes in target density in the vicinity between the strobes and the sluicegate, just prior to and following downstream strobe activation. In Table 1, the high number of "minor" responses at the surface could be due to either low initial shad densities (so that an accurate determination of the shad response could not be made) or debris clutter of the ensonified area (especially towards the end of the study when flood waters transported large quantities of debris into the forebay). The response of the fish to the strobe lights in 1990 was the same as that observed in the past two years. However, while avoidance of the strobes was observed in all tests, the fish were not observed passing out the sluiceway in very large numbers (A visual estimate of an average of 50 shad per strobe test in 1990 while hundreds were observed passing out the sluiceway in previous year's tests).

In nearly all of the 1990 tests, groups of fish from about 5 individuals to over many hundred were observed to pass through the gate. However, these fish were oriented upstream and appeared to be swimming at burst speed in an

# OF TESTS	ANGLE OF SONAR SCAN	# TESTS WITH NET POSITION	AVG.# FISH NETTED	AVG.# FISH OBSERVED IN SLUICEWAY	MAJOR/MINOR RESPONSE*
45	SURFACE (+2 to −3)	NO NET – 19 SURFACE – 16 MIDDLE – 4 BOTTOM – 6	TOTAL – 4 SURFACE – 2 MIDDLE – 5 BOTTOM – 8	27	22/23
63	MIDDLE (−4 to −8)	NO NET – 27 SURFACE – 20 MIDDLE – 11 BOTTOM – 5	TOTAL – 5 SURFACE – 3 MIDDLE – 3 BOTTOM – 14	57	45/18
7	BOTTOM (−9 to −12)	NO NET – 4 SURFACE – 1 MIDDLE – 0 BOTTOM – 2	TOTAL – 3 SURFACE – 0 MIDDLE – 0 BOTTOM – 5	55	7/0

* # OF TESTS WITH HIGH FISH DENSITIES VS. TESTS WITH LOW DENSITIES (DENSITIES ESTIMATED FROM VIDEO IMAGES OF SONAR TARGET RETURNS)

TABLE 1 SUMMARY OF 1990 TESTS

attempt to move upstream. This behavior is very different from that observed in 1988 when large masses of fish moved head first downstream through the gate when the downstream strobe lights were activated. Nonetheless, the strobe lights were highly effective in moving fish out of the lighted area. Further, trammel net data and scanning sonar observations indicated that the predominant movement of shad was upstream. The number of fish collected in a net sample ranged from zero to 58; most of the samples had no or few fish. A total of 306 fish were collected in 65 samples. By comparison, hundreds of fish were visually observed passing through the sluiceway during the 115 tests performed.

The data indicates that the strobe lights continued to create a strong avoidance response in juvenile shad whether or not they were in a migratory mode. It had been hoped that testing would continue long enough into the fall migration period to demonstrate that most fish do not pass through the trash racks when the lights were activated. Unfortunately, several unseasonably severe floods occurred over a short period of time during the active outmigration period. After the flood flows subsided, few fish remained and the study was terminated after several additional nights of monitoring for fish with the scanning sonar units.

CONCLUSIONS

The results obtained are very encouraging. It has been shown that it is possible to repel American shad from the face of the trash racks as well as to bypass shad through the trash sluiceway under normal river conditions. Variations in riverine and climatic conditions caused variations in the shad migration, their behavior, and the effectiveness of the strobe system. It is anticipated that additional testing in the future will definitively demonstrate that the strobe lights do not repel fish through the trash racks while continuing to bypass fish out the sluiceway. With this final question answered, strobe lights should become an acceptable and cost-effective means of preventing turbine passage at York Haven and other sites and providing a means for bypassing downstream migrating American shad.

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The use of IFIM for evaluating effects of a flow alternative on fish habitat in a river system with competing water demands.

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ABSTRACT

The Instream Flow Incremental Methodology (IFIM) was used to evaluate instream fish habitat in the Platte River in central Nebraska. The IFIM analysis presented herein incorporates 1) water temperature modeling and water quality, 2) fish species composition and distribution, 3) physical habitat data and 4) 43 years of flow records. The Platte River system has competing water demands from hydropower, agricultural irrigation, municipal uses, recreation and most recently from recommended instream flows for fish and wildlife resources. IFIM was the tool used to develop the data base required for a comprehensive instream flow analysis of the system. When compared to the baseline flow regime, an alternative flow regime significantly increased modelled fish habitat area during critical periods of the year. The time series results demonstrated that the flow alternative would be beneficial to the existing fish resources, while still providing water for power production and irrigation.

INTRODUCTION

The Instream Flow Incremental Methodology (IFIM) was the fish habitat assessment technique being used in the relicensing of F.E.R.C. Projects 1835 and 1417 in the Platte River system in central Nebraska. The projects are operated by Nebraska Public Power District and The

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Central Nebraska Public Power and Irrigation District, respectively. The IFIM is a tool used to predict changes in aquatic habitat as a function of stream flow (Bovee 1982) based on analysis of macrohabitat and microhabitat parameters. Macrohabitat includes variables that change longitudinally in streams such as hydrology, temperature and water quality. Microhabitat variables attempt to describe the actual living space of the organism and include water depth, velocity, streambed substrate, and cover.

A complete IFIM analysis uses four component sets of information, 1) hydraulic data, 2) microhabitat {fish habitat suitability curves}, 3) microhabitat/discharge curves combined with macrohabitat to produce estimates of total habitat available and 4) hydrologic flow regimes. The combination of the total available habitat with hydrologic flow regime allows the user to compare operating alternatives on fish habitat response. All four components were developed during the relicensing studies on the Platte River system in central Nebraska to provide an analysis of the effects of Projects 1835 and 1417 current and proposed operations on fish habitat.

METHODS

The IFIM (Bovee 1982) was applied as the primary aquatic habitat assessment tool for a comprehensive study of the Platte River system in Nebraska. The entire study area consisted of 56.1 mi (89.8 km) on the North Platte River from Lake McConaughy downstream to the confluence with the South Platte River, 27.0 mi (43.2 km) on the South Platte River from the Sutherland highway bridge downstream to the confluence, and 159.5 mi (255.2 km) on the mainstem Platte River from the confluence of the North and South Platte Rivers downstream to the highway bridge near Grand Island (Chadwick & Associates, Inc. 1990a). This paper presents the results of studies on 94.0 mi (150.4 km) of the Big Bend Reach of the central Platte River from near Lexington to near Grand Island (Fig. 1).

A total of 8 river segments and 10 PHABSIM study sites were used to represent the habitat in this portion of the river (Fig. 1). These study sites were established by the Platte River Management Joint Study in the early to mid 1980's. Study sites were chosen to represent typical conditions in each river segment.

Habitat suitability curves were developed from site specific data collected in 1987 (Chadwick & Associates 1990b) for five fish species, red shiner (Notropis lutrensis), sand shiner (Notropis stramineus), channel catfish (Ictaluris punctatus), plains killifish (Fundulus zebrinus),

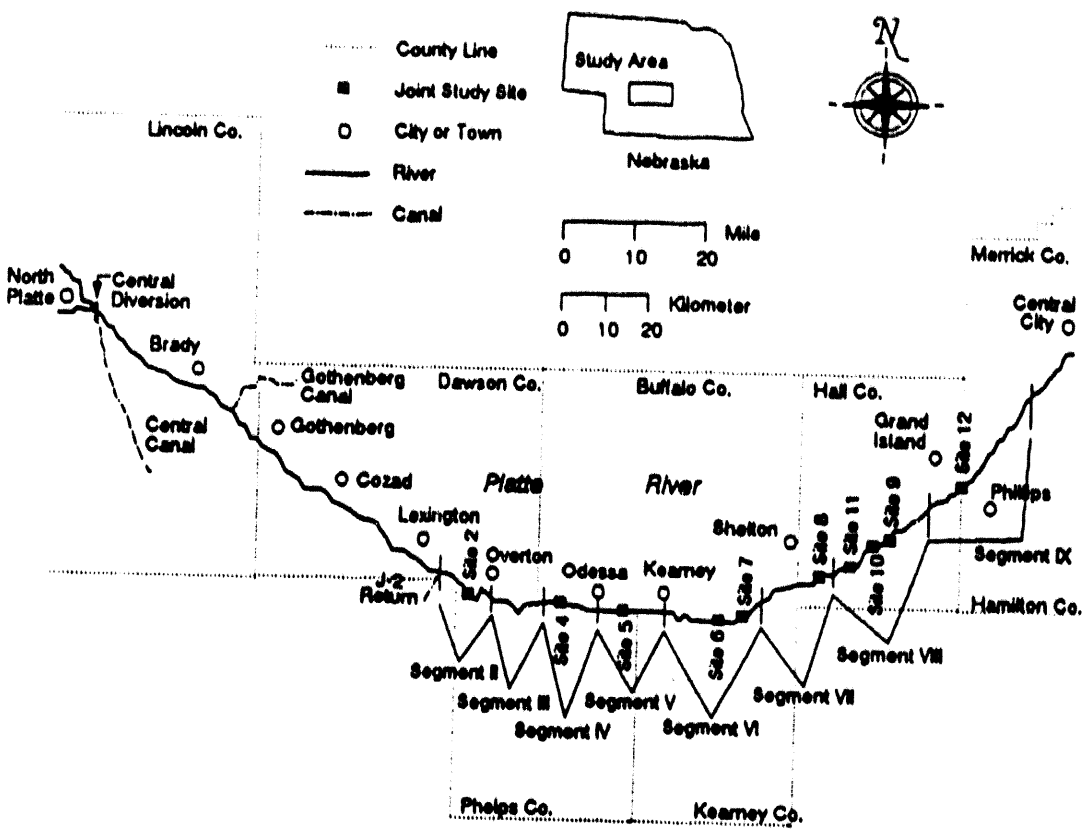

Figure 1. IFIM segmentation and study site locations for the Platte River, Nebraska.

and common carp (Cyprinus carpio). These species are among the most frequently collected in the reach (Chadwick & Associates 1990b) and provide representation of several habitat usage types.

Portions of the river segment presented in this analysis contain nesting populations of least terns, an endangered species, which feed on the forage fish species in the river. Results from two of the species noted above, sand shiner and plains killifish, were chosen to illustrate the change in habitat under the various flow regimes. These species use distinctly different habitat types. The sand shiner is a generalist, with the majority found in the shallow main channel. The plains killifish is usually associated with shallow, slow moving water near the margins of the stream channel and in backwaters.

Macrohabitat analysis Macrohabitat variables used in this analysis include 1) water temperature and 2) water quality. In addition, fish distribution was used as a secondary indicator of suitability of temperature and water quality. The analysis of available data on fish distribution, temperature, and water quality indicates that all segments in the study area provide suitable macrohabitat for the target fish species.

Temperature Longitudinal change in water temperature is a key macrohabitat variable. Water temperature monitoring and modelling were conducted on the central Platte River to determine limits of suitable macrohabitat.

Water temperature modeling was conducted on the central Platte River which included areas that experienced elevated temperatures in 1987 and 1988. The modeling showed that elevated water temperatures can occur in the summer months and that these elevated temperatures were highly dependent on weather patterns, not flow conditions (Miller 1990). The modelled temperatures in some instances were in the lethal range for the target fish species. However, fish sampling after these events indicated that there were abundant and diverse populations after these localized events occurred. As such, no segments on the Platte river system were designated as unsuitable for warm water species.

Water Quality Water quality records published by the USGS were reviewed to evaluate suitability for fish in the Platte River. All water quality data reviewed indicate suitable conditions for the fish species modelled as part of this study.

Fish Distribution Fish were sampled in 1987 and 1989. Sampling in 1987 consisted of electroshocking discreet points in various habitat types as part of the habitat suitability criteria development. Additional sampling in 1989 consisted of electroshocking distinct habitat areas at 15 sites in the study area. Sand shiners and plains killifish were collected throughout the study area. For these species suitable macrohabitat evidently exists in all segments of the central Platte River.

Hydrology The study area receives controlled inputs from releases out of Lake McConaughy on the North Platte River and from upper South Platte River. Water can be diverted through a series of supply canals and offstream reservoirs where it is held or released for irrigation and power production. Power and irrigation water can be returned to the river at the Jeffrey Return Number 2 (J-2 Return)(Fig. 1). The J-2 return is capable of returning up to 1700 cfs to the mainstem Platte River. There are numerous small irrigation returns and several small tributaries, but the J-2 Return is the last major hydrologic input to the Platte River upstream of the lower study area boundary. Under current conditions there is no minimum flow specified for any segment of the river system. Historically there were periods of zero flow in the Platte River downstream of the J-2 return.

A hydrologic model, a version of the Bureau of Reclamation's OPSTUDY model modified to more accurately represent the Districts operation of reservoir and diversions (Simons & Associates, Inc. 1990), was used to model two flow regimes over a 43 year period of record, 1942-1984, representing baseline flow conditions and the Districts proposed alternative flow regime.

The low flows in this section of the river occur during the August - September time period under base flow conditions. The Districts' proposed alternative flow regime decreases flow in the winter and increases flow in summer. Average flow during August is 182 cfs in the most downstream section under the alternative flow regime, which is greater than the August baseline flow of 160 cfs. The minimum 80% exceedence flow for September is also much higher for the Districts flow regime, 69 cfs, than for the baseline flow regime, 0 cfs.

IFIM Analysis The flow regimes were compared in terms of modelled fish habitat for sand shiner and plains killifish using the time-series portions of IFIM. Prior to running the time-series, the Weighted Usable Area (WUA) versus discharge relationships were converted from WUA in ft^2/1000 ft of river to ft^2/river segment. This produced time series results for each target species expressed as monthly habitat in ft^2/segment over the 43 year time period. Hydrologic and habitat time series data were analyzed using the LPTDUR subroutine of IFIM. The duration statistics used in this analysis were the Index B (a measure of average conditions) and the 80% exceedence levels (approximately the 1 in 5 year low habitat or flow condition) over the 43 year period.

There is an inherent margin of error in all of the data collecting and modelling steps in the IFIM process. Therefore, when evaluating and comparing the differences in percent changes in habitat levels between two flow regimes, there should be a certain threshold level to separate true significant changes in habitat from model "noise". Based on professional judgement and experience with IFIM, the threshold level for this analysis was set at 15%. Thus, only differences in habitat of 15% or greater were considered significant.

In addition to this level of significance, the lowest habitat month that occurs within one year was termed the critical limiting period. This "critical period" is based on the bottleneck theory of population control (Wiens 1977), which assumes that populations are controlled by periods of minimal habitat availability rather than average conditions (Wiens 1977, Grossman, et al. 1982). This critical limiting period is used by the USFWS in Milhous (1986). Both the Index B and 80% exceedence level were evaluated for critical limiting periods.

RESULTS

The IFIM analysis resulted in WUA versus discharge relationships for both sand shiner and plains killifish at each of the 10 study sites in the central Platte River. These WUA discharge curves were combined with the hydrology for each of the eight river segments to produce a 43 year period of record habitat time series for each operating alternative.

Baseline Flow Regime For both species there is a relatively large difference in habitat levels between Index B conditions and 80% exceedence conditions (Fig. 2 and 3). Habitat levels in August for 80% exceedence conditions are only 46% of August Index B levels. These relationships indicate that there is considerable yearly variability in habitat conditions.

Habitat for sand shiner is at a minimum during August and September, the months of lowest flows for both Index B and 80% exceedence conditions and highest during October - April period. Higher flows generally result in higher levels of habitat. The time-series relationship for sand shiner suggests that the low levels of habitat during late summer act as a bottleneck or a "critical period" for populations of these species. The minimum habitat levels occur during the end of the spawning period and there is probably no chance for these species to reproduce and recruit fry to the adult stage when habitat levels increase during October and November.

Habitat for plains killifish varies over the year but does not follow the trend for total area which indicates that habitat for this species is maximized at intermediate flows. Minimum habitat for plains killifish generally occurs in September of an average year. Eighty percent exceedence habitat levels are less than half of Index B habitat levels. This indicates considerable year to year variability for this species. Population levels for this species may not vary greatly month to month but may be substantial on a year to year basis.

Comparison to Districts' Alternative Flow Regime This alternative flow regime results in a significant increase in habitat levels for sand shiners during the critical summer period during both Index B and 80% exceedence flow years (Fig. 2). Habitat levels during the August-September critical period increase by 22-41% for Index B conditions (Fig. 2). Habitat increases are even greater under the 80% exceedence conditions (Fig. 2). Sand shiner habitat during the August-September critical period increases by 84-106% over baseline conditions. The reductions in habitat occurring during periods of the year other than the critical, minimum habitat period should have no effect on the populations.

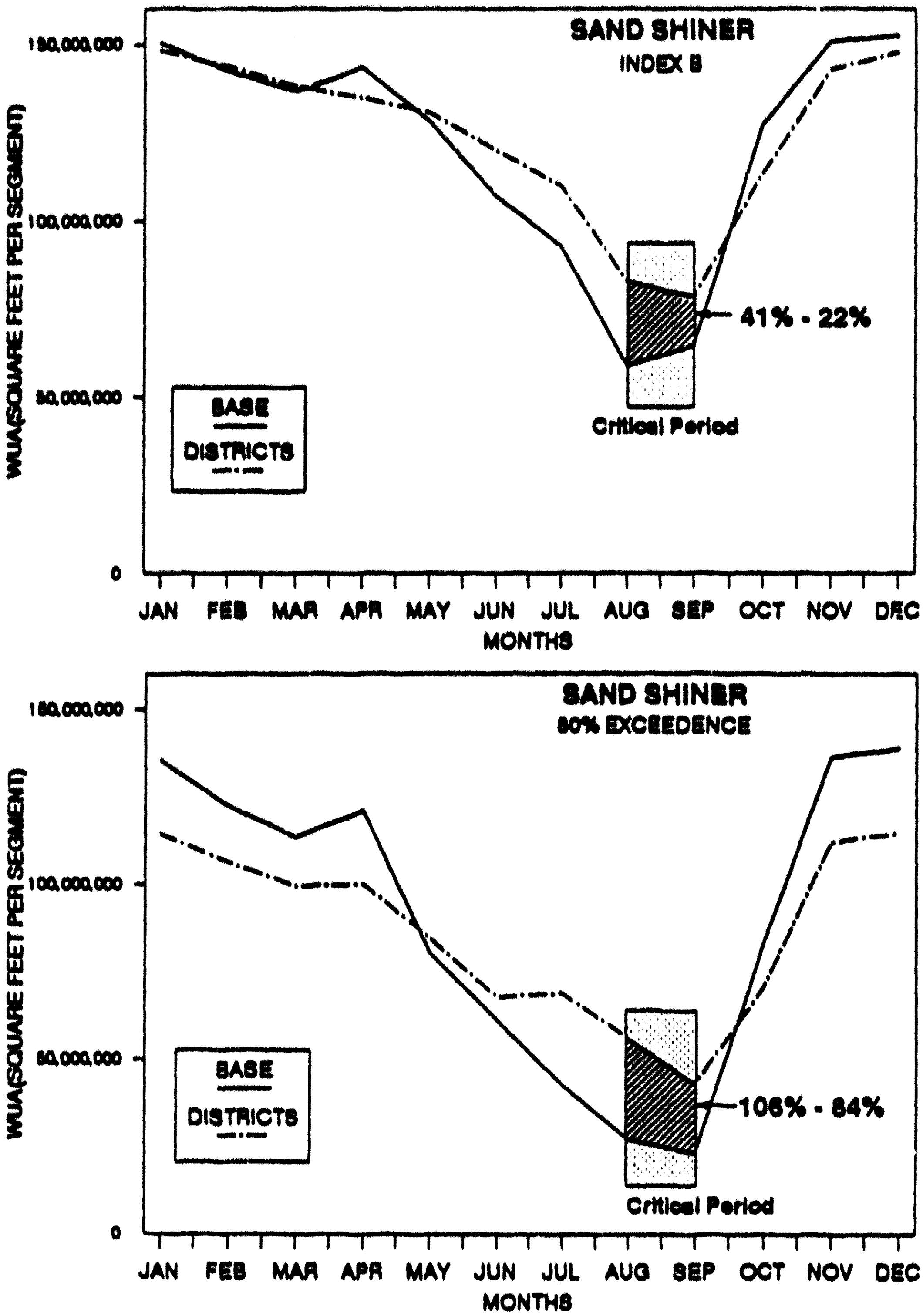

Figure 2. Comparison of habitat levels for sand shiner with baseline and alternative flow regime in the Platte River downstream of the J-2 Return.

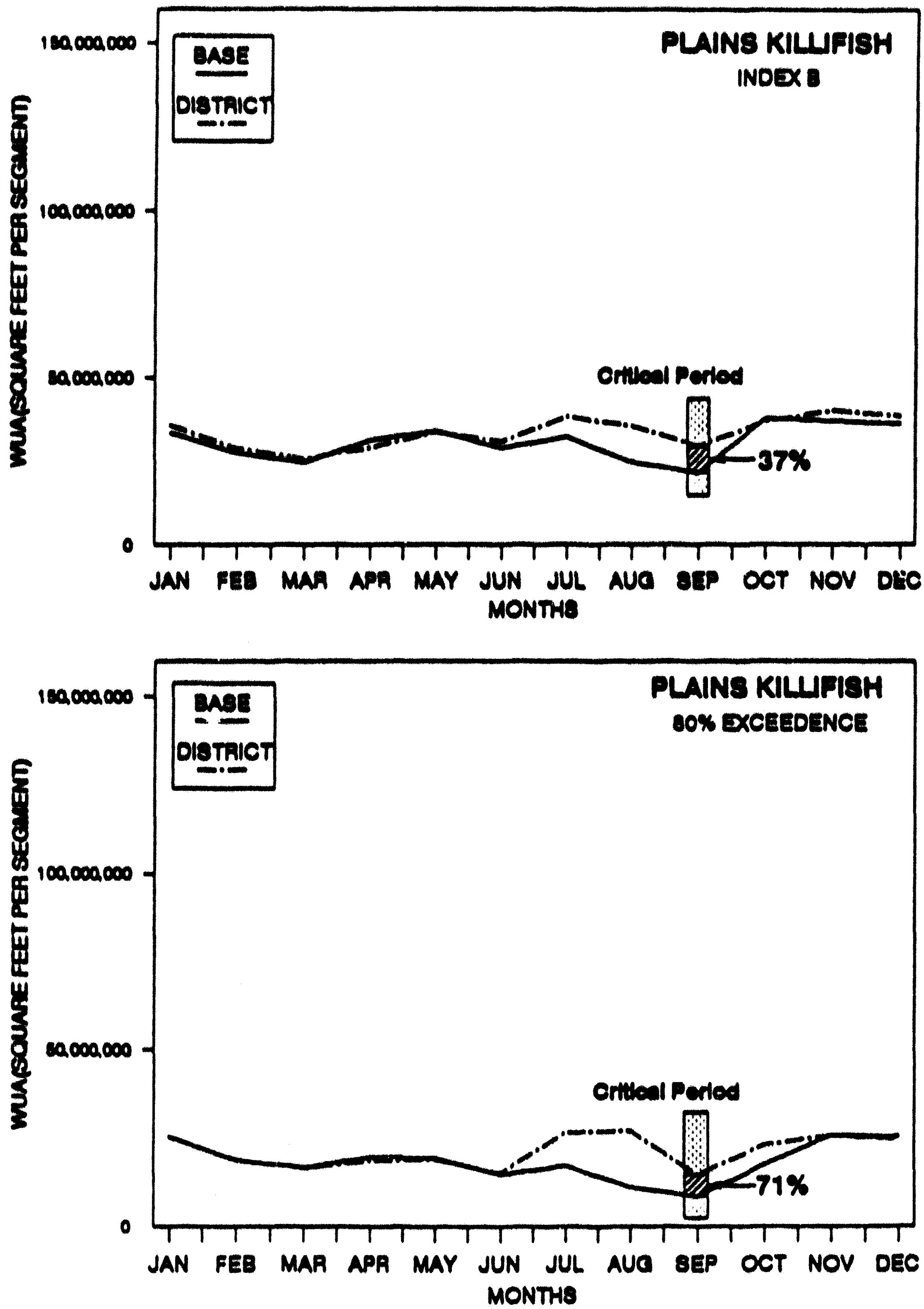

Figure 3. Comparison of habitat levels for plains killifish with baseline and alternative flow regime in the Platte River downstream of the J-2 Return.

The alternative flow regime also resulted in significant increase in habitat levels for plains killifish during the critical September period (Fig. 3). The Districts flow regime increases Index B habitat for this species by 37% (Fig. 3). As with sand shiners, habitat increases for plains killifish are even greater under the 80% exceedence conditions (Fig. 3). Plains killifish habitat increases by 71% during the September critical period.

CONCLUSIONS

The proposed alternative flow regime resulted in significant increases in modelled fish habitat in the central Platte River from the J-2 Return downstream to the lower study area boundary. Habitat increases of the magnitude seen with the alternative flow regime would be expected to result in increased populations of the fish species modelled in this section of the Platte River. The Districts flow regime moderates the yearly and monthly fluctuations in habitat and results in significant increases in habitat during the late-summer critical habitat period. These increases are especially important using the 80% exceedence values, which would represent low flow conditions. These changes should result in less fluctuations in population levels in both the short term and long term for fish populations in this portion of the Platte River system.

Portions of the area from the J-2 Return downstream are a nesting area for the endangered least tern, which feed primarily on small fish in the Platte River system. The Districts alternative flow regime significantly increases habitat for sand shiner, one of the dominant forage species. The alternative flow regime significantly increases critical summer habitat and should result in increased populations of the modelled species. In addition, reduced monthly and yearly fluctuations in habitat and flow levels should reduce fluctuations in fish populations. The alternative constitutes an enhancement of existing conditions and if implemented should lead to increased abundance of forage fish as well as reduced year-to-year fluctuations in their population size.

ACKNOWLEDGMENTS

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ALTERING FEDERAL CVP POWER OPERATIONS TO ACCOMMODATE FISHERIES' SURVIVAL ON THE SACRAMENTO RIVER

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Glen Youman[2]
David Coleman, Fellow ASCE, Member IEEE[3]

ABSTRACT

Balancing the needs of the river users, water and power users, and the fishery needs is a formidable task requiring sacrifices by all the users, particularly during this time of drought in California.

These drought conditions have existed in the Sacramento-San Joaquin Valley since 1986 further stressing the already reduced salmon populations. In order to help insure the survival of the salmon populations during the drought, releases of water have been made from Shasta Dam through lower elevation outlets (bypassing generators) to provide colder water for spawning and hatching of the salmon eggs.

This paper describes how Western Area Power Administration has assisted the Department of Interior from an energy replacement standpoint; emphasized and encouraged energy conservation; and assisted in the development of a long term plan to address Sacramento River fishery protection.

INTRODUCTION

When the Federal Central Valley Project (CVP) in California was authorized by Congress in 1937, it was designated a multi-purpose project. The main thrust of the project was to provide flood control, and

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water supply for irrigation. Other very important features included hydroelectric power production, M&I water, recreation, fish and wildlife and navigation. Major features of the project, including large dams and powerplants on the Sacramento and American Rivers, have been in operation for over 40 years. Great enhancements have been realized by most of the multi-purpose functions of the project. One exception appears to be in the area of anadromous fisheries--particularly, during periods of prolonged drought. The population of these fisheries, which had their spawning and migratory routes disturbed by the construction of water development projects such as the Shasta Dam on the Sacramento River and Folsom Dam on the American River, has not achieved desired levels particularly when lower river releases and higher temperatures have occurred. Although mitigation has been provided by both the Federal and State governments through hatcheries and other improvements, certain of these fisheries have now reached the poin. f being listed as a threatened or endangered species. The "winter-rı hinook Salmon", which is currently listed as a threatened (Federal)/eı dangered (State) species, reached a peak population in 1969 - there is no definitive data on Pre-CVP populations or even if the run existed prior to Pre-CVP.

The fisheries problem on the Sacramento and American Rivers and their tributaries continues to be exacerbated by the extended drought in California. As California moves into 1991 with only one-third of the fall and winter precipitation, it faces a fifth year of drought, which started in late 1986.

The fishery problems particularly those related to the anadromous fisheries (Chinook Salmons - winter, spring and fall runs and Steelhead Trouts) have received national attention. Both Federal and State fishery agencies are working cooperatively to save these fisheries and considerable efforts are being made to enhance their spawning habitats and increase the survival rate of these fisheries. These State and Federal fishery agencies have determined that during the eight to ten week incubation period when the fertilized salmon eggs (redds) are developing into small fish, they require temperatures that are no warmer than 56 degrees. These agencies have also determined that the eggs are most sensitive to elevated temperatures in the earliest development stage (fertilized pre-eyed eggs) and the survival of eggs decreases exponentially with increases in temperature of the water in the spawning areas. When these spawning areas are located downstream from a major dam and reservoir, such as from Shasta Dam on the upper Sacramento River and Folsom Dam on the American River, the temperature of the water that is released from these reservoirs will have a direct impact on the temperature of the water that flows through these spawning areas. In deep reservoirs, such as Shasta and Folsom, an adequate supply of cold water is normally available. However, because drought conditions have existed in California since the fall of 1986, reservoir levels are lower than usual and water temperatures are higher at reservoir levels where the intakes to the powerplant penstocks are located. At times, during the summer months, the water temperature at the powerplant penstock levels is too warm and releases downstream of this warmer water can cause harm to the spawning winter-run salmons that spawn during summer months. In order to compensate and provide colder water, the Bureau of Reclamation (Reclamation), in coordination with the Western Area Power Administration (Western), has been bypassing the Shasta generators and releasing colder water through the lower level outlets in Shasta Dam to maintain a lower temperature in the river. From 1987 through 1990, approximately 1,050,000 acre-feet of water has bypassed the generators and about 340 million kilowatthours of energy losses have occurred. This represents enough power to serve a city of 1 million people for about one month. This loss in energy requires Western to purchase replacement energy which to date has amounted to about $8.3 million in additional costs. As Western continues its role of cooperating with Reclamation and the fishery agencies in the development of a long term plan to enhance fishery production on the Sacramento and American rivers, Western will continue to place emphasis on the need for energy conservation as well as a fishery program.

DESCRIPTION OF THE CENTRAL VALLEY PROJECT

General Description

The CVP, located in the Central Valley Basin of California, extends nearly 500 miles in a northwest-southeast direction from near the Oregon border on the north to the Tehachapi Mountains on the south. It averages about 120 miles in width. The basin is surrounded by mountains except for a gap in its central western edge at the Carquinez Straits. The valley floor occupies about one-third of the basin, the other two-thirds are mountainous. The Cascade Range and Sierra Nevadas on the north and the east rise in elevation to approximately 14,000 feet and the Coast Ranges on the west to as high as 8,000 feet. The two major watersheds in the basin are the Sacramento Valley in the north and the San Joaquin Valley in the south. The Sacramento River and its tributaries flow southward, draining the northern portion of the basin. The San Joaquin River and its tributaries flow northward, draining the central southern portion. The two river systems join at the Sacramento-San Joaquin Delta flowing through the Suisun Bay and the Carquinez Straits into San Francisco Bay and then out the Golden Gate to the Pacific Ocean. The average annual natural runoff of the basin for the 30-year period beginning in 1903 was about 33,000,000 acre-feet, 22,000,000 acre-feet of which originated in the Sacramento River watershed. The Sacramento River system, the more important system of the two in a coordinated operation, has a maximum annual runoff on record of over 43,000,000 acre-feet and a minimum on record of about 9,200,000 acre-feet.

Project Facilities

The CVP consists of over 10 major dams and reservoirs, including two in the Trinity River Basin, five in the Sacramento River Basin, two on the American River and one on the Stanislaus. Total generating capacity is approximately 2,000 MW's. In addition, the Federal government, in a joint arrangement with the California Department of Water Resources, operates two pump storage facilities at San Luis and O'Neill, with a generating capacity of approximately 450 MW's. Although these facilities were constructed primarily to store and convey water for irrigation and flood control, power production has taken on great importance over the past 30 years because hydroelectricity has proven to be very economical and has not had the environmental problems of other power generating facilities, such as nuclear or coal-fired steam, have had. In addition to the powerplants, the Federal government constructed substations, switchyards and high voltage transmission lines to transmit the CVP power to points of interconnection with other electric utilities in northern and central California for distribution to its power customers. Also, in the mid-1960's arrangements were made for a new Pacific Northwest-Southwest Intertie to transmit surplus power from the northwest and Canada to California. The Federal government is part owner of this 500 kV AC line and Western has the responsibility of maintaining the line and purchasing surplus power from the northwest and supplying this power as a supplement to CVP generation.

Role of the CVP Hydropower Generation in California

Federal power was first generated at Shasta Dam in 1944 and to date Shasta has generated in excess of 90 billion kwh of electricity. Also, since 1950 other power features of the CVP have generated in excess of 60 billion kwh and some 85 preference power customers in northern California have come to depend on CVP hydropower resources to provide their basic electrical needs. A preference power customer is generally defined as a non-profit entity such as a public utility district, municipal utility district, an irrigation district, or a Federal or a State agency. Western markets over 1,450 MW's and 8 billion kwh annually to its preference customers plus an additional 250 MW's and associated energy for CVP pumping loads (project use). Repayment provisions of the CVP are dependent on revenues received from the sale of power from the project. Federal power is not subsidized but is sold on a cost-based formula. Consequently, when changes in the operation of the project, such as cold water fishery bypass releases occur, then as a general rule, there is an increase in the cost of CVP power that must be repaid by either the power customers or other CVP multipurpose users or the Federal government.

CVP Power Cost

The various hydro projects throughout Western were constructed primarily during the 1935-1970 era and consequently hydroelectric power is sold at rates that reflect those relatively low construction costs. CVP power is sold by Western to its preference power customers at a current composite rate of about 29 mills per kwh. The energy component is valued at approximately 16 mills per kwh. While this price is substantially higher than other Federal projects in the western U.S., it is still comparatively lower than the price for wholesale power which the public utilities and irrigation districts would be paying if they purchased their power from investor owned utilities or most other suppliers in northern California. Because of this price differential, CVP power is a very attractive resource in northern California.

Future Power Shortage Predicted

A major factor in looking at the potential reduction in CVP generation for purposes such as additional mitigation or fish enhancement, is the future need for, and growth in power demands. From where will this additional power be supplied? The North American Energy Reliability Council (NERC) studies of 1990 show that the United States will experience growth or/need for 85,000 MW's of additional power to meet load growth and the retiring of existing power facilities by the year 2000.

Conventional generation currently under construction, or in various planning stages, amounts to approximately 20,000 MW. Consequently, additional conventional or non-conventional generation or a redirection in usage or conservation will be needed in order to avoid brown outs and black outs, or major shifts in industry from region to region. Because of this prediction, it behooves the government to carefully evaluate its plans in terms of reducing its own power generation in order to enhance some other objective of the project.

PRESENT AND FUTURE ACTIONS TO ENHANCE THE FISHERIES

Importance of the Central Valley Fisheries

There are over 30 game fish species in the Central Valley that are popular with sportsmen. However, only four major species (all anadromous) are of significant value to the commercial fishing industry. All four species of anadromous fish, which consists mainly of the four races of the Chinook Salmon, use the Sacramento and American Rivers for spawning and propagation. Several hatcheries are located in these river systems or tributaries to mitigate for the construction of both Federal and State dams. Both the Federal and State fishery agencies have recorded evidence of a major decline in the available commercial fishery.

They have also predicted substantial loss to the commercial fisheries with the possible extinction of the winter run salmon if drastic measures are not taken to insure their survival.

What Is Being Done

Western, in cooperation with Reclamation and other Federal and State agencies, has been involved in the process of bypassing water through the lower level outlets at Shasta Dam and foregoing the generation. This is only for an initial period until some permanent solution can be achieved. While it is true that the drought has greatly exacerbated the problem, it appears that even when the drought is abated, and normal rainfall and run- off/storage returns, colder water will still be needed to maintain desired cooler temperatures in the Sacramento River spawning area.

Long Range Solution

Reclamation, in cooperation with Western is refining the design for a temperature control device (TCD) which would be installed at Shasta Dam. The TCD will be a shutter arrangement and will allow water to be withdrawn from various levels of the reservoir to provide the desired water temperature of down stream releases. Both colder and warmer water release could be made to effect the best conditions for fish propagation. Funding for the TCD, which is estimated between $50 and $60 million, would be shared by the water and power users and it is now hoped that this device would be in place for use by 1993. Other measures are being explored by Reclamation and fishery agencies for long term protection of the anadromous fisheries in the Sacramento and American Rivers. Additional releases are being contemplated from other tributaries and rivers such as Trinity, Clear Creek and Stanislaus. If these additional releases are found to improve fishery conditions and losses of power generation were to occur, Western, in a cooperative effort, would make up the loss with power purchases in a manner to limit the impact on its power customers and power rates.

SUMMARY AND CONCLUSION

Western recognizes that power production is only one of the multi-purposes of the CVP, and that the protection of fish and wildlife, the environment and other functions are also priority functions of this great multi-purpose project. However, Western is also committed to providing its preference power customers with a reliable and economical source of power consistent with good business-like principles. By working together with its sister Federal agencies, State agencies and local entities we believe that these goals can be achieved.

SALMON AND STEELHEAD COUNTS, RED BLUFF DIVERSION DAM SACRAMENTO RIVER

YEAR		FALL	LATE FALL	WINTER	SPRING	TOTAL SALMON	STEEL HEAD TROUT
1967	a,b	89220	32891	57306	23441	202858	13011
1968	b,c	122095	35632	84414	14817	256958	17416
1969	b,d	133815	8899	117808	26471	286993	13648
1970	b	80935	23203	40409	10264	154811	11590
1971		63918	16741	53089	5830	139578	10876
1972		42503	32651	37133	7346	119633	5641
1973		53891	23010	24079	7762	108742	7978
1974	e	54952	7855	21897	3933	88637	6101
1975		63091	19659	23430	10703	116883	5205
1976		60719	16198	35096	25983	137996	8196
1977	f	40444	10602	17214	13730	81990	5928
1978		39826	12586	24862	5903	83177	2467
1979		62108	10398	2364	2900	77770	3487
1980		37610	9481	1156	9696	57943	10994
1981		53744	6807	20041	21025	101617	2898
1982		48431	4913	1242	23438	78024	2394
1983		42096	15190	1831	3931	63048	3150
1984		73254	7163	2663	8147	91227	1969
1985		97707	8436	3962	10747	120852	4404
1986		104873	8286	2464	16691	132314	3358
1987		103063	16049	1997	11204	132313	2809
1988		139966	11597	2094	9781	163438	1796
1989		84057	11639	533	5255	101484	432
1990		55710	7305	441	3922	67378	2322
10-YR AVR (1981-90)		80290	9739	3727	11414	105170	3420

a: 8-hour counts, adjusted for 14-hour counting period (x 1.75).

b: Counts reconstructed for late fall, winter and spring runs by adjusting actual fish counts to respective run components each week using 1971-82 averages. Fall chinook counts are spawning stock estimates above Red Bluff Diversion Dam.

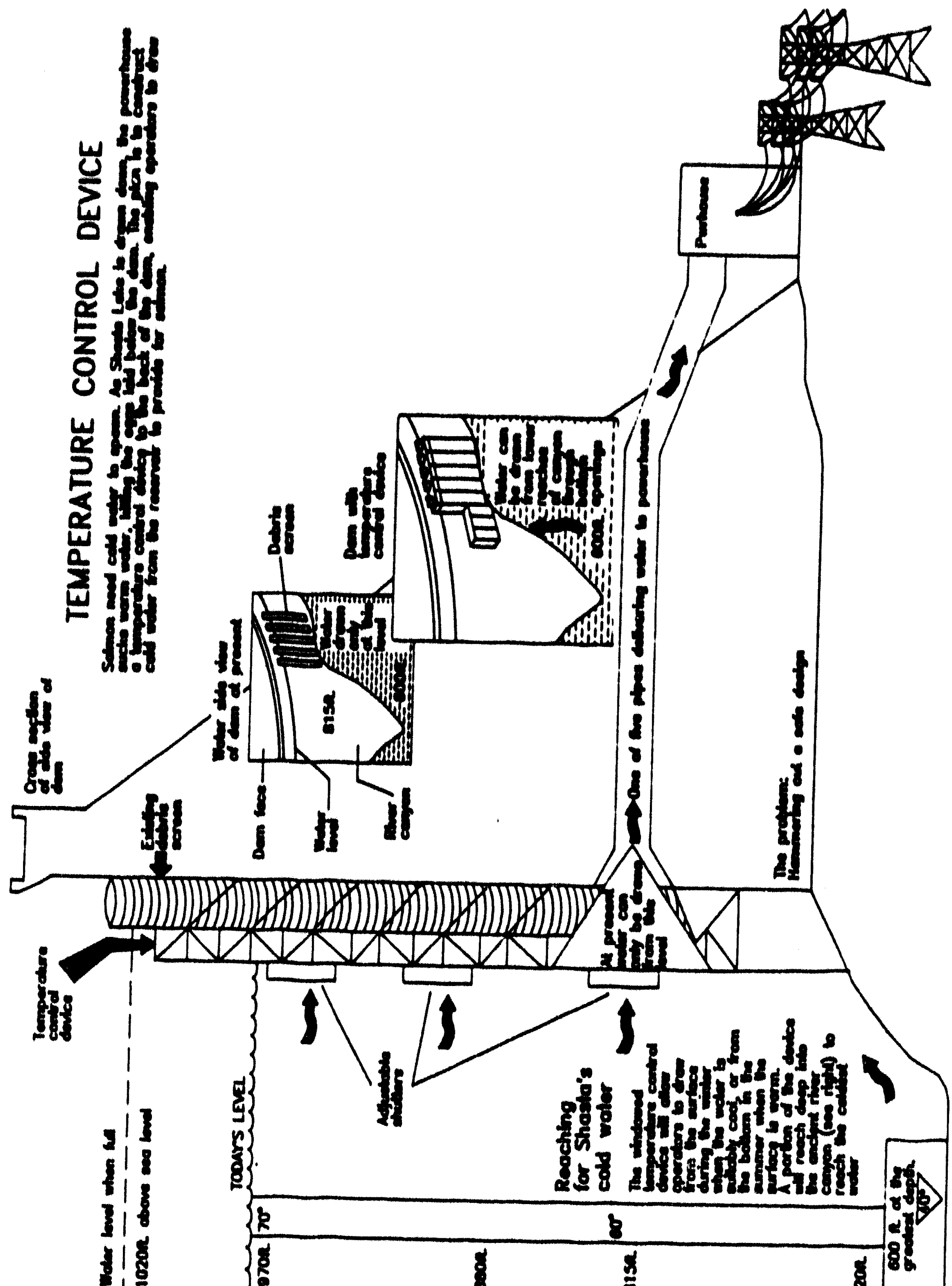
c: Winter chinook adjusted for missing counts (actual count 61369). Steelhead adjusted for missing counts (actual count 6389).

d: Fall chinook count unadjusted (21 weeks of missing counts due to high flows). Winter chinook adjusted for missing counts (actual count 80934).

e: Fall chinook count unadjusted (6 weeks of counts missing).

f: Less 1625 spring and 20539 fall chinook trapped and transported to tributaries and hatcheries because of the drought.

RBDDFISH 1/28/91 (U.S. Fish and Wildlife Service)


TEMPERATURE CONTROL DEVICE
Salmon need cold water to spawn. As Shasta Lake is drawn down, the powerhouse sucks warm water, killing the eggs laid below the dam. The plan is to construct a temperature control device to the back of the dam, enabling operators to draw cold water from the reservoir to provide for salmon.
Temperature control device
Cross section of side view of dam
Water level when full
1020ft. above sea level
Existing debris screen
TODAY'S LEVEL
970ft.
70°
880ft.
815ft.
60°
720ft.
600 ft. at the greatest depth.
40°
Adjustable shutters
Reaching for Shasta's cold water
The windowed temperature control device will allow operators to draw from the surface during the winter when the water is suitably cool, or from the bottom in the summer when the surface is warm. A portion of the device will reach deep into the ancient river canyon (see right) to reach the coldest water
At present water can only be drawn from this level
One of five pipes delivering water to powerhouse
The problem: Hammering out a safe design
Water side view of dam at present
Dam face
Water level
River canyon
815ft.
Debris screen
Water drawn only at this level
800ft.
Dam with temperature control device
Water can be drawn from lower reaches of canyon through bottom openings
800ft.
Powerhouse

COLD WATER BYPASS RELEASES FROM SHASTA DAM

Year	Bypass Releases Months/(Days)	Bypass Releases 1,000 AF	Energy Losses at Tracy (GWh)	Replacement Energy Cost $\$10^6$
1987	Aug (7), Sept (15)	157	52	0.9
1988	Jul (11),Aug (31), Sept (17)	395	130	3.4
1989	Aug (20), Sept (28)	203	63	1.9
1990	May (7)[1], Jul (20), Aug (31), Sept (30), Oct (5)[2]	296	92	2.1
1991 (Projection)	May (10), Jul (15) Aug (30), Sep (30)	890	230	6.9[3]

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1 Warm water releases were made in May to encourage several radio tagged fish to move further up stream so their spawning area would be in the section of the river where colder water caused by bypass releases would be available.

2 Bypass releases were made in October to provide protection for the Fall run salmons which are not threatened or endangered, but are the larger run for commercial fishery.

3 Replacement energy cost is estimated at $0.03/kwh.

CENTRAL VALLEY PROJECT
HYDROPOWER PLANTS DATA

Plant Name	Operating Agency	River	Date In Service	Maximum[2] Operating Capability MW[3]	Average Annual Net Generation[10] GWH
Carr	BuRec	Lewiston Tunnel	1963	154.0	471.2
Folsom	BuRec	American	1955	215.0[4]	608.9
Keswick	BuRec	Sacramento	1949	90.0	451.9
Nimbus	BuRec	American	1955	14.0	70.1
O'Neill	BuRec	San Luis Creek	1967	29.0[5,6]	3.1
San Luis	CA[1]	San Luis Creek	1968	202.2[5,7]	130.4
Shasta	BuRec	Sacramento	1944	578.0	2030.4
Spring Creek	BuRec	Clear Crk. Tun.	1964	200.0[8]	531.8
Trinity	BuRec	Trinity	1964	140.3[9]	447.7
New Melones	BuRec	Stanislaus	1979	383.0	448.4
Stampede	BuRec	Little Truckee	1986	3.3	6.7

Total Maximum Operating Capability - MW:	2,008.9
Total Number of Plants:	11
Total Net Generation - GWH:	5,200.6

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1 Operated by State of California for BuRec.
2 Recalculation of maximum operating capability in cooperation with BuRec and Corps.
3 Maximum operating capability is defined as the maximum generating capability of the units at unity power factor without exceeding the specified heat rise on each unit and independent of water constraints. See individual footnotes for clarification.
4 Operating head limits operation to 210.2 MW.
5 Reversible pump/generation.
6 Turbines limit operation to 25.2 MW.
7 Eight 53 MW unites for a total installed capacity of 424.0 MW of which the BuRec share is 202.2 MW.
8 Capacity limited to 192 MW by tunnel restrictions.
9 Includes 350-kW Powerplant at Lewiston Dam.
10 Net generation amounts shown reflect total generation at powerplant less plant use. These amounts are based on current operating limits and 56 years of hydrogical data, but have not been reduced to reflect priority uses such as project use and irrigation pumping.

Twin Falls Mitigation Plan: Long Term Monitoring of Fish Populations

Allan C. Solonsky[1]
Phillip J. Hilgert[2]

The Twin Falls Hydroelectric Project diverts water from a one mile reach of the South Fork Snoqualmie River in Washington State. The developer, Twin Falls Hydro Associates (TFHA) has agreed with state, federal and tribal agencies to maintain a minimum flow of 75 cfs (2.1 m^3/s) or natural flow, whichever is less, through the bypass reach for nine months of the year, August through April, in order to protect resident trout rearing habitat. On an interim basis, during the months of May, June and July, an instream flow of 150 cfs (4.2 m^3/s) is required to protect resident trout spawning habitat. In order to obtain lower minimum flows during May, June and July, TFHA has agreed with the Washington Department of Wildlife, Tulalip Tribe and U.S. Fish and Wildlife Service to conduct a fishery monitoring and enhancement plan.

According to the Twin Falls Mitigation Plan (TFMP), instream flows may be reduced to 75 cfs (2.1 m^3/s) during May, June and July if surveys indicate that numbers of trout in areas affected by the project are not significantly lower than pre-project levels. Flows may also be reduced if TFHA's efforts at stream habitat improvement are shown successful through monitoring of fish populations, i.e. enhancement efforts are shown to compensate for any reduction of resident trout numbers in areas affected by the Project. Modification of the instream flow regime would take place following two years of post-project monitoring.

Index sites were selected in 1984 to represent the dominant habitat type in each of the treatment areas, i.e. bypass, diversion, control and enhancement (Figure 1). The bypass site will be affected by reduced flows and is within the reach where agencies and tribes requested spawning flows. The diversion site is located where the diversion weir inundates a portion of the existing river channel and creates a small pool immediately

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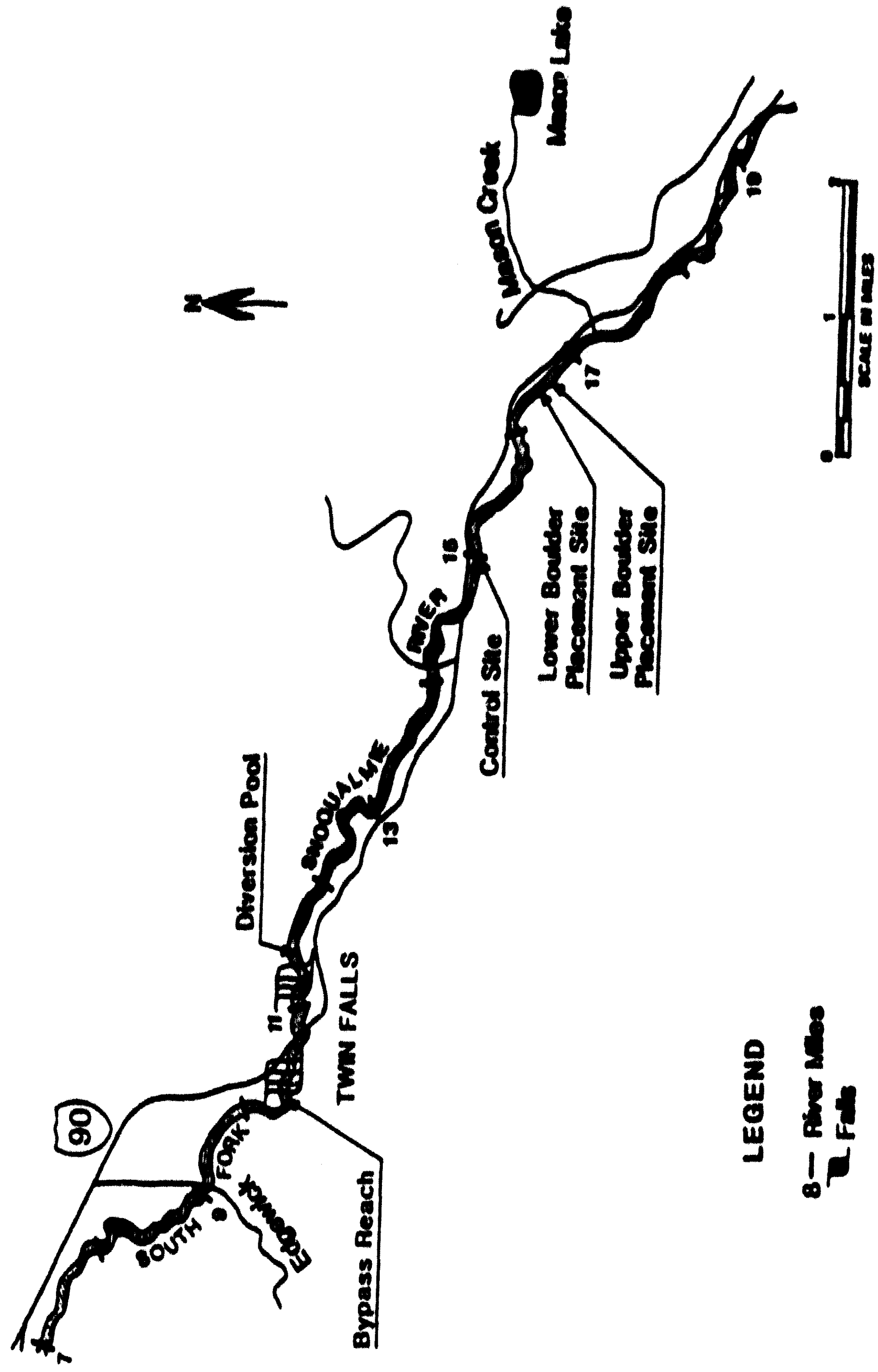

FIGURE 1. Twin Falls Mitigation Plan Study Sites

upstream of the weir. The enhancement, or boulder placement site is located upstream of project facilities and has been severely impacted by channelization for highway construction. This site could potentially demonstrate positive fishery response to habitat improvement. The control site was selected to serve as a reference to natural trends in fish populations in the watershed and an index to non-project related factors.

To estimate the abundance and size frequencies of trout within each study site, five years of pre-project population surveys were conducted from 1984 thorough 1988. Snorkel surveys were conducted in mid-June, mid-July and late August of each year in an effort to account for seasonal variation related to fishing pressure. In order to calibrate snorkel surveys, electrofishing was conducted following the August survey. Due to variability in fry densities, population estimates were developed from fish larger than 3 inches (7.5 cm) in length. Pre-project monitoring was completed in 1988 and baseline population levels of resident trout were established at all study sites. In the fall of 1988, following the completion of all pre-project data collection, approximately 100 boulders three feet in diameter were placed in the preselected enhancement stream reach.

Post project surveys began in 1990 and will continue until testing of the following two hypotheses can be answered; H1: There is no change in numbers of fish in reaches affected by the project, and H2: There is no change in trout numbers in the boulder placement reach. To test each hypothesis, target values were determined for the project's affected sites and enhancement site, based on the pre-project population estimates and a confidence interval of one standard deviation. Ultimate acceptance or rejection of the hypotheses depend on a determination of an overall no net loss of fish in the combined project and enhancement areas.

While the TFMP is conceptually straight forward, natural temporal and spatial variation in fish populations has presented a challenge to the accurate assessment of project-related impacts. The allowable statistical variance (one standard deviation) in determining the no net loss criteria was broad but acceptable to all parties involved.

Mercury in Fish and Water in New Impoundments
A Review of the Literature

David B. Pott[1/]

Abstract

Evidence to date indicates that only one metal, mercury, systematically bioaccumulates to ecologically significant concentrations as a direct result of impoundment. This bioaccumulation results from microbial methylation of naturally occurring mercury in the topsoils of newly flooded reservoirs. The organic and nutrient content in the topsoils and temperature appear to strongly influence the rate of methylation and bioaccumulation.

Introduction

In the 1960's and 1970's, it was reported that fish from unpolluted lakes sometimes contained high concentrations of mercury (Hg). Fish from these uncontaminated lakes have been found to have muscle Hg concentrations exceeding 2 μg/g, well above the US Food and Drug Administration's action level of 1 μg/g (Lathrop, et al. 1989, Bodaly, et al. 1984). Gradually, it became clear that these instances are representative of either low-alkalinity lakes receiving acid deposition, or, new impoundments (Wiener and Stokes 1990). The latter are the topic for this review.

The Mercury Cycle

The form or species of Hg greatly controls the metal's environmental behavior and toxicity. Atmospheric Hg is generally elemental, but photo-oxidation occurs in the atmosphere, producing mercuric ion (Hg[II]) that is scavenged by precipitation (Lindqvist and Rodhe 1985). In terrestrial and aquatic environments, Hg[II] strongly favors association with

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particulates (Moore and Ramamoorthy 1984), both organic and inorganic. However, dissolved organic carbon in lakes and streams, notably humic substances, will bind Hg[II] (Schnitzer and Kerndorff 1981, Kerndorff and Schnitzer 1980). Hg[II] can also be reduced to elemental Hg, which is volatile and can return to the atmosphere, or, be precipitated as mercuric sulfide (HgS) in anoxic environments.

Hg is generally bioaccumulated in the methylated form (MeHg), as methylmercury or dimethylmercury, in aquatic environments. The latter is a neutral molecule and can therefore be volatilized. Hg[II] is methylated by microbial action in aerobic and anaerobic environments (Jensen and Jernelov 1969). Methylation has been reported to occur both in the water column as well as in sediments (Winfrey and Rudd 1990). In general, conditions enhancing the metabolism of soil and aquatic microorganisms will enhance mercury biomethylation. Demethylation of MeHg is also mediated by microorganisms and results in the formation of elemental Hg and methane (Begley et al. 1986).

Mercury Methylation in New Impoundments

Several researchers have shown mercury levels in aquatic biota to increase following impoundment and reservoir formation (Abernathy and Cumbie 1977, Abernathy et al. 1985, Bodaly et al. 1984, Cox et al. 1979, Meister et al. 1979). The source of this mercury is the inundated soils. Bodaly et al. (1984) implicated organic topsoil horizons as the major source of bioaccumulated mercury in the northern Manitoba Churchill River Diversion Project. Rudd et al. (1983) studying industrially produced Hg in a northwest Ontario river system reported that most Hg in the system was buried below surficial sediments (in organic-poor material); they found that this Hg probably did not contribute significantly to Hg biomethylation, which was found to occur primarily in the water column and surficial sediments.

Researchers studying a Savannah River reservoir in South Carolina and Georgia prior to, during, and after impoundment found that the percent of total Hg occurring as MeHg increased slightly following impoundment (Abernathy et al. 1985). These same researchers found Hg mobilization from the flooded soil into the reservoir hypolimnion increased concentrations of Hg there, relative to the epilimnion. When the hypolimnion became anoxic, total Hg dropped nearly two orders of magnitude, suggesting that Hg precipitated out of solution as mercuric sulfide (HgS); this was confirmed by analysis of a sediment core.

Cox et al. (1979) and Meister et al. (1979) studied Hg levels in fish and soils in and around a two-year old water supply reservoir in southern Illinois. They found Hg levels in the lake bottom sediments to be well below nearby terrestrial soil, and the shoreline soils to be at intermediate levels. These authors concluded that soil Hg is insoluble, but can enter the food chain through microbial action in the aquatic environment.

The mobilization of Hg from soils flooded by new impoundments apparently is greatest upon initial reservoir filling, and decreases as the reservoir ages. Abernathy and Cumbie (1977) studied three adjacent reservoirs of different ages in the upper Savannah River basin, and found the youngest, most upstream of the three had the highest levels of Hg in largemouth bass (Micropterus salmoides) tissue. Other data complimented this observation and the authors concluded that elevated Hg levels in fish from new impoundments are a transitory phenomenon, declining within three to five years after reservoir filling.

In a study of Hg speciation in several California freshwater systems, Gill and Bruland (1990) found Hg entering Davis Creek Reservoir to be primarily inorganic Hg. In the reservoir water however, the speciation of Hg was largely particulate Hg or dissolved organic Hg. Dissolved inorganic Hg was lost to sedimentation in the reservoir.

Concentrations in Reservoir Waters and Fish

None of the new reservoirs where increased fish Hg levels have been demonstrated had water concentrations of Hg higher than typical of most US surface waters. The increased Hg burdens in fish are from mobilization of Hg from newly inundated soils. The magnitude of the increase is directly related to the flooded area of the new impoundment and the quality of the topsoil.

This was clearly demonstrated by Bodaly et al. (1984) in their study of the Churchill River Diversion Project in northern Manitoba. Southern Indian Lake was increased in area by 21% in 1976; northern pike (Esox lucius) and walleye (Stizostedion vitreum) muscle Hg levels increased from baseline values of 0.2 to 0.3 μg/g to 0.5 to 1.0 μg/g in 1978-82. Rat and Notigi lakes were increased in surface area by 282%; walleye muscle Hg levels averaged 1.1 to 2.9 μg/g in 1978-1882. Nearby lakes that were not flooded by the project did not show any increase in fish muscle Hg concentrations. Bodaly et al. did not observe declines in these mean levels eight years after flooding. They hypothesized the observed fish mercury level increases were due to bacterial methylation of naturally occurring Hg in flooded soils.

Data extracted from published studies on Hg accumulations in largemouth bass taken from new impoundments are tabulated and discussed in more detail below. Although insufficient data exists for rigorous comparisons of these results, some trends can be seen, such as the rapidity with which the process occurs and the decrease in fish Hg burdens with impoundment age.

Abernathy and Cumbie (1977) studied Hg bioaccumulation in the Savannah River reservoirs Hartwell, Keowee, and Jocassee. In downstream to upstream sequence, these reservoirs were impounded in 1962, 1970, and 1973, respectively. Hg muscle concentrations in largemouth bass collected in 1973-1975 decreased with reservoir age, and increased with fish size. Total Hg in Lake Hartwell largemouth bass ranged from 0.38 to 0.68 μg/g. Immediately upstream of Hartwell is Lake Keowee, where largemouth bass had muscle concentrations of 0.58 to 3.99 μg Hg/g for the same size fish. Above Keowee, Lake Jocassee had Hg concentrations of 1.87 to 4.49 μg/g for the same size largemouth bass. Mercury concentrations in Lake Jocassee water and its tributaries were generally less than 0.1 μg/L; Lake Jocassee sediment Hg levels were typically 0.04 μg/g.

In another study of a new Savannah River impoundment, the Richard B. Russell Reservoir, Abernathy et al. (1985) found largemouth bass muscle Hg concentrations increased from an average baseline level of 0.16 μg/g to post-impoundment mean level of 0.54 μg/g just months after reservoir filling.

Lake Powell, a large impoundment of the Colorado River, filled during the period 1963 to 1971. During 1971 and 1972, Potter et al. (1975) collected fish and water samples for analysis, and, reported Hg levels in largemouth bass muscle ranging between 0.19 and 0.69 μg/g, while total Hg in reservoir water samples was about 10 ng/L.

Davis Creek Reservoir in California completed filling in 1986. Gill and Bruland (1990) studied Hg speciation in, upstream of, and downstream of that reservoir. An abandoned Hg mine adjacent to the stream produced total Hg concentrations of 12 to 34 ng/L in Davis Creek feeding the reservoir. Reservoir total Hg was measured to be about 6 ng/L, about half of which was dissolved organic Hg.

MERCURY IN LARGEMOUTH BASS (_30 cm) OF NEW IMPOUNDMENTS

Impoundment	Surface Area (ha)	Year Impounded	Year Sampled	Average Total Hg in Fish Muscle (µg/g)	Reference
Lake Powell	65,300	1963-71	1971-72	0.31[1/] (0.19-0.69)[2/]	Potter et al. 1975
Cedar Lake	710	1976	1975	0.49 (0.11-0.81)	Cox et al. 1979
Lake Hartwell	22,800	1962	1973-75	0.38	Abernathy and Cumbie 1977
Lake Keowee	7,500	1970	1973-75	0.58	Abernathy and Cumbie 1977
Lake Jocassee	3,000	1973	1973-75	1.87	Abernathy and Cumbie 1977
Russell Lake	10,800	1984	1984	0.54[3/]	Abernathy et al. 1985

[1/] Concentrations of Hg in various fish size classes was not reported and the concentrations shown reflect all largemouth bass sampled.

[2/] Range.

[3/] No correlation was found between fish size and total Hg concentrations. Hg concentration shown is average of all largemouth bass sampled.

Mitigation Measures

Permitting requirements for new impoundments generally require mitigation plans for anticipated adverse environmental effects. Hg levels in edible fish flesh will increase following impoundment; the degree and rate to which this will occur will depend upon site specific factors such as inundation area, climate, water quality, soil type, etc. Several studies have shown the increased Hg levels in fish to exceed the US Food and Drug Administration action level of 1 μg/g. If the impoundment is expected to become a fishery, measures may be warranted to mitigate the potential public health effects of consuming these fish.

During construction, clearing of vegetation and topsoil in the reservoir inundation area should minimize the potential for Hg methylation and bioaccumulation. Conditions enhancing the metabolism of aquatic organisms, like nutrients and organic substrates, generally enhance Hg biomethylation. Wright and Hamilton (1982) showed an increase in microbial nutrients in sediments resulted in higher rates of Hg methylation. Rudd and Turner (1983b) demonstrated increased Hg bioaccumulation with increased primary productivity. Hence, minimizing aquatic microorganism activities should reduce biomethylation and accumulation.

Rudd and Turner (1983a) studied Hg bioaccumulation in large *in situ* enclosures and found that addition of organic-poor sediment to the enclosures decreased the rate of Hg bioaccumulation by 8 to 16 times. This was apparently due to the binding of Hg to the inorganic particles making the Hg less available for methylation. Although much research is needed in the field of Hg depuration, Turner and Rudd (1983) and Turner and Swick found that bioaccumulation of selenium (Se) in fish resulted in concomitant reductions in body burdens of Hg.

Clearing of topsoil from reservoir inundation areas is generally cost prohibitive for large impoundments. Addition of clays or Se to impoundments will likely have environmental effects more adverse than the fish Hg levels. Until further research uncovers new depuration techniques, mitigation should focus of an evaluation of the potential for Hg bioaccumulation, monitoring of Hg levels in fishes targeted by anglers and commercial fishermen, and, if necessary, issuance of fish consumption advisories until fish Hg levels fall below the FDA action level.

Acknowledgements

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Relative Survival of Juvenile Chinook Salmon Through Bonneville Dam On The Columbia River

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Abstract

Preliminary results of a multiple year study indicate that juvenile chinook salmon passing through the juvenile bypass system at Bonneville Dam second powerhouse during the summer have significantly lower survival rates compared to other treatment groups (upper and lower turbine, spillway, and downstream control). The spillway groups had the highest survival rate, followed by the downstream, frontroll, turbines, and finally, the bypass groups. There was no significant difference between the survival rates of the upper and lower turbine groups. Estimates of long term survival using adult returns are incomplete at this time. However, both the juvenile and adult data indicate that passage through the juvenile bypass system versus the turbines does not improve the survival of subyearling juvenile chinook salmon.

Introduction

Bonneville Dam is located at river mile 146 on the Columbia River, approximately 40 miles east of Portland, Oregon (Fig. 1). The first powerhouse was completed in 1938. A second powerhouse was added in 1983 to provide additional plant peaking capacity. Other features of the site include a navigation lock, spillway, adult and juvenile fish passage facilities at each powerhouse, the Bonneville Fish Hatchery (salmon rearing facility), and visitor facilities. All of these features were designed and built by the Corps of Engineers, Portland District, North Pacific Division.

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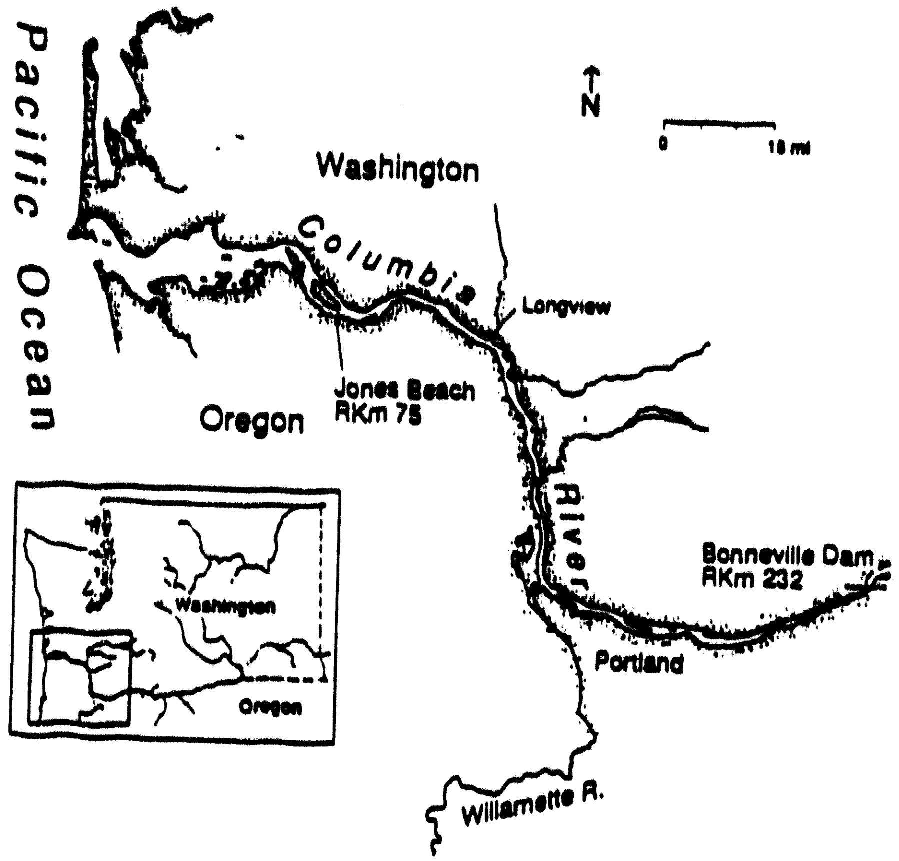

Figure 1. The lower Columbia River showing the location of Bonneville Dam

The Corps of Engineers (COE) has designed and constructed adult salmon passage facilities into each of the eight Columbia River dams operated on the mainstem Columbia river. The COE has also funded an extensive program to retrofit four of these powerhouses with juvenile bypass systems to provide protection to downstream migrating juvenile Pacific salmon (Oncorhynchus sps). In addition, juvenile salmon passage facilities were included in the original design of the two most recent powerhouses, Lower Granite Dam and the Bonneville second powerhouse. Since Bonneville second powerhouse was the most recent powerhouse constructed, its juvenile bypass system design incorporated the cumulative knowledge gathered from juvenile bypass research funded by the Corps of Engineers during the last 20 years.

The Bonneville second powerhouse juvenile bypass system is comprised of one 20' submersible traveling screen (STS) in each intake of all eight turbines, for a total of 24 screens. These screens set up a hydraulic cushion which deflects downstream migrating juvenile salmon away from the turbine intakes and into vertical bulkhead slots. Once in the vertical slots the fish exit on their own volition through 12" orifices into a collection gallery which travels the length of the powerhouse and transports the fish exiting the orifices to a dewatering station. Here a subsample of the fish population is taken for the purpose of monitoring the migration, and a majority of the bypass flow is removed through an inclined dewatering screen. The remaining 200 cfs travels down a buried 36" diameter pipe at 18 to 29 fps and discharges through an underwater outlet structure in the tailrace. The release site was designed to provide optimum survival conditions through the use of 3.5 fps ambient river flow past the outlet structure to reduce predation. Also, the outlet structure is located approximately 20' to 48' under the surface elevation of the tailrace and near the middle of the tailrace. Adjacent turbine units are operated to provide flows past the outlet structure to improve the survival of juveniles eggressing the bypass system.

In 1983 the Corps funded the National Marine Fisheries Service (NMFS) to conduct a routine evaluation of the bypass system to ensure the system was functioning properly. This included the condition of the fish being bypassed as well as the efficiency by which the STS's were guiding fish away from the turbines.

The NMFS research conducted on the bypass system since 1983 has shown that the efficiency of the STS's was initially poor for all species. Typically a guidance efficiency of 70% during the spring and 50% during the summer migrations is acceptable according to regional fisheries agencies and Indian Tribes. However, at Bonneville second powerhouse, the guidance of the subyearling (zero aged) juvenile chinook migrating in the summer was 24%. The yearling aged spring migrants responded favorably to modifications to the guidance screens. Three test devices were found to significantly increase the guidance of spring migrants into the bypass system from 19% to roughly 67%. While these devices worked well to improve the guidance of spring migrants, they did not improve the guidance of the summer migrants beyond the original 24%.

As a result of the poor guidance of subyearling chinook into the bypass system at Bonneville second powerhouse, most of the juvenile subyearling salmon would pass through the turbines if the powerhouse were operated during the summer. These fish did not respond to any bypass improvements and our knowledge regarding the survival rates of these fish through various passage modes at Bonneville Dam was limited. Therefore, further information was needed to make operational decisions which would afford protection for subyearling salmon.

The Corps of Engineers funded NMFS to conduct a multiple year evaluation of the comparative survival of juvenile subyearling chinook salmon through various passage modes at Bonneville Dam. The study was designed to examine both juvenile and adult data The ultimate goal of the study was to provide definitive scientific information regarding the survival rates of the test fish through the various passage routes (turbines, spillway, and bypass). Using this information, operational scenarios could then be formulated to provide additional juvenile protection while meeting power system demands.

Methods

The evaluation was designed to estimate both short and long term survival rates. Short term relative survival was based on recoveries of marked fish just above the Columbia River estuary and approximately 157 km downstream from Bonneville Dam. Long term relative survival will be based on the returns of tagged (coded wire tagged) adult fish to the ocean fisheries, Columbia River fisheries, and Columbia River hatcheries.

The estuary sampling of the marked juveniles provided information on the success of the various release strategies by comparing recovery percentages. This sampling was also designed to identify differences among treatment groups which might compliment observations of recovery differences or reveal influences which are unrelated to the effect of passing the route tested. The short term recoveries were included in the study design to provide survival information immediately and to ensure that the release sites were properly designed and functioning correctly.

Approximately 2.2 million subyearling upriver bright fall chinook salmon were reared each year of the juvenile component of the study (1987-1990) at the Bonneville Fish Hatchery, operated by the Oregon Department of Fish and Wildlife. The fish were reared to a release size to match the main production from the hatchery (45-75 fish/lb and 83 to 99 mm at release). Test fish were marked prior to release using two fish marking crews. Special measures were taken to ensure that marked groups did not differ in fish size, condition, rearing history or mark quality. Each marked group had a unique coded-wire tag. Cold brands were used to visually identify recovered fish from the various treatment groups.

Six release sites were tested:

1. upper turbine
2. lower turbine
3. bypass system
4. turbine frontroll*
5. spillway
6. downstream (mid-river)

* frontroll is the downstream side of the upwelling turbine boil

The downstream site was located approximately 2.5 km downstream from the dam (Fig. 2). The site was assumed to be downstream from the effects of the dam and located mid-river to be away from the effects of shoreline oriented predators such as northern squawfish (*Ptychocheilus oregonensis*).

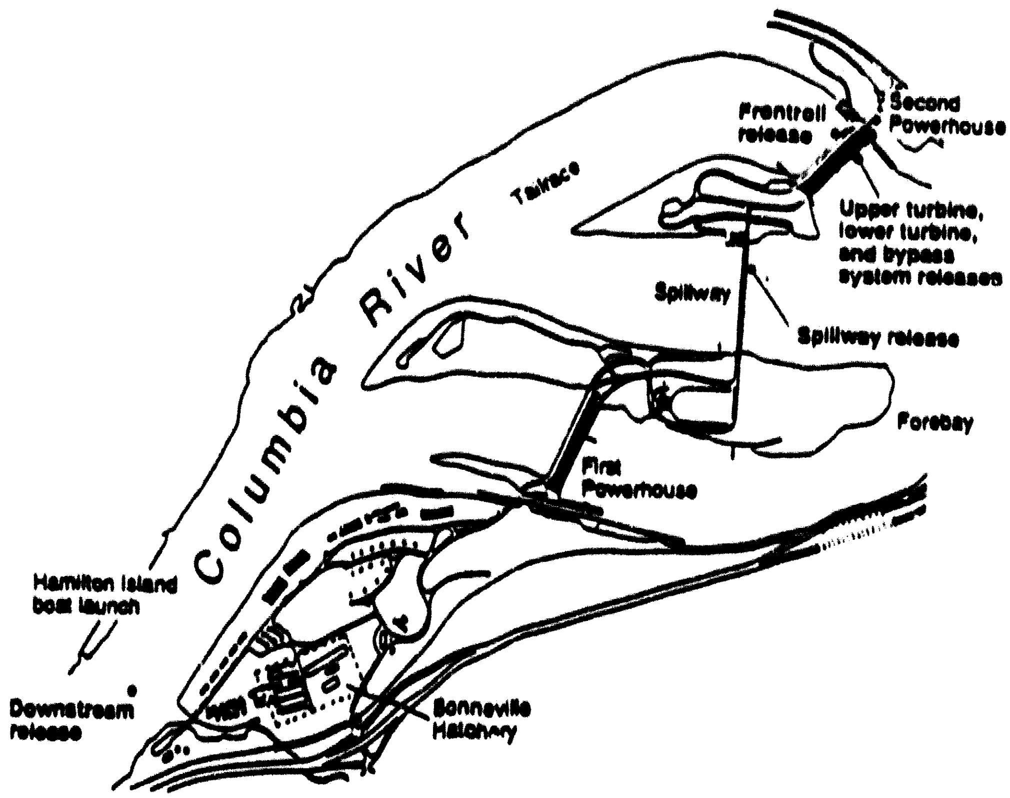

Figure 2. Release locations for the Bonneville survival study.

During the tests turbines were operated at maximum efficiency for the available hydraulic head and prevailing river conditions. Second powerhouse units were selected and operated to provide good flows downstream from the project. Test units were operated for 2 to 3 hours prior to each release and for approximately 6 hours after each release. Releases were made at approximately 0200 hours each test day to minimize predation and to coincide with normal periods of passage. All six release groups tested each night were released to enter the tailrace at approximately the same time.

The assessment of short-term relative survival among release groups was obtained by comparing marked fish recovered near the upper end of the estuary (Fig. 1). Both beach seines and mid-river purse seines were used to recover the juveniles. Sampling was conducted from 8 to 16 hours per day, 7 days per week. Diel purse seine sampling was conducted periodically each year. Captured fish were processed aboard the purse seine vessels and examined for brands, excised adipose fins, descaling, injury, and fork length. Heads of test fish containing coded wire tags were removed for later processing. Samples of 20 fish were periodically sacrificed at the hatchery and the juvenile recovery site to measure gill Na^{+}-K^{+} ATPase activity to indicate the level of smoltification.

Differences among juvenile recovery percentages for each tagged group were evaluated (Ledgerwood, et al. 1990) by analysis of variance (ANOVA) using a randomized block design where each release day was considered a block (Sokal and Rohlf 1981). Differences among descaling percentages of branded groups were also evaluated using ANOVA. Fisher's protected least significance procedures were used to rank treatment means for significant F-tests (Peterson 1985). Chi-square goodness of fit was used to test the hypothesis that different marked groups released the same day had equal probability of capture through time (Zar 1974). Chi-square was also used to test the hypothesis that each treatment group had equal probability of capture during darkness.

Results - Short Term Survival

Juvenile recoveries at the upper end of the estuary ranged from 0.44% to 0.96% for 1987 - 1990. These recoveries are for the most part within the design criteria of 0.5% recovery percentage. Handling mortality of recovered fish was less than 0.5%, and there was no significant difference between the descaling rates among treatment groups. In general, there was not a statistically significant difference in the timing of the migrations of the treatment groups (Ledgerwood, et al. 1990).

According to Ledgerwood (1990, and manuscript in preparation) statistical analyses of the coded-wire tagged fish recovered above the estuary indicate there were statistically significant differences ($a = 0.05$) in mean recovery percentages among the various treatment groups. For the 1987 - 1990 release period the order of recovery from lowest to highest was bypass, lower turbine, upper turbine, frontroll, downstream, and spillway, although not every treatment was tested all three years (Table 1).

The estimated difference in survival through the various passage routes tested suggest there is little benefit in passing juvenile subyearling chinook through the juvenile bypass system at the Bonneville second powerhouse. In the first two years of the study (1987 and 1988), the percentage of bypassed fish recovered was significantly lower than the turbine groups. The mean differences were 10.9% in 1987 and 13.6% in 1988. These data suggest that passage through the bypass system was detrimental to the survival of the juvenile salmon tested, when compared to passage through the turbines. In 1989 and 1990, the percentage of bypassed fish recovered were also lower than the turbine passed fish, but the differences were not statistically significant. The mean differences were 3.2% in 1989 and 2.5% in 1990. The combined data for all four years indicate a significant difference between the lower turbine release and the bypass release groups of 6.8% (Ledgerwood, manuscript in preparation).

There was not a statistically significant difference between upper and lower turbine release recoveries. The percentages recovered for these two groups were almost identical each year.

Comparisons of recovery differences can also be made among the bypass and non-turbine treatments (Table 1). These comparisons are based on less than four years of recovery data. For example, based on data collected in 1988, 1989, and 1990, the bypass groups were recovered at rates from 3.6% to 14.1% lower than the tailrace groups released into the frontroll of the turbine. Based on 1988 and 1989 releases, the bypass recoveries were 23.1% and 11.6% lower than the downstream groups. Based on 1989 data, the bypass release recoveries were 16.6% less than the spillway groups.

Long Term Survival

Recoveries of adults from the 1987 juvenile releases indicate there is no significant difference between the long term survival of bypassed and turbine passed fish. Approximately 1.9% more bypassed fish were recovered than turbine passed fish. There have been insufficient adult recoveries to date from the 1988-1990 releases for analysis at this time (Ledgerwood, manuscript in preparation).

Conclusions

According to Ledgerwood (1990) the data collected to date on the juvenile and adult returns of subyearling fall chinook released through various passage modes at Bonneville Dam indicate the following:

1. Recovery differences among treatment groups appear to represent differences in passage survival. Fish released into the juvenile bypass system had significantly lower rates of survival than other passage routes.

2. Differences in survival between the upper and lower turbine treatments were not detected. Fish released into the spillway (1989 only) had significantly higher mean recovery percentages than bypass and turbine treatment groups.

3. The decrease in recovery percentage associated with passage through the tailrace downstream from the second powerhouse was of greater magnitude than the decrease associated with passage through the turbines. NMFS speculates that predation by squawfish is causing this reduction in survival.

4. Estuarine sampling of juveniles allows for statistical comparisons among treatment groups that are more sensitive than comparisons from expected adult recovery data.

Discussion

The Bonneville second powerhouse survival study indicates the type of results which can be achieved when a well formulated research design is implemented. The study assumptions and the estimated levels of recovery for determining statistical significance were met. The study design allowed for the use of preliminary results, based on juvenile recoveries in the estuary, to guide the development of future release sites. The results have provided scientific information which will be used to improve salmon populations through the adoption of improved powerhouse operations.

The preliminary data from the estuary recoveries are also being used to develop other evaluations which will examine further the survival issues raised by the Bonneville survival study. In this regard, the study has functioned as a planning tool.

The study results have broad implications. The Bonneville second powerhouse was designed and constructed with a state-of-the-art juvenile bypass system which included all the current knowledge regarding what a good bypass design should be. The study results indicate that survival through the turbines was significantly better than survival through the bypass.

The results from the survival study question the assumption that bypasses are better than turbines in all cases. They indicate that at least some turbines, such as those at Bonneville second powerhouse, provide better passage conditions and higher rates of survival than generally assumed, at least under the conditions tested. The results are limited to subyearling chinook and the conditions tested, and will be finalized once all adult returns are in and analyzed. However, the consistency of the preliminary data cannot be ignored.

The study indicates that fish passing through the juvenile bypass system suffer a high rate of mortality, which is presumed to be caused by predation from resident northern squawfish. Predators are apparently keying on the single point outfall of the juvenile bypass, which is functioning as a source of constant prey.

Table 1.--Summary of juvenile recovery percentages and percentage differences among groups, Bonneville Dam survival study, 1987-1990.

	Year			
Treatment	1987	1988	1989	1990[a]
	Recovery percentages			
Bypass	0.5764	0.4376	0.8007	0.5577 (10 groups)[b]
Bypass				0.5106 (21 groups)[b]
Upper turbine	0.6402	0.5024	0.8298	nt[c]
Lower turbine	0.6528	0.5104	0.8256	0.5721 (10 groups)[b]
Tailrace	nt	0.5095	0.8637	0.5686 (10 groups)[b]
Tailrace				0.5299 (21 groups)[b]
Downstream	0.5567[d]	0.5690	0.9061	nt
Spillway	nt	nt	0.9604	·nt
	Percentage difference from bypass[e]			
Turbine[f]	+10.9*	+13.6*	+3.3	+2.5 (10 groups)
Tailrace	nt	+14.1*	+7.3	+3.6 (21 groups)
Downstream	[d]	+23.1*	+11.6*	nt
Spillway	nt	nt	+16.6*	nt

[a] Data from 1990 are considered preliminary until appropriate review.

[b] In 1990, the first 11 turbine release groups were compromised, thus only the last 10 groups can be compared to bypass or tailrace release groups. All 21 groups can be used for comparing the bypass to tailrace release groups.

[c] nt = not tested.

[d] The downstream release in 1987 was made at the shoreline. Subsequently, lower recovery percentages of that treatment led to an *a posteriori* decision not to use these data for assessing relative survival of the treatments released in mid-river.

[e] Calculated using annual means for recovery percentage of bypass groups (BY): [(treatment % - BY %) ÷ treatment %] x 100.

[f] Average of upper and lower turbine percentages.

* Indicates significant difference at $\alpha = 0.05$.

Recommendations

Further investigations of the issues raised by the survival study are warranted and planned. The juvenile bypass system should be performing better than the turbines as a passage route or it should be redesigned or not used during the summer. Additional studies using spring migrants will be conducted to determine whether the bypass system is negatively influencing spring migrants as well.

The results from the survival study question the assumption that turbines are always a poor passage route and that bypasses provide improved survival rates for juvenile salmonids. This critical and fundamental assumption should be examined further at other powerhouses to assure that juvenile bypass system are improving survival. Predator removal studies are ongoing in the Columbia River Basin to assess the impact of predators on juvenile salmon populations. The predator control programs associated with these studies should be expanded. If survival through the bypass at Bonneville second powerhouse is still less than the turbines after the predators are removed, the bypass should not be used during the summer outmigration.

Project operators which have installed or are considering installing bypass systems to protect juvenile salmon should evaluate the effectiveness of these systems to assure that survival is being improved. Factors outside of the bypass itself, such as predation in the tailrace, may substantially influence the success a bypass system.

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Effects of Hydroelectric Turbine Passage on Fish Early Life Stages

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Abstract

Turbine-passage mortality has been studied extensively for juveniles and adults of migratory fish species, but few studies have directly quantified mortality of fish eggs and larvae. An analysis of literature relating to component stresses of turbine passage (i.e., pressure changes, blade contact, and shear) indicates that mortality of early life stages of fish would be relatively low at low-head, bulb turbine installations. The shear forces and pressure regimes normally experienced are insufficient to cause high mortality rates. The probability of contact with turbine blades is related to the size of the fish; less than 5% of entrained ichthyoplankton would be killed by the blades in a bulb turbine. Other sources of mortality (e.g., cavitation and entrainment of fish acclimated to deep water) are controlled by operation of the facility and thus are mitigable. Because turbine-passage mortality among fish early life stages can be very difficult to estimate directly, it may be more fruitful to base the need for mitigation at any given site on detailed knowledge of turbine characteristics and the susceptibility of the fish community to entrainment.

Introduction

One of the major environmental issues facing hydroelectric development is fish mortality resulting from turbine passage. Whether the action involves licensing a proposed installation or relicensing an existing facility, the potential for turbine operation to kill downstream-moving fishes must often be considered. Turbine-passage mortality has been studied extensively for migratory fishes, but little is known about corresponding

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impacts to resident fisheries resources of inland waters, the location of many existing and planned facilities. Studies of the susceptibility of fish eggs and larvae (i.e., ichthyoplankton) to turbine-passage mortality have been especially rare, probably because of the extreme difficulty of obtaining reliable estimates.

Although few studies have directly examined the issue of turbine-caused ichthyoplankton mortality, the same types of stresses experienced by turbine-passed fishes have been considered in other contexts, notably entrainment studies at steam-electric power plants and pumped storage projects. Cada (1990) reviewed and synthesized these studies to assess the level of ichthyoplankton mortality that could be expected at hydroelectric power plants. This paper summarizes that study and suggests an approach for assessing the level of turbine-passage mortality in lieu of direct measurements. Emphasis is placed on propeller-type turbines (e.g., bulb or STRAFLO turbines), which are commonly installed at low-head hydroelectric plants.

Influence of Turbine Characteristics on Mortality

An entrained fish egg or larva may experience three general types of stress during turbine passage: (1) rapid pressure changes and cavitation, (2) contact with the turbine blades, and (3) shear forces and turbulence. Pressure changes, shear, and turbulence occur throughout the system, whereas blade contact and cavitation are restricted to relatively small areas. The expected magnitudes of each of these sources of stress for bulb turbines, as well as studies that relate to the effects of these stresses on early life stages of fish, have been reviewed in Cada (1990) and are summarized here.

Pressure and Cavitation - The pressures experienced by a turbine-passed fish will depend on characteristics of the turbine (design and flow rate) and on the location of the fish in the water column when it is entrained in the intake flow. A fish inhabiting the surface waters will be adapted to an absolute pressure of approximately 100 kPa (i.e, 1 atm). When entrained in the turbine intake flow, the fish may experience pressure increases caused by the change in depth before reaching the gatewell, and, if the penstock leads downward from the gatewell, a pressure increase between the gatewell and the turbine blades. On the other hand, a fish entrained from greater depths is already adapted to higher pressures and may experience little or no change in pressure upstream of the turbine.

Immediately downstream of the turbine blades, the fish may be briefly exposed to subatmospheric pressures (as low as 80 kPa) before returning to normal hydrostatic pressures in the draft tube and tailwaters. This negative pressure will be only a little less than that to which a surface-dwelling fish is adapted, but it represents a substantial, short-term pressure decrease for a bottom-adapted fish.

Depending on factors such as flow rate and penstock length, passage through the turbine (and the sequence of associated pressure changes) may occur in as little as 15 seconds; subatmospheric pressures would be experienced for less than 1 second. A fish drawn from surface waters would experience a doubling of pressure upstream of the turbine blades followed by a momentary pressure decrease to approximately 80% of the pressure to which it is adapted. Fish drawn from deep waters would be exposed to continuous pressure decreases; for example, the hydrostatic pressures experienced by a fish drawn from a depth of 20 m would decline from 300 kPa to 80 kPa, then return to around 100 kPa at the tailwater surface. Other turbine types or higher-head installations could cause more severe hydrostatic pressure changes.

Several laboratory studies have examined mortality of fish early life stages under more severe pressure conditions. These pressure regimes, depicted in Figure 1, were applied to a wide variety of freshwater fish species (e.g., whitefish, carp, rainbow trout, white bass, bluegill, and channel catfish). In all cases, mortality was very low or not significantly different from controls. It appears from these studies that the range of pressures experienced by most young fish during hydroelectric turbine passage will not result in significant mortality. Most entrained ichthyoplankton would be drawn from depths at or above the turbine and consequently would be exposed to relatively minor, nonlethal pressure increases before returning to natural pressures in the tailwaters.

Fish are more sensitive to pressure decreases than to increases, so the most stressful period of turbine passage may be the momentary decompression immediately behind the turbine blades. The fish that are exposed to the greatest decompression are those that are acclimated to deep waters upstream from the dam. For example, a fish rapidly drawn from a depth of 20 m and exposed to the turbine pressures depicted by the bold line in Figure 1 would experience a gradual initial pressure decrease of about 30% in front of the turbine, followed by a rapid, momentary decrease of as much as 75% from that to which it was originally acclimated. Fish eggs and newly hatched larvae have not developed swim bladders and therefore are unlikely to be damaged by this brief exposure. However, if juveniles are drawn into the intake so rapidly that they cannot adjust the pressure within their swim bladders, they may suffer mortality from burst swim bladders (Cada 1990).

Cavitation, an extreme case of subatmospheric pressures within a turbine, can cause pitting damage to the machinery and have concomitantly severe effects on fish. The mortality that can be expected from cavitation at hydroelectric facilities is difficult to predict. It is certain that implosive forces sufficient to tear metal fragments from the turbine will kill fish. However, model tests and damage evidence indicate that the zone of

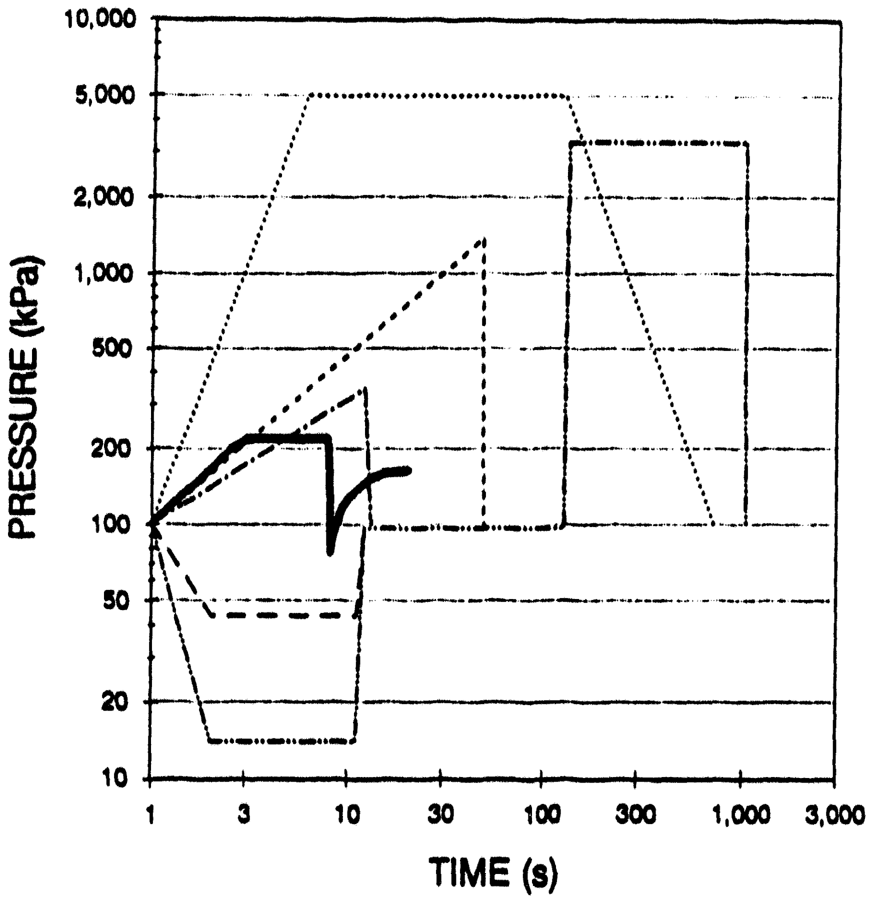

Figure 1. Hydrostatic pressure regimes that resulted in little or no mortality of fish early life stages in laboratory studies. Solid line represents the pressures that would be experienced by a surface-dwelling fish entrained in an example bulb turbine facility. Other lines are pressure regimes used in studies cited in Cada (1990).

cavitation effect is relatively restricted; assuming random distribution, most small fish entrained in the turbine may not pass close enough to an implosion to be harmed. Furthermore, cavitation is an undesirable, costly condition from the standpoint of turbine operators as well as fisheries managers, and considerable effort is expended to avoid the problem by proper design.

Contact with Runner Blades - The probability that an entrained fish will be struck by a turbine blade is a function of both the characteristics of the turbine and the size of the fish. Von Raben (1957) based the following equation on knowledge of the dynamics of turbines and his own empirical studies:

$$P = \frac{l \cdot n \cdot R \cdot a \cdot \cos \alpha}{f}$$

where

- P = probability of blade contact (percent);
- l = fish length (cm);
- n = number of runner blades;
- R = revolutions per second;
- a = cross-sectional area (m^2) of water passage, i.e., π(runner diameter^2 - hub diameter^2)/4;
- α = blade angle, i.e., the angle formed by the water flow with the axial direction at the moment of impact with the edges of the runner;
- f = discharge (m^3/s).

This equation can be used to estimate the probability of contact for turbines that have blades, but should not be used for hydroelectric installations that have Pelton wheels. Because of the small sizes of ichthyoplankton, the probability of blade contact will also be relatively small. For example, the estimated chance of an entrained 1.0-mm-diam fish egg being struck by a turbine blade is 0.1% or less at one example bulb turbine installation (Cada 1990). Probabilities for most larvae are 2% or less. Juvenile fish (4 cm total length) have an estimated probability of contact of 5% or less (Cada 1990).

Turbulence and Shear Stresses - A fish passing through hydraulic machinery at high and varying velocities will be influenced not only by pressure changes but also by accelerative and shear forces. Average velocities of the bulk flow through a turbine may be around 3 m/s or less, but under high flow, velocities can momentarily reach up to 12 m/s near the turbine blades. The tip of a large turbine blade may travel in excess of

20 m/s. The result is extreme accelerations and turbulent flows, at least on the size scale of a fish egg or larva.

A number of studies have examined the component stresses of thermal power plant entrainment independently, for example, by quantifying effects of turbulence and shear forces on fish early life stages without concomitant thermal and biocidal stresses. For example, seven species of freshwater fish larvae were passed through 2.2-cm-diam condenser tubing at velocities of up to 5.8 m/s (Kedl and Coutant 1976). The stresses generated by rapid passage through these narrow tubes resulted in less than 5% mortality. O'Connor and Poje (1979) exposed striped bass larvae to shear in condenser tubes at velocities as high as 3.0 m/s. Mortalities were not significantly different from controls. The power plant simulator used by Cada et al. (1981) subjected fish larvae and juveniles not only to moderate pressure changes (56 to 146 kPa) but also to shear forces associated with passage through 3.2-cm-diam pipes at velocities of 2.4 m/s. The combined stresses caused high mortalities among carp larvae but insignificant mortalities among larval bluegill, channel catfish, and largemouth bass. These empirical studies indicate that the shear stresses caused by average bulk flow velocities through a turbine are unlikely to cause mortality among fish eggs and larvae. Although fragile early life stages should be sensitive to shear damage, their small size apparently minimizes the velocity differentials (and therefore the shear forces) to which the fish are exposed. It should be remembered, however, that water velocities in particular areas (e.g., at the blade edges and especially near the tip) may be considerably higher. The localized shear stresses generated in these areas would be greater than those tested in laboratory studies.

Influence of Fish Behavior on Turbine-Passage Mortality

The interactions of migratory fishes with hydropower plants have been studied for many years, especially in connection with economically important anadromous species such as salmon and American shad. The juvenile forms of these species instinctively move from their natal streams to the ocean (or lake), traveling over or through any intervening dams on the way. Salmon smolts and juvenile shad are relatively large, ranging in length from approximately 5 to 20 cm, and as a result may experience high rates of injury or mortality from passing through small turbines with closely spaced blades.

In contrast, resident (i.e., nonmigratory) fishes are less likely to be exposed to turbine passage. Larger fishes are strong swimmers and, lacking the downstream migratory urge, may avoid the intake area. Some species migrate only short distances upstream to spawn, and some not at all (Hildebrand 1980a). Those early life stages that are spawned upstream will tend to drift downstream and may be entrained in the turbine intake flow. The eggs of most species of freshwater fish are found in nests or adhere to rocks and vegetation; as a consequence, hydropower impacts on eggs normally result not from turbine entrainment but rather from water-level fluctuations in either the reservoir or tailwaters (Hildebrand 1980b). Floating eggs and weakly swimming early larvae are the most susceptible stages of resident fish species. Although they may not instinctively move downstream as do anadromous species, they may be distributed in the intake water and would be unable to avoid turbine passage. Fish in these life stages range in length from about 0.1 to 3.0 cm; beyond this size, juvenile fish are less susceptible to entrainment because they are stronger swimmers, and many reside near the bottom rather than in the open waters.

Fish early life stages may be susceptible to entrainment only during brief seasons or hours of the day. This information can be used to minimize impacts. For example, some species may remain on the bottom during the day and move downstream only at night. Reducing power generation or increasing spill during the night could reduce rates of turbine passage. Other species may be found only at certain depths (e.g., surface waters), such that multilevel intakes could be used to reduce entrainment.

Discussion

It seems likely that at well-designed, well-operated hydroelectric installations the level of ichthyoplankton mortality resulting from turbine passage will be quite low. Large fish drawn from deep waters are expected to experience the greatest mortality, because of large pressure changes and an increased chance of blade contact. On the other hand, surface-dwelling eggs, larvae, and early juveniles would be expected to suffer only minimal turbine-passage mortality, perhaps no more than 5%. Much of this mortality would unavoidably result from blade contact and is to some extent predictable from turbine characteristics and size of the fish.

The turbine characteristics considered in this paper represent relatively new designs (bulb and STRAFLO turbines). Older turbines or turbines that frequently operate outside of optimal design conditions may have significantly different pressure regimes, blade/wicket gate configurations, or velocity regimes from those considered in this analysis. These characteristics could greatly influence turbine-passage mortality and should be quantified for the purpose of assessing losses of fish resources as part of licensing or relicensing activities.

Because of the difficulty of measuring turbine-passage mortality of fish early life stages directly, it may be preferable to base an assessment of the potential problem on detailed knowledge of the turbine characteristics and the fish community that is susceptible to entrainment. Information about the season or time of day that fish move downstream, the size and species of fish that are susceptible to entrainment, and their location in the water column must be obtained in order to assess the likelihood of turbine entrainment. Knowledge of the turbine characteristics described in this paper (e.g., number and spacing of blades and wicket gates; depth of water withdrawal; and velocity and pressure regimes within the turbine) can be used to estimate the consequent mortality of entrained ichthyoplankton. If mitigation of turbine-passage impacts is found to be necessary, these same studies can point to the most cost-effective technique for dealing with the problem.

Acknowledgments

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Fish Entrainment and Mortality at the French Landing Hydroelectric Powerhouse

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Mark J. Sundquist, P.E.[2]

Abstract

This case study explains the fish mortality study performed and results obtained at an existing hydroelectric powerhouse in Michigan. Undertaken in 1989 and 1990, this study provides data for determining effects of turbine passage on area fish.

Introduction

The French Landing Dam and powerhouse is located on the Huron River in VanBuren Township, Wayne County, approximately 20 miles west of the city of Detroit, Michigan. The project impounds Belleville Lake which has a surface area of approximately 1,270 acres.

The dam and powerhouse were built in 1924 and operated by the Detroit Edison Company until the powerhouse was decommissioned in 1967. The dam and powerhouse were donated to VanBuren Township in 1973.

A FERC license was issued on September 16, 1987 for the renovation of the hydroelectric facility. The powerhouse contains two turbine bays and was originally equipped with a total capacity of 2,300 kw. Presently, the FERC license allows for the placement of a single turbine unit with a capacity of 1,800 kw.

Renovation of the powerhouse was complete and the new turbine/generator unit was on line by January 1, 1989. The turbine is a vertical Francis type and rotates at 120 rpm. Maximum total discharge through the turbine is 800 cfs. The hydraulic head at the site is 32 feet.

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Belleville Lake supports a fishery composed of a mixture of warmwater and coolwater species. Sport fish include yellow perch, walleye, bluegill, black crappie, smallmouth bass, largemouth bass, and northern pike. Other species include rock bass, white bass, black bullhead, channel catfish, white sucker, and carp.

Methods and Materials

Adult and Juvenile Fish Entrainment. A net was constructed of sufficient size to be placed across one of the two tailrace bays so as to sample half of the project discharge. A second net was obtained in September 1989 so that the entire discharge could be sampled (Figure 1).

At the start of a sampling period, the nets were attached to brackets mounted in the tailrace stop-log grooves. The turbine was shut down during net deployment. After the net was attached, the turbine was allowed to run for approximately 30 minutes, at which point the turbine was again shut down and the live box was emptied. Since fish tend to congregate in the tailrace area, any specimens captured in the initial sample were examined and counted, but were not considered to have been entrained.

After the initial "flush" sample, the net was emptied as often as was deemed necessary to minimize fish stress and mortality. Entrained fish were examined for external injuries.

Net efficiency was tested on several occasions by releasing marked dead fish into the intake. Percent net efficiency was determined by dividing the number recaptured by the number released.

Data were analyzed on the basis of number of fish per hour; night catches were analyzed separately from day catches. Means and standard errors were calculated based on each net lift, and 95% confidence limits were determined. The values thus derived were multiplied by the total number of day (or night) hours within the approximately two week period represented by the sampling period.

Controlled Fish Passage Experiments. Controlled turbine passage tests were conducted during 8 sample periods over the 12 month study. Fish for the tests were captured with a hoopnet set in Belleville Lake near the powerhouse. The fish were tagged, measured, and held in a 90-gallon stock tank with continuously flowing water for up to 24 hours before testing. The fish were then randomly divided (by species) into three groups:

a. Test - fish were released into the turbine intake.

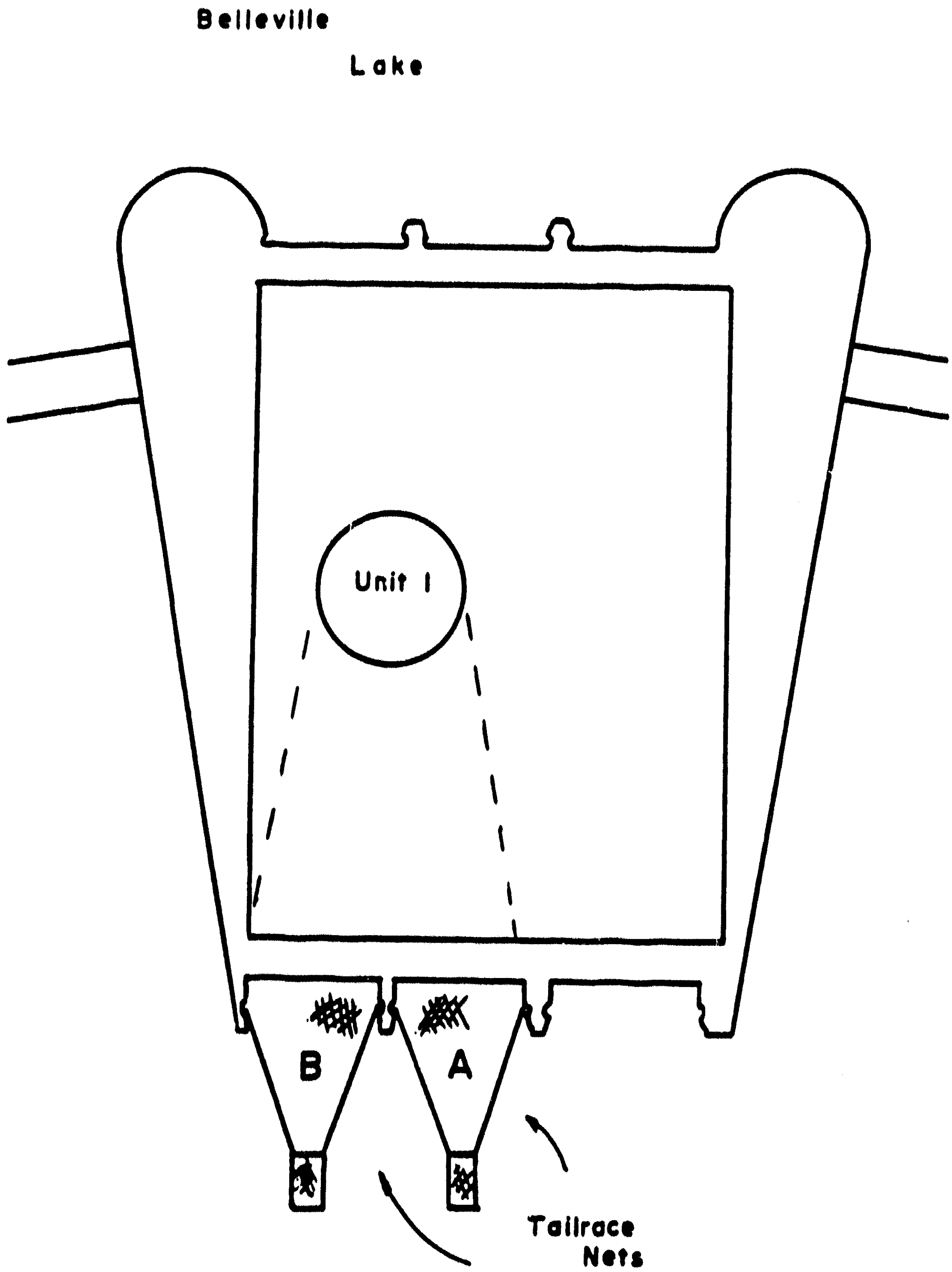

Figure 1

Diagram of the French Landing Powerhouse showing the position of the two tailrace nets.

b. Net Control - fish were released directly into the net in order to evaluate the effects of net damage.

c. Control - fish remained in the holding tank to evaluate the overall effect of handling and holding.

The net was emptied within 45 minutes of the release of test fish and the recaptured fish were promptly returned to the holding tank. Any dead fish were examined for kidney hemorrhaging or other obvious internal damage. Live fish were held for a 72-hour period to evaluate delayed mortality.

Results and Discussion

Adult and Juvenile Fish Entrainment. Fish entrainment was monitored with tailrace nets at the French Landing Powerhouse on 15 sampling periods during 1989-1990 for a total of 742.3 hours, excluding the initial "flush" samples of each sampling period.

A total of 61,349 fish were captured during the sampling periods, flush samples excluded (Table 1). Black crappie dominated both the day and night catches, were present on every sample date, and in nearly every net lift. Bluegill, pumpkinseed, and hybridized sunfish (Lepomis spp.), together with the black crappie comprised nearly 96% of the total catch.

Of all the fish caught, 11 had sustained definite turbine damage. Seven black crappie (135-194 mm), 2 bluegill (128 & 147 mm), and 2 gizzard shad (170 & 172 mm) were found that had been cut in half. Six other fish, all crappie, had received injuries such as deep cuts or damaging bruises, must likely caused by turbine passage. A total of 88 other fish sustained injuries (abrasions, scale loss, and skin deep cuts), possibly caused by turbine passage, but more likely caused by net confinement.

Net efficiency tests were run using dead marked fish on 11 different occasions with project operation levels from 30% to 80%. Recapture rates ranged from 9% with Net B alone at 35% of maximum discharge to 61% recapture with both nets at 55% of generation. Recapture rates were not perfectly correlated with generation rates but a significant regression equation was developed such that net efficiency could be predicted for all generating levels and for each net position.

Net efficiency test data were used in regression equations to develop catch conversion factors. Net efficiency varied by net position and by rate of generation. Net A (east) filtered more water than net B (west), and efficiency increased for both nets with increased turbine discharge. Estimates of the total catch for the year were made using both the raw data and data converted using the net efficiency test information.

Table 1

Total numbers of fish captured by the tailrace net at the French Landing Powerhouse during 1989 and 1990

	DAY		NIGHT		OVERALL	
Species	Total Number	%TN	Total Number	%TN	Total Number	%TN
Black crappie	40912	75.1	5683	82.8	46595	75.9
Bluegill	10322	18.9	533	7.8	10855	17.7
Pumpkinseed	941	1.7	18	0.3	959	1.6
Gizzard shad	643	1.2	115	1.7	758	1.2
Notropis spp.	435	0.8	146	2.1	581	0.9
Lepomis spp.	240	0.4	19	0.3	259	0.4
Morone spp.	213	0.4	190	2.8	403	0.6
Unid. cyprinid	202	0.3	0	0	202	0.3
Warmouth	145	0.3	34	0.5	179	0.3
Largemouth bass	114	0.2	2	<0.1	116	0.2
Brown/black bullhead	56	0.1	58	0.8	114	0.2
Golden shiner	50	0.1	4	0.1	54	0.1
Walleye	47	0.1	19	0.3	66	0.1
Smallmouth bass	40	0.1	1	<0.1	41	0.1
Yellow perch	36	0.1	4	0.1	40	0.1
Brook silversides	23	<0.1	2	<0.1	25	<0.1
Fathead minnow	21	<0.1	11	0.2	32	<0.1
Greenside darter	17	<0.1	15	0.2	32	<0.1
Logperch	12	<0.1	3	<0.1	15	<0.1
Tiger Muskellunge	10	<0.1	0	0	10	<0.1
White sucker	3	<0.1	0	0	3	<0.1
Carp	2	<0.1	0	0	2	<0.1
Blackside darter	1	<0.1	0	0	1	<0.1
Channel catfish	1	<0.1	2	<0.1	3	<0.1
Yellow bullhead	0	0	1	<0.1	1	<0.1
Green sunfish	0	0	1	<0.1	1	<0.1
Goldfish	0	0	1	<0.1	1	<0.1
Central stoneroller	0	0	1	<0.1	1	<0.1
TOTAL	54486		6863		61349	

The catch rate was slightly negatively correlated with the discharge (r = -.34), but this was not statistically significant. Peak discharges occurred during the November and February sampling periods when fish activity is low, and in the late May sampling period when fish activity would be high. Despite the high spring discharge, the peak catch rates occurred during the September sampling. That the catch is independent of discharge suggests that either fish are not in the powerhouse area during peak flow periods or that the catch rate is affected more by other factors, the most important of which we believe is net infiltration.

Infiltration of the sampling nets was a significant factor affecting the catch rate. We began fin-clipping fish before release to the tailwater during sampling on August 18, 1989. Live fish taken from the tailrace nets were given a fin-clip and released. A total of 10,574 fish, mainly crappie and bluegill, were clipped and released during 9 sample periods. A total of 412 (3.9%) were caught in subsequent net lifts during the sample periods when the clips were made. Recapture rates varied from a low of 0.5% to a high of 40%. The rate of recapture appeared independent of the project discharge.

The turbine discharge is split between two bays; when only one net was deployed, fish were able to swim into the unblocked bay and from there into the net. Infiltration also occurred when two nets were used, suggesting that fish were able to enter between the net and the attachment brackets.

Assuming all fish captured were entrained and that the nets were 100% efficient in capturing entrained fish, an estimated 635,531 (±401,080) fish were entrained during the 12 month sampling period. This estimate is derived by multiplying the mean number of fish caught per hour during sampling by the total number of hours represented by that sampling period (generally 2 weeks) and summing over the entire year.

Since netting efficiency was never 100% and varied measurably with discharge, the estimate was modified using net efficiency test data. Factoring in the reduced efficiency resulted in an estimate of 1,593,342 (±853,866) fish entrained, assuming no infiltration.

However, significant infiltration did occur, thus, the actual number entrained must be significantly lower. This is supported by the extremely low percentage of turbine damaged fish.

Controlled Fish Passage Experiments. Turbine passage tests were conducted during 8 sampling periods in 1989 and 1990. A total of 393 fish captured by hoopnet in Belleville Lake were used in the experiments. Of these, 150 were released into the intake downstream of the trash racks, 126 were released directly into the net, and 117 were used as controls. Forty (26%) of the turbine test fish and 70 (56%) of the net fish were recaptured.

Table 2

Survivorship by species of fish 72 hours after controlled turbine passage tests at the French Landing Hydroelectric Powerhouse

	# Survivors / # Tested		
Species	**Turbine**	**Net Control**	**Control**
Black crappie	11 / 22 50%	18 / 36 50%	53 / 55 96%
Bluegill	4 / 7 57%	13 / 18 72%	19 / 20 95%
Bullhead	2 / 2 100%	11 / 11 100%	23 / 23 100%
White sucker	1 / 3 33%	3 / 3 100%	8 / 8 100%
Walleye	1 / 2 50%	1 / 1 100%	6 / 6 100%
Channel catfish	1 / 1 100%	-----	2 / 2 100%
White bass	1 / 3 33%	2 / 2 100%	3 / 3 100%
Overall	21 / 40 52%	48 / 71 68%	114 / 117 97%

Obviously, fish were able to swim into the current and out of the net, and more importantly, perhaps 30% of the fish released at the intake escaped through the trash racks into Belleville Lake.

The majority of the test fish (55%) were black crappie, followed by brown bullhead, bluegill, and Morone spp. Other species used were white sucker, walleye, and channel catfish.

Results by species are shown in Table 2. Black crappie provide the most valid data for analysis based on the number of fish tested. Low number of other species were recaptured. In addition, black crappie were the dominant species in the entrainment samples.

None of the turbine passed crappie sustained external injury. The 72-hour survival of the turbine-passed fish equaled that of the net control fish (50%). Thus, delayed mortality is not a factor at the French Landing site.

Conclusion

The controlled passage results support the entrainment sampling results in that insignificant turbine-related mortality is occurring at the French Landing site.

Fish Entrainment and Relicensing: Truths and Consequences

Dr. John Pizzimenti, Dr. John Meldrim, Kevin Malone[1]

Abstract

The states of Michigan, Wisconsin, and the U.S. Fish and Wildlife Service have issued guidelines that presuppose entrainment/turbine-induced mortality at most hydroelectric projects are having a significant impact on fisheries resources. Unfortunately, there has been little data to support or refute this assertion and study costs to irrefutably answer this question will be expensive. This paper provides representative examples of entrainment study results. We categorize them by type of resource and type of facility. We conclude that entrainment impacts at each project are highly dependent on the resource in question. Finally, we present an alternative approach that allows the use of common sense, economics and resource protection, such that the things we study and mitigate make the most sense for each specific project.

Introduction

Approximately 175 hydroelectric owners must acquire new licenses prior to 1993. Many of these projects to be

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relicensed are small (less than 5 MW) and do not occur on rivers with anadromous fisheries. Prior to this major historical relicensing event, little attention has been paid to fish entrainment or turbine-induced mortality outside of the Pacific Northwest or the Northeastern U.S. where important anadromous species have declined in the face of large scale hydroelectric development. Nevertheless, our experience to date indicates that resource agencies are concerned about the effects of turbine-induced mortality at all projects regardless of fisheries resources present in the project waters. In fact the states of Wisconsin and Michigan have issued guidelines that assume most hydro projects are having a significant impact on fisheries. Unfortunately, there have been little direct data to support or refute this assertion. This paper will provide data indicating that the impacts from entrainment at each project are highly dependent on the resource in question.

Costs and Benefits

We would not even be discussing this topic were it not for the fact that the economic value of small hydroelectric projects are limited and the cost to complete definitive studies to establish the significance of the turbine-induced mortality can be quite high. The alternative choice to go directly to screening or other fish bypass facilities and avoid "studies" is even more cost prohibitive. Hence, some owners are facing difficult, and in some cases economically untenable positions. To satisfactorily resolve this issue we believe that by following an approach that incorporates common sense, agency and project owner cooperation, and possibly some creative thinking, these problems can be solved. To this end we offer several suggestions that should be considered by owners, agencies and the FERC. To contrast traditional approaches with our proposed methods, we use a flow chart developed by the U.S. Fish and Wildlife Service and the Wisconsin Department of Natural Resources (agency) to characterize the current agency approach. We then offer a flow chart of our own as an alternative approach. We illustrate the approaches with examples from three general categories:

1. High head/low flow, Rocky Mountain Project

2. Low head/high flow, Midwestern Project

3. High head/high flow, Columbia River Project

These cover the range of extremes of projects currently facing relicensing.

Methods

To begin, we performed a literature review of entrainment and turbine-induced mortality studies conducted in the U.S. Using this information we compared it with what we learned from our relicensing work at hydro facilities across the nation. From this comparison we were able to categorize most hydroelectric facilities based on the fishory resource affected. These categories are:

1. Economically valuable anadromous species
2. Resident fisheries of mixed valves
3. Heavily stocked and managed fisheries

Study results provide evidence that entrainment at each project is highly dependent on the resource in question. We then illustrate a flow chart (Figure 1) developed by the agencies to demonstrate their approach. Finally, we present an alternative flow chart (Figure 2) designed to allow more cost effective approaches to establish the significance of the problem, and to develop mitigation where appropriate.

Results

Put-and-Take Fishery Resource - A high head, low flow Rocky Mountain project.

As part of the relicensing effort for the 1 MW Salida Hydroelectric Project, an entrainment study was undertaken to assess turbine-induced mortality on 350 catchable size rainbow trout stocked in the projects forebay (Bizer, Malone, 1991). Sampling was performed prior to, during, and after stocking by using a modified trawl net mounted in the tailrace. A total of seven fish were captured over a twelve day period, none of which were the species of interest.

Resident Species - Two low head projects with populations of common resident species such as rock bass, bluegill and black crappie.

Scott Worldwide conducted a fish entrainment study from April 1990 through March 1991, at its 7 MW Park Mill Hydroelectric Facility on the Menominee River in Marinette Wisconsin (Boltz et al, 1991). Fyke nets covering approximately 60 percent of the intake area, located behind the trashracks and in front of the turbines, were used to determine entrainment numbers. Sampling was conducted 40 hours per week from March through November and 40 hours per month from December through February. Total catch from this intensive sampling effort resulted in 1902 fish being captured (as of December 1990), representing 36 species. Rock Bass was the most common species (22.3 percent), followed by bluegill (18.8 percent), and carp (18.5 percent). The majority (51.8 percent) of the catch was less than 2.5 inches in length.

A study with similar results to that of Scott, was performed at a low head hydro facility on the Kalamazoo River in Michigan (Bohr, Liston 1987). At that site, an entrainment study was undertaken to estimate the number, species and size of fish that were entrained by the Morrow Hydroelectric Powerplant. The study took place over a 199 day period and nets were used as the sampling method. Over 45,000 fish were estimated to have been entrained by the four turbines, "Of these an estimated 970 plus or minus 686, or an average of five fish per day sustained turbine injuries". Bluegill was the most abundant species captured, followed by common shiner, black crappie and pumpkinseed.

Anadromous Species - Large hydroelectric dam with commercially important anadromous species.

Entrainment studies conducted at great expense to large hydro projects (> 800 MW) on the Columbia River indicate that anadromous salmon populations are severely impacted by entrainment mortality. These studies state that on average between 10 and 15 percent of those individuals entering the turbines suffer mortality (Shoeneman et al, 1961). As an example of the numbers of juvenile salmon becoming entrained at a typical Columbia River hydroelectric facility, we use a hydroacoustic study performed at Wanapum Dam (Ransom, Malone, 1989).

Downstream migrating juvenile salmon were hydroacoustically monitored at Wanapum Dam for a five week period, 24 hours a day, 5 days per week. Data were gathered on the number of fish passing the project via the turbines, spillway, and sluiceway. Total estimate of fish passing the project through the turbines was 1.2 million. Species composition data collected in the gatewells indicated that 99 percent of these fish were the target species (salmon).

Discussion

It would appear that the issue of entrainment, and its associated mortality for a hydroelectric facility, is highly dependent on the fishery resource present. The data indicate, species that exhibit migratory behavior are more likely to be entrained into turbines than those species which do not.

Lack of entrainment mortality on a trout put and take fishery is not surprising due to the size of the individuals planted. Because these fish are planted with the single purpose of providing harvestable fish for the recreational fisherman, they are generally large (8 to 10 inches). Large fish, being better swimmers, are not as susceptible to entrainment velocities as smaller individuals of the same species (Jones 1980). Further, the densities of planted fish are low, and therefore, entrainment numbers are resultingly low.

Resident species such as bass and bluegill do suffer entrainment as evident from the above data. However, it appears that the number of individuals is small (970 +/- 686, Kalamazoo River) compared to the source population as a whole. Further, because the modal age class of these fish are between 0+ and 1+, the impacts on the population is likely to be insignificant if the populations are otherwise healthy. Unlike anadromous species, resident species generally do not need to travel past series of dams. Given sufficient local habitat, resident populations can be maintained locally in river systems with dams on them. The probability of entrainment is high only for any individual residing in close proximity to the project. We suspect that the probability of a resident fish becoming entrained is inversely proportional to both their age (size), and their distance from the project.

Anadromous species are more vulnerable to turbine mortality because juveniles must migrate from historical spawning and rearing areas past hydroelectric facilities to complete life cycles. The toll on the anadromous species is clearly a significant issue. Estimates on the Columbia River indicate that the cumulative turbine-induced mortality for juveniles passing four mainstem dams is over 50 percent (NWPPC 1986). This in turn has been one factor in reducing adult returns from a historical high of approximately 16 million to less than three million today.

There is sufficient evidence to indicate that entrainment mortality is not an issue for all hydroelectric projects. Our opinion contrasts sharply with that espoused by some regulatory agencies who have apparently concluded that entrainment is indeed an issue for all hydro facilities and request that entrainment/turbine-induced mortality studies be performed at most, if not all, facilities (USFWS, 1988). A flow chart of current agency approach for addressing entrainment/turbine-induced mortality is shown in Figure 1. A flow chart outlining our approach to the entrainment question is shown in Figure 2. In the following paragraphs we compare the two.

The Agency Approach

The agency approach presupposes there is an entrainment problem at every hydroelectric facility. Therefore each project regardless of resource present is treated in the same fashion. Each project must demonstrate no turbine mortality by conducting entrainment and/or turbine-induced mortality studies under Phase 1 and Phase 2 guidelines, or go directly to mitigation. The agencies never ask the question is the resource declining or depressed. At projects such as Salida, with a stocked put-and-take trout pond fishery, even if entrainment losses were high (which they were not), the resource in question are planted hatchery fish and can be replaced quite readily at minimal cost.

Project owners with resident species may also suffer needless expenditures of time and money when following agency methodology. These projects are also required to perform entrainment/turbine-induced mortality studies or proceed to mitigation. Agencies make no exceptions for projects which have fishery resources at or near carrying capacity, resources that have increased since project completion or where entrainment studies at similar projects have demonstrated impacts to be minimal. One or all three of these characteristics may be present at projects with resident species. Some projects (dams) have actually enhanced resident fisheries by creating habitat. Most hydropower reservoirs do have substantial resident fisheries, many with national reputations among sport fishermen. Also, entrainment mortality over a six month period can be as low as the daily catch of a single fisherman (5 fish). The agency approach makes no provision for those projects that are not having an impact, or are actually enhancing the resource.

The one category where the agency approach is effective is anadromous species. It is in this category that the agencies assumptions that a problem exists and mitigation will be required are likely correct. The severity of entrainment/turbine-induced mortality impacts to anadromous species are well documented from extensive work performed at hydro facilities in the Northwest and Northeast U.S. These studies indicate that without some form of mitigation, the fishery resource can be expected to decline or remain at depressed levels.

Harza Approach

Our approach assumes that entrainment/turbine -induced mortality at each hydroelectric facility is highly dependent on the size of the project, the fishery resource present and the status of that resource.

Therefore, entrainment impacts and their severity need to be evaluated and are determined on a project by project basis.

To begin, each project must identify the resource and its status in the project waters. It is here that arguments for low value of or no impact to the resource can be given as reasons for not performing entrainment studies. If an owner can show that the resource has "low value" , easily replaced at minimal cost, then no entrainment work is needed. Also, no entrainment studies are necessary if the owner can demonstrate that the fishery resource is "healthy". This is defined as waters at or near carrying capacity or fish populations increasing since project development.

After determining that a problem exists we begin looking for the cause of the problem. In the agency approach this is assumed to be entrainment and its associated mortality component. We prefer to look for all possible causes and attempt to rate them according to the degree of impact they have on the fishery resource. Once we have established the causes for the resource decline, we determine which of those are project related and focus are attention on the one with the highest rating. Our selection of a mitigation method is based on a cost/benefit evaluation and its ability to meet the goals we have established for the resource. We then implement the mitigation method and establish a monitoring program to assess its effectiveness over time.

Summary

Relicensing economics and fishery resources are highly variable. They are dependent on project size, configuration, geographic location and fisheries present. A uniform approach to evaluating and categorizing the effect of turbine mortality across all these situations is contrary to both sound ecological judgement and economics.

Instead, we should put our energies into solving fishery problems where fishery problems exist. Common sense and existing data should allow us to recognize those areas where it makes little sense from an ecological, economical or recreational perspective to spend large sums of money with no clear benefit to the resource from our efforts.

We recommend that the FERC, EPRI or other similar organizations develop a national data base and methodologics that will be useful in both an economic and environmental sense to help resolve this issue.

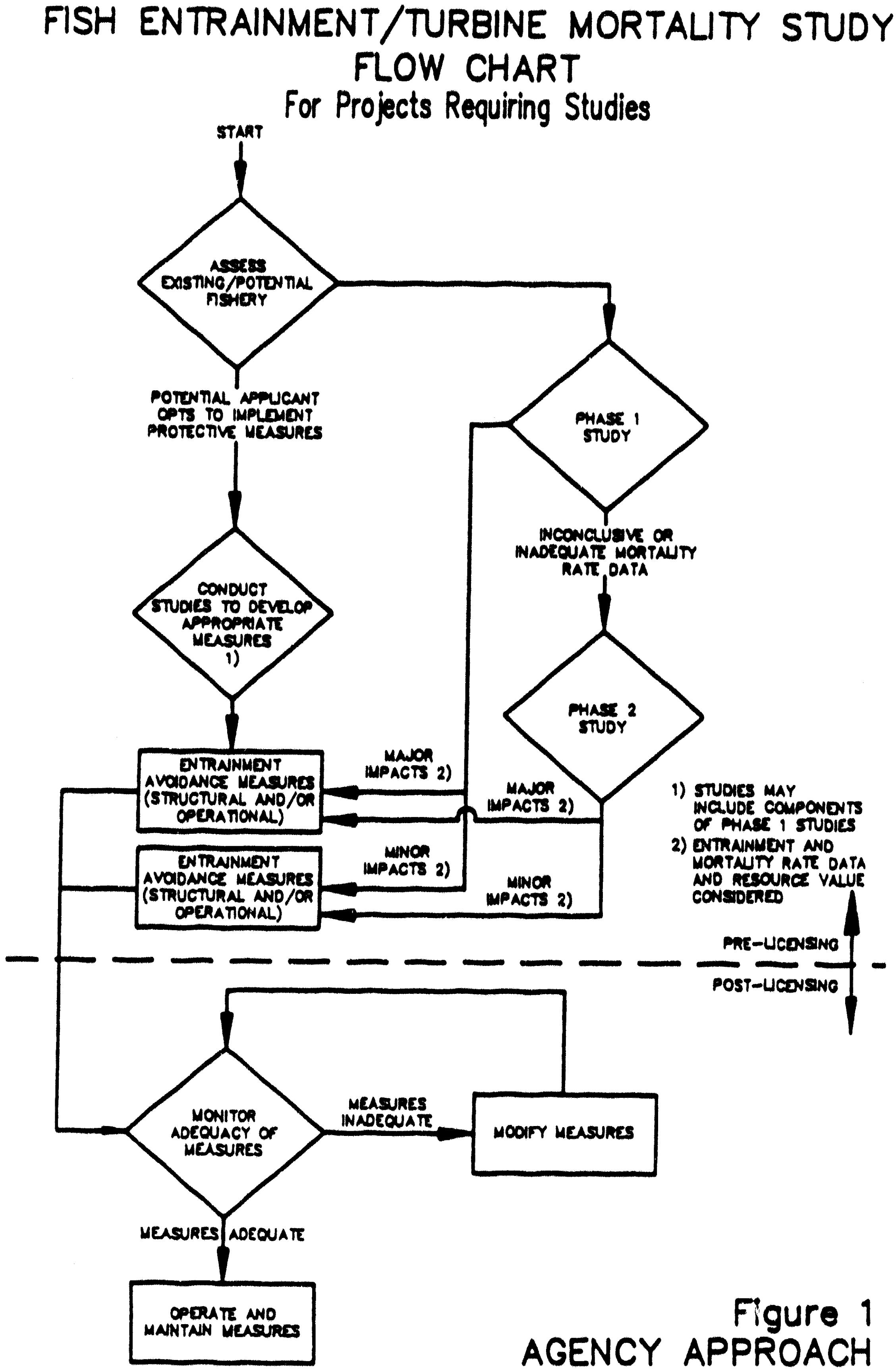

Figure 1
AGENCY APPROACH

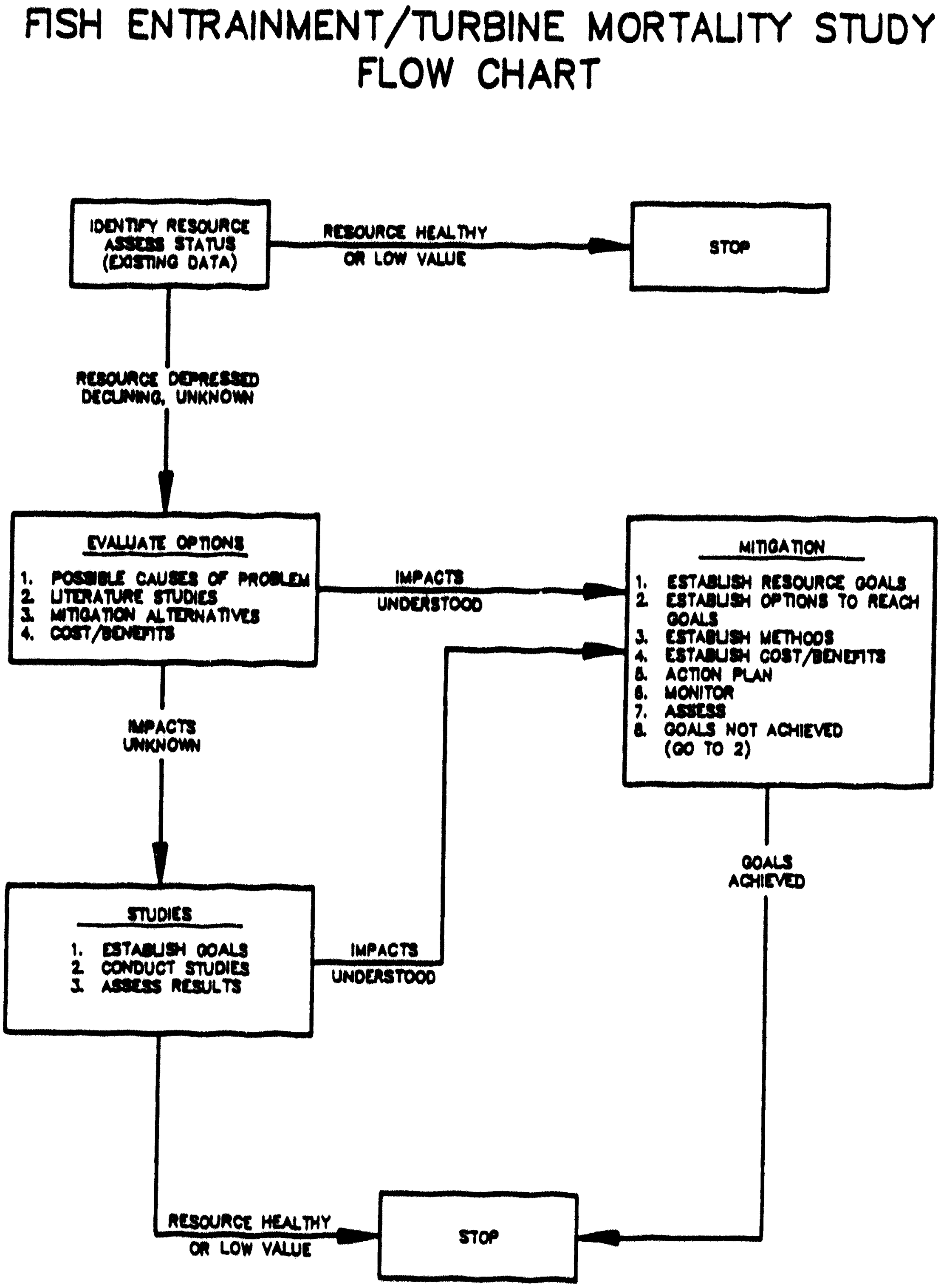

Figure 2
HARZA APPROACH

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DESIGN OF EXTENDED LENGTH SUBMERGED TRAVELING SCREEN AND SUBMERGED BAR SCREEN FISH GUIDANCE EQUIPMENT

David Bardy, EIT, Mark Lindstrom, PE, Don Fechner, PE[1]

ABSTRACT

The hydropower projects on the Snake and lower Columbia Rivers in the Pacific Northwest are unique because these rivers are also the spawning grounds for migratory salmon. The salmon swim upstream from the ocean, lay their eggs, and die. The newly hatched fingerlings must then make their way past the hydroelectric dams to the ocean. Two separate bypass systems are needed, one to pass the adult fish going upstream, and one to pass the fingerlings going downstream. This paper will address the design considerations for two of the components of the downstream migrant fish passage facilities, the extended length Submerged Traveling Screen and Submerged Bar Screen.

INTRODUCTION

The standard submerged traveling screen (STS) and the standard submerged bar screen (SBS) are devices that are installed in the intake gate slots or the bulkhead slots upstream of the turbines at several of the dams. These screens help to divert the fish away from the turbines and into the migratory channel that will take them around the dam. Several of the dams currently have STS's that are approximately 20 feet by 20 feet in size. These screens only intercept fish in the upper 20 feet of the intake. To increase the number of fish that are bypassed, fisheries biologists recommended that longer screens be installed. After completing feasibility studies it was determined that a screen size of 20 feet by

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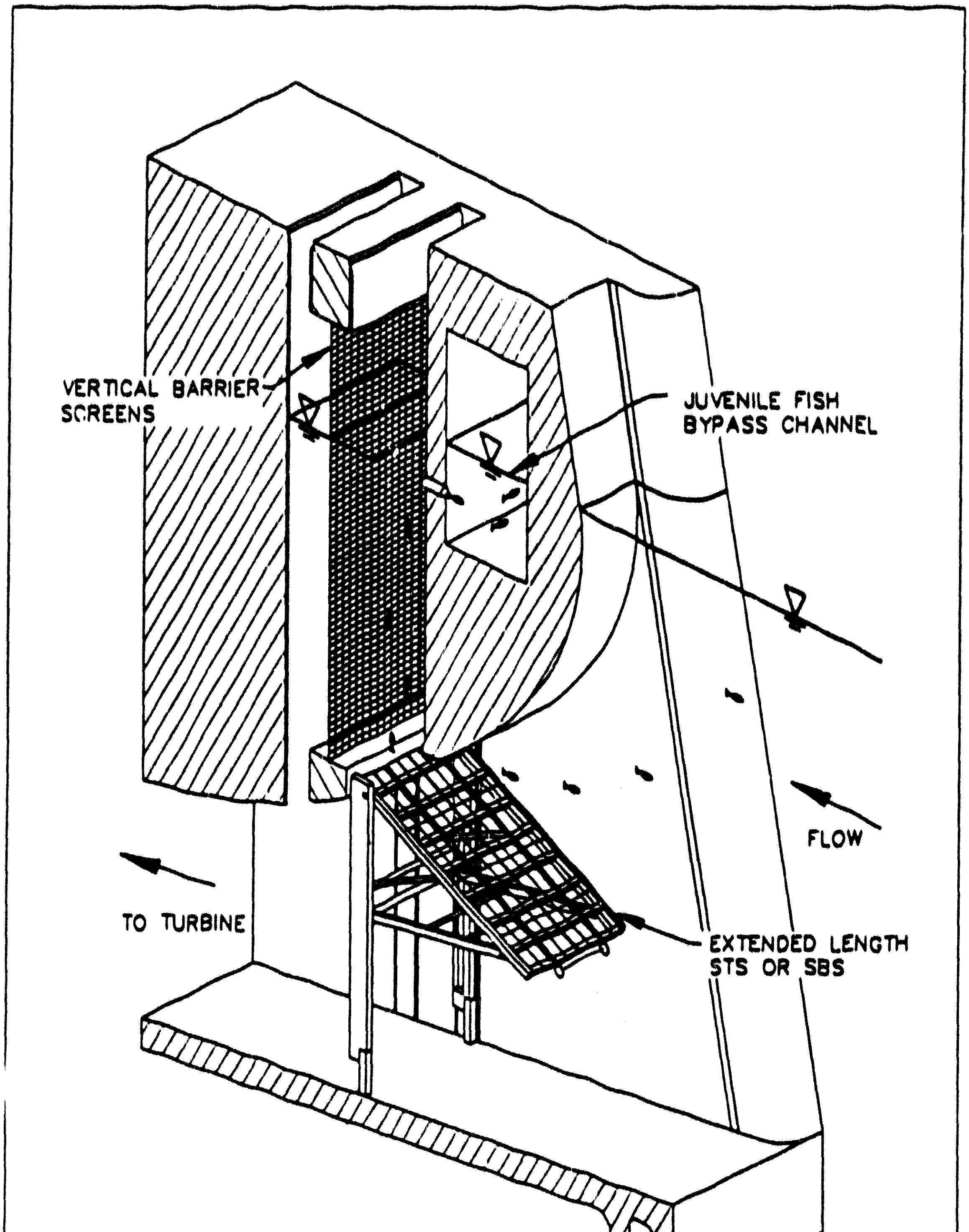

Figure 1 - General Arrangement of Fish Guidance Equipment.

40 feet was the maximum feasible screen size that could be installed and handled by the projects. This paper will describe the many unique problems that were encountered while designing these large underwater structures and the mechanisms on them.

The extended length STS and SBS consist of an inner frame, outer frame, and an extending mechanism. See figure 1. The assembly hangs vertically and must be lowered down the gate slot and the inner frame extended into operating position, which is typically -35 degrees from horizontal. This extending is accomplished with a slider and extending arms. Another set of arms are used to further support the inner frame when it is in the operating position. To retrieve the screens the inner frame must be retracted and the support arms moved into the vertical position. The assembly can then be brought up the gate slot with a crane. When in their operating position these screens are totally submerged to a depth of up to 120 feet.

To keep debris from plugging the screens two types of systems are employed. On the STS the screen consists of a flexible mesh that is mounted in a conveyer belt arrangement. An electric motor and gearbox are used to drive the belt system and carry any debris off of the leading face of the screen. The SBS has a stationary stainless steel screen surface and a brush is driven up and down the face of the screen, by an electric motor and gearbox, to push off any debris that might accumulate. Underwater electronic components are employed to reverse the direction of travel of the brush at the top and bottom of its stroke. The porosity of these screens and the porosity of the frames were determined by model tests conducted at the Waterways Experiment Station and by tests using existing standard length STS's and SBS's.

HANDLING

A major challenge in designing the screens was to provide means to place them in the bulkhead slot, extend and retract the inner frame, pull them out of the bulkhead slot, and lay them down on the intake deck for transportation elsewhere.

The outer frame of the screens had to be short enough to enable the gantry crane to lift them above deck level out of the bulkhead slot. This necessitated an outer frame that is different than the standard screens because the standard design would lead to an outer frame that would be too long to enable the crane to lift the screen above deck level. The new outer frame design should lead to better fish guidance because the upper beam would not be located in the path of the fingerlings going up the bulkhead slot.

Two auxiliary hoists are needed to handle the actuating cables for the inner frame. One hoist lifts the extending cables for extending the inner frame while the other hoist holds the lower arm cable until the inner frame is extended and then lowers the lower arm assembly into operating position. Other small tugger hoists are used to handle cables during the lowering and raising operations.

The crane at McNary dam has the necessary features to handle the long screens, however the cranes at most of the other projects do not have these features and it is not feasible to design a screen so these cranes could handle them. This would require replacing or extensively modifying the intake gantry cranes at most of the projects.

STS DESCRIPTION

The inner frame of the STS is somewhat similar to the standard STS except that it is twice as long. There are two rotating belt assemblies for backflushing purposes. Since the belt assemblies are twice as long as the standard STS, the required torque to drive the belts has doubled. It is not possible to fit a motor and reducer large enough to drive both belts in the available space envelope on the inner frame. Therefore two motors and reducers of the same size as the standard STS are utilized to drive the belts, each motor and reducer driving a belt assembly.

Other types of drives were investigated, but the current drive system was the only one that would fit into the available space with the required horsepower and torque and had good reliability. The components of the drive and mesh assembly are composed of designs that have been developed by years of experience with standard length STS's and have proven reliability. The configuration of the rest of the components of the STS are similar to the standard STS.

The take-up assembly that removes the slack in the belt assembly and supports the idler rolls and sprockets is much larger than on the standard STS. The loading on the long STS take-up assembly is twice as large as on the standard STS. The take-up assemblies on the standard STS's have poor wear characteristics, so the new take-up assembly has much larger bearings to provide longer life.

The mesh material on the rotating belts has a porosity such that the flow is directed up the surface of the screen and into the bulkhead slot. In addition, the mesh has a plate with round perforations located a specific distance behind it. The combination of the mesh backed up by the perforated plate give the required flow pattern to guide the fish into the slot. This mesh-perforated plate combination has been derived by many years of testing on standard screens and can be changed if needed to improve the flow characteristics after further testing.

INNER FRAME DESIGN

The layout of the primary structural members is controlled by the mechanical equipment they must support, namely the two rotating belt assemblies, the two drive motors with speed reducers, and the drive chain take-up assemblies. This resulted in three longitudinal members which fit between the belts and provide the tracks for the drive chains. Three connecting transverse members bring the track loads from the center longitudinal member back to the two side members. The inner frame is supported at three points along the side members. The primary members are closed box sections which provide good torsional stiffness and high strength to weight ratios. They are built-up to satisfy dimensional requirements dictated by the mechanical equipment. With submergence in excess of 100 feet, the members are open to water to prevent their collapse. The inner frame is designed to resist a static pressure differential of 180 psf that would occur if the mesh becomes completely plugged under normal turbine operation.

In addition to static load requirements, the inner frame is designed to meet certain dynamic load criteria. The inner frame is fitted with perforated plates sandwiched within the rotating belts. They are designed to reduce the flow velocity through the mesh so that the small fingerlings are guided along free of the mesh rather than being scraped or impinged on the mesh surface. The flow through these perforated plates is not uniform but tends to experience some pressure fluctuation according to the inflow demands of the turbine. The resulting dynamic load can not be clearly defined making a transient dynamic analysis impossible, but model studies conducted in the development stage of the STS's indicated that the dynamic response of an inner frame with a natural frequency not less than 10 cps could be considered insignificant. Based on the model studies, the 10 cps natural frequency criteria was adopted and the inner frame an supports were designed accordingly using the STAAD-III computer program on a PC-XT. Structures were modeled with beam elements, and frequencies were checked for fundamental modes both in the plane of the structure and normal to the plane. The submerged environment of the structures was modeled by the virtual mass method.

To satisfy dynamic criteria, it was necessary to support each side beam at three points even though the depth of these members as dictated by the track locations is quite large. It is noted that the current 20 foot long STS's have support at only two points. The three transverse members are sandwiched within the rotating belts causing a clearance requirement which limits their depth. This limitation along with the mass of the center longitudinal beam acting at their midspan required the transverse members to have heavy sections to satisfy the dynamic stiffness requirement. Thus the dynamic criteria produced a relatively heavy inner frame design which required the extra set of support points. The computer model was also used to determine the static stresses under the 180 psf static live load. The static stresses do not exceed 10,000 psi in the inner frame.

SBS DESCRIPTION

The plastic mesh of the STS is fragile and requires many hours of labor to repair or replace. The SBS is designed to reduce the maintenance costs, reduce the initial costs, and provide equal if not better fish guidance.

FRAME DESIGN

The design of the outer frame and support mechanism is identical to the STS. The inner frame is substantially different than the STS. The structural design loadings and natural frequency requirements are as described in the STS inner frame discussion above. The SBS has a ladder type space frame that is much lighter than the STS. This was achieved because the mechanical equipment requirements of the SBS do not require as much support in the middle of the frame. The bar screen does not require as much support to handle the water load requirements because of its built in support and because the load is more evenly distributed over the surface of the inner frame. Each bar screen panel has a supporting understructure and the water loading is transmitted by this understructure to nine lines of support that run the length of the inner frame. In contrast, the STS has only three lines of support, two on the outside of the frame and one down the middle. This puts a greater stress on the middle of the STS inner frame and therefore increases the weight of the frame because larger members are needed. Because of the reduced weight of the inner frame, the natural frequency of the frame was above the 10 hertz minimum without any increase in the frame member sizing.

CLEANING DEVICE DESIGN

Because of the silt and submerged debris, it is necessary to clean the surface of the bar screen on regular intervals. The suggested cleaning cycle of once every 15 minutes was determined by experience with STS's. The cleaning device consists of a brush bar that spans the width of the inner frame and is driven up and down the surface of the bar screen by an electric motor and chain drive. The drive system consists of a 1800 rpm submersible motor driving a 500:1 gearbox at the top of the inner frame. The gearbox in turn drives two sprockets located at the 1/3 points along the top of the frame and connected by a common shaft. These sprockets drive two chains that run the length of the inner frame from top to bottom of the frame. A matching set of idler sprockets are located at the bottom of the inner frame to take up the slack in the chain. The brush bar is attached to the chains and travels up and down the surface of the bar screen.

The stopping and reversing of the brush bar is accomplished by one of two methods currently being tested. The first method consists of two proximity switches mounted on the inner frame at the top and bottom of the screen. An actuating magnets are mounted on the drive chain and trip the hall effect proximity switches that stop and reverse the drive motors. The cycle consists of one trip up the screen and back down to the rest position at the bottom of the screen. The second control scheme consists of allowing the brush bar to come up against bumpers on the top and bottom of the screen. The motor controls sense the rise in current caused by the stall condition and stop and then reverse the motor.

EXTENDING AND SUPPORT MECHANISMS

To reduce design and fabrication costs, it was decided to make the extending and support mechanisms identical for both the SBS's and STS's. A number of schemes were investigated. From these, two schemes emerged as being the most viable. The first scheme suspends the outer frame from the heavy concrete beam that spans the gate well just above the water passage roof. It uses a slider-actuating arm mechanism similar to the one currently being used on the 20 foot STS's to rotate the inner frame to the correct operating angle. The support mechanism for this scheme consists of latch pins that would extend outward from the side members of the inner frame to engage two support brackets bolted to each of the pier faces at the sides of the water passage. The second scheme provides support to the outer frame by allowing the base of the frame to bear on the water passage floor. It uses the same slider-actuating arm mechanism to rotate the inner frame to the correct operating angle as described for the first scheme, but in this scheme the slider is then latched to the outer frame causing the actuating arms to provide the middle point of support to the inner frame. The lower support point is provided by a lower arm frame assembly with one end of the assembly pinned to the inner frame near the free end of the side members and the other end bearing against a housing located on the slider. The lower arm assembly rotates into position after the inner frame has been rotated into operating position.

The second scheme was selected based on several key factors. These will now be discussed briefly. Perhaps the greatest problem with the first scheme is the difficulty of installing the support brackets on the face of the piers. These brackets would be located upstream of the bulkhead slots so it is impossible to un-water the area to install the brackets. This requires them to be very accurately located and installed under water at diving depths in excess of 100 feet. The second scheme offered several advantages for the prototype screens that would facilitate research work to determine the most favorable inner frame orientation for fish guidance efficiency. First, with the base of the outer frame seated on the water passage floor, it was simple to provide an adjustment to vary the vertical position. Second, it was also possible to provide for different screen angles by supplying additional slider-actuating arm latch point locations on the outer frame, and incorporating a telescoping feature to change the length of the lower arm assembly. These features would have been difficult or impractical to achieve in the first scheme.

The general procedure for extendinᵔ an STS or SBS into operating position will now be presented. This will help indicate some of the design challenges that were encountered. There are three separate actuating cables that are used to extend the screen. Two of these cables are attached to four part reeved sheave assemblies located on each side of the slider. These cables function to raise or lower the slider which in turn increases or decreases the screen angle. The third cable is attached to the midpoint of one of the transverse beams that form a part of the lower arm assembly. It functions to rotate the lower arm assembly downward so the free ends of the arms can be positioned in the housings on the slider. In addition to the these three cables, a tag line is attached to the counterweight which is part of the slider latching mechanism. This tag line is used to cause the two latch pins to engage the slots, or be released from the slots which are provided at strategic locations along the outer frame side members.

To begin describing the installation, we will assume that the retracted screen is in the normal stored position, dogged-off at the intake deck with the upper half of the screen projecting above deck level. First the intake gantry main hoist lifting beam is latched to the two heavy lifting ears provided at the top of the outer frame, and the screen is released from the dogs and lowered down the bulkhead slot until it comes to rest on the floor of the water passage. During this process, it is necessary to stop momentarily to add-on lengths of actuating cable. The lifting beam is then unlatched and removed, and the two slider actuating cables are rigged to the intake crane auxiliary hoist-1 using a special lifting beam. Using the auxiliary hoist, the slider is raised and the inner frame rotated in increments that range between approximately 10 and 23 degrees. At the completion of each increment, the tag line is used to engage the latch pins in the appropriate slots in the outer frame. The support provide by the slider actuator cables is then transferred through the latched slider to the outer frame, so that lengths of slider actuator cable may be removed and the lifting beam re-rigged to a new section of cable. This procedure is repeated until the inner frame has been rotated to a precisely established position just beyond the desired operating angle. This position is accurately defined when the extended latch pins bear against the top of the slots in the outer frame that are designated for that particular screen angle. During the entire slider raising phase, the lower arm actuator cable has been rigged to auxiliary hoist-2 and held securely in place causing the lower arm assembly to remain essentially in the retracted position. Now with auxiliary hoist-1 supporting the inner frame in the established position just described, auxiliary hoist-2 is used to rotate the lower arm assembly downward until the cable goes slack indicating that the free ends of the arms have come to rest on the slider housing seats. In the final step, auxiliary hoist-1 is used to lower the slider slightly until the latch pins bear on the bottom of the slots. During this final step, the free ends of the lower arms slide several inches along the housing seats and finally come to bear against the back face of the slider housings. The actuator cables and tag line are dogged-off at deck level and the screen is in operating position.

PROTOTYPE SCREENS

Because of the unknown reliability of these systems it was decided that six prototype screens be made first. These screens are scheduled for completion in April of 1991 at McNary Dam on the Columbia River. These screens will have adjustable supports so that two operating angles for the inner frame can be tested to determine the best fish guidance configuration. There are two types of cleaning devices for the SBS that will be evaluated as described above.

A second contract has been awarded to dynamically test the structure using electronic measurements while the screen is in the operating environment. The results of this testing and the mechanical testing of the systems will help to optimize the design when full production starts.

CONCLUSIONS

The design of these unique devices posed some difficult challenges for the design team of the Hydroelectric Design Center. Potentially, a total of 110 of these screens could go into production in the next 5 years and total production could reach 150. At approximately $375,000 apiece this is a total of $56.3 million, additional money is also needed for miscellaneous equipment and modifications to the projects to accommodate the longer screens. The design effort and short deadlines required a concentrated effort and extensive computer analysis and design to complete the prototype units for testing.

FISH PROTECTION AT WATER INTAKES USING A NEW SIGNAL DEVELOPMENT PROCESS AND SOUND SYSTEM

P. H. Loeffelman[1], D. A. Klinect[2], and J. H. Van Hassel[1]

Abstract

American Electric Power Company, Inc., is exploring the feasibility of using a patented signal development process and sound system to guide aquatic animals with underwater sound. Sounds from animals such as chinook salmon, steelhead trout, striped bass, freshwater drum, largemouth bass, and gizzard shad can be used to synthesize a new signal to stimulate the animal in the most sensitive portion of its hearing range. AEP's field tests during its research demonstrate that adult chinook salmon, steelhead trout and warmwater fish, and steelhead trout and chinook salmon smolts can be repelled with a properly-tuned system. The signal development process and sound system is designed to be transportable and use animals at the site to incorporate site-specific factors known to affect underwater sound, e.g., bottom shape and type, water current, and temperature.

Because the overall goal of this research was to determine the feasibility of using sound to divert fish, it was essential that the approach use a signal development process which could be customized to animals and site conditions at any plant site. The results of this four-year research program indicate that the sound signal development process and sound system equipment will divert warm and coldwater fish in spite of normal environmental stimuli such as water temperature, sunrise, and sunset. The guidance system has shown high diversion rates and 100% survival of diverted fish during field trials. This biological effectiveness should be compared to the effectiveness of other mitigation options considered for plants.

The high diversion rates and potential for reduced costs for installing, operating, and maintaining a sound system compared to costs for physical screens or other mitigation are encouraging for further evaluation. During the research, the temporarily-installed sound system was easy to retrofit, reliable, and easy to maintain. The system was programmed to generate a signal customized for single or multiple target species. Costs of an actual permanent system are

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unknown because these field trials have only recently been completed. No full scale permanent system has been installed, and costs will depend on plant site and target species characteristics.

These results indicate that underwater sound should continue to be explored as one possible means to make hydro and other power plants more compatible with fish, should it be necessary to do so. Underwater sound should be more seriously considered than it has been in the past as one possible means to relieve some environmental imitations on hydropower. The U.S. National Laboratories identified these limitations in a white paper for the U.S. Department of Energy as a major constraint limiting development of the remaining 50% of hydroelectric power capacity in the United States (Idaho National Engineering Laboratory, et.al, 1990).

<u>Research Objective</u>

To accomplish the overall objective of determining the feasibility of using sound to divert fish, it was essential that the approach use a signal development process which could be customized to animals and site conditions at any plant. The guidance system would ideally have these desirable characteristics:

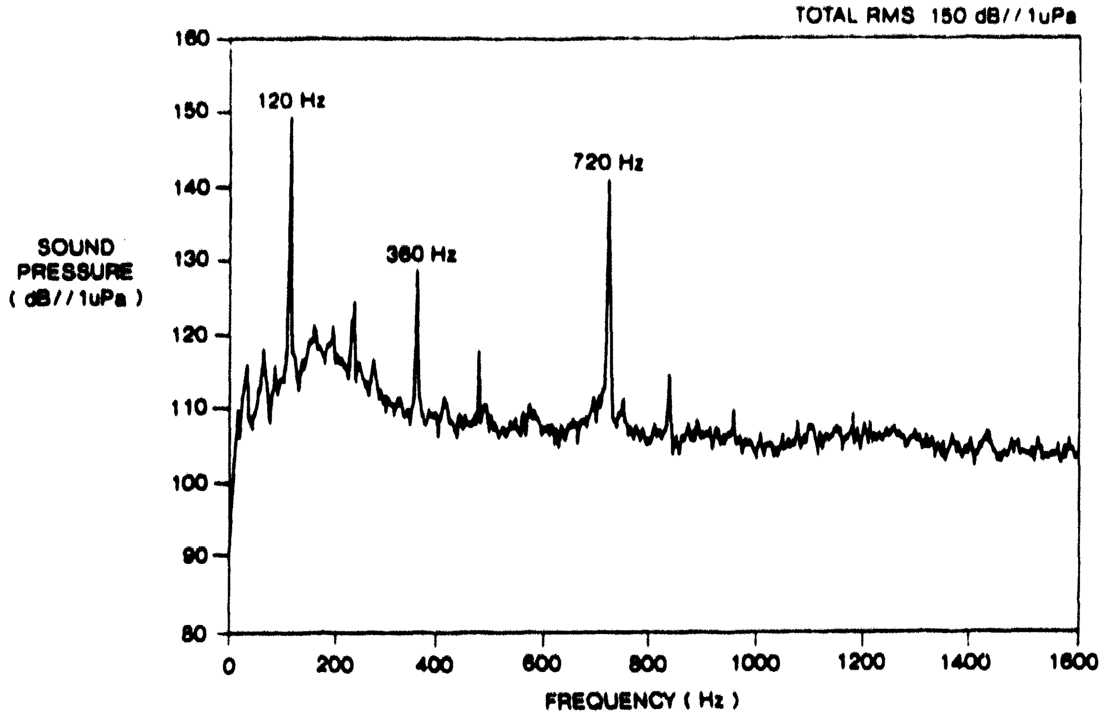
- be biologically effective with high guidance and survival rates compared to existing rates at plants and other possible mitigation alternatives;
- be easy to retrofit, reliable, and easy to maintain;
- be operated without head or flow reductions from debris loading;
- be installed without requiring new fish bypasses to be constructed;
- be less expensive than other possible mitigative measures.

<u>Description of the Signal Development Process</u>

This research followed AEP's discovery in 1986 that the submerged generator bulb turbine units at its Racine Hydroelectric Project (FERC Project 2570) on the Ohio River near Pomeroy, Ohio, produced a low-frequency (<1kHz), high-amplitude (approximately 150 dB//1uPa) underwater sound in the project's forebay. Coincident side-scan sonar observations of forebay fish distributions with sound measurements suggested the sound was influencing the distribution and limiting entrainment of fish into the turbines (WAPORA 1987). In 1988, AEP verified that the 120, 240, 360, and 720 Hz frequencies (harmonics of 60 Hz) predominated in the intake spectra when the units were in service (Figure 1). AEP hydro plants with vertical units and generators outside the water passage show different acoustic signatures at their intakes with lower numbers of harmonics at lower amplitudes.

In 1986, AEP hypothesized that fish were hearing sounds produced by Racine's generator and avoiding the intake area. In fall, 1987, AEP began developing a process to develop a signal with a sound system to repel fish by using characteristics of sounds produced by Ohio River fish. These fish sounds, heard by other fish during communication, were evaluated to help narrow the sound stimulus to the most sensitive portion of the fishes' hearing range so artificial signals could be created with selected frequencies, amplitudes, durations, waveforms, and patterns. Results of this research through 1990 are described elsewhere (Loeffelman 1990 and Loeffelman, et al. [IN PREP a and b]).

Determining how to develop a signal for maximum diversion was very important because the scientific literature showed that fish vary in

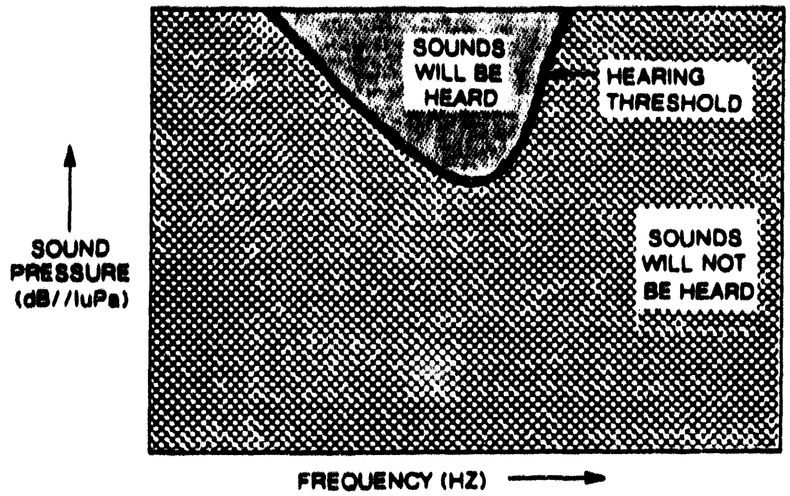


INTAKE AREA SPECTRUM DURING
RACINE PROJECT TEST CONDITIONS
UNIT 1 OFF,UNIT 2 AT 62.1 RPM,15.5MW LOAD,1080 AMP FIELD,SITE D,5/26/88

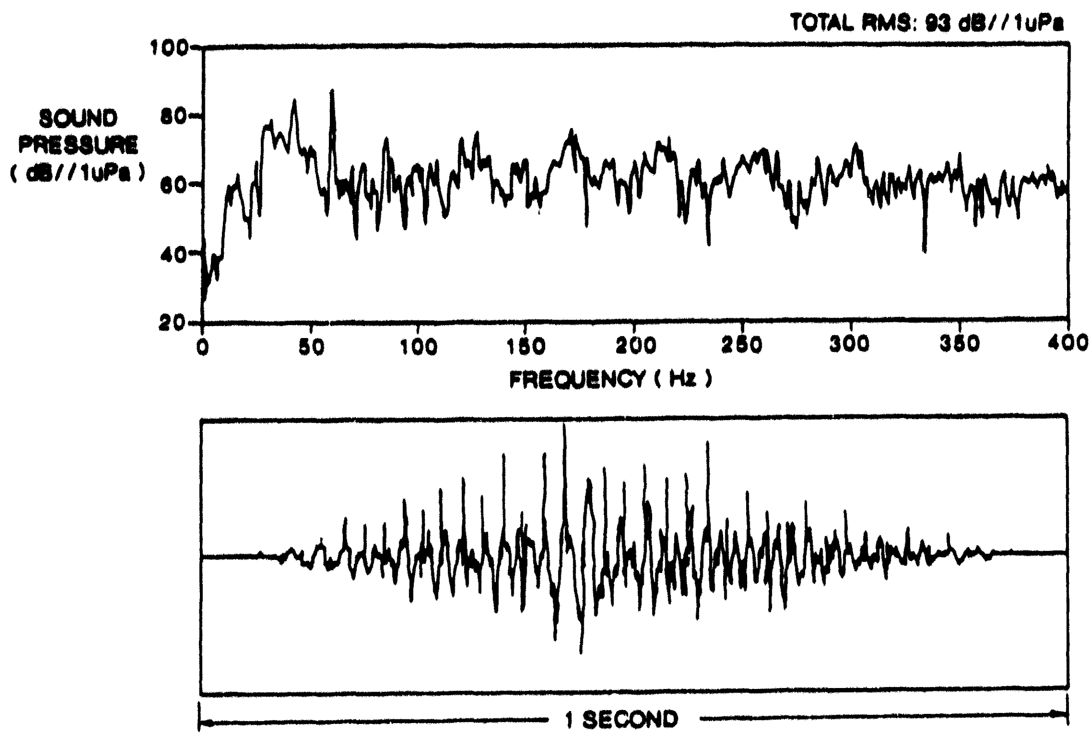
FIGURE 1

their hearing ability due to differences in sound receiving organs and the way they are coupled together (eg., Hawkins and Johnstone 1978; Popper and Fay 1973). Fish have hearing thresholds which can be graphically plotted in a form shaped like the letter U. That is, if a low frequency sound is too quiet or outside their frequency range, they will not hear it, much less respond to it. Because fish produce sounds as one means to communicate, AEP hypothesized that those fish sounds could be used to determine the most sensitive portion of the hearing range (the bottom of the U curve) for fish listening for those sounds. The literature showed that fish makes sounds like knocks, clicks, rasps, and drumming by vibrating muscles along the air bladder and rubbing skeletal parts against each other. Using a portable recording chamber to acoustically isolate the fish, AEP recorded and analyzed sounds from over two-dozen warm and cold water freshwater fish. These sounds are consistent with descriptions in the literature and sound recordings in the Borror Laboratory of Bioacoustics at Ohio State University, Columbus, Ohio. For example, see Figures 3-6 showing sounds from adult freshwater drum, adult striped bass, adult steelhead trout, and chinook salmon smolts recorded during AEP's research. The technical analysis of fish sounds considerably narrows the possible frequency range to ensure the fish hear the sound in the most sensitive portion of their hearing range.

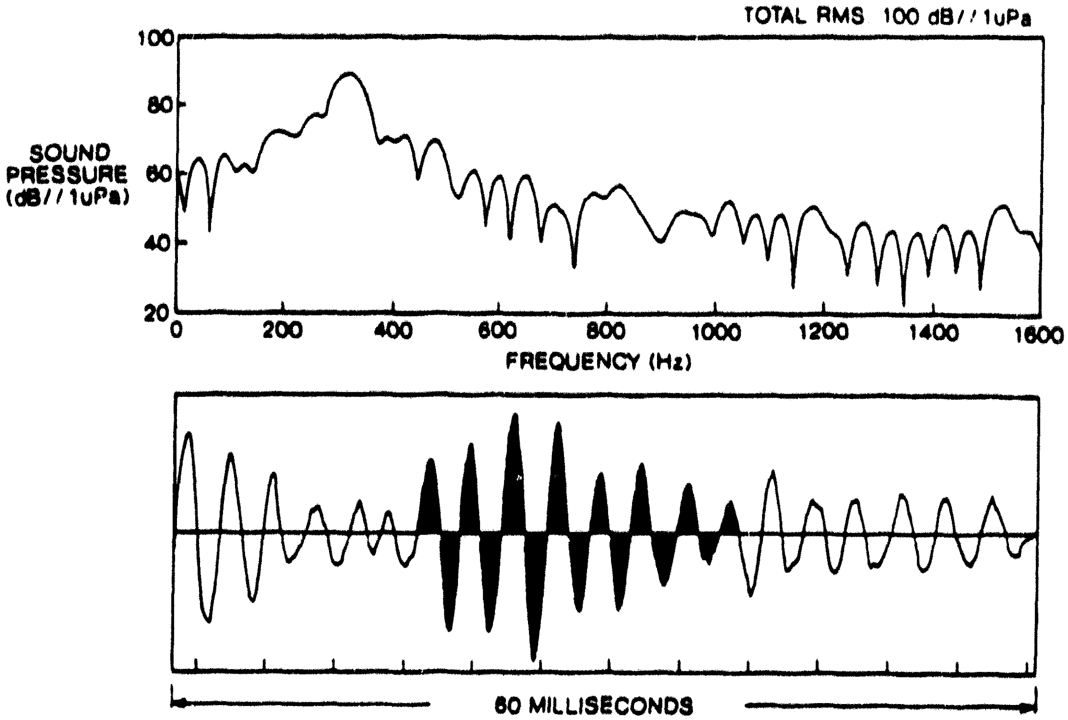
The signal development process and sound system were built upon field trials with warmwater fish at the 48 MW Racine Project (FERC Project No. 2570) on the Ohio River in 1987 and 1988; upmigrating steelhead trout and chinook salmon at the Berrien Springs Project on the St. Joseph River, Michigan in 1989; and downmigrating steelhead trout and



AUDIOGRAM OF A FISH
FIGURE 2

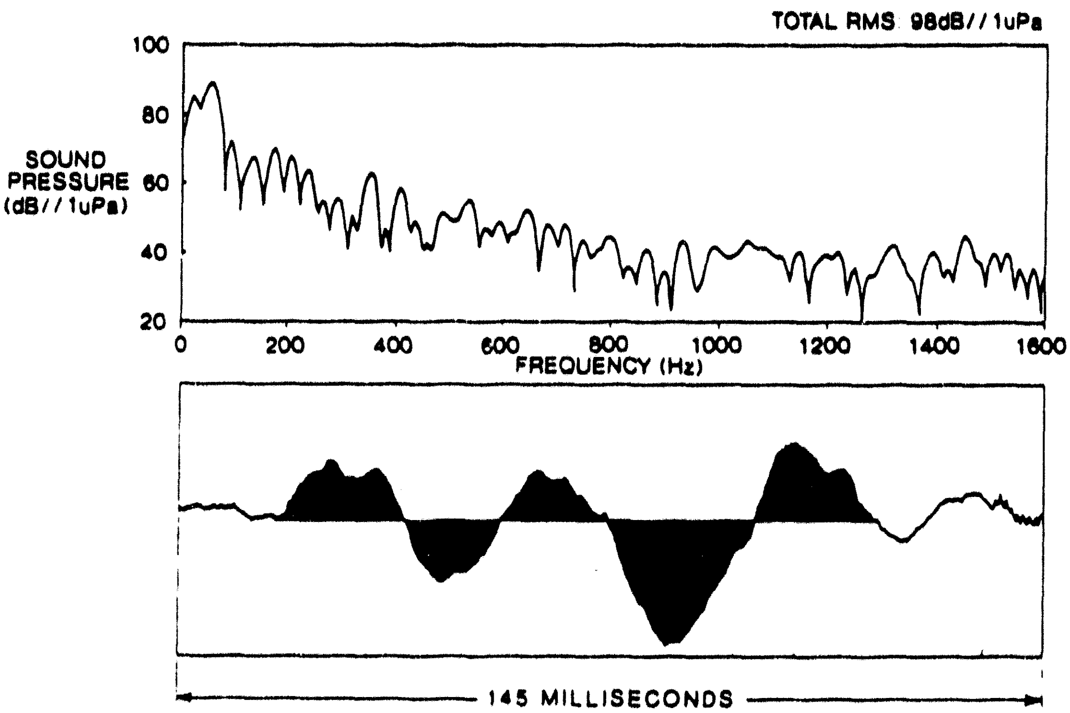


ADULT FRESHWATER DRUM SOUND, RACINE PROJECT, SPRING 1988
FIGURE 3



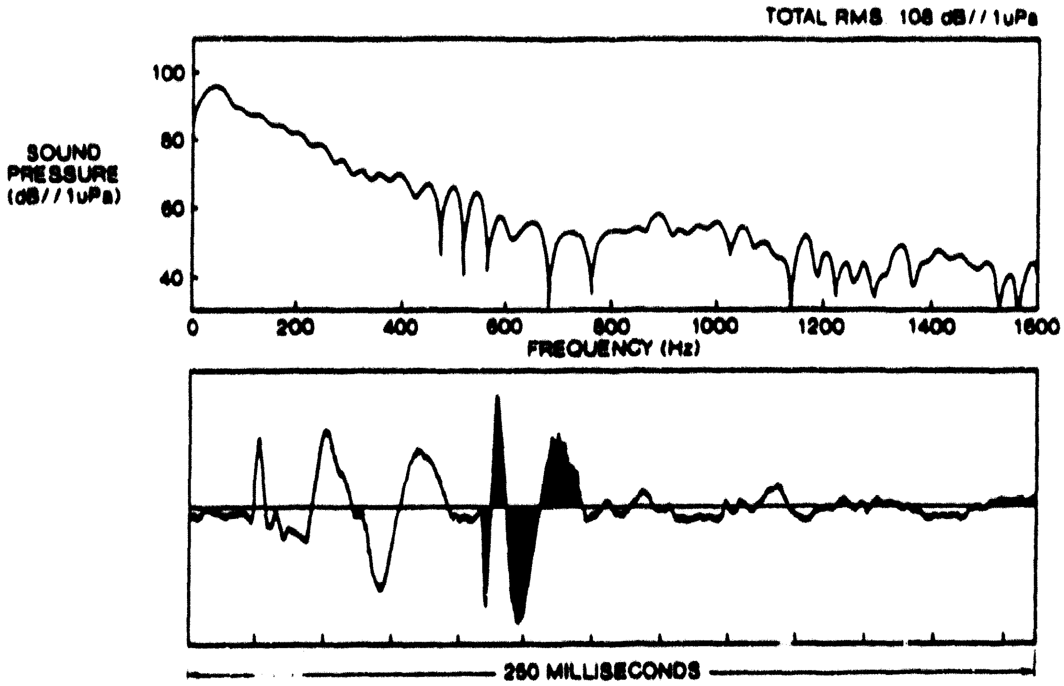
ADULT STRIPED BASS SOUND, RACINE PROJECT, SPRING 1988

FIGURE 4



ADULT (30 IN.) MALE STEELHEAD TROUT SOUND, BERRIEN SPRINGS, FALL, 1988

FIGURE 5



YOUNG (3IN.) CHINOOK SALMON SMOLT SOUND AT HATCHERY

FIGURE 6

chinook salmon smolts at the 4 MW Buchanan Project (FERC Project No. 2551) on the St. Joseph River, Michigan in 1990.

Description of the Sound System Hardware

Sound Monitoring System

Underwater sounds are monitored and analyzed with a Bruel & Kjaer (B&K) 8104 hydrophone coupled with a B&K 2635 charge amplifier and B&K 2034 spectrum analyzer. Audio recordings of sound are stored on Sony ES90 metal audio tape by either a Sony WM-D6C or Onkyo TA-R240 recorder. Hard copies are produced on a Hewlett Packard 7475A plotter coupled to the B&K analyzer. Figure 7A is a block diagram of this system.

Fish sounds are recorded from specimens collected from the waterbody and placed in an acoustically-isolated recording chamber. Flexwrap Corporation manufactured the chamber. Recording sessions usually are 45 minutes long before fish are removed to avoid being stressed from oxygen depletion. Fish movements in the chamber are videotaped in synchrony with fish sound recording so that sounds on the tape such as fish bumping the hydrophone can be verified on videotape. Natural fish sounds are isolated this way for technical analysis.

Specimens are placed in an underwater behavior observation chamber (Flexwrap Corporation) with side-scan sonar or television cameras. Videotaping during sonar or television observations (e.g., Echotec 2000 sonar unit with direct input into a Nikon VN-3000 camcorder) preserves the observations for possible later statistical treatment of the duration of time specimens spend in different areas of the sound field created by the projectors. The chamber is acoustically transparent, and the sound field is monitored by moving the hydrophone alongside the chamber.

Sound Generating System

The signal is synthesized on a Data Precision 2020 Polynomial Waveform generator, enhanced when necessary by an MXR 1/3 octave equalizer, Model 128, amplified by Crown MA1200 or Techron 7560 amplifiers and radiated by Argotec Model 219 or Model 220 moving coil projectors (underwater speakers or transducers). Figure 7B is a block diagram of this system. One Model 219 projector was capable of producing a sound pressure level of 160 dB//1uPa at 100 Hz with about 200 watts power. The Model 220 produces a sound pressure level of 180 dB//1uPa at 100 Hz with about 1,500 watts power. The projectors are mounted on platforms during the tuning process and can be permanently mounted, suspended, or towed. The Model 219 weighs about 135 lbs, and the Model 200 weighs about 250 lbs. For tests up to the spring 1990 test at Buchanan, six Model 219 projectors were operated together for a combined rated output of about 166 dB//1uPa. The Model 220 projector was a prototype scheduled for use in the fall, 1989, tests but was unavailable. The prototype was available and used for the spring, 1990, tests.

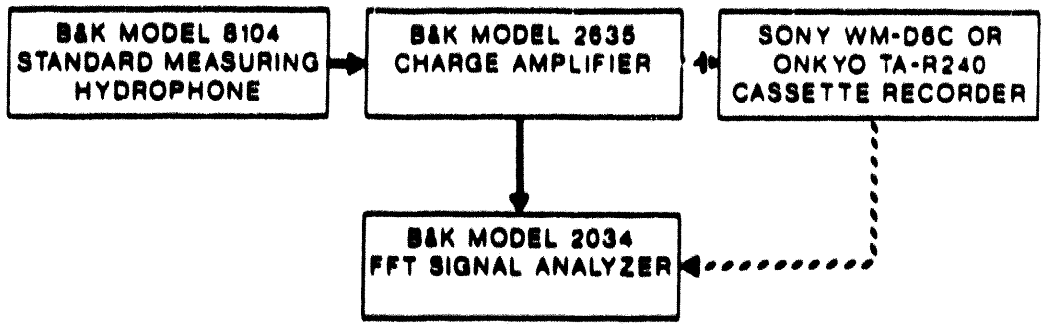
Results of Field Tests

Warmwater Fish

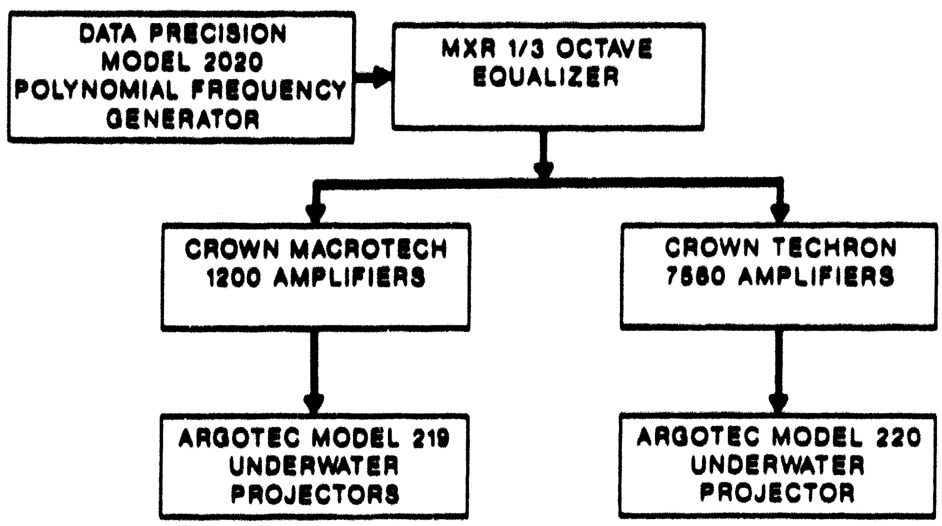
To test the hypothesis that the Racine unit sound diverted fish, paired, replicate tests were performed with the recorded Racine unit sound played back through the projectors in the Racine forebay. Significantly more fish were collected by electroshocking and gillnetting in an area with the sound off compared to fewer fish when the sound was on. Non-parametric statistical tests show $p<0.05$. In non-statistical terms, 66% of all fish and 70% of fish other than gizzard shad were diverted from the area in these tests. These results were encouraging because they supported the hypothesis that the Racine unit sound was heard by the fish, and they were stimulated to move. The Racine unit frequencies fall within the frequency range of the species' sounds and were sufficiently high in sound pressure to stimulate certain species. Based on research results after this experiment, new signals created for guiding gizzard shad and other species would increase the guiding effectiveness of underwater sound.

Upmigrating Steelhead Trout and Chinook Salmon

AEP began tests of its process to develop customized guiding sound signals on upmigrating adult steelhead trout and chinook salmon in the fish ladder at its Berrien Springs Hydroelectric Project on the St. Joseph River, Michigan, in 1988 and 1989. The literature shows salmonids have a narrower hearing range, requiring sounds to be greater in sound pressure amplitude other most fish. Trout and salmon sounds were recorded and analyzed. Frequency mixes and signal patterns were synthesized and evaluated on trout and salmon by observing behavior changes in an acoustically-transparent cage at the site. The tuning process was tested by installing projectors in the fish ladder and counting fish passing up the ladder during their six-week runs with and without the sound and counting fish while different sounds were generated. In Spring, 1989, statistically-significant differences in counts of fish show trout were repelled down the ladder ($p=0.1$; statistical power 0.99, maximum power = 1.0).



SOUND ANALYSIS INSTRUMENTATION BLOCK DIAGRAM
FIGURE 7A



SOUND GENERATION INSTRUMENTATION BLOCK DIAGRAM
FIGURE 7B

A two-frequency crescendo signal was successfully used in these tests. In non-statistical terms, 72% of the adult steelhead trout were diverted in these tests. The sound stimulus apparently modified fish movement in spite of environmental stimuli like water and air temperature. When the sound was on, the influence of these other stimuli on fish counts was not significant. When the sound was off, the influence of some of these other stimuli on fish counts was significant ($p<0.01$). In all analyses, statistical power was greater than 0.6 to discriminate to statistically-significant levels.

Counts of chinook salmon and total fish could not be shown to be statistically influenced by sound and sound on-off compared to other variables like water temperature ($p>0.69$). Fish hear at various sound pressure levels at the same frequencies. The effect of sound on the chinook salmon probably would have been greater if a signal of higher sound pressure had been used. Unfortunately, the new prototype projector capable of 180 dB//1uPa (approximately 20 dB greater than the sound level used) was available only after the tests concluded.

Statistical analyses were performed comparing the effect of the signals used on steelhead in Spring, 1989, and a new 3-frequency crescendo signal developed from chinook sounds on the influence of variables like water temperature on chinook salmon and total fish counts. Chinook salmon and total fish counts were significantly ($p<0.10$) influenced by the variables while the signal for steelhead was on. Counts were not significantly influenced by other variables when the signal for chinook was on. The power of the statistical tests is adequate considering both the species classified by variable tests and variable classified-by-species tests. These results suggest that the new frequency mix improved the acoustic stimulus sufficiently to override the influence of the other variables on chinook salmon.

Downmigrating Steelhead Trout and Chinook Salmon Smolts

Tests on downmigrating 7-inch steelhead trout and 3.5 inch chinook salmon smolts in Spring, 1990, demonstrated that they were diverted from nets in the headrace of the Buchanan Hydro station on the St. Joseph River, Michigan, (FERC Project No. 2551) with an angled sound field established in the river at the entrance of the headrace to "bump" these downmigrating salmonids away from smolt trap nets in the headrace. The strategy was to guide them toward the middle of the river and low head dam. The sound field was generated by two sets of projectors. Results of non-parametric statistical analyses of paired, replicate six-hour sound on/six-hour sound off tests at night for two months show;

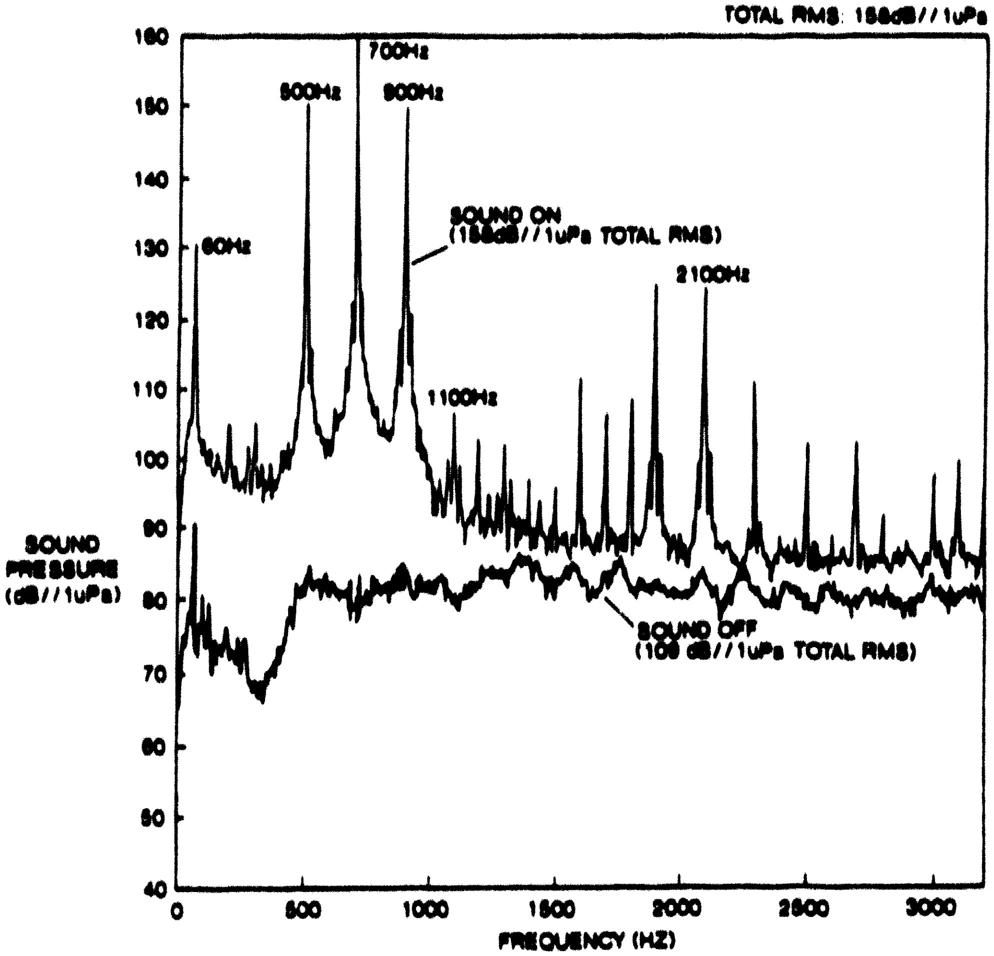
a) that the probability was greater than 99.9% that the sound influenced the catches in the headrace nets ($p=0.0042$; statistical power greater than 0.9). In non-statistical terms, results of tests at this project show 94% steelhead smolt diversion and 81% chinook smolt diversion with sound from nets in the headrace; the greatest diversion from a single headrace net was 100% for steelhead and 83% for chinook smolts and 88% for both species combined. Figure 8 shows the acoustic environment in the St. Joseph River with and without the 3-frequency crescendo signal used to divert chinook from the nets;

b) that sound modified the fishes' movement in spite of normal environmental stimuli such as sunrise and sunset. Environmental variables were significant with sound off ($p<0.05$) but not with sound on ($p>0.1$). Statistical power was greater than 0.4;

c) that signals need to be and can rapidly be customized to fish species, life stages of fish, and project site conditions. Signals which affected steelhead smolts and adult chinook salmon were not as effective on chinook smolts; a new signal developed specifically for chinook smolts was more effective. The effectiveness was determined by multi-variate rank tests of counts of smolts in the underwater observation chamber at the headrace entrance.

Performance and Durability of Sound System Equipment

The components of the sound system consisted of underwater projectors, amplifiers, and a waveform generator to electronically create the signal. During tests after maximum drive levels were established and problems with a prototype projector were resolved, these components were reliable and operated without maintenance. The projectors weigh less than 250 lbs each and were suspended from floats, holding promise for relatively easy deployment at new or old plants compared to installation of physical screens. The electronic system was programmed to generate the same signal customized for target species.



ACOUSTIC ENVIRONMENT IN ST. JOSEPH RIVER DEVELOPED TO GUIDE CHINOOK SALMON SMOLTS (3 IN.) AT BUCHANAN PROJECT HEADRACE ENTRANCE, SPRING 1990

FIGURE 8

Conclusion

The results of this research indicate that the sound signal development process and sound system equipment will divert warm and coldwater fish in spite of normal environmental stimuli such as water temperature, sunrise, and sunset. The guidance system has shown high diversion rates and 100% survival of diverted fish during the research. These results are particularly encouraging because salmonids do not hear very well compared to other fish, according to the literature from laboratory studies on fish hearing. This biological effectiveness should be compared to the effectiveness of other mitigation options considered for plants.

The high diversion rates and potential for reduced costs for installing, operating, and maintaining a sound system compared to costs for physical screens or other mitigation are encouraging for further evaluation. During the research, the sound system was easy to retrofit, reliable, and easy to maintain. Costs of an actual permanent system are unknown because these field trials have only recently been completed. No full-scale, permanent system has been installed; and costs will depend on plant site and target species characteristics.

The results show underwater sound should be more seriously considered than in the past as an option to relieve constraints on electrical generation from hydropower.

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ATLANTIC SALMON SMOLT MOVEMENT AND BEHAVIOR AT VERNON HYDROELECTRIC STATION

Douglas D. Royer[1], Brian N. Hanson[1], And Milton R. Anderson[2]

ABSTRACT

Behavior of emigrating Atlantic salmon smolts (Salmo salar) was studied at New England Power Company's (NEP) Vernon Hydroelectric Station located on the Connecticut River, Vernon, VT, to determine smolt travel time for 50 km from Bellows Fall to Vernon, approach routes, residency periods, and exit routes at the station. Some 35.6% of 122 radio tagged smolts were detected at Vernon Dam after release. Most approached the station from the eastern side of the river. Residency times of smolts ranged from <1 min to 5 days. Of the known exit routes of 40 smolts, 42.9% utilized open tainter gates, 21.4% passed through a log/ice sluiceway, and the remaining 30.9% passed through turbines. Data indicate smolts are attracted to surface spills or overflows.

INTRODUCTION

Passage of emigrating Atlantic salmon (*Salmo salar*) smolts at hydroelectric dams on the Connecticut River has become a concern of utilities and resource agencies. Smolts encounter five mainstem hydroelectric dams (Wilder, Bellows Falls, Vernon, Turners Falls, and Hadley Falls) and may pass over the dams through open spill gates, open log/ice sluices, turbines or at some dams, fishways.

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New England Power Company (NEP) is modifying Vernon Station (Vernon) to improve downstream fish passage. The log sluice gate at Vernon is currently opened continually during smolt emigration to provide a passage route. Additionally, a fish passage pipe within the forebay will be completed prior to the spring smolt emigration in 1991.

The objective of this study was to characterize smolt emigration and behavior at Vernon, including travel time from Bellows Falls to Vernon, approach routes, residency periods, and passage route efficiencies at Vernon.

SITE DESCRIPTION

Vernon Dam is located 50 km below Bellows Falls at river kilometer 229 on the Connecticut River in the towns of Vernon, VT and Hinsdale, NH. The project consists of a 290 m concrete gravity type dam, including a 183 m concrete spillway section and an integral powerhouse 107 m long. The spillway is equipped with 6 tainter gates, having the capability of passing up to 2408 m^3/sec in a controlled discharge. The plant has a nominal capability of 24.4 MW at a maximum discharge rate of 425 m^3/sec. There are 10 main generating units consisting of single and triple runner Francis wheels.

METHODS

Approximately 400 one year old salmon smolts were obtained from the U. S. Fish and Wildlife Service's White River National Fish Hatchery in Bethel, VT. They were maintained in three 1.8 m diameter x 0.8 m deep holding tanks at Bellows Falls Station. River water was supplied to each tank at approximately 22.7 lpm.

Smolts were anesthetized, then a 9.3 mm diameter, 27 mm long radio transmitter (Lotek Engineering Company) weighing 4.6 g in air was inserted orally into each fish's stomach. Transmitters propagated signals on 42 unique frequencies from 148.588 to 150.523 MHz, separated 60 kHz apart with three pulse rates per frequency. Battery life was calculated to be 15 days. Each smolt was then transferred to a holding tank and held overnight to acclimate to the transmitter and recover from handling stress. The following day, smolts were transported 0.8 km downstream of the Bellows Falls Station and released.

Eight Lotek SRX_400 receivers were deployed at 5 locations for the study (Figure 1). One of two receivers at Station 1 monitored the tainter gate area, and was coupled to a main antenna and four 4-element Yagi (Cushcraft Model P150-4) auxiliary antennas through a switch box. The main antenna was positioned on the southeast corner of the dam and oriented upstream at a 45° angle. This main/auxiliary antenna array provided detailed coverage of tagged smolts. When a signal was detected on the main antenna the frequency was scanned sequentially on each auxiliary antenna. The second receiver, coupled to the same main antenna, at Station 1 continually monitored the area to detect other tagged smolts in the event the first receiver was scanning auxiliary antennas.

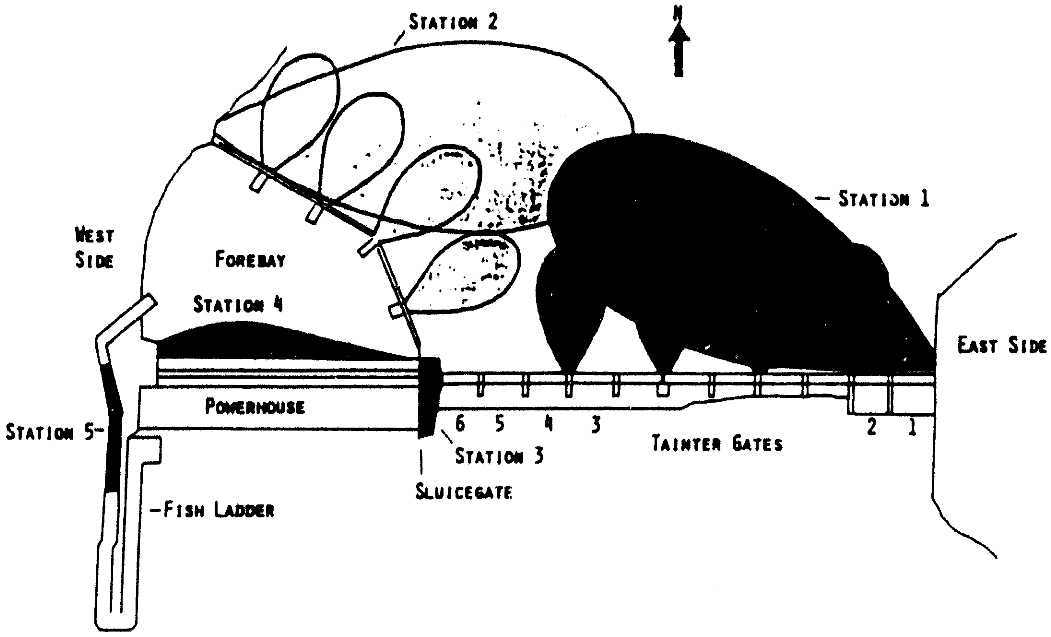

FIGURE 1

Map of Vernon Station showing telometric monitoring stations.

Station 2 was configured identically to the first receiver at Station 1. The main antenna was deployed on the westernmost concrete log boom support pier (Figure 1). One auxiliary antenna was installed at each of the four remaining log boom piers. The auxiliary antenna ranges were approximately 15 m in front of each log boom pier.

Station 3 monitored the log/ice sluice (Figure 1). Three receivers were coupled to one 30 m long 14 gauge insulated copper wire antenna suspended along the length of the sluice. Receivers scanned frequencies out of synchronization and at high rates (>1 freq/sec) to ensure detection of tagged smolts.

Station 4 monitored the inner forebay near the turbine intakes (Figure 1). A 100 m long 14 gauge insulated copper wire antenna, strung across the length of the intakes, was connected to the receiver approximately 1/4 the distance from its western end to achieve the desired reception area.

The Station 5 receiver, positioned at the fish counting house, was coupled to a 14 gauge copper wire antenna suspended approximately 1/4 the length of the fish ladder (Figure 1).

Data, off loaded from the receivers with a lap top computer, were consolidated into a PC database for review and verification.

RESULTS

A total of 122 radio tagged smolts was released in four groups on 26 April (n=30), 1 May (n=30), 11 May (n=30), and 15 May (n=32). The groups are referred to, hereafter, as groups 1, 2, 3, and 4 (Table 1). Four smolts (three from group 1 and one from group 2) were excluded from data analyses. Two had detached transmitter antennas and two others were inadvertently given frequencies associated with extremely high background noise at Vernon.

TABLE 1

Data summary of all salmon smolts which were recorded at the Vernon Station, 1990.

Group	1	2	3	4	Total
*No. Released	27	29	30	32	118
Date	26 Apr	1 May	11 May	15 May	26 Apr-15 May
Time	0930	0945	1030	1730	0930-1730
Water temp.(C)	9.0	10.5	11.4	11.0	9.0-11.4
River Flow(m^3/sec)	368	397	306	878	306-878
No. at Vernon	9(33.3%)	14(48.3%)	12(40.0%)	7(21.9%)	42(35.6%)
Elapsed Time					
Range	39:00-70:45	24:16-142:24	17:19-49:00	13:39-20:30	13:39-142:24
Mean	60:19	64:53	25:16	16:47	44:25
Approach Route					
East	7(77.8%)	12(85.7%)	11(91.7%)	7(100.0%)	37(88.1%)
West	2(22.2%)	2(14.3%)	0	0	4(9.5%)
Mid-River	0	0	1(8.3%)	0	1(2.4%)
Residency Time					
Range	00:02-30:32	00:07-120:57	00:00-06:08	00:00-03:35	00:00-120.57
Mean	04.16	21:41	00:37	00:32	08:09
Exit Route					
Turbine	4(44.4%)	7(50.0%)	1(8.3%)	1(14.3%)	13(30.9%)
Tainter Gate	4(44.4%)	0	8(66.7%)	6(85.7%)	18(42.9%)
Sluice Gate	1(11.1%)	5(35.7%)	3(25.0%)	0	9(21.4%)
Unknown	0	2(14.3%)	0	0	2(4.8%)

* Excludes 4 fish due to transmitter problems

Overall condition of tagged smolts prior to release was excellent for the first three groups. Ten specimens tagged for the fourth group, however, had died or become lethargic after tagging. These fish were replaced with 10 more tagged smolts and all tagged fish were released the following day.

Some 42 (35.6%) of 118 tagged salmon smolts migrated to and were monitored in the vicinity of Vernon (Table 1). Time to reach Vernon ranged from 13 h 39 min (Group 4) to 142 h 24 min (Group 2) and averaged 44 h 25 min. Average travel times generally decreased with groups released later in the study.

A total of 37 (88.1%) smolts which reached Vernon approached from the eastern side of the river. Four fish approached from the west and only one approached from mid-river. On average, smolts resided at the dam 8 h 9 min; maximum time was 5 days. Tainter gates were utilized by 42.9% of smolts at the station for passage. An additional 21.4% of smolts passed through the sluice. Generating turbines were passage routes utilized by 30.9% of the smolts. Passage routes for two smolts were unknown.

Nine smolts (33.3%) from Group 1 reached Vernon in an average 60 h 19 min (Table 1). River flow and water temperature at time of release was 368 m^3/sec and 9 C, respectively. Most (77.8%) approached Vernon from the eastern side of the river. Passage routes available to this group included the sluice, generating turbines, fish ladder and tainter gate #1. Smolts remained at Vernon for an average 4 h 16 min before passage. Four passed through tainter gate #1, four exited through turbines and one passed over the sluice gate.

All four specimens which passed through the tainter gate approached the dam from the east side. Two passed in 2 min, one in 7 min and the other in more than 30 h. The latter fish was recorded upstream of the tainter gate area then disappeared until the following day when it passed over the gate.

Of the four which passed through turbines, 2 approached from the west side of the river. One entered the forebay area and passed immediately (<3 min); the other entered and remained close to the units for 6 h before passing. Two smolts approached the dam from the east and migrated into the forebay. One remained in the area for approximately 8 min before entraining. The other moved upstream out of the forebay area to approximately mid-river. Within 8 min it returned and passed through a turbine.

The final fish of Group 1 approached the dam from the east and migrated toward the forebay area. It delayed at the mouth of the sluice gate for only 2 min before passing through it.

Almost half (48.3%) of Group 2 smolts reached Vernon (Table 1). They arrived in 24 to 142 h (Mean = 64 h 53 min) after release. River flow and water temperature, at time of release, was 397 m^3/sec and 10.5 C, respectively. Approach routes again, were primarily from the east (85.7%). Passage routes available to this group were the fish ladder, sluice gate and turbines until 4 d after release when tainter gate #6 was opened. High water events and varying river flows necessitated various tainter gate openings, thereafter. All smolts but one arrived at Vernon when all tainter gates were closed. Consequently, half (50.0%) of the smolts passed through the turbines, five passed through the log/ice sluice, and two smolt passage routes were not determined. Smolts remained near Vernon for an average 21 h 41 min.

Both fish which approached from the west side passed through the turbines. One passed less than 7 min after it was logged on Station 2. The other entered the forebay and remained near the trash rack area for more than 4 h before entraining.

Twelve (40.0%) smolts from group 3 reached Vernon in an average of 25 h 11 min (Table 1). River flow at time of release was 306 m^3/sec at Bellows Falls and water temperature was 11.4 C. All fish, but one, approached from the east side of the river; the one approached from mid-river.

High water events, after fish release, resulted in an availability of multiple passage routes. Tainter gates 4, 5 and 6 were open and available to earlier arrivals and gates 5 and 6 were still open when the last three smolts arrived. Consequently, residency times were minimal and most (75%) passed through tainter gates. Only one smolt passed through turbines. It moved into the forebay and remained near the trash rack for just over 6 h before passing.

Only seven (21.9%) smolts released in group 4 reached Vernon (Table 1). River flow was high (878 m^3/sec) and water temperature dropped to 11 C. Time to reach Vernon varied from 13 h 39 min to 20 h 30 min (Mean = 16 h 47 min). All smolts approached the dam from the eastern side of the river. High flows necessitated spillage and tainter gates 3, 4, 5 and 6 were available for passage during the time period most specimens were present. Six smolts passed over the gates; average residency time was less than 2 min. The other specimen entered the forebay area and delayed near the trash rack for 3-1/2 h before entraining.

DISCUSSION

The difference in proportions of tagged smolts arriving at Vernon was probably related to the condition of the specimens at the time of tagging. The initial condition of salmon smolts held at Bellow Falls was excellent. A large proportion of these fish reached Vernon. As time progressed and water temperature increased, smolts exhibited signs of stress. When group 4 fish were tagged, many smolts showed signs of descaling and fungal infections, and mortality in the holding facility increased. These factors probably contributed to the relatively low numbers of group 4 fish arriving at Vernon. The fate of those smolts which did not reach Vernon is unknown.

In addition to the four smolts excluded from the sample of tagged specimens it is likely additional smolts may have been present at Vernon, but were never logged. Receivers were configured to exclude pulse rates higher than 200 bpm. All transmitters supplied by the manufacturer were below this value. However, during data analyses, it was noted that most transmitter pulse rates had increased from values supplied by Lotek. After extensive testing, Lotek concluded that due to radical voltage destabilization exhibited by the same type of batteries used to power transmitters, pulse rates could be expected to increase as much as 20% after activation. This pulse rate increase would have eliminated 26 transmitters from being logged on the monitors.

As expected, most smolts approached Vernon from the east side of the river. This is consistent with the study of Saunders and Mudre (1988) which found 72.7% selected an eastern approach. Time to reach Vernon from Bellows Falls was variable for group 1 and 2 smolts. This was probably a function of water temperature, river flow, and individual smoltification stage. As temperature and flow increased, as with groups 3 and 4, smolts arrived at Vernon more rapidly with less variability in times.

Upon reaching Vernon, smolt passage routes and residency times were diverse and generally dependent on passage routes available. When group 1 fish arrived, tainter gate #1 (eastern most gate) was open. Although

77.8% approached from the east side, only 44.4% passed through this gate. The remaining fish moved towards the forebay/sluice gate area. Mean residency time was just over 4 h. In contrast, when group 2 smolts reached Vernon, passage routes were limited to turbines and sluice gate and residency times averaged 21 h 41 min. Group 3 and 4 smolts were offered multiple passage routes and they remained at Vernon an average of 37 min and 32 min, respectively. Most passed through open tainter gates. There was, however, an apparent hesitancy in some smolts to enter the high velocity fields generated by the open gates. Many were recorded on auxiliary antennas, just upstream of the gates for up to 13 min. Others passed rapidly. There was one occurrence when a smolt may have been guided by the log and ice boom to the sluice. It was logged on the west main antenna, then on auxiliary 3 just prior to passing through the sluice.

Utilization of passage routes varied with the availability of routes (Figure 2). When only the turbines and sluice were available, all specimens approaching down the west shoreline were entrained; those approaching from the east utilized both routes equally. During the period tainter gate #1 was open, all western approaching smolts were entrained and the

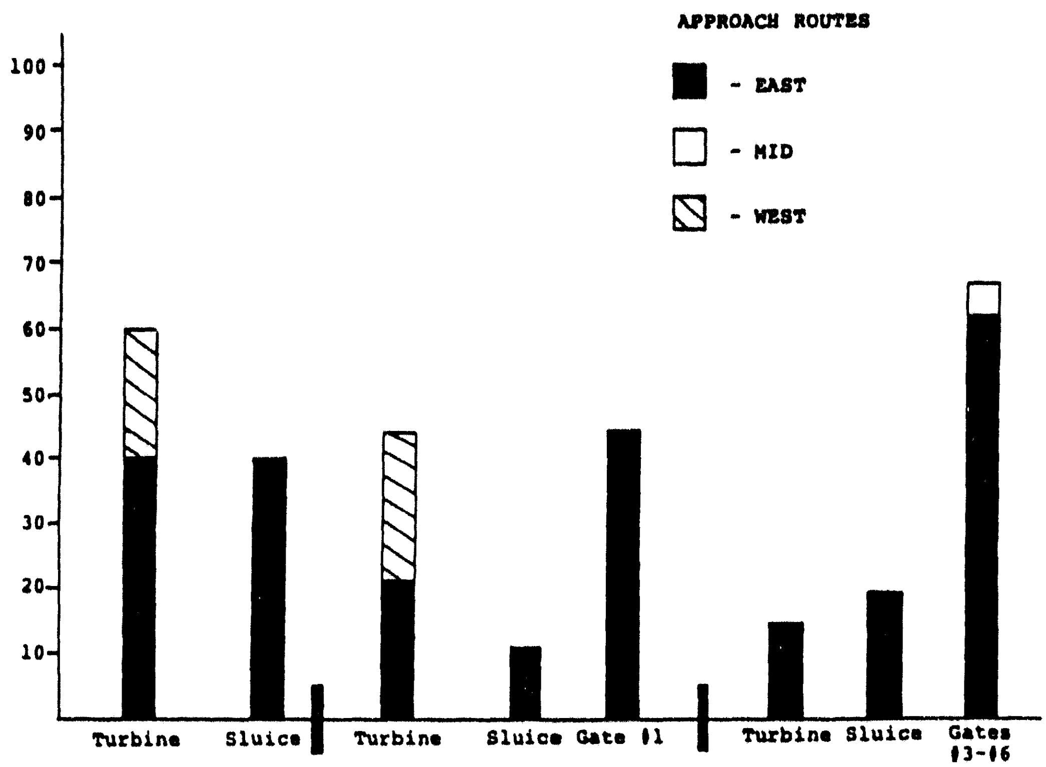

FIGURE 2

Proportion of smolts utilizing available passage routes at Vernon Dam, 1990.

majority of eastern approaching specimens utilized the gate. However, almost twice as many eastern approaching smolts utilized turbines as the sluice. During the high flow event, when any combination of tainter gates #3 - #6 were open, most smolts passed through the gates; approximately equal numbers utilized the sluice and turbines.

The most extensive movement patterns at Vernon were exhibited by group 2. Generally, those smolts which approached from the east, followed the dam westerly and either entered the forebay area or passed down the sluice. Some smolts moved about the forebay extensively, others left the forebay and returned later. No smolts, after entering then leaving the forebay, exited through the sluice. They eventually returned and passed via turbines.

A fish passage pipe with a surface entrance within the forebay may prove to be an efficient bypass device. Telemetered smolts which entered the forebay, remained in the area for greater lengths of time than other locations (Table 2). Turbine passed smolts remained in the forebay area an average of 2 h 31 min after being detected on monitor Station 4. In contrast, sluice passed smolts were delayed an average of only 35 sec after initial detection on the sluice gate monitor. This was likely due to their surface orientation behavior, and the location of the turbine intakes, which are approximately 6 m below the surface. Smolt's inability to find a surface fed passage route contributed to their delay in this area. Eventually they swam deep and entrained.

TABLE 2

Comparison of residency times for smolts passing via turbines vs. sluice gate, 1990.

	PASSAGE ROUTE	
	TURBINE	SLUICE
Number	13	9
Residency Time		
Range	<00:01-09:45	<00:01-05:18
Mean	02:31	00:35

One factor that may need consideration in design of a fish bypass is the volume and velocity of flow. It appeared that the lesser volume of flow at the sluice gate may have been more attractive to the salmon smolts than higher flows at open tainter gates. Passage times at the tainter gates ranged from immediate to 21 min later (Table 3). Mean residency time was 1 min 47 sec. In contrast, smolts only resided near the sluice gate from immediate passage to five min. Mean residency time was only 35 sec (Table 2).

TABLE 3

Residency times of smolts logged on Station 1 auxiliary antennas prior to passage.

	PASSAGE ROUTE Gate	Sluice
Number	11	1
Residency Time		
Range	<00:01-12:21	00:40
Mean	2.19	-

ACKNOWLEDGMENTS

We would like to thank personnel at Vernon Station (NEP), Bellows Falls Station (NEP), and the White River National Fish Hatchery (USFWS) for their cooperation in making this study a success.

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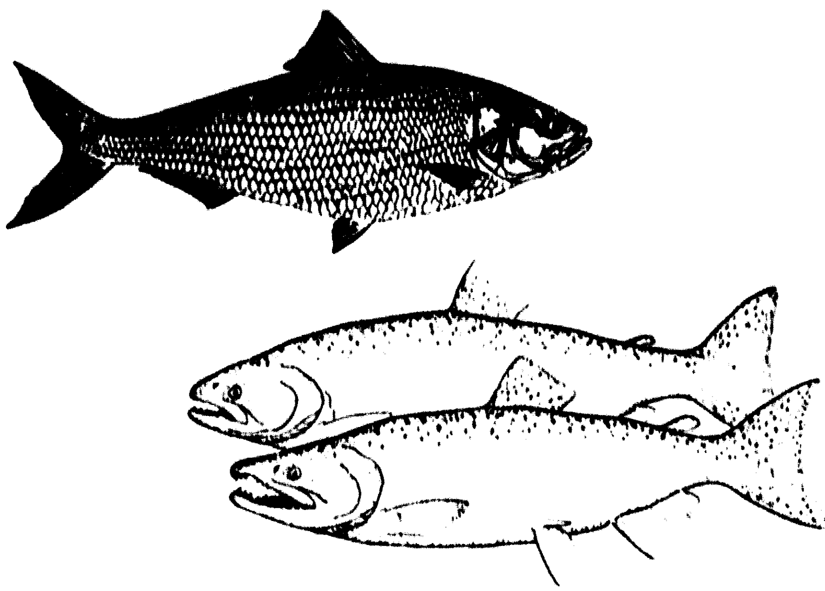

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Presented at the Northwest Hydroelectric Association Conference
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Are Inflatable Weirs Effective at Passing Gravel?

A Case Study from the Weeks Falls Hydroelectric Project

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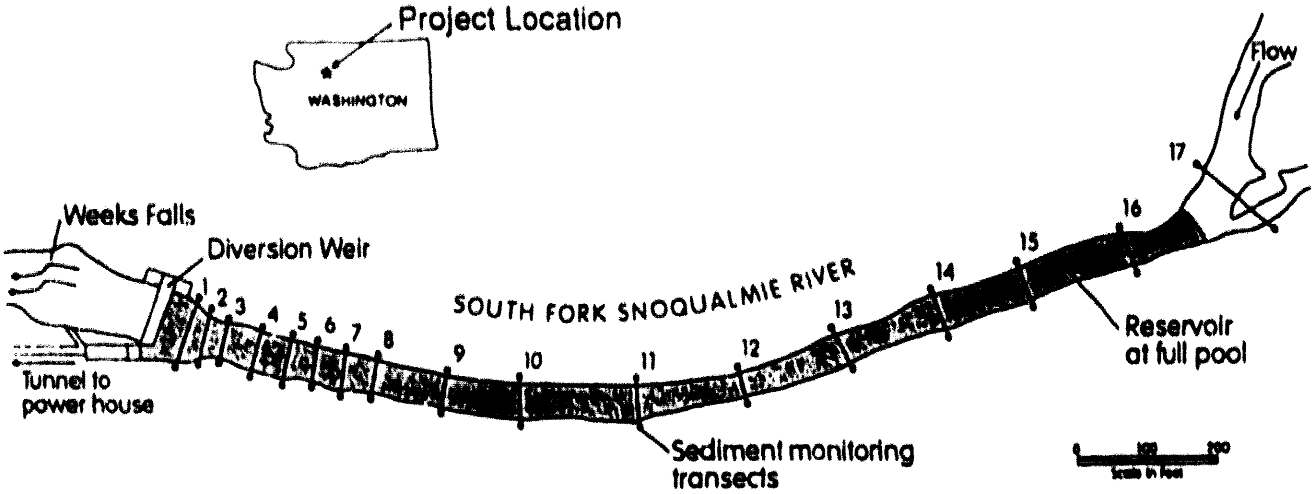
Deposition of sediment in project impoundments creates a number of operational and environmental problems, including loss of storage capacity, sediment-clogged intakes, interruption of spawning gravel transport, and coarsening or erosion of downstream substrate. Inflatable weirs are often suggested as one means of minimizing these sedimentation problems. The weirs can be deflated during high flows, allowing bedload transport to continue unimpeded. Inflatable weir technology is relatively new in the Pacific Northwest. The Weeks Falls Hydroelectric Project, online in 1987, was one of the first such installations. A sediment monitoring program was conducted at the project to test the effectiveness of the weir at passing bedload sediments. Seventeen transects were surveyed prior to project operation and annually for the next four years. During the four years of study, minimal amounts of erosion and deposition occurred in the impoundment. The downstream shifting of erosion and deposition patterns suggest natural bedload transport processes continue with the inflatable weir in place. The results of the monitoring program have been accepted by the resource agencies and FERC, and no additional monitoring or sediment mitigation measures are required.

Construction of diversion structures, whether they are large dams or small weirs, change the sediment transport regime of rivers. The impoundment created by diversions slows water velocities, resulting in the deposition of sediment and gradual filling of the pool. The magnitude and duration of this effect depends upon the size of the structure. Large dams trap bedload sediment and the majority of suspended sediment for a period of tens to hundreds of years. Small impoundments trap bedload sediment and only a small fraction of the suspended load during the few to tens of years required to fill the impoundments.

This process creates a number of operational and environmental problems, including loss of storage capacity, sediment-clogged intakes, interruption of spawning gravel transport, and coarsening or erosion of downstream substrate. Inflatable weirs have been proposed as one method of minimizing these effects at small diversion sites by allowing bedload transport to continue uninterrupted.

Inflatable weirs are essentially large tubes of rubber, bolted across the river bed along one edge, that can be inflated to create a dam. When deflated, the weirs lay flat, only a few inches higher than the original river bed. By deflating the weir during the appropriate high flows, bedload transport can, at least theoretically, continue unimpeded through the reservoir. An inflatable weir was proposed for use at the Weeks Falls Hydroelectric Project. Since this was one of the first installations in the Pacific Northwest, there were questions from resource agencies concerning how effective the weir would be at allowing spawning-sized gravel to be transported through the impoundment. A monitoring program was devised to test the weir, and to help define when the weir should be deflated.

Figure 1. Weeks Falls Hydroelectric Project



Project Description

The Weeks Falls Hydroelectric Project is located on the South Fork Snoqualmie River, King County, Washington (Figure 1). The project diversion consists of an inflatable rubber weir located immediately upstream of Weeks Falls. At maximum inflation, the weir has a height of six feet, and impounds 12 acre-feet of water. The impoundment extends 1,500 feet upstream of the weir. Water is diverted into a tunnel leading to a powerhouse below the falls with a generation capacity of 4.7 MW.

The mean annual flow of the South Fork Snoqualmie River at the project diversion is 280 cfs. The river channel at the diversion weir is 80 feet wide and is underlain by the bedrock that produces a waterfall. Upstream of the weir, the river channel is constrained to a 60 to 100 foot-wide channel by a rip rap armored left bank and a steep, erosion-resistant right bank. The small and infrequent gravel bars in this reach indicate sediment is transported rapidly through this reach. A quarter mile upstream of the weir the river channel makes an abrupt bend, widens considerably, and contains large, shifting gravel bars indicative of a depositional zone.

Based upon sediment transport calculations in the reach upstream of the diversion weir, flows at or above 3,000 cfs are capable of disrupting the armor layer and transporting bedload sediment. These flows have a recurrence interval of 1.8 years, indicating bedload transport occurs sporadically. Average annual bedload transport rates were calculated to be 2,200 tons (1,570 yd^3) by Dunne (1984). Assuming average annual transport rates, it would take approximately 12 years for the impoundment to fill with bedload sediment if the weir was not deflated. During this time, no bedload would be transported past the weir.

Monitoring Procedures

The rubber weir at the Weeks Falls Project is deflated during summer low flows and at least once a year during flows over 3,000 cfs, if flows of this magnitude occur. The hypothesis to be tested by the monitoring plan is whether or not this deflation schedule allows bedload to be transported past the weir. The basic assumption of the test procedures is if bedload does not accumulate in the impoundment upstream of the weir, gravel supply to the downstream river channel is not being interrupted.

Prior to operation of the Weeks Falls Project, seventeen transects were established upstream of the weir. The location of these transects are shown on Figure 1. The elevation of points every three feet across each of the transects was surveyed prior to project operation (February, 1987). Surveys after the start of project operation were conducted during low flows in September of 1988, 1989, and 1990, and October 1991.

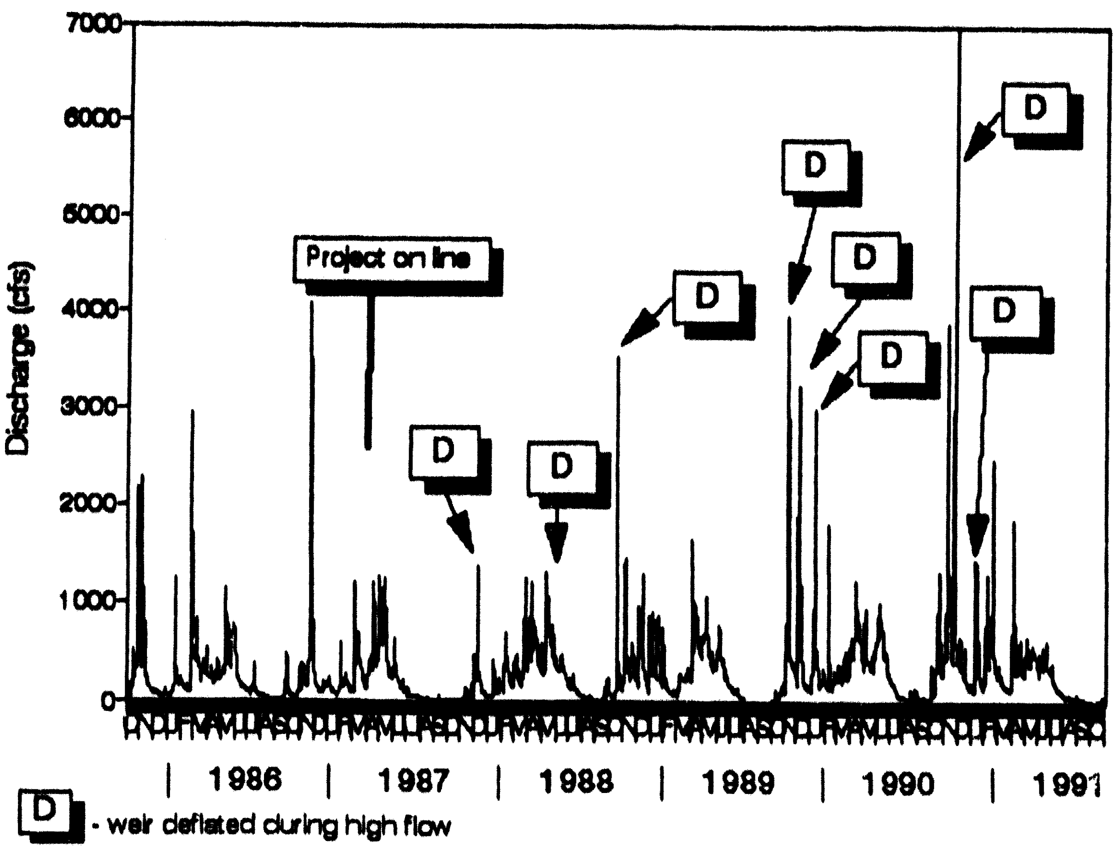
The net area of sediment erosion or deposition at each transect was calculated by multiplying the change in elevation at each station by the length between stations. This net area at each transect was then multiplied by the distance halfway to the next transect downstream plus halfway to the next transect upstream to calculate the volume of sediment erosion or deposition at that transect. Sediment volume changes at the transects were summed to produce a net change in sediment volume over the entire study area. In order to determine the impacts of the changes in sediment volume, the results of the surveys were compared to the originally computed average sediment transport rates.

Hydrology and Project Operation during the Study Period

Figure 2 shows discharge at the Garcia Gauge (USGS 12143400; 3.7 miles upstream of the project) during the study period.

Records of project operation show operation began on May 22, 1987. Between that time and the September 1988 measurements, the weir was deflated three times: December 9, 1987 (1,130 cfs); May 13, 1988 (1,180 cfs); and on August 20, 1988 during low flows (the sluice gates were also opened at that time). The highest recorded flow during the period was 1,270 cfs on December 10, 1987. The weir remained deflated and the sluice gates open between August 20 and the September 1988 measurements.

Figure 2. Discharge at the Garcia Gauge during the Study Period



Between the 1988 and 1989 surveys, high flows occurred on October 16, 1988 (3,925 cfs); November 5 and 6, 1988 (1,500 cfs) and December 13, 1988 (1,411 cfs). The weir was deflated during the October 16, 1988 high flow event. The weir was also deflated from mid-July through the September 1989 measurements.

Between the 1989 and 1990 surveys, high flows occurred on November 9, 1989 (4,120 cfs), December 4, 1989 (3,350 cfs) and January 9, 1990 (3,110 cfs). The weir was fully deflated on all three of these days and from late July through the September 1990 survey.

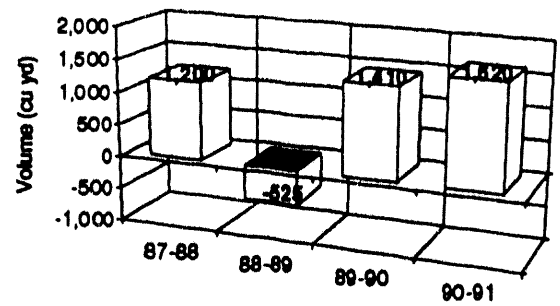
Between the 1990 and 1991 surveys, high flows occurred on November 9, 1991 (3,870 cfs), November 24, 1991 (6,950 cfs), and February 19, 1992 (2,460 cfs). The weir was deflated during the November 1991 floods, on January 13 (1,430 cfs) and January 19, 20, and 21 1992 (442, 336, and 315 cfs) during ice flow episodes, and from late July through the 1991 survey.

Results

The results of the surveys are displayed graphically in Figure 3, showing the volume change in sediment stored in the study reach between each of the surveys.

The total increase in sediment volume between the 1987-1988 surveys was approximately 1,200 yd^3 (80 percent of the estimated average annual volume of bedload transport). Between the 1988 and 1989 surveys, 525 yd^3 of sediment (33 percent of average annual transport) was lost from the study area. A total of 1,410 yd^3 of sediment (90 percent of average annual transport) was added to the study area between the 1989 and 1990 surveys, and 1,620 yd^3 (103 percent of average annual transport) was added between 1990 and 1991. Thus, the net change over the four years is an accumulation of 3,740 yd^3 (the equivalent of 2.4 years worth of average annual sediment transport). It should be noted that the recorded volumes of sediment deposition or erosion include sand and finer-grained sediments as well as gravel. Thus, the total amount of *gravel* (the concern for replenishing downstream spawning habitat) accumulated over the study period is actually less than 3,740 yd^3.

Figure 3. Change in Sediment Storage between Surveys



Discussion

Several observations can be made regarding sediment transport and the effects of weir operation over the course of the study. As mentioned above, theoretical sediment transport calculations predict that bedload transport takes place at flows above about 3,000 cfs. However, between the February 1987 and September 1988 surveys, when the highest flow was 1,180 cfs, accumulation of sand and gravel and shifting of gravel on the bed took place. Based on grain sizes of accumulated sediments, it is estimated that 800 yd^3 of the total 1,200 yd^3 accumulated was gravel sized and the rest was sand sized. This indicates that the flow required to transport gravel-sized sediment is less than 3,000 cfs.

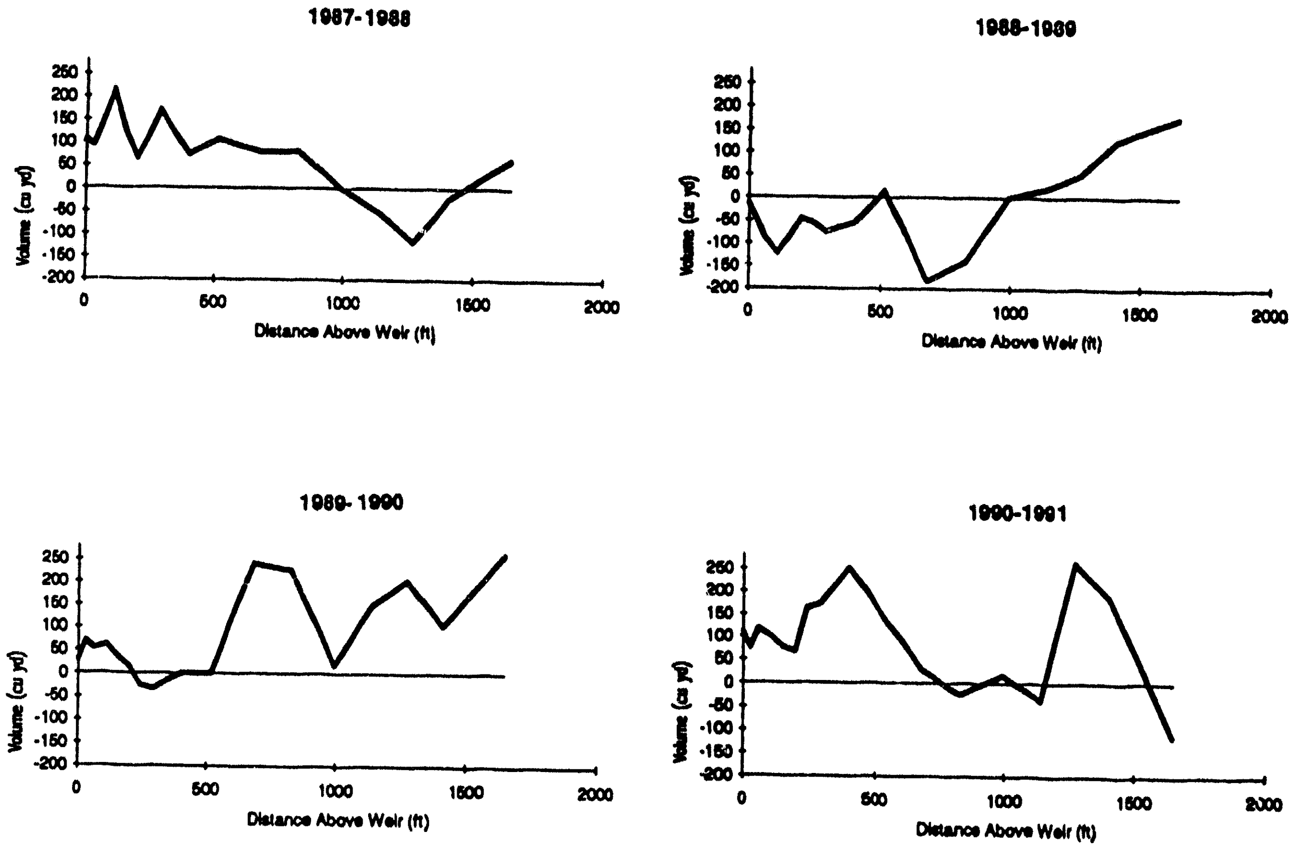
A second observation is that based on the available evidence, there does not appear to be any correlation between number or magnitude of high flows and net deposition or erosion in the study reach. During the first year, several moderate flows (less than 1,500 cfs) occurred, the weir was deflated twice, and 1,200 yd^3 accumulated. This would seem to indicate that accumulation can occur during flows lower than 3,000 cfs. However, during the second year, one high flow (nearly 4,000 cfs) with the weir deflated took place followed by several moderate flows (at least three near 1,500 cfs) during which the weir was not deflated, resulting in a net loss of 525 yd^3 of sediment. This indicates that the weir deflation was effective in removing sediment from the impoundment, and that, contrary to the previous year, the moderate flows did not cause a net accumulation. During the third year, three flows above 3,000 cfs occurred (the weir was deflated during each) and 1,410 yd^3 accumulated in the reach. During the fourth year of study, the weir was deflated during two high flows (one extremely high; 6,950 cfs), but not during the following high flows (one of 2,460 cfs and another of almost 2,000 cfs). Accumulation of 1,620 yd^3 occurred during the year, indicating that if the impoundment was cleared of sediment during weir deflation, additional sediment accumulated during subsequent flows.

These results show that prediction of accumulation or erosion in the study reach based on hydrology and weir deflation is not possible. Another mechanism must be responsible for the patterns of accumulation and erosion in the reach.

Researchers of sediment transport dynamics often report that bedload movement is not continuous during floods, but rather moves in pulses. They also note that bars, or accumulations, of gravel often migrate downstream as units. Examination of Figure 4, showing the change in sediment storage at each transect between the four surveys, indicates that this phenomenon may be occurring in the study reach.

Between the first two surveys, accumulation took place in the lower transects and erosion in the upper transects. Between the 1988 and 1989 surveys, the erosion zone appears to have moved downstream and a deposition zone has moved into the upper transects. Between the 1989 and 1990 surveys, these deposition and erosion zones appear to have moved downstream. Between the last two surveys, the lower deposition zone has moved downstream, with an erosion zone in the middle of the study area, and a new deposition zone moving through the upper end of the area.

Figure 4. Change in Sediment Storage at each Transect



Although the patterns are not exact, downstream migration of gravel as pulses may be an explanation for the erosion/deposition zones noted during the study. This would indicate that normal channel bedload transport phenomenon are occurring in the impoundment and that the weir deflation is effective at allowing natural transport mechanisms to continue.

The results of the Weeks Falls sediment monitoring program were accepted by the resource agencies and FERC. No additional studies, mitigation, or alterations of project operation schedules are required.

Acknowledgments

This study was funded by the owners of the Weeks Falls Hydroelectric Project and by the Harza Engineering Company's Research and Development Committee.

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Design Flood and Fisheries Studies
at the Upper and Lower Occoquan Dams

Edward F. Carter[1], John R. Bizer[2], and Marc I. Schwartz[3]

Abstract

Two significant studies were conducted on behalf of the Fairfax County Water Authority (FCWA) to comply with Federal Energy Regulatory Commission Regulations pertaining to the operation of a hydroelectric project associated with the Occoquan River Water Supply Project. The two studies, one to evaluate design flood and stability for the Upper Occoquan Dam and the other to evaluate the potential for reintroducing anadromous fish populations to the upper Occoquan River Basin, were prompted by regulatory requirements.

In 1988, the probable maximum flood (PMF) for the Upper Occoquan Dam was revised using the most recent estimate of the probable maximum precipitation and present urbanized basin conditions affecting runoff to the Occoquan River. The revised estimate indicated a peak PMF 62 percent higher in 1988 than in 1972. A consequence of the increased estimate of the PMF and the revised dam stability guidelines used by the FERC was that modification of the project structures was required to increase the stability of the dam and powerhouse. Modifications recommended to increase the stability of project structures included installation of post-tensioned anchors to satisfy PMF loading conditions. Stabilization of the non-overflow section of the Upper Occoquan Dam required installation of nine anchors providing 15,540 kips of force. The powerhouse required three anchors (6,440 kips) and the overflow spillway required 41 anchors (59,150 kips).

The second study was conducted in response to FERC regulations for enhancing environmental resources and recreation opportunities associated with hydroelectric projects. Annual migrations of American shad (***Alosa sapidissima***), alewife (***A. pseudoharengus***), and blueback herring (***A. aestivalis***) to the Occoquan River

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downstream from the project facilities prompted federal and state resource agencies to recommend modifying the project to provide for passage of adult fish upstream around the dams to the upper Occoquan basin for spawning. To determine if suitable spawning habitat for the three species was present, aerial reconnaissance coupled with ground confirmation of habitat conditions was performed. Results of the reconnaissance, analysis of the site-specific data and comparison with the fish habitat requirements provided sufficient information regarding the feasibility of providing for fish movement upstream from the project structures.

Introduction

The development of water resources encompasses a diverse range of engineering and environmental evaluations to fully meet regulatory requirements both at the state and federal levels. This diversity is evident in the range of evaluations conducted for the licensing of the hydroelectric generating facilities associated with the Occoquan River Project owned and operated by the Fairfax County Water Authority.

The Occoquan River Project, operated primarily as a water supply source, was the subject of studies conducted in support of an application for license required by the Federal Energy Regulatory Commission (FERC) for operating hydroelectric facilities designed to use the energy available when the reservoirs are full and water must be released.

Studies conducted during the licensing process included evaluations of power generation capacity, water quality, basin management programs, land use in the vicinity of project features, aesthetics, and recreational use. The breadth of evaluations is represented, however, by two studies involving an evaluation of dam safety under probable maximum flood (PMF) and an evaluation of the effect of the project on anadromous fish populations in the basin. These two areas were selected as subjects of this discussion primarily because of relatively new types of evaluation techniques which were used to acquire the information requested by both state and federal agencies. Results of the dam safety evaluation and determination of the PMF led to the conclusion that the stability of the Upper Dam needed augmentation. Results of the anadromous fish study led to the conclusion that because of a lack of suitable spawning habitat in the upper basin of the Occoquan River, installation of a mechanism to allow fish access to spawning areas upstream from the project could not be justified from an economic basis.

Dam Stability Analysis and Post-Tensioned Anchor Remedy

The Occoquan River Project is located on the Occoquan River in the northern part of the Commonwealth of Virginia. The Occoquan River is a tributary of the Potomac River and delineates the boundary between Fairfax and Prince William Counties. The project is operated first as a water supply project and is an integral part of the Washington Metropolitan Water Supply System. The project consists of two dams, each with raw water intakes for the water supply system and with powerhouses and associated intakes for power generation using excess water.

The Upper Dam is composed of a 523-foot-long overflow spillway section built to a height of 65 feet above the base rock, a 200-foot-long non-overflow with a maximum height of 70 feet above the foundation, a raw water intake structure, and an integral intake/powerhouse section (60 feet long) between the overflow and non-overflow sections. The dam impounds the Upper Occoquan Reservoir with a total area of 1,840 acres and a storage volume of 33,700 acre-feet.

The Lower Dam is composed of a short non-overflow embankment, a 387-foot-long overflow spillway, and a raw water intake structure. The raw water intake structure delivers water via a cut-and-cover pipeline to a Low Service Pump Station where water is either diverted to the treatment plant or to one turbine/generator unit. The dam impounds a small reservoir with an area of 19 acres and a storage volume of 170 acre-feet.

The Occoquan River Project and reservoirs are located in the Piedmont Structural Terrane where the Occoquan granite of lower Cambrian age is the predominant rock. The Upper Dam is located in a narrow, asymetrical, V-shaped canyon about 180 feet deep. The Lower Dam is in the same canyon about one-half mile downstream of the Upper Dam; both of the dams are founded on the Occoquan granite. The Piedmont area is tectonically stable and seismicity is relatively quiescent. Consequently, the seismic hazard posed to structures in this region is very low.

A 1988 FERC Part 12 safety inspection found that the project structures did not meet current FERC guidelines for stability under loadings imposed by the revised Probable Maximum Flood (PMF) estimate. PMF calculations conducted for the safety analysis increased the previous PMF by 62 percent primarily because the coefficient of infiltration in the drainage basin was lowered to account for increased intensity of residential and industrial development. The subsequent studies to evaluate the stability of the Upper Dam resulted in the design and installation of a post-tensioned anchor system to improve the stability of the dam under PMF conditions.

The post-tensioned anchor system for the Upper Dam was designed on the basis of geotechnical investigations conducted in 1989 and 1990. The first geotechnical investigation of concrete and foundation parameters at the Upper Dam resulted in the assumption of an internal friction value (Φ) of 51°, a cohesion shear strength of 50 psi, and a 1.5 factor of safety (the ratio of the vertical forces to the horizontal displacement forces). FERC agreed with these assumptions with the exception that $\Phi = 51°$ did not appear reasonable for much of the left abutment area of the dam and recommended additional geotechnical investigations to determine a more appropriate internal friction value. The second geotechnical investigation consisted of the recovery of drilling cores from the concrete/rock interface. Cohesive shear strength tests of core samples obtained from the concrete/rock interface along the dam axis and downhole-camera inspection of the interface resulted in the acceptance of the internal friction factor, shear strength and safety factors derived from the previous investigations for the central portion of the dam. However, for the extreme left and right abutments (including the powerhouse), the internal friction value was revised to 45° and a cohesion shear strength of 10 psi.

Based on the stability calculations, assuming additional structural integrity associated with the post-tensioned anchors for each segment of the Upper Dam, a recommendation for the installation of 53 anchors comprised of 35 to 53 steel strands was indicated. The specific distribution of the anchors to dam segments and the sizes of the respective anchors are summarized in Table 1. Also included in the table is the ad litional anchor force attributed to the anchors in each segment. The safety shear-friction factor resulting from these installations for the normal loadings and for the PMF condition are also summarized in the table. Evaluation of the anchor installation indicates that the safety of the dam under PMF loading conditions is within the 1.5 safety ratio acceptable under the FERC safety guidelines.

Evaluation of the Need for Fish Passage Around Occoquan Dams

In response to the initial agency consulation process for the licensing of the Occoquan River Project, the Fairfax County Water Authority was requested to provide a mechanism for the upstream and downstream migration of three fish species, members of the herring family, genus ***Alosa***. These species are anadromous: oceanic adults migrate to fresh water rivers to spawn, juveniles migrate to salt water to grow. Target species for the evaluation were American shad (***Alosa sapidissima***), blueback herring (***Alosa aestivalis***), and alewife (***Alosa pseudoharengus***). The request, made by the Virginia Department of Game and Inland Fish, the U.S. Fish and Wildlife Service and the National Marine Fisheries Service, was based on the assumption that suitable spawning habitat for the three species was available upstream from the two Occoquan Dams. During a meeting between the Authority and the resource agencies, the participants agreed that a first step in determining whether provision for passage around the dams was needed was to evaluate the availability of suitable spawning habitat upstream from the dams.

The Occoquan River arises at the confluence of Broad Run and Cedar Run approximately 13 miles from the Potomac River. Bull Run flows into the Occoquan River from the north at approximately five miles upstream from the Occoquan River mouth. The lower end of Bull Run is impounded by the Upper Occoquan Dam. With the exception of the first one mile of river, nearly the entire length of the Occoquan is impounded or is at least influenced by the impoundment at high water levels: the Lower and Upper Occoquan Dams impound the majority of the river with Jackson Lake Dam impounding the upper end of the river to the confluence of Broad and Cedar Runs.

The evaluation of the availability of suitable spawning habitat was accomplished with two field components and a comparison of the field data with spawning habitat descriptions derived from the literature. The first of the two field components consisted of an aerial reconnaissance of the majority of the drainage basin, via helicopter, to identify reaches of the three major tributaries potentially suitable for use by the three species for spawning. The second component consisted of a more detailed analysis of the suitability of stream reaches identified during the aerial reconnaissance as potentially suitable for spawning by one or more of the three species. The more detailed evaluation consisted of obtaining cross section profiles (depth) and velocity distributions at representative location within the selected river reaches. The descriptions of spawning habitat for each of the species included a search of historic records to determine if any of the species ever inhabitated the Occoquan, prior to construction of the Occoquan Dams. Depth, velocity and substrate and cover conditions utilized by each species for spawning were derived from various literature sources.

Figure 1 presents the reaches of the major tributaries of the Occoquan River which were viewed during the aerial reconnaissance. Photographs and video tape record of the characteristics of the reaches were obtained for later delineation of habitat characteristics throughout the entire reach. Also presented in Figure 1 are the locations at which detailed depth and velocity profiles were obtained.

Results of the ground observations are summarized in Table 2. The hydraulic characteristics of the streams were compared with habitat requirements derived from the literature for each of the target fish species. The habitat characteristics which are considered suitable for spawning for each species are summarized in Table 3. The comparison of water depths and water velocities observed at each of the stream sites with the spawning habitat requirements for each species are presented in Figures 2 and 3, respectively. Table 4 presents a summary of the stream reach lengths of various habitat types within the surveyed area of the basin.

The aerial and ground reconnaissance of the three main tributaries of the Occoquan Basin indicated that little, if any, suitable spawning habitat for American shad occurs in the basin upstream from the Upper Occoquan Reservoir. Figures 2 and 3 demonstrate that, while velocities in the run and riffle habitats are suitable for American shad spawning, they are generally not sufficiently deep to provide suitable habitat for spawning.

Of the 63 miles of free-flowing stream in the drainage, only 20.7 miles, as demonstrated in Figures 2 and 3 and summarized in Table 3, appear to have marginally suitable depth characteristics for blueback herring spawning. Suitable velocities for blueback herring spawning were present at several locations. However, the locations where velocity appeared suitable, were generally too shallow for spawning.

The majority of the study reaches in the three streams consist of pool-type habitat. This habitat is particularly suitable for spawning by alewife. Of the 63 miles of free-flowing stream, it was estimated that 42.2 miles could be used by alewife for spawning. The fact that the alewife population already inhabiting the Occoquan Reservoirs is declining suggests that the presumably suitable spawning habitat available in the tributaries may either be inaccessible or unsuitable. If it is suitable and some spawning does occur in these areas, the decline may be due to some other factor such as predation or competition with other species.

Results of the habi. : survey indicated that: Suitable spawning habitat for American shad is virtually non-existant in the three main tributaries of the Occoquan River; run and riffle habitat in the streams could provide some spawning habitat for blueback herring, but the queality of this habitat is marginal; however, the streams do provide adequate pool habitat for alewife spawning. In conclusion, the study showed that the potential benefits of providing upstream fish passage mechanisms for the herring species at the Occoquan River projects are questionable. Passage mechanisms (fish ladders or trap and haul) would not contribute to the American shad populations in the Chesapeake Bay because of the lack of suitable spawning habitat. Access to some blueback herring spawning areas could be gained, although any recruitment of fish would probably not be detectible. Alewife spawning habitat available in the streams is currently used, but, because the reservoir population is declining, any potential benefits of providing fish passage mechanisms would be minimal.

In further evaluation of providing a mechanism to allow the three species access to spawning habitat upstream of the Occoquan dams, costs for constructing and operating a trap and haul program were estimated. Costs for construction of the necessary facilities for trapping and hauling the migrating fish were estimated at approximately $900,000. Operation and maintenance of the facilities was estimated to cost approximately $200,000 per year with a concurrent monitoring program to cost approximately $100,000 per year. Based on these estimates, the resource agencies and the FERC agreed that the anticipated benefits to the fish populations did not justify the costs associated with providing the trap and haul program.

Table 1: Summary of Stability Analyses for Upper Dam with Post-Tensioned Anchors Installed

	Monolith No.1 Non-Overflow	Monolith No.2 Non-Overflow	Monolith No.3 Non-Overflow	Powerhouse	Sections 1-6 Spillway	Section 7 Spillway	Section 8 Spillway	Section 9 Spillway	Section 10 Spillway
No. Anchors/No. Strands Required[1]	2/44	3/48	4/53	3/44	4/41	5/48	5/42	4/45	3/35
Total Anchor Force (kips)	3080	5040	7420	4620	5740	8400	7350	6300	3675
Shear-friction Factor, S_{s-f}, Calculated for:									
Case I - Normal Load	18.06	5.05	3.84	4.83	4.97	3.0	3.22	3.52	5.71
Case II - PMF Load	1.73	7.63	1.5	1.52	1.5	1.5	1.5	1.51	1.52
Case IIa - Normal + Ice Load	9.35	4.52	3.62	4.56	1.82	2.87	3.08	3.33	4.74
Case III - Normal + Seismic Load	9.82	3.62	2.85	3.24	3.78	2.25	2.43	2.64	4.06
Case III - Drawdown	63.94	16.55	8.30	[2]	[2]	[2]	[2]	[2]	[2]

[1]Based on 0.6-inch-diameter 270 ksi ultimate strength steel strands.

[2]Denotes not analyzed because it is not a critical section based on adjacent section analysis.

Table 2: Summary of Hydraulic and Physical Conditions at Observed Locations, April 10-17, 1989.

Site (Letter Designation as in Figure 1)	Type	Flow	Average Depth	Average Velocity	Substrate Type	Temp.	DO
		(cfs)	(ft)	(fps)		(°C)	(mg/L)
BULL RUN							
Rte. 659 (Gum Springs Road) Bridge							
A	Run	16	1.1	0.5	silt, cobble, lg gravel few boulders	9.0	11.6
B	Pool	16	1.2	0.3	silt, gravel	N.A.	N.A.
C	Riffle	16	0.4	1.4	cobble, gravel,boulders	N.A.	N.A.
Bull Run Regional Park							
D	Run	35	0.9	1.1	silt, gravel	10.0	11.4
E	Pool	35	1.8	0.5	silt, cobble, clay banks	N.A.	N.A.
Rte. 28 (Centerville Road) Bridge							
F	Run	78	1.0	1.0	gravel	13.5	12.4
BROAD RUN							
Lake Manassas Dam (Glenkirk Road)							
G	Run	35	1.4	0.6	sand, silt, cobble boulders	11.5	10.4
Rte. 619 (Linton Hall Road) Bridge							
H	Run	42	1.2	0.6	gravel, cobble, silt	12.0	11.1
Rte. 28 (Nokesville Road) Bridge							
I	Run	43	1.0	1.8	gravel, boulder	12.0	11.4
Rte. 660, downstream from Rte. 28 Bridge							
J	Pool	44	1.7	0.4	sand, silt	12.5	12.6
Brentsville Historic Recreational Park							
K (10 am)	Run	103	1.4	1.1	small boulder	9.0	11.4
(4 pm)		53	1.0	0.8		13.0	12.8
KETTLE RUN							
Rte. 619 (Bristow Road) Bridge							
L	Pool	7	2.2	0.1	mud, silt	8.5	12.6
CEDAR RUN							
Rte. 602 (Auburn Mills) Bridge							
M	Run	12	1.2	0.4	bedrock, silt	12.0	11.0
Rte. 806 (Elk Run Road) Bridge							
N	Run	33	1.2	0.7	cobble, boulder	12.0	13.0
Rte. 646 (Aden Road) Bridge							
O	Run	72	1.5	0.8	mud, gravel, cobble	10.0	11.5

Table 3: Habitat Criteria for Herring Species

Species	Depth (ft)	Velocity (fps)	Substrate	Temp. °C	DO (mg/L)
American Shad	1.5-40	1.0-3.0	sand, gravel (clean)	14-21	≥4
Blueback Herring	>1.0	1.0-3.0	hard	14-27	≥4
Alewife	>0.5	0	soft	12-16	≥4

Table 4: Summary of Available Habitat Types in Upper Occoquan River Basin

Stream		Pool	Run	Riffle	Total
Bull Run	Miles	11.8	5.5	1.5	18.8
	Percent	63.0	29.0	8.0	100.0
Broad Run	Miles	14.8	1.2	1.6	17.6
	Percent	84.5	7.0	9.0	100.0
Cedar Run	Miles	15.6	4.0	6.9	26.5
	Percent	59.0	15.0	26.0	100.0
Total	Miles	42.2	10.7	10.0	62.9
	Percent	67.1	17.0	15.9	100.0

Figure 1: Stream Reaches Observed from Helicopter in Comparison with Ground Observations

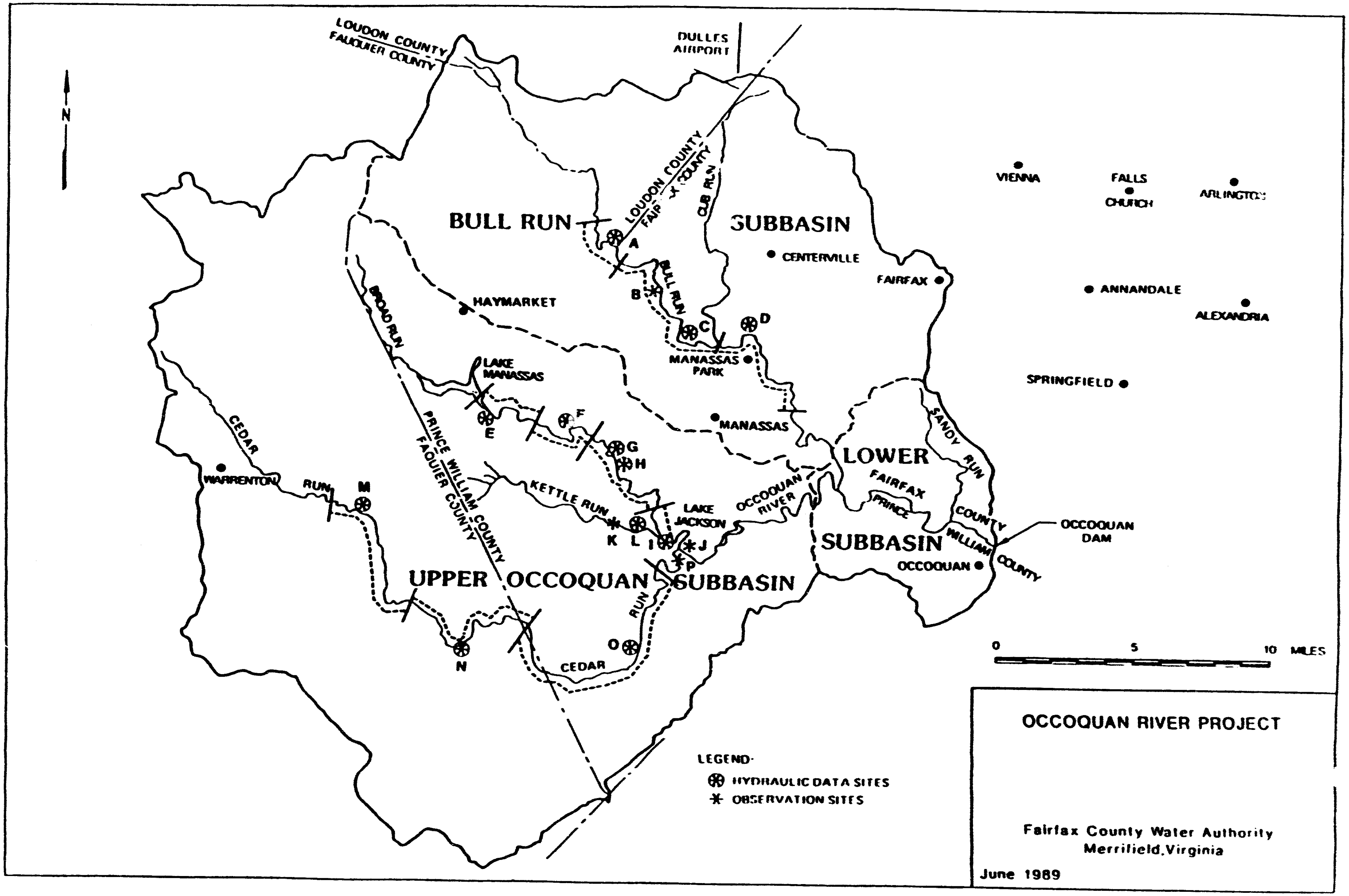


Figure 2: Comparison of Suitable Depth Criteria with Stream Conditions

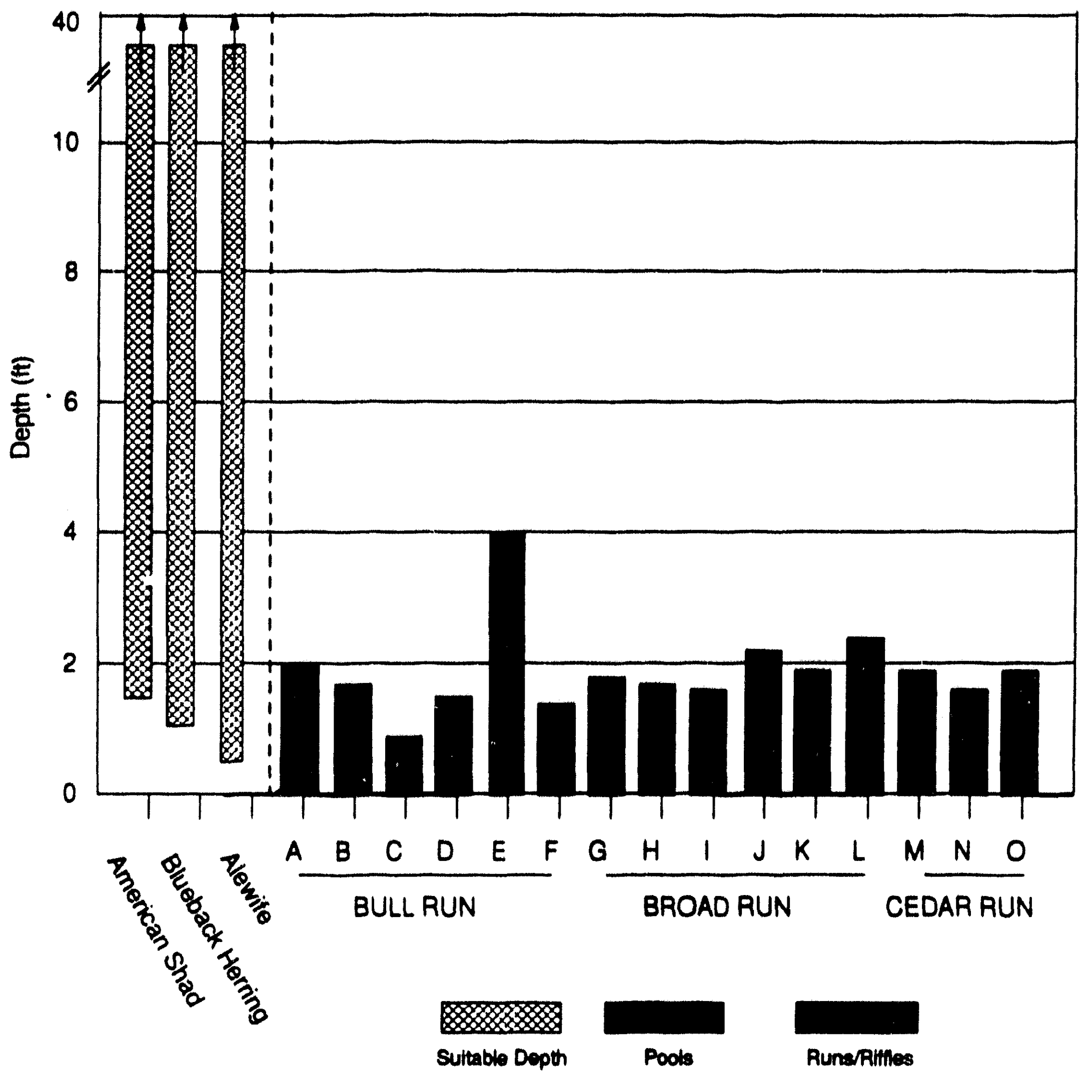
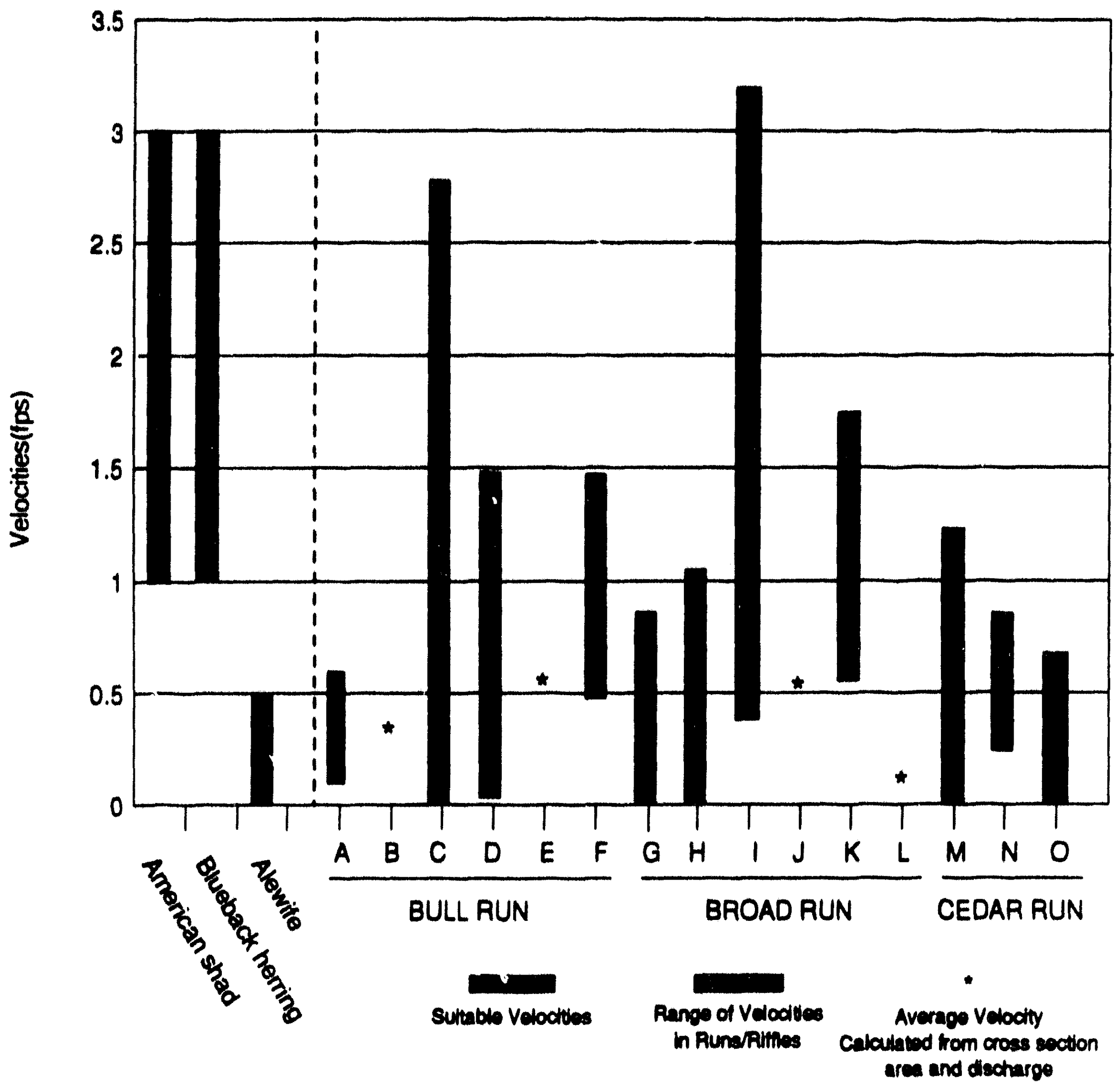


Figure 3: Comparison of Suitable Velocity Criteria with Stream Conditions



DEVELOPMENT OF AN EICHER SCREEN AT THE ELWHA DAM HYDROELECTRIC PROJECT

Pieter Adam, P.E.[1], Donald P. Jarrett, P.E.[2]
Allan C. Solonsky[3], Larry Swenson, P.E.[4]

ABSTRACT

The Eicher Screen is a relatively new concept for screening juvenile fish out of hydroelectric turbine penstocks. The concept was developed by Mr. George Eicher and one was recently installed and evaluated at the Elwha Hydroelectric Project in Washington State. The Eicher Screen was installed inside a 9-foot diameter penstock in March 1990. The screen assembly consists of wedgewire panels of varying porosities mounted on a support frame. A pivot shaft inside the penstock allows the screen to be rotated and backflushed for cleaning. Hydraulic analyses, operational testing and initial biological evaluation were conducted from April through June 1990. Maximum headloss measured through the screen never exceeded two feet (0.61 m) and debris has not created any problems at the site to date. Biological evaluations consisted of passing 5,000 coho salmon smolts through the screened penstock. Over 99 percent of the fish were recovered from the penstock and survived a three day holding period. Additional biological evaluations will be performed in 1991.

INTRODUCTION

The Elwha Hydroelectric Project is currently undergoing FERC licensing. The Project was constructed in 1911 without upstream or downstream fish passage facilities and restoration of anadromous fish runs above the Project is a central licensing issue. Restoration is a goal shared by the Project's

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owner, James River II, Inc. (JRII), federal and state resource agencies and the Lower Elwha Indian Tribe.

To provide effective protection for future downstream migrants (juvenile fish), several alternatives were reviewed representing a range of complexity, cost and potential for success. These included conventional systems acceptable to regulatory agencies, such as traveling belt or angled drum screens or shutdown and spill options. An alternative, the Eicher Screen, is a relatively new concept of screening that holds promise for good performance. An economic evaluation indicated that, assuming reasonable Eicher Screen bypass flow requirements, its life cycle costs would be lower than a forebay screening facility or the shut down and spill alternative. The Eicher Screen alternative was attractive to JRII as a cost effective method to provide passage survival rates necessary to achieve restoration of anadromous fish. James River is presently engaged with the Electric Power Research Institute (EPRI) in the evaluation of the effectiveness of the Eicher Screen technology.

The basic concept of the Eicher Screen is a smooth, elliptical screen positioned at a shallow angle inside a penstock. Bypass flows exit the penstock through a pipe at the downstream end of the screen. According to George Eicher, successful fish passage is provided as long as the ratio of V_x (velocity component in the plane of the screen, parallel to the screen centerline) to V_z (velocity component perpendicular to the plane of the screen) is maintained at three to one (Figure 1).

In 1980, a prototype installation was tested at the T.W. Sullivan Plant at Willamette Falls, Oregon. Although poor hydraulic conditions were present at the site, studies indicated that the screen had a diversion efficiency near 100 percent. An accurate assessment of injuries to fish was precluded by injuries caused in the fish collection facilities. The collection facilities are currently being rebuilt and further testing will occur in 1991. With promising passage results, EPRI funded model tests at the University of Washington in 1984. During these tests, various species of fish were passed through an inclined plane screen in a rectangular cross-sectional model. Screen angles of 10.5, 16.5 and 30 degrees were tested over a range of varying bypass and approach flows. Results from the model tests indicated that fish touched the screen more frequently when screen angle was increased. These initial test results provided a starting point for the Elwha design.

Fisheries Considerations

Federal and Washington State design criteria (Vx and Vz) for conventional screening technology are based upon the site specific size and swimming capabilities of the juvenile fish present. At Elwha Dam, primary anadromous species targeted for restoration are chinook salmon, coho salmon and steelhead trout. Chinook salmon migrate downstream as sub-yearlings at approximately four inches (10 cm) in length. Coho salmon and steelhead trout migrate downstream as yearlings reaching lengths of five to eight inches (13 to 21 cm), respectively.

Using conventional forebay screening facilities, fish at Elwha Dam would limit the maximum Vz velocity component to 0.8 fps (0.24 m/s). A Vx velocity component at least twice the Vz velocity component would also be required according to federal and Washington State screening criteria. Because the Eicher Screen does not adhere to conventional screening methodology, only general guidelines were available to engineers and biologists during development of the Eicher Screen technology. Resource agencies and the Tribe required that careful evaluation of the Eicher Screen be performed to demonstrate that it can achieve equal or better passage rates than conventional screens.

Design Objectives

In the absence of established design criteria, development of screen parameters was a product of a consensus among the resource agencies, tribal representatives, JRII, JRII's consultant (Harza NW staff), George Eicher, EPRI, and EPRI's consultant (Stone & Webster). The process of design and evaluation was guided by a study plan which was jointly developed. The overall goal for the system was to provide 95 percent passage survival for all downstream migrating fingerlings and yearlings.

Because there was general belief that velocity components should have absolute limits, specific hydraulic objectives to provide effective fish protection were to develop a uniform Vx component (not to exceed about 10 fps (3 m/s) at full-gate) and limit the Vz component as much as practical. Additional design objectives were to minimize economic costs, such as initial capital cost and lost power generation due to fish bypass flows, minimize operational constraints, minimize headloss and provide effective debris management.

The Elwha Eicher Screen required several sub-assemblies and fabrications (Figure 1). Provisions were made for pivoting the screen, viewing ports, lighting ports, velocity measurement ports and mandoors for access into the penstock.

Hydraulic Model

A model study was conducted by Engineering Hydraulics, Inc. to help achieve the desired velocity patterns near the screen and minimize headloss. A 1:4.7 scale hydraulic model of the intake, penstock, screen and bypass was constructed. The penstock was modeled using 24-inch clear acrylic tubing. Maintaining the same screen headloss coefficients in the model and the full-scale penstock screen required using penstock screen material in the model and operating at penstock velocities, thereby producing full-scale Reynolds Numbers in the model. Since the scale of the screen material was 1:1 and the support beams were scaled 1:4.7, the model did not have strict geometric similarity. The screen bars and openings of the model were large relative to the size of the support beams and to the model penstock diameter. Nevertheless, it was believed that the overall flow patterns in the model would be similar to the full-scale screen because of the high model Reynolds Number (in the range of 0.7×10^6 to 1.4×10^6).

Three flow combinations were tested in the model: 4 fps (1.2 m/s) average velocity in the penstock and bypass pipe, 6 fps (1.8 m/s) in each and 8 fps (2.4 m/s) in each (referred to as 4-4, 6-6 and 8-8 respectively). Velocity measurements were made using a United Sensor five-hole prism probe. The probe was inserted through ports in the wall of the penstock at various locations (Figure 1). The probe axes were parallel to and about 3/8-inch (0.01 m) above the screen surface. The piezometric head measured at each of the five prism sensor ports was resolved to determine the three orthogonal velocity components for each velocity reading. Velocities are presented in a normalized format, where the actual velocity component (either Vx or Vz) is divided by the average penstock velocity. Normalized velocities allowed easy comparison of the velocity profiles under different flow conditions (Figure 2).

An initial model test using 63% porosity screen was performed. This test indicated a peak normalized Vx component in excess of 1.5 and a peak normalized Vz component of 0.4. Subsequently, a series of tests were performed with various combinations of baffles to simulate different screen surface materials. The objective of these tests was to develop a screen design with a uniform normalized Vx component along the length of the screen and to limit the normalized Vz component to as uniformly low a value as practical. The variation of the normalized Vx and Vz components along the length of the screen are illustrated in Figure 2. A final model test was performed with actual wedgewire porosity to confirm the results with baffles.

In order to handle the hydraulic load caused by accumulated debris under emergency conditions, the design criterion for the screen (and frame) was set at 7 psi (48 kPa). This criterion required relatively deep backing bars for support. During model testing it was determined that the deep backing bars created excessive head loss (greater than 3 feet (.9 m)) and consequently, the backing bars were rotated to be more in line with the direction of the flow. It was also determined that spacing between the support bars should be kept as large as practical (8.25-inches (0.2 m) for the

Hendrick material selected) in order to minimize head loss. Screen induced head losses were determined by measuring the difference in average piezometric head upstream and downstream of the screen. Figure 3 illustrates the head loss measured in the model study for the initial and final screen support bar arrangement.

Screen Configuration

A major design issue was the selection of the screen surface material. All parties believed that a screen built from stainless steel profile bars (referred to as wedgewire screen) was the best material to minimize debris accumulation and injury to fish. Several types of wedgewire screen were reviewed. Ultimately, material from Hendrick Screen Co. was selected.

Screen porosity was an additional design issue. Screen porosity affects head loss, debris management, velocity distribution and fish injury. Relatively large openings between screen bars could increase injury to fish and increase debris retention. A 63% porosity was considered to be a reasonable compromise between the need to minimize head loss, provide fish protection and maintain the ability to pass debris. The 63% porosity was achieved by using the manufacturer's standard bar width and the maximum allowed Washington State Department of Fisheries' opening between bars of 0.125-inch (0.3 cm).

Most participants agreed that some type of variation in porosity would be required in order to maintain uniform velocities along the length of the screen. This variation in porosity would eliminate the tendency for most of the flow to go through the downstream end of the screen, as has been observed in angled and inclined bypass facilities. Based on model studies, the final porosity configuration selected for the Elwha penstock screen was 63% for the upstream 2/3 of the screen and 32% and 8% for the remainder. This combination of porosity, based on the model results, was found to yield a relatively uniform Vx component along the length of the screen with reasonable limits to both Vx and Vz components.

Fish Bypass

Design of the bypass entrance area (transition from penstock to bypass) was considered critical for successful fish passage. Most participants felt that velocities through the transition section should not exceed about 10 fps in order for fish to maintain orientation into the flow. Original concepts had a small pipe (2-foot (0.6 m) or less) intersecting at a shallow angle to the penstock section. The pipe would intersect a small area on the top of the penstock. This would require fish to travel to the extreme downstream end of the screen to be swept into the elliptical shaped bypass entrance. This geometry concerned fisheries biologists who felt that fish following the peripheral areas of the penstock could sustain high injury rates at the abrupt transition into the bypass.

There also was a concern about a potential drop in velocity at the bypass entrance. Subsequently, George Eicher suggested a modified bypass entrance geometry which would solve these problems and the new geometry was selected for the screen (Figure 1). The modification provides a more gentle transition from penstock to bypass.

The dimension of the bypass entrance was also an economic issue because it established the required bypass flow. The bigger the entrance the larger the bypass flow and the greater the economic cost of operating the Eicher Screen. A small entrance opening would run the risk of becoming clogged with debris. Ultimately the parties agreed to a final entrance height of 16-inches (0.4 m).

The bypass design includes a truncation of the screen at the downstream end, a transition to a rectangular shape and a second transition from a rectangular shape into the 24-inch (0.6 m) diameter bypass pipe. The bypass portion of the penstock section was consequently complex and considerable reinforcement was required to maintain the penstock's structural integrity. The model study indicated a more favorable Vx distribution along the length of the screen if 8% porosity wedgewire screen was used in the floor of the transition section. According to the model, porosity higher than 8% created excessively high velocities in the fish bypass entrance (1.5-1.6 normalized Vx).

Screen Support Frame & Pivot System

The wedgewire screen was mounted on a structural frame for support. The frame was required to be strong enough to support a fully clogged condition. Based on the model studies performed at the University of Washington, an angle of 16.5 degrees was selected as a reasonable compromise between effective debris management, fish passage and cost of construction.

The support frame was designed to pivot in order to enable backflushing the screen for cleaning. Two options were evaluated during the design phase to pivot the screen: hydraulic cylinders and a lead screw arrangement. Operator loads were expected to become quite large if debris loading was non-uniform. Because of the size of the support frame, it was decided to use two operators, one at each corner of the downstream end of the frame. Hydraulic cylinders were not used because the long rods would be subject to buckling. Furthermore, the frame could be subjected to distortion if debris prevented one side of the screen from returning to the "fishing" position. Twin lead screws were selected as being relatively inexpensive and not subject to imposing a torsional load on the frame, since the lead screws would be driven by a single gearbox.

Installation

Site specific installation issues that were unusual at this site included an old penstock with an irregular diameter and limited access. The condition of the penstock material was assessed by a metallurgical analysis. The penstock shell material was found to be readily weldable, but only .19-inch (0.5 cm) thick. The interior of the penstock was physically inspected and found to be in reasonably good condition for its age. Due to the difficulty of field fabricating the bypass transition section and numerous penetrations, it was decided to fabricate a new penstock section and install the screen assembly into place on site.

Due to schedule constraints, the replacement penstock section and the screen were not assembled in the fabrication shop together. This resulted in field modifications which were required to align the 8% screen surface to the bypass transition section within allowed tolerances (0.125-inch). Because the existing penstock was out-of-round and could not be brought into a round condition, a short transition section was field fabricated and installed between the penstock and the replacement penstock section.

Biological Evaluation Results

An injury classification system developed by the National Marine Fisheries Service for studies on the Columbia River was used to evaluate fish passage success through the Eicher Screen. Categories of injuries were:

"partially descaled" (scattered or patchy scale loss 3 to 16% per side);

"descaled" (over 16% scale loss on one side); and

"other injuries" (bruises, cuts, eye injuries, etc.).

All fish were held from three to ten days following tests. Results from over 5,000 fish passed through the screened penstock in groups of 100 fish indicated that the recovery rate averaged over 99 percent. Little or no injury was observed during tests conducted at low penstock velocities and at highest penstock velocity (full gate) only 3.6 percent of the test fish showed substantial injury (descaled). At full gate, an average of approximately 24% of the fish also exhibited partial descaling. Actual mortality (fish killed) during spring tests was 0.21 percent; all these fish died during fresh water holding. Studies to determine the effectiveness of diverting larger and smaller fish (steelhead yearlings and chinook sub-yearlings) will be conducted in 1991.

Hydraulic Evaluation

Velocity measurements at the Elwha screen were made in locations close to those in the model, but were shifted slightly due to interference with penstock stiffener rings. Measurements indicated reasonably good agreement with the model for the normalized Vx velocity component, but a higher peak normalized Vz velocity component (Figure 2). Observations made during the biological tests indicated that there were short term fish contacts with the screen in the area where the peak Vz velocity was measured (only at 8-8 condition).

The higher peak Vz components measured at the Elwha screen may be due to the fact that the model was not fitted for the screen seal and clamping bars. These two items increase the Vz component by blocking about 15% of the surface of the main screen. The higher velocities may also be due to different locations used for velocity measurements. The measurement location for 5H, for example, was situated over higher porosity screen and an area of unexpected high velocities.

Head loss measurements at the Elwha Screen were made in the same manner as the model study. The head losses measured in the field indicated a maximum of 1.9-feet (0.6 m) and the maximum measured in the model was 1.3-feet (0.4 m), see Figure 3. The difference in head loss between the full scale and model measurements could be due to the lack of seals and clamping bars in the model. Additionally, some of the wedge wire support u-clips were removed during the model runs, which probably resulted in lower head loss.

Operational Impacts and Costs

No operational impacts have been noted to date. The screen cleaning system has been successful in removing any accumulated debris. Screen head loss at the site represents a negligible reduction in generation.

The construction cost for the installation of the Eicher Screen was about $400,000 (1989 dollars). This construction cost included about $60,000 for the installation of a crane to service this installation as well as other nearby construction. Additionally, there was another $400,000 incurred for professional services, the hydraulic model and lost generation (during installation and evaluation). A cost estimate to install Eicher Screens in all four penstocks at the Elwha Project, including bypass facilities is $3 million. A series of forebay drum screens is estimated to cost approximately $7 million.

Recommendations for Refinement

Based on the results of the biological evaluation and the prototype hydraulic tests performed to date, minor refinements may be made to improve performance. If refinements are made, it will be important to make hydraulic measurements following any modifications to the existing design. These measurements will provide a better understanding of observations made during biological tests.

Conclusion

Initial results from the Elwha Dam Eicher Screen are very encouraging. It is expected that with some minor modifications, fish contacts with the screen can be reduced. Future testing will determine the effectiveness of the screen to handle debris loading and the ability of the screen to successfully pass other species of fish. Gaining information at new sites with different fish species will also provide valuable information with which to understand required velocity conditions for the Eicher Screen technology. If tests continue to be successful, it is expected that the Eicher Screen will be a viable solution to downstream passage at other sites.

Acknowledgements

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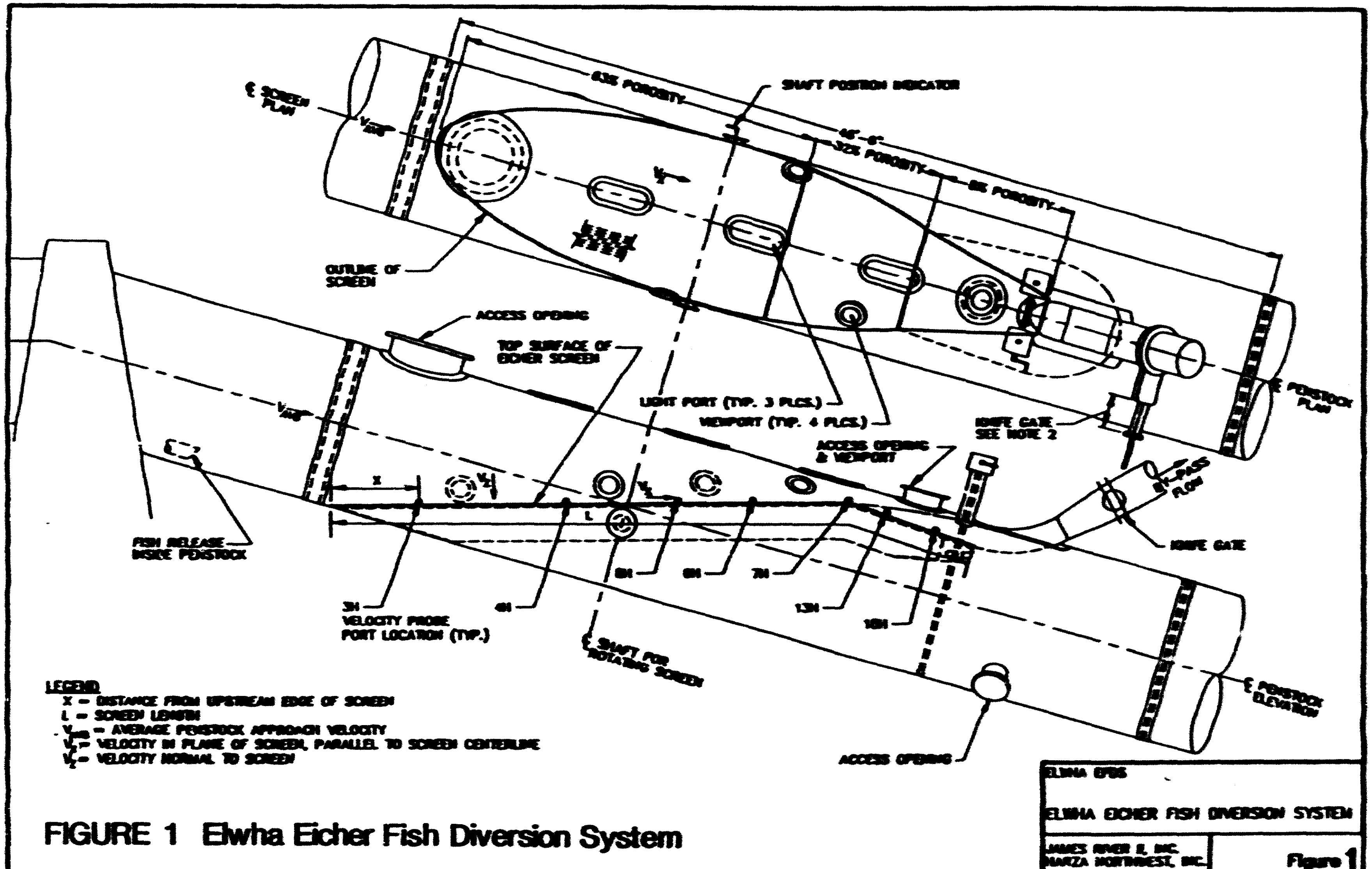

LEGEND
X = DISTANCE FROM UPSTREAM EDGE OF SCREEN
L = SCREEN LENGTH
V_{AVG} = AVERAGE PENSTOCK APPROACH VELOCITY
V_P = VELOCITY IN PLANE OF SCREEN, PARALLEL TO SCREEN CENTERLINE
V_N = VELOCITY NORMAL TO SCREEN

FIGURE 1 Elwha Eicher Fish Diversion System

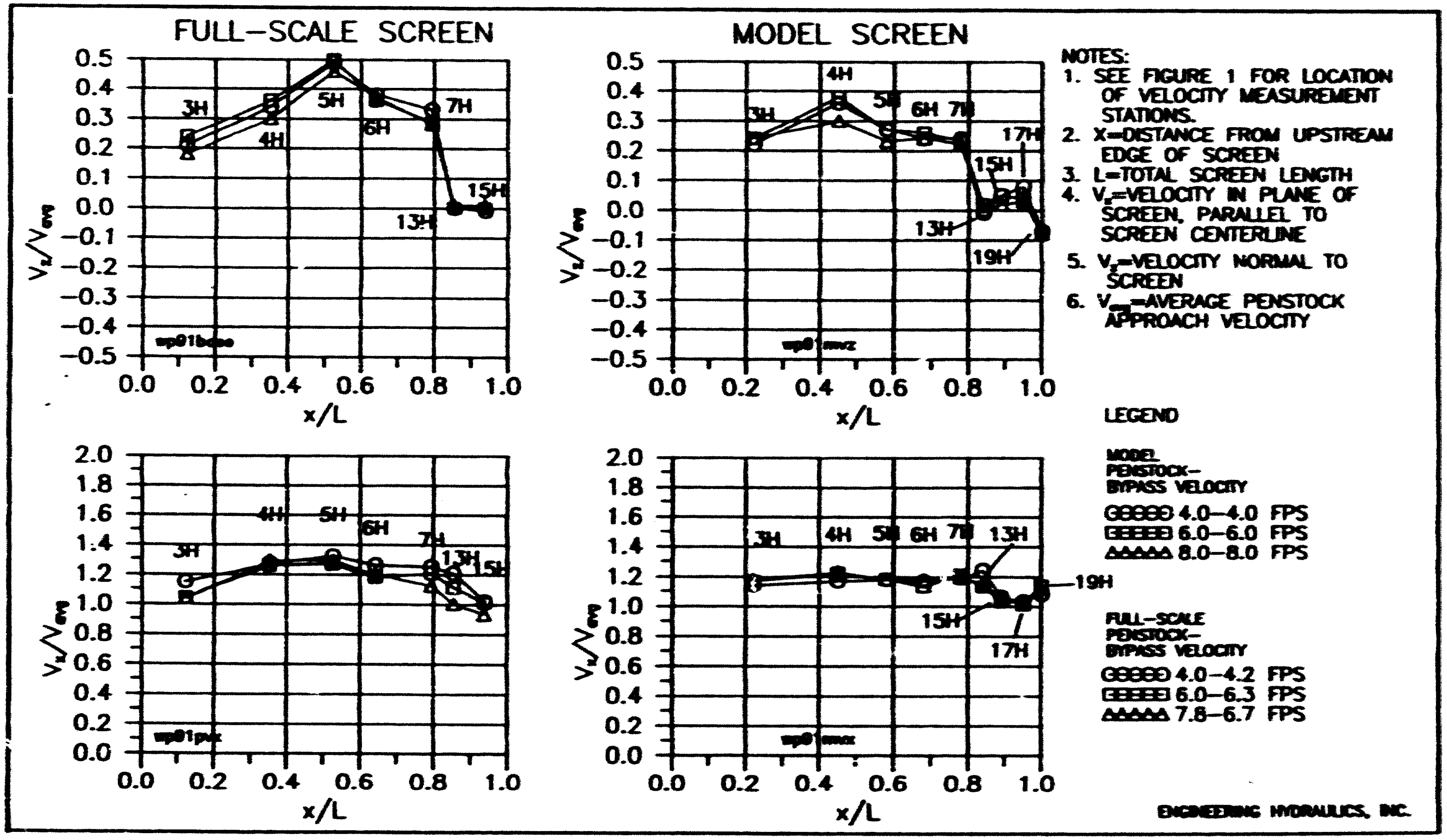

Figure 2 Full–Scale and Model Screen Velocity Data – Traverse Averages

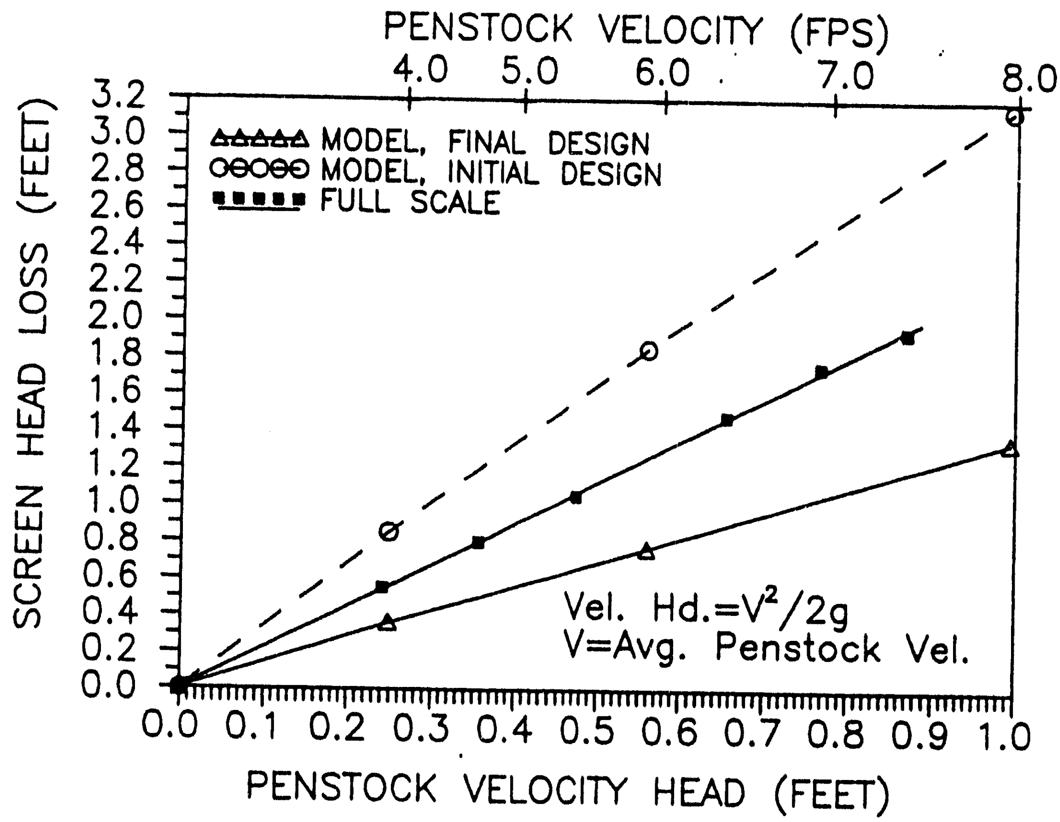

Figure 3 Full–Scale and Model Screen Head Loss

FISH ENTRAINMENT AND RELICENSING: TRUTHS AND CONSEQUENCES

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FISH ENTRAINMENT AND RELICENSING: TRUTHS AND CONSEQUENCES

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ABSTRACT

The states of Michigan, Wisconsin, and the U.S. Fish and Wildlife Service have issued guidelines that presuppose entrainment/turbine-induced mortality at most hydroelectric projects are having a significant impact on fisheries resources. Unfortunately, there has been little data to support or refute this assertion and study costs to irrefutably answer this question will be expensive. This paper provides representative examples of entrainment study results. We categorize them by type of resource and type of facility. We conclude that entrainment impacts at each project are highly dependent on the resource in question. Finally, we present an alternative approach that allows the use of common sense, economics and resource protection, such that the things we study and mitigate make the most sense for each specific project.

INTRODUCTION

Approximately 175 hydroelectric owners must acquire new licenses prior to 1993. Many of these projects to be relicensed are small (less than 5 MW) and do not occur on rivers with anadromous fisheries. Prior to this major historical relicensing event, little attention has been paid to fish entrainment or turbine-induced mortality outside of the Pacific Northwest or the Northeastern U.S. where important anadromous species have declined in the face of large scale hydroelectric development. Nevertheless, our experience to date indicates that resource agencies are concerned about the effects of turbine-induced mortality at all projects regardless of fisheries resources present in the project waters. In fact the states of Wisconsin and Michigan have issued guidelines that assume most hydro projects are having a significant impact on fisheries. Unfortunately, there have been little direct data to support or refute this assertion. This paper will provide data

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indicating that the impacts from entrainment at each project are highly dependent on the resource in question.

COSTS AND BENEFITS

We would not even be discussing this topic were it not for the fact that the economic value of small hydroelectric projects are limited and the cost to complete definitive studies to establish the significance of the turbine-induced mortality can be quite high. The alternative choice to go directly to screening or other fish bypass facilities and avoid "studies" is even more cost prohibitive. Hence, some owners are facing difficult, and in some cases economically untenable positions. To satisfactorily resolve this issue we believe that by following an approach that incorporates common sense, agency and project owner cooperation, and possibly some creative thinking, these problems can be solved. To this end we offer several suggestions that should be considered by owners, agencies and the FERC. To contrast traditional approaches with our proposed methods, we use a flow chart developed by the U.S. Fish and Wildlife Service and the Wisconsin Department of Natural Resources (agency) to characterize the current agency approach. We then offer a flow chart of our own as an alternative approach. We illustrate the approaches with examples from three general categories:

1. High head/low flow, Rocky Mountain Project

2. Low head/high flow, Midwestern Project

3. High head/high flow, Columbia River Project

These cover the range of extremes of projects currently facing relicensing.

METHODS

To begin, we performed a literature review of entrainment and turbine-induced mortality studies conducted in the U.S. Using this information we compared it with what we learned from our relicensing work at hydro facilities across the nation. From this comparison we were able to categorize most hydroelectric facilities based on the fishery resource affected. These categories are:

1. Economically valuable anadromous species
2. Resident fisheries of mixed valves
3. Heavily stocked and managed fisheries

Study results provide evidence that entrainment at each project is highly dependent on the resource in question. We then illustrate a flow chart (Figure 1) developed by the agencies to demonstrate their approach. Finally, we present an alternative flow chart (Figure 2) designed to allow more cost effective approaches to establish the significance of the problem, and to develop mitigation where appropriate.

RESULTS

Put-and-Take Fishery Resource - A high head, low flow Rocky Mountain project.

As part of the relicensing effort for the 1 MW Salida Hydroelectric Project, an entrainment study was undertaken to assess turbine-induced mortality on 350 catchable size rainbow trout stocked in the projects forebay (Bizer, Malone, 1991). Sampling was performed prior to, during, and after stocking by using a modified trawl net mounted in the tailrace. A total of seven fish were captured over a twelve day period, none of which were the species of interest.

Resident Species - Two low head projects with populations of common resident species such as rock bass, bluegill and black crappie.

Scott Worldwide conducted a fish entrainment study from April 1990 through March 1991, at its 7 MW Park Mill Hydroelectric Facility on the Menominee River in Marinette Wisconsin (Boltz et al, 1991). Fyke nets covering approximately 60 percent of the intake area, located behind the trashracks and in front of the turbines, were used to determine entrainment numbers. Sampling was conducted 40 hours per week from March through November and 40 hours per month from December through February. Total catch from this intensive sampling effort resulted in 1902 fish being captured (as of December 1990), representing 36 species. Rock Bass was the most common species (22.3 percent), followed by bluegill (18.8 percent), and carp (18.5 percent). The majority (51.8 percent) of the catch was less than 2.5 inches in length.

A study with similar results to that of Scott, was performed at a low head hydro facility on the Kalamazoo River in Michigan (Bohr, Liston 1987). At that site, an entrainment study was undertaken to estimate the number, species and size of fish that were entrained by the Morrow Hydroelectric Power plant. The study took place over a 199 day period and nets were used as the sampling method. Over 45,000 fish were estimated to have been entrained by the four turbines, "Of these an estimated 970 plus or minus 686, or an average of five fish per day sustained turbine injuries". Bluegill was the most abundant species captured, followed by common shiner, black crappie and pumpkinseed.

Anadromous Species - Large hydroelectric dam with commercially important anadromous species.

Entrainment studies conducted at great expense to large hydro projects (> 800 MW) on the Columbia River indicate that anadromous salmon populations are severely impacted by entrainment mortality. These studies state that on average between 10 and 15 percent of those individuals entering the turbines suffer mortality (Shoeneman et al, 1961). As an example of the numbers of juvenile salmon becoming entrained at a typical Columbia River hydroelectric facility, we use a hydroacoustic study performed at Wanapum Dam (Ransom, Malone, 1989).

Downstream migrating juvenile salmon were hydroacoustically monitored at Wanapum Dam for a five week period, 24 hours a day, 5 days per week. Data were gathered on the number of fish passing the project via the turbines, spillway, and sluiceway. Total estimate of fish passing the project through the turbines was 1.2 million. Species composition data collected in the gatewells indicated that 99 percent of these fish were the target species (salmon).

DISCUSSION

It would appear that the issue of entrainment, and its associated mortality for a hydroelectric facility, is highly dependent on the fishery resource present. The data indicate, species that exhibit migratory behavior are more likely to be entrained into turbines than those species which do not.

Lack of entrainment mortality on a trout put and take fishery is not surprising due to the size of the individuals planted. Because these fish are planted with the single purpose of providing harvestable fish for the recreational fisherman, they are generally large (8 to 10 inches). Large fish, being better swimmers, are not as susceptible to entrainment velocities as smaller individuals of the same species (Jones 1980). Further, the densities of planted fish are low, and therefore, entrainment numbers are resultingly low.

Resident species such as bass and bluegill do suffer entrainment as evident from the above data. However, it appears that the number of individuals is small (970 +/- 686, Kalamazoo River) compared to the source population as a whole. Further, because the modal age class of these fish are between 0+ and 1+, the impacts on the population is likely to be insignificant if the populations are otherwise healthy. Unlike anadromous species, resident species generally do not need to travel past series of dams. Given sufficient local habitat, resident populations can be maintained locally in river systems with dams on them. The probability of entrainment is high only for any individual residing in close proximity to the project. We suspect that the probability of a resident fish becoming entrained is inversely proportional to both their age (size), and their distance from the project.

Anadromous species are more vulnerable to turbine mortality because juveniles **must** migrate from historical spawning and rearing areas past hydroelectric facilities to complete life cycles. The toll on the anadromous species is clearly a significant issue. Estimates on the Columbia River indicate that the cumulative turbine-induced mortality for juveniles passing four mainstem dams is over 50 percent (NWPPC 1986). This in turn has been one factor in reducing adult returns from a historical high of approximately 16 million to less than three million today.

There is sufficient evidence to indicate that entrainment mortality is not an issue for all hydroelectric projects. Our opinion contrasts sharply with that espoused by some regulatory agencies who have apparently concluded that entrainment is indeed an issue for all hydro facilities and request that entrainment/turbine-induced mortality studies be performed at most, if not all, facilities (USFWS, 1988). A flow chart of current agency approach for addressing entrainment/turbine-induced mortality is shown in Figure 1. A flow chart outlining our approach to the entrainment question is shown in Figure 2. In the following paragraphs we compare the two.

THE AGENCY APPROACH

The agency approach presupposes there is an entrainment problem at every hydroelectric facility. Therefore each project regardless of resource present is treated in the same fashion. Each project must demonstrate no turbine mortality by conducting entrainment and/or turbine-induced mortality studies under Phase 1 and Phase 2 guidelines, or go directly to mitigation. The agencies never ask the question is the resource declining or depressed. At projects such as Salida, with a stocked put-and-take trout pond fishery, even if entrainment losses were high (which they were not), the resource in question are planted hatchery fish and can be replaced quite readily at minimal cost.

Project owners with resident species may also suffer needless expenditures of time and money when following agency methodology. These projects are also required to perform entrainment/turbine-induced mortality studies or proceed to mitigation. Agencies make no exceptions for projects which have fishery resources at or near carrying capacity, resources that have increased since project completion or where entrainment studies at similar projects have demonstrated impacts to be minimal. One or all three of these characteristics may be present at projects with resident species. Some projects (dams) have actually enhanced resident fisheries by creating habitat. Most hydropower reservoirs do have substantial resident fisheries, many with national reputations among sport fishermen. Also, entrainment mortality over a six month period can be as low as the daily catch of a single fisherman (5 fish). The agency approach makes no provision for those projects that are not having an impact, or are actually enhancing the resource.

The one category where the agency approach is effective is anadromous species. It is in this category that the agencies assumptions that a problem exists and mitigation will be required are likely correct. The severity of entrainment/turbine-induced mortality impacts to anadromous species are well documented from extensive work performed at hydro facilities in the Northwest and Northeast U.S. These studies indicate that without some form of mitigation, the fishery resource can be expected to decline or remain at depressed levels.

HARZA APPROACH

Our approach assumes that entrainment/turbine-induced mortality at each hydroelectric facility is highly dependent on the size of the project, the fishery resource present and the status of that resource. Therefore, entrainment impacts and their severity need to be evaluated and are determined on a project by project basis.

To begin, each project must identify the resource and its status in the project waters. It is here that arguments for low value of or no impact to the resource can be given as reasons for not performing entrainment studies. If an owner can show that the resource has "low value" , easily replaced at minimal cost, then no entrainment work is needed. Also, no entrainment studies are necessary if the owner can demonstrate that the fishery resource is "healthy". This is defined as waters at or near carrying capacity or fish populations increasing since project development.

After determining that a problem exists we begin looking for the cause of the problem. In the agency approach this is assumed to be entrainment and its associated mortality component. We prefer to look for all possible causes and attempt to rate them according to the degree of impact they have on the fishery resource. Once we have established the causes for the resource decline, we determine which of those are project related and focus are attention on the one with the highest rating. Our selection of a mitigation method is based on a cost/benefit evaluation and its ability to meet the goals we have established for the resource. We then implement the mitigation method and establish a monitoring program to assess its effectiveness over time.

SUMMARY

Relicensing economics and fishery resources are highly variable. They are dependent on project size, configuration, geographic location and fisheries present. A uniform approach to evaluating and categorizing the effect of turbine mortality across all these situations is contrary to both sound ecological judgement and economics.

Instead, we should put our energies into solving fishery problems where fishery problems exist. Common sense and existing data should allow us to recognize those areas where it makes little sense from an ecological, economical or recreational perspective to spend large sums of money with no clear benefit to the resource from our efforts.

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FISH ENTRAINMENT/TURBINE MORTALITY STUDY FLOW CHART

For Projects Requiring Studies

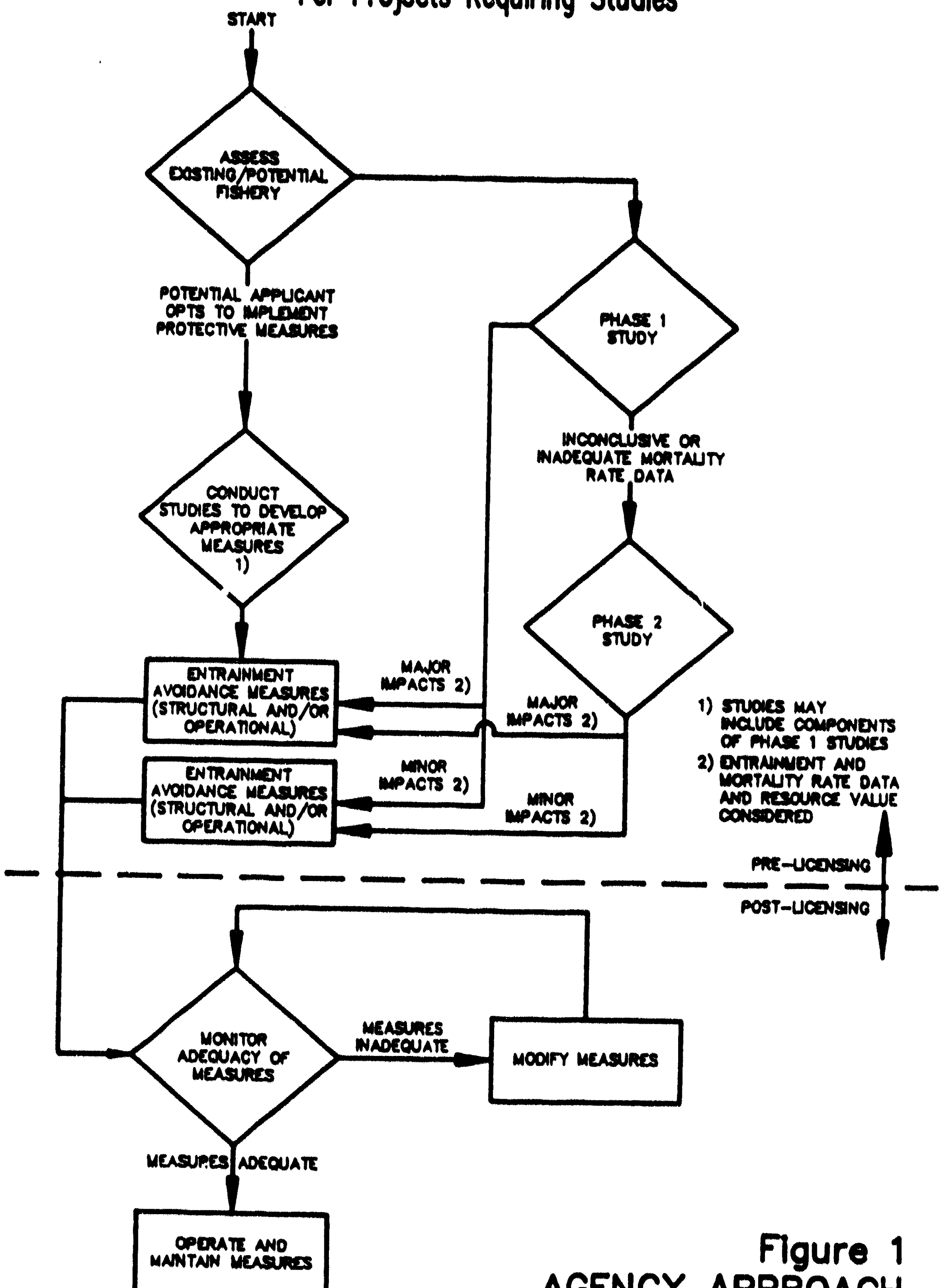

Figure 1
AGENCY APPROACH

FISH ENTRAINMENT/TURBINE MORTALITY STUDY FLOW CHART

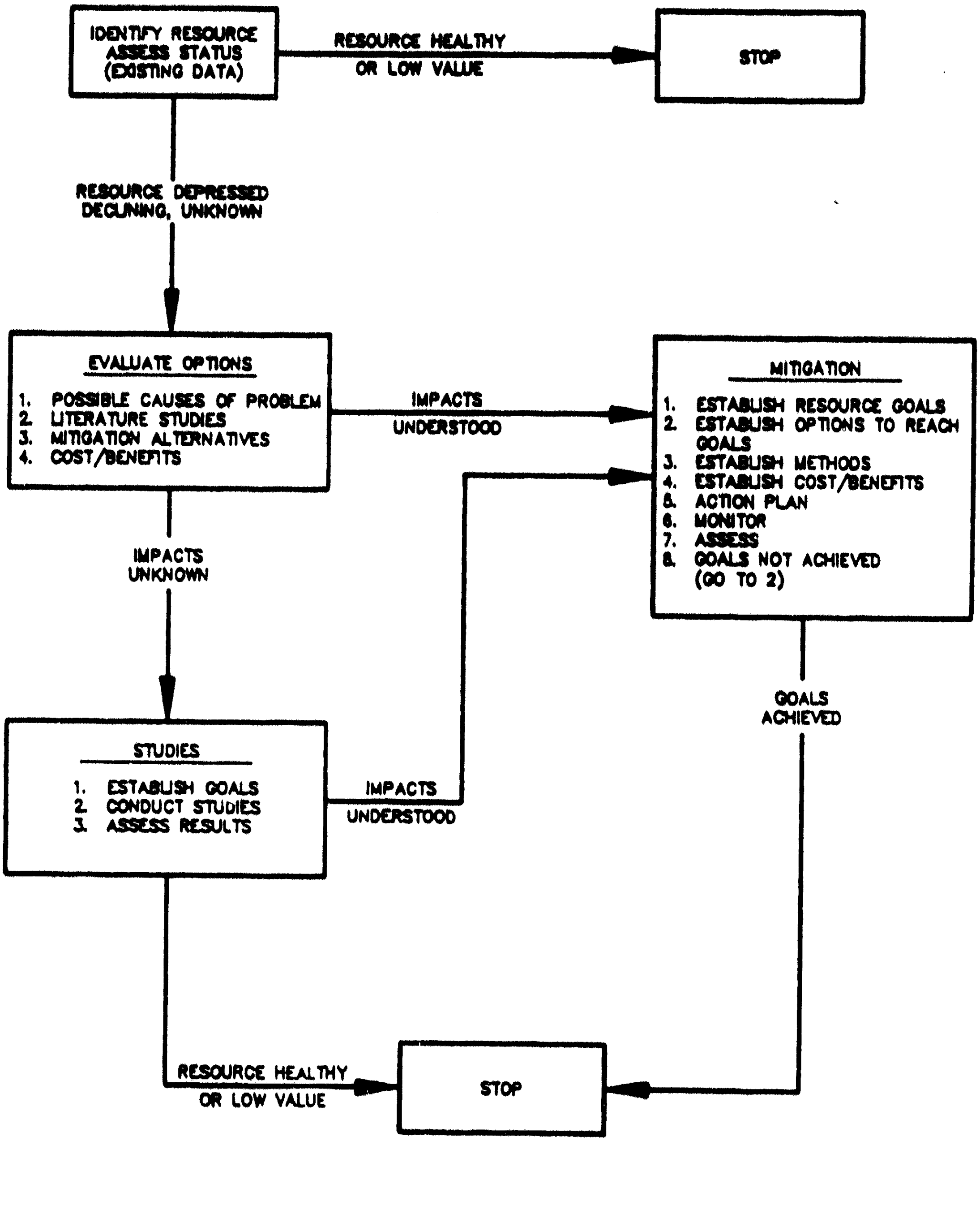

Figure 2
HARZA APPROACH

KEY WORDS

Anadromous
Bass
Columbia River
Fish Entrainment
Hydroelectric
Midwest
Resident
Salmon
Stocked Fishery
Turbine-induced Mortality

PRESENTED AT THE SYMPOSIUM ON SMALL HYDROPOWER AND FISHERIES
May 1-3, 1985, Aurora, Colorado

Fisheries Concerns at Small Hydropower Facilities in Four Regions of the USA[1]

David B. Pott, John W. Meldrim, and John J. Pizzimenti[2]

Abstract.--Regional differences in fish species, water quality and water quantity have led us to employ site-specific approaches to fisheries mitigation in the development of hydropower facilities. Herein we present fisheries mitigation plans developed in association with the licensing of hydropower projects in four different regions of the United States. Differences in the concerns over each project reflect both biological differences and site specific concerns expressed by the commenting agencies.

INTRODUCTION

Our experience in the development of hydroelectric power resources shows regional differences exist in the potential impacts upon the aquatic ecosystem and in the emphases state and federal fisheries agencies place on these problems. Projects highlighted in this paper are located on the Pearl River in Mississippi, the Wisconsin River in Wisconsin, the Blue River in Colorado, and the Moose River in the Adirondack Mountains of New York. All except the project in New York involved an existing impoundment. During the licensing process, various agencies expressed concerns regarding instream flow, water quality, recreational fishing access, and turbine impacts on fisheries.

PROJECT CASE HISTORIES

PROJECT:	Ross R. Barnett Hydroelectric Project
LOCATION:	Ross R. Barnett Reservoir on the Pearl River, near Jackson, Mississippi
LICENSE APPLICATION:	Major Project - Existing Dam (Competing Application)
PRIMARY ISSUES:	Tailrace water quality, recreational access and turbine-related fish mortality

Like many productive southern reservoirs, Ross Barnett Reservoir strongly stratifies during summer. In July, the hypolimnion may have 0.0 mg dissolved oxygen per liter and dissolved manganese concentrations as high as 4.0 mg/liter. Manganese was a special concern as Jackson's waterworks are located about 18 kilometers downstream of the dam.

To avoid downstream water quality problems associated with discharging hypolimnetic water during the summer, Harza recommended seasonal installation and removal of forebay stop logs. By utilizing stop logs in the summer, the project will discharge only epilimnetic water of acceptable quality from the upper nine feet of the reservoir. The stop logs limit the hydropower potential to 50% of the project capacity. Summer flows are usually low anyway, so energy losses will be minimal.

Seasonal appearances of striped bass *Morone saxatilis* attract large numbers of fishermen to the project site. During summer of 1980, an average of 324 visitors per day came to the spillway (project site) to fish (Bumgardner and Burchell 1982). Since recreational fishing is a significant use of the site, both protection and enhancement of access was a major concern of agencies and the public. The project would remove 46 m of important shoreline access. However by design, we increased the total available shoreline by 15 m. Special design of the tailrace precluded entrapment of fish attracted there. The increased recreational fishing access and opportunity included additional parking areas and fishing walkways and platforms adjacent to the tailrace and spillway area.

The Mississippi Game and Fish Commission expressed concerns about turbine-related fish mortalities, specifically for striped bass. This

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[1]Poster session presented at the Symposium on Small Hydropower and Fisheries. (Ramada Renaissance Hotel, Aurora, Colorado, April 30-May 3, 1985).

[2]The authors are ecologists with Harza Engineering Company, Chicago, IL.

species has been stocked in Ross Barnett Reservoir since 1963 although reproduction of these fish has not yet been documented. A substantial sport fishery exists in the spillway area, due primarily to passive migration of striped bass over the spillway. Hence, the potential for entrainment of striped bass (and other fishes) into the turbine does exist.

To assess the possible impact on the fishery, Harza developed a hypothetical turbine-induced mortality model based upon the planned operation of the hydroelectric project and existing flow duration information. At discharges less than 42 m^3/second, the turbine can not operate, and there will be no impact. When flows exceed 1,558 m^3/second, there will be insufficient elevation head for the project to operate, and again there will be no impact. Low levels of impact occur at flows between 170 (turbine capacity) and 1,558 m^3/second. Under these conditions the turbine will be operating at maximum efficiency and water will also be spilling. Fish passage success is known to directly follow turbine efficiency (Bell 1981). A proportion of fish near the spillway/turbine intake will pass over the spillway, as they do under non-project conditions. The third and greatest level of impact occurs between 42 and 170 m^3/second. In this flow range all discharges pass through the turbine.

When these three defined impact levels are paired with monthly flow duration information, a seasonal idea of the potential impact is obtained. At this project, average flows for winter months result in a high potential for turbine-related fish mortality. Further definition of impact potential will require seasonal reservoir fishery studies which will be undertaken by the applicant when the project receives a Federal Energy Regulatory Commission (FERC) license.

PROJECT: Blue River Hydropower Project

LOCATION: Blue River at Dillon Dam near Dillon, Colorado

LICENSE APPLICATION: Exemption

PRIMARY ISSUES: None

This project presented few potential fishery problems. The FERC has issued an exemption from licensing for the project. The water release works of an existing water supply dam and reservoir will be slightly modified to add the power generating facilities. The existing intake will be used; a penstock, powerhouse and tailrace will be added. The project will operate in a run-of-river mode utilizing existing downstream release requirements. No changes in existing reservoir drawdown or water release patterns will occur from development of this project. Nor will any changes in downstream water quality occur.

The reservoir has a good recreational trout and salmon fishery. No data on fish entrainment into the existing intake were available. Since the intake is in very deep water at normal pool and will remain so, it is assumed that very few fish are currently passed from the reservoir, downstream. Local residents indicated no significant entrainment existed. If fish are occasionally entrained, the existing project will do nothing to change the rate of entrainment. Of those fish that do pass through the intake, however, there may be increased mortality as they pass through the horizontal Francis turbine.

PROJECT: Moose River Hydroelectric Power Project

LOCATION: Moose River near Lyonsdale, New York

LICENSE APPLICATION: Major Modified Project

PRIMARY ISSUES: Instream Flow

This 11.8 MW hydropower project will develop 41 m of head by diverting water through a proposed penstock and power house. This diversion will bypass a 1.6 km reach of the Moose River.

Agencies objected to the applicant's initial proposal of a 1.7 m^3/second minimum instream flow. The agencies recommended a minimum flow of 7.8 m^3/second (median flow during August); or, alternatively, that an Instream Flow Incremental Method (IFIM) study be conducted to determine the minimum discharge to protect the recreational fishery in the bypassed reach. Harza and the applicant conducted the instream flow studies during 1984. We performed fishery surveys to assess species presence and abundance, and thoroughly reviewed the literature to select the best habitat suitability information for use in the Physical Habitat Simulation (Milhous et al. 1984) analysis. The IFIM study supported the applicant's initial recommendation of 1.7 m^3/second. It provided optimum or near optimum habitat for spawning and rearing of target species. As a consequence, the agencies accepted the applicant's initial instream flow proposal.

PROJECT:	Grandfather Falls Hydroelectric Project
LOCATION:	Wisconsin River near Merril, Wisconsin
LICENSE APPLICATION:	Major Project - Existing Dam (Relicense)
PRIMARY ISSUES:	Improvement of sport fishery in bypassed reach of stream

For a variety of reasons, the sport fishery in the Grandfather Falls Flowage (reservoir) is very poor relative to nearby fisheries in and around the Wisconsin River. A survey of the reservoir showed 88% of the captured fishes were black bullhead *Ictalurus melas*, the majority being less than 15 cm long. Past attempts by the Wisconsin Department of Natural Resources (DNR) to improve the reservoir sport fishery have been fruitless. During the relicensing process, we searched for a means to improve the riverine fishery in other sections of the project because of the inherent difficulties in improving the reservoir fishery.

The existing project diverts the Wisconsin River through a power canal and penstocks to the powerhouse, bypassing a 1.6 km reach of original river channel. This reach is currently dry most of the year. During agency consultation for the relicensing of this project, it was decided to attempt to re-establish a fishery in this old river channel by providing a minimum conservation flow at the dam and restoring the aquatic habitat between the dam and the powerhouse.

The method of establishing a minimum conservation release at this project is in contrast to the incremental method. Preliminary observations in which controlled amounts of water were spilled from the dam indicated that a minimum flow of between 0.7 and 1.4 m^3/second might be sufficient to create a variety of fish habitats in the historic river channel. To achieve the minimum flows required for the project, Harza recommended installing a 76 cm diameter pipe between the reservoir and the tailrace. The pipe would be installed in an existing concrete wall which forms a portion of the dam, and would be fitted with a valve to permit adjustment of the flow up to 2.1 m^3/second. Adjustments to the flow would be made during the early phases of the project and operated at a fixed setting in the future. During the initial phases of this project, the applicant will monitor and adjust flow rates to determine the minimum flows required, consistent with the creation of adequate habitat for the renewed fishery. A professional fisheries scientist, in consultation with the Wisconsin DNR will assess the habitat in the historic river channel at various discharges. Using visual and professional judgement, followed by field surveys of recolonization over three to five years, a long-term conservation release program will be recommended.

ACKNOWLEDGMENTS

We would like to thank our clients for allowing us to publish this information on their projects: Mississippi Power and Light Company, Jackson, Mississippi; Denver Water Department, Denver, Colorado; Long Lake Energy Corporation, New York, New York; and Wisconsin Public Service Corporation, Green Bay, Wisconsin.

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TWIN FALLS MITIGATION PLAN: LONG-TERM MONITORING OF FISH POPULATION

By
Al C. Solonsky
Harza Northwest, Inc.

Presented at
WATERPOWER '91
Denver, Colorado

July 1991

TWIN FALLS MITIGATION PLAN: LONG-TERM MONITORING OF FISH POPULATIONS

by Allan C. Solonsky[1], Phillip J. Hilgert[2]

The Twin Falls Hydroelectric Project diverts water from a one mile reach of the South Fork Snoqualmie River in Washington State. The developer, Twin Falls Hydro Associates (TFHA) has agreed with state, federal and tribal agencies to maintain a minimum flow of 75 cfs (2.1 m^3/s) or natural flow, whichever is less, through the bypass reach for nine months of the year, August through April, in order to protect resident trout rearing habitat. On an interim bases, during the months of May, June and July, an instream flow of 150 cfs. (4.2 m_3/s) is required to protect resident trout spawning habitat. In order to obtain lower minimum flows during May, June and July, TFHA has agreed with the Washington Department of Wildlife, Tulalip Tribe and U. S. Fish and Wildlife Service to conduct a fishery monitoring and enhancement plant.

According to the Twin Falls Mitigation Plan (TFMP), instream flows may be reduced to 75 cfs (2.1 m_3/s) during May, June and July if surveys indicate that numbers of trout in areas affected by the project are not significantly lower than pre-project levels. Flows may also be reduced if TFHA's efforts at stream habitat improvement are shown successful through monitoring of fish populations, i.e., enhancement efforts are shown to compensate for any reduction of resident trout numbers in areas affected by the Project. Modification of the instream flow regime would take place following two years of post-project monitoring.

Index sites were selected in 1984 to represent the dominant habitat type in each of the treatment areas, i.e. bypass, diversion, control and enhancement (Figure 1). The bypass site will be affected by reduced flows and is within the reach where agencies and tribes requested spawning flows. The diversion site is located where the diversion weir inundates a portion of the existing river channel and creates a small pool immediately upstream of the weir. The enhancement, or boulder placement site is located upstream of project facilities and has been severely impacted by channelization for highway construction. This site could potentially demonstrate positive fishery response to habitat improvement. The control site was selected to serve as a reference to natural trends in fish populations in the watershed and an index to non-project related factors.

To estimate the abundance and size frequencies of trout within each study site, five years of pre-project population surveys were conducted from 1984 through 1988. Snorkel surveys were conducted in mid-June, mid-July and late August of each year in an effort to account for seasonal variation related to fishing pressure. In order to calibrate snorkel surveys, electrofishing was conducted following the August survey. Due to variability in fry densities, population estimates were developed from fish larger than 3 inches (7.5 cm) in length. Pre-project monitoring was completed in 1988 and baseline population levels of resident trout were established at all study sites. In the fall of 1988, following the completion of all pre-project data collection, approximately 100 boulders three feet in diameter were placed in the preselected enhancement stream reach.

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Post project surveys began in 1990 and will continue until testing of the following two hypotheses can be answered; H1: There is no change in the numbers of fish in reaches affected by the project, and H2: There is no change in trout numbers in the boulder placement reach. To test each hypothesis, target values were determined for the project's affected sites and enhancement site, based on the pre-project population estimates and a confidence interval of one standard deviation. Ultimate acceptance or rejection of the hypothesis depend on a determination of an overall no net loss of fish in the combined project and enhancement areas.

While the TFMP is conceptually straightforward, natural temporal and spatial variation in fish populations has presented a challenge to the accurate assessment of project-related impacts. The allowable statistical variance (one standard deviation) in determining the no net loss criteria was broad by acceptable to all parties involved.

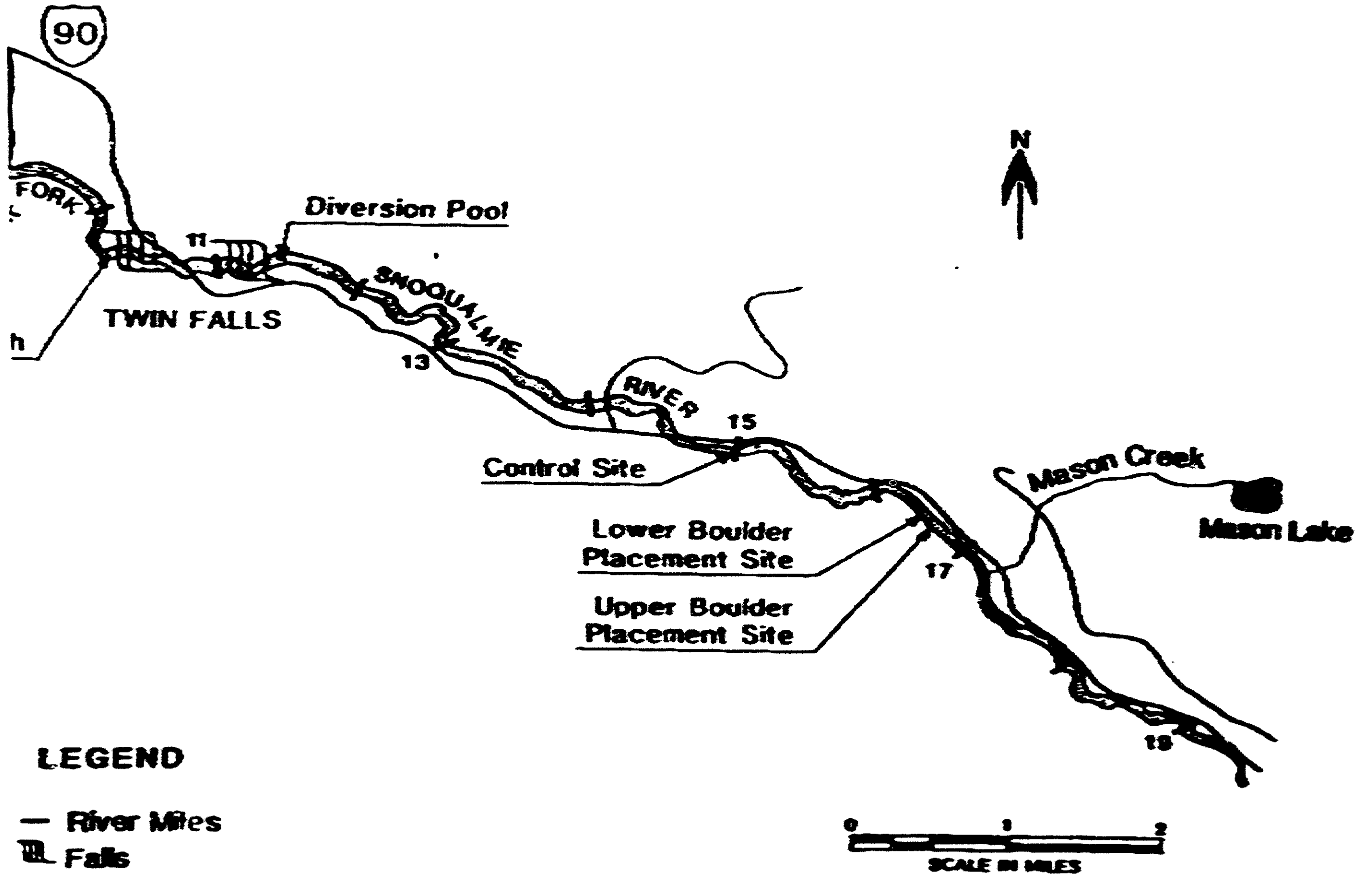


FIGURE 1. Tw.. Falls Mitigation Plan Study Sites

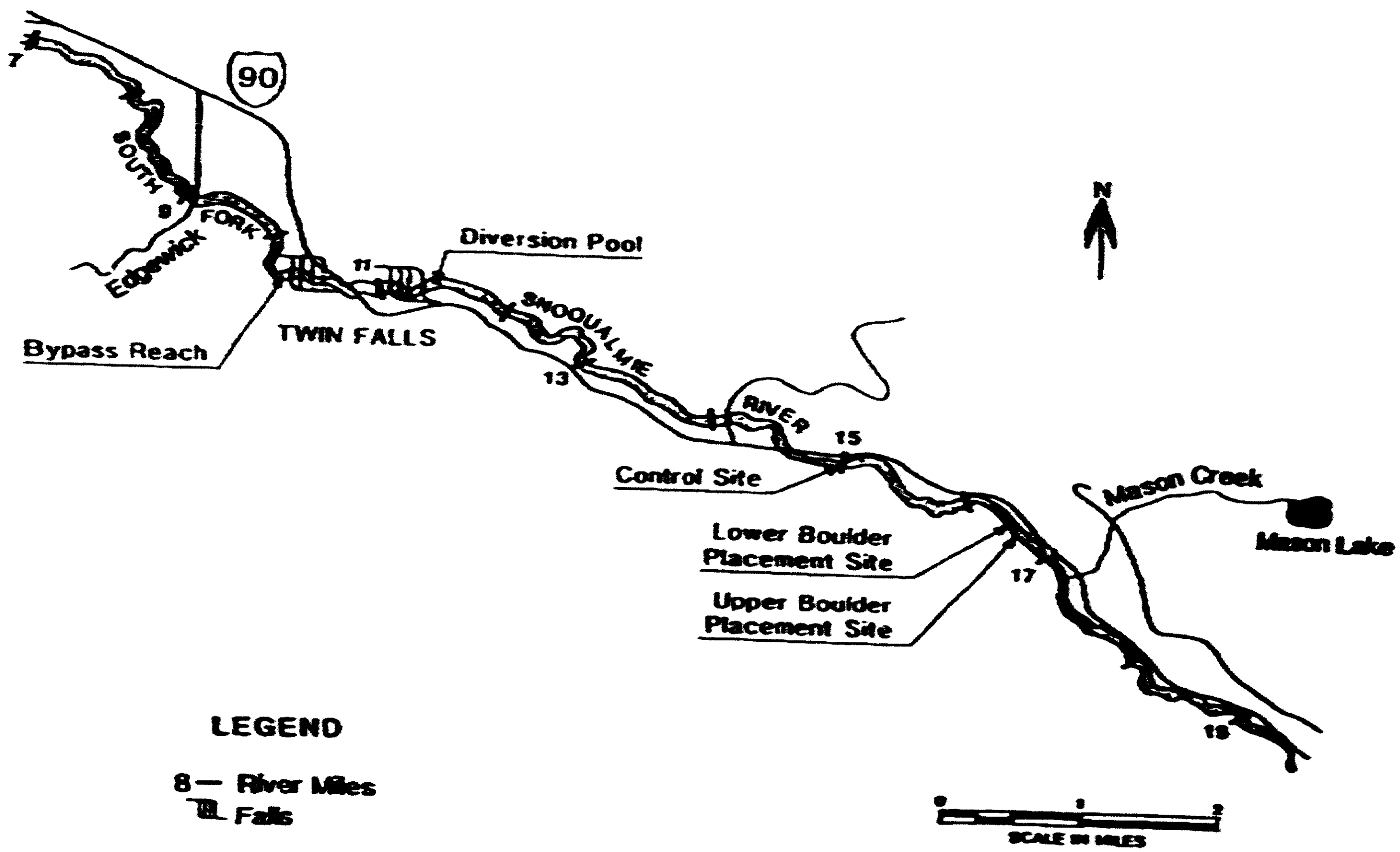
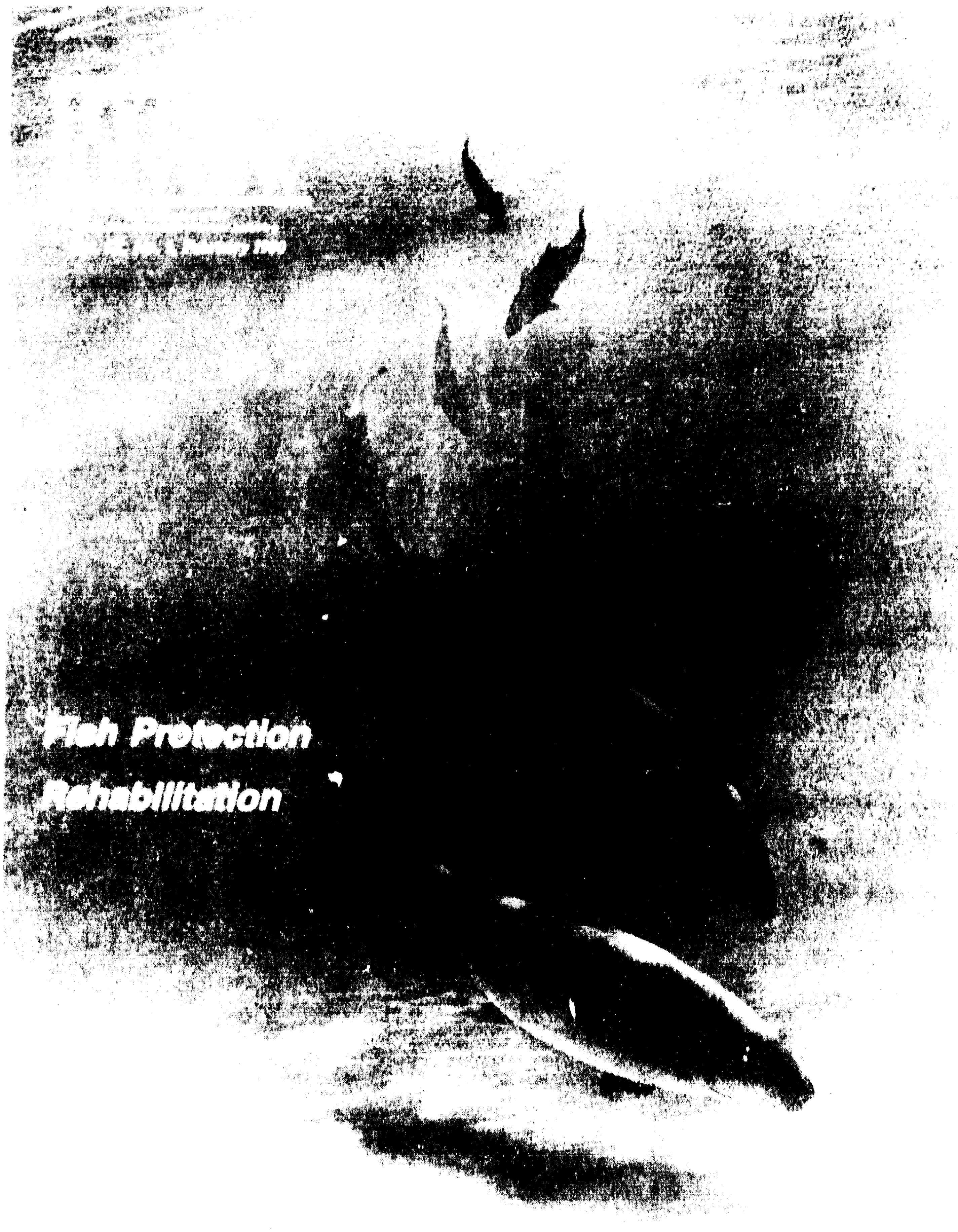


FIGURE 1. Twin Falls Mitigation Plan Study Sites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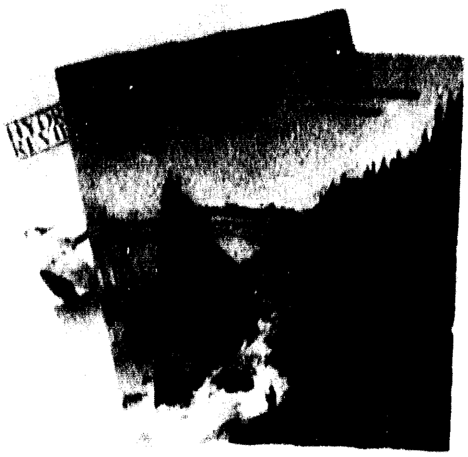

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Assessing Fish Mortality Rates

Fish mortality resulting from turbine passage is a major issue facing the hydro industry—and more research is needed. Limited studies suggest probable low death rates for fish eggs and larvae.

By Glenn F. Cada

Turbine passage is not likely to harm fish eggs and larvae, if hydroelectric facilities are operating at optimal design conditions and cavitation is not excessive.

That conclusion comes from an analysis of existing laboratory and field studies done by Oak Ridge National Laboratory in early 1989 at the request of the Federal Energy Regulatory Commission. Hydro facilities can use the results of the analysis to assess effects on fish, and FERC can use the information in licensing decisions.

Fish mortality resulting from turbine passage is a major environmental issue in the hydro industry. Developers attempting to get a license for a proposed installation or a plant owner relicensing an existing facility must consider the potential for turbine operation to kill significant numbers of fish.

Turbine-passage mortality has been studied extensively for migratory fishes. But, little is known about the impacts on resident fish in inland waters.

Studies of ichthyoplankton (fish eggs and larvae) mortality from turbine passage have been especially rare, probably because it is extremely difficult to get reliable estimates of numbers of mortalities. However, the same types of stress experienced by turbine-passed fish have been considered in entrainment studies at thermal power plants and pumped storage projects.

Oak Ridge reviewed and synthesized these studies, then applied them to hydro facilities to estimate ichthyoplankton mortality levels at plants with a bulb or STRAFLO turbines. The same approach can be applied to determine mortality rates at plants with high head turbines and low head Francis turbines, assuming the required physical information about these turbines is available.

Glenn F. Cada is a research staff member in the Environmental Sciences Division of Oak Ridge National Laboratory in Oak Ridge Tennessee. Oak Ridge National Laboratory is operated by Martin Marietta Energy Systems, Inc. for the U.S. Department of Energy.

Which Fish Are Susceptible

Migratory fish, especially salmon and American shad, often experience high rates of damage and mortality when they pass through small turbines with closely spaced blades or buckets. Young salmon and juvenile shad are relatively large, ranging in length from 5 to 20 centimeters (cm). They instinctively move from streams down to an ocean or lake. On the way, they travel over or through any intervening dams and often come into contact with turbines.

In contrast, resident fish are less likely to be exposed to turbine passage. Larger fish are strong swimmers, and lacking the downstream migratory urge, they may avoid the intake area. Most eggs of freshwater fish are found in nests or adhere to rocks and vegetation. Consequently, hydro impacts on eggs normally stem from water level fluctuations, not turbine entrainment.

Floating eggs and weakly swimming larvae, which typically range in length from 0.1 to 3.0 cm, are most susceptible to damage. They are often distributed in the intake water and unable to avoid turbine passage. As these fish grow, they become stronger swimmers and thus are less susceptible to damage. And, many reside near the bottom.

Turbine-Passage Stresses

Entrained fish eggs or larvae experience three general types of stress during turbine passage: rapid pressure changes and cavitation, contact with the turbine blades, and shear forces and turbulence. Pressure changes, shear, and turbulence occur throughout the system. Blade contact and cavitation are restricted to relatively small areas and may not occur at all.

The following sections describe the expected magnitude of each stress as well as how each one affects ichthyoplankton.

Pressure

Pressure changes experienced by fish passing through a turbine depends on the turbine's design and flow rate and where the fish is in the water column when it is entrained in the intake flow. Figure 1 shows examples from bulb-type turbines. A Francis turbine would have a similar pressure regime.

In the example, fish inhabiting surface waters will be adapted to an absolute pressure of approximately 100 kPa (one atmosphere). When entrained in the intake flow, they may experience pressure increases caused by the change in depth. And, if the penstock leads down from the intake, the fish will experience more pressure

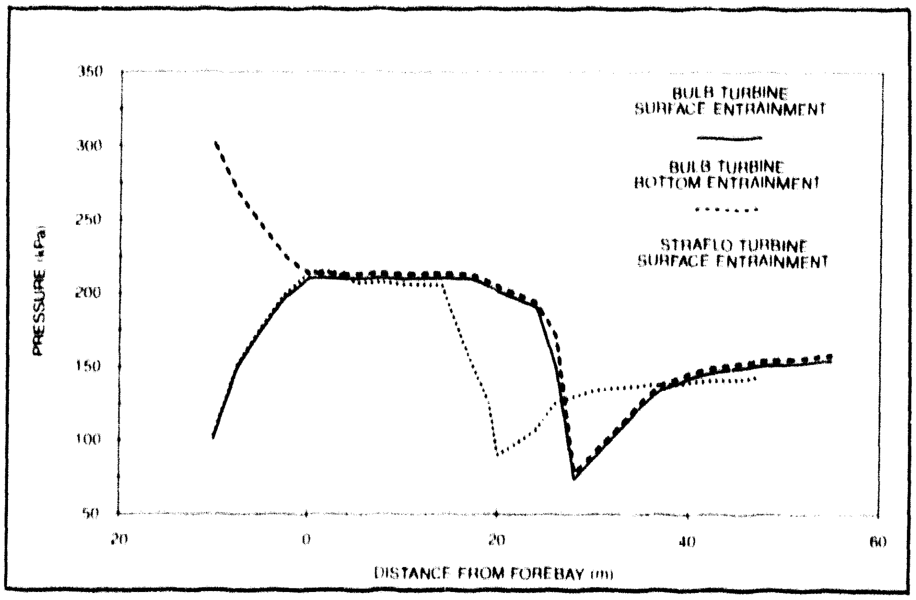

Figure 1: Estimated pressure regimes experienced by fish during passage through hydro plants. STRAFLO turbine values are taken from the source listed in Note 2. Bulb turbine values are taken from the source listed in Note 1; the solid line represents pressures experienced by a fish drawn from the surface, whereas the dashed line represents a fish drawn from a depth of 20 meters.

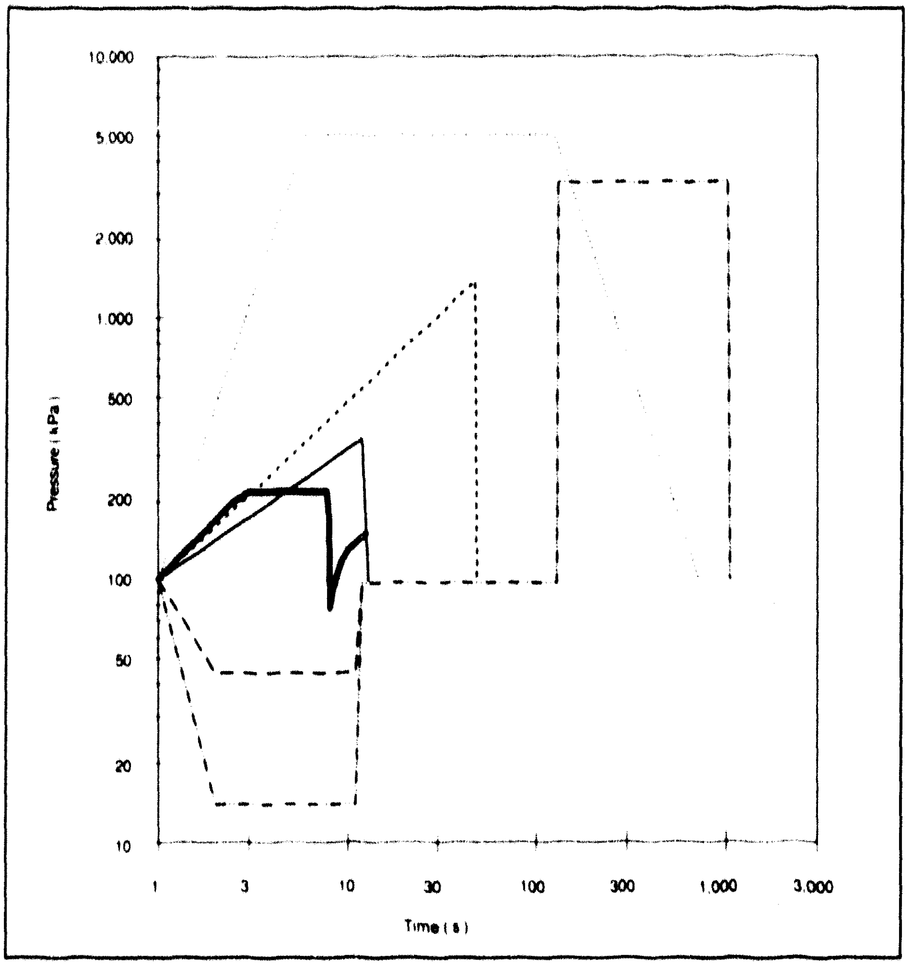

Figure 2: Various pressure regimes applied to early life stages of fish. The solid bold line depicts the estimated pressure regime experienced by fish entrained at the Racine Hydroelectric Power Plant on the Ohio River. Other lines represent regimes from three laboratory studies (Notes 3, 4, and 5). All experiments resulted in little or no mortality to early life stages of fish.

increases between the intake and turbine blades or buckets. Total pressure upstream of the turbine can double from levels the fish are normally adapted to.

On the other hand, fish entrained from greater depths are already adapted to higher pressures (about 300 kPa) and may experience little or no change in pressure upstream of the turbine, as shown in Figure 1. Pressure decreases from normal levels would amount to about 30 percent in this example.

Immediately downstream, fish drawn from surface waters experience a momentary pressure decrease of about 20 percent from levels they're adapted to. The bottom-entrained fish may be briefly exposed to pressures as low as 80 kPa then return to more normal pressures in the draft tube and tailwaters. This continuous, short-term pressure for bottom-adapted fish amounts to a decrease of 75 percent from their normal pressure levels.

Depending on flow rate and penstock length, pressure changes may occur in as little as 15 seconds; subatmospheric pressures are experienced for less than 1 second.[1,2] Other turbine types or higher-head installations could have more severe hydrostatic pressures.

Fish are more sensitive to pressure decreases than increases. Therefore, the most stressful period of turbine passage may be the momentary decompression immediately behind the turbine blades or buckets. Rapid decompression causes the swim bladder of the fish to expand rapidly, sometimes to the point of rupture.

Fish eggs and many early larvae don't have swim bladders so are unlikely to be damaged. However, if larger fish are drawn into the intake so rapidly that they cannot adjust the pressure within their swim bladders, they can die. Studies show pressure reductions of 60 percent of the acclimated value could burst the swim bladders of juvenile perch.[3] Based on these results, larger larvae or juveniles with swim bladders entrained from depths of ten meters or more may die from rapid decompression.

Ichthyoplankton seem to be more tolerant to decompression. In one study, hydrostatic pressure on striped bass larvae was reduced by 86 percent with few harmful effects.[1] So for the turbine pressure regimes illustrated in

Figure 1, the critical depth for entrainment would be 48 meters or more.

Few laboratory studies have reproduced exactly the pressure regimes depicted in Figure 1. However, several studies have examined mortality of fish in early life stages under more severe conditions. The pressure regimes shown in Figure 2 were applied to a wide variety of freshwater species including whitefish, carp, rainbow trout, white bass, bluegill, and catfish. In all cases, mortality was very low or not significantly different from controls.[4-6]

These studies indicate that pressures experienced by most young fish during hydro turbine passage will not result in significant mortality. Most ichthyoplankton are drawn from depths at or above the turbine; consequently, they are exposed to relatively minor, nonlethal pressure increases before returning to natural pressures in the tailwaters.

Cavitation

Cavitation is an extreme case of unsteady pressures within a turbine that can cause pitting damage to the machinery. Cavitation may have the greatest effect on fish of all turbine passage stresses.

Cavitation most often occurs at high loads, when pressure drops in the turbine are greatest. But, it also can occur at low loads when the turbine is operating off design. Pressure on the suction side of the blades or buckets declines to the vapor pressure of the water, forming pockets or bubbles. These vapor pockets are transported downstream to higher pressure regions. There, they collapse violently, creating local shock waves. Shock wave intensity depends on bubble size, static pressure in the collapse region, and dissolved gas content, but it may reach tens of thousands of kilopascals at the point of collapse.[7] Pressure waves decrease rapidly as they move away from the center of collapse.

Shock waves have been simulated in the laboratory and in open waters. In both studies, it was the rapidity of the pressure changes and shock waves, not absolute pressures, that killed the fish.[7-10]

Mortality rates caused by cavitation at hydro facilities is difficult to predict. Obviously implosive forces sufficient enough to indent a steel runner will kill fish. However, damage evidence from model tests indicate cavitation affects an area of only inches.[11]

Most small fish entrained in the turbine, assuming they're randomly distributed, may not pass close enough to an implosion to be harmed. Also, because cavitation is an undesirable, costly condition for turbine operators (as well as for fisheries managers), considerable effort is expended on design to avoid the problem.

Two design factors that influence cavitation are turbine setting and net head; the relationship between the two is called the plant's sigma. Turbine setting is the elevation of the runner's centerline with respect to tailwater elevation. If the turbine setting is too high relative to tailwater elevation, extreme subatmospheric pressures and cavitation may result. The potential for cavitation can be minimized by increasing the plant's sigma, for example, by decreasing the turbine setting, the net head, or both.

Contact with Turbine Blades or Buckets

The probability that an entrained fish will be struck by a turbine blade depends on the turbine's characteristics and the size of the fish. In the late 1950s, K. Von Raben developed the following equation to estimate probability of fish contact with turbine blades. This equation doesn't apply to hydro facilities with Pelton wheels. It is based on Von Raben's knowledge of turbine dynamics and his own experiments.[12]

$$P = \frac{l \times n \times R \times a \times \cos\alpha}{f}$$

where

P = the probability of blade or bucket contact (percent);
l = fish length (cm);
n = number of runner blades;
R = revolutions per second;
a = cross-sectional area (m^2) of water passage, i.e., π (runner diameter^2–hub diameter^2)/4;
cos α = blade or bucket angle (the angle formed by the water flow with the axial direction at the moment of impact with the edges of the runner);
f = discharge (m^3/sec)

The probability of contact will be relatively small for young fish. Figure 3 shows the range of probability values estimated by Von Raben's equation for various sizes of fish at different bulb turbine flow rates. For example, the chance of an entrained 0.1-cm diameter fish egg being struck by a turbine blade is 0.1 percent or less over the range of flows. Probabilities for most larvae are 2 percent or less. Juvenile fish that are 4 cm long have an estimated probability of contact of 5 percent or less.

Trends in contact probability for any other turbine (Francis, Kaplan, or a different bulb) would be similiar, although actual values would change somewhat. Higher probabilities of blade contact would be expected for turbines that are smaller and operate at higher runner speeds and lower flows.

These probabilities, while small, may overestimate fish losses for two reasons. First, the equation estimates probability of blade contact, but contact does not necessarily cause mortality. Contact with the blade may range in severity from head-on collisions to slight glancing blows. This has led some workers to multiply P in the equation by 0.43 (the theoretical/observed mutilation ratio) to get an estimate of obvious damage or mortality from blade contact.[13] Given the fragile nature of fish eggs and larvae, it's probably appropriate to assume all contacts result in mortality.

Second, the flexibility of fish larvae may result in less blade contact. Rather than passing through the turbine as rigid bodies, larvae are curved or bent by the flow lines. They present a smaller target, thus a smaller probability of contact, than would be predicted by assuming rigid length.

Turbulence and Shear Stresses

Hydro plants can gauge probable impacts of fluid-induced stresses on fish larvae and eggs by using related studies of thermal power plant cooling systems. Several studies have examined independently the component stresses of thermal power plant entrainment.

In one study, seven species of freshwater fish larvae were passed through 2.2-cm diameter condenser tubing at velocities of up to 5.8 meters per second (m/sec). Stress generated by rapid passage through these narrow tubes resulted in less than 5 percent mortality in all cases.[14]

In another, researchers exposed

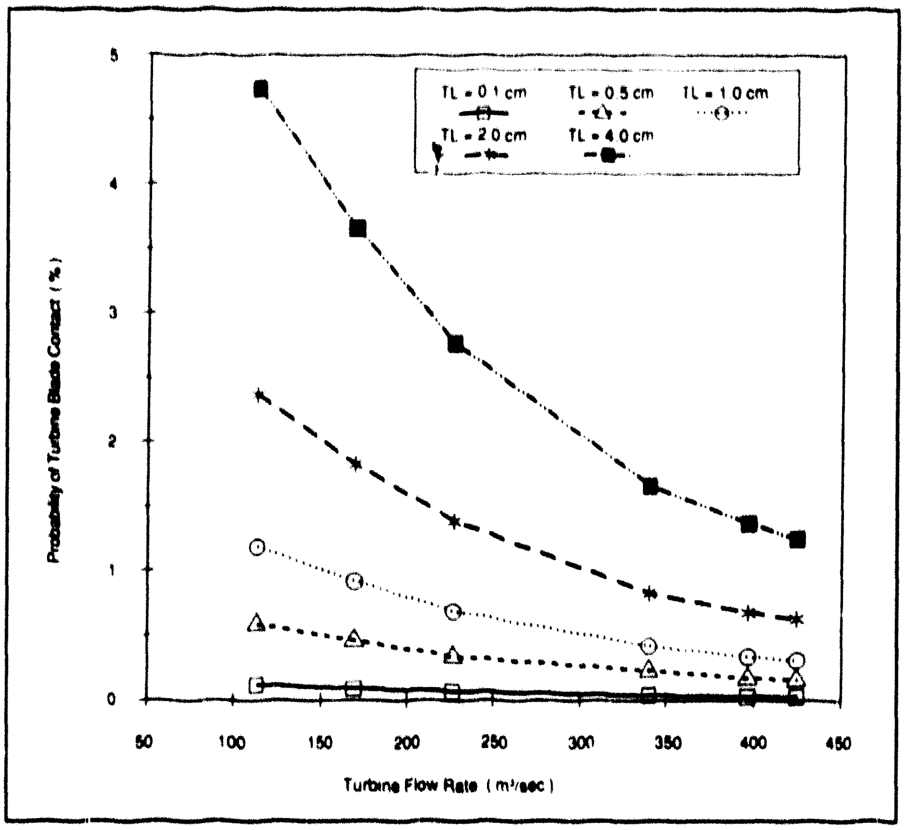

Figure 3 Probability of contact with the turbine blade for early life stages of fish of various sizes TL = total length. For these fish, blade contact probably will result in mortality

striped bass larvae to shear in condenser tubes at velocities as high as 3.0 m/sec. Mortalities were not significantly different from controls. The conclusion—fluid-induced stresses are not a major reason for striped bass mortality.[11]

A third study used a power plant simulator to subject fish larvae and juveniles to moderate pressure changes (56 to 146 kPa) as well as shear forces associated with passage through 3.2-cm diameter pipes at velocities of 2.4 m/sec. The combined stresses caused high mortalities among carp larvae but insignificant mortalities among larval bluegill, channel catfish, and largemouth bass.[11]

These experimental studies indicate shear stresses caused by average bulk flow velocities through a turbine are unlikely to kill fish eggs and larvae. Although fragile early life stages should be sensitive to shear damage, their small size apparently minimizes exposure to velocity changes and shear forces.

Conclusions

Few studies have directly examined turbine-passage mortality of early life stages of fish in hydro facilities. None have collected information in a way that would be directly useful for predicting impacts at other facilities. But, many studies have examined the same types and levels of stress that small larvae and fish eggs at a hydro plant experience. Based on these studies, it seems likely that at well-designed, well-operated hydro operations the level of ichthyoplankton mortality due to turbine passage will be quite low.

In addition, the following conclusions can be made.

—The range of pressure changes experienced by most fish will cause little or no mortality.

—Cavitation can cause ichthyplankton mortality, but the extent is impossible to predict based on available information. The surest way to mitigate damage to both fish and turbines is to operate the turbines close to peak efficiency, or at least avoid operating regions with excessive cavitation.

—Probability of contact with the turbine runner blade or bucket is related to the size of the fish and characteristics of the turbine.

—Shear forces and turbulence in a turbine are extremely difficult to quantify, so the resulting level of mortality cannot be predicted precisely. Researchers have exposed fish larvae to turbulence and shear stresses by passing them through narrow pipes at high velocities. They rarely observed statistically significant mortalities.

This technique of estimating mortality rates is valid for most turbines. The estimates can then be used to determine which, if any, field studies to apply to a given site.

The turbine characteristics presented are based on examples of relatively new designs, bulb and STRAFLO turbines. Older turbines or ones that frequently operate outside of optimal design conditions may have significantly different pressure and velocity regimes or blade/wicket gate configurations. This could greatly influence mortality rates. So, when assessing losses of fish as part of licensing or relicensing activities, all physical conditions should be quantified. □

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A New Technology for Diverting Fish Past Turbines

The Eicher Fish Screen may offer a compact, economical, and highly effective system for diverting fish from penstocks at hydroelectric projects, according to test results.

By Fred C. Winchell

Fish protection is an important consideration at many hydroelectric facilities across North America. In new license applications currently on file with the Federal Energy Regulatory Commission, three-fourths of all provisions for natural resource mitigation have to do with fish protection. As the number of expiring hydro licenses increases in the next few years, many hydro projects will require fish protection systems.

Finding a system that meets agency requirements for providing effective protection and, at the same time, minimizes costs can be a challenge. Conventional technologies acceptable to most regulatory agencies—such as traveling belt or angled drum screens—have high initial costs, take up large amounts of space, and are costly to maintain. These limitations preclude use of conventional systems at many sites. A relatively new, simple screening system that is more compact, less costly, and appears to be equally effective as conventional systems may offer the solution to the fish passage dilemma at many hydro projects.

Full-scale tests of the Eicher Fish Screen performed last spring at James River II Inc.'s Elwha Hydroelectric Project in Washington State has shown the design to be over 99 percent effective in bypassing coho salmon smolts without mortality. The tests were part of a $3 million research project funded jointly by the Electric Power Research Institute (EPRI) and James River II Inc. If future testing confirms early results, the screen could be used on a permanent basis to bypass juvenile salmon moving downstream at the Elwha project. The screen could also be used at other hydroelectric projects with exposed penstocks.

Fred Winchell is a senior environmental scientist with Stone & Webster Environmental Services. He is the principal investigator in EPRI's testing program of the Eicher Screen at the Elwha Hydroelectric Project.

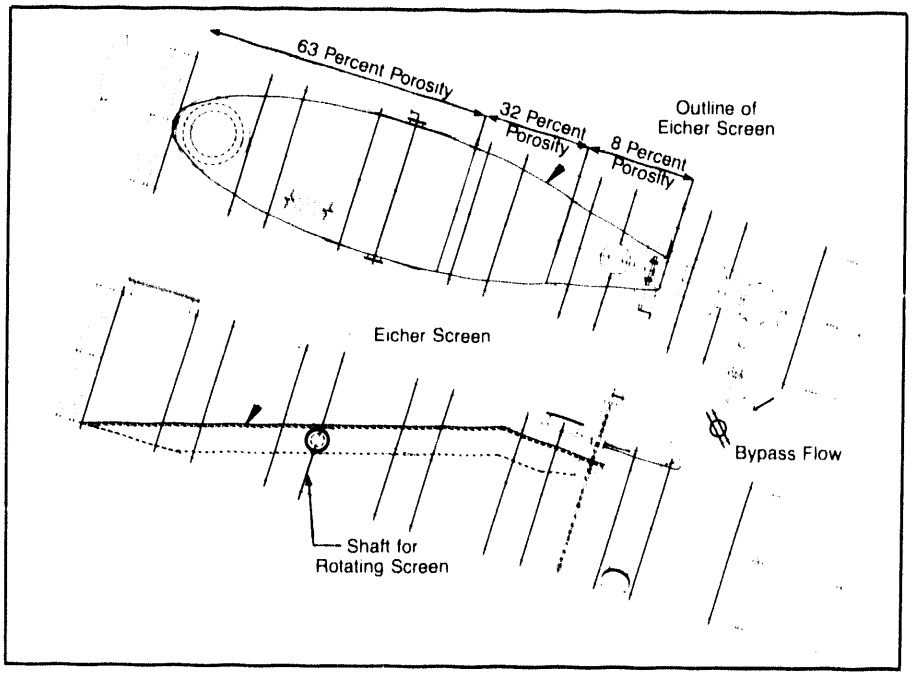


Figure 1: The Eicher Fish Screen, as shown in the overhead view (top), is an elliptical-shaped screen divided into three sections. The screen sits in the penstock at about a 16-degree angle to the water flow (see bottom illustration). In the tests, fish are released inside the penstock and are carried by the flow toward the bypass entrance. (Courtesy Hosey & Associates Engineering Company)

The Concept Behind the Eicher Screen

The concept of inserting an elliptical screen in a penstock at a shallow angle to the flow to divert fish from a turbine

Turning a Novel Idea into a Successful Fish Diversion Method

George Eicher has been working to protect fish all over the world for nearly half a century. His development of the Eicher Fish Screen appears to be a significant advancement in the ongoing effort to move anadromous fish past hydroelectric facilities. However, his invention actually came about by default.

Portland General Electric hired Eicher in 1979 to design a fish protection system for its 13-unit, 15-MW T.W. Sullivan hydroelectric facility on the Willamette River in Oregon. Since there was no room in the forebay for a traveling screen, Eicher decided his only option was to put a screen in one of the unit's penstocks—something that had never been done before.

Eicher's final design consisted of a 21-foot-long stainless steel wedgewire screen with 0.08-inch bars and 0.08-inch openings between bars. The screen was placed inside the 11-foot-diameter penstock, and was inclined at a slope of 19 degrees to the flow. The average water velocity through the penstock and into the bypass was approximately 5 fps. The fish traveled through the penstock, over the screen, and into an existing bypass trap.

Eicher says he was always confident that the screen would protect the fish from the turbine. However, he was concerned about debris collection and had developed several possible cleaning scenarios. Before he had the opportunity to implement any of the methods, though, he had to leave for another consulting job in Australia. Upon his return, he discovered the screen had been operating for over a month with no debris problems. His next telephone calls were to the federal patent offices in the U.S. and Canada! (Eicher now holds patents for his device in both countries.)

The screen at the Sullivan plant has been operating successfully for nearly 11 years. The system has required no maintenance and has been very inexpensive to run—only a fraction of the cost of a conventional system.

The Eicher Screen installed at the Sullivan project has been successful in diverting fish. However, the configuration of the original collection facility did not allow Portland General Electric to accurately evaluate the injury rates of bypassed fish. PGE has redesigned the collection facility and will soon resume testing.

was conceived by biologist George Eicher a little over a decade ago. His system, commonly referred to as the "Eicher Screen," was installed at the T.W. Sullivan Hydroelectric Project in Oregon in 1980 and continues to operate. (See the accompanying story.)

The primary difference between the Eicher Screen and conventional screening systems is that it can function at relatively high water velocities. Most conventional screening systems operate at channel velocities of about 1 to 2 feet per second (fps), while the Eicher Screen may be successful at velocities as high as 8 fps. Fish passing through screening systems with a low flow velocity are exposed to the facility for much longer and can be delayed or stressed if they do not voluntarily seek out and enter the bypass system. In addition, predators sheltered in low velocity areas can take a substantial toll on passing fish. A high velocity system is not likely to harbor predators and will not cause delay since fish are swept rapidly through the system and into the bypass.

The primary risk to fish passing through a high velocity system is the possibility of physical injury or impingement on the screen. These factors can be easily assessed and appear to be avoidable with careful design.

The Eicher screening system requires no space in the forebay area—a decided advantage at sites where space is limited. In addition, placing a screen inside an existing penstock does not alter the aesthetics of the site. Other advantages include very low operating costs, no risk of icing during cold weather, and insensitivity to forebay levels.

Upon installation and initial operation of the screen at the Sullivan plant, Eicher began working to gain resource agency acceptance of his device. In 1984, he initiated a study at the University of Washington to test the efficiency of his screen and collect data to share with agencies. Eicher soon realized that refining the screen's design and demonstrating its effectiveness would require a substantial research effort. So, in 1985, he contacted the Electric Power Research Institute (EPRI) and shared his idea. EPRI agreed to sponsor continuing research at the University of Washington to refine the design of the screen. EPRI's ultimate goal was to test the concept's potential at an actual site.

Laboratory Study: Screen Appears Effective

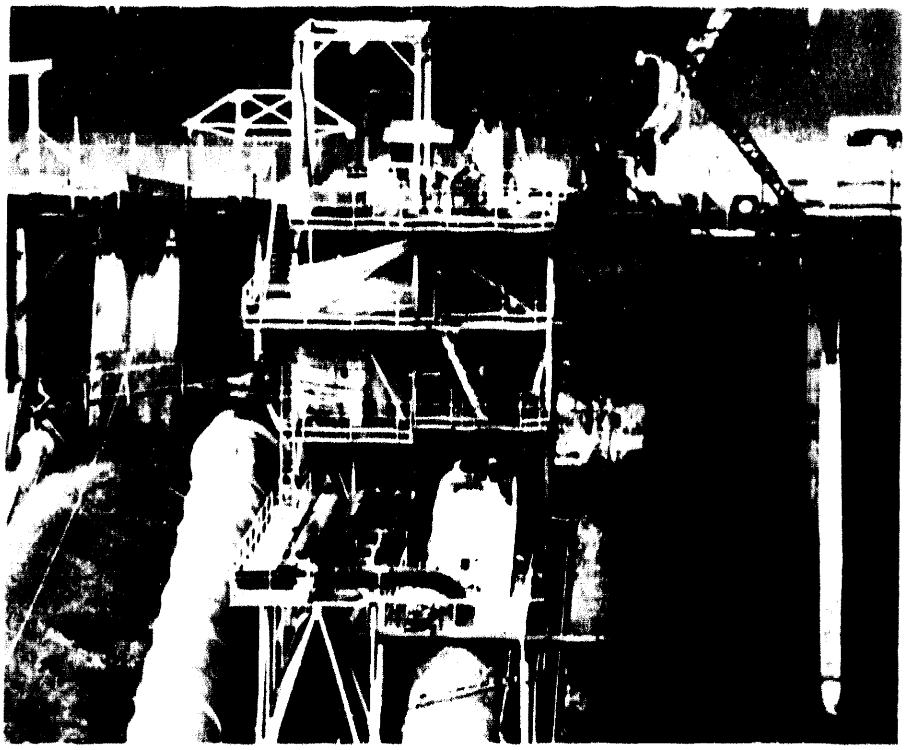
Laboratory studies of the Eicher Screen at the University of Washington investigated many parameters. Researchers evaluated the effect of screen angle, bypass and penstock water velocities, lighting, and various screen types on passage success for coho and chinook salmon and rainbow and steelhead trout. The study found that the Eicher Screen was effective at diverting fish under a range of hydraulic conditions with little or no injury.[1,2]

Fish were most vulnerable to impingement in the area just upstream of the bypass entrance. However, impingement occurred primarily at low penstock velocities, and when the water velocity approaching the bypass was less than the average velocity in the penstock. Impingement was reduced when the opening between bars was changed from 2 millimeters (mm) to 1 mm in the 18 inches of the screen closest to the bypass entrance. This change reduced the velocity through the screen in the area where most impingement occurred.

Full-Scale Evaluation: Installing and Testing a Prototype

Soon after beginning the laboratory tests, EPRI undertook a search for a suitable site to test a prototype installation. The Elwha Hydroelectric Project, located on the Elwha River near Port Angeles, Washington, was selected. With four 3.2-MW units and a total project flow capacity of 2,000 cubic feet per second (cfs), the site offered a high degree of operational flexibility for testing.

In 1989, EPRI entered into an agreement with the project owner, James River II Inc., to evaluate the Eicher Screen in one of the 9-foot-diameter penstocks at the Elwha project. James River II, Inc. funded design and installation of the screen, including an extensive hydraulic model study used to refine the initial design.



The test facilities at the Elwha project were built directly below the dam and over the penstocks that lead to the powerhouse. The configuration consists of the wooden collection tank and three work decks. Test fish are released into the penstock on the right which contains the Eicher Screen. The fish are then carried through the bypass that comes out of the top of the penstock and leads to the collection tank (see Figure 2).

EPRI funded design and installation of testing facilities and is also funding the ongoing biological and hydraulic evaluation at the facility.

The Eicher Screen at Elwha

James River II Inc. contracted with Hosey and Associates Engineering Company in Bellevue, Washington, to design the prototype screen and oversee hydraulic modeling. Hosey, in turn, contracted with Engineering Hydraulics, Incorporated in Redmond, Washington, to build the model and conduct the laboratory tests.

A model of the intake, penstock, and screen on the scale of 1 to 4.7 was constructed to develop detailed information on the flow field immediately upstream of the Eicher Screen and in the fish bypass. In the lab, the porosity (percent open area) of screen sections in the model was varied between tests. The goal was to achieve a uniform flow distribution along the length of the screen while minimizing head loss. The sixth screen porosity configuration seemed most successful and was adapted in the final design of the prototype. In this configuration, the upstream section of the screen is 20 feet long and has a porosity of 63 percent with an opening between bars of 0.125 inches. The middle 7.5-foot section has a screen porosity of 32 percent with an opening between bars of 0.035 inches. The downstream section is 7 feet long and has a porosity of 8 percent with an 0.008-inch opening between bars. (See top illustration in Figure 1).

The Eicher Screen prototype at Elwha consists of an elliptical screen sloping upward at a 16-degree angle toward a fish bypass at the top of the penstock. The screen was installed as part of a 46.5-foot-long prefabricated penstock section that replaced a section of the existing penstock. The screen is comprised of stainless steel profile bar (often referred to as wedgewire) made by the Hendrick Screen Company. The bars on the screen are oriented parallel to the flow, presenting a very smooth surface to diverted fish and maximizing debris passage efficiency. The screen is designed to pivot to be cleaned by back-flushing when required. Figure 1 shows overhead and side views of the screen in the penstock.

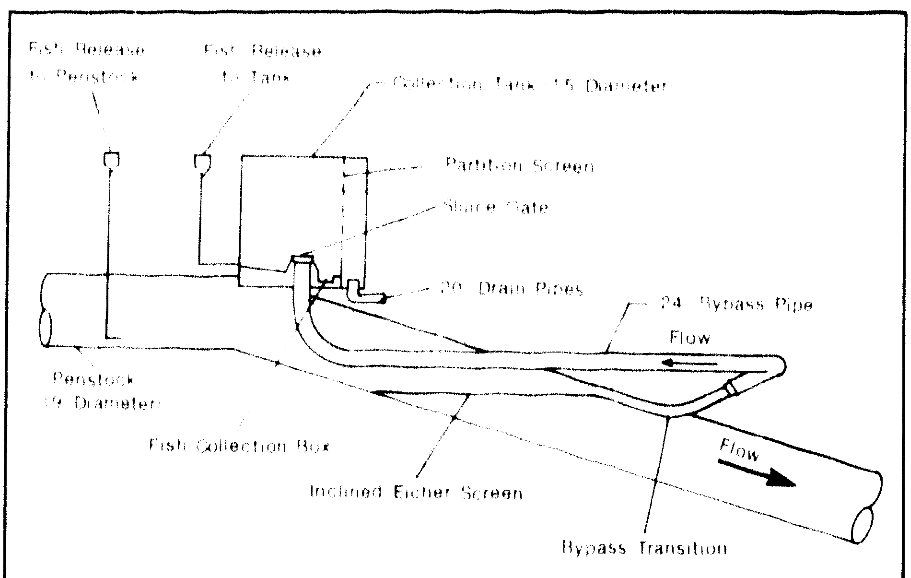


Figure 2. A schematic of the testing facilities. After the fish pass through the bypass entrance, they are transported through a 24-inch horizontal bypass pipe into the collection tank.

EPRI's Testing Program

EPRI initiated a multi-year testing program last spring with construction of testing facilities and completion of the first series of tests with coho salmon smolts. EPRI retained Stone & Webster Environmental Services based in Boston, Massachusetts, to review hydraulic modelling efforts and design the testing facilities. The testing program was developed in a cooperative effort by Stone & Webster and Hosey & Associates with extensive input from state and federal fishery agencies and the Lower Elwha Tribe. A detailed report on the tests performed last spring will be presented in EPRI Re-

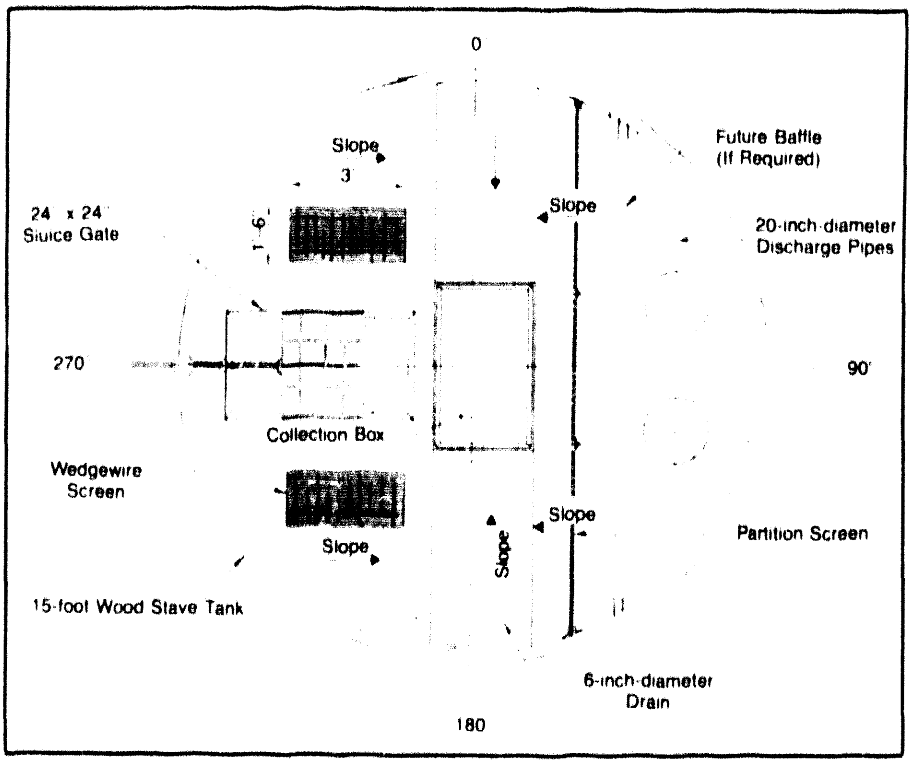


Figure 3 This overhead view of the fish collection tank used at the Elwha project shows the various tank components. Fish enter from the base of the tank via the bypass pipe with the sluice gate fully open. When a test is completed, the sluice gate is closed, tank drained, and fish recovered in the collection box

port No. GS-7036 to be published by the end of 1990.[5]

Testing will continue in following years with smolts of steelhead trout, chinook salmon, and additional coho salmon. Plans are to carry out tests in the spring seasons to correspond with the natural migration timing of these species. EPRI is planning at least two more years of testing.

Testing Facilities

Since the Elwha site is the first installation of the refined Eicher Screen design, a very conservative approach was taken in designing the testing facilities. A collection tank design was selected to ensure that fish could be recovered without causing injury. The tank also served to control bypass flows to achieve the desired test conditions. The final design of the testing facilities is shown in Figure 2.

A pressurized system is used to release test fish into the penstock upstream of the screen. This system is composed of a 60-gallon fish release tank (24 inches in diameter by 30 inches deep) connected to an 8-inch release pipe. The fish are released into the penstock by gradually displacing the water from the release tank and pipe with compressed air. The system releases the fish at the base of the penstock approximately 15 feet upstream of the leading edge of the screen. This location is considered to be the "worst case" scenario, since it exposes fish to the full length of the screen as they travel to the bypass. An identical pressurized system releases the control fish into the collection tank.

The bypass system that leads from the penstock to the collection tank delivers test fish to the tank through a 24-inch pipe. The bypass flow and the fish in the pipe are discharged vertically upward through a fully open sluice gate at the floor of the tank. Bypass flows are regulated by adjusting the elevation of the water in the tank. Depths ranged from 7 to 10 feet for the bypass flows evaluated (4 to 7.8 fps). The water level in the tank is regulated by adjusting two 20-inch valves in the bottom of the tank. These valves drain water from the tank behind a screened partition designed to retain collected fish. Figure 3 shows the various components of the tank.

When fish are collected, the tank is drained and the fish are guided by the sloped floor into a 60-gallon collection box. The box is then lifted to the uppermost of three work decks that surround the collection tank. Twelve 100-gallon tanks and twelve 200-gallon tanks are provided on the middle and upper decks to hold groups of fish prior to release and following recovery.

Test Parameters

Six combinations of penstock and bypass velocities were evaluated, as shown in Table 1. Penstock velocities were selected to cover the normal operating range of the turbine. Based on results of the laboratory studies at the University of Washington, the velocity at the bypass entrance was set equal to or greater than the average velocity in the penstock. This level of bypass velocity minimized the potential for fish impingement. The condition with 7 fps in the penstock and bypass was added after a slight increase in injury rate was noted between the 6 fps and 7.8 fps (full gate) penstock conditions.

A study schedule was developed that replicated each test condition 12 times over a 15-day period. Since the 7 fps condition was added later in the tests, it was only replicated five times. In order to examine time of day as a variable that could affect passage success, each of the five primary conditions were replicated six times during daylight hours and six times during hours of darkness.

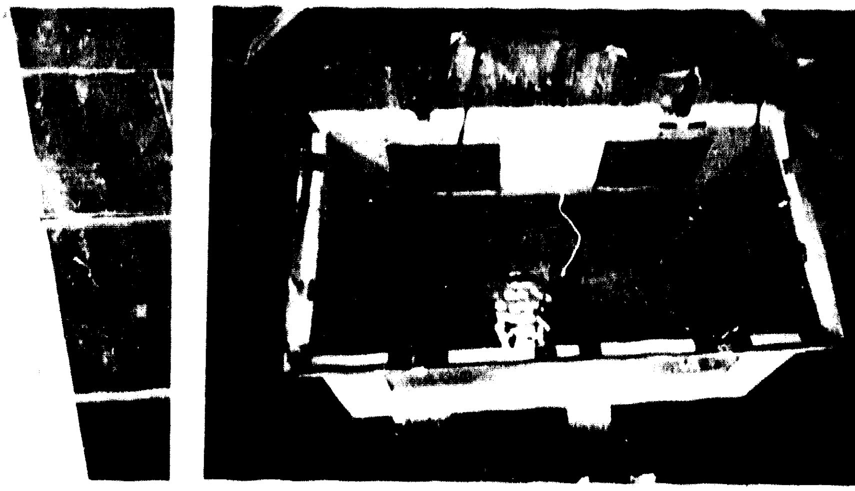
Test Methods

The coho smolts used in the 1990 testing program were obtained from the Lower Elwha Tribal Hatchery.

Table 1: Velocity Conditions Tested at the Elwha Hydroelectric Project, Spring 1990

Penstock Velocity	4 fps	4 fps	6 fps	6 fps	7 fps*	7 8 fps
Bypass Velocity	4 fps	6 fps	6 fps	7 8 fps	7 fps	7 8 fps**
Turbine Flow	240 cfs	240 cfs	360 cfs	360 cfs	425 cfs	475 cfs
Bypass Flow	11 8 cfs	17 7 cfs	17 7 cfs	23 cfs	20 6 cfs	23 cfs
Wicket Gate Position	48%	48%	70%	70%	88%	100%

* This condition was added after a slight increase in injury rate was noted between the 6 fps and 7 8 fps penstock conditions
** 7 8 fps is the highest bypass velocity that could be maintained due to wave action in the collection tank



The collection tank is made of wood staves, which makes it inexpensive and easy to modify. The water and test fish in the bypass pipe are discharged into the tank. At the same time, control fish are purged from a release tank directly into the collection tank. When all the fish are collected, the water is drained. The partition screen dividing the tank (see left photo) keeps the fish on the left side of the tank, away from the drain holes. As the water level recedes, the fish move into a collection box at the bottom of the tank. The box is then hoisted to the work deck above the tank (see photo on the right).

They were reared for five months to an average size of 135 mm in a net pen located in the forebay of the Elwha project. The fish were monitored to assure that they were in peak migratory (smolted) condition—when they are most prone to scale loss injury—for the tests. The 15-day test program was initiated on May 19 and covered the period of peak smoltification.

Before testing, fish were marked with four colors of dye pneumatically injected at seven locations, producing a total of 28 distinct marks. Marked groups of 100 fish each were held in square, 100-gallon fiberglass tanks situated on the middle deck of the

An on-site laboratory was erected on the top deck of the test structure to evaluate the condition of the fish. As soon as the fish were lifted out of the collection tank, researchers anesthetized each fish and recorded its dye mark, length, and condition. A total of six different velocity conditions were tested, and each test condition was replicated several times.

testing facility. Each fish was later examined to assure that its mark was visible, to cull out any fish with significant scale loss or other injuries, and to obtain an accurate count of the fish remaining in each mark group.

Each day at the initiation of testing, the Eicher Screen was moved from the "neutral" position (screen parallel to penstock flow) to the "fishing" position (screen at a 16-degree angle). Penstock and bypass flows were set to the first scheduled test condition. A final count was made as the fish were transferred into buckets. The fish were then poured into the appropriate release tanks (test or control) and the covers were closed and sealed. The fish were then gradually purged from the release systems.

The bypass flow specified for the test condition was maintained for five to ten minutes after fish were released. In the tests with a velocity of 7 fps or less, a run time of ten minutes was used. At a 7.8 fps bypass velocity, the run time was reduced to five minutes. These durations were found to be sufficient to allow the fish to pass through the system into the collection tank.

After a run was completed, the inlet sluice gate was closed and the collection tank was gradually drained. Most of the fish moved readily into the collection box when the water depth dropped to less than 3 feet. The collection box was then hoisted to the upper deck of the testing facility.

Fish were evaluated immediately after recovery, directly from the collection box. Each fish was anesthetized and its dye mark, fork length, and condition was recorded. A classification system developed by the National Marine Fisheries Service for studies on the Columbia River was used to categorize injuries. The categories used were:

—"partial descaling" (scattered or patchy loss between 3 and 16 percent per side);
—"descaled" (over 16 percent scale loss on one side); and
—"other injuries" (bruises and eye injuries).

Extensive videotape was recorded during testing that shows examples of fish collected at each test condition and of each of the injury types observed. The tape provides concrete evidence regarding the extent of injury to the fish passing over the screen.

All of the fish recovered during each test were held for at least three days following recovery to assess delayed mortality. In the last half of the study, the loading density in each tank was increased to enable fish to be held for six or more days.

Test Results

Results from over 5,000 test fish passed through the Eicher Screen prototype indicate that the screen safely diverts coho salmon smolts under a wide range of operating conditions (see Table 2). The recovery rate for test and control fish averaged over 99 percent for the test conditions evaluated. Recovery rates increased with time as release and recovery techniques were improved. During the last ten days of testing, only five fish

Table 2: Test Results for Coho Salmon Smolts Passing Over the Eicher Screen at Elwha, Spring 1990

Test Velocities		Fish Group	No. of Replicates	Total Fish Released	Percent Recovery	% Injury for Fish Recovered During Test			% Delayed Mortality
Penstock	Bypass					>16% Descaled	<16% Descaled	Other Injuries	
4 fps	4 fps	Test	12	1003	99.6%	0.0%	0.8%	1.0%	0.3%
		Control	12	1058	100.0%	0.0%	1.2%	0.7%	0.0%
4 fps	6 fps	Test	12	1045	99.2%	0.0%	1.4%	0.7%	0.2%
		Control	12	1010	100.1%	0.1%	0.5%	0.9%	0.2%
6 fps	6 fps	Test	12	1030	99.7%	0.1%	3.3%	0.5%	0.0%
		Control	12	1035	99.9%	0.0%	0.5%	0.9%	0.1%
6 fps	7.8 fps	Test	12	1056	99.9%	0.0%	4.1%	1.1%	0.3%
		Control	12	1031	100.0%	0.0%	1.0%	0.8%	0.2%
7 fps	7 fps	Test	5	390	99.8%	1.3%	10.4%	1.4%	0.0%
		Control	5	372	99.7%	0.0%	0.8%	1.0%	0.3%
7.8 fps	7.8 fps	Test	12	1112	98.8%	3.6%	18.1%	0.9%	0.3%
		Control	12	1021	100.4%	0.0%	1.4%	0.7%	0.2%
All Conditions		Test	65	5636	99.5%	0.8%	6.3%	1.0%	0.21%
		Control	65	5527	100.0%	0.0%	0.9%	0.8%	0.14%

out of the 3,365 released into the penstock—a tenth of a percent—were unaccounted for. Four of these fish were lost when the penstock velocity was at 4 fps, which appears to be too low to prevent some coho smolts from escaping upstream.

The nearly perfect diversion efficiency indicated by this data is significant, since it is rarely this high at conventional screening facilities. Losses from predation, delay, and/or escape past the seals along the edge of the screens commonly result in substantially lower recapture rates.

Little or no injury was observed during tests conducted at penstock velocities of 4 or 6 fps. Slightly more injury occurred at higher velocities, but even at the highest velocity condition tested (7.8 fps) only 3.6 percent of the test fish showed substantial injury. These injury rates are comparable to those seen at modern conventional screening facilities.

Of over 10,000 fish recovered during testing (5,000 test fish and 5,000 controls), only 12 test fish and 8 controls died during the three- to ten-day holding period. The mortality rate was quite low even for the few fish that showed substantial levels of descaling. (See Table 3).

Although the salmon smolts used in the tests ranged from 101 to 165 mm in length, no relationship was found between fish length and injury rates. Small numbers of hatchery steelhead (188-282 mm in length), resident rainbow trout (53-122 mm), and sticklebacks (32-60 mm) were also recovered in good condition.

No operational problems were evident during the testing period. Head loss measured across the screen never exceeded 2 feet at any test condition out of the 100 feet of head available at the project. The screen appears to be largely self-cleaning, and backflushing by screen rotation has effectively removed any debris pinned on the screen.

Table 3: Delayed Mortality Rate for Fish Held for 3 to 10 Days after Recovery

Injury Class	Total Observed	No. of Mortalities	Mortality Rate (%)
Descaled (>16% Loss on One Side)	46	4	8.7%
Partially Descaled (3-16% Per Side)	386	2	0.5%
Other Injury (Bruises or Eye Injuries)	93	4	4.3%
OK (<3% Scale Loss)	10,611	10	0.1%
Total	11,136	20	0.2%

Conclusions

Results of the first test series of the Eicher Screen prototype at the Elwha Hydroelectric Project indicate that the screen has excellent potential for protecting downstream migrating fish. If future tests show that the Eicher Screen can pass other species and sizes of fish effectively, the device may see widespread application at hydroelectric projects. The screen's modest space requirements, low initial cost, and low operation and maintenance costs constitute significant advantages over conventional screening systems. □

Mr. Winchell may be contacted at Stone & Webster Environmental Services, 245 Summer St., Boston, MA 02107; (617) 589-2856.

Notes:

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Using Sound to Divert Fish From Turbine Intakes

Electronically-generated signals developed after analyzing "fish talk" can reduce fish entrainment in turbine intakes at hydro facilities, according to a recent study. System developers are urging further industry evaluation.

By Paul H. Loeffelman, John H. Van Hassel, and David A. Klinect

Experiments using underwater sound to deflect fish away from turbine intakes indicate that acoustical signals can potentially make hydroelectric projects more compatible with fish. Four years of development and field tests conducted by the American Electric Power Company, Inc. (AEP), Columbus, Ohio, demonstrated that synthesized low frequency sounds can divert warm and cold freshwater adult and juvenile fish.

Test results indicate that underwater sound merits further exploration by the hydropower industry as a possible alternative to physically screening power plant intakes and other mitigation measures. The potential effect on the future of the industry is great, since project compatibility with fish is one constraint limiting development of new hydroelectric facilities, according to the U.S. Department of Energy.

In a patented process, AEP used sounds from fish such as chinook salmon, steelhead trout, striped bass, freshwater drum, largemouth bass, and gizzard shad to synthesize signals capable of stimulating fish in the most sensitive portion of their hearing range. The process can create either attracting or repelling sound signals—depending on how the user wants to behaviorally guide the fish. So far, AEP has refined its ability to create repelling sounds, and has customized these signals for single or multiple-target species. Although the hearing range of a few fish species has been determined previously in laboratory tests, the data is not comprehensive and doesn't include hearing ranges of many species at various life stages living near AEP's hydro plants.

Paul Loeffelman and John Van Hassel are senior biologists in the Environmental Engineering Group and David Klinect is an engineering technologist in the Electrical Laboratory at the American Electric Power Service Corporation in Columbus, Ohio.

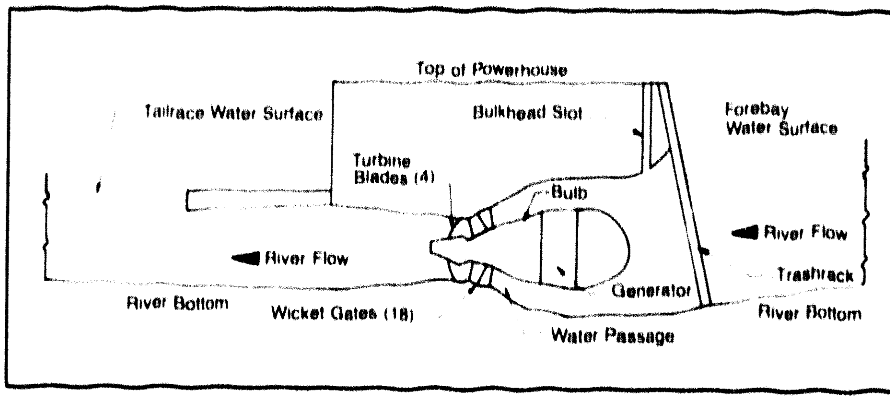
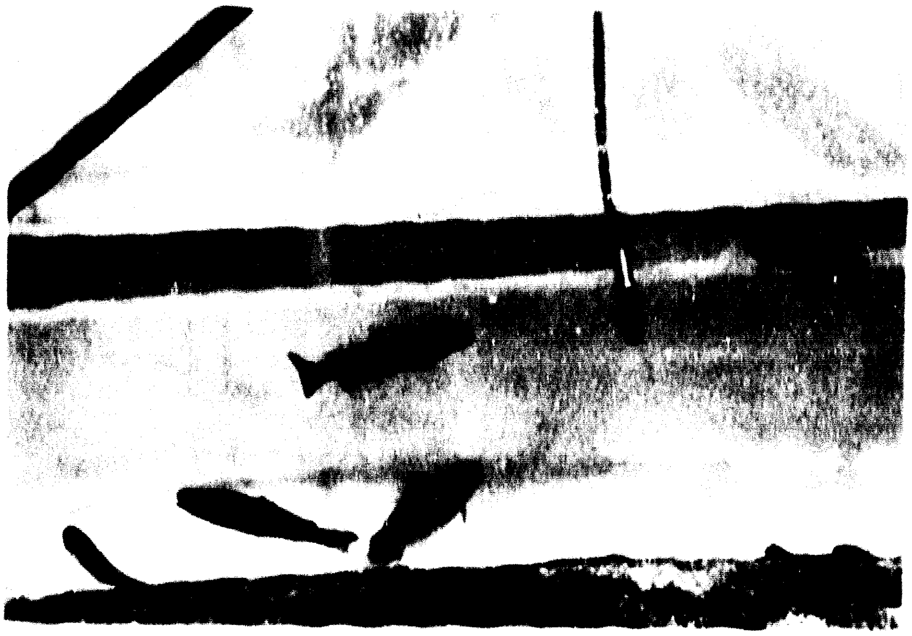


Figure 1: The generators at American Electric Power's Racine hydro project on the Ohio River are enclosed in steel bulbs and submerged in the water passage. AEP began its research into a fish guidance sound system after noticing that generator-induced sound from the hydro project's two units deflected fish away from the intake.

Developing the Hypothesis That Sound Diverts Fish

At AEP's two-unit Racine Hydroelectric Project on the Ohio River near Pomeroy, Ohio, the generators are enclosed within bulbs in the water passage upstream of the turbines. (Figure 1 is a sectional view of one of the units.) During fish entrainment and survival studies in 1986, sonar detected more fish in the water passage when the unit was off line than when it



A Recording Studio for Fish
Researchers at American Electric Power collected fish from the Ohio and St. Joseph rivers near the company's hydroelectric facilities, and placed them in this portable recording chamber made from a large, water-filled plastic bag suspended from a frame. The researchers then used a hydrophone to record sounds from these specimens. To prevent fish from being stressed by oxygen depletion, recording sessions were usually limited to about 45 minutes. AEP videotaped the fish at the same time they recorded them auditorily so researchers could distinguish natural fish sounds from sounds such as those made by fish bumping the hydrophone.

was operating, AEP researchers hypothesized that sound from the unit was repelling the fish.

This hypothesis was supported by the plant manager's observation that on calm days there were ripples on the water surface moving upstream in the forebay, away from the intakes. The ripples could have been caused by sound waves from the units, much like a pebble dropped into a pond causes ripples to travel through the water.

Sound measurements in the forebay just upstream of the intakes confirmed that the units produced sound when they were operating. These measurements showed that the units produced low-frequency, high-amplitude underwater sound in the forebay. (The sounds were less than 1 kilohertz (kHz) and approximately 150 decibels relative to 1 micropascal (dB 1uPa), which is a unit of pressure.) Sonar observations of fish in the forebay and tailwater of the project showed few fish in areas where the amplitude of the sound was greatest, and the most fish where the amplitude was lowest. This relationship suggested that sound was limiting entrainment of fish in the turbine.[3]

AEP later verified that 120, 240, 360, and 720 Hertz (Hz) frequencies were predominant in the intake spectra when the Racine units were in service. In contrast, tests of underwater sound fields at intakes of other AEP plants with vertical units and generators outside the water passage resulted in frequencies fewer in number and lower in amplitude.

Differences in sound fields are caused by differences in design and components of units. For instance, the relatively straight Racine water passage acts like a cheerleader's megaphone which directs sound toward the forebay. In contrast, the water passage in vertical units is not straight and tends to trap sound rather than amplify it. At Racine, despite vibration-dampening design, the steel bulbs surrounding the generators vibrate and efficiently transmit those vibrations to the surrounding water. Generators outside of water passages do not transmit vibrations to the water passage as efficiently because vibrations, which are undesirable for the health of the machine, are purposely dampened through engineering design. When vibrations are not transmitted efficiently to the water passage, sound fields at the intakes are lower.

Designing a System to Guide Fish Away from Intakes

Based on these findings, AEP began developing a process and sound system at Racine in the fall of 1987 that would produce a fish-repelling signal to be broadcast underwater. This guidance signal would be created using

Sound projector technology has advanced dramatically from early models weighing thousands of pounds to models such as the one weighing between 130 and 250 pounds. The lightweight units are practical for mounting, suspending, or towing during fish protection applications.

Fish Talk

This may sound fishy, but it's true: those scaly, finny creatures talk to each other. In the course of developing a signal to guide fish away from turbine intakes, Paul Loeffelman and other researchers at the American Electric Power Company, Inc. studied sounds emitted by fish. Loeffelman reports that the fish don't carry on organized conversations, but they definitely do communicate.

The AEP researchers put fish and a hydrophone in a large, suspended, water-filled plastic bag, then listened to the ensuing sounds. Loeffelman discovered that one fish alone won't make much noise: apparently, fish don't like to talk to themselves. Put several fish in the bag, however, and "they'll have a party," says Loeffelman.

Males talked together at about the same rate as females did, but males and females together seemed to do the most talking. Courting pairs were very vocal. More conversations took place at night than at any other time, and fish talked more when the water was warm than when it was cold.

It takes special equipment to listen in on the action because the fish sounds are quiet and of very short duration, as quick as a finger snap. Different species make different sorts of sounds. For example, steelhead trout make a clucking sound that lasts just a millisecond, whereas freshwater drum purr like kittens for about a second. Younger chinook salmon talk at a higher pitch than older members of the same species, which is similar to how human children sound compared to their parents, Loeffelman says. In addition to making a knocking sound, adult chinook salmon grind their teeth together when in the company of other fish. Schooling fish seem to be quite vocal, which Loeffelman speculates might help them stay in formation.

Since fish don't have vocal chords, they use other parts of their anatomy to make sounds. For instance, one theory holds that fish create lower-level sounds by moving muscles that vibrate their air bladders. Fish might create other, more raspy noises by rubbing their mouth bones together.

The guidance signals AEP developed do not attempt to mimic fish speech exactly. Instead, AEP selects just a few frequencies that a particular species can hear and electronically generates a new signal at sufficient volume that the fish want to avoid it. Loeffelman compares the situation to a human leaving a heavy metal rock concert because it isn't acoustically comfortable.

While no one knows what the fish are saying to each other and to us, Loeffelman believes the fish know what he is saying to them: stay away.

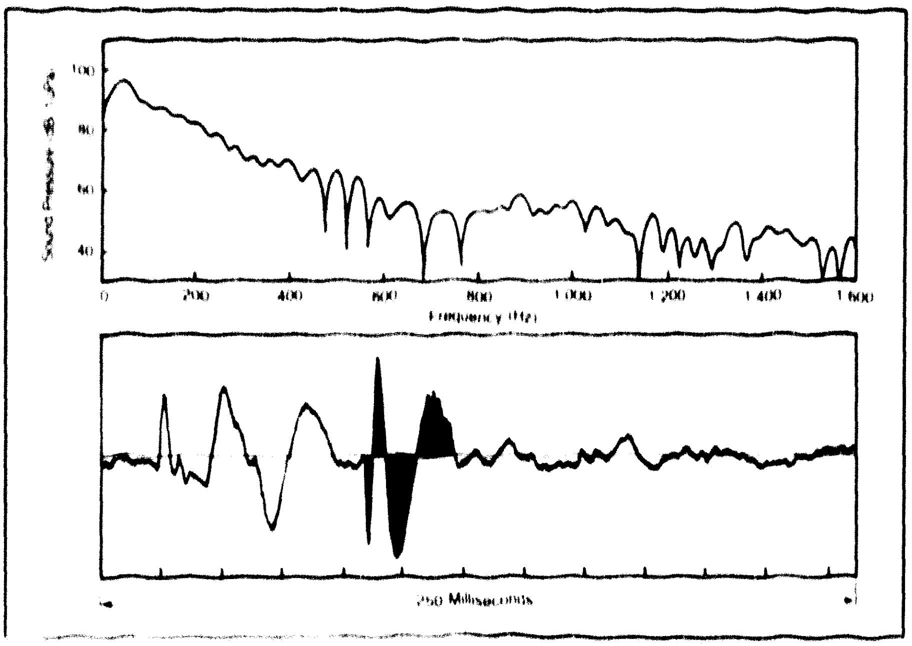


Figure 2. AEP analyzed fish sounds in order to customize a guidance signal for each target fish species and fish life stage. These graphs visually depict sounds made by young, 3-inch chinook salmon smolts at a hatchery. These smolts produce a short, high-pitched, chirpy sound. Adult chinook salmon make a lower, knocking sound.

characteristics of sounds produced by the fish themselves.

Guidance System Objectives

To accomplish the overall objective of determining the feasibility of using sound to divert fish, AEP felt it was essential to use a signal development process that could be customized to animals and site conditions at any plant. Ideally, the guidance system would be:

—Biologically effective, with high guidance and survival rates, compared to other possible mitigation alternatives;

—Easy to install and maintain, and reliable;

—Operated without head or flow restrictions or problems due to debris loading;

—Installed without requiring new fish bypasses; and

—Less expensive than other possible mitigative alternatives.

Placing physical screens upstream of turbines is a common option considered for mitigation of fish mortality at hydro facilities. These screens by themselves can cause head and flow restrictions and increase debris loading, which, in turn, can affect machine performance ranging from unwanted vibration to complete shutdown. According to studies reported in scientific literature, screens also can cause fish mortalities as fish contact the screen, depending on the screen type and species and life stage of the fish. Fish survival through turbines can be lowered as screens alter hydraulic conditions, and turbine performance is changed. Therefore, another AEP objective was to find an alternative to fish screens.

Talking Fish

The process AEP developed to quickly determine the hearing ranges of fish near its hydro plants relies on the concept of communications between animals. It assumes, as various research studies have shown, that sounds made by one fish are heard by other fish and will cause them to respond behaviorally (see the accompanying story "Fish Talk."). We evaluated fish sounds to help target the most sensitive portion of the fish's hearing range. If fish don't hear the low frequency signals, the signals will not be effective, and predictable, consistent behavioral response will not be

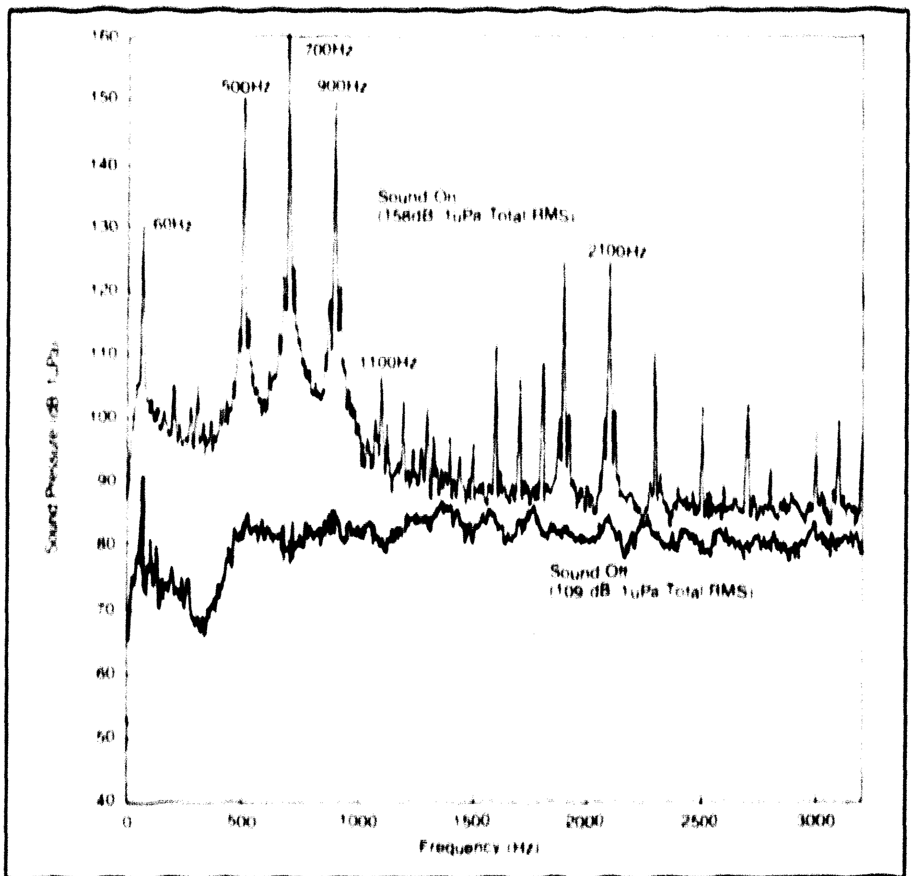


Figure 3. AEP measured changes in fish's acoustic environment during diversion tests in the Ohio and St. Joseph rivers. In tests at the Buchanan hydro project, AEP monitored the sound field for both chinook salmon and steelhead trout smolts with the synthesized sound off and on. As this spectrum for chinook salmon illustrates, AEP was able to dramatically change the fish's normal acoustic environment. (Sound off represents the river sounds the smolts normally hear; sound on represents the sound in the river with the diversion signal on, which sounded somewhat like a busy signal on a telephone.)

possible.) Then, we artificially created signals by selecting the frequencies, amplitudes, durations, wave forms, and patterns that produce the greatest stimulus for the fish.

Using a portable recording chamber to acoustically isolate the fish, we recorded and analyzed sounds from over two dozen warm and cold freshwater fish. These sounds are consistent with descriptions referenced in scientific literature regarding sounds from fish in natural and laboratory conditions and with sound recordings made by the Borror Laboratory of BioAcoustics at Ohio State University. Figure 2 is an illustration of sounds AEP obtained from young chinook salmon smolts at the Twin Branch Hatchery in Indiana. During the research, we also collected sound information from specimens such as adult gizzard shad, adult freshwater drum, adult striped bass, and adult and juvenile steelhead trout, and analyzed it to learn the frequency range where these fish hear best.

A Review of the Sound System Hardware

AEP used a hydrophone coupled with an amplifier to monitor and analyze sounds made by fish that were placed in the acoustically isolated recording chamber. We analyzed the recorded sounds for characteristics such as duration, wave form, amplitude, and frequency.

After we recorded and analyzed the sounds, we moved the fish to a different chamber and observed their reaction to the synthesized signals we created. The observation chamber was a polyethylene cage placed in the river. We used high-frequency hydroacoustic equipment and television cameras to observe the fish's movements in response to the broadcast signals. We also videotaped the sessions for later statistical analysis of the duration of time specimens spend in different areas of the sound field. The polyethylene cage was acoustically transparent (i.e., it did not alter the sound field created by the equipment), and we monitored the sound field by moving the hydrophone alongside the cage.

Sounds to repel fish are created much like music is produced in recording sessions. Musicians use instruments to make sounds that are then amplified and played through speakers in the recording studio. As the music is being played and recorded, a sound engineer "mixes" the sounds with equalizers to emphasize or de-emphasize musical passages, bass notes, the rhythm section, and vocals. In AEP's case, the music, or sound signal, to repel fish was synthesized in a wave form generator, amplified with amplifiers, and played through projectors (underwater speakers or transducers). The signal was mixed with the generator and a graphic equalizer.

AEP used two models of sound projectors manufactured by Argotec, a company in Ft. Lauderdale, Florida, that manufactures advanced sonar transducers. The Model 219 projector has a sound pressure level rating of 160 dB/1uPa at a frequency of 100 Hz. The projector uses 200 watts of electrical power to produce the sound pressure. This projector was used during field tests at the Racine and Berrien Springs hydroelectric projects. The Model 220 projector, used at the Buchanan hydro project, is more powerful. It is rated at 180 dB/1uPa at 100 Hz and uses 1,500 watts of power.

Conducting Field Tests

To test the hypothesis that sound from the Racine generating unit diverted fish, AEP performed paired, replicate tests during which the recorded unit sound was played back through the underwater projectors. The predominate frequencies of 120, 240, 360, and 720 Hz corresponded well to most fish's sound spectra and hearing ranges. We collected significantly more fish by electroshocking and netting when the sound was off than we did in the same area when the sound was on. Statistical tests showed that the probability was greater than 95 percent that sound limited fish movement into the collection zone. In these tests, 66 percent of all fish (and 70 percent of fish other than gizzard shad) were diverted from the area.

Based on results of tests after this experiment, AEP believes new signals customized specifically for gizzard shad and other Ohio River species would

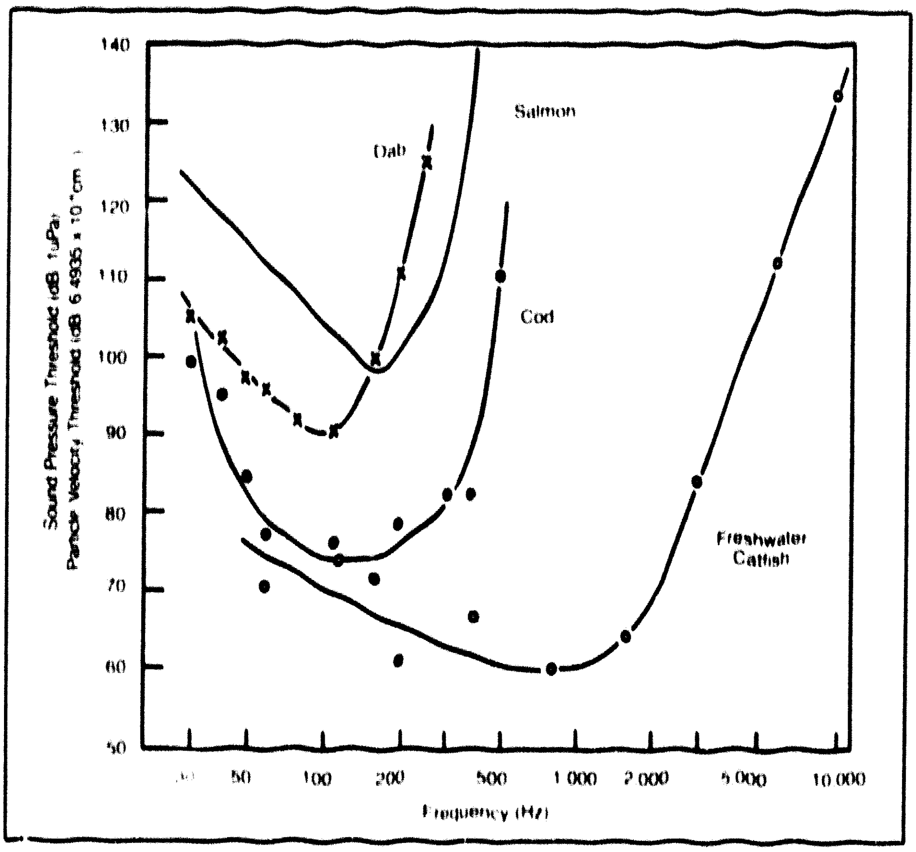


Figure 4 Some fish hear better than others, as shown in this audiogram. Each species hears only the sounds falling inside its hearing threshold curve. Salmon, for instance, don't hear softer sounds that other species do. Guidance signals targeted for salmon must be of sufficient amplitude for the fish to hear them over background environmental noise. (Adapted from the article "The Hearing of the Atlantic Salmon, Salmo Salar" published in the *Journal of Fish Biology* in 1978.)

increase the effectiveness of underwater sound.

Up-Migrating Steelhead Trout And Chinook Salmon

AEP began refining its process for customizing sound guidance signals in the fall in 1988. The initial target fish were up-migrating adult steelhead trout and chinook salmon in the fish ladder at AEP's Berrien Springs Hydroelectric Project on the St. Joseph River in southwestern Michigan just north of South Bend, Indiana. Laboratory tests reported in scientific literature indicate that salmon have a narrower hearing range than other fish. Salmon can only hear the sounds other fish hear if the sounds are greater in sound pressure. Therefore, the customized sounds we tested underwater in a localized area were quite loud.

We installed projectors in the fish ladder, and counted fish passing up the ladder in tests with no sound and with different sounds being generated. We used the fish ladder to help refine our process. We used sound to temporarily stop fish who wanted to swim up the ladder. The number of fish in the ladder provided statistical test results clearly defining the effectiveness of the repelling sound signal. The repelling signal for adult steelhead trout was synthesized with 60 Hz and 120 Hz frequencies in a pulsed pattern that increased in loudness to a peak and was then repeated again.

Statistically significant differences in counts of fish at the top of the ladder showed trout were being repelled down the ladder. The probability was 90 percent that sound limited fish movement at the top of the ladder.

In these tests, 72 percent of the adult steelhead trout were stopped from reaching the top of the ladder. The sound stimulus apparently modified fish movement in spite of environmental stimuli such as water and air temperature. When the sound was off, some of these other stimuli had a significant influence on fish counts. However, with chinook salmon and total fish counts, the effect of sound could not be isolated from the effect of other variables such as water temperature. Fish hear various sound pressure levels at the same frequencies. The effect of sound on the chinook salmon probably would have been greater if a signal of higher sound pressure had been used.

We developed a new three-frequency crescendo signal from chinook sounds. We then compared the effect this new signal had on chinook salmon and total fish counts to the effect that the steelhead trout signal had on them. Statistical analyses showed that chinook salmon and total fish counts were significantly influenced by natural environmental variables such as water temperature when the signal for steelhead was on. However, counts were not significantly influenced by other variables when the new signal for chinook was on. These results suggest that the new frequency mix sufficiently improved the acoustic stimulus to change the chinook salmon's behavior in spite of the influence of normal environmental conditions.

Down-Migrating Steelhead Trout And Chinook Salmon Smolts

In the spring of 1990, we conducted tests at the Buchanan Hydroelectric Project on the St. Joseph River in southwestern Michigan just north of South Bend, Indiana, on down-migrating 7-inch steelhead trout and 3.5-inch chinook salmon smolts. These fish had been stocked by the Indiana Department of Natural Resources approximately 30 miles upriver from the hydro project. The strategy was to "bump" these down-migrating salmonids away from smolt trap nets placed in the headrace canal of the project.

Using an angled sound field established in the river by projectors at the entrance of the headrace, we were able to divert these fish away from the nets. The effective field from each projector resembled a sphere of sound at least 70 feet in diameter, based on statistical analyses of fish movements at each end of the underwater observation chamber. At that location, the effective angled sound field was at least 100 feet long by 70 feet wide. The sound field changed the acoustic environment that the fish normally experience in the St. Joseph River, as shown in Figure 3.

Our success in diverting the fish is important because salmonids do not hear very well compared to other fish, according to literature from laboratory studies on fish hearing. Statistical analyses of paired, replicate six-hour sound-on-six-hour sound-off tests at night for two months showed:

—The probability was greater than 99.9 percent that the sound influenced the catches in the headrace nets. Results of tests at this project show 94 percent steelhead smolt diversion and 81 percent chinook smolt diversion from nets in the headrace. The greatest diversion from a single headrace net was 100 percent for steelhead and 83 percent for chinook smolts and 88 percent for both species combined;

—Sound modified fish movement in spite of normal environmental stimuli such as sunrise and sunset. Natural environmental factors significantly influenced fish movement when the sound was off but not with sound on; and

—Signals need to be customized to fish species, life stages of fish, and project site conditions. Signals that affected steelhead smolts and adult chinook salmon were not as effective on chinook smolts. A new signal developed specifically for chinook smolts was more effective.

Performance and Durability Of Sound System Equipment

The components of the sound system that electronically created the customized signals, in general, were reliable and operated with minimal maintenance during approximately 1,000 hours of testing. On one occasion, lightning struck the distribution line servicing the electronics trailer at the Buchanan project and caused a power surge. The amplifiers and wave form generator housed in the trailer were automatically shut down. None of the equipment was damaged and the system was easily restarted. In a permanent system, the equipment would be designed to protect the amplifiers and wave form generator from line voltage fluctuations.

Except for a projector power cable that was severed in the spring of 1990 at Buchanan, the power cables for the projectors were never damaged during four years of research. The cables were exposed to potential damage when placed over riprapped riverbanks, from debris hitting them in the Ohio and St. Joseph rivers, and from handling by crews installing the equipment. The cables used in the tests were not armored (metal sheathed). For permanent installations, cables should be armored, or unarmored cables should be surface-supported with a buoy system or log boom.

The projectors we used weigh less than 250 pounds each and were suspended from floating platforms. Because of this lightweight feature, the projectors could be deployed at new or old plants with relative ease compared to the installation of physical screens. The projectors are well suited for suspension from existing log booms; buoys, such as marine navigation buoys or boat safety line buoys; or horizontal cables above or in the water.

Taking a Step Back: AEP's Lessons Learned

AEP concluded its fish sound research program in 1990. As a result of our work, we discovered that sound can be an effective guidance stimulus if a signal is produced that fish will hear and to which they will respond in a predictable manner. Our tests with repelling signals show that the fish will consistently avoid sound fields without habituating to the sound. Previous attempts at guiding fish with sound have generally not been successful, according to a study funded by the Electric Power Research Institute.[7] However, the signals in the studies EPRI reviewed may not have been heard by the fish or they may not have triggered a suitable change in fish behavior. AEP's research has shown that the sound stimulus needs to be of the right frequency mix, amplitude, and pattern for fish to hear the signal and change their swimming direction.

In the three tests we conducted at Racine, Berrien Springs, and Buchanan, fewer fish were caught in nets, electrofished, and counted on underwater television monitors when sound was being broadcast than when it wasn't. These counts confirmed that fish were swimming away from sound fields.

For maximum effect, it is important to present a signal to the target fish species within the most sensitive portions of its hearing range. The hearing and sensitivity ranges of fish are wide, as shown in Figure 4.[11] If a low frequency sound is too quiet or outside the fish's frequency range, they will not hear it, much less respond to it. In addition, the ambient acoustic conditions in the body of water can influence the effectiveness of the stimulus by masking it.

In the Berrien Springs fish ladder, for instance, fish at the top of the ladder normally experience sound levels of about 150 dB/1uPa from water cascading down the concrete and steel ladder. The masking effect of this ambient sound contributed to the poor response obtained in preliminary scoping tests when projectors were placed at the top of the ladder. Fish could not hear the signal over the background sound. Slightly farther down the ladder, the ambient sound level decreased to about 130 dB/1uPa so our signal there was heard much better by the fish. We kept the projectors at this location throughout our experiments. When the test signal was less masked, the up-migrating steelhead trout exhibited a strong avoidance response. Fish actually broke the water surface trying to escape the stimulus.

The temporarily-installed electronic sound system used in the three field tests was easy to retrofit, reliable, and operated with minimal maintenance. New, relatively lightweight sound projectors enhance the practicality of installing such a system at other hydroelectric facilities. Costs of an actual permanent system are unknown; no full-scale, permanent system has been installed.

The Federal Energy Regulatory Commission relicensing process for AEP projects has progressed only to the stage where fish entrainment and survival studies are being conducted and data have been collected. The need for fish protection has not yet been determined. If mitigation is required, AEP will include this sound system among the options we evaluate when selecting appropriate mitigation measures to propose to regulatory bodies for approval.

AEP Encourages Further Industry Evaluation

The results of AEP's fish protection research indicate that sounds customized for target fish, using a signal development process and broadcast by specialized sound system equipment, will divert warm and cold freshwater fish. The research further indicates that the fish can be diverted in spite of normal environmental stimuli such as water temperature, sunrise, and sunset. During tests of the signal development process and during field trials, the guidance system showed high diversion rates and 100 percent survival of diverted fish. The biological effectiveness of this technique should be compared to the effectiveness of other mitigation options currently considered for fish protection at hydroelectric plants.

The high diversion rates and potential for reduced costs for installing, operating, and maintaining a sound system compared to costs for physical screens or other mitigation methods indicate that the guidance system merits further evaluation by the hydro industry. We believe that we have developed an encouraging mitigation option that can potentially relieve constraints on hydropower and increase utilization of untapped capacity in the U.S. □

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Acknowledgments:

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Analyzing Turbine Bypass Systems at Hydro Facilities

For many years, biologists have contended that turbine bypass systems provide improved passage conditions for juvenile salmon. But recent studies question whether bypasses perform as well as assumed. Further investigations are warranted.

By John W. Ferguson

In the 1960s, biologists for several federal and state resource agencies investigated turbine mortality at U.S. Army Corps of Engineers' hydroelectric projects along the Columbia River. Their findings suggested that turbine bypass systems would provide improved passage conditions for juvenile salmon. In response to these findings, the Corps installed bypass systems at many of its facilities. However, evaluations of salmon after the bypasses were installed indicated that these systems are not completely benign.

The bypass system, guidance devices, and tailrace predation can cause variable levels of stress, injury, and mortality. When compared to a favorable turbine environment of deeply submerged runners and low head, certain bypass systems may even *reduce* survival in some cases. For example, preliminary results of a survival study conducted by biologists at the National Marine Fisheries Service (NMFS) from 1987 through 1990 at Bonneville Dam indicate bypassed juvenile chinook salmon have significantly lower survival rates than those passing through turbines. Consequently, comprehensive analyses of bypass components are necessary to ensure bypass passage improves survival, relative to turbine passage.

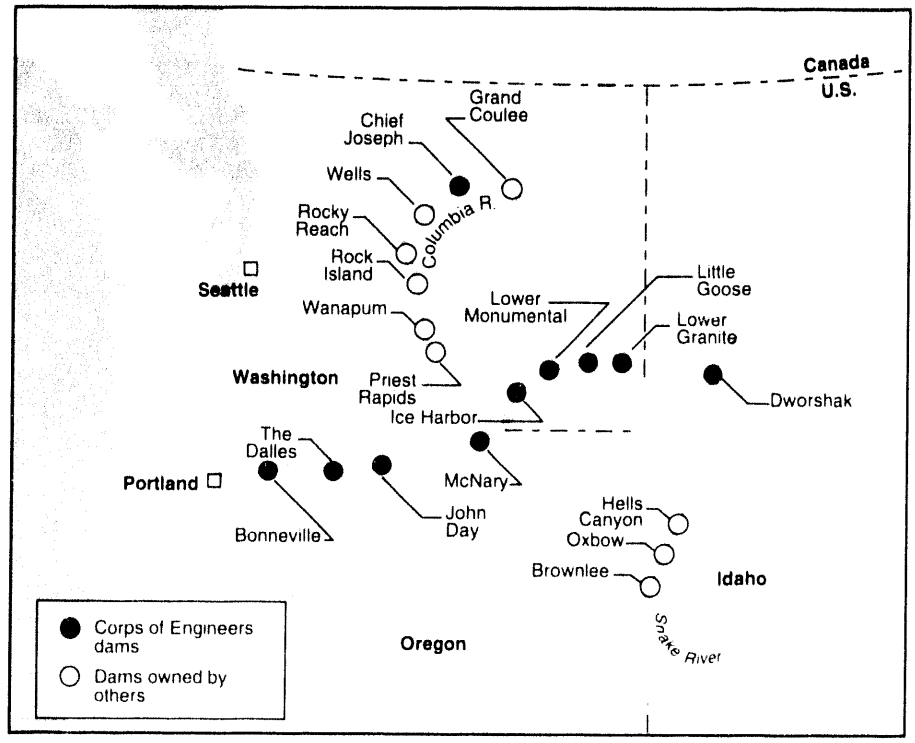

Figure 1: This map outlines the Columbia River hydroelectric system, including Corps and non-Corps projects.

Fish Bypass Systems In the Northwest

The Columbia River hydroelectric system has been under development since the Chelan County Public Utility District completed Rock Island Dam in 1933. The Corps subsequently developed much of the lower Columbia and Snake rivers by constructing nine powerhouses at eight mainstem run-of-the-river projects between 1938 and 1982. The Corps plants have a combined capacity of 9,210 MW. Figure 1 is a map of the Columbia River hydroelectric system, including Corps and non-Corps projects.

Early Corps development on the Columbia occurred relatively slowly—only three dams were built by the Corps between 1938 and 1962. Between 1962 and 1975, however, the Corps completed a series of four dams on the lower Snake River. During that 13-year period, populations of Pacific salmon began declining. One NMFS biologist evaluated fish passage rates on the Snake River between 1966 and 1975, and concluded that significant losses of juvenile chinook salmon were responsible for record poor returns of adults to spawning grounds. He sug-

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gested that the causes of mortality were turbine passage, reservoir predation, migration delays through the series of dams, and exposure to lethal concentrations of dissolved nitrogen from water spilled in high flow years. Other activities such as logging, water diversions, agricultural runoff, and potential over-harvesting of fish also likely contributed to the decline.[1]

In response to declining populations of salmon, NMFS conducted turbine survival studies at Ice Harbor Dam in 1968. Clifford Long, a NMFS researcher, concluded that turbine mortality was 10 to 19 percent.[2] (These estimates were similar to ones made at McNary Dam by researchers from the Washington Department of Fisheries and the Oregon Department of Fish and Wildlife.) Long also indicated that mortality associated with passing through turbines could range as high as 32 percent. Long hypothesized that this range in turbine mortality was due, in large part, to northern squawfish preying heavily on test fish in the tailrace.

Results of these early investigations of turbine mortality led the Corps to incorporate juvenile bypass systems into the design of five new powerhouses on the Columbia River: Lower Monumental and John Day dams in 1968; Little Goose Dam in 1972; Lower Granite Dam in 1975; and Bonneville second powerhouse in 1982.

Table 1: Fish Bypass System Installations at Corps Hydroelectric Projects in the Columbia River Basin

Facility	*Number of Screens*
Bonneville #1	30
Bonneville #2	24
Ice Harbor	18*
John Day	48
Little Goose	18
Lower Granite	18
Lower Monumental	18*
McNary	42
The Dalles	70*
Total Screens	286

*Planned installation

The Corps is currently improving existing fish bypass systems at McNary and Lower Granite dams, replacing the system at Lower Monumental Dam, and designing systems for The Dalles and Ice Harbor dams at a total construction cost of $300 million to $350 million. By 1998, bypass systems will be installed in all nine powerhouses that the Corps operates on the Columbia and Snake rivers.

While these efforts are supported by regional interests, a substantive body of information recently collected by the Corps and NMFS, among others, questions whether bypasses perform as well as assumed. This information suggests that bypass effectiveness is site- and species-specific and influenced by many variables.

A researcher for the National Marine Fisheries Service holds a freeze-branded chinook smolt prior to releasing it into a fish bypass system at Bonneville Dam on the Columbia River. NMFS recently conducted an assessment of survival through various passage routes at Bonneville to determine how the dam should be operated to enhance juvenile fish survival.

Evaluations of Columbia River juvenile fish bypass systems have addressed three main components:

—the turbine intake and guidance devices;

—the bypass orifices, collection, and transportation conduits; and

—the tailrace environment into which the bypassed fish are released.

All three components individually and together can significantly influence the level of protection that bypasses afford, relative to turbine passage.

Turbine Intake and Guiding Devices

One area of concern is the effect that guiding devices have on bypassed fish and the hydraulics of the operating unit. The effectiveness of a guidance device is a measure of how well fish are diverted into the bulkhead bypass slot, compared to the total number of fish passing through the unit. In the early 1970s, NMFS investigated potential options for bypassing fish around turbines at various dams, including Ice Harbor. From this investigation, the agency decided to develop the submersible traveling screen (STS) for guiding downstream migrants away from turbines. The STS, installed in the turbine intakes of a hydro plant, guides juvenile fish into a collection channel from which they are transported via a flume or pipe to the tailrace and released into the powerhouse discharge. Each mesh screen unit is 20 feet long by 20 feet wide and weighs 35 tons. The screen rotates to minimize debris build up. Table 1 summarizes the number of screens currently installed at Corps projects as well as planned installations.

Most standard STSs induce a low rate of injury and mortality, especially at the upstream dams where the fish arrive from their natal streams in good condition. A team of NMFS biologists studied screen guidance performance at Lower Granite Dam in the mid-1980s. They concluded that condition of the guided fish was generally good, and that descaling typically averaged from 1 to 6 percent. They also found guidance efficiency on spring chinook to be highly variable, ranging from 35 to 75 percent within a single year.[3]

The amount of descaling caused by the STSs is an important factor to evaluate because loss of scales affects long-term fish survival. The descaling standard used by Corps and NMFS

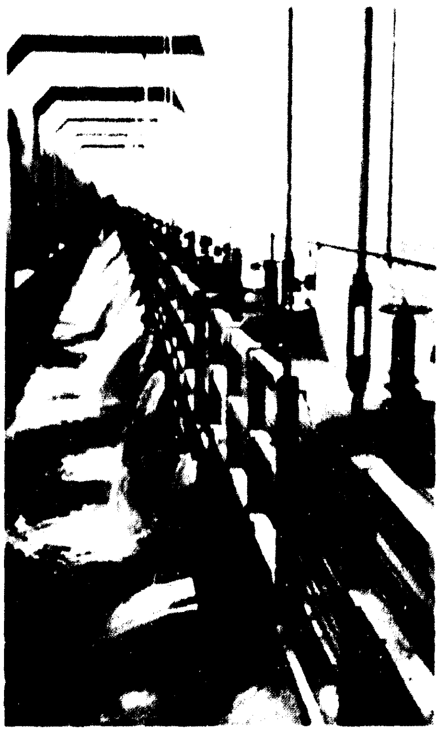
Table 2: The Range in Descaling and Mortality Rates from 1981 to 1990 at Collector Dam Bypass Systems in the Columbia River Basin

Dam	*Percent Annual Descaling Rates (all species)*	*Percent Annual Facility Mortality (all species)*
Lower Granite	0.8 to 16.8	0.1 to 1.2
Little Goose	1.0 to 26.0	0.1 to 6.2
McNary	2.2 to 17.8*	0.1 to 4.1

*Based on 1989-1990 data

biologists (developed by the Fish Transportation Oversight Team) holds that a fish must lose more than 10 percent of its scales to be considered "descaled." NMFS researchers found the five-day delayed mortality of descaled yearling chinook to be significantly higher than non-descaled fish (18 percent versus nearly 2 percent) at the Bonneville Dam first powerhouse bypass.[3] Similarly, NMFS observed a 27 percent short-term (48-hour) mortality rate for descaled fish collected at the Bonneville Dam bypass system.[4]

Descaling rates vary between dams and appear to be dependent on the site and species involved. Each bypass system is different, and, as Pacific



This photo depicts the 1,400-foot-long juvenile fish bypass system collection channel installed by the U.S. Army Corps of Engineers at McNary Dam. The collection channel, which is inside the ice-trash sluiceway, picks up fish as they exit the gatewells (the orifice valves and pipes on the right). The fish are transported to a collection facility.

salmon migrate downstream through the hydro system, they change physiologically as they prepare to enter salt water. These changes tend to loosen their scales, and as a result, they become more susceptible to the various hydraulic environments encountered when passing through turbines, spillways, and bypass systems. Consequently, fish arriving at dams lower in the hydro system tend to be more descaled.

The guidance device's screen design also may affect fish condition. Of primary concern is how porous or open the screen material is relative to the flow, and the length of the screen (which determines how much flow the screen intercepts). In 1991, NMFS evaluated Corps-designed experimental STSs and fixed bar screens at McNary Dam. These screens are 40 feet long compared to the standard 20 feet. While these longer screens appeared to improve guidance efficiency, they also increased the percentage of descaled fish. For yearling chinook salmon, the extended STS induced the highest descaling rates, followed by the extended fixed bar screen, and then the standard 20-inch STS. In one test series, the descaling rates were 21 percent, 12 percent, and 7 percent, respectively, according to Teri Barila, fishery biologist for the Corps in Walla Walla, Washington. Descaling rates on summer migrating subyearling chinook exhibited a similar trend.

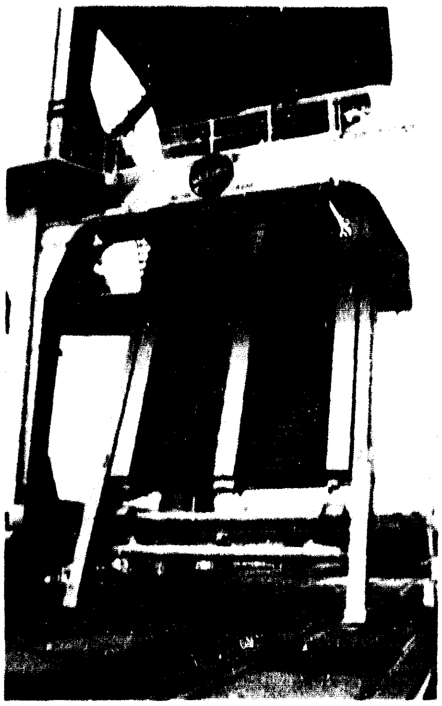
The guiding device also has an effect on the hydraulic environment of the turbine, altering intake flow patterns. Corps facilities along the Columbia River use vertical Kaplan turbines. The STSs are lowered into the turbine intake via the bulkhead gate slot, where intake velocities typically range from 4 to 8 feet per second (fps). Field investigations at McNary and Bonneville dams conducted by the Corps of Engineers Hydroelectric Design Center indicate that power loss from the standard 20-foot STS is on the order of 1 percent, depending on intake velocities.

To better understand the effect that guidance devices are having on the hydraulic environment within the turbine, the Corps plans to conduct turbine model studies in 1992 and 1993. These tests will help determine the influence that the guidance screen has on the modeled efficiencies of various turbine units. The 40-foot-long guidance screens being prototype tested at McNary are a concern in this regard, since turbine unit efficiency could decrease as much as 4 to 5 percent.

This potential loss of turbine efficiency could affect both power and fish survival. The relationship between unit efficiency and fish survival is well documented. In 1966, two researchers from the Corps' Walla Walla District found turbine survival was highest when the Kaplan units at Big Cliff were run at peak efficiency.[5] The district found similar results for Francis units at Cushman and Shasta dams. A Canadian consulting firm, Monenco Maritime Limited, also made a similar discovery in 1981 using Francis units at Lequille Dam in Nova Scotia.[6] Based on these findings, a reduction in unit efficiency caused by the installation of guidance devices could reduce the survival rates of non-guided fish as they pass through the turbine. If this occurs, it would decrease the benefits associated with constructing a bypass system.

Bypass System Collection And Transportation Conduits

Fish condition is monitored daily at many Columbia River bypass systems. These measurements include the effects of being guided as well as passing through the bypass system. A team of biologists from the cooperative Fish Transportation Oversight Team (representatives from NMFS, the Idaho Department of Fish and Game, and the Corps' Walla Walla District) summarized fish condition and mortality rates for the past ten years at three collector dams with bypass facilities (Lower Granite, Little Goose, and McNary dams). (At collector dams, fish are collected in a bypass system and transported by barge around all remaining downstream dams.) Table 2 gives average annual descaling and mortality rates for the three dams. Although the rates are generally low, the range can be substantial, depend-



This extended submersible travelling screen (ESTS) is part of a prototype installation of fish bypass screens at McNary Dam. These screens are "extended" because they are 40 feet long compared to standard STSs, which are 20 feet long. The Corps of Engineers installed three bypass screens at each of McNary's 14 turbine intakes - for a total of 42 screens - to intercept migrating fish and shunt them past the turbines.

ing on the year, species, and bypass systems.

Certain species such as sockeye are more susceptible to physical injury while being guided into and passing through a bypass system. In 1989, researchers led by a NMFS scientist found that head and body injuries (bruised bodies or ripped gill coverings) and descaling rates in the sample tank within the McNary bypass system averaged 20.2 percent for sockeye. This figure was compared to 5.1 percent for subyearling chinook, 13.8 percent for yearling chinook, 9.4 percent for wild steelhead, 22.9 percent for hatchery steelhead, and 8.4 percent for coho. Annual short-term (48-hour) mortality of sockeye in the sample tank was nearly 11 percent compared to 0.6 to 2.4 percent for other species. Additional evidence from Corps- and Bonneville Power Administration-funded research suggests that bypass passage also can affect long-term survival. In a 1985 NMFS study, biologists held yearling chinook salmon collected from various locations within the Lower Granite Dam bypass system for 43 days in sea water. Researchers found long-term mortality rates of the bypassed fish to be higher than non-bypassed fish. The mortality associated with bypass passage ranged from 4.4 percent to 7.6 percent.

These findings suggest that bypass systems may have a negative influence on fish survival rates both immediately and for a period after having passed through the bypass system. In addition, one has to consider the effect that a series of dams and bypass systems can have on survival. For example, researchers from the Oregon Cooperative Fishery Research Unit at Oregon State University found the effects from exposure to two or three consecutive stresses were cumulative.

Tailrace Environment

As mentioned earlier, Clifford Long, during his 1968 studies, suggested populations of northern squawfish in the tailrace reduced turbine survival. These results presented the first documentation that predation could influence survival through the Columbia River hydro system.

In 1977, NMFS researchers evaluated the bypass outfall at McNary Dam, and concluded that the recovery rate of fish released near the outfall was 50 percent less than releases made into a powerhouse release site. They speculated that the low recovery of marked test fish at the downstream collection site may have been related to tailrace predator activity.

Since 1983, predator abundance, food habits, and consumption rates have been intensively evaluated in the John Day Reservoir. Biologists from the Oregon Department of Fish and Wildlife in 1991 concluded that the combined abundance of the three primary predators (northern squawfish, walleye, and smallmouth bass) in the reservoir ranged from 50,000 to 500,000 individuals. It is estimated that 2.7 million juvenile salmonids are lost annually to predation in the John Day Reservoir alone.

Several studies indicate that predation is higher in the tailraces of projects than in other areas of the Columbia River system. For example, at McNary Dam, although northern squawfish is the dominant predator and commonly found throughout the reservoir, populations are concentrated in the tailrace. Losses per kilometer are estimated to be more than 50 times greater immediately below the dam than in the remaining reservoir.

These studies suggest that bypass performance is most likely affected by predators. One hypothesis is that predators are accumulating below bypass outfalls and actively preying on single point sources of prey. This theory is supported by observations of avian predators feeding heavily at bypass outfalls and northern squawfish feeding at Bonneville first powerhouse and McNary Dam bypass outfalls.

Assessing the Bypass System At Bonneville Dam

Ideally, comprehensive investigations of bypass performance should include comparative assessments of other passage routes. NMFS recently conducted an assessment of survival through various passage routes at Bonneville Dam to determine how the dam should be operated to enhance juvenile survival. The comprehensive study was designed to provide comparative assessments of both short-term (1987-1990) and long-term (1988-1994) survival through various passage routes (turbines, spillway, and bypasses).

The first powerhouse at Bonneville was completed in 1938. A second powerhouse was added in 1982 to provide additional peaking capacity. The design of the second powerhouse included a juvenile fish bypass system. The system's design is significant because it incorporated over 20 years of Corps' bypass design experience and was considered "state-of-the-art" by many groups, including NMFS. The bypass system is comprised of a standard length STS in each intake of the eight turbines for a total of 24 guidance screens. The screens deflect juvenile salmon into vertical bulkhead slots, which the fish exit through 14-inch orifices into a collection gallery. This gallery travels the length of the powerhouse and transitions into a pipe that transports the fish to the tailrace outlet structure. Approximately 200 cubic feet per second of water flows down the 36-inch transportation pipe at 18 to 29 fps. Discharge into the tailrace is through an outlet structure that is submerged from 20 feet to 48 feet, depending on tailrace water surface elevation. The bypass release site was designed to provide optimum survival

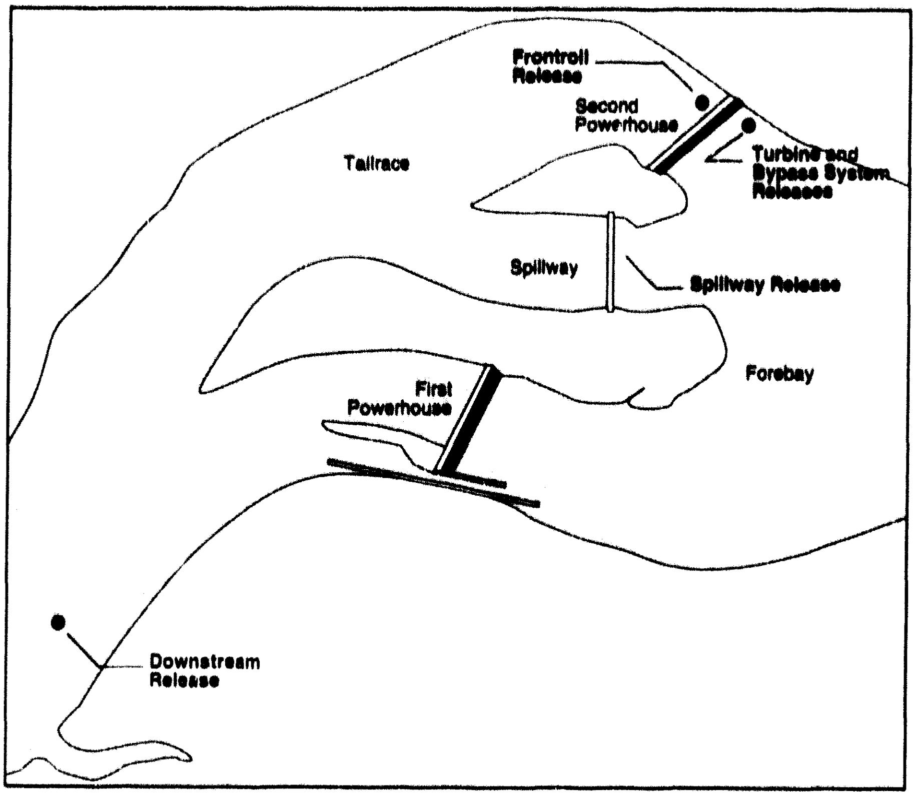


Figure 2 This diagram shows where biologists released fish during various survival studies conducted between 1987 and 1990 at Bonneville Dam on the Columbia River.

conditions by providing 3.5 fps ambient river flow past the outlet structure to reduce predator accumulations. The outlet is submerged, located near the middle of the tailrace, and streamlined to reduce areas behind it where predators can accumulate.

During the survival tests, adjacent turbine units were operated to provide adequate flow past the outlet structure. Turbines were operated at maximum efficiency. Biologists released the fish at 2 a.m. (the darkest time of day when there is less ambient light for predator fish to see their food).

Approximately 2 million subyearling fall chinook salmon were marked each year prior to release using coded-wire tags. Cold brands were used to visually identify recovered fish from the various treatment groups. Releases were made from 1987 through 1990 at the following sites, although not each site was tested every year:

—upper turbine;
—lower turbine;
—bypass system;
—turbine frontroll (the downstream side of the upwelling turbine boil);
—spillway; and
—downstream (mid-river).

The downstream site was located approximately 2.5 kilometers downstream from the dam, as shown in Figure 2. The site was assumed to be downstream from the effects of the dam and located mid-river to be away from the effects of shoreline-oriented predators such as northern squawfish.

Short-term relative survival was based on recoveries of marked fish just above the Columbia River estuary, approximately 100 miles downstream from Bonneville Dam. Long-term relative survival will be based on the returns of coded wire tagged adult fish to the fisheries and hatcheries.

NMFS concluded, based on juvenile recoveries, that fish released in the bypass system had significantly lower survival than all other treatment groups. The decrease in recovery percentage associated with passage through the tailrace downstream from the second powerhouse was of greater magnitude than decreases associated with passage through the turbines. Predation by northern squawfish may be causing the decrease in survival. Fish passing over the spillway (1989 only) had higher survival rates than fish passing through the second powerhouse turbines or bypass.[11]

The Bonneville Dam survival study suggests that there is little benefit in passing juvenile subyearling chinook through the juvenile bypass system at the Bonneville second powerhouse. It also indicates that turbine survival for 1988 and 1989 was approximately 97 percent, when the recoveries of turbine-passed fish were compared to frontroll releases.

Conclusions

While Columbia River bypass systems generally handle fish well, they are at times neither benign nor without cost to fish. Screening fish out of high velocity turbine intakes, routing them through collection and transportation channels, and placing them into tailrace areas all incur varying degrees of descaling, injury, and direct and/or delayed mortality. Designing a successful bypass system is never guaranteed. It is not the intent of this article to suggest that turbines are always better fish bypass routes than bypasses. Rather, bypass systems are complicated hydraulic environments, and survival while entering, passing through, and exiting these systems does not always meet expectations or assumptions made prior to construction. In some cases, certain species may have higher survival rates if they pass through turbines. Owners of existing bypass systems and designers of new systems should consider each site individually to determine the most effective passage route.

Ideally, survival through future and existing bypass systems should be compared to other passage routes to determine whether the bypass performance will improve survival past the hydroelectric facility. The Bonneville Dam study indicates the type of comparative results that can be achieved when a well formulated research design is implemented. It has provided scientific information that now can be used to make decisions on bypass system improvement at operating hydro plants. These studies are expensive, take years to complete, and require large numbers of test fish to detect small differences among treatment groups. However, comprehensive evaluations of bypass systems including the effects of the system on the turbine environment and the survival of non-bypassed fish are needed to fully understand the actual benefits associated with bypass passage. □

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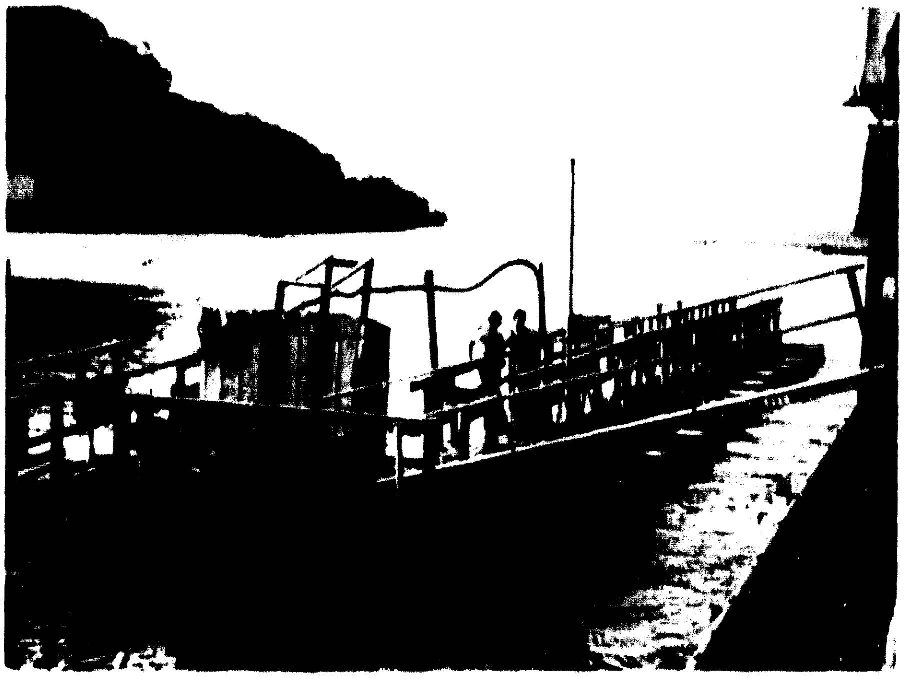
Guiding American Shad with Strobe Lights

Among the various potential techniques for guiding migrating fish past hydroelectric facilities, the use of strobe lights has proven effective at one hydro site in the Northeast.

By Paul D. Martin and Charles W. Sullivan

During a recent study conducted at the York Haven Hydroelectric Project on the Susquehanna River in Pennsylvania, underwater strobe lights repelled 94 percent of the juvenile American shad away from turbine intakes and through a trash sluiceway. The results of this study indicate that strobe lights are effective in guiding juvenile shad past the York Haven project, and may be appropriate at other hydroelectric projects where owners are attempting to provide dowstream passage for this migratory fish species.



Researchers at the York Haven hydroelectric project on the Susquehanna River in Pennsylvania have demonstrated the effectiveness of using strobe lights to guide juvenile American shad past the turbine intakes to the trash sluice bypass. Researchers lowered strobe lights mounted on long vertical poles into the water to repel fish away from the turbine intakes.

Launching the Study: Lights Are Not a New Idea

In 1986, the Electric Power Research Institute (EPRI) published a report titled *Assessment of Downstream Migrant Fish Protection Technologies for Hydroelectric Projects.*[1] Although fish diversion protection systems had been developed for steam electric facilities, these are often too costly on a per unit flow or per megawatt capacity basis to be transferred to hydroelectric facilities. In its 1986 study, EPRI wanted to assess available technologies to discover which ones were appropriate for hydro plants. One recommendation of that report was to conduct further research on behavioral diversion systems, including strobe lights, to minimize fish entrainment.

Based on this recommendation, in 1988 EPRI, Metropolitan Edison Company (Met-Ed), and the Susquehanna River Anadromous Fish Restoration Committee (SRAFRC) co-funded a study to evaluate the use of strobe and mercury lights for diverting outmigrating juvenile American shad (*Alosa sapidissima*) at Met-Ed's York Haven hydro project. The objective of the study was to determine whether these devices could be used to divert shad away from the hydro plant turbines and through an existing trash sluiceway near the downstream-most unit. The results of the 1988 study demonstrated that strobe lights repelled the juvenile shad, and indicated that the fish could be directed into the sluiceway.[2] On the basis of these results, EPRI contracted with Stone & Webster Environmental Services to conduct a prototype evaluation of a strobe light and bypass system.

A Look at York Haven

The York Haven project is on the west bank of the river, at the end of an 8,000-foot-long dam that slopes up-

Paul Martin is a project scientist for Stone & Webster Environmental Services in Boston, Massachusetts. He served as the lead biologist for the York Haven study. Chuck Sullivan is the hydro program manager for the Electric Power Research Institute in Palo Alto, California.

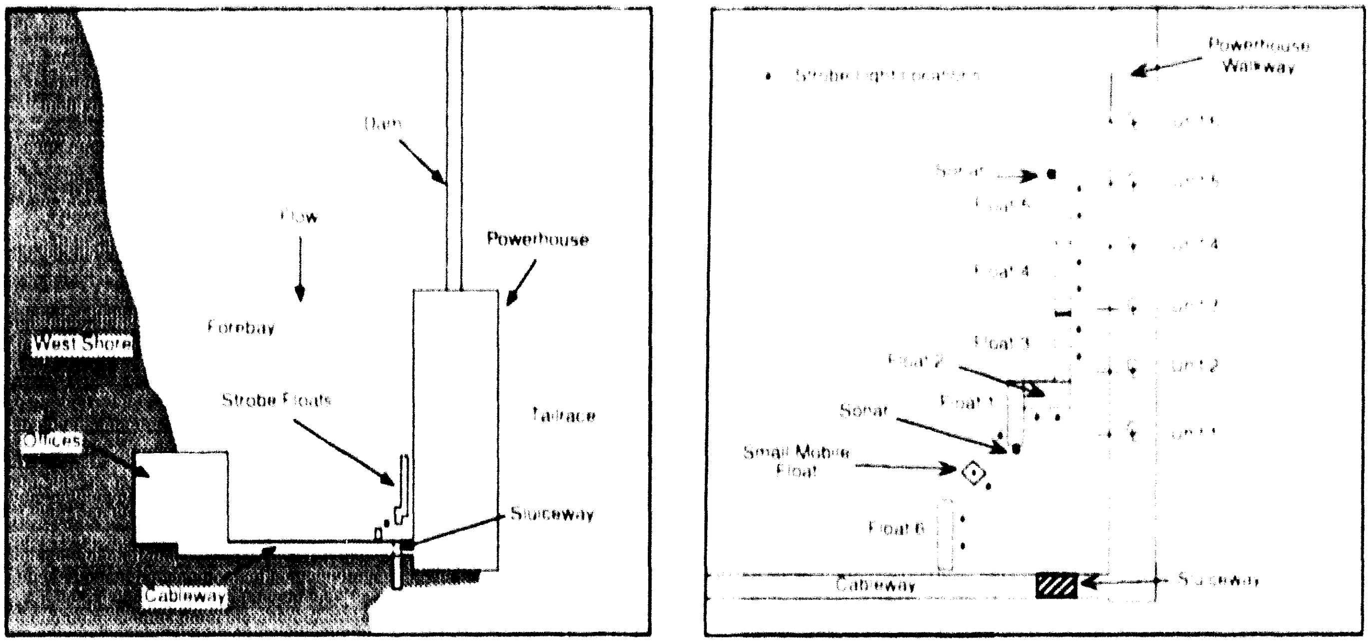
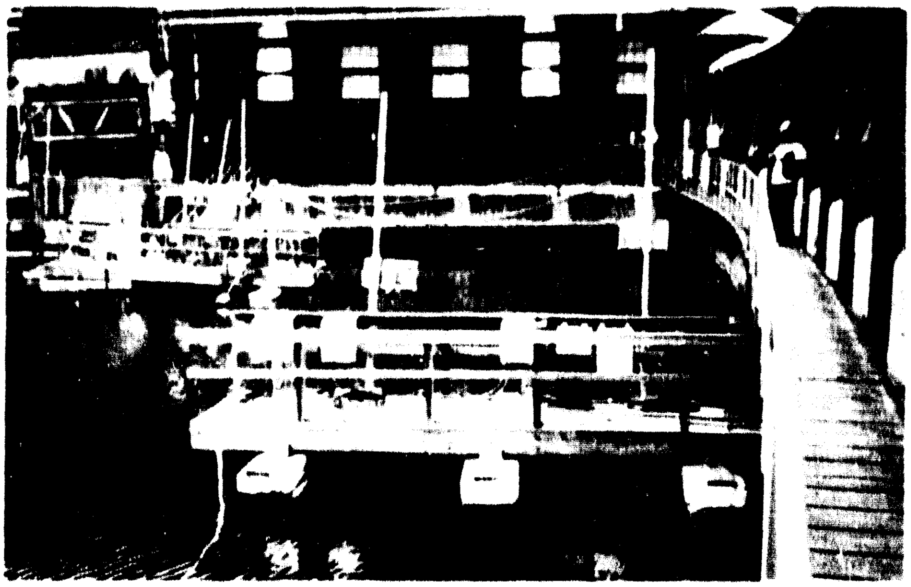


Figure 1 This figure shows the strobe light test system positioning in the York Haven forebay. The left illustration is an overhead view of the project; the right illustration is a cutaway showing the test area in detail

stream to the east bank. The powerhouse consists of six Kaplan and 14 Francis turbines, each capable of passing about 800 cubic feet per second (cfs) of water. The station is capable of generating 19.6 MW of electricity with a head of 23 feet. Water velocities range from 1 to 2 feet per second (fps) approaching the trashracks with full unit operation, and increase to 3 fps immediately in front of the trashracks.

During the shad out-migration period (late September to early November), river flows are low enough that most of the river water passes through the powerhouse. Because of the oblique angle of the dam and powerhouse relative to the river flow, shad tend to congregate in the downstream end of the forebay near the sluiceway (see left side of Figure 1).

For the prototype study, Stone & Webster positioned strobe lights in front of Units 1 through 6 at York Haven, the units that are most likely to be operating during the fall shad out-migration period. The objective was to provide a full-scale demonstration of the effectiveness of a strobe light system in guiding juvenile American shad past the turbine intakes to the trash sluice bypass. In both 1989 and 1990, flooding resulted in most fish passing over the dam. In 1991, low flow conditions prevailed throughout the out-migration period, and so Stone & Webster was able to complete a thorough testing program.



This photo illustrates some of the components shown above in Figure 1 (an overhead view of the strobe light system at York Haven). The cableway runs along the right side of the photo; the powerhouse, in the background of the photograph, is perpendicular to the cableway. Float 6 (foreground) and Floats 1 and 2 (background) are shown in the photograph. The vertical poles that support strobe lights are attached to the floats, and used to repel fish away from the sluice gate (located in the upper right corner of the photo).

Description of the Strobe Light System

Figure 1 shows the strobe light test system set up in the York Haven forebay in 1991. The system consisted of five floats anchored upstream of the trashrack between the sluiceway and Unit 6. A sixth float was placed about 50 feet from the sluiceway, as shown in Figure 1. Researchers were attempting to reduce upstream escapement of fish, which had been a problem in previous test years.

The strobe lights on Floats 3, 4, and 5 were attached to steel poles, and these assemblies were then mounted on the floats. Each pole supported two lights; the lights were located 3 feet and 9 feet below the water surface. The poles were spaced at 12-foot intervals on the floats paral

The strobe light test system at York Haven consisted of five floats anchored upstream of the trashrack between the sluiceway and Unit 6, as shown in the upper center of the photograph. A sixth float, partially shown in the right foreground of the photo, was positioned perpendicular to the cableway, 50 feet from the sluiceway. The strobe lights, mounted on vertical poles attached to the floats, were located 3 feet and 9 feet below the water surface.

lel to the trashracks, with the flash heads of the lights aimed into the flow. The horizontal and vertical spacing was selected based on the beam spread of the lights and was designed to create a continuous "wall" of light across Units 2 through 6.

Lights on the floats closest to Unit 1 (Floats 1, 2, and 6) were similarly mounted but were oriented to flash in the direction of the sluiceway, and were operated independently from the upstream lights.

A small, moveable float supporting a single pole with two lights was positioned in a variety of locations between Float 1 and the powerhouse cableway to augment and more finely direct the repulsion of fish out the sluiceway.

The strobe light system was configured as two arrays: the lights on the upstream floats (3, 4, and 5) in front of the trashracks were operated together and sequenced by one controller; and the lights near the sluiceway operated together on a separate controller. This design allowed the upstream-oriented strobes to operate continuously to divert shad from the turbine intakes and to encourage them to congregate near the sluiceway. Periodically, based on the sampling design, the sluiceway gate was opened and the strobes near the sluiceway were activated to repel fish through the sluiceway.

Determining Effectiveness

Researchers demonstrated the effectiveness of the strobe light system through scanning sonar and net sampling techniques.

Two WESMAR Model SS390 scanning sonar systems were used to monitor fish behavior and response to the strobe lights. Each sonar system was connected to a time-lapse video recorder and color video monitor with data recorded in VHS format. One sonar unit was deployed from Float 1 (with its range set at 50 feet) to monitor fish in the area of Unit 1 and the sluiceway. The second sonar unit was deployed in front of Unit 5 (set at a range of 150 feet) to monitor fish as they entered the forebay area and approached the strobe light system.

Researchers determined behavioral response to the strobes by reviewing the sonar video recordings and interpreting the strength of the response based on changes in fish density in the vicinity between the strobes and the sluice gate, just prior to and following downstream strobe activation.

To quantify the passage of fish through the sluiceway relative to turbine passage, researchers installed nets in the sluiceway and in the tailrace of Unit 1. Researchers deployed the nets just before the downstream strobes were activated and retrieved them immediately following strobe deactivation. The nets sampled 3 percent of the sluiceway flow and 4 percent of the discharge from Unit 1.

Designing the Test

Testing within each sample day consisted of running sequential control and test conditions from approximately dusk to dawn throughout most of the out-migration period. The following sequence of tests was repeated from six to eight times per night:

Control: Sluice gate open for two minutes (downstream strobes off), and sluice and tailrace nets retrieved at end of test.

Strobe: Sluice gate open for one

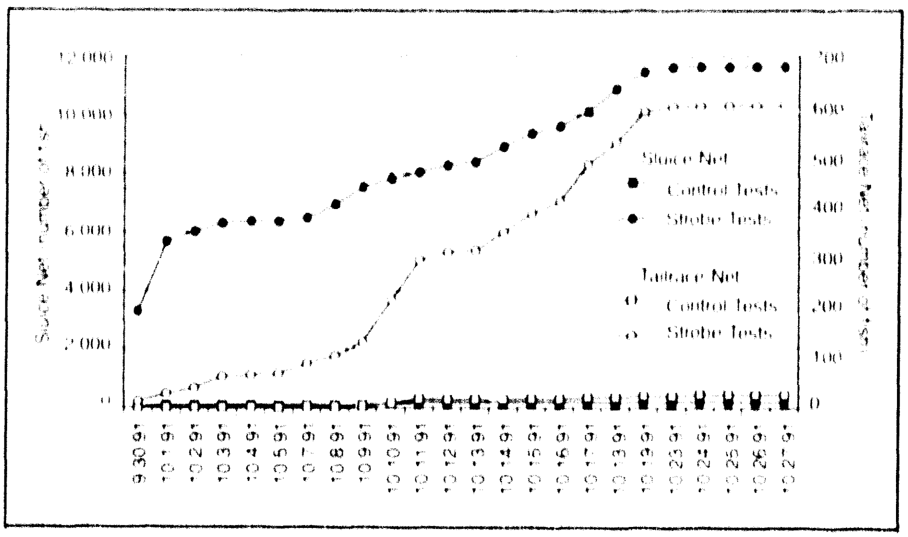
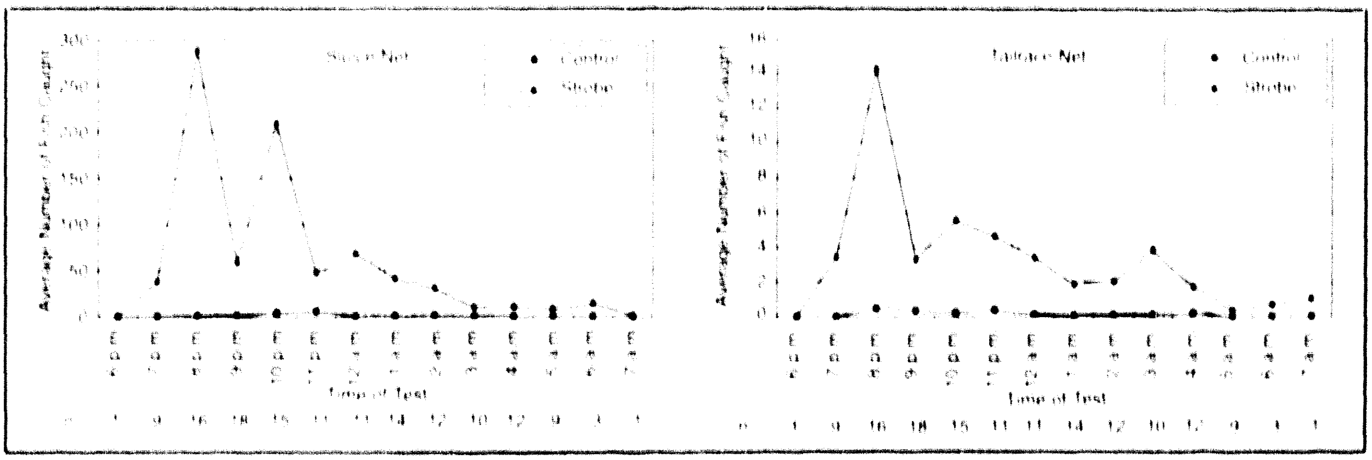


Figure 2. This graph shows the cumulative number of fish netted with both the sluice net at the sluiceway and the tailrace net at the Unit 1 tailrace over the 27 days of testing in the fall of 1991. These numbers were estimated by comparing scanning sonar and netted fish counts.



Figures 2 and 3 These graphs present the average numbers of shad collected in the sluice net (left) and tailrace net (right) with and without the use of strobe lights. N equals the number of tests conducted at each time over the study period

minute before strobes were turned on, strobe lights then illuminated for one minute, and strobes off and sluice gate closed (this timing resulted in the sluice gate being opened for a total of two minutes), and sluice and tailrace nets retrieved at the end of the test.

Test Results

Stone & Webster researchers conducted the 1991 field evaluation from September 29 to October 27. Over the 29-day sampling period, researchers conducted 155 strobe light tests. During the testing, large masses of fish moved downstream through the gate when the downstream strobe lights were activated. Scanning sonar observations indicated that the predominant movement of shad was downstream and into the sluiceway.

The average estimated numbers of American shad passing through the sluiceway and the Unit 1 tailrace per

Table 1: Numbers of American Shad Passing through Sluice Gate and Unit 1 per Test in 1991

	Control Condition	*Strobe Light Test Condition*
Sluice Gate Net	37	1,712
Tailrace Net	5	106

test under strobe light test and control conditions are summarized in Table 1. This table shows that many more fish were pulsed through the sluiceway with the strobes on than in the control condition when the strobes were off. These results have important implications relative to plant capacity. The sluice gate at York Haven cannot be left open without wasting 300 cfs of water and restricting access to a popular fishing platform and the powerhouse loading dock. The strobe lights moved nearly all of the shad through the sluice gate, while the control conditions moved less than 3 percent through during a similar time period. Therefore, periodic opening of the sluice gate and operation of the downstream strobe lights will effectively bypass fish while minimizing spill flow.

Figure 2 shows the cumulative number of fish collected in the sluiceway and the tailrace nets over the testing program. This figure indicates the overwhelming number of shad that passed out the sluiceway (sluice net) as opposed to through Unit 1 (tailrace net). Furthermore, comparison of the control to the strobe tests for the sluice reveals the necessity for the use of strobes lights (as opposed to only opening the gate) in order to bypass the shad.

Figure 3 shows the average number of fish collected in the sluiceway and tailrace nets during different times of the night. Revealed in the figure is a trend of minimal fish passage prior to sunset, maximum fish passage during early night, and a gradual tapering off toward morning. Peak shad passage occurred at 8 p.m.

Conclusions: The Results Are Encouraging

The test data demonstrate that the strobe lights create a strong and repeatable avoidance response in actively out-migrating juvenile American shad. Under the conditions existing at York Haven, the lights effectively repel fish through the sluiceway with only a small proportion of the fish passing through the turbine. Further, the avoidance response to the strobe lights lasts as long as the lights are activated; there is no evidence of acclimation to the light even after many hours of operation.

The study has shown that strobe lights provide a cost-effective means of reducing turbine passage and bypassing migrating juvenile American shad past the York Haven Hydroelectric Project. EPRI is continuing research to determine whether strobe light systems can be used to guide other fish species past hydro projects and other water intakes. □

Mr. Martin may be contacted at Stone & Webster Environmental Services, 245 Summer Street, Boston, MA 02107; (617) 589-2979. Mr. Sullivan may be contacted at the Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA 94303; (415) 855-8948.

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1 ***Assessment of Downstream Migrant Fish Protection Technologies for Hydroelectric Application***, EPRI Report AP-4771, Research Project 2694-1, Electric Power Research Institute, 1986, Palo Alto, California.

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Introducing a 'Modular' Approach To Fish Screen Installation

A new fish screen design—the modular inclined screen—promises to offer a versatile and cost-effective solution for fish protection in many situations.

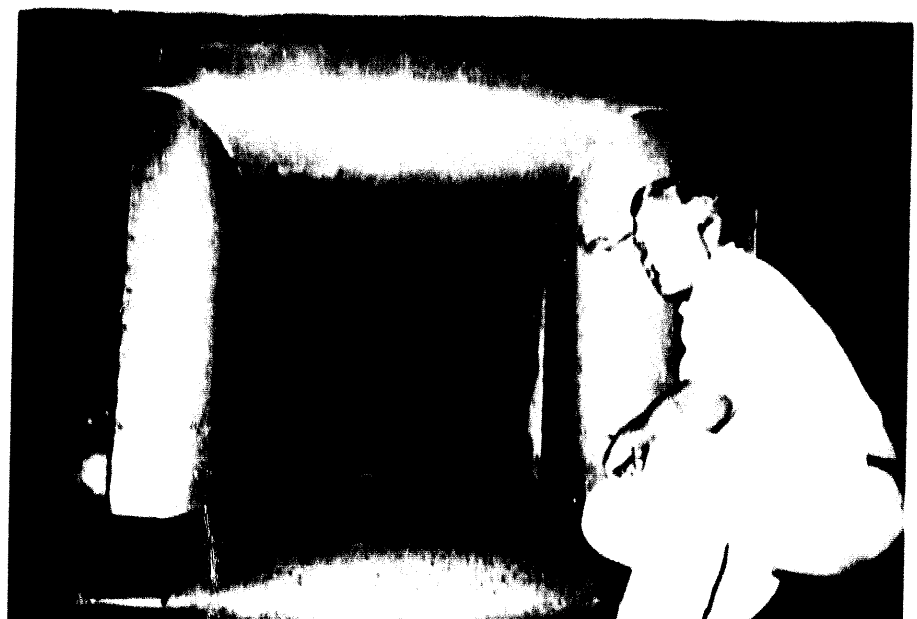
By Edward P. Taft, Fred C. Winchell, Thomas C. Cook, and Charles W. Sullivan

In an effort to provide the hydroelectric industry with more cost-effective alternatives to existing fish screen designs, the Electric Power Research Institute (EPRI) recently has undertaken several research projects. One focus of EPRI's research has been on the development and testing of high-velocity fish screens. This program has led to the development of a new screening concept, which shows promise for providing effective protection for a wide range of fish species at hydro plants, steam generating facilities, and irrigation diversions. The concept, known as the Modular Inclined Screen (MIS), currently is being evaluated in laboratory studies prior to field application.

The screen is of "modular" design so as to provide the flexibility necessary for application at a broad range of water intakes. The module is suitable for installation in penstocks, canals, and head pond intakes.

The MIS module (shown in Figure 1) consists of an entrance with a trashrack, dewatering stoplog slots, an inclined wedgewire screen set at a shallow angle of 10 to 20 degrees to the flow, and a bypass for diverting fish to a transport pipe. The screen is mounted on a pivot shaft so that it can be cleaned via rotation and back-flushing. The module is completely enclosed, and is designed to operate at water velocities ranging from 2 to 10 feet per second depending on the fish species and life stages to be protected.

Laboratory studies are under way to evaluate the design configuration that yields the best hydraulic conditions for



Ned Taft, program manager for Stone & Webster Environmental Services, is kneeling at the entrance of the 1:3.3 scale model of the modular inclined screen being used for biological testing at Alden Research Laboratory. Tests will be performed using rainbow trout (two size classes), blueback herring, walleye, channel catfish, and several additional species (including Pacific salmon). For each species and size class, the diversion efficiency, injury, and latent mortality of test and control groups will be determined.

Ned Taft is a program manager, Fred Winchell is senior environmental scientist, and Tom Cook is a principal civil engineer for Stone & Webster Environmental Services. Charles Sullivan is the hydro program manager for the Electric Power Research Institute.

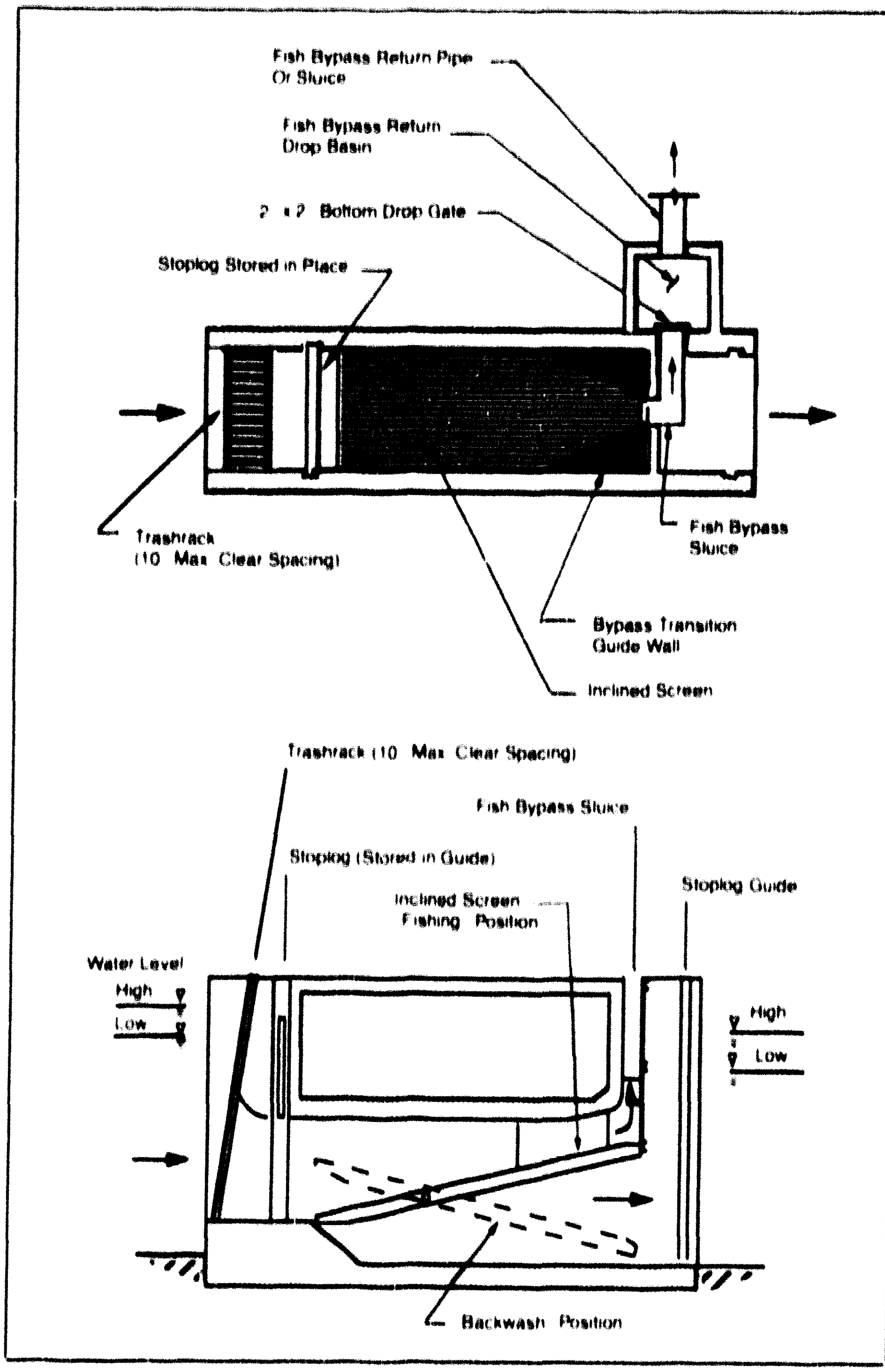


Figure 1. These drawings are overhead (top) and side (bottom) views of the Modular Inclined Screen design. The MIS module, which is completely enclosed, consists of an entrance with a trashrack, stoplog slot, an inclined wedgewire screen set at a shallow angle of 10 to 20 degrees to the flow, and a bypass for directing diverted fish to a transport pipe. The screen is mounted on a pivot shaft so that it can be cleaned via rotation and backflushing.

safe fish passage, and the biological effectiveness of this design in diverting selected fish species to the bypass.

Background on EPRI's MIS Research Program

EPRI has been conducting research since 1985 to develop and evaluate a number of technologies that can be used to prevent fish from passing through hydroelectric turbines. The goal of this program is to identify technologies that can provide effective fish protection at reasonable costs.

Much of the EPRI-sponsored research has focused on the evaluation of behavioral devices that can be used to attract or repel fish. For example, strobe lights have been shown to provide effective guidance of juvenile American shad at the York Haven hydro plant on the Susquehanna River in Pennsylvania.[1] Recent field studies conducted by researchers other than EPRI indicate that sound-producing devices may provide effective protection for some species.[2,3] However, the response of fish to most behavioral devices appears to vary between species, and also may be affected by the characteristics of the site. Although behavioral devices offer the potential to provide cost-effective protection at many sites, knowledge of behavioral devices has not evolved to the point where these technologies can be applied without conducting site-specific evaluation studies.

Fish screens offer a less species-specific approach to fish protection; however, most of the designs accepted by regulatory agencies are very costly to construct. High costs are related to the large screen area needed to meet established velocity criteria that ensure the fish to be protected can swim away from the screening structure.

EPRI's research in the area of fish screens has focused on development and evaluation of systems that offer the potential for reduced costs by diverting fish at higher water velocities. In this way, the size of the facility required to screen a given volume of flow can be reduced. The first phase of this research was focused on refining and proving the effectiveness of the Eicher Screen, designed for application within penstocks. This program culminated in a two-year evaluation of a full-sized prototype installed in a 9-foot-diameter penstock at the 12.8-MW Elwha Hydroelectric Project in Washington State. Tests conducted at Elwha have shown that the screen, which was installed at a 16-degree angle, provides effective protection for juveniles and smolts (juvenile migratory stage) of chinook and coho salmon and steelhead trout at penstock velocities of up to 7.8 feet per second.[4]

Moving on from Elwha

Although the testing program at Elwha was successful in demonstrating the effectiveness of the Eicher Screen technology for diverting juvenile salmonids, three questions were left unanswered. First, how can the high-velocity screening concept be applied at the many hydro projects and other types of water intakes that don't utilize penstocks? Second, can a steeper or shallower screen angle be used to reduce screening costs or to improve fish passage? Third, does the concept hold promise for diverting other species of fish? Answering these questions formed the basis of EPRI's modular inclined screen development program.

The MIS Development Program

The program for developing the MIS concept consists of four phases:
1) Development of the conceptual design;
2) Hydraulic model studies;
3) Laboratory testing of passage for several species of fish; and
4) Evaluation of an application at an existing site.

The program has been developed with the guidance of the EPRI Fish Protection Review Team, a group of representatives from interested utilities and resource agencies.

In the conceptual design phase, a modular approach was selected with the following goals and objectives:
—The design is standardized to minimize the need for site-specific adaptations, engineering, and biological evaluation studies;
—The approach velocity can be controlled to meet the flow requirements of a site and of the species to be protected by installing the appropriate number of modules;
—The velocity distribution along the face of the screen should be as uniform as possible; and
—The entrance configuration should minimize the effects of skewed approach flows on fish passage conditions at the screen face.

A standard MIS module, as currently envisioned, would use a screen 10 feet wide and up to 28 feet long. The screen would be set at an angle of 10, 15, or 20 degrees depending upon the species to be protected and the findings of biological testing. The total length of an installed module, including entrance and trashracks, would be a maximum of 45 feet. The module would have the capacity to screen a maximum of 500 to 1,000 cubic feet per second (cfs) of water at 10 feet per second, depending on the screen angle selected.

The velocity distribution at the screen face and the potential need for porosity control was evaluated in a 1:6.6 scale hydraulic model, constructed at the Alden Research Laboratory in Holden, Massachusetts. The model was used to evaluate three specific concerns related to successful fish guidance:
1) The effect of module entrance conditions on the velocity distribution at the screen;
2) The ability to achieve relatively uniform velocities along and across the screen; and
3) The effect of bypass geometry on flow separation and head loss in the bypass channel.

The results of hydraulic model tests demonstrated that the MIS entrance design created a uniform velocity distribution with approach flows skewed as much as 45 degrees. The modular design features were effective in developing uniform velocities over the screen surface without any high velocity zones or the need to vary the porosity (percent open area) of the screen material. The uniform velocity distribution of the MIS is expected to facilitate fish passage at higher velocities than can be achieved using any other currently available type of screen design.

Preliminary fish releases made into the hydraulic model at approach velocities of 2 and 4 feet per second resulted in the successful diversion of 2- to 3-inch bluegill, 4- to 6-inch alewives, and 4- to 8-inch Atlantic salmon. A comprehensive evaluation of passage success, currently underway, will be completed in the spring of 1993. The tests are being conducted in a biological test flume, using a 1:3.3 scale model of the MIS. Tests will be performed using rainbow trout (two size classes), blueback herring, walleye, channel catfish, and several additional species (including Pacific salmon) to evaluate passage at screen angles ranging from 10 to 20 degrees and at approach velocities ranging from 2 to 10 feet per second. For each species and size class, Stone & Webster Environmental Services researchers will determine the diversion efficiency, injury, and latent mortality of test and control groups.

At the completion of the laboratory tests, EPRI plans to co-fund the installation and evaluation of a prototype MIS at an existing water intake. This final phase of the development program is intended to confirm whether the passage success rates found in the laboratory studies are consistent with those observed in a full-scale field application. Owners of potential test sites are encouraged to contact Charles Sullivan, EPRI Hydro Program Manager, at (415) 855-8948.

The MIS testing program should provide valuable information on the effectiveness of high-velocity screening systems for protecting different species and size classes of fish, and on the potential for using different screen angles for optimizing fish passage success at the minimum possible cost.

Advantages of the MIS

The modular intake screen concept has the potential for providing cost-effective fish protection at various water intakes. Depending on the application, the installed cost of an MIS may be less than half that of screens designed to meet conventional screening criteria. The development of an effective modular design also should reduce or eliminate many costs associated with the engineering and biological testing that are usually required to meet site-specific conditions. □

Messrs. Taft, Winchell, and Cook may be contacted at Stone & Webster Environmental Services, 245 Summer Street, Boston, MA 02210; (617) 589-2227. Mr. Sullivan may be contacted at the Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA 94303; (415) 855-8948.

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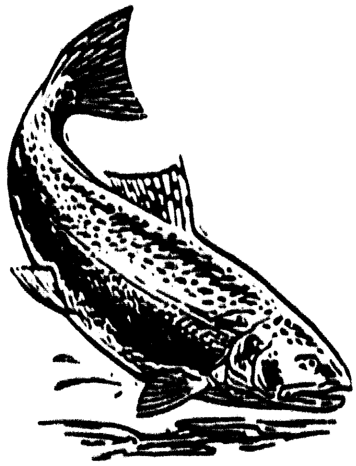

INEL

Idaho National Engineering Laboratory

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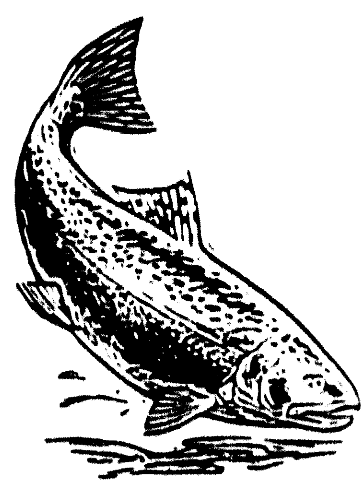

EGG-EEL-10523

CONTAMINANT MONITORING STRATEGY

FOR HENRYS LAKE, IDAHO

J. S. Irving[1]
R. C. Rope
R. P. Breckenridge

December 1992

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Idaho Falls, Idaho 83415

Prepared for the
U. S. Department of Energy Field Office, Idaho
and the
Division of Environmental Quality
Idaho Department of Health & Welfare
Under DOE Contract No. DE-AC07-76ID01570

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[1] To request a copy of the full report contact John S. Irving, EG&G Idaho, Inc., P.O. Box 1625, MS 2213, Idaho Falls, ID 83415 or call (208)526-8745.

EXECUTIVE SUMMARY

Introduction

Background

Henrys Lake, located in southeastern Idaho, is a large, shallow lake (6,600 acres, ≈ 17.1 ft. maximum depth) located at 6,472 ft. elevation in Fremont Co., Idaho at the headwaters of the Henrys Fork of the Snake River. The upper watershed is comprised of high mountains of the Targhee National Forest and the lakeshore is surrounded by extensive flats and wetlands, which are mostly privately owned. The lake has been dammed since 1922, and the upper 12 ft. of the lake waters are allocated for downriver use.

Henrys Lake is a naturally productive lake supporting a nationally recognized "Blue Ribbon" trout fishery. There is concern that increasing housing development and cattle grazing may accelerate eutrophication and result in winter and early spring fish kills. There has not been a recent thorough assessment of lake water quality. However, the Department of Environmental Quality (DEQ) is currently conducting a study of water quality on Henrys Lake and tributary streams.

Septic systems and lawn runoff from housing developments on the north, west, and southwest shores could potentially contribute to the nutrient enrichment of the lake. Many houses are on steep hillsides where runoff from lawns, driveways, etc. drain into wetland flats along the lake or directly into the lake. In addition, seepage from septic systems (drainfields) drain directly into the wetlands enter groundwater areas that seep into the lake.

Cattle grazing along the lake margin, riparian areas, and uplands is likely accelerating erosion and nutrient enrichment. Also, cattle grazing along riparian areas likely adds to nutrient enrichment of the lake through subsurface flow and direct runoff. Streambank and lakeshore erosion may also accelerate eutrophication by increasing the sedimentation of the lake Natural phosphorus deposits within the basin also contribute to the nutrient enrichment of the lake..

Approximately nine streams feed the lake, but flows are often severely reduced or completely eliminated due to irrigation diversion. In addition, subsurface flows can occur as a result of severe cattle grazing along riparian areas and deltas. Groundwater and springs also feed the lake, and are likely critical for oxygen supply during winter stratification.

During the winter of 1991, Henrys Lake experienced low dissolved oxygen levels resulting in large fish kills. It is thought that thick ice cover combined with an increase in nutrient loads created conditions resulting in poor water quality. The Idaho Department of Health and Welfare, DEQ is currently conducting a study to determine the water quality of Henrys Lake, the sources contributing to its deterioration, and potential remedial actions to correct problem areas.

Role of the Idaho National Engineering Laboratory (INEL)

In June of 1991 the Department of Energy's Idaho Operation Office (DOE-ID) received a request for Department of Energy's Idaho Operation Office technical assistance from the State of Idaho's DEQ. The DEQ was initiating the development of a lake management plan for Henrys Lake and requested the participation of the INEL. DEQ's proposed *Lake Management Plan* for Henrys Lake includes

- Description of the Basin
- Description of the Hydrologic System
- Identification of Nutrient Sources
- Identification and Evaluation of the Dynamics of Nutrient Removal, Use, and Dispersal
- Identification and Discussion of Water Quality Goals
- Identification of Critical Areas/Activities
- Identification of Preventative or Remedial Actions

The INEL Center For Environmental Monitoring and Assessment (CEMA) agreed to assist DEQ by providing a description of the Henrys Lake Watershed. In addition, the CEMA agreed to conduct contaminant monitoring assessment of Henrys Lake. The methodology used for characterizing the environmental conditions was developed under a Work-for-Others projects with the U. S. Fish and Wildlife Service (FWS). The Contaminant Monitoring and Assessment (CMA) Process is a systematic approach for developing a routine contaminant monitoring program. The process was developed for use on the FWS's 485 National Wildlife Refuges. The types of contaminants routinely sampled include metals, pesticides, herbicides, nutrients, bacteria, etc. In addition, organisms are selected as bioindicators (e.g., benthic invertebrates, aquatic plants).

The objectives of this effort were (1) to develop a long-term contaminant monitoring strategy specifically designed for the Henrys Lake watershed, (2) further test the CMA process, and (3) provide the state and other federal agencies with a consistent approach for developing long-term monitoring strategies.

To initiate the project a Workshop was held at the INEL Research Center in Idaho Falls on December 17-18, 1991. The Workshop brought together many individuals that had a management responsibility or interest in Henrys Lake. The goal of the Workshop was to complete a Contaminant Monitoring Workbook. The purpose of the Workbook is to provide a short, concise format for developing contaminant monitoring strategies on FWS lands and/or other areas used by trust resources managed by the FWS. This Workbook was modified for use at Henrys Lake by the state and federal agencies.

A summary of the information collected during the Workshop follows. The subsequent sections give an introduction to the CMA process and describe the *Contaminant Assessment Area* (CAA) and the *Monitoring Strategy*. This includes specific strategy developed for air, groundwater, surface water, lake sediment, and biological monitoring. The Workbook (**see Appendix A**)[1] contains the information collected and used to develop the long-term monitoring strategies.

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[1] **Appendix A is not included with this Executive Summary. To request full report, including Appendix A, see footnote on title page.**

Contaminant Monitoring Strategy Development

The purpose of this section is to discuss a standard approach for developing contaminant monitoring strategies. Its application will provide a consistent contaminant monitoring approach. The Workbook is intended to guide personnel from state and federal agencies, local governments, and special groups in developing a contaminant monitoring strategy for Henrys Lake. It provides the steps and considerations that should be incorporated into routine contaminant monitoring activities and will provide data to assess the current status and evaluate trends of contaminant concentrations. This Workbook establishes an *institutional memory* of previous monitoring efforts and this new effort.

The approach to designing contaminant monitoring activities must be based on scientific understanding and should be applied consistently across all areas. This will help ensure that all concerns are addressed and the appropriate decisions are made in accordance with the management agencies goals and objectives. The design of contaminant monitoring activities should use the same scientific approach regardless of the area's location and characteristics. However, this approach remains flexible to adequately address the variety of conditions that exist across the country.

The major components of the contaminant monitoring approach and management objectives are:

- Assess management goals and objectives relevant to contaminant monitoring
- Environmental / Ecological characterization
- Prioritized the contaminants to monitoring based on risk to resource
- Identify optimum location, media / parameters and time to monitor
- Design and implement contaminant monitoring activities
- Evaluate data and make recommendations
- Review and revise monitoring strategy as appropriate

During the Workshop, the first three steps were completed by the Workshop participants. Scientists at the INEL completed step 4 based on the information provided by the Workshop participants. The remaining steps depend upon the individual needs and resources of the agencies conducting the monitoring program.

Monitoring Preface

The contaminant monitoring approach presented in the Workbook is based on multimedia monitoring and an ecosystem approach derived from numerous years of monitoring and research experience at areas including U.S. National Parks, Biosphere Reserves (Wiersma et al. 1984, 1985; Wiersma and Otis 1986), and U. S. Wilderness Areas (Bruns et al. 1982, 1984).

Components of an ecosystem approach (Wiersma et al. 1986; Bruns and Wiersma 1988) to environmental monitoring include:

- Evaluation of source-receptor relationships
- Assessment of contaminant transport mechanisms/pathways

- Multimedia monitoring (i.e., air, water, soil, biota, sediment) of key contaminant pathways within the environment
- Use of selected ecosystem parameter measurements to detect anthropogenic effects
- Development of a conceptual diagram of the system.

The ecosystem approach begins with a general conceptualization (diagram) of the system to be monitored. Such a diagram is intended as a tool for identifying ecological compartments of concern, delineating potential contaminant pathways through the system, and identifying potential important receptors. This allows one to view the monitoring problem as one of contaminant sources and pathways to critical receptor components of the ecosystem. For example, certain contaminants (e.g., lead) may be expected to reach high levels of accumulation in forest litter (Wiersma and Otis, 1986). Evaluation of contaminant sources relative to sensitive receptors is critical in the selection of sampling locations appropriate to monitoring objectives.

This approach to environmental monitoring design allows for reevaluation of data sets based on the conceptual diagram and, possibly, model calculations. Often this results in the ability to modify the monitoring design in a way that will allow for more effective monitoring and potential cost-saving.

The ecosystem approach to monitoring design for both contaminant and ecosystem measurements is based on a watershed/drainage basin (Likens 1985; Minshall et al. 1985) and airshed perspective, and links together key aspects of the atmosphere, forest, soils, stream, and lake components along selected ecological pathways within the system (Wiersma et al. 1986).

For example, the forest canopy is viewed as a major interceptor for deposition of atmospheric contaminants. Contaminants (and nutrients) may move to the soil component as *litterfall* or *throughfall* where they may be stored, taken up by organisms, leached to groundwaters, or transported to surface flow in runoff, streams, and lakes. Similar processes (e.g., storage, biological cycling, transport) may occur in these aquatic systems. The crucial aspect in this part of the monitoring design reflects the linkages between terrestrial and aquatic components and the storage, cycling, and transport of materials (and contaminants) through the system.
Atmospheric contaminants are also monitored as inputs to study areas because the atmosphere is an important contaminant exposure pathway to ecosystems in remote areas, far from local sources of pollution (Bruns et al. 1987, 1987a; Bruns and Wiersma 1988). This may include measurements of ambient levels of contaminants like trace metals, nitrates, sulfates, ozone, and oxides of nitrogen and sulfur (Bruns and Wiersma 1988). Also, as part of the multimedia ecosystem approach to environmental monitoring, contaminant levels (e.g., trace metals) may be measured in vegetation, soils, litter, and water.

In summary, the monitoring design discussed in this Workbook is based on an ecosystem view of environmental contamination and potential effects on ecosystems. Contaminant sources (local, regional, global) are identified along with critical receptors in the ecosystem; contaminants are monitored on a multimedia basis; key ecosystem parameters are utilized to assess impacts to both terrestrial and aquatic components of the system; and linkages between the terrestrial and aquatic compartments are delineated for important environmental pathways on a conceptual basis. Thus, an ecosystem approach integrates biogeochemical (including contaminants), meteorological, and ecological monitoring.

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DEVELOPMENT OF TECHNOLOGY TO TREAT AND DISPOSE OF FISH FARM WASTE

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DEVELOPMENT OF TECHNOLOGY TO TREAT AND DISPOSE OF FISH FARM WASTE

(SUMMARY)

J.S. Irving, G.L. Olson, and R.M. Lugar[1]

INTRODUCTION

Along the Snake River, in the Thousand Springs area of southern Idaho, water from the Snake River Plain aquifer seeps out of cliffs at a constant temperature of about 59 degrees F (± 2 degrees). The constant flow of clean, cool water has attracted over 125 fish farms and hatcheries to concentrate within a 20-mile stretch of the Snake River. These farms produce about 65% of the nation's rainbow trout (U.S. Department of Agriculture [USDA], 1990).

Fish manure, silt, and unused feed are a by-product of aquaculture operations. Although most of the solids occur naturally in free-flowing systems, their unnaturally high concentrations from fish farming can pose environmental threats. When flushed into waterways, the solids can cause algae blooms, increased turbidity of streams, decreased oxygen in water, and nitrate pollution.

Regulators and fish farmers have traditionally viewed fish manure as a waste management problem; however, its agronomic value could qualify it as a soil additive with market potential. In the Thousand Springs area, twenty-two million gallons of fish manure slurry are produced annually, enough to fertilize several hundred acres of crops. Fish manure contains moderate amounts of essential plant nutrients (compared to other organic fertilizers), is easily land-applied in its liquid form, and is a practical fertilizing option for organic farmers.

The objective of this project was to evaluate and test (1) solids removal techniques from fish farm raceways and (2) sludge disposal technology for the fish farming industry of southern Idaho. This work was an opportunity for scientists and engineers from the Department of Energy's (DOE) Idaho National Engineering Laboratory (INEL) to (1) explore and promote the conversion of a waste product to an energy source (i.e., fertilizer) and (2) expand knowledge in the treatment of low strength wastewater that effects the quality of water resources. Specifically, our concern was the removal and utilization of solids that could pollute surface waters. This project was a collaborative effort between the Idaho Aquaculture Association (IAA), the College of Southern Idaho (CSI), state and federal agencies, and state universities.

State and federal regulations require the fish farm industry to remove most of these solids from the hatchery outflow before emptying into the receiving waters. The Division of Environmental Quality (DEQ) has stipulated fish farm effluent limitations in response to the U.S. Environmental Protection Agency (EPA) mandates on water degradation. The total suspended solids (TSS) and settleable solids (SS), are considered in wastewater discharge permits. Currently, solids are partially controlled using settling basins. Solid wastes are removed from the raceways, then discharged to a settling basin or pond.

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[1] **To request copies of the report contact John Irving, EG&G Idaho, Inc., P.O. Box 1625, MS 2213, Idaho Falls, ID, 83415, Phone: (208)526-8745.**

Fish manure slurry is about 8-12 percent solids, thus, it is mostly water. This presents logistic and financial problems with disposal. A large volume of water accompanies the solids. This makes transportation of the solids beyond a couple of miles from the fish farm too costly. Methods that reduce the amount of water (dewatering) would concentrate the waste and make disposal more efficient.

In addition, the labor to remove the solids from the raceways is intensive. In large hatchery operations it is often an all day, everyday effort to keep up with the removal of solids. Methods that reduce the amount of effort would help reduce costs of waste treatment.

A lack of information on disposal of the fish sludge as a fertilizer and soil amendment contributes to the problem. Farmers are hesitant to accept the fish manure for crop production without guidance on application rates, effects on production, and influence on soil crusting. The first task was to determine the effectiveness of fish manure as an agricultural fertilizer. The second task evaluates methods to improve collection and removal of solids from raceways and settling basins. We also discuss the use and limitations of fish manure.

TASK 1 - EFFECTIVENESS OF FISH MANURE AS A FERTILIZER

Fish manure was analyzed for nutrient and trace element content. We conducted experiments in the field and in a greenhouse to test the nutrient potential of manure on Idaho crops. The experiments compared the agronomic performance of fish manure to commercially available nutrient sources.

Manure Characterization: We analyzed samples of fish, from the Thousand Springs area, for trace elements (1990) and nutrients (1990 and 1991). The total nitrogen in fish manure is present in two forms. About 10-14% is ammonium, much of which is lost through volatilization when applied to a field. The rest is in the organic form, but only about one-third of that is available for plant uptake during the first year. Fish manure is higher in nitrogen and phosphorus than most other manures and lower in potassium. Unlike municipal sludge, fish manure does not contain elevated levels of trace elements. The consistency of fish manure (not dried) is similar to muddy water.

Greenhouse Experiment: During the 1990 and 1991, Borah spring wheat was grown in the greenhouse at the INEL Research Center. The experimental design included three commercial fertilizer treatments, three fish manure treatments, and a control (no additives). In 1990, the nitrogen rates (or treatments) were: 100, 200, and 300 pounds of nitrogen per acre for both commercial fertilizer and fish manure. Experiments during 1990 showed that the 300 pounds per acre treatment of commercial fertilizer was excessive. Therefore, during 1991, we adjusted the rates for the commercial fertilizer treatments to 50, 100 and 200 pounds of nitrogen per acre. Fish manure treatments remained the same during 1991. Seven replicates of each of the seven treatments were tested. A Latin Square statistical design was used to set up a total of forty-nine 12-gallon pots. We applied fertilizer to the surface of each pot mixed it to a depth of about 4 inches.

We watered plants as needed, and later harvested when mature. All aboveground biomass was harvested and weighed for each pot. Seeds were separated from the heads and weighed separately (seed weight represent pot yield). Seeds from each pot were analyzed for protein content and soil for nitrogen, phosphorus, and potassium content.

Results from both 1990 and 1991 showed that fish manure has nutrient value, although it is not identical to the value of commercial fertilizer. Pots treated with fish manure produced higher wheat yields than the untreated pots, but do not necessarily produce higher yields than commercial fertilizer applied at the same rates (see Figure 1). This is due to the different forms of nitrogen that are in fish manure versus those that are in commercial fertilizer. Commercial fertilizers release nutrients to crops in the first season of application. In contrast, nutrients in fish manure are not all readily available for plant growth during the first year. However, fish manure has long-term benefits for organic farming in that it can develop a storage of nitrogen in the soil while increasing organic matter.

Field Experiments: In 1990 and 1991, fish manure (in slurry form) was compared to commercial fertilizer (urea) and a control under field conditions. Sweet corn was grown both years. Fish manure produced higher yields than the controls in 1990 and 1991 (see Figure 1). Results from the 1991 study show fish manure outperformed the control and the commercial fertilizer.

In summary, fish manure is a viable source of fertilizer for agricultural crops. It contains about 10% solids, of which 4% is nitrogen. About 90% of the total nitrogen is organic, and about ⅓ of that is available during the first year of application. The rest of the manure carries over to the next year or is lost through leaching, volatilization, or runoff. In addition, fish manure does not contain elevated levels of heavy metals as does most municipal sludge. In its slurry form, fish manure, is easily applied to farm land with a tanker truck.

Limitations to using fish manure are its odor, and its propensity to form a crust when dry (if not incorporated or injected into the soil) and expense of hauling and spreading.

TASK 2 - COLLECTION AND REMOVAL OF SETTLEABLE SOLIDS

Fish farms use a variety of methods to collect and remove solids from hatchery raceways. Most hatcheries (80-90%) with concrete raceways collect settleable solids in a settling zone at the downstream end of the raceway. Collection of the fish manure varies from farm to farm, but generally involves vacuuming the manure from the raceways and transferring it to settling basins. Some smaller fish farms with earthen rearing ponds allow the manure to collect within the pond until fish harvest; then the manure is generally dried and transferred to a disposal area. Some fish farms pump fish manure slurry directly from the settling basin, through irrigation pipes, to agricultural fields. Current techniques for removing fish manure from the raceway are labor intensive.

Fish farm operators are required to monitor their total raceway and settling pond effluent for total suspended solids (TSS), settleable solids (SS), and total flow through the hatchery. TSS must not exceed 5 mg/l in the hatchery effluent. Also, settling ponds must achieve at least 85% removal of TSS during active cleaning of the raceways. The TSS in the settling pond effluent cannot exceed 100 mg/l. In addition, hatcheries must achieve at least 90% removal of SS from their settling pond effluent.

We evaluated six prototype systems (see Figures 2-7) designed to remove solids from the raceways. The objective was to improve efficiency of solid removal and to reduce labor. The prototype designs were tested at Clear Springs Trout Hatchery located near Buhl, Idaho. To help in the evaluation of each prototype, we asked several questions: (1) Do the prototype collect solids?, (2) Do the prototype remove solids? , and (3) Do the prototypes remove solids better then current removal methods? In addition, visual observation and the results of water quality sampling helped evaluate prototypes. Other criteria included: cost of labor and material, ease of construction and operation, and compatibility with current hatchery goals and operation.

It was not possible to answer the question of "How much better" the prototypes are than current methods. Water quality sampling proved too variable to allow for adequate evaluation of the differences between control and test raceways. Working with high volumes of water and low levels of solids made it difficult to detect difference when testing only one prototype in one raceway.

All prototypes successfully collected and removed solids. Three prototypes surpass the others ,when considering the costs of labor and material, ease of construction and operation, and compatibility with hatchery practices (Figures 4, 5, & 6). These prototypes all consist of variation on a "false-floor concept" located in the settling zone area. The benefits of the preferred prototype (see Figure 6) include low cost (about $300 for materials plus twenty-five hours labor per raceway), ease of operation, compatibility with current hatchery operations, and reduction in labor cost for raceway cleaning. However, further testing is required to refine the design and operation of the "false floor" prototype. Generally, the prototype works and holds promise for being better than the current methods.

We recommend that the fish farm industry continue testing of the "false floor" prototype to refine its design and operation. Some questions remain unanswered. How frequent should raceways be cleaned? How efficient is the prototype at removing solids? To answer these question, it may be necessary to use prototypes in a partial or full (large-scale) test.

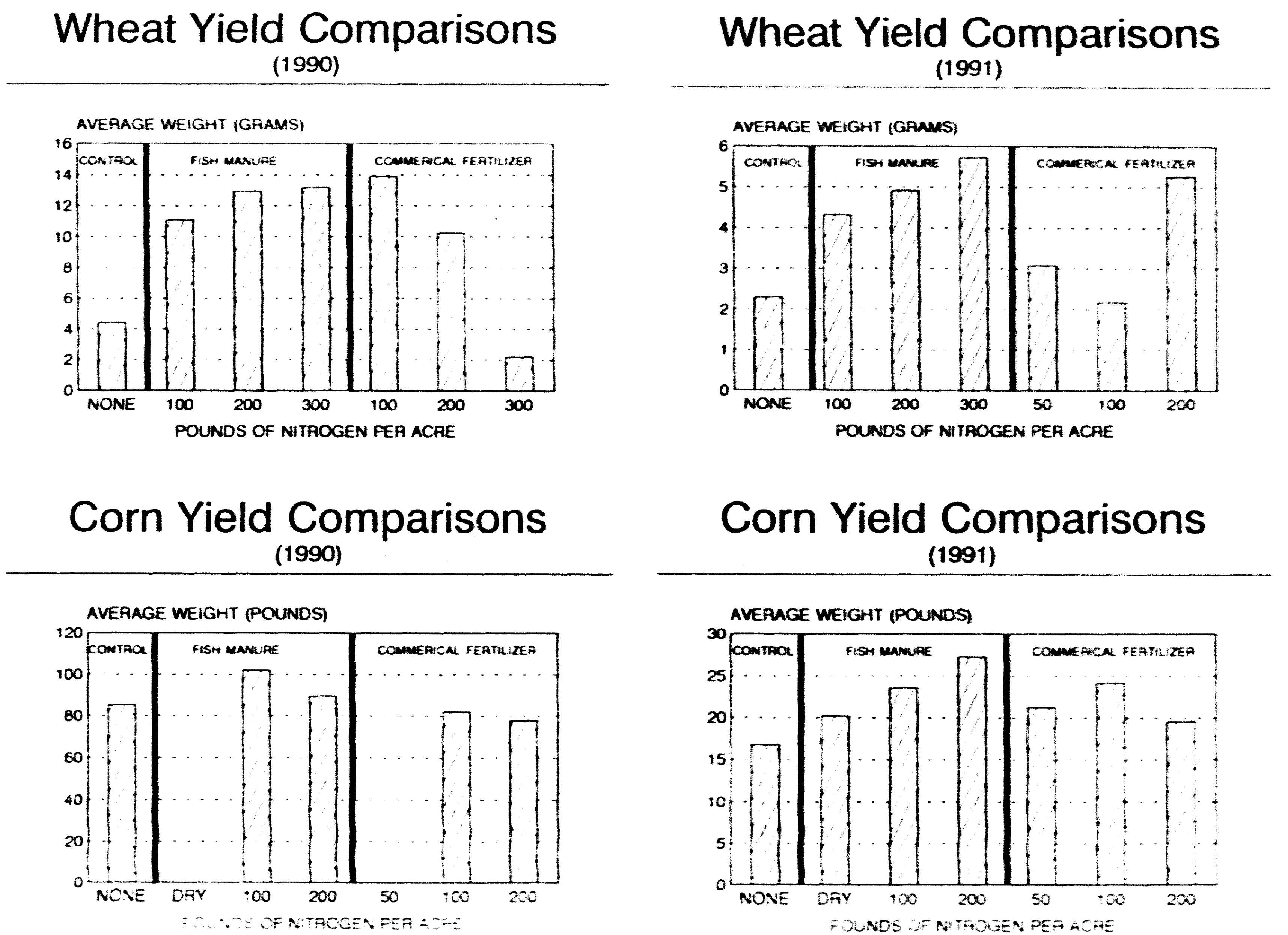

Figure 1. Comparison of Commercial Fertilizer and Fish Manure at Different Applications Rates in Greenhouse (Wheat) and Field (Corn) Experiments.

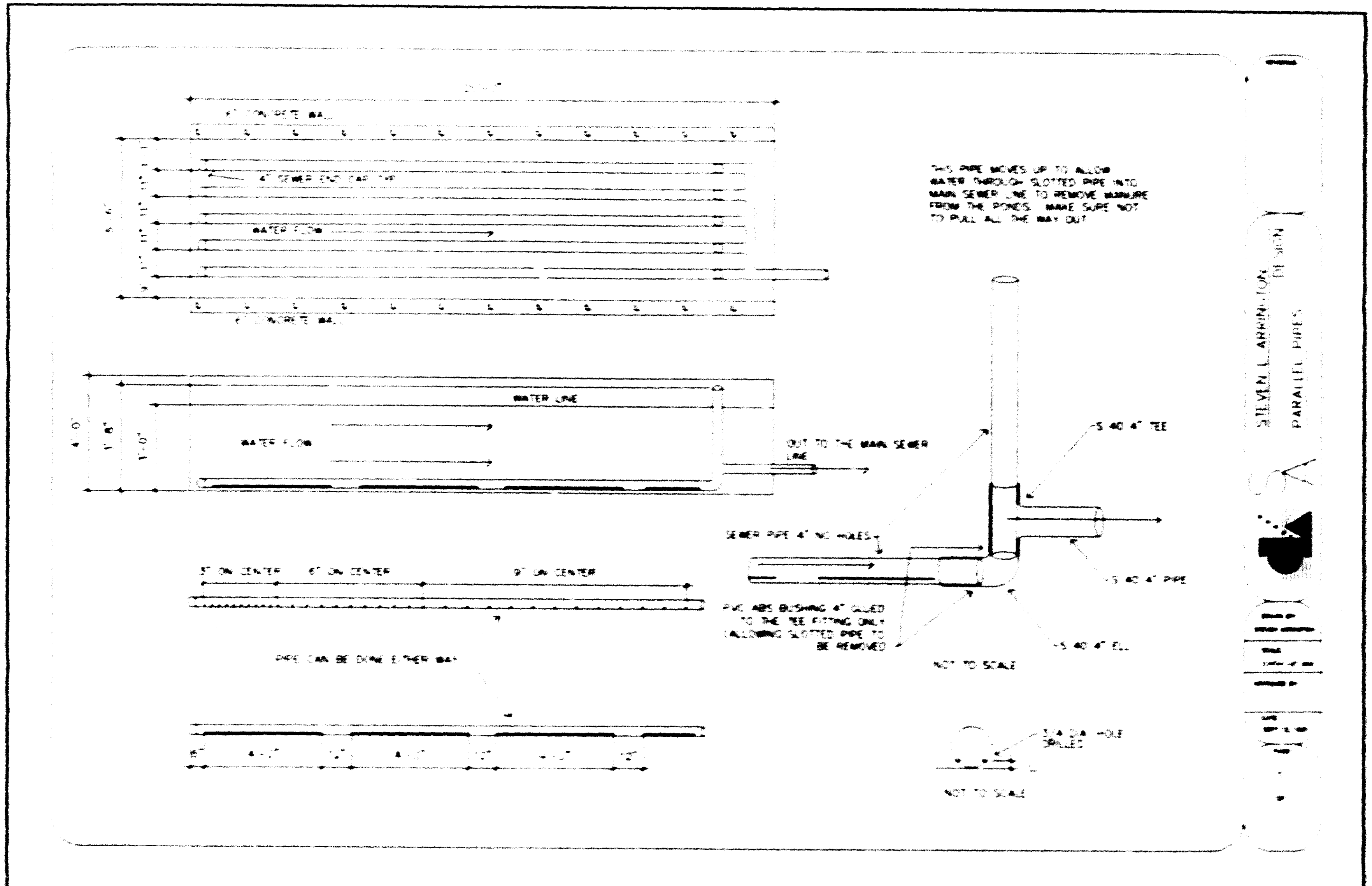

Figure 2. Prototype Design for Solids Removal from Hatchery Raceways using Parallel Pipes to Collect Solids.

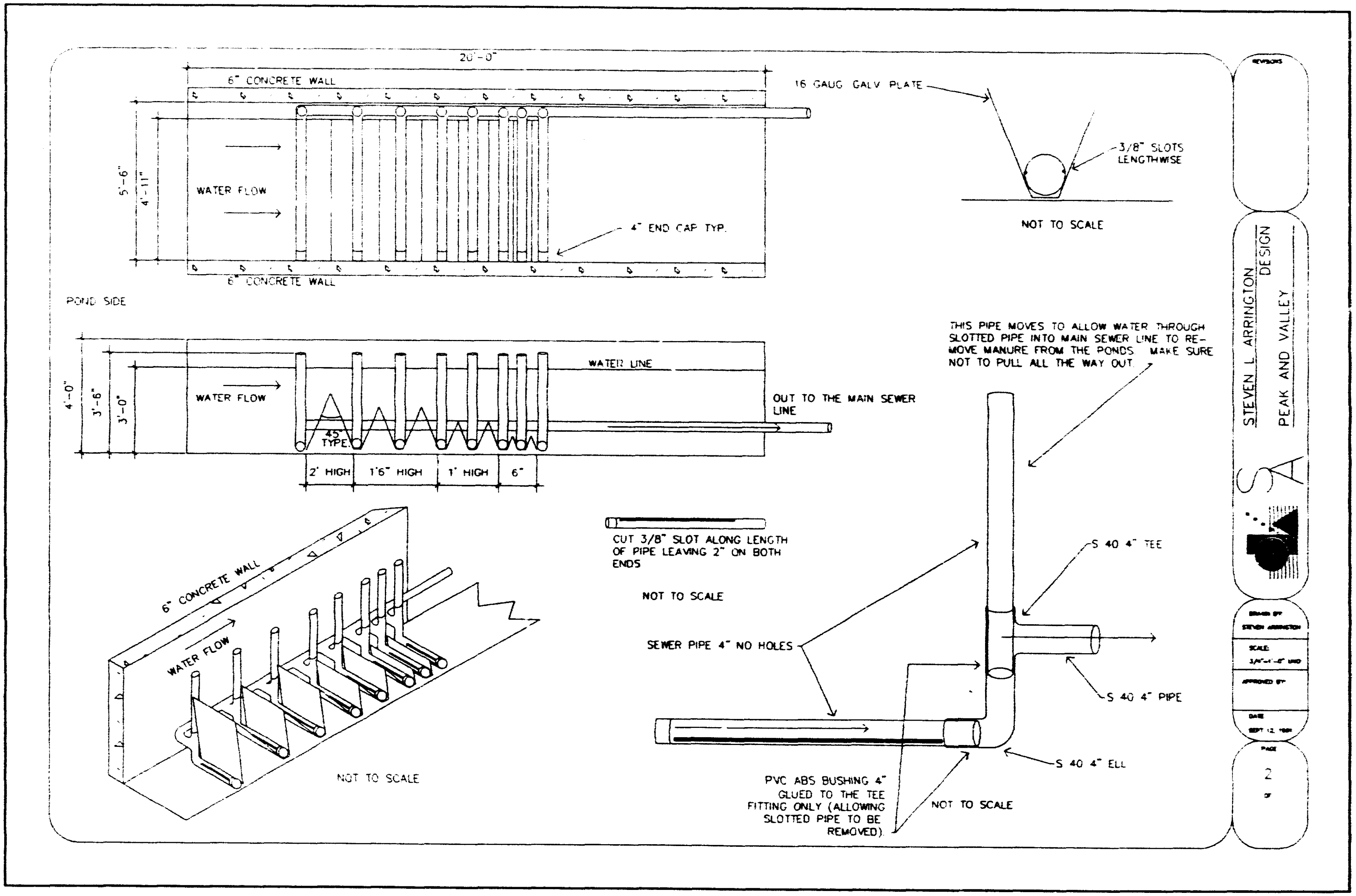

Figure 3. Prototype Design for Solids Removal from Hatchery Raceway using Vertical Deflectors to Slow Water Velocity and Pipes to Collect Solids.

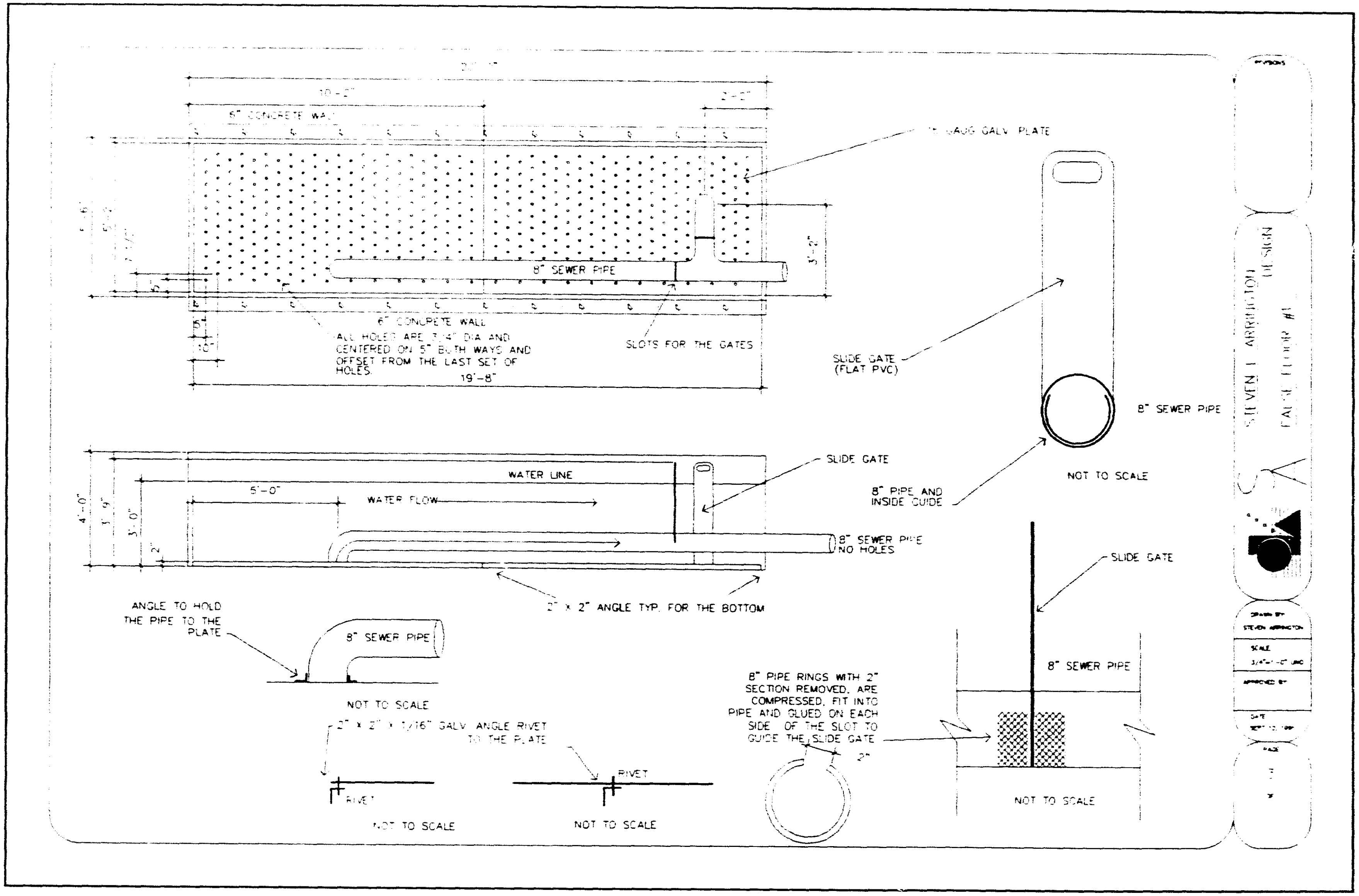

Figure 4. Prototype Design for Solids Removal from Hatchery Raceway using a Perforated False-Floor to Collect Solids.

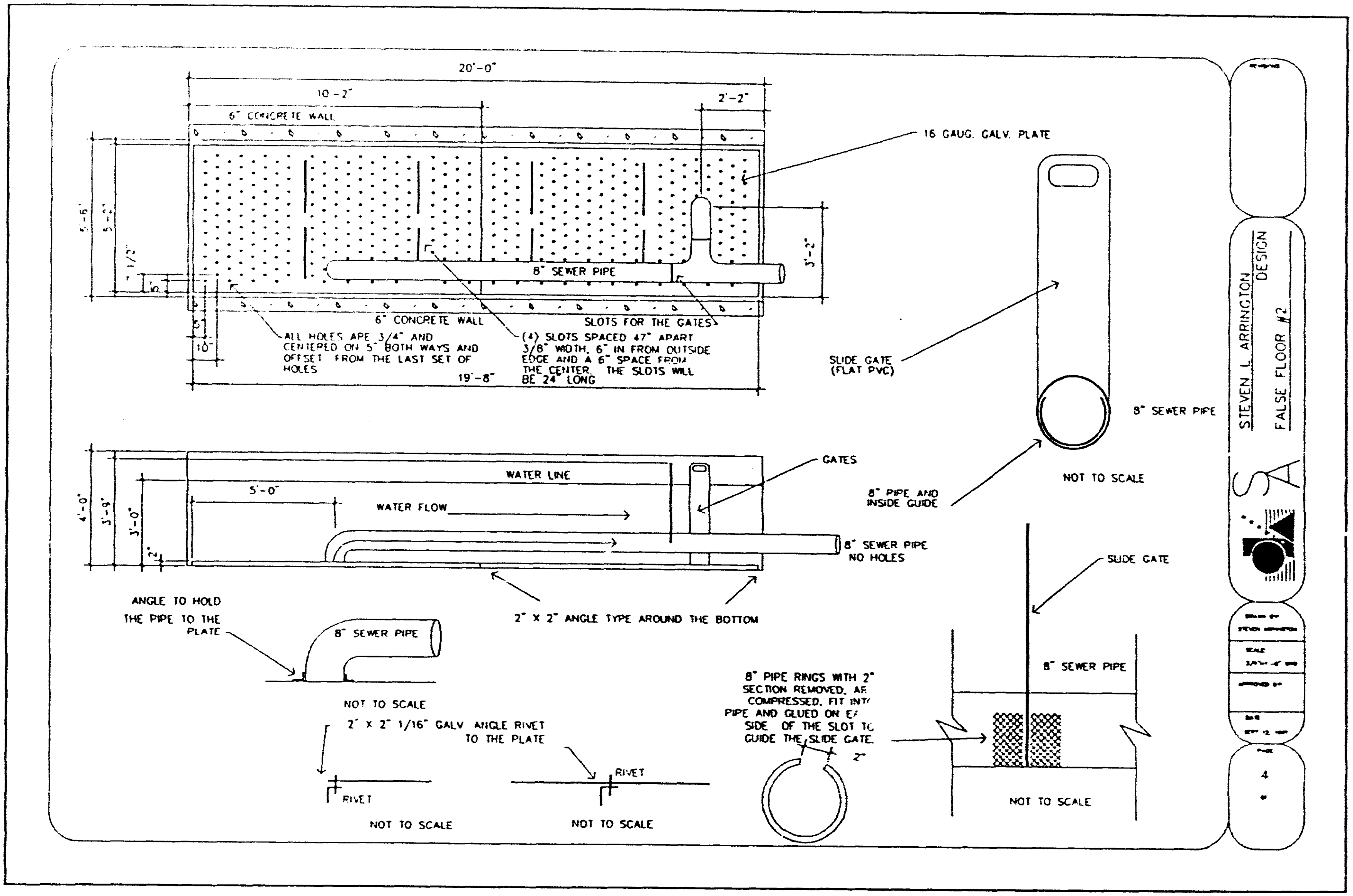

Figure 5. Prototype Design for Solids Removal from Hatchery Raceway using a Perforated and Slotted False-Floor to Collect Solids.

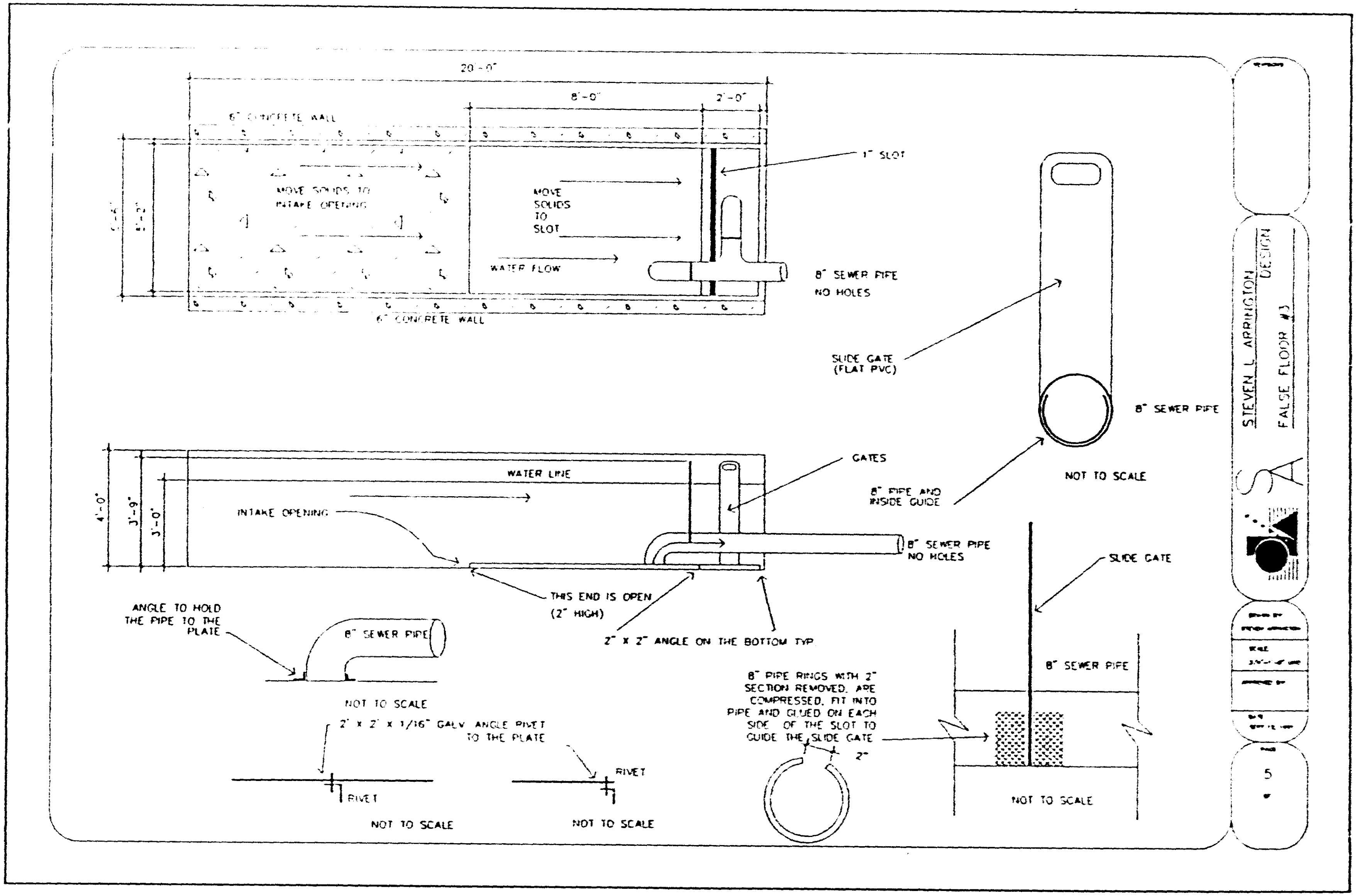

Figure 6. Prototype Design for Solids Removal from Hatchery Raceway using a Half-Length, Rear-Slotted False-Floor to Collect Solids.

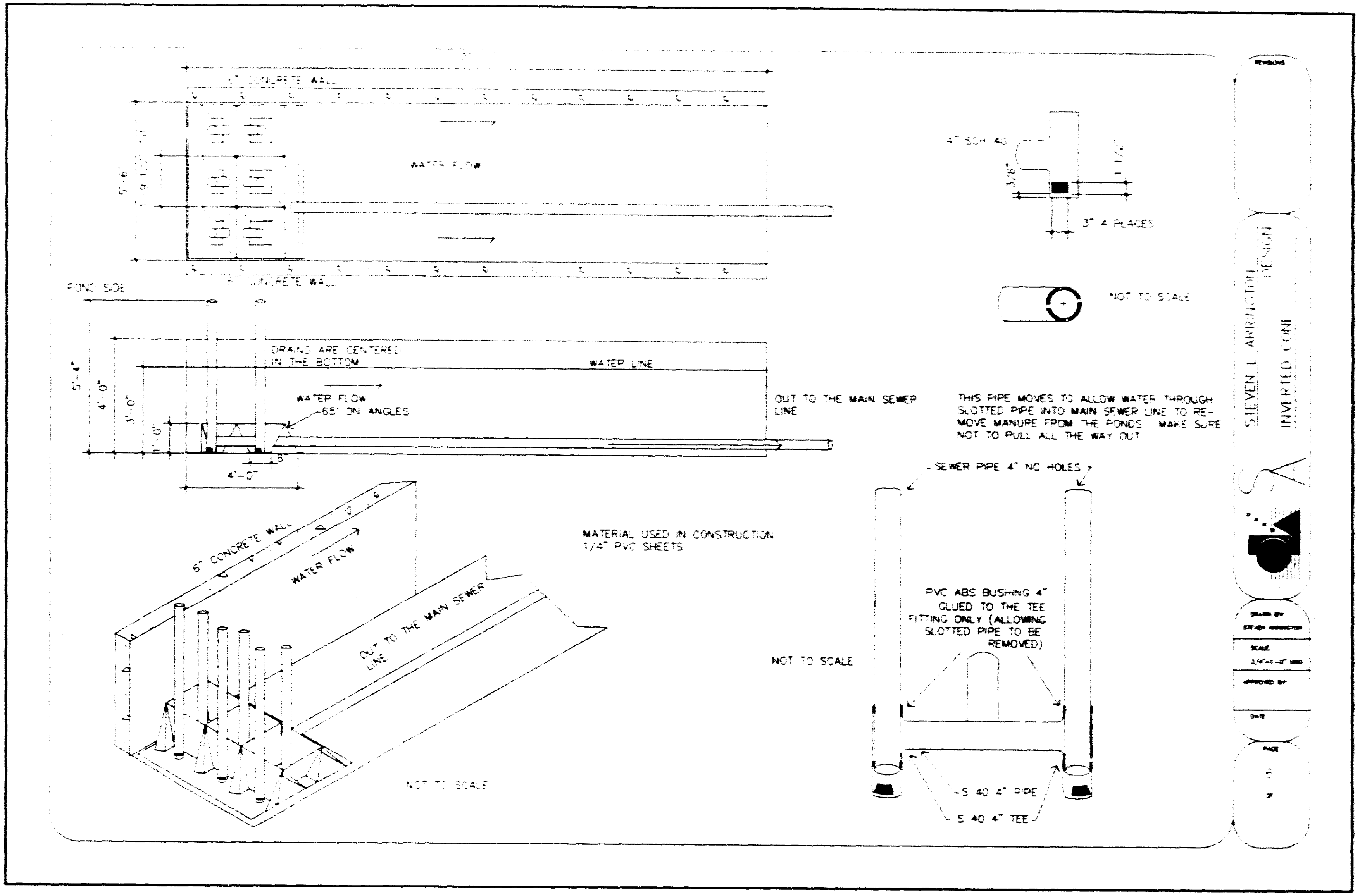

Figure 7. Prototype Design for Solids Removal from Hatchery Raceway using Inverted Cones to Slow Water Velocity and Pipes to Collect Solids.

Assessing Cumulative Impact on Fish and Wildlife in the Salmon River Basin, Idaho

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ABSTRACT

The National Environmental Policy Act of 1969 (NEPA) alluded to cumulative impacts, although no formal definition was recognized until 1978 when the Council on Environmental Quality (CEQ) addressed the issue. Subsequently, several legislative acts, federal and state regulations, and court rulings required that cumulative impacts studies be included in environmental impact assessments. Attempts to include cumulative impacts in environmental impact assessments, however, did not begin until the early 1980s. One such effort began when the Federal Energy Regulatory Commission (FERC) received over 1200 applications for hydroelectric projects in the Pacific Northwest. Federal and state agencies, Indian tribes, and environmental groups became concerned that numerous small developments could have potentially significant cumulative impacts on fish and wildlife resources. In response to this concern, FERC developed the Cluster Impact Assessment Procedure (CIAP) which consists of (1) public scoping meetings; (2) interactive workshops designed to identify projects with potential for cumulative effects, resources of concern, and available data; and (3) preparation of a NEPA document (EA or EIS). The procedure was modified to assess the cumulative impacts of 15 hydroelectric projects in the Salmon River Basin, ID. The methodology achieved its primary objective of evaluating the impact of multiple hydroelectric developments on fish and wildlife resources.

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However, the paucity and low quality of data limited the analysis. In addition, the use of evaluative techniques to express and analyze impacts and interactions among proposed projects hindered acceptance of the conclusions. Notwithstanding these problems, the cumulative impact study provided a basis for decision makers to incorporate the potential impact of multiple projects into the hydropower licensing process.

INTRODUCTION

The traditional approach to environmental impact assessment has been to identify the effect of a single development project on individual resources of public interest. Little effort has been made to evaluate the impact of multiple projects on multiple resources. The term *cumulative impact assessment* is often used to refer to a holistic approach to environmental analysis and planning. The National Environmental Policy Act (NEPA) indirectly addressed cumulative impact by referring to interrelations of all components of the natural environment. The Council on Enviornmental Quality (CEQ) defined cumulative impact as the incremental impact of multiple current and future actions with individually minor but collectively significant effects (40 CFR Pts. 1508.7 and 1508.8). Cumulative impact can be concisely defined as the total effect of multiple land uses and developments, including their interrelationships, on the environment. This definition, and current usage of the term, implies that the total effect of several separate projects may be different from the simple sum of single-project impacts.

Cumulative impacts have been recognized in several federal legislative acts (e.g., NEPA Northwest Power Act, Endangered Species Act, and the Federal Water Pollution Control Act), federal regulations (such as those by CEQ referred to above), and court rulings (Horak et al. 1983). The scientific community has widely accepted the influence of an interacting set of factors on the well-being of a species ever since Hutchinson (1957) introduced the multidimensional niche concept. The biological basis for considering multiple factors and their interactions has been recently reviewed (Vernberg 1978; Livingston 1979; Coats and Miller 1981; Sheehan 1984; Reed et al. 1984); and reviews of impact assessment practices (Rosenburg et al. 1981; Beanlands and Duinker 1984; Orians 1986) have specifically identified the lack of cumulative effect considerations as a significant shortcoming. Despite legal and scientific recognition of the need for cumulative impact analysis, there is little indication that progress had occurred before 1985 (Vlachos 1985), one reason being the absence of suitable assessment methods (Contant and Ortolano 1985; Paquet and Witmer 1985). Reviews of existing methods that could be used indicate that none effectively addresses multiple projects, multiple resources, and impact interactions (Horak et al. 1983; Vlachos 1985). A few studies (e.g., Cada and McLean 1985; Leathe et al. 1985) addressed the impacts of multiple projects, but only aggregated or summed these impacts without explicitly considering the environmental impact associated with interactions among the projects.

Consequently, this area of environmental analysis is only beginning to develop conceptually and in practice.

In the early 1980s, increasing electricity rates and demand, as well as incentives in the Public Utilities Regulatory Policy Act, resulted in well over a thousand applications for small-scale hydroelectric developments being filed with FERC (FERC 1984). The public and several federal and state agencies voiced concern that the combined effect of numerous small-scale hydroelectric developments could severely impact valuable fish and wildlife resources. The concern was not so much for the impact from many single projects as it was for the potential combined effects (i.e., cumulative impacts) of several projects potentially affecting an important fish or wildlife population. In response to these concerns, the Federal Energy Regulatory Commission (FERC) proposed the Cluster Impact Assessment Procedure (CIAP) (FERC 1985a). This procedure included many aspects of an earlier FERC cumulative impact study conducted in the San Joaquin River Valley (FERC 1985b). The CIAP was primarily a schedule of interactive workshops intended to determine the number of proposed projects, to identify target fish and wildlife resources for analysis, to define important components of the target resources, and to determine sources and availability of data.

Initial applications of the CIAP were conducted in three western river basins: the Owens (California), the Snohomish (Washington), and the Salmon (Idaho). The Owens CIAP application was conducted essentially as proposed by FERC (FERC 1985b). The Salmon and Snohomish CIAP applications varied considerably from the FERC-defined procedure, although a series of workshops were retained. Based on the responses of the public and government agencies to the FERC request for comments (FERC 1985a) on the CIAP methodology and on input at scoping meetings and workshops, the original CIAP methodology was supplemented (Witmer et al. 1987) with a structured multiple analysis method (Bain et al. 1986, 1989).

This paper describes an application of a structured multiproject assessment method in the context of the CIAP to evaluate the cumulative impact of 15 small-scale hydroelectric projects in the Salmon River Basin of Idaho (FERC 1987). The Salmon River is part of the Columbia River system, the major river basin in the Pacific Northwest. The headwaters of the Salmon River provide important spawning and rearing habitat for salmon and steelhead trout. The areas surrounding these headwaters provides habitat for large mammals such as elk, mule deer, and the gray wolf, a threatened and endangered species. Although this assessment study involved several aquatic and terrestrial target resources analyses, details for chinook salmon will be used as an example.

PROCEDURE

The CIAP process, as proposed by FERC (FERC 1985a), includes four steps: (1) geographic scoping, (2) resource scoping, (3) multiple-project assessment, and

(4) documentation. The purpose of geographic scoping is to identify target resources (e.g., fish and wildlife species, special habitats) that could be affected in a cumulative manner and the proposed projects that could have a cumulative impact on target resources. The resource scoping step finalizes the list of target resources and identifies components of the target resources for analysis. Target resource components are distinct attributes considered to be directly related to the well-being or quality of the target resource (e.g., spawning habitat for chinook salmon, calving areas for elk and mule deer, or the impact to prey animals for the gray wolf). The multiple-project assessment step is the part of the CIAP added by Argonne National Laboratory (ANL) staff[1] and includes (1) assigning impact values to each resource component, (2) assessing impact interaction among projects, (3) integrating impacts for configurations of proposed projects using matrix calculations, and (4) determining criteria for selecting configurations for detailed evaluation.

Geographic Scoping

The geographic scoping meeting lasted 1 week and involved approximately 50 scientists from the U.S Bureau of Land Management, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, U.S. Geological Survey, U.S. Forest Service, National Marine Fisheries Service, Idaho Department of Fish and Game, Idaho State Historical Society, Columbia River Inter-Tribal Fish Commission, Northwest Power Planning Commission, several tribal representatives, businesses, organizations, and individuals. Discussions focused on what resources could be cumulatively impacted by two or more proposed projects. The initial target resources considered were chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*), steelhead trout (*O. mykiss*), westslope cutthroat trout (*O. clarki*), elk (*Cervus elaphus*), white-tailed deer (*Odocoilues virginanus*), mule deer (*O. hemionus*), and soils (stability). Fish and wildlife agencies (e.g., Idaho State Department of Fish and Game, U.S. Fish and Wildlife Service) argued for inclusion of rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinus fontinalis*), and bull trout (*S. confluentus*). Other target resources discussed were water quality, visual quality, recreation, land use, and cultural resources. Only white-tailed deer were considered unaffected by the proposed projects in a cumulative manner.

Eighteen proposed projects in the Salmon River Basin were conceivably appropriate for the analysis. However, the meeting group determined that three of the projects did not pose any potential for cumulative adverse impacts to target resources and could be studied independently. The remaining 15 projects, located in the Lower Salmon River, Little Salmon River, and South Fork Salmon River subbasins, were included in the cumulative impact study because of their potential to cause cumulative impacts on the target resources (Figure 1).

[1] Argonne National Laboratory, acting as an extension of the FERC staff, considered an environmental assessment on the proposed hydroelectric projects in the Salmon River Basin, ID.

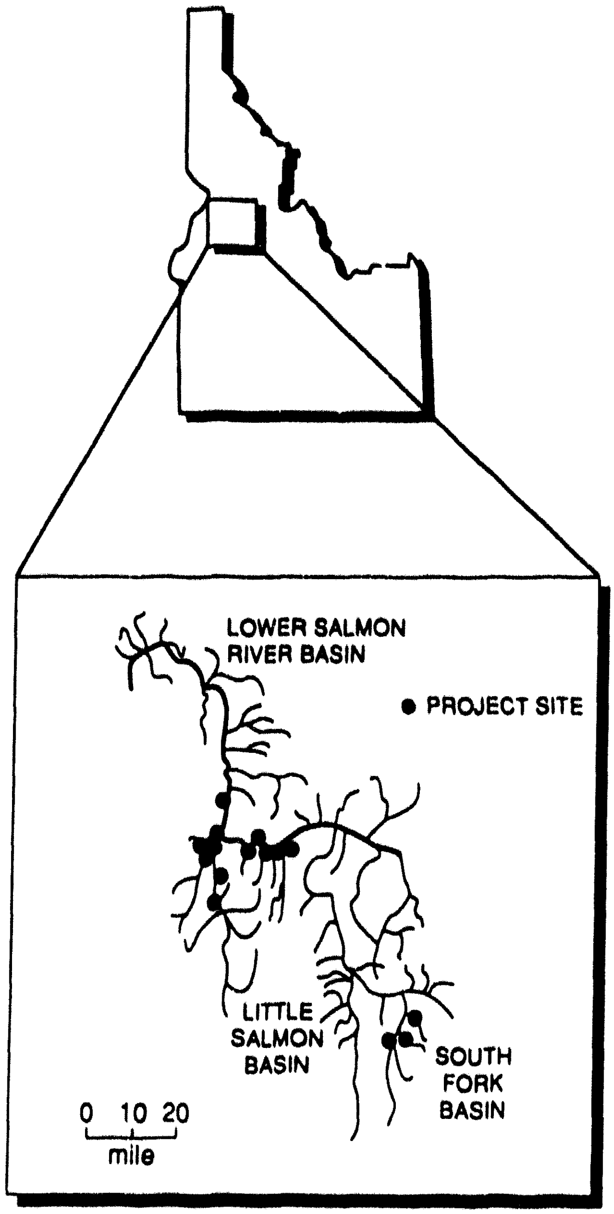

Figure 1. Location of proposed hydroelectric projects in the Salmon River Basin, ID.

Resource Scoping

The resource scoping meeting lasted 3 days and involved approximately 40 scientists representing federal and state agencies, developers, utilities, and conservation groups. Assessment of impacts to important resources requires the identification of resource components that describe the species lifecycle or habitat. Target resources and resource components do not need to include all items to model the environment; however, target resources should be significant elements of the environment that may be affected by project developments. An evaluation of each resource component requires an integrated analysis of several factors that actually describe the physical characteristics of that lifecycle or habitat (e.g., spawning, incubation, rearing). During the resource scoping workshop, a final list of target resources was developed; it included chinook salmon, steelhead trout, resident trout,[2] elk and mule deer, gray wolf (*Canus lupus*),[3] and riparian habitat. Resource components were identified for each target resource, although we will emphasize chinook salmon to illustrate the remaining study steps.

The major activities associated with hydroelectric developments include the placement of facilities in or near streams and the alteration of streamflow characteristics. Impacts to fish (salmon) and aquatic environments were categorized into three major groups: (1) impacts from alteration of streamflow, (2) impacts from interference with migration and movement of salmon within the stream, and (3) impacts from alternation of sedimentation and bedload movement (salmon spawning habitat).

Changes in sedimentation and streamflow were probably the most important impacts associated with the construction and operation of the proposed hydroelectric developments. Many of the proposed projects occur in areas of unstable soil types or where past disturbance has increased the baseline sedimentation in the streams and rivers. Changes in streamflow may affect all life stages of the chinook salmon (spawning, incubation, rearing, and migration). Many other impacts were associated with hydroelectric development (e.g., loss of cover, changes in water temperature, decrease in dissolved oxygen), but it was determined that concentration on the effects of sedimentation and streamflow during the matrix analysis was sufficient to assess significant impacts.

The chinook salmon resource components analyzed further were (1) spawning/incubation habitat, (2) juvenile rearing habitat, (3) adult holding habitat, (4) migration/movement disruption, and (5) sediment/transport. Similar rationale was used to determine resource components for the resident trout, elk and mule deer, gray wolf, and riparian habitat.

Component impact values represent impact magnitudes on a standardized scale. Use of a common scale simplifies the combining of component values into one impact value for a target resource. Without some form of standardization, component values would vary in magnitude, depending on the units involved. Any standardized scale can be used, and in this study, a 0–4 range (no impact to very high impact) was selected. Impact-level criteria for chinook salmon components of spawning/incubation, juvenile rearing, and adult holding habitat are shown in Table 1. Similar criteria were developed for other target resources and components.

Multiple-Project Assessment

The multiple-project assessment step was conducted by ANL staff using resources, components, and impact criteria identified in scoping meetings. For

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[2] Rainbow,cutthroat, and bull trout were grouped together as resident trout for this analysis.

[3] The gray wolf was added as a target resource following the matrix-technical workshop because of new information and its status as an endangered species.

Table 1. Description of Impact Level Criteria for Chinook Salmon Resource Components: Spawning/Incubation, Juvenile Rearing, and Adult Holding Habitat.[a]

Impact Levels[b]	Description of Impact Levels[c]
4 (High)	>25% decrease in weighted usable area (WUA) or if WUA not available, then <30% of the mean annual flow
3 (Moderate)	>15–25% decrease in WUA or if WUA not available, then 30 to <60% (April–September) or 30–<40% (October–March) of the mean annual flow
2 (Low)	>5–15% decrease in WUA or if WUA not available, then 60 to <80% (April–September) and 40–<80% (October–March) of the mean annual flow
1 (Negligible)	>0–5% decrease in WUA or if WUA not available, then 80–100% of the mean annual flow
0 (None)	0% or an increase in WUA or if WUA not available, then 100 or >100% of the mean annual flow

[a] Weighted usable area and mean annual flows generated from the applicants' information were used to assign impact values (0, 1, 2, 3, or 4) for increasing levels of impact.
[b] When using the percentage of the mean annual flow, impacts levels were adjusted downward by 1 unit of impact (e.g., 3 to 2) if only a limited amount of anadromous fish habitat was available and by 2 if there was no or very little anadromous fish habitat present.
[c] Where possible, impact levels were assigned using information from approved instream flow modeling study results. If the study results were not available or not approved, then the percentage of the mean annual flow was used to assign impact levels.

each proposed project and target resource, impact levels were determined. For chinook salmon, and the Riordan Creek Project,[4] impact values were developed as follows assuming full implementation of recommended mitigation. Based on surveys conducted by the applicant, it was concluded that chinook salmon do not use Riordan Creek for spawning or adult holding habitat. Therefore, the spawning/incubation and adult holding components were assigned an impact level of 0 (Table 2). Based on the same surveys, juvenile chinook salmon were observed and captured in the lower part of Riordan Creek. The recommended instream flow would decrease the weighted usable area between 0 and 5% from that of a normal water year. Therefore, an impact level of 1 was assigned to the juvenile rearing habitat component based on analysis of instream flow information. The risk of upstream obstruction, impediment, or loss of juvenile chinook salmon from the powerhouse discharge would be low, assuming full implementation of mitigation. An impassable barrier prevents adult salmon from reaching the diversion dam. Therefore, the migration/movement component was assigned an impact level of 1. Based on analysis of the development plans, soils and geology, and streamflow and water quality, we concluded that the Riordan Creek drainage is relatively undisturbed with a low sedimentation potential and a low to moderate mass-wasting potential. Therefore, an impact level of 2 was assigned to the sediment/transport component. In summary, impact levels were assigned based on existing conditions and expected impacts, with recommended mitigation, then compared

[4] The proposed Riordan Creek Hydroelectric Project (FERC Preliminary License Number 6433) is located on Riordan Creek, a tributary of Johnson Creek in the South Fork of the Salmon River Basin, ID.

Table 2. Summary of Impact Levels for the Chinook Salmon Resource Components for the 15 Proposed Projects with Staff-Recommended Mitigation.

	Impact Levels by Resource Component[a]				
Project[b]	Spawning/ Incubation	Juvenile Rearing	Adult Holding	Migration/ Movement	Sediment/ Transport
Riordan Creek	0	1	0	1	2
Ditch Creek	0	0	0	0	1
Trapper Creek	0	1	0	1	2
Fall Creek	0	0	0	1	3
Lower Squaw Creek	0	0	0	0	1
China Creek	0	0	0	0	0
Upper Squaw Creek	0	0	0	0	3
Grave Creek	1	1	1	2	4
Lower Hat Creek	1	1	1	0	2
Elkhorn Creek	1	1	1	2	3
Partridge Creek	1	1	1	2	3
Lake Creek	1	1	1	2	2
Allison Creek	1	1	1	2	3
Shingle Creek	1	1	1	1	2
French Creek	1	1	1	2	4

[a] Impact levels are 0 = none, 1 = negligible, 2 = low, 3 = moderate, and 4 = high.
[b] Proposed hydroelectric projects in the Salmon River Basin, ID.

with the criteria for each target resource component.

To assess cumulative impacts of multiple projects, we used a model-based methodology that accounts for interactions among project impacts. The model format is matrix oriented and accepts information from any discipline. Matrix algebra is used to compute values representing cumulative impact on each target resource for every project configuration (combination) of the proposed projects. Essentially, a relative cumulative impact score for each configuration is computed. The general formula can be simply stated as

$$\text{Total impact} = \text{sum of project impacts} \pm \text{interaction impacts}$$

This general computation was applied to all possible configurations of the developments under consideration. The interaction impact could cause the total impact to be either greater or less than the project-specific impacts. At this point in the analysis, all configurations are screened separately for each target resource to reduce the number of potential project configuration.

To identify when multiple-project impacts interact, the following question was considered for all project-by-project pairs: Can the level of impact of one project affect the level of impact of another project? If the answer is no, the impact of the projects on the component is strictly additive. If the answer is yes, then there

[c] Interactions that result in impacts beyond the sum of project-specific impacts (i.e., in addition to strictly additive impacts).

Table 3. Interaction Coefficients and Criteria for the Migration/Movement Component of the Chinook Salmon Interaction Matrix.

Interaction Coefficient	Criteria
0.0	No project interaction on migration/movement of target resource
0.1	Project interaction on migration/movement possible but not likely to occur with negligible impact to target resource
0.5	Project interaction on migration/movement likely to occur with low to moderate potential impact to target resource
1.0	Project interaction on migration/movement likely to occur with high or severe potential impact to target resource

is an interaction among project impacts, which can be either *supraadditive*[5] or *infraadditive*.[6] Two interaction coefficients for the model were selected to represent impact interactions between one project and any other in the configuration. For one pair of projects, A and B, one coefficient would represent the effect of A on B and another coefficient the effect of B on A. The interaction is supraadditive if the coefficient is positive and infraadditive if it is negative. An example of interaction coefficient criteria for the chinook salmon is shown in Table 3.

In assessment studies involving many projects, the model calculations become cumbersome. Therefore, project-by-project matrices were completed, and a computer program was developed to execute calculations (details in Bain et al. 1986). The basic matrix computations are illustrated with an example of one target resource, three resource components, and two projects in Figure 2. No weights are used to place emphasis on any resource component so the component matrix and adjusted component matrix are the same (Figure 2). The adjusted component matrix is summed across resources components to derive the weighted sums for each project. An interaction matrix is used to derive an interaction effects matrix, which is then summed across resources components to derive the interaction effects sum. Additive, supraadditive, and infraadditive effects for each project are accounted for by adding the weighted and interaction effects sums. A total cumulative impact score is derived by adding across projects, and this score is used as a relative index of cumulative impact for the two-project configuration. Also, although impact values are summed across target resource components, they are not summed across target resources. This prevents problems with averaging impact scores across target resources.

The utility of the model depends on whether the potentially numerous project configurations can be ranked so that some manageable subset can be considered further. Ranking would be simple if only one target resource was involved. With multiple target resources, no single ranking of configurations can be obtained. A total of 35,767 project configurations was possible with the 15 proposed hydroelectric projects in the Salmon River Basin. The ANL staff developed

[6] Interactions that result in impacts that are less than the sum of project-specific impacts (i.e., causing the total impact to be less than strictly additive).

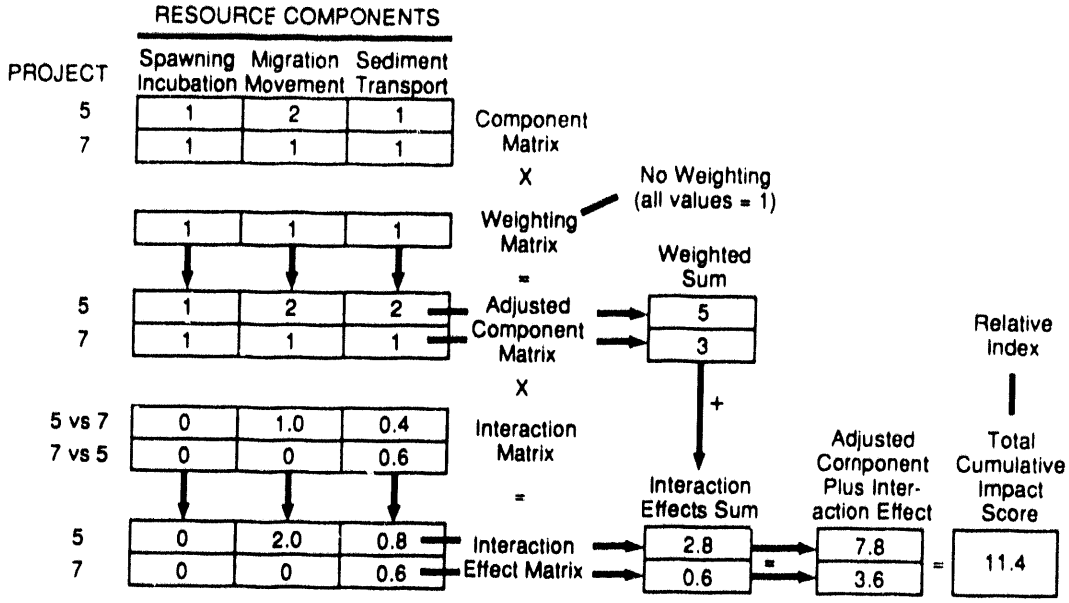

Figure 2. Example of cumulative impact computations for a target resource with three resource components and two projects.

cumulative impact scores for all these configurations for all target resources using the computerized model. Screening this large set of configurations by multiple criteria reduced it to a manageable subset.

Screening criteria were developed for all target resources and are illustrated here for chinook salmon. Each project configuration was compared with screening criteria and placed into one of three management scenarios. The configuration with the largest number of projects meeting all the criteria for a particular scenario was selected for discussion of impacts.

Scenario A, the resource agency management scenario, is a development strategy resulting in no or negligible impact to chinook salmon in the basin. Management policies of the Idaho Department of Fish and Game, National Marine Fisheries Services, and U.S. Fish and Wildlife Service are directed at permitting no or negligible impacts to salmon populations and habitats in the basin. The strictest application of this strategy would allow no projects to be developed if they affected anadromous fish populations or habitats. In practice, consultation and negotiations on project design and location, minimum flows, and other mitigative measures between project proponents and resource agencies have lead to the development of projects that would have negligible impacts to chinook salmon. That is, the projects would not have a significant impact on chinook populations or habitats.

For Scenario A, the following criteria were used to screen all project configurations: (1) a single resource component could not exceed an impact level of 1 (negligible level of impact), and (2) the cumulative impact score could not exceed five times the number of projects in the configuration. Therefore, project configurations with individual impact levels exceeding 1 or with cumulative impact scores greater than five times the number of projects in the configuration [e.g., greater than 75 (15 projects × 5 components = 75 relative impact score)] would be excluded from Scenario A.

As proposed, none of the projects met the above criteria. Implementation of recommended mitigative measures would reduce impacts for all proposed projects and result in three projects meeting the none or negligible impact criterion. The other 12 projects exceeded the first criteria (impact level greater than 1) in one or more resource components and were eliminated from further discussion under Scenario A.

Thus, for the chinook salmon target resource, Scenario A includes seven project configurations: three configurations involving one different project each (three one-way configurations), three configurations involving different combinations of two projects each (three two-way configurations), and one configuration involving three projects (one three-way configuration). The three-way configuration was the largest combination of projects meeting the criteria for Scenario A and, therefore, was used to represent the scenario.

Scenario B, the biological threshold management scenario, represents a strategy resulting in an insignificant biological impact. For Scenario B, the following criteria were used to screen all project configurations: (1) a single resource component could not exceed an impact level of 2 (low level of impact), and (2) the cumulative impact score could not exceed ten times that number of projects in the configuration. Seven projects exceeded the first criteria (impact level greater than 2) in one or more of the resource components and were eliminated from further discussion under Scenario B. The remaining eight projects met the low-impact criterion. Scenario B includes 248 configurations (8 one-way, 28 two-way, 56 three-way, 70 four-way, 56 five-way, 28 six-way, 8 seven-way, and 1 eight-way) and is represented by the eight-way project configuration.

Scenario C, the unrestricted development scenario, is a development strategy that would not restrict the amount of cumulative impact that occurs to chinook salmon. This strategy includes all 15 proposed projects.

Each target resource was evaluated similarly using these same development scenarios. Screening by microcomputer allowed trials with all target resource criteria set at different levels. Iterations of the screening process with successively more selective criteria helped to fine-tune the subset of configurations.

Documentation Phase

A detailed description and concise summary of the impacts associated with any recommended configuration are important, since relative ratings and indexes are used in much of the analysis and evaluation work. Those reviewing or using the study recommendations need a clear disclosure of the anticipated environmental impacts in terms familiar to them. Although text descriptions can be used to elaborate details, a summary (preferable a one-page table of major points) is needed to convey the magnitude of the impacts and their probability of occurrence for each target resource.

Table 4. Largest Project Configuration Under Each Development Management Scenario.[a]

	Scenario		
	A	B	C
Target resource	Resource agency management	Biological threshold management	Unrestricted management
Chinook salmon	B,E,F[b]	A,B,C,E,F,I,L,N	All projects
Steelhead trout	B,E	A,B,C,E,I,L,N	All projects
Resident trout	B,E	A,B,C,E,I,L,N	All projects
Elk/mule deer	All projects	All projects	All projects
Gray wolf	All projects	All projects	All projects
Riparian habitat	All projects	All projects	All projects

[a] The entries in this table represent the largest combination of proposed projects that could be developed (with implementation of staff-recommended mitigation) under each of the three developments scenarios (A, B, C) for each target resource.
[b] Project codes: A = Riordan Creek, B = Ditch Creek, C = Trapper Creek, D = Fall Creek, E = Lower Squaw Creek, F = China Creek, G = Upper Squaw Creek, H = Grave Creek, I = Lower Hat Creek, J = Elkhorn Creek, K = Partridge Creek, L = Lake Creek, M = Allison Creek, N = Shingle Creek, and O = French Creek.

In the Salmon River Basin analysis, none of the projects proposed by the applicants would result in insignificant impacts across all target resources (Table 4). Consequently, each project as proposed had a potential to contribute to the cumulative impacts occurring to one or more of the target resources. With appropriate mitigation, however, seven of the proposed projects would not individually cause significant impacts to any of the target resources. Additionally, if the recommended mitigation (e.g., staggering construction of certain sets of configurations, erosion control plans) would be implemented, there would be no significant interactions between projects. The remaining eight projects would cause significant cumulative impacts to several target resources even with recommended mitigation.

Using the three management scenarios, we evaluated the combined impact of various combinations of the 15 proposed projects to determine what levels of cumulative impacts would occur. A two-project configuration met the Scenario A criteria across all target resources (Table 4). These two projects, with recommended mitigation, would have a negligible level of impact to any target resource. This conclusion was reached because for each target resource, the number of individual animals and the amount of habitat affected (both in absolute terms and relative to the total present in the basin) would be negligible. No critical areas would be affected, and impacts to any specific resource component would be negligible. Because the scenario included two widely separated projects, no or negligible interaction would occur.

A seven-project configuration met the Scenario B criteria across all target resources (Table 4). These seven projects, with recommended mitigation, would have a low level of impact to any target resource. The number of animals and habitat affected would be low, not exceeding any biological threshold. No critical areas would be affected, and impacts to any specific resource component would be low. However, Scenario B does include groups of projects that would have a high potential for interaction (mainly from sedimentation). Staggering the construction of projects with moderate or high interaction potential would reduce cumulative impact from interaction to low levels.

We concluded that under Scenario C, the cumulative impacts to all target resources except elk, mule deer, and riparian habitat would be significant. We reached this conclusion because moderate or moderate to high levels of impact would occur to several resource components for each target resource and because of the high potential for interaction (mainly from sedimentation) among many of the proposed projects. Populations and habitats of chinook salmon would be significantly reduced beyond reductions that were already occurring in the basin.

We concluded, that with proper mitigation, including that of staggering project construction, impacts would be low for those projects meeting the requirements of Scenario B (Table 4). However, based on economic analyses that were not part of the environmental study, four projects did not have a positive net economic benefit. Therefore, we recommended the configuration of three projects meeting biological threshold management Scenario B criteria and having a positive net economic benefit (Table 4).

DISCUSSION

The success of any impact assessment methodology is largely determined by the extent to which assumptions and simplifications can be defended. From its onset, the CIAP met with broad-based resistance from developers, environmental groups, and federal and state agencies. Many practical and procedural questions were raised concerning the CIAP and the multiple-project analysis model we used. How would preliminary permits be incorporated into the process? How could the analysis be conducted with inadequate information? Would the averaging of impact values mask the true impacts across projects or target resources? What does the cumulative impact score mean? Despite these kinds of questions, FERC directed its "staff to proceed with the CIAP as it has been specified ... making such modifications to the CIAP as are appropriate ... ."[7] Modification of the CIAP, while addressing many of the above issues, never did fully allay the concerns of the developers, environmental groups, or agencies. Although a great deal of time and effort was spent attempting to eliminate perceived problems, little debate actually focused on basic assumptions and appropriate simplifications.

One of the major strengths of the CIAP was the workshops and meetings scheduled early in the process. Designed to be interactive, the workshops and meetings solicited comments and suggestions from developers, environmental groups, and state and federal agencies. These meetings were designed to collect

[7] Memorandum to the commission from the Office of General Counsel, Federal Energy Regulatory Commission, April 18, 1985.

baseline information, to scrutinize method assumptions, and to determine the structure and scope of the analysis. The identification of project clusters, target resources, resource components, and impact criteria was used to scope the analysis. While the workshops and meetings succeeded for some of these purposes, it failed at others. The workshops and meetings provided an opportunity for political statements and agency posturing. An exchange of biological information was replaced by position statements by developers, environmental groups, and federal and state agencies. A *court hearing* type of atmosphere contributed to this largely unproductive exchange. In the end, the workshops and meetings were used to state positions and criticisms. They were not conducive to a genuine debate and defense of the CIAP method.

Although not a weakness of the methodology, inadequate information hindered the acceptance of the CIAP's conclusions. The methodology was capable of handling both qualitative and quantitative information. With the use of evaluative techniques, impact values (ranging from 0 to 4) were assigned to a wide range of information. This dimensionless scale circumvents the problem of limited quantitative data and poorly understood resource-impact relationships. When an evaluative approach is used, the development of appropriate impact criteria is key to the success of the methodology. The impact assessment team was challenged, and sometimes divided, by the task of criteria development, but the involved agencies and organizations devoted relatively little attention to this difficult technical step.

An important component of our analysis that was never widely appreciated was the multiproject assessment model. The model was just another step in the analysis, a tool, used to derive the cumulative impact score. In this case, the cumulative impact score was used to develop a *relative* ranking of the many different project configurations. Workshop participants never fully scrutinized the role of the impact criteria, matrix analysis (impact scores), and project screening (cumulative impact scores). Instead they developed suspicions about the assessment method solely from the model inputs and final results.

Another difficult task was assigning of nonadditive interactions (i.e., supraadditive and infraadditive). Little is known of the actual interactions among environmental factors and resources. Without good information, a qualitative system of incorporating interaction was used. Although this simplification still accounted for project interactions, it may have been unacceptably simplified and therefore may not parallel actual resource responses. Basic research is needed on how biological resource populations are affected by numerous, spatially dispersed changes in their environment. Until biological responses are even superficially known on a landscape level, analysis methods like the one we used will not have a firm biological basis.

The documentation phase was the final and most visible part of the process. This phase evaluated the environmental impacts of select configurations of projects identified using impact levels and project screening. This was accomplished using actual biological information, not impact levels. This phase was the key to linking the impact levels to the actual potential project impacts. The impact levels, criteria, and interaction coefficients merely provided the assessment team with a small, manageable subset of potential project configurations to describe in full detail. Probably the greatest achievement of this study was our ability to shift discussion and analyses from individual projects to specific configurations of projects (i.e., numerous single impacts to complex scenarios with a cumulative impact). By considering configurations of proposed projects, we were able to make one of the first comprehensive attempts at addressing the cumulative impact issue.

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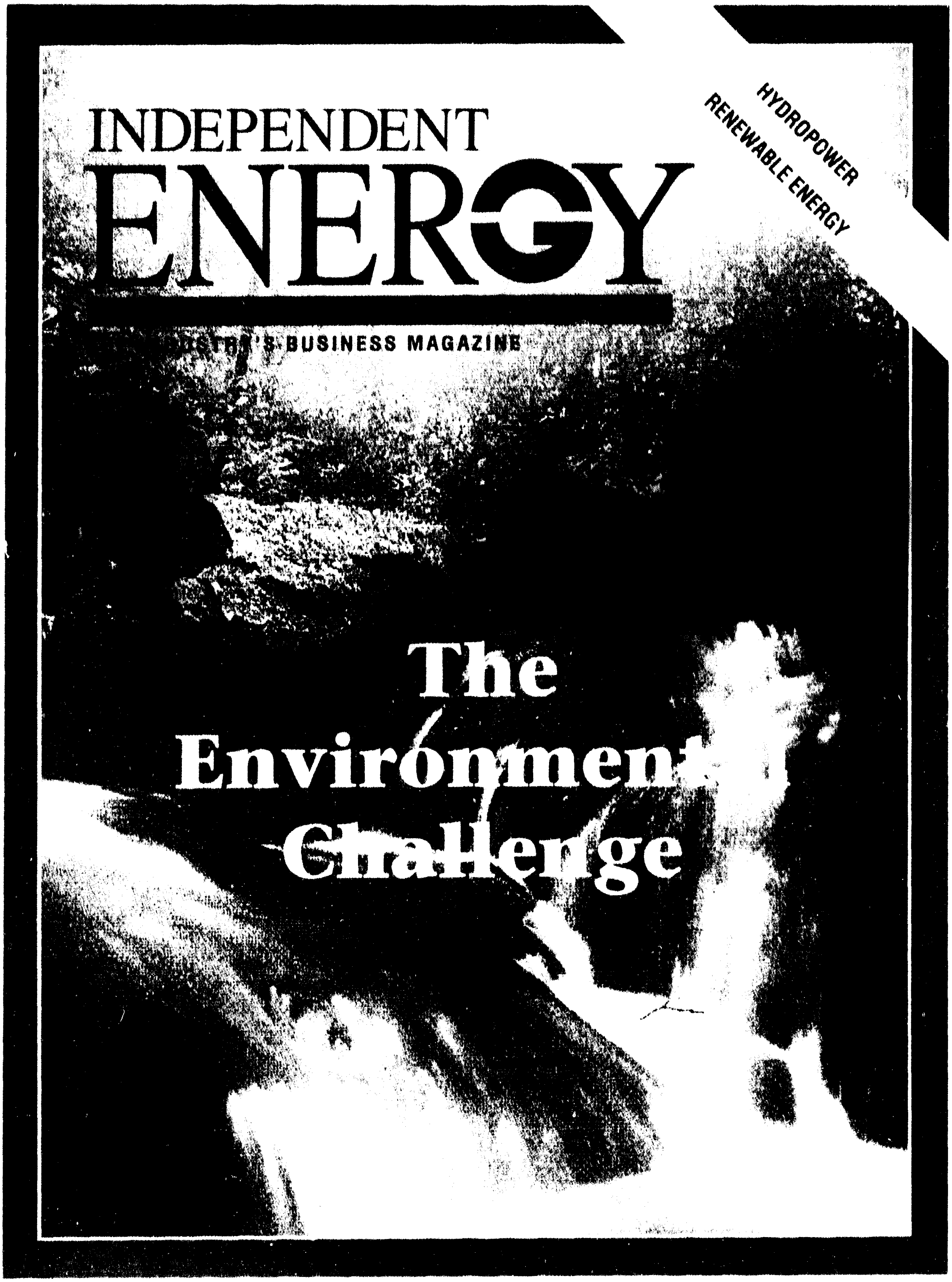
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Fisheries Out Of Balance

Regulators are passing more and more fish mitigation costs on to hydropower projects. For some smaller projects, these costs are far out of proportion with the revenues from power sales.

By Richard Hunt and Judith Mohsberg

INDEPENDENT ENERGY

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Last year only four wild northwestern sockeye salmon made it to their spawning ground via the Columbia and Snake Rivers, and the National Marine Fisheries Service subsequently declared the species endangered. (See "Sacrificing for Salmon," Washington Post, Jan. 14, 1992). Similar protection may soon be extended to certain Snake River Chinook salmon. An effort that supersedes all other interests will now be made to save the wild salmon runs of the Columbia River and Snake River regions.

Improving salmon survival will require a mixture of habitat improvement, reduction in the number of salmon allowed to be caught, and mechanical improvements to the large federal hydroelectric dams that have interrupted the downstream journey of some salmon from their spawning grounds in Idaho to the Pacific ocean. Some advocates propose severe yearly drawdowns of the lower Snake reservoirs to reduce the water level behind the dams and speed the movement of the fish downstream. The proposed drawdowns would last from four weeks to six months and would significantly affect commercial, agricultural and transportation interests along the river.

Salmon Recovery

Over the 60-year existence of the Columbia River dams, hundreds of millions of dollars have been spent on hatcheries, fish screens and elaborate schemes to transport migrating fish around the dams. However, these efforts have not reversed the decline of the salmon population that must travel around eight federal dams on the Columbia.

The Northwest Power Planning Council has developed a comprehensive Salmon recovery plan that it hopes will be the basis of any recovery approach ordered by the National Marine Fisheries Service. The plan balances competing interests by offering "a more modest drawdown strategy to be in place by 1995 with an escape valve if it proves structurally or economically infeasible."

Fisheries issues have long been accorded serious consideration in hydropower development. But the framers of the original Federal Power Act (FPA) and its amendments in the Electric Consumers Protection Act of 1986 (ECPA) always envisioned balancing all resources, including power resources, in the ultimate setting of conditions. A careful look at fisheries articles in relicenses issued from 1982 through 1990 as compared to the interest in these same issues for relicenses in process today indicates a rapidly growing imbalance between fishery and other resource issues.

Fisheries issues have assumed an importance and cost far out of proportion to the effects of the project when applied to small hydropower. Encouraged by bureaucratic overinterpretation, state and federal fisheries agencies are flexing their muscles. First, the FERC must provide written justification in order to reject a license condition recommended by fisheries agencies. Section 10(j) (1) of the Federal Power Act requires that each license include conditions "to adequately and equitably protect, mitigate damages to, and enhance, fish and wildlife (including related spawning grounds and habitat) affected by the development, operation, and management of the project ..." Section 10(j) (2) provides that the FERC should attempt to resolve with the agencies any recommendation that it believes to be inconsistent with applicable law. However, in order to exercise this authority, the FERC must "publish each of the following findings (together with a statement of the basis for each of the findings):

(A) A finding that adoption of such recommendation is inconsistent with the purposes and requirements of ... applicable provisions of law ...

(B) A finding that the conditions selected by the Commission comply with the requirements of [section 10(j) (1)]."

This statutory requirement introduces a clear bias in favor of recommendations from state and federal fish and wildlife agencies into the licensing process.

Second, hydropower licensees pay all costs incurred by the FERC, and license applicants pay for resource agency time to review their applications. Under section 30(e) of the FPA, the FERC "shall establish fees which shall be paid by an applicant for a license or exemption for a project that is required to meet terms and conditions set by fish and wildlife agencies. ... Such fees shall be adequate to reimburse the fish and wildlife agencies ... for any reasonable costs incurred in connection with any studies or other reviews carried out by such agencies for purposes of compliance with this section." Thus, state and federal fish and wildlife agencies reviewing hydroelectric development applications have no fiscal stake in the length of the process and no incentive to shorten the process or make it more efficient.

In the Department of the Interior Appropriations Bill, 1992, for the U.S. Fish and Wildlife Service, there is evidence of shifting costs onto hydroelectric applicants. The Committee on Appropriations recommended "a reduction of $450,000 from funds requested to review hydroelectric relicensing applications ... [and] the funding allowed for license reviews has been retained at the fiscal year 1991 level." However, the overall budget of the U.S. Fish and Wildlife Service increased 11 percent over its fiscal year 1991 allocation. The report language also encouraged the Service to "expend greater effort on preapplication consultations." This indicates that the U.S. Fish and Wildlife Service is better funded to oppose hydropower development in fiscal year 1992 than it was in fiscal year 1991.

The media also has contributed to the problem by creating the impression that all hydropower projects are extremely large. Recent articles in the Washington Post have featured: the sockeye salmon, endangered by the large dams in the Columbia River system; the Indian uprising over the encroachment of Hydro Quebec's expansion plans on their reservation; and the proposed uprooting of more than 1 million people to build the Three Gorges Hydro Project in China. The negative news coverage accorded only to these huge, government-owned or operated hydroelectric plants is eliminating reasoned and objective discussion of small hydropower projects.

In fact, the average size of the FERC-licensed projects placed in service in the 1980s was 3 MW, as compared to the 19 MW average for all FERC-licensed projects. Small increases in capacity at these small hydropower projects at relicensing should offer an environmentally acceptable way to increase the energy resources of the United States. But small projects being relicensed are experiencing losses in capacity rather than gains.

A Growing Burden

The result of the imbalance in favor of fish and wildlife agencies is a dramatically growing burden on small hydropower plant operators to comply with virtually all terms and conditions fisheries agencies can devise. This is true regardless of the size or location of the plant and

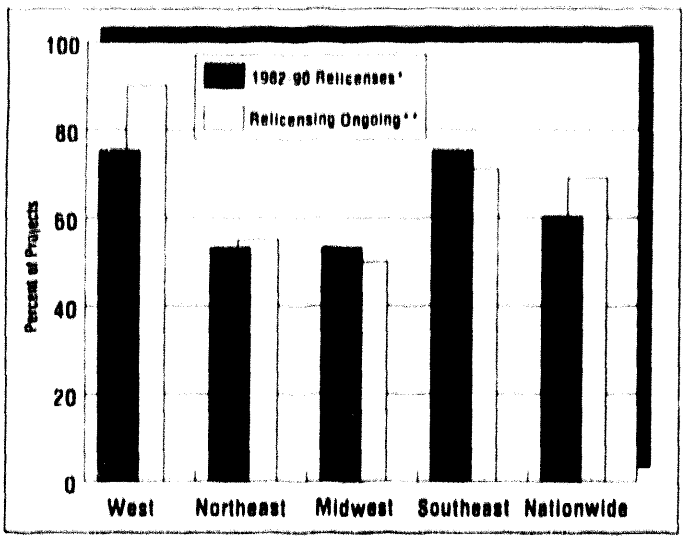

Figure 1: Percentage of relicenses with instream flow requirements (1982-1990) versus percentages of relicenses in progress with instream flow study requirements. (* 50 Relicenses. ** 46 Relicenses in progress.)

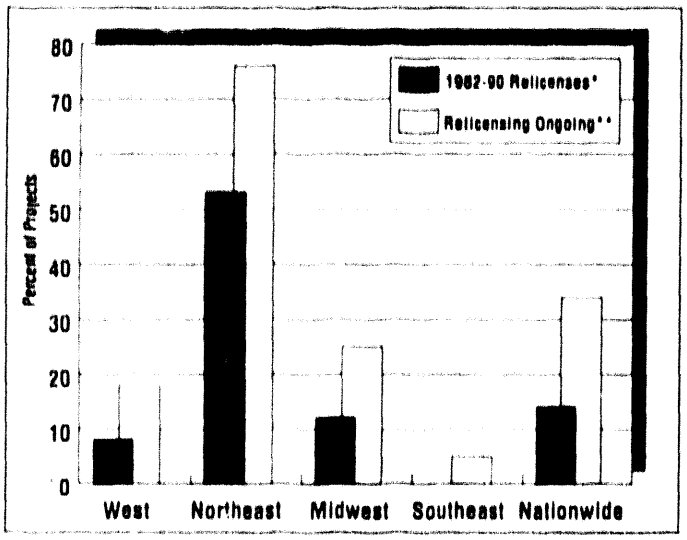

Figure 2: Percentage of relicenses with fish passage requirements (1982-1990) versus percentage of relicenses in progress with fish passage study requirements. (* 50 Relicenses. ** 46 Relicenses in progress.)

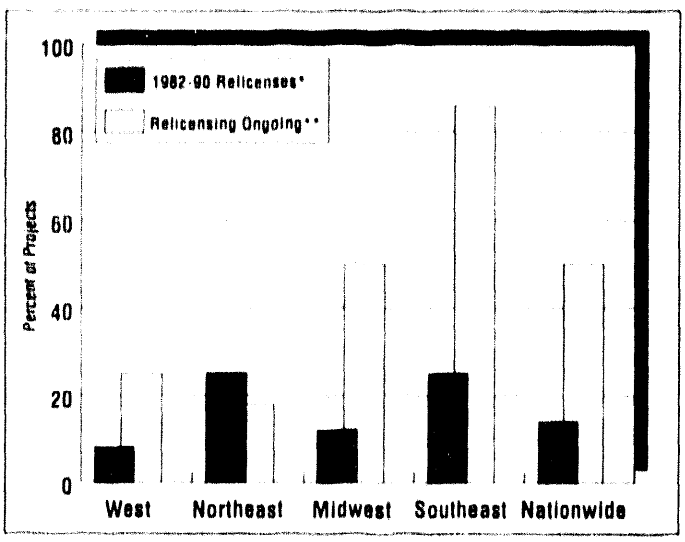

Figure 3: Percentage of relicenses with fish screen requirements (1982-1990) versus percentage of relicenses in progress with fish screen study requirements. (* 50 Relicenses. ** 46 Relicenses in progress.)

even for projects being relicensed after operating in excess of 50 years.

From 1982 through 1990, 50 relicenses were issued by the FERC. These licenses, in the review process for up to 14 years, were analyzed to determine the type and number of fisheries requirements placed on these projects as a condition of relicensing. In addition, 46 projects were reviewed that were still in process, to identify the importance of fisheries issues as reflected in the studies that applicants were required to conduct by agencies. Because studies inevitably lead to license conditions for the particular concern, a then and now comparison of the percentage of projects where these issues pertain makes sense. Moreover, until the relicenses are actually issued by the FERC, further studies and conditions can still be required of each applicant.

Instream Flow

The FERC always has required hydropower projects that redirect flow from the river to a powerhouse using bypass canals or penstocks to maintain a minimum flow of water in the bypassed river segment to avoid unacceptable environmental consequences. However, other types of hydroelectric plant configurations, such as those where the powerhouse is constructed as an integral part of the dam and discharges directly below the dam, have not normally received minimum flow requirements in their licenses.

Minimum flow issues have received major licensing and relicensing attention since 1980. Even so, the percentage of projects facing minimum flow hurdles has markedly increased for those currently being relicensed and now involves fully 90 percent of all projects in the western United States (See Figure 1).

Recently, the agencies recommending minimum flow requirements have directed applicants to conduct detailed studies to assess the effects of various minimum flows on a wide variety of resources such as water quality, recreation, fish habitat expansion and aesthetics. The resulting minimum flow recommendations are most often crafted to maximize benefits to fisheries-related resources to the exclusion of others. The data show a growing licensing and relicensing burden associated with minimum flow in terms of the number and cost of studies and license conditions resulting from reviews of fisheries agencies. Furthermore, the use of minimum flow to maximize fisheries benefits to the exclusion of other water interests has disproportionately slighted power production.

Fish Passage & Screening

When the operation of a hydroelectric plant can interrupt the upstream movement of fish, hydroelectric projects are required to construct facilities aiding the movement of these fish upstream past the project dam. Not all rivers or project sites are located in areas where fish species require passage facilities. Most sites requiring such installations are situated in the Northeast, where Atlantic salmon are being re-introduced, and in the Northwest, where salmon have long been of commercial importance. However, state and federal fisheries agencies have begun requesting relicensing studies of moving nonanadromous fish around hydroelectric projects in the Midwest and Southeast. The purpose of these fish passage studies is much less clear.

There has been a dramatic increase in fish passage studies and conditions throughout the country for projects now involved in relicensing. For projects now involved in relicensing, the percentage affected has more than doubled compared to those relicensed from 1982 through 1990 (See Figure 2).

In the Northeast, three-fourths of the projects now being relicensed are receiving agency attention for fish passage issues. Compared to projects relicensed from 1982 through 1990, there was a 50 percent increase in the number of projects receiving such attention. This is the result of a program to re-establish Atlantic salmon runs in rivers in the Northeast over the past two decades.

Of further note is the situation in the Southeast where fish passage has never been an issue. Eager resource agencies, bolstered by success, are now requiring studies of this issue for projects that have been operating more than 50 years. In several recent cases, fisheries agencies in the Southeast have required applicants to perform a laundry list of studies without addressing the need for each study at the affected project.

Another mitigation method involves fish screens, which are used to prevent fish from being pulled through the turbines. Screens also direct fish away from the turbines as they move downstream past the project. Screen design must also ensure that fish cannot be harmed by impingement on the screen itself.

There has been an overwhelming leap in fish screening activity nationwide (See Figure 3). Comparing projects now being relicensed with those relicensed in the 1982 to 1990 period, the percentage of projects involved with fish screening issues has increased more than 300 percent.

The fisheries agencies have grown increasingly inflexible on the subject of fish mortality, refusing to accept the possibility of the death of a single fish. Recent studies show mortality rates as low as 3 percent to 4 percent for fish that are actually drawn through turbines. However, state and federal fisheries agencies have met with such success in imposing their conditions on hydropower projects, they are requiring licensees to build expensive fish screening devices in nearly every case.

In their study requirements, fisheries agencies have demonstrated no interest in establishing how many fish actually go through the turbines at any particular site or how the fish populations are faring around a particular project. A more reasonable approach in balancing the objectives of all parties would be to measure the effect of the project operation by its effect on fish populations in the area.

The Need For Power

Because the FERC accepts the recommendations of fisheries agencies as license conditions without question more than 95 percent of the time, these agencies are inflexible and have no incentive to negotiate with hydropower operators. In order to reject a fisheries recommendation, the FERC would have to do significant additional analysis and paperwork. This places the burden on hydropower plant operators to prove themselves innocent rather than on fisheries advocates to prove them guilty.

This should not be the case. The FPA requires the FERC to equally consider all resources in their licensing deliberations. Section 4(e) of the FPA states: "In deciding whether to issue any license ... for any project, the Commission, in addition to the power and development purposes for which licenses are issued, shall give equal consideration to the purposes of energy conservation, the protection, mitigation of damage to, and enhancement of, fish and wildlife (including related spawning grounds and habitat), the protection of recreational opportunities, and the preservation of other aspects of environmental quality." The inconsistency of this language with the section 10(j) bias toward fisheries is exactly the type of question the Congress intended the FERC to settle. ECPA amended the FPA, adding section 10(j)(2) as a statement of safeguard against control of the process by the fisheries agencies.

A balancing in the true spirit of the applicable laws would demand greater consideration by the FERC of the need for the power in a given locality and the unique benefits the hydroelectric plant would provide to the area. The hydropower industry should insist the FERC take more objective account of the following positive benefits on the side of hydropower. These are:

- Hydropower is the lowest-cost electricity generation available over the life of a project because of its long life span and low operating and maintenance cost;
- Hydropower is the only major source of electricity that does not consume water resources;
- Hydropower is the only major source of electricity that does not pollute rivers or the air;
- Hydropower is the only generating source that provides multiple benefits to the surrounding community, such as flood control, water supply, irrigation, recreation, fisheries enhancement and wetlands maintenance;
- And hydropower is the only energy source that pays up front for mitigation measures to offset the effects of the project on the environment.

Fisheries Agencies' Control

Reasonable capacity increases at small hydropower plants now being relicensed offer the best near-term opportunity to increase clean, renewable energy supplies in the United States. Moreover, independently produced power should generate additional business opportunities and create jobs.

Today, fiscal and administrative forces disproportionately favor the fisheries. The growth of the fisheries agencies' budgets coupled with the increased fees licensees must pay for studies, agency and FERC review, and inadequately justified mitigation have left the developers of small hydropower operations the decided underdog in their struggle for equal consideration.

Because of what is at stake, the industry should demand that fisheries agencies focus their attention on empirically verifiable issues with respect to small hydropower and that the level of effort required of small hydropower entrepreneurs should be in relation to the effect of their plants on the environment. Above all, the FERC must enforce the intended role of fisheries agencies in licensing hydropower projects. ■

Richard T. Hunt is principal of Richard Hunt Associates, a consulting firm based in Annapolis, Md., and an *Independent Energy* magazine contributing editor. Judith Mohsberg is an associate with the firm.

Weighing The Costs

Environmental mitigation presents the hydropower industry with uncertainty about effects. Recent studies demonstrate the costs and will help developers, agencies and regulators understand the risks.

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INDEPENDENT ENERGY

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The hydropower industry in the United States is experiencing increasingly stringent environmental regulation. The numerous players influencing hydropower development, such as state fisheries agencies and hydropower developers themselves, often disagree as to the best use of water resources. Also, special interest groups such as recreational boaters, Indian tribes, irrigators, and transportation companies have their own expectations of how to best manage a water resource. The Federal Energy Regulatory Commission (FERC) must consider all of these competing resource demands as well as the public's demand for low-cost power.

The U.S. Department of Energy (DOE) Hydropower Program is studying the various practices and costs of environmental mitigation at hydroelectric projects. Environmental mitigation requirements are likely to increase in the future, yet little is actually known of quantitative environmental benefits. The first in a series of reports, jointly conducted for the DOE by the Idaho National Energy Laboratory (INEL) and the Oak Ridge National Laboratory (ORNL), has been completed. This initial volume, *Environmental Mitigation at Hydropower Projects, Volume 1 - Current Practices for Instream Flow Needs, Dissolved Oxygen, and Fish Passage*, discusses the practices and costs of environmental mitigation. The benefits derived from environmental mitigation requirements at hydropower projects proved difficult to quantify. The INEL was primarily concerned with accumulating a sample of the costs of mitigation.

A FERC database, the Hydropower Licensing Compliance Tracking System, identified 707 hydropower projects with some type of mitigation requirement for either instream flows, dissolved oxygen levels, upstream fish passage (UPFP), and/or downstream fish passage and protection (DWFP). Information was requested from all 707 projects and from these, 141 hydropower projects —a 20 percent response— provided cost information that was identified as usable for the environmental mitigation study. Only actual cost data was used for this study; estimates of future costs and modeled costs were excluded.

Environmental Mitigation

The types of cost data accumulated and analyzed are capital, study, operations and maintenance (O&M), and annual reporting costs. Generation losses due to mitigation requirements also have been accumulated. All costs are converted to 1991 dollar values using the consumer price index. Study and capital costs are assumed as one-time expenditures. The O&M, annual reporting costs, and generation losses are assumed as annually occurring costs.

The average capital and study costs for each project varied significantly among the four mitigation practices (See Figure 1). The relatively low capital and study costs for instream flow —$199,000— and dissolved oxygen —$212,000— are a function of the methods used to meet the mitigation requirements. Both of these mitigation requirements were often met by using non-capital intensive methods such as releases of water through spillways or the turbines. The larger average project capital and study costs for downstream fish passage and protection, $1.6 million, results from the construction of facilities such as bypasses, screens and angle bar racks. The highest average capital and study costs are for upstream fish passage, $6.1 million. The methods used to comply with the UPFP mitigation requirements include trapping and hauling fish, fish elevators, and fish ladders.

The fish elevators and ladders are the most capital intensive methods used. Of the three projects larger than 100 MW with UPFP mitigation requirements, two use fish ladders with an average per project capital cost of more than $30 million. Both of these projects have annual flows of more than 100,000 cubic feet a second. The third uses a fish elevator to raise fish to sorting tanks. This elevator cost $15 million.

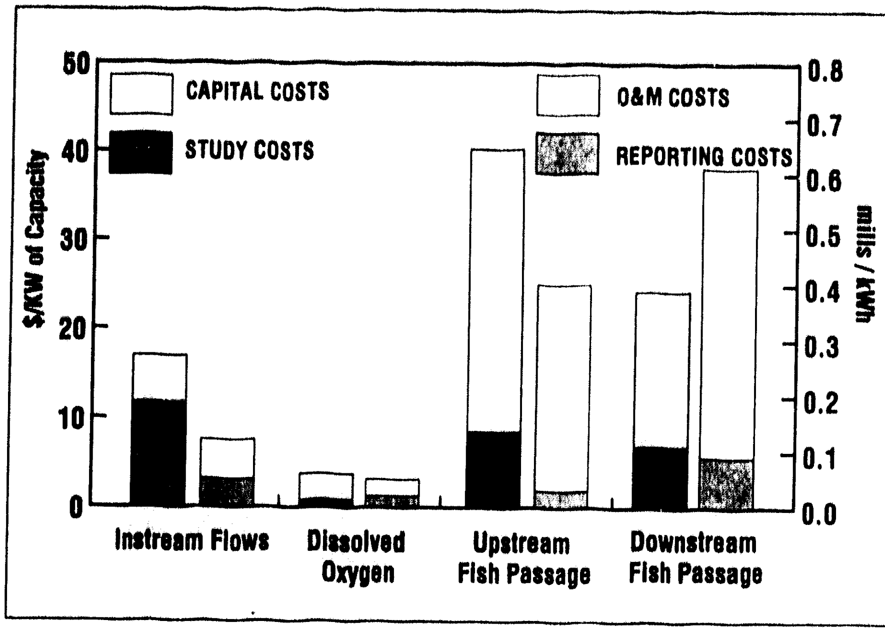
The average O&M and annual reporting costs for environmental mitigation requirements are fairly similar with the exception of the UPFP costs. The average UPFP O&M costs are skewed by the annual O&M cost of a large project in the Eastern United States. This project, the aforementioned project with the $15 million capital cost, uses a fish elevator system to pass American shad upriver. The O&M cost is $700,000 a year. The American shad are raised 40 feet to a sorting tank. Biologists then sort the fish by species and transport them upstream around the project and three other dams. The average O&M cost for UPFP at each project, minus this large project, is $8,900 a year. The average UPFP annual reporting costs are also skewed upward by a few large projects with higher annual reporting costs. The costs of O&M and annual reporting, as a function of energy produced, are all under 1 mill (0.1 cent).

Many projects reported generation losses for each type of mitigation issue. Of 141 projects, 85 reported a total generation loss of 260 million kWh. Assuming a 5 cent a kWh energy value, this equates to $13 million in generation losses. While the loss for each project may not be a significant burden to a large utility, the generation losses because of mitigation can make some projects unviable.

Not all 141 projects provided costs for each mitigation issue and few projects had all four types of mitigation requirements. The number of projects reporting each type of mitigation requirement are: Dissolved oxygen — 22; instream flows — 118; upstream fish passage — 21; and downstream fish passage and protection — 56. This is not the frequency of environmental mitigation requirements for all hydropower projects in the United States. These 141 projects were used only because they provided mitigation costs. This is a non-scientific sample. Nevertheless, the costs are representative of the those imposed on hydropower developers when mitigation is required. Limited numbers of reviewers suggested a bias in the costs. Those reviewers from agencies that place restrictions and requirements on hydropower projects said they believed the costs were overstated. Reviewers from the hydropower industry said they believed the costs were understated. These bipolar views, as well as secondary cost data, increased the cost analyst's confidence that the costs obtained are an accurate reflection of the costs. It appears mitigation requirements are escalating, and the costs of compliance are also expected to increase.

Project Costs

The costs of mitigation for the 141 projects were extrapolated to the 707 projects identified by the Hydropower Licensing Compliance Tracking System to approximate the total cost of environmental mitigation during the 1980s. The cost for the four types of mitigation requirements is estimated at $500 million. The average yearly generation losses extrapolated to the 707 projects amounts to $33 million when assuming a kWh value of 5 cents. Assuming an average five-year time span for annual costs —some projects incurred costs for one year, some for 10 years— the total cost is $665 million for these FERC licensed projects. These costs are only for those projects subject to the FERC licensing process, and does not include the costs of mitigation at federal hydropower facilities.



Environmental Mitigation Costs: Bar on left shows average capital and study costs per kilowatt of capacity for each mitigation requirement. Bar on right shows average annual reporting and operations and maintenance costs as mills per kilowatt hour of energy.

Measuring the future costs of hydropower mitigation involves many assumptions and uncertainties. Identifying the numbers and sizes of projects requiring relicensing is relatively easy, but the licensing outcomes and requirements, including the frequency of environmental mitigation requirements, are difficult to predict. The number of new projects that will be successfully developed is also uncertain and depends on future trends in energy prices, regulatory requirements, legislation and other possible externalities. While temporal trends of mitigation requirements are evident for the 1980s, it is not certain whether these trends will continue. Nevertheless, recent experience strongly suggests the number of future projects with mitigation requirements will increase. The time span used for future cost estimation is 1992 to 2010. The magnitude of future costs of mitigation is influenced by the substantial number of large hydropower projects due for relicensing during the next 18 years.

Informal hydropower industry and FERC reports estimate the number of new licenses at 1,316, and successful relicensing is assumed for all 436 projects due for relicensing. It was also assumed the frequency of mitigation requirements would increase. The costs for each mitigation requirement at each project exhibited by the 141 projects in the Volume 1 study were used to estimate future costs. With non-inflated, 1991 cost values, the estimated future cost of hydropower mitigation for the period 1992 to 2010 is $2 billion. This does not include the cost of lost generation which amounts to $81 million annually at an energy value of 5 cents a kWh. The specific years these future projects will come on line or be relicensed, and mitigation generation losses incurred, is not known. An eight-year average time period is assumed for total generation losses — some projects experience losses for one year, some for 18 years. It must be emphasized that the total cost of future mitigation, $2.65 billion, is not the total future cost of mitigation to the nation. This is the estimated mitigation cost only for those projects subject to FERC licensing. Possible future rule changes such as exempting projects of less than 5 MW of capacity from the FERC licensing process may influence costs in unknown ways.

Weighing The Costs

The total economic costs of environmental mitigation at hydropower projects will continue to grow as mitigation requirements become more frequent and complex. When a hydropower project becomes uneconomical, any generation losses must be replaced by conservation or other power sources. Replacement power sources have their own notable environmental effects when energy resources are extracted, transported, consumed and any residual waste is disposed of.

The hydropower developer can quantify the hydropower mitigation costs. Like any business person, the developer will want to know the benefits or payback associated with these costs. Unfortunately, this attempt to measure tradeoffs can lead to confrontations between the developer and the various agencies involved in the regulation of hydropower operation. This happens because the developer is sometimes encouraged to practice mitigation methods with unknown benefits. This is not to suggest that the hydropower environmental mitigation costs are unreasonable or that they must have an economic payback; rather, the costs of mitigation and substitute power generation should be rationally valued. Greater emphasis should be placed on attempts to quantify the benefits derived from mitigation practices. This would enable the evaluation of which mitigation methods provide the best use of scarce resources — water, land, or other commodities with economic or non-economic value.

Volume 1 of the environmental mitigation study concentrated on gathering hydropower environmental mitigation cost data as it relates to the hydropower developer. Several additional mitigation costs were not measured. These additional costs include the expanded costs of longer and more intricate licensing hearings, and the procedures and paperwork required at the FERC and at the hydropower developers, due to hydropower mitigation requirements. The various state agencies' costs of studying hydropower proposals and the associated possible effects on recreation and terrestrial and aquatic species also were not measured. All these costs are eventually passed on to electrical consumers.

Environmental protection and restoration is a desirable objective. However, one hydropower industry argument is that the costs of environmental mitigation are not justified because of the lack of evidence of benefits. For instance, while fish ladders can provide a benefit, the cost of construction and O&M to consumers may be so great as to exceed any reasonable fish value. Instream flows and dissolved oxygen requirements may improve habitat but if no quantifiable benefit results —such as specific increases in the numbers of desired fish species— the gain is difficult to measure and may be negligible. Greater effort must be undertaken to effectively measure the benefits of mitigation requirements, not just to justify any requirements. The ability to measure the benefits and compare the costs can be used as a tool to select specific mitigation methods that provide the greatest total benefits at the least-cost to society. ■

Jim Francfort is an engineering economist and Ben Rinehart is a senior engineering specialist at the Idaho National Engineering Laboratory. The *Environmental Mitigation at Hydroelectric Projects Volume 1* report may be obtained by contacting the authors at EG&G Idaho Inc. in Idaho Falls, Idaho. Volume 2 of the DOE environmental mitigation study is currently underway, focusing on upstream and downstream fish passage mitigation, costs and benefits. Additional volumes are expected to follow.

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Relicensing Entanglements

A greater number of participants in the relicensing process has increased the expense and uncertainity of relicensing a hydropower project. Relicense applicants are increasingly becoming entangled with multiple agency recomendations and burdened with a financial risk that continues even after relicensing.

By Richard T. Hunt and Judith Mohsberg

INDEPENDENT ENERGY

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The Federal Power Act authorizes the Federal Energy Regulatory Commission (FERC) to license hydropower plants for a period of 50 years. Between 1992 and 1995, the licenses for nearly 200 hydropower plants are due to expire, and the burden on the FERC will be tremendous. This boom of relicensing activity will occur in a relicensing environment that has become increasingly complicated and slow-moving during the past five years. For applicants, the relicensing process has become more risky, with far greater participation and influence by environmental interests; markedly increased federal participation; and a conspicuous lack of sound guidelines that project managers can follow to ensure their projects will be relicensed. Already, the greater number of participants in the process —and their recommendations— has increased the time and cost of relicensing a hydropower project. Further, the prevalence of unresolved details in articles subject to future FERC mandates greatly increases the risks of plant owners, and could lead to rising financing costs.

Because of the lack of information concerning hydropower relicensing, the Electric Power Research Institute (EPRI) contracted a review of recent relicense cases to obtain up-to-the-minute data on relicensing issues and strategy. As a part of this larger effort, the following profile of issues is based on a review of all relicense orders issued by the FERC between 1984 and 1989. Thirty-nine relicenses were issued during this period (with the eight Linweave orders issued in 1989 being considered a single relicense), for a total of 426 articles based on 522 recommendations.

> Currently, 11 percent of all articles are "open-ended," involving reopener statements that allow the FERC to mandate further conditions —such as fish passage facilities or changes in project operations— at unspecified future dates in response to unspecified future needs.

Focus On Fish And Recreation

As a part of a three-stage consultation process in hydropower relicensing, the FERC solicits recommendations from all parties interested in the operation, land use, power generation, recreational use, environmental impact and economic consequences of the project. Although anyone can provide opinions and recommendations during the relicensing process, certain resource agencies enjoy particular influence, and their role has been specified in recent amendments to the Federal Power Act.

Since the enactment of the Electric Consumers Protection Act of 1986 (ECPA), the FERC must include conditions in relicenses that are based on state and federal agency recommendations for the protection, mitigation and enhancement of fish and wildlife resources. If these recommendations are not considered, the FERC must explain —in writing— why the recommendations were not accepted.

For the 39 relicenses issued from 1984 through 1989, 522 resource agency recommendations were documented. Federal resource agency participation in the relicensing process has increased since ECPA was enacted. In 1984, state agencies submitted 70 percent of the recommendations and federal agencies submitted 30 percent. By 1989, federal agencies were submitting 50 percent of all recommendations.

These recommendations focus on enhancing conditions for fish and wildlife (especially minimum flow, fish passage and fish screening) and increasing recreational opportunities in the project area (See Figure 1).

Fish and wildlife agencies submitted a total of 355 recommendations for relicenses issued from 1984 through 1989. These recommendations varied between 56 and 75 percent of all recommendations submitted during that period, with minimum flow, fish passage and fish screening issues being the topic of more than half of the fish and wildlife agency recommendations.

There were 110 recommendations for minimum flow requirements for the 39 relicenses. Minimum flow requirements establish the volume of water that must bypass the turbines at the dam, increasing the amount and depth of water for fish habitat downstream from the dam. However, these requirements also increase the expense of power generation and reduce the project's energy output. The percentage of all recommendations that involved minimum flow increased from 16 percent in 1984 to 25 percent in 1989. Minimum flow releases have been added or increased in virtually all recent relicenses.

There were 99 recommendations for fish passage or fish screening requirements for the 39 relicenses. Fish passage devices allow the fish to bypass a dam, either upstream or downstream, or enable their safe diversion around the area of turbine activity. Fish screening devices absolutely prevent the fish from going through the project turbines. Both types of devices are expensive to install and reduce project efficiency. They are especially unwelcome in cases where no compelling evidence exists to demonstrate that they are needed to protect fish. The percentage of all recommendations related to fish passage and fish screening varied between 13 and 29 percent from 1984 through 1989.

Agencies submitted a total of 96 recreation recommendations for the 39 relicenses. Recreation recommendations varied from general requirements for overall recreational plans to specific items such as the development of campgrounds, picnic areas and boat launch facilities. These requirements comprised between 13 and 25 percent of all recommendations made during the period studied.

The data indicate the FERC accepts nearly all resource agency recommendations (See Figures 2 and 3). Ninety percent of all recommendations were accepted as conditions for relicenses in 1989, compared to 72 percent acceptance of all recommendations in 1984. In 1984, 17 percent of recommendations were rejected outright by the FERC, but by 1989, the rejection rate had fallen to 5 percent. In addition to the recommendations accepted outright, another 5 percent were accepted in principle but modified in 1989. In 1989, when the treatment of recommendations is considered by issue area:

❒ 100 percent of all fish passage and screening recommendations were accepted, doubling the 50 percent rate in 1985.

❒ 88 percent of all recreation recommendations were accepted, up from from 50 percent in 1984.

❒ 80 percent of all minimum flow recommendations were accepted. The rate jumped from 64 percent in 1984 to 89 percent in 1988 (See Figure 3).

Emphasis On Special Articles

The requirements or conditions included in a relicense are called "articles." Following the trend of agency recommendations, the highest percentage of articles (25 percent) relate to fish and wildlife issues, of which 60 percent specify minimum flow, fish passage and fish screening conditions. Recreation issues —the subject of the second highest number of agency recommendations— account for another 7 percent of all articles.

Project-specific articles may be designated either "standard" or "special."

Standard articles are those included in all licenses but modified to apply to a particular project. In relicenses issued in 1984, standard articles comprised 67 percent of all articles. By 1989, only 36 percent of all articles were standard. By and large, financial, land management, and cultural and historical articles fell under the heading of standard articles.

Special articles are written specifically for a particular relicense, and they require post-licensing actions by the licensee. Incidents of these show the reverse trend from standard articles. *All* fish and wildlife, general environmental, and recreation articles were written as special articles during the period studied. By 1989, 64 percent of all articles were special articles.

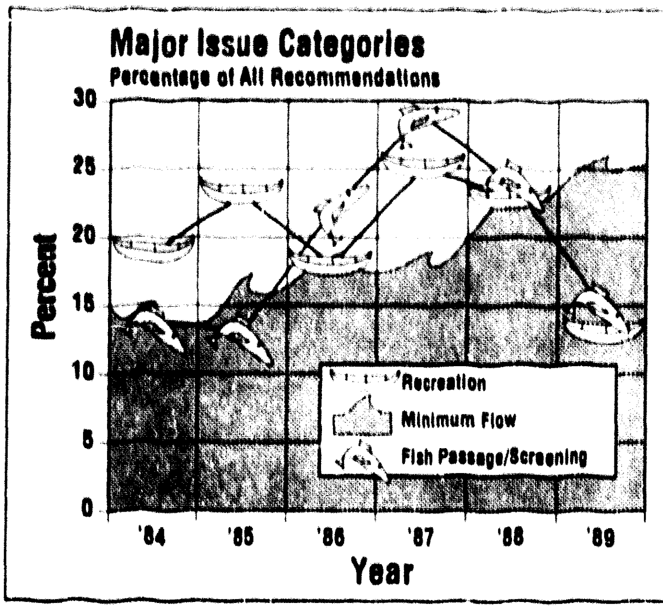

Figure 1: The percentage of resource agency recommendations received by the FERC for each of the three major areas of concern, during the years 1984 through 1989.

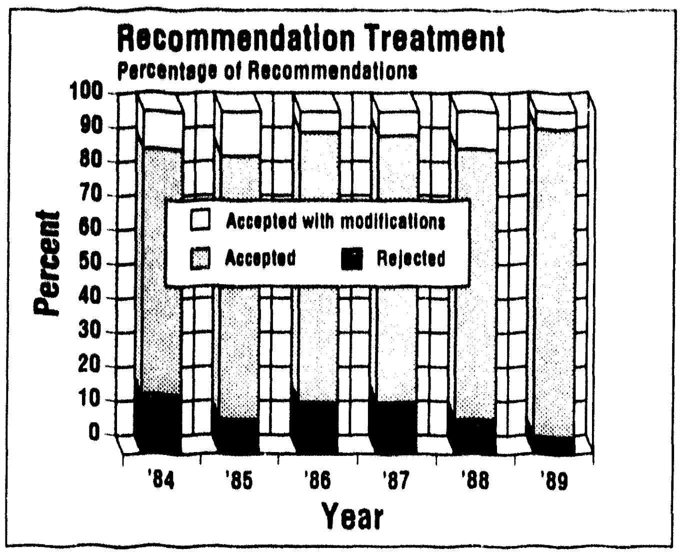

Figure 2: The percentage of all resource agency recommendations rejected and accepted by the commission for the years 1984 through 1989.

Life After Relicensing

There is a trend toward using post-relicensing requirements (see Figure 4), with articles that:

❒ Allow unspecified changes in project requirements, structures or operations (referred to as "open-ended" articles);

❒ Require continued monitoring and report of findings;

❒ Require studies or plan development and a report of findings;

❒ Require continuing consultation with resource agencies or the FERC, in addition to those in the normal, three-stage consultation process of licensing.

The data show steady growth in relicense articles with continuing requirements throughout the 1980s. By 1989, 60 percent of relicense articles required some form of post-

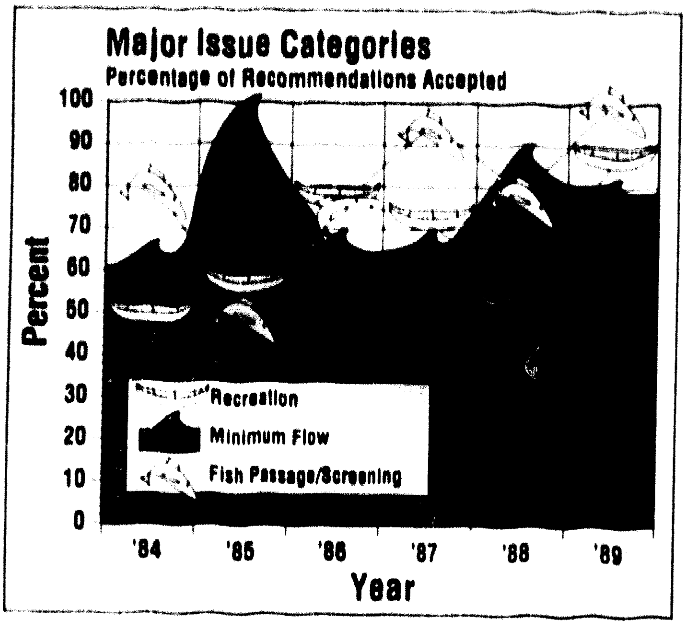

Figure 3: The percentage of recreation, fish passage and screening, and minimum flow recommendations accepted for the years 1984 through 1989.

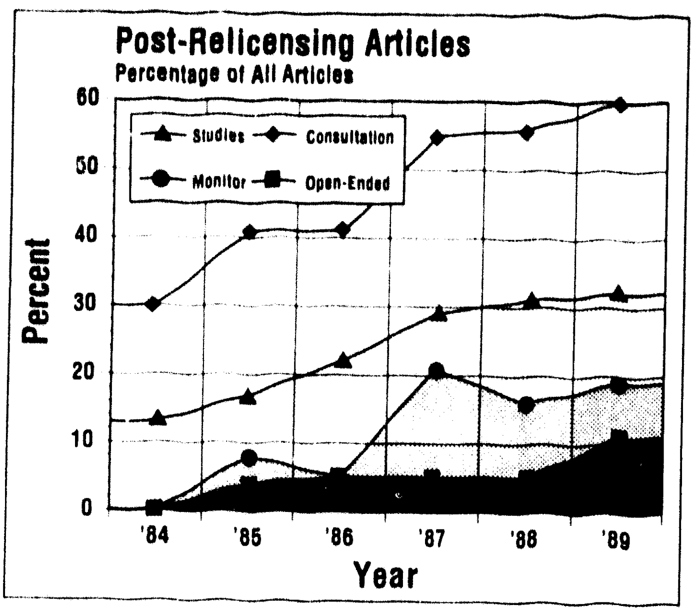

Figure 4: The percentage of relicensing articles that include post-relicensing requirements for the years 1984 through 1989.

relicensing consultation, 32 percent required post-relicensing studies, and 19 percent required continuing monitoring and reporting after relicensing. Currently, 11 percent of all articles are "open-ended," involving reopener statements that allow the FERC to mandate further conditions — such as fish passage facilities or changes in project operations — at unspecified future dates in response to unspecified future needs.

Even as the time required to complete the process for relicensing has increased beyond all expectations, the tendency to write articles that leave many unresolved details has grown. Relicense articles with non-specific or continuing requirements could result in surprisingly large costs and increase the economic uncertainty for a licensee.

Priority Issues

The data indicate that certain issues take clear precedence in the relicensing of a hydroelectric plant in today's regulatory environment. Forty percent of all recommendations and 15 percent of all articles were related to minimum flow, fish passage and fish screening issues in 1989. Another 15 percent of all recommendations and 7 percent of all articles were related to recreation issues.

By 1989, virtually all fish and wildlife recommendations were being accepted as relicense conditions by the FERC, and there is a greater acceptance rate for all agency recommendations since the passage of ECPA. Given this near-automatic acceptance of agency recommendations by the FERC, the time and cost required to relicense a hydroelectric project should be decreasing instead of increasing.

Because of the anticipated huge increase in the FERC's relicensing work load, regulators and industry representatives alike need to take a critical look at ways to streamline the process. ■

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Judith Mohsberg, an associate of Mr. Hunt, has worked for 10 years with the Health Care Financing Administration in Washington, D.C. Her legislative experience includes staff assignments with both the Senate Finance Committee and the Public Assistance Subcommittee of the House Ways and Means Committee.

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The Hydropower Industry's Fishway Principles

Introduction

The hydropower industry recognizes and takes very seriously its responsibility to ensure the protection of fish and wildlife and acknowledges the necessity of requirements under the Federal Power Act. To that end, the National Hydropower Association has developed the following principles underscoring certain issues which must be addressed when defining the term "fishway" under Section 18 of the Federal Power Act. We are eager to work closely with all interested parties in an effort to develop a definition which accounts for the protection of fish and wildlife and supports the value of clean renewable hydroelectric generation.

Rationale For a Definition

The parameters of a "fishway" prescription under Section 18 of the Federal Power Act must be defined in general terms to allow resource agencies to effectively target fish passage concerns and provide project owners and license applicants notice of the extent of their responsibilities. Prescriptions must be made on the basis of standards that are understandable and acceptable to all involved.

Balance Must Remain the Rule

Although it is understandable that fishery agencies would prefer to have exclusive control over all aspects of hydroelectric projects that affect fisheries, the premise of federal regulation of hydropower projects under Part I of the Federal Power Act has properly been that all competing interest must be considered and balanced. Limited exceptions to this balancing requirement are provided by unilateral prescriptive authority granted certain agencies and targeted at specific interest (i.e., fish passage, navigation, and navigation safety). In order for this regulatory system to provide for the responsible development of hydroelectric power and meet fish, wildlife, recreation and other needs, prescriptive authority must be limited to specifically identified tasks. Prescriptions should not serve as a pretext to assume control over project operations generally. Procedures are necessary to protect this balance and hold all responsible parties accountable for enacting appropriate measures.

A Compelling Biological Justification For Passage Is Required

Fish passage has been traditionally required only for fishery stocks requiring passage to complete their life cycle. Expansion of prescriptive authority to require fishways to address fishery benefits beyond actual life cycle requirements raises the concern that expensive fishways may be required where unknown or only marginal benefit will result. Electric power consumers and other beneficiaries of multipurpose hydropower development should not be needlessly burdened with these significant costs. Accordingly, prescriptions should be supported by a written biological justification explaining the life cycle or other compelling fisheries concerns. Agencies must be accountable for their decisions, and applicants must be given an opportunity to effectively evaluate and/or change prescriptions.

Project Operation (Flows) Must Remain Subject to Balancing

It is acknowledged that the general operation of a project may have a temporary or permanent impact on fish. However, in the vicinity of the project, general operational requirements (i.e. flows) also directly affect a variety of other vital public interests (i.e. generation, economic feasibility, flood control, municipal water supply, recreation). As such, general project operations should not be the subject of mandatory prescriptive authority by agencies with no mandate to consider or balance these interests with fishery interests.

Because of the exclusive focus on the biological need to provide fish passage, prescriptive authority is properly limited to requiring fish passage structures, flows within such structures, and screening devices.

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Using Hydroacoustics to Monitor Fish Entrainment

Abstract by

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Hydropower producers looking for an unobtrusive and cost-effective way to evaluate how their facilities affect fish may want to consider hydroacoustics. Hydroacoustic results have been accepted by FERC and many state and federal fisheries agencies. Hydroacoustics, or sonar, can be used to take intensive samples of fish populations over time and space without disturbing the fish. In the last decade, more than 200 hydroacoustic evaluations of fish entrainment at hydropower dams have been conducted in the U.S., many of them in the northwest.

Entrainment studies are potentially expensive, labor intensive, and (at least temporarily) affect project operations. Estimates of fish entrainment may be required 24 hour/day for several months. The greatest asset of hydroacoustics is its speed and accuracy as a fish quantification technique. The high sample power of hydroacoustics is difficult or impossible to obtain with more traditional means of fisheries research, such as netting or radio tracking.

The advantages and disadvantages of hydroacoustic monitoring of fish entrainment are discussed.

It is important that those applying this technique be well versed in the theory of using hydroacoustics for quantifying fish entrainment. However, equally important is his experience in solving the logistic challenges of applying this theory to hydropower sites. The predominant challenge in applying hydroacoustics to monitoring fish entrainment is a mastering of logistics involved with transducer placement and orientation. This considered, monitoring fish entrainment at hydropower dams is usually a relatively routine matter.

Examples of various equipment deployments and methods used at hydropower dams are presented. Typically, at hydropower dams one or more transducers are attached to a fixed structure, for example the trashrack upstream of a turbine intake. Fish are sampled as they pass through the ensonified beam. A mathematical weighting is applied to the "raw" fish counts to compensate for reduced probability of detection at ranges near the transducer, and to account for the entire width of the passage orifice (e.g., turbine intake).

Examples of results from completed evaluations at hydropower dams are given, including fish entrainment estimates, spatial and temporal distributions of entrainment, and evaluations of the effectiveness of various fish protection methods.

Bruce H. Ransom is President and Program Manager for Hydroacoustic Technology, Inc., in Seattle, Washington. He is a fisheries biologist by profession, and has over 10 years of experience in the application of hydroacoustics to the evaluation of fish passage at hydropower dams, most of it in the northwestern U.S.

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Using Sound Waves to Monitor Fish Entrainment

Hydroacoustics—the method of using sonar to estimate fish entrainment—works at many types of hydropower sites, and offers significantly lower operating costs than other monitoring options.

By Bruce H. Ransom

Hydropower producers looking for an unobtrusive and cost-effective way to evaluate how their facilities affect fish may want to consider hydroacoustics. Hydroacoustics, or sonar, has been accepted by the Federal Energy Regulatory Commission (FERC) and many state and federal fisheries agencies as a valid fish monitoring method. Hydroacoustics can be used to take intensive samples of fish populations over time and space without disturbing the fish. In the last decade, more than 100 hydroacoustic evaluations of fish entrainment at hydropower dams have been successfully conducted in the U.S.

The technology does have certain limitations, such as a lack of capability to directly characterize the species of the entrained fish. On the other hand, it provides round-the-clock monitoring of entrained fish regardless of their size or behavior. This is a key advantage, since FERC and various resource agencies may require estimates of fish entrainment at hydropower projects 24 hours a day for up to a year in licensing or relicensing procedures. Because hydroacoustic systems typically require minimal field manning, their costs are lower than virtually any other type of fish evaluation technique. Unlike other monitoring techniques, hydroacoustic systems do not interfere or harm the fish, nor do they alter fish behavior.

Hydroacoustics is not only cost-effective, but also well-established in regulatory settings. Many state and federal fisheries agencies accept hydroacoustically derived data. In the states of Michigan and Wisconsin, the departments of natural resources strongly recommend the use of hydroacoustics to estimate entrainment. In a recent FERC relicensing hearing, hydroacoustic results were successfully defended as an accepted monitoring method.[1]

With licenses for nearly 300 hydropower projects due for renewal between now and the year 2001, and about 150 licenses being sought for new sites, the technology's regulatory acceptability takes on special significance.

These advantages of hydroacoustic systems have made them the method of choice for many dam owners and fisheries managers monitoring entrainment rates and fish mortality at hydropower sites. Yet the technology's potential in hydropower settings still remains far greater than actual applications.

The Nature and Use Of Hydroacoustics

People have used sound waves for underwater monitoring for centuries. In 1490, for example, Leonardo da Vinci used a long tube to listen to the sounds from distant ships underwater. Starting with World War I, scientists developed sonar technology for use in echo ranging (gauging the location of vessels by sound waves echoing back from their hulls) and in depth sounding (determining the depth of water by measuring the time required for a sound wave to be reflected from the bottom).

After World War II, commercial fishermen began using sonar in their search for fish. The first effective applications of the technology occurred in the 1960s when shipboard users employed it to conduct surveys of fish stocks.

The emergence of microprocessors

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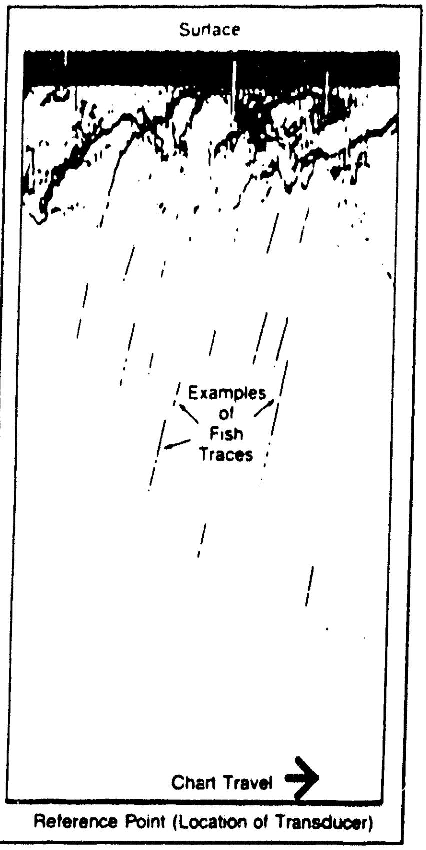

Figure 1: This echogram shows recordings from a bottom-mounted, upward-oriented transducer at a hydropower project. The steep fish traces in the mid-water column indicate that fish were moving toward the transducer relatively rapidly in that area. The meandering traces near the surface indicate slow-moving fish (wallowers) that are not migrating and thus would not be counted as entrained fish.

in the 1970s triggered the development of smaller, cheaper, and more efficient and user-friendly hydroacoustic equipment. During this period, owners of hydroelectric projects first began using fixed-location hydroacoustic techniques to monitor fish.

Fixed-location hydroacoustic techniques use stationary transducers to monitor fish passage. Hydroacoustic assessments have traditionally employed mobile surveys from ships to evaluate fish abundance and distributions. Fixed-location techniques can provide some of the same distributional information as well as additional migrational and behavioral data not available from mobile surveys. Fixed-location systems are especially useful in monitoring fish activity in restricted regions—near structures such as dams, coolant intakes, and piers—and in other locations where traditional fisheries techniques cannot be applied easily or cost-effectively.

Although useful and reliable when properly applied, hydroacoustic systems are not at the "black box" stage. Users need to understand the underlying physical and engineering parameters involved. These include the physics of sound in water (velocity, spread, and attenuation); the reflective properties of fish and other targets (size, density, orientation, and location relative to the axis of the acoustic beam); and the equipment's transmitting and receiving characteristics (signal frequency, band width, pulse width, and repetition rate); and data analysis processes.[2,3]

In view of the complexities associated with hydroacoustic systems, hydro project owners should seek trained, experienced personnel to operate their systems. Experience is important because training courses, though available from a few sources, do not alone ensure the proper collection and analysis of results. Owners should also hire consultants well versed in the use of the technology. Particularly important is a consultant's experience in applying hydroacoustic techniques at hydropower sites, because the placement and orientation of the transducers (sound transmitter and receivers) is crucial to the successful use of the technology.

A Review of the Technology: Hydroacoustic Equipment

A typical hydroacoustic monitoring system includes a high-frequency echo sounder, a chart recorder, an oscilloscope, one or more transducers and transducer cables, and a computer-based processing system. If the system involves more than one transducer, it must also include a multiplexer to systematically switch between two transducers.

The echo sounder is usually the most costly component. It is the source of the signals involved in the operation of the system. It also receives, amplifies, and times the signals from the transducers.

Data from the echo sounder is fed into a computer, and a chart recorder connected to the computer displays the echo signals on paper recordings called echograms. Figure 1 is an example of an echogram. Echograms provide a record of all targets with an amplitude at or above a predetermined minimum.

The oscilloscope monitors the system's operation, and visually depicts the amplitude of returning signals. Its role is particularly important where acoustic interference such as entrained air and turbulence is a concern.

The transducers emit and receive the sound signals. Most have relatively narrow beam widths—6 degrees to 15 degrees—to minimize the problem of interference. Transducers with narrow beams can be aimed close to boundaries, such as the water surface, stream bottoms, and dams. And, since the target areas are typically very close to these boundaries, the narrow beam is best suited to focus on the target area.

The microprocessor and other electronic components of the system collect, process, and transmit data. Such components are what make it possible for hydroacoustic systems to operate unattended for weeks at a time and, with a modest amount of attention, for months. They can also transmit data to the consultant's office via modem, thus minimizing the need for on-site operators.

Typically, a hydroacoustic system collects a variety of data on each fish, including distance from the transducer, time of entry into and departure from the beam, acoustic size (which can then be related to a fish's actual size), direction of travel, trajectory angle, and velocity.

An automatic fish tracking program analyzes the returning echoes. It recognizes the presence of a fish by determining that the signal is at or above a predetermined amplitude, contains an appropriate pulse width and shape, and includes a sufficient number of sequential echo detections.

There are many manufacturers of hydroacoustic equipment. Only a few, however, offer electronics systems that ensure accurate and reliable fisheries evaluations. Only equipment that can be accurately calibrated and does not drift in its parameters will allow meaningful comparisons of results from month-to-month or from day-to-day.

Equipment that is not of sufficient quality may also lack time-varied-gain (TVG) compensation, or its TVG measurements may be inaccurate. An accurate TVG allows the echo from a fish of a given size to be constant, regardless of the fish's distance from the transducer. Typical problems associated with TVG include a lack of stability in the measurements over time, or variability caused by changes in ambient temperatures or other climatic factors. An inaccurate TVG system may lead to a failure to detect some fish, to the counting of fish below a specified minimum size, or to an erroneous extrapolation of total fish entrainment figures from the numbers and sizes of the fish detected.

In light of the deficiencies associated with some systems, hydro project owners should generally obtain the best quality equipment available consistent with budgetary constraints. A typical installation would cost between $30,000 and $60,000; however, the cost range can be much wider and depends on the specific application and sampling effort. While equipment costs may seem high, they often represent a fraction of the manpower and related costs associated with other monitoring techniques. Some manufacturers lease their equipment and provide consulting services. Although it depends on the scope and duration of the study, hydroacoustic equipment can be leased for approximately $3,000 to $5,000 a month.

Using Hydroacoustics At Hydropower Projects

Engineers deploying a hydroacoustic system at a hydropower project attach one or more transducers to various fixed structures. Typically, these might include the trashrack upstream of a turbine intake or a pole mounted in front of the intake. Transducer mounting methods and orientations are very site-specific. A typical orientation is shown in Figure 2.

As fish pass through the beam, the system spatially sub-samples them. (In other words, the system samples fish in a certain portion of the intake.) It then applies a mathematical adjustment to compensate for the fact that fish near the transducer are less likely to be detected than those further away. The system also employs a mathematical weighting procedure for the width of the opening being monitoring, ensuring that the counts accurately represent entrainment across the full width of the opening.

The system separately weights each range bin. (Range bins are the individual "slices" of the cone of water covered by the sonar beam. Users typically specify widths of 1 foot per bin.) The weighting process is a simple geometric one except where there is reason to believe the distributions of fish entrainment are uneven across the turbine intake.

If the system is designed to take sub-samples over discrete periods such as a specified number of minutes each hour, it will also weight its counts to adjust for this feature. Most systems estimate fish entrainment on an hour-by-hour basis, and then combine these figures to generate daily entrainment rates.

To scale relative fish abundance to absolute entrainment counts, an estimate of mean fish acoustic size is needed. This is most reliably obtained from either dual-beam or split-beam hydroacoustic techniques, which are able to determine where fish are in the beam by the strength of their echo.[4,5] In turn, the strength of the echo is used to estimate the acoustic size of the fish. Although these systems are not widely available, a few manufacturers are offering these features on their hydroacoustic equipment to calculate absolute entrainment counts.

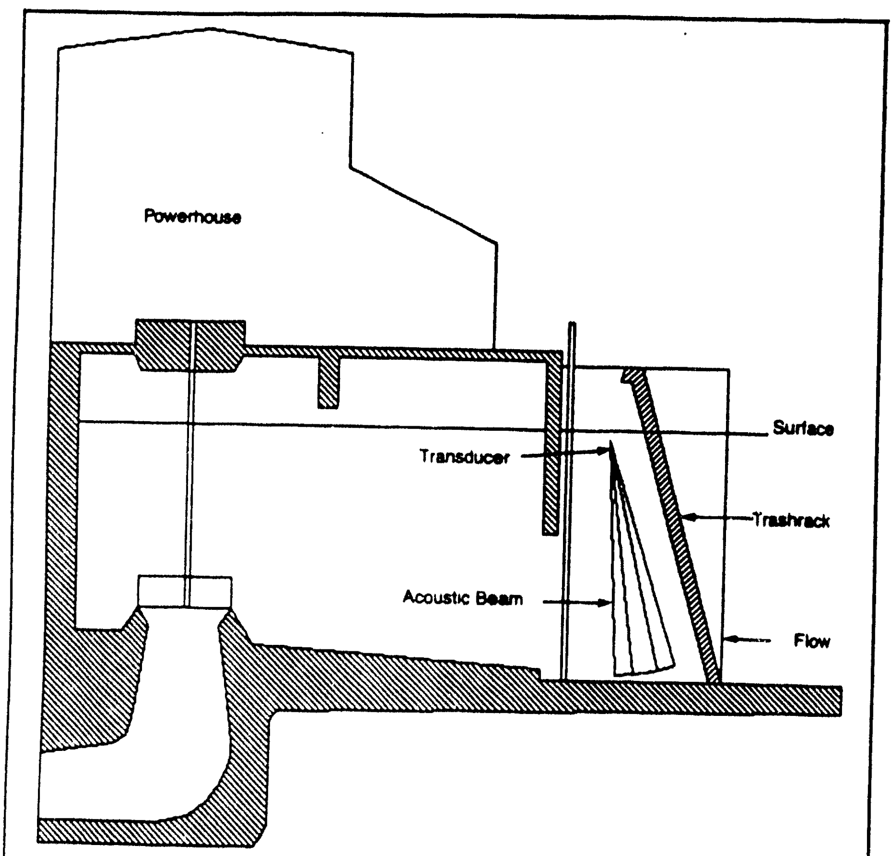

Figure 2: This diagram shows the location of a transducer and indicates its a[illegible]oustic sample volume within the turbine intake of a small hydropower plant. This orientatio[illegible] was selected to maximize sample volume

Hydroacoustics at Work

Hydroacoustics has been used extensively for monitoring fish entrainment at power plants throughout the world for more than 20 years. In the northwestern U.S., state and federal resource agencies and several hydropower producers have been using results from hydroacoustic monitoring to make decisions about fisheries management on the Columbia River for more than a decade. At least 130 hydroacoustic studies have been conducted at hydro projects in the U.S. Although the majority of the work has been conducted on the Columbia and Snake rivers, hydroacoustic techniques are being used throughout the country. Hydroacoustics is used at hydro projects for estimating fish entrainment rates and evaluating fish protection measures.

Measuring Fish Entrainment

Entrainment rates are usually expressed in terms of the number of fish per hour entering a given intake. These estimates are generally tracked on a daily basis over the course of a season or a year to determine the variability in entrainment rates over time.

Hydroacoustic systems can estimate size distributions, diel (24-hour) distributions, and vertical and horizontal distributions of entrained fish. To monitor fish size, the system records an "acoustic size" (the target strength) and derives from that a physical size estimate. A change in the size distribution of entrained fish over time may indicate either changes in the age class of the species recorded, or a change in the species composition of the sample.

To calculate fish entrainment distributions over a 24-hour period, hydroacoustic systems estimate entrainment on an hourly basis. By relating each hourly count to the 24-hour figure, the systems reveal how fish passage varies during the course of a full day.

At hydropower projects, one or more hydroacoustic transducers are attached to a fixed structure. For example, a transducer and rotator may be mounted on the trashrack upstream of the turbine intake.

These two calculations can provide valuable information to hydro plant operators trying to protect fish and, at the same time, generate as much power as possible. One method of safely bypassing fish around turbine units is to pass water over the dam as spill. However, water that is spilled cannot be used to generate electricity. At Lower Monumental Dam in southeastern Washington State, the U.S. Army Corps of Engineers wanted to spill water during the days and hours when juvenile salmon and steelhead trout would be coming through at the highest rates.

Hydroacoustic Technology, Inc. (HTI) used hydroacoustic techniques to estimate fish passage rates for both the turbine units and the spill bays during the spring and summer outmigration. We then plotted daily fish entrainment rates against daily river flow. As Figure 3 shows, entrainment rates were closely correlated with the level of flow.

The Corps also wanted hourly estimates of fish entrainment rates. Using hydroacoustic techniques, HTI found that entrainment rates were disproportionately high at night, as shown in Figure 4. As a result, the Corps has concentrated its passage of water as spill during the nighttime hours, and thus maximized power production during the day when energy needs are greatest.

Hydroacoustic systems are valuable not only for generating estimates of fish size and distributions throughout a 24-hour period but also for determining vertical and horizontal distributions of entrained fish.

Vertical distributions can be calculated from a transducer aimed downward or upward. By using the distances from the transducer for the fish that pass through the volume covered by the beam, the system can produce an estimate of the vertical distribution. This is typically expressed in terms of number of fish passing through each 1-foot range bin.

When the Grant County Public Utility District wanted assistance in designing an in-turbine diversion screen for its Wanapum Dam in central Washington State, it asked HTI to measure the vertical distribution of fish passing through the turbine. Using hydroacoustic measurements, we found that normally surface-oriented juvenile salmon and steelhead trout consistently exhibited distributions that were deeper at night than during the day. These results indicated that the bypass screen would probably be less effective at night than during the day.

In measuring horizontal distributions of fish, one method is to place transducers at representative turbine intakes. Using this approach, HTI produced a distribution across the ten-unit powerhouse at Wanapum Dam. As Figure 5 indicates, the study showed that fish passage was concentrated at one end of the powerhouse, thus providing data that may aid in fish protection measures. Additional hydroacoustic testing is continuing at Wanapum.

Evaluating Fish Protection Methods

In addition to fish distributions, hydroacoustic systems can evaluate fish protection methods by measuring fish velocities and trajectory angles.

Hydroacoustic systems generate fish velocity data based on two types of measurements: the fish's distance from the transducer as they enter and leave the volume scanned by the beam (from which the distance traveled may be calculated), and the entrance and exit times (from which time-in-the-beam may be calculated). Dividing the mean length of travel through the beam by the mean time-in-the-beam produces an estimate of mean velocity for each range bin.

At the Chelan County Public Utility District's Rock Island Dam in central Washington State, HTI used velocity data for juvenile salmon and steelhead trout to assess the effectiveness of a prototype diversion screen. Engineers prepared fish velocity profiles in the area below two screens of differing lengths, and compared these with a base line (no screen) condition, as shown in Figure 6. The results indicated that inserting of a screen increases fish velocities below the screen. A longer screen produces even higher velocities. The higher velocities below the screen would cause the fish to be swept below the screen and into the

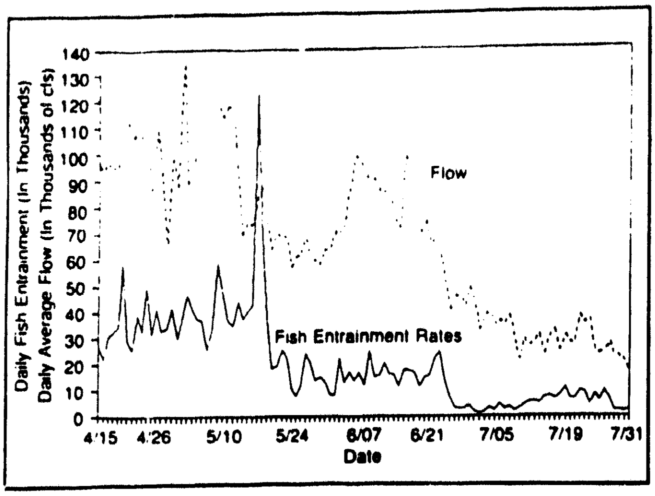

Figure 3: This graph shows the correlation between daily fish entrainment rates and total river flow at the Lower Monumental Dam during the spring and summer of 1989.

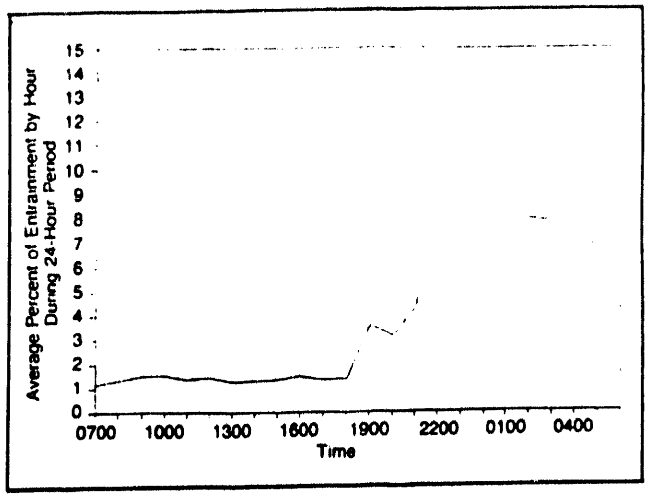

Figure 4: This graph charts the average distribution of fish entrained at the Lower Monumental Dam in 1989 during several 24-hour periods. Entrainment rates were disproportionally higher at night.

turbine intake. The longer the screen, the less effective it was. Based on these results, the project owner decided to look at alternative methods for fish passage instead of spending money on an ineffective screen.

Hydroacoustic evaluation of fish trajectory angles may also reveal useful information. For example, the trajectory angle at which fish appear near turbine intakes can indicate whether they are entering or leaving. Similarly, fish angle can indicate the behavior of the various species as they approach different types of diversion screens.

In calculating fish trajectory profiles, the first step is to segregate data on each fish by range bin. (The bins in such cases may be anywhere from 1 to 5 feet in width). Then, the mean entrance and exit distances from a given transducer are calculated for all fish within a specific bin. It is then possible, taking into account the transducer's beam width, to calculate a mean trajectory angle for each bin.

HTI developed such a trajectory profile for intakes at Grant County PUD's Priest Rapids Dam on the Columbia River. Engineers considered velocity and trajectory readings from a single transducer, and found that fish velocities and trajectory angles generally reflected the flow lines and velocities of the water. The conclusion: without anything in the way, fish are likely to move with the flow. The next step is to evaluate fish movement when some type of screen is placed in the intake.

At Chelan County PUD's Rocky Reach Dam in eastern Washington, HTI analyzed the effects of placing a diversion screen in a turbine intake. Studies indicated that fish change their angle of approach when such a screen is in place. Obviously, the screen had an effect on the orientation of the fish,

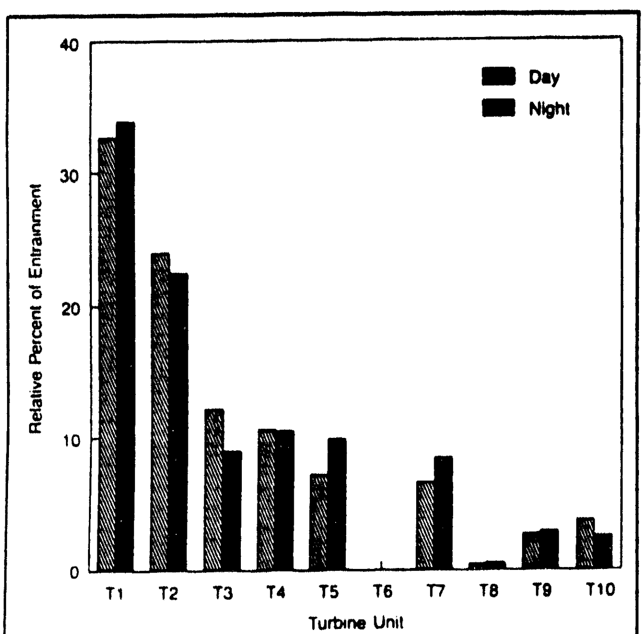

Figure 5: This graph shows daytime and nighttime horizontal distributions of entrained fish at the Wanapum Dam during the summer of 1988

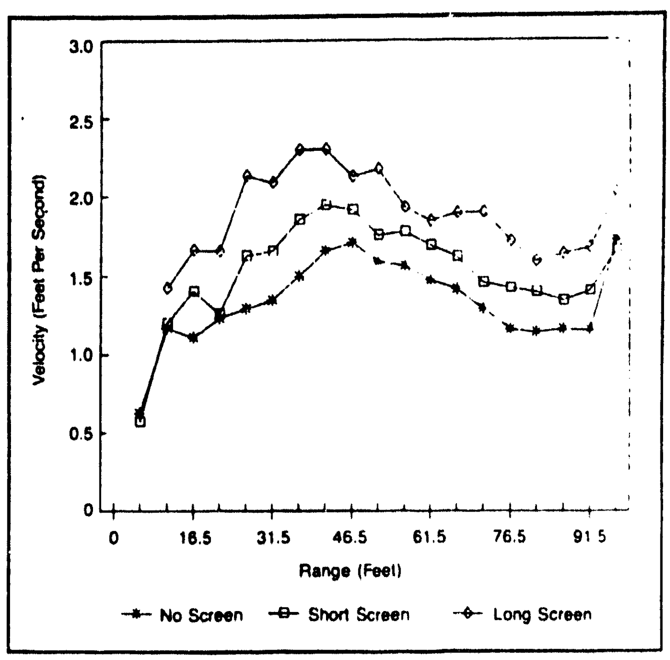

Figure 6: This graph compares the fish velocity profiles measured in 1988 for a long in-turbine screen, a short screen, and no screen at Rock Island Dam.

helping explain why it had a lower-than-expected efficiency in diverting fish.

Examining Pros and Cons Of Hydroacoustics

Experience shows that hydroacoustic technology has significant advantages over other forms of fish monitoring techniques. Among its advantages is cost-effectiveness, a feature that reflects not only the fact that such systems require relatively little on-site labor, but also their high sampling power. A related benefit is that hydroacoustic techniques permit the collection of more data over a given amount of time than virtually any other method.

Other advantages include the fact that hydroacoustic systems are unobtrusive. They do not interfere or harm the fish monitored, nor do they alter fish behavior, as other techniques invariably do. And, the systems are non-selective: users can monitor fish in a wide range of sizes and behaviors.

What about disadvantages? A notable one is the inability of hydroacoustic systems to characterize fish by species. In controlled laboratory studies, researchers have had some success associating distinctive acoustic signatures with particular species. Field applications of these techniques, however, are not yet reliable. As a result, hydro project owners and fisheries agencies must rely on other techniques, such as net sampling.

Although some states strongly recommend the use of hydroacoustics to estimate entrainment, most regulatory agencies still require "ground truthing" (verification) of hydroacoustics with a netting effort. The cost of the required netting efforts can equal or exceed the cost of the hydroacoustic work.

Another disadvantage is that the use of hydroacoustic systems requires special training for individuals who will operate them, and periodic recalibration of equipment. Another drawback is the fact that ambient debris may interfere with hydroacoustic signals from very small fish.

Various physical aspects of some hydropower projects, such as submerged reinforcing structures or penstocks and turbine intakes that are sometimes inaccessible, can also make it difficult to use hydroacoustics. Similarly, excessive turbulence (such as found in tailraces), entrained air, or electronic interference may limit the usefulness of hydroacoustic systems.

On balance, however, hydroacoustic systems have proven their value in fish entrainment monitoring. As one report that evaluated several fisheries management techniques concluded, "Under conditions favorable for acoustic surveys, no other estimation procedure can provide the quality of information, accuracy of estimation, and speed of data acquisition on the demographics of fish."[6]

Hydroacoustics' Role In the Future

With improvements now in development, hydroacoustic systems should be even more useful in the years ahead. For example, manufacturers will be creating systems that are more automated than today's, and so require less attention from trained hydroacousticians. In addition, improvements in the electronics will increase signal-to-noise ratios, thereby making it easier to monitor relatively small fish.

Since the passage of the Electric Consumers Protection Act of 1986, hydro project owners have seen an increase in demand for and intensity of fish entrainment studies. These studies are potentially expensive, labor intensive, and can temporarily affect project operations. As more and more projects are required to conduct these studies as part of licensing and relicensing procedures, hydroacoustics will offer one unobtrusive and cost-effective way to evaluate a hydro project's effect on fish and determine if mitigation is needed. □

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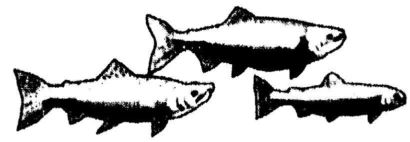
Salmon Passage Notes

June 1993

Saving Salmon:



The Role of Research

In 1888, Major William Jones, in charge of one of the Corps of Engineers' Portland offices, reported to Congress "an enormous reduction in the numbers of spawning fish" in the Columbia River as a result of industry fishing and stream pollution. He admitted he did not have enough information to solve the problem and recommended further study of the salmon.

To the impacts of overfishing, pollution, unscreened irrigation ditches, and spoiled spawning grounds that began over a hundred years ago was added installation of big multiple-purpose dams. The Corps realized the dams posed a threat to the fish runs and acknowledged a responsibility to address those dangers. In 1929, Division Engineer Colonel Gustav Lukesh advised the Chief of Engineers that "provision should be made (in dam design) for the passage upstream of fish, especially salmon migrating to breeding places." When Bonneville Dam was completed in 1938, it contained fish ladders, an experimental lock system for fish, and a migratory canal around the project.

The recommendations of people like Jones and Lukesh are examples of an early commitment to ensure that the design, construction and operation of Columbia and Snake River projects include provisions for the safe and efficient passage of anadromous fish. To meet this commitment, research has pioneered in the areas of fish responses to dam structures, fish passage facilities, and river operation strategies, to evaluate and improve fish passage effectiveness.

These efforts have led to formation of a Corps-funded regional research program. Today, the Corps' Fish Passage Development and Evaluation Program (FPDEP) has about fifty on-going or proposed research studies on juvenile fish bypass and transportation, adult fish passage, and related issues such as spill effectiveness and dissolved gas effects. This applied research program allows a high degree of confidence that costly, extensive design changes for new and existing fish facilities at the dams will bring expected returns in fish passage improvement.

In 1951 the Corps entered an intensive design and construction phase on water resource projects in the Willamette Basin and the lower Snake and Columbia rivers. Very little was known about the migratory behavior of Pacific salmon. A Corps research program was initiated to provide the information needed to design and construct adult fish passage facilities at dams.

During the early years research focused on how to assist adult fish over the fifty to hundred foot climb at the dams. Fish ladder attraction flow and collection system designs were needed. Biologists studied how well the ladders passed fish, and engineers looked at increased design efficiency. Most of the knowledge gained from that research has been carried forward and embodied in subsequent water resource project design and operation throughout the nation.

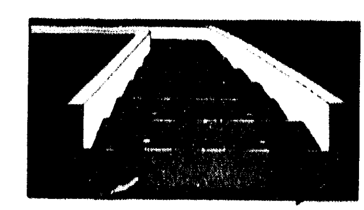
As more dams were completed in the fifties and sixties, more attention was given to the welfare of juvenile salmon and steelhead and their migrations through mainstem reservoirs and dams to reach the ocean. Juvenile fish passage systems that existed at that time were not effective. Many juveniles passed dams over spillways, or through the turbines where injuries and mortality were higher.

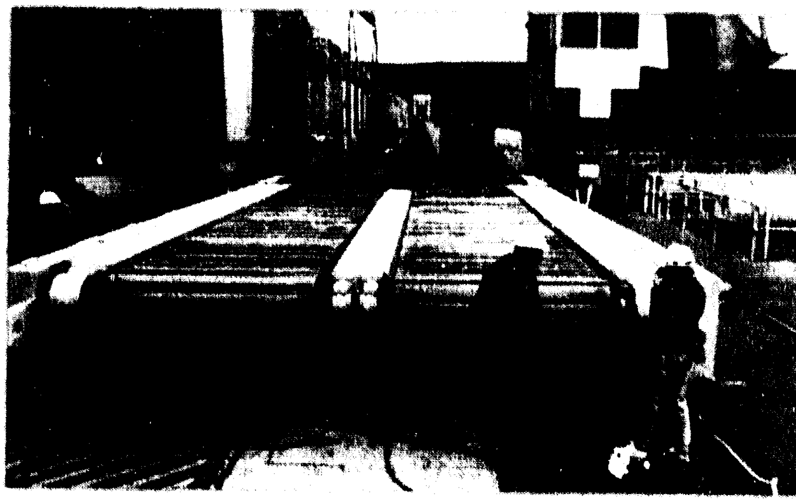
During the sixties and early seventies, scientists became aware of the hazard to fish of gas bubble disease (similar to the "bends" in human divers) from supersaturated gases caused by spilling water and fish over the dams. Research concentrated on protection of juvenile fish from both turbines and gas supersaturation. These efforts resulted in the development and installation of spillway deflectors (also called "flip lips") to lessen the problems of supersaturation, and the genesis of turbine intake screens to deflect juvenile fish away from turbines and into bypass systems. Research begun in 1969 by National Marine Fisheries Service (NMFS) on a juvenile fish transport system was stepped up in the 1970s.

Lower Granite, the last of the eight mainstem Corps dams on the lower Snake and Columbia rivers, was completed in 1975. Concern over the possible impact on fish migration from extensive river regulation continued to increase. Research intensified on transportation operations and improving adult and juvenile fish passage facilities. Design of the turbine deflector screens continued to evolve, and transport of fish for release below the dams became a part of yearly operations.

The problems that the Corps is challenged to resolve today are increasingly complex. Three Snake River salmon species are currently listed under the Endangered Species Act as either threatened or endangered: spring/summer chinook, fall chinook, and sockeye salmon. The primary objective is to get fish through the hydroelectric system with minimum mortality and delay.

According to Rudd Turner, Corps of Engineers fishery biologist and FPDEP coordinator, "Much has been learned about project operations and fish passage facility design. But as this information has been acquired, additional factors have come into play. More hydro projects are on line now than in the past, cumulative impacts are greater, habitat quality continues to need improvement, there are more people in the region and more demands on both the fishery and water resource, and the Columbia River Basin has experienced several years of drought. All this has combined to result in a continuing decline, particularly in wild stocks of fish."





A 40-foot extended submersible traveling screen.

Research that looked at ladder design was very successful. From 1955 to about 1970, the National Marine Fisheries Service maintained experimental sections of ladders at Bonneville. They worked with slope, flow rate, and placement of orifices in the weirs. The design changes that resulted were more efficient from an engineering standpoint and passed fish as well as or better than the old design.

For example, the newer ladders at the Bonneville second powerhouse are 16 feet across and several hundred feet long, with a one-on-ten slope (one foot of elevation gained for every ten feet of length). The original ladders at the first powerhouse are 40 feet across and have a one-on-sixteen slope, so they are 60 percent longer. The older, larger structure requires more water—about 200 cubic feet per second (cfs) vs. 75 cfs. Salmon migrate just as well with the narrower and steeper ladder. In this case, research led to ladders that are less expensive to construct and require less water, without compromising fish passage.

The strong forces associated with passage through turbine units can injure and kill juvenile fish on their downstream migration. Turbine deflector screens, known as submersible traveling screens (STSs), have been added to most of the lower Columbia and Snake projects as a result of intensive research on ways to minimize those losses. STSs guide fish away from the turbines and into collection and bypass systems.

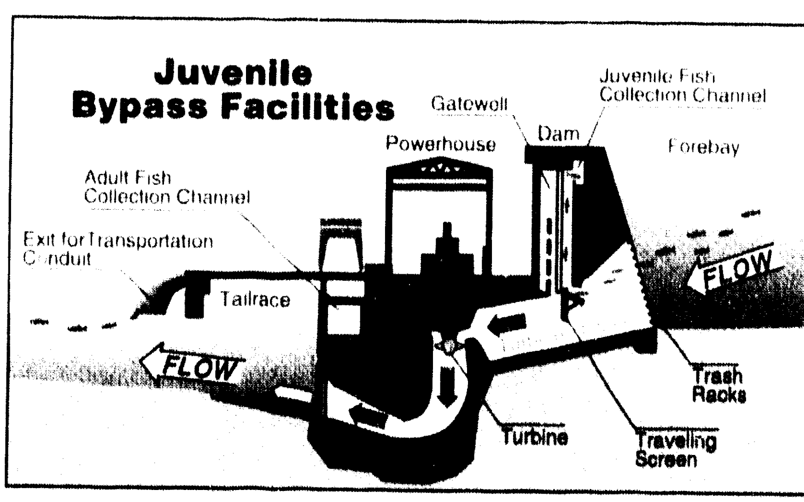
The STS design has been extensively studied to find the least stressful and most efficient way to guide juvenile fish away from turbines and up into the bypass system. Research has evaluated the angle at which the screens are placed, porosities of various materials to control the flow of water through the screens, bar versus mesh screens for maintenance considerations, use of lighting to attract fish, and others.

Extended-length STSs are currently being studied. These screens are twice the usual 20-foot length to reach even lower and deflect more fish. But tests of some extended-length screens indicate that increasing the length of the screen beyond a certain point may create its own problems by guiding more water into the gatewell slots and creating stronger, more turbulent flows that can injure fish. The Corps is currently funding studies to address extended-length STS design.

Another area of study associated with juvenile bypass systems is reducing the predictability associated with where juveniles are discharged back to the river. A bypass system deposits the fish at constant, fixed points in the tailrace downstream of the dam, and predators quickly learn where those points are. The Corps is considering alternatives for improving bypass outfalls—varied locations for discharging fish from the system, putting more fish in the middle of the river where the current is stronger, and transporting the juveniles to different locations several miles below the dam—so predator populations do not build up at one location.

Four lower Snake and Columbia river dams—Lower Granite, Little Goose, Lower Monumental and McNary—have juvenile collection and transport facilities. Juvenile fish diverted away from the turbines are collected and placed into barges or trucks for transport below Bonneville Dam. The Corps began experimental barging in the early 1970s because of the problems with cumulative impacts of gas supersaturation, turbine mortality and predators on the juvenile fish moving through the reservoirs and past the projects.

Research on the transport program has resulted in many improvements to barging. A constant supply of fresh water pumped into the barge directly from the river provides fish with homing cues. The number of fish that can be safely carried, based on a maximum loading rate of one-half pound per gallon of water, is factored



in to the operation. And the barges are equipped with aeration chambers which remove supersaturated gases from the water.

Although there is debate over whether the transport system is the appropriate way to get juvenile fish downriver, most research indicates that it has benefitted fish stocks. Many people prefer allowing in-river migration, however, barging is currently considered a necessary interim solution for safer fish passage. (Also see Litigation Update, this issue.)

The Players

Research funded through FPDEP is developed and coordinated with a number of other regional bodies including NMFS, U.S. Fish and Wildlife Service, Columbia River Inter-Tribal Fish Commission, and Oregon, Idaho and Washington fish and wildlife/game agencies. Other entities also participate in advising and recommending research activities.

The scope of research is developed during each fiscal year including recommendations from the Tribes and state and federal fish and wildlife agencies, and coordinated with their programs. Participants meet regularly to coordinate work, discuss research progress and proposals, and stay informed of specific problems being encountered at the projects.

Current research includes:

(1) transportation studies looking at improved collection and handling techniques, the impact of bacterial kidney disease on spring/summer chinook, and lower fish barge release sites on the Columbia river;

(2) adult passage studies on such topics as determination of hatchery/wild ratios, mainstem dam passage patterns, and evaluation of adult fallback at dams;

(3) survival studies of juveniles through turbines or bypass systems;

(4) fish passage efficiency studies, including techniques for determining fish guidance efficiency of structures within turbine intakes, and effectiveness of different extended length traveling screens; and others.

FPDEP is an applied environmental studies program – a set of scientific investigations directed toward understanding biological phenomena, addressing specific practical problems, and providing design and operation criteria. The Corps and other operating and fishery management agencies want to understand more about salmon behavior, to improve the efficiency of project operations, both biologically and practically.

Turner notes, "I think the Corps can still improve juvenile and adult salmon passage success. But there are also other problems in the Columbia river basin that need to be taken care of. Everyone needs to work to preserve wild stocks of fish – to provide high quality spawning and rearing habitat, reduce competition from hatchery stocks, control adult harvest, as well as provide safe mainstem passage conditions – otherwise, the endangered species list could grow."

It is a complicated problem that will require complex solutions. Is it possible? Turner says he believes so. "I'd have a hard time coming to work if I didn't. A crucial goal is maintaining wild fish stocks. Maintaining the natural diversity of species results, over the long term, in population resiliency that can overcome environmental problems. That's where we need to head now."

WES

Corps research lab looking at ways to increase salmon survival

Vicksburg, Mississippi, 3,000 miles from Portland, is home to the Corps Waterways Experiment Station (WES), a 673-acre compound with six research laboratories: Hydraulics, Coastal Engineering, Geotechnical, Structures, Environmental and Information Technology. At WES, working physical models of Northwest dams are helping engineers and biologists find ways to increase anadromous fish survival rates and rebuild the Northwest's traditional fish runs.

Established in 1929, WES's original mission was to develop flood control plans for the Mississippi River after the disastrous 1927 flood. Today WES is one of the largest and most diverse engineering research and development organizations in the world. Its mission is "to conceive and execute engineering and scientific investigations in support of the military and civil programs of the Corps of Engineers, the Army and the nation."

In the Hydraulics Lab, most of the work WES is currently doing for the North Pacific Division is related to fish passage. Researchers are looking for the best ways to move adult and juvenile fish past the Corps projects as they migrate to and from the ocean.

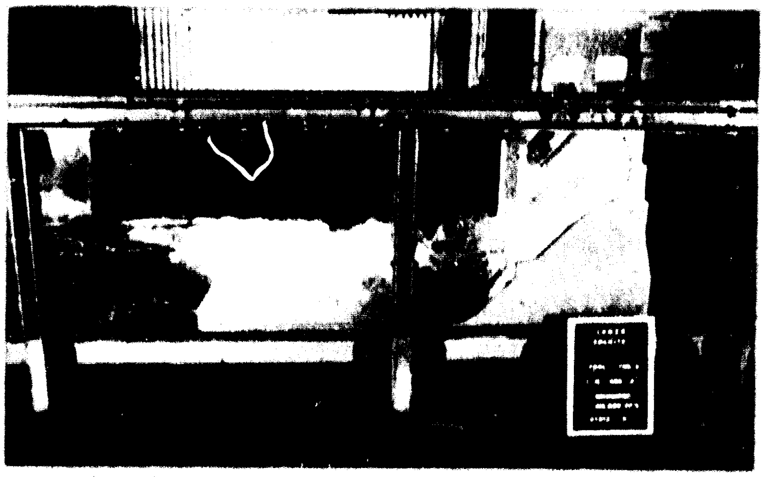
Leading edge research techniques are used on models of the Columbia and Snake river projects. General models, built at a scale of 1' to 80' or 1' to 100', reproduce large portions of projects. General models of Bonneville, The Dalles, McNary and Lower Granite dams are useful tools for analyzing general flow conditions. Scientists can evaluate hydraulic conditions salmon encounter as they pass the projects, and thus narrow the range of on-site tests needed.

There are also sectional models at WES. Those models focus on specific portions of projects and are generally constructed at a larger scale such as 1' to 25'. Sectional models currently being used for fish passage studies include three-bay turbine intake sectionals of Lower Granite, McNary, Bonneville and The Dalles and the Lower Granite spillways.

One WES model is a replica of Bonneville Lock and Dam and 3.4 miles of the Columbia River above and below the project. The model is more than half a football field long, and includes the first and second powerhouses, the spillway and the new navigation lock. At the project, Turbine Intake Extensions (TIES), also called roof extensions, are installed over the turbine bays on the upstream side of the second powerhouse. These extensions break up the flow at the river surface, creating flow patterns that guide juvenile fish toward the fish screens and up the gatewell more successfully. At WES, tests were performed to determine the most effective TIE placement and length for this installation.

The Dalles general model includes the powerhouse, fish ladders, spillway (gates, chute and stilling basin) and navigation lock, as well as a two and one half mile stretch of the Columbia River. A deep channel in the basalt floor of the river downstream of The Dalles dam is clearly visible in the model and is a determining factor in flow patterns below the dam. Model operators can duplicate river flows through The Dalles powerhouse, adjusting discharges to simulate various river conditions. Dye and confetti are used to track flow patterns at varying velocities. Dye illustrates flows from the surface to the river bottom, while confetti tracks surface flow patterns. Other techniques, such as video tracking which provides velocity information, are also used at WES.

The Portland District office is



Sectional model of Lower Granite Dam spillway

At WES, working physical models of Northwest dams are helping engineers and biologists find ways to increase anadromous fish survival rates and rebuild the Northwest's traditional fish runs.

currently designing a mile-long transportation flume to move juvenile fish through and downstream of The Dalles project. This flume is part of a new juvenile bypass system being designed for The Dalles. Current model work is under way to determine the best site for releasing juveniles from the flume back into the Columbia river.

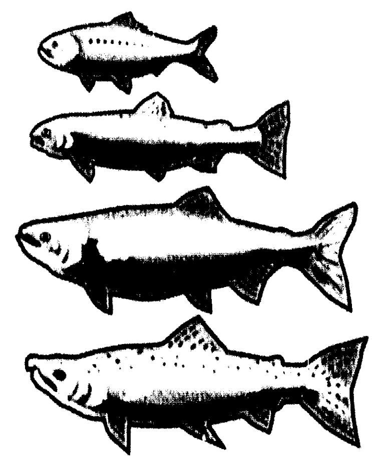
Also at WES are three models of Lower Granite Lock and Dam — a sectional model of the spillway, a general model of the entire dam, and a turbine intake sectional model. The general model includes the Snake River environment from 2,000 feet upstream of the dam to 3,500 feet downstream.

These models are being used to evaluate physical effects of possible drawdown operations for the Lower Snake River reservoirs — Lower Granite, Little Goose, Lower Monumental and Ice Harbor — and what structural modifications may be required if drawdown is implemented as a long-term option. Annual operation of one or more of these projects at levels substantially below their normal levels (drawdown) is under study as one alternative for improving salmon migration conditions past the dams.

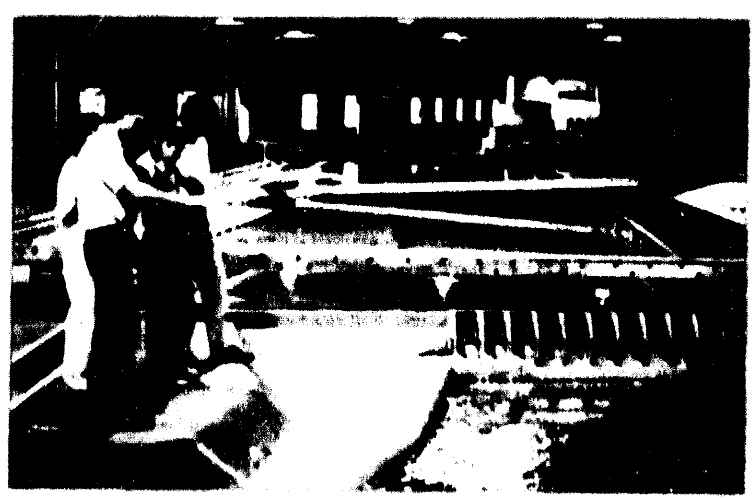
A March 1992 drawdown test at the Lower Granite and Little Goose projects did not provide biological information regarding effects of drawdown on juvenile fish travel time and survival. Although the model studies at WES will not provide this missing piece of information, they will help provide information necessary to the decision process, such as what happens in the spilling basins under drawdown spill conditions. (Please see related article on planning for biological test of drawdown in this issue.)

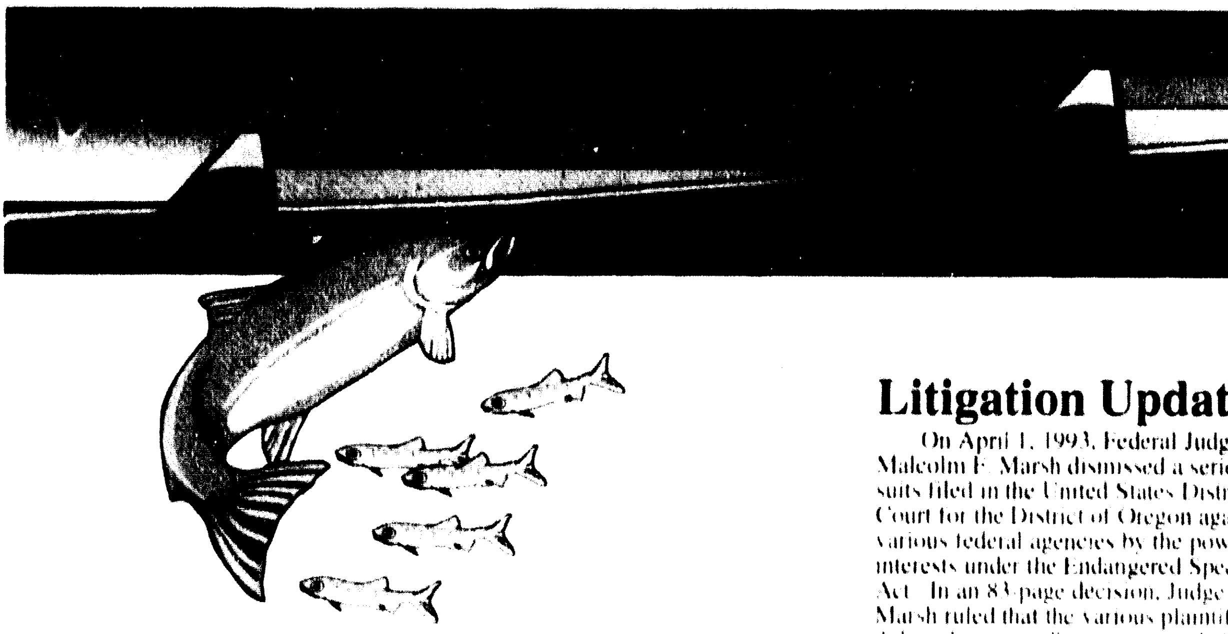
Model testing saves time and money. The models allow researchers to test many alternative operational techniques more quickly and thoroughly than they could with on-site testing. An advantage of modeling over physical site testing is that modeling allows evaluation of a variety of alternatives quickly, with no effects on other elements of the river system, including existing ecosystems. Using data from monitoring on-site river conditions, combined with modeling results, Corps researchers and designers can identify alternatives that will most benefit the anadromous fish population. That knowledge is needed now, as regional interests work together to revitalize declining salmon runs.

Today WES research, along with biological and physical research on the river, is contributing vital knowledge to help the Corps make physical improvements and better operate the hydro system for anadromous fish.



General WES model of working dam





NMFS/Corps to conduct biological test of reservoir drawdown

Officials of National Marine Fisheries Service and the Corps of Engineers announced April 6 that they plan to conduct a biological test of reservoir drawdown. Their objective is to gather scientific data to help in deciding whether operation of Lower Snake River reservoirs below normal operating ranges is an effective means of increasing juvenile salmon survival.

The concept of lowering the reservoirs has been proposed as a means of increasing water velocity through the reservoirs. In theory, increased water velocity reduces the time needed for juvenile salmon to reach the ocean and increases their survival rate.

Both the Corps and NMFS consider biological testing of reservoir drawdown an essential element in evaluating and making a decision on the use of drawdown for recovery of the listed salmon species.

In 1992, when the Corps conducted a two-reservoir drawdown test to gather information on the physical effects of a drawdown condition, few salmon were present. NMFS has initiated a study this year to gather biological data on the relationship of river flows to juvenile fish survival. The next step is a drawdown test when salmon are present so that biological effects can be measured.

According to NMFS, their recovery planning process requires sound scientific information to determine how the Federal projects could be operated longterm to assist recovery of the listed salmon stocks. The Corps also needs the information to support its technical analyses in both the ongoing System Configuration Study and the multi-agency System Operation Review. In response to the Northwest Power Planning Council's Fish and Wildlife Program, these studies are examining potential modifications to federal dams and reservoirs and how they are operated under drawdown alternatives.

NMFS and the Corps will prepare an Environmental Impact Statement covering the biological test options. As a part of that effort public meetings were held in May to present test alternatives and solicit comments and suggestions.

Currently, the two agencies are working with regional experts to design a detailed biological test scenario. Timing of the drawdown test will depend on a number of considerations, including the relationship to NMFS' ongoing flow survival study, and the design and construction of any special equipment or project modifications required to be in place before testing can occur.

Litigation Update

On April 1, 1993, Federal Judge Malcolm F. Marsh dismissed a series of suits filed in the United States District Court for the District of Oregon against various federal agencies by the power interests under the Endangered Species Act. In an 83-page decision, Judge Marsh ruled that the various plaintiffs did not have standing to pursue their claims against the federal agencies.

Following the heels of that ruling, another complaint was filed April 19 in the same court by Northwest Resource Information Center, Inc., the Confederated Tribes and Bands of the Yakima Indian Nation, American Rivers, Oregon Natural Resources Council and the Sierra Club.

This suit challenged the Corps of Engineers juvenile fish transportation program and the issuance of a permit for the program by the National Marine Fisheries Service on April 14. Plaintiffs sought a temporary restraining order and preliminary injunction to stop the Corps from proceeding with the transport program.

After an April 22 hearing, Judge Marsh denied the request for a temporary restraining order and on April 29 after a continuation of the previous hearing, he denied plaintiffs' request for a preliminary injunction. In denying the injunctive relief, Judge Marsh indicated that it was not his role to substitute his judgment for that of the agencies after they had properly considered other operational alternatives as well as conflicting scientific material. Judge Marsh indicated that the agencies' decision to commence the barging program was not arbitrary or capricious.

The Fish Transport Debate

What is this battle over barging all about? Readers of previous Salmon Passage Notes have learned how the system of hydro projects on the Snake and Columbia rivers -- so beneficial in terms of power, irrigation, flood control, navigation and recreation -- have created difficult migration conditions for salmon, particularly young salmon going downstream to the ocean.

Dangers in the slow-moving reservoirs include predation and the potential for nitrogen supersaturation when water is spilled over the dams. And, while many juvenile fish are diverted through the powerhouse bypass systems, some are still killed or injured as they pass through turbines.

Over the years, NMFS has conducted numerous studies which indicate that transportation has increased survival of Snake River salmon. More recent studies were conducted in 1986 when river flows were average and 1989, when flows were low. The NMFS studies found that transportation increased the spring/summer chinook survival rate by about 1.6 times in 1986 and 2 times in 1989 compared to in-river migration.

These same studies became the subject of controversy this year when an ad hoc review group of the Columbia Basin Fish & Wildlife Authority (CBFWA) issued a report critical of the NMFS studies. CBFWA represents state and federal fish agencies and Northwest Indian tribes.

Judge Marsh, in his April 22 decision not to grant a temporary restraining order to stop barging salmon, expressed concern that scientists on both sides of the issue were losing sight of science and becoming advocates. "Let's just deal with this from a scientific standpoint," he said.

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This issue of Salmon Passage Notes features an explanation of the Water Budget — another of the programs in place in the Columbia and Snake River system which seek to improve migration conditions for salmon. Although the water budget has been in use for over a decade, interest in its use has increased since the listing of three Snake River salmon species under the Endangered Species Act in December 1991 and May 1992. Flow augmentation increases water velocity in the river system and, in theory, aids juvenile fish in their migration to the ocean by reducing their travel time.

This issue also addresses operation of the Federal hydropower system for fish in the 1993 operating season that begins April 15. The water budget becomes a part of that plan of operations and as such was examined in the 1993 Supplemental Environmental Impact Statement now in final form for public review. (For information on the SEIS call Pete Poolman in our Walla Walla district at 509-522-6619.)

We also provide an update of the System Configuration Study, and the lawsuits heating up in the region over fish.

THE WATER BUDGET AND FLOW AUGMENTATION

In the early 1980s, the Northwest Power Planning Council, in consultation with Congressional leaders, project operators, fishery agencies, Indian Tribes, and Northwest utilities, established the concept of a Water Budget as part of its Fish and Wildlife Program.

The Water Budget called for specific amounts of water to be released from upstream storage reservoirs to increase and shape river flow during the spring, the major juvenile fish migration period. The idea was to partially restore and simulate the effects of a spring freshet, the heavy runoff from spring rains and melting snow that naturally replenished river flows and helped push the juveniles to the ocean before the dams were in place.

With the Salmon Summit meetings in 1990, the region began to focus more on the concept of augmenting river flows to help move juvenile fish downstream. The 1991-92 Endangered Species Act listings of the Snake River sockeye salmon as endangered, and the spring/summer and fall chinook species as threatened prompted further attention.

Water Budget and flow augmentation became important not only to mimic the spring freshet but as a tool to assist in later spring and summer migrations and adult returns.

The initial water budget concept has further evolved through amendments to the Council's Fish and Wildlife Program and today provides for an integrated, systemwide plan to provide help to anadromous stocks and in particular naturally spawning salmon that are listed as endangered or threatened.

Starting in January, federal project operators, the Fish Passage Center, the Council's Water Budget Advisor, National Marine Fisheries Service (NMFS), Bonneville Power Administration, and utility representatives review the current year's runoff forecasts and coordinate plans for reservoir system operation consistent with the Council's Fish and Wildlife program. This will be the tenth year of formal water budget implementation through a Coordinated Plan of Operation (CPO).

Water available for the water budget and for flow augmentation is determined by considering water supply forecasts, flood control requirements, probability of refilling reservoirs for the following year's operation, impacts to recreation and other uses of storage reservoirs. Consultation with NMFS under the Endangered Species Act has become a critical part of the process.

During the operating season the Fish Passage Center, representing fisheries agencies and Indian Tribes, monitors smolt activity and calls for water budget and augmented flow releases when additional flows are expected to be most beneficial to the migrating juvenile spring/summer and fall chinook salmon. They also request releases to regulate flows and temperatures for adult fall chinook.

To provide water budget flows, water is held back in storage reservoirs during the winter months for later release during the outmigration period. This reduces the amount of energy available from the hydroelectric system during the winter months when regional demand is higher and forces the production of energy (as water budget flows are released through turbines) during the spring when demand is lower.

The Snake River water budget relies upon Dworshak and Brownlee Reservoirs and any additional unallocated water from the upper Snake River Basin. Grand Coulee and the upstream reservoirs provide flows on the Columbia River.

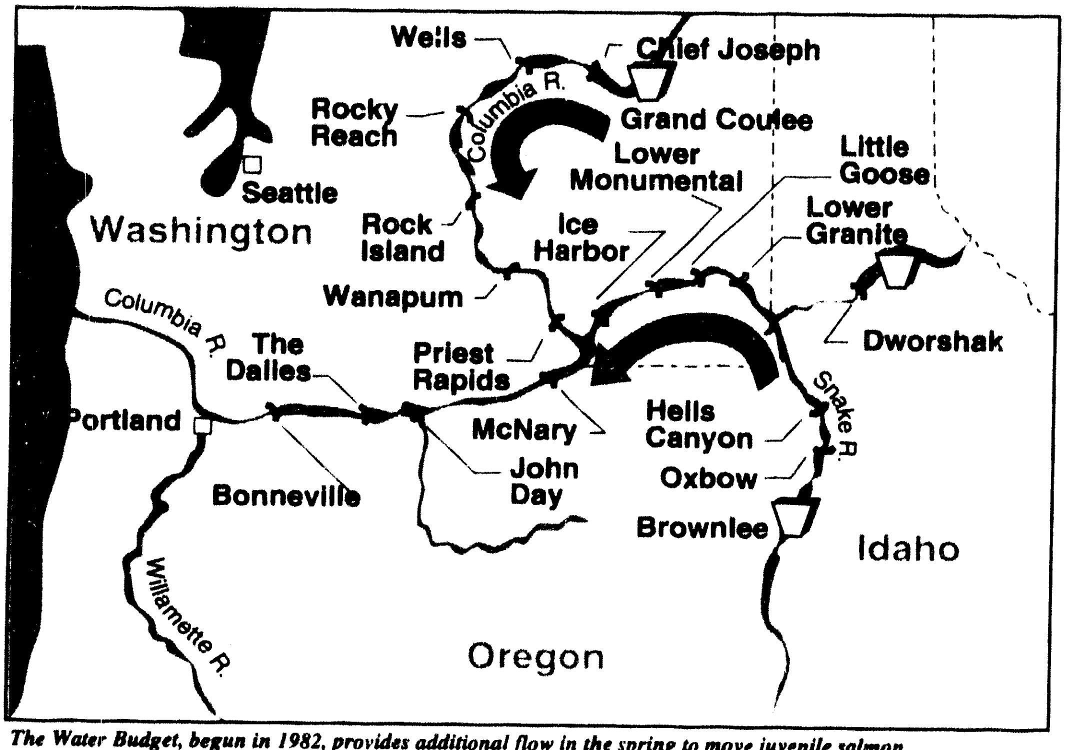
Before the Endangered Species Act listings, an annual water budget of 3.45 million acre-feet (MAF) was made available on the Columbia River and about 1.19 MAF from the Snake River. Since the listings, additional flow augmentation of up to [illegible] MAF in the Columbia and varying amounts from the upper Snake has been supplied. An acre-foot of water is equal to 325,850 gallons and would cover a one-acre area to a depth of one foot.

1992 Operations

Operation of the Columbia and Snake reservoir system in 1992 was the initial year for flow augmentation beyond the spring water budget and added flows in the July, August and September timeframes as well, focusing on the lower Snake River flows.

During the 1992 spring water budget period (May 1 to June 30) 3.45 MAF of water budget was provided, and 3.0 MAF of flow augmentation water was released to the Columbia River from Grand Coulee and Arrow.

Between mid-April and mid-June, base outflow plus water budget volumes resulted in over one million acre feet of water released into the Snake River from Dworshak for the spring migrations. One hundred and ten thousand acre feet was released from Brownlee dam.



The Water Budget, begun in 1982, provides additional flow in the spring to move juvenile salmon downriver to the ocean.

In July, about 270 thousand acre feet was released from Dworshak, for flow augmentation for the juvenile fall chinook migration and to provide cooler water into the Snake River which was expected to benefit fish. The temperature of water released from Dworshak dam can be controlled by drawing water from various reservoir depths (with cooler water being at lower elevations). Also during July about 140 thousand acre feet was released from Brownlee.

And again in September, 200 thousand acre feet was released from Dworshak to improve conditions for returning adult Snake River salmon. All of these actions were taken in consultation with the NMFS to ensure compliance with the Endangered Species Act.

Depending upon expected run-off and reservoir levels, some storage space for flood control may be shifted from one dam to another. Shifting this storage space from Dworshak to Grand Coulee frees up space to store water at Dworshak, while still meeting flood control storage requirements. Because of low run-off forecasts in 1992, there was no need for flood control space at Dworshak and thus no shift was possible.

Proposed Flow Augmentation for 1993

The 1993 Supplemental Environmental Impact Statement's preferred alternative for flow augmentation includes 1992 actions that were implemented and adds more flexibility for summer flows with augmentation water from Dworshak.

Two primary differences are:

1) 200 thousand acre feet normally planned for September release could be shifted to July and/or August to benefit summer juvenile migrants; and

2) the criterion for the flood control transfer from Dworshak to Grand Coulee is modified so the probability of flood control transfer is improved.

In both spring and summer, timing of flows will depend upon actual runoff conditions, and numbers and movements of fish. The Fish Passage Center will monitor these conditions and request water releases accordingly. Consultation with NMFS will continue.

Pros and Cons

Most state, tribal and Federal fisheries agencies and many salmon advocates believe the increased flows help "flush" fish down the river and reduces their exposure to predators and other hazards in the usually slow-moving flows within the reservoirs.

Just as there are supporters of augmented flows to benefit the salmon's downstream migration, there are critics. They point to a lack of credible cost/benefit analysis or biological evidence that augmented flows result in increased fish returns.

Some recent data suggests that juvenile fish are not passive during their downstream migration. Unlike a stick thrown into the river which floats downstream only where and as rapidly as the flows take it, fish may stop and rest or daily along the way and voluntarily time their downstream descent to match their biological time clock regardless of flow velocities.

Clearly, as with so many of the other alternatives being considered to save the salmon, there is still a need for more biological information or "science" to confirm benefits of augmented flows to fish and just how much augmentation is needed to provide the benefits. NMFS will be conducting research on the relationship of flow/water particle travel time to survival beginning this year.

SYSTEM CONFIGURATION STUDY

In our last issue (December 1992) we summarized the information contained in the Corps' Interim Status Report to the Northwest Power Planning Council, on the Columbia River System Configuration Study (SCS). The SCS is a two-phase study of alternatives for physically modifying or reconfiguring the Federal hydropower projects on the Columbia and Snake Rivers to better operate for fish.

The Interim Status Report presented information available to date from Phase I of the study. The report provided preliminary design, cost and scheduling estimates for the alternatives under consideration.

The complete Phase I study report is scheduled for completion and public distribution in the fall of this year. In addition to information covered in the Interim Status Report, it will contain mitigation plans and a preliminary analysis of economic and environmental effects, including effects on salmon survival, for each of the alternatives. The draft final report will compare each alternatives with the others and make recommendations for which options will be carried into Phase II for further study.

The Corps gave a brief presentation to the Northwest Power Planning Council on the Interim Status Report on December 9 in Portland. An independent contractor, Harza Northwest, also briefed the Council and the Corps on the results of its independent review of the Corps' interim study results.

Harza Northwest was retained by the Snake River Drawdown Oversight Committee (a Council committee) to review Corps analysis of each SCS alternative.

The Harza analysis report found that since this is a reconnaissance-level study, the conservative engineering and cost estimates the Corps used were appropriate, but there could be room for innovation in engineering techniques and cost and construction-time savings in later study and design phases. The report provided Harza's preliminary investigation of existing biological information on flow-survival relationships and causes of salmonid mortality, and indicated that available information is conflicting and inconclusive.

The Harza report recommended that a few of the alternative drawdown scenarios and the migratory canal alternatives be dropped from the study. Harza made specific recommendations for refining or expanding certain elements of the study, and for building upon existing biological studies and adding new ones to fill in information gaps.

On February 8 members of the Corps study team met to discuss these and other report recommendations with Harza, the Drawdown Committee and the Technical Advisory Group (TAG). (TAG includes representatives from the Corps, other Federal and State agencies, interest groups and the biological community.)

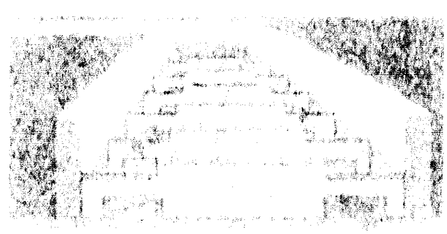
At this time the Corps plans to continue the reconnaissance level study of all alternatives covered in the Interim Report, so the region can have a more complete report on the various alternatives before dismissing any of these. In addition, the study will be expanded somewhat to include variations of the alternatives.

At the request of the Drawdown Committee, the concept of a single-pool drawdown (Lower Granite) was added to the alternatives under analysis. A one-pool drawdown would probably act as a precursor to the four-pool drawdown under study, but could allow the drawdown concept to be impiemented more quickly and provide research opportunities.

The study will be expanded to consider Harza's suggestion of using side channel spillways to allow juveniles to bypass the dams altogether. Channels would be built into the embankments flanking the dams with some sort of system to guide juveniles to the entrance to the channel and assure that adults continue to use the adult ladders.

Recommendations from Harza and others for using and expanding upon existing biological studies and for additional studies are being considered by the various regional players. Decisions at the end of Phase I of the SCS for deleting or adding alternatives for further study will be based on existing biological data.

Phase I studies are continuing, headed by the Corps' Walla Walla district. A final draft report is expected to be released to the region in the fall and will be followed by a series of public meetings. Your participation in these meetings will help to determine which alternatives will be retained or added for further study in Phase II of the SCS. We will keep you posted on the study report and meeting locations and schedules.



NEED FOR BIOLOGICAL INFORMATION

The lack of biological data to support decisions for listed Snake River salmon species is a serious challenge in the search for solutions. The Corps believes that more information on biological effects is needed to make meaningful decisions on flow augmentation, bypasses, spill, drawdown options, the juvenile transport program, and others. Biological information on ocean survival of adults and hatchery impacts on wild populations is also lacking.

Complicating Factors

Several factors complicate the search for sound biological data. The life cycle of salmon takes them from their place of origin, sometimes far upriver, to a two-to-five year adult life in the ocean before returning to spawn. Measuring the effects of an experimental action taken on a juvenile population often includes collecting data on returning adults to get a more complete picture. This can add five years to the length of a study before results are available for analysis.

Protection of listed species under the Endangered Species Act adds another consideration. The National Marine Fisheries Service may not be able to allow tests that might further endanger survival chances of a species already suffering from reduced populations. For example, modifications to the way dams are operated to determine effects on juvenile populations must carefully consider the potential side effects on returning adult populations.

Do We Need Biological Certainty

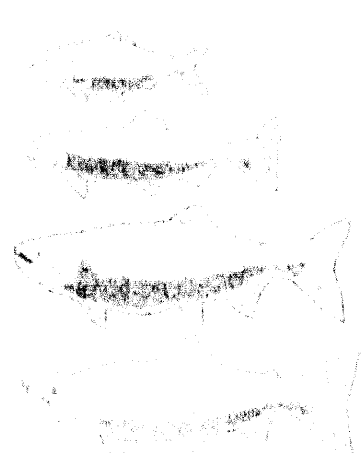
The Corps believes that the region should have a good idea of how fish will benefit by a certain course of action. While there is some information available, there is a need for more and better biological or scientific data to show that actions taken for fish will be beneficial and not harmful. Some potential actions are extremely costly and may neither benefit nor harm the fish, but would diminish the other beneficial uses of the river.

The Corps is working with the region through the Endangered Species Act consultation process, coordination and cooperation with other Federal agencies, participation in the Technical Advisory Group (of representatives from Federal and State agencies, interest groups and the biological community), and support of regional initiatives, to review available biological data and seek needed additional information.

Biological Tests

The Corps recently received a request from NMFS to cooperatively develop test procedures to better understand fish survival through the reservoirs under various conditions. One of the test conditions could include drawing down one or more reservoirs to levels below minimum operating pool to determine biological impacts of the drawdown. The test would require appropriate National Environmental Policy Act and Endangered Species Act documentation.

Our Walla Walla office is cooperating with NMFS in facilitating the planning and development of biological test procedures. We will provide further information as it becomes available.



LITIGATION UPDATE

In our September 1992 issue we described a number of lawsuits that have been filed against various Federal agencies under the Endangered Species Act concerning Columbia River System operations. As predicted, the number has grown, and the Corps, National Marine Fisheries Service, Bonneville Power Administration, Bureau of Reclamation, U.S. Department of the Interior's Fish and Wildlife Service and Bureau of Land Management and U.S. Department of Agriculture Forest Service are all facing potential battles in court. The Northwest Power Planning Council faces legal actions under the 1980 Northwest Power Planning Act.

The grounds for suits against the Federal agencies include harvest-, hatchery- and habitat-related actions or lack thereof, too much or too little augmented water flows for fish, insufficient consultation under the Endangered Species Act, and others.

Plaintiffs and intervenors include: the Sierra Club Legal Defense Fund, Direct Service Industries, the Public Power Council, regional port and irrigator associations, Pacific Northwest Generators, Northwest Forest Resource Council, Coalition for Idaho Water, Salmon for All, and the States of Washington and Oregon. (Some plaintiffs have filed for intervention in others' suits.) Several Indian Tribes and the Idaho Department of Fish and Game have filed for amicus status in some of the suits.

Suits have been filed in the United States District Court for the District of Oregon, the United States District Court for the Western District of Washington, and the Ninth Circuit Court of Appeals. The Justice Department is working with the Federal agencies to coordinate responses.

NMFS has now also received a 60-day Notice of Intent to sue concerning a permit application to continue the Corps of Engineers fish transport program. The Notice of Intent came from the National Resource Information Center, Inc., headquartered in Idaho.

1993 OPERATIONS FOR FISH

How is the coming passage season looking for upper Snake River salmon juveniles ready to begin migration to the ocean? What is being done to help move them safely past the dams, the maze of predators and other obstacles?

The Corps is looking ahead to the spring and summer operating season to plan flows for fish. The final Supplemental Environmental Impact Statement (SEIS) and Biological Assessment just released for public review, lay out a preferred plan of operations jointly prepared by the Corps, Bonneville Power Administration and Bureau of Reclamation. NMFS also informally cooperated in preparing the SEIS.

This year is shaping up to be another challenging year. Current forecasts indicate that this will be the seventh consecutive year of below average Snake River flows at Lower Granite and the second such year for flows at The Dalles on the Columbia River. Petitions to list the White Sturgeon and Bull Trout under the Endangered Species Act have agencies considering water levels in lake habitats of these resident fish while attempting to provide sufficient flows downstream for salmon. Additionally, a Notice of Intent to sue the NMFS, to prevent issuance of a permit to the Corps for collecting juvenile fish and barging them past the dams, may add a note of uncertainty. (See update on Litigation, this issue.)

[illegible]

The preferred plan for 1993 is similar to 1992 operations. River flows would be augmented to help move migrating juvenile fish, by timing water releases from upstream storage dams on the Columbia and Snake River dams. (Please see related article on the Water Budget.) From early April to the end of July lower Snake River reservoirs would be operated at the minimum levels for which they were designed to operate; and the John Day pool on the lower Columbia would be operated at lower than its normal level. These flow and operation regimes are designed to increase water velocities during juvenile migration periods. Releases of water in the late summer may also help to augment flows and regulate river temperatures during juvenile and adult salmon passage periods. At certain times, water will be "spilled" over the dams to push young fish over the spillways.

Non-flow Measures

We will continue a program called Project Improvements for Endangered Species (PIES) to make a number of mechanical, structural and operational improvements to fish passage systems. Construction of bypass facilities is scheduled to continue at Ice Harbor under the Juvenile Bypass Program. Research progresses on a variety of topics related to improved survival of salmon species, under the Corps' Fish Passage Development and Evaluation Program.

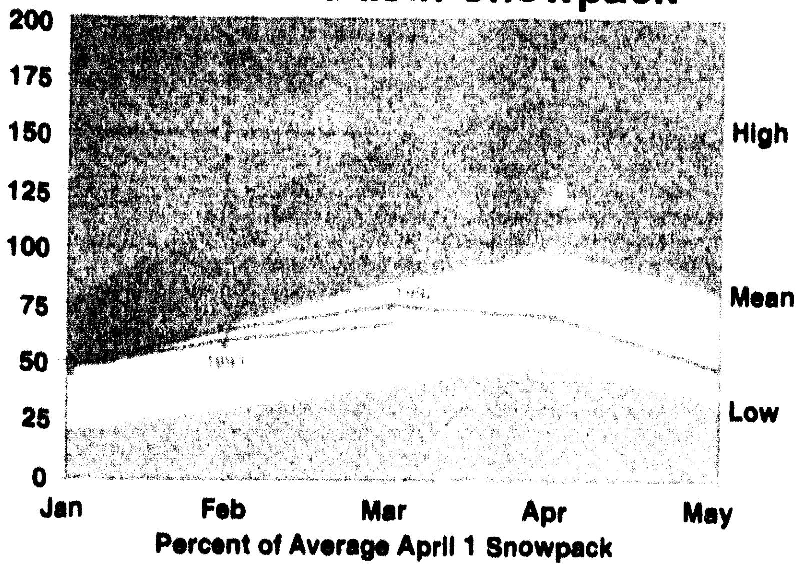
And, provided that NMFS issues a Section 10 permit requested by the Corps under the Endangered Species Act, the Juvenile Fish Transportation program will continue. Through this program the Corps collects smolts at upstream dams and barges them past the remaining downstream dams.

The challenge will be to do even more to monitor and shape water flows in a potentially low water year and to continue studies for fish in cooperation with the region, while responding to multiple lawsuits and continuing to meet the needs of a variety of river users.

Releases of water from Dworshak Reservoir in Idaho help to augment flows and regulate water temperatures during Snake River salmon migrations.

"This year is shaping up to be another challenging year. Current forecasts indicate that this will be the seventh consecutive year of below average Snake River flows at Lower Granite and the second such year for flows at The Dalles on the Columbia River."

Columbia Basin Snowpack



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Salmon Passage Notes

Snake and Columbia River Fish Programs December 1992

The Corps is evaluating a series of alternative ways to reconfigure or physically modify the federal hydropower system on the lower Columbia and Snake rivers to improve migration conditions for salmon. The System Configuration Study (SCS) examines measures identified by the Northwest Power Planning Council in its Fish and Wildlife Program Amendments.

This issue of Salmon Passage Notes provides a summary of study results so far. The summary is based on information in an Interim Status Report the Corps has prepared at the Power Council's request.

The Interim Status Report contains preliminary design, cost and construction schedule estimates for each of the alternatives. Benefits to fish from the various alternatives under study, and analysis of environmental and economic effects will be addressed in the full study report which will be presented to the region in late 1993.

INTERIM STATUS REPORT

The Corps of Engineers is conducting a System Configuration Study (SCS) of alternative configurations or physical modifications that can be made to the federal dams and reservoirs on the Columbia and Snake rivers to improve anadromous fish survival. The study examines the engineering, environmental, and economic effects of the alternatives. It was initiated in response to increasing competition among rivers users and in support of the Northwest Power Planning Council Fish and Wildlife Program amendments.

The Corps has produced an Interim Status Report of study results to date. It contains preliminary design and cost information on the alternatives examined, and gives estimates of completion times for engineering designs, planning and construction.

A complete preliminary analysis of the alternatives, including expected benefits to salmon, will be presented in the full report to the region expected in late 1993.

A brief summary of information on each of the alternatives included in the Interim Status Report follows.

LOWER SNAKE RIVER DRAWDOWN

Annual lowering of pool levels at the four lower Snake projects (Lower Granite, Little Goose, Lower Monumental and Ice Harbor) is being considered as one way to improve downstream migration of juvenile salmon. The objective is to increase river velocities and thereby, theoretically, reduce the travel time for smolts to reach the ocean.

The Interim Status Report includes an evaluation of the technical feasibility of making the necessary modifications to the lower Snake projects to enable operation under extreme drawdown conditions and, at the same time, maintain safe and effective juvenile and adult fish passage through the four-project area.

Three basic drawdown concepts are being considered. First are the **variable pool** alternatives. Once a desired drawdown level is achieved, the pool is allowed to fluctuate above or below that level as river flows change.

The second concept maintains a **constant pool** level at the desired drawdown elevation regardless of river flow fluctuations.

The third concept would be complete drawdown to a free flowing **natural river** condition (near pre-dam).

From an initial consideration of 21 options in these categories, nine of the most promising alternatives were evaluated in detail. These are:

- two variable pool options—with or without powerhouse modifications
- three constant pool options with existing powerhouse (existing, modified, or new low level spillway)
- three constant pool options with modified powerhouse (existing, modified, or new low level spillway)
- "natural river" option

Costs for implementing the drawdown alternatives at the four lower Snake River dams range from $1.3 billion to $4.9 billion. These amounts include design, engineering and construction management costs, and costs of real estate, but not the required biological research, feasibility studies nor model studies. These estimated costs do not include economic effects of drawdown nor costs of potential mitigation strategies.

Implementation time will vary, depending on the alternative selected. Modifications to the four dams are anticipated to take from 14 to 17 years to complete assuming full and continuing funding from start to finish.

Every drawdown measure will require significant modifications at each dam and to many facilities located along existing reservoirs. All except the natural river option require new juvenile bypass facilities.

All the options would stop commercial navigation and fish barging operations during times reservoir elevations are below minimum operating levels. Juvenile fish would have to transit every dam and reservoir from Lewiston to McNary Dam rather than being collected and transported.

Power production would be less during the drawdown period due to reduced pool elevation, loss of turbine efficiency, and shutdown of turbines at drawdowns below their operating range.

Because of these unknown and known effects, there are a number of studies that must be accomplished prior to implementing any of the drawdown options. These include additional engineering, operational, biological, environmental and economic evaluations and planning for mitigation measures. Biological effectiveness of drawdown is perhaps the most important focus of further evaluations.

JOHN DAY MINIMUM OPERATING POOL

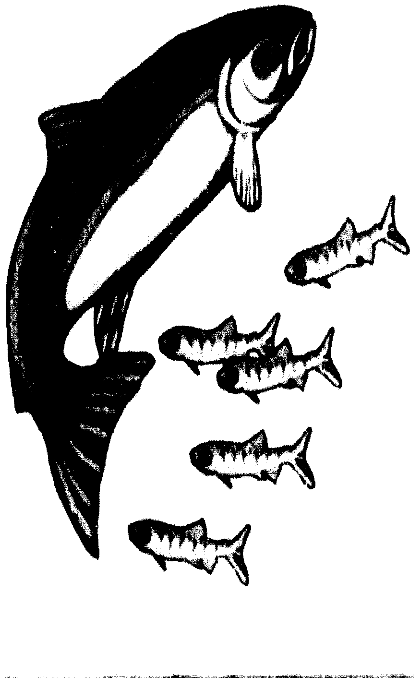
Drawdown of the John Day reservoir on the Columbia River to its minimum operating pool is also under consideration. Under this measure, the reservoir would be operated from May 1 to August 31 at elevation 257, which is eight to ten feet lower than its normal operating range. Again, the objective is increased river velocities for migrating juveniles.

To operate at minimum operating pool for extended periods, certain measures would be necessary to mitigate impacts to surrounding facilities and structures, other water users, and fish and wildlife.

For example, boating and fishing access to Lake Umatilla would be affected when water levels fall below the reach of docks. Fish and wildlife habitat would change—wetland areas would dry up temporarily and land bridging to some islands would occur allowing access by predators. Irrigators, hatchery managers, and municipal, private and commercial water users would feel impacts of lower water levels at their pumps and wells.

These impacts can be mitigated. Recreation areas and docking facilities can be modified by extending or dredging around boat ramps and extending swimming beaches.

For fish and wildlife, land bridged islands could be reconstructed. Offsetting wildlife habitat acreage could be purchased and developed. Backwater areas could be diked, and water pumped in to keep wetland levels constant, although this option is less attractive due to high costs and construction impacts of the massive infrastructure that would be needed. Another option would be to draw down the reservoir to elevation 257 year-round to allow habitat and wildlife to adapt to the lower level.



Irrigation pumps can be modified, replaced or relocated depending upon the drawdown effects. The potential for building an irrigation canal along the Oregon and Washington shorelines is also under consideration. Water treatment plants and modifications to wells can mitigate effects to municipal, private and commercial water supplies and the hatcheries. A water reuse system could be installed at the hatcheries.

The total cost estimate for implementing mitigation measures would be in excess of $77 million. Annual average maintenance costs are estimated at $5.3 million. Some impacts, such as the loss of shallow water habitat for resident fish, cannot be mitigated and would be considered a loss.

UPSTREAM COLLECTION AND CONVEYANCE

This alternative combines the idea of collecting juvenile fish upstream of Lower Granite, with new or better ways of moving them downstream past the dams.

It is estimated that as many as 30 to 60 percent of fish die before reaching Lower Granite Dam. Construction of collector systems farther upstream might help reduce these losses, by reducing exposure to predation or other mishap. Two possible sites are being considered. One, called the Silcott site, is seven miles downstream of Lewiston, Idaho. The other is a dual collector with facilities on both the Snake and Clearwater rivers, upstream of Lewiston.

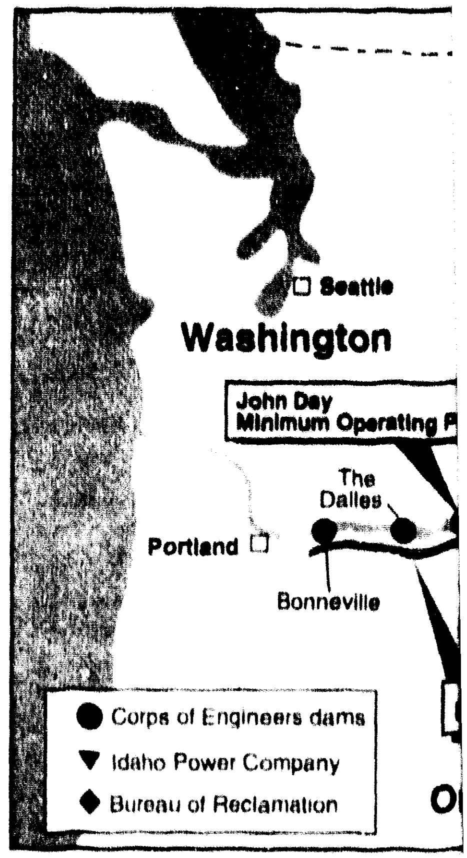
Several new transport systems are being studied in conjunction with the upstream collector. One of these is an open concrete canal to carry juveniles past the dams from the new collector facility to below Bonneville Dam, about 350 miles downstream. It would be elevated at its upstream end and built on a continuously declining slope using gravity to move water and fish.

Another option being examined is a large diameter steel or concrete pipe section buried along the shoreline. The intakes and exits of the pipeline would be submerged to create a pressure system to move water through.

In contained systems such as these, provision must be made to allow the juveniles to rest and feed, and get a chemical imprint of the river so they can return to spawning areas as adults. Both the canal and pipeline systems would provide ponds every ten miles for feedi[ng] and resting, and exchange of river wate[r]. Over a 350 mile stretch, 35 of these are would be needed.

Although barging fish is not a new idea, it is an option for moving fish fro[m] the potential new collector sites. Costs and effects of an expanded and improve[d] barge fleet are being analyzed under the collector/conveyance alternative.

The final fish transport alternative i[s a] flexible, thin-membrane, in-reservoir conduit, proposed by Idaho National Engineering Laboratory. A built-in



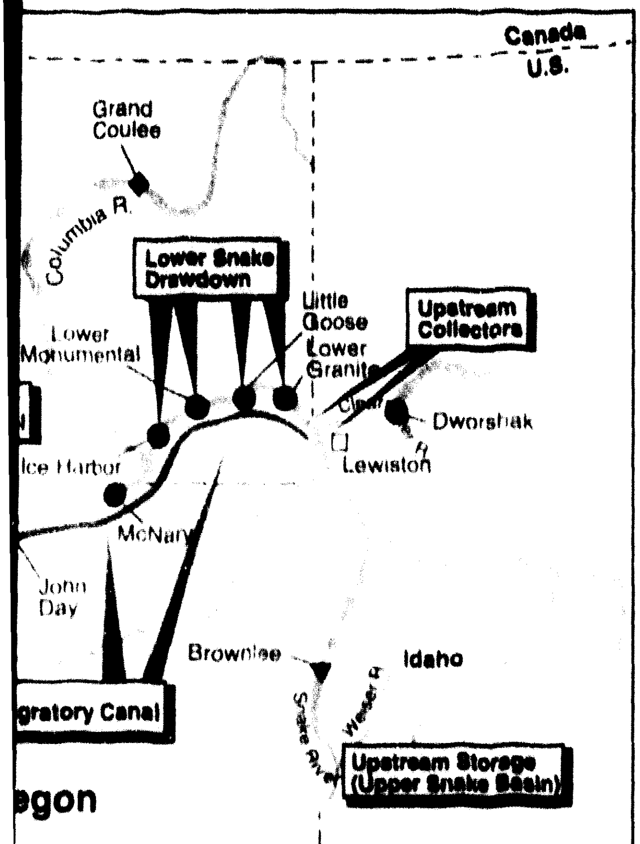
mechanical system would keep water flowing through at an appropriate speed for juvenile migration. Net pens in the reservoir would provide resting areas.

The preliminary cost estimates to construct the canal or pipeline and collector systems range from $5.4 billion to $6.1 billion, with annual operating and maintenance costs of from $9.5 million to $10.6 million. Costs for the improved barge/collector system range from $641 million to $991 million, with annual costs to operate and maintain of around $5 million. Costs to construct the in-reservoi[r] conduit and collector system range from $1.1 billion to $1.41 billion, with annual costs of around $32 million to operate and maintain.

The entire start-to-finish process for the canal/collector alternatives would take 15 to 20 years. Expanding and improving the barge fleet would require eight years to plan, design and construct, including the new collector.

SYSTEM IMPROVEMENTS

This alternative examines potential improvements to juvenile and adult fish passage facilities, the juvenile fish transportation program, fish hatcheries and to the projects themselves. The objective is to reduce fish stress, predation, and



physical injury.

One option is to replace existing turbines on the lower Columbia and Snake projects with newer models. Modern turbines produce power more efficiently and would minimize mortality for fish not collected in the bypass/transport system. This improvement would not have construction impacts on fish or other water users.

A relatively simple concept for improving juvenile survival is to periodically change the release sites from bypass facilities so that predators don't learn where the fish are deposited. Two hundred-foot bypass flumes/pipes could be installed with multiple drop gates. These changes could be made at McNary, Little Goose and Lower Monumental dams in less than three years per project at a cost of $957 thousand to $1.25 million at each. Other improvements under study include:

- ◆ construct sun shelters at raceways to protect fish from too much light exposure and high temperatures
- ◆ transport juveniles in net pens, buoyed by four-foot diameter pontoons, instead of barges
- ◆ construct additional, better-designed fish barges
- ◆ reduce water temperatures in adult fish ladders
- ◆ install another ladder at dams that have only one
- ◆ expand hatchery facilities and renovate Dworshak hatchery.

The costs for these improvements range from $600,000 for modifications to adult collection channels at McNary (to correct velocity problems) to $190 million to modify spillways/stilling basins at the lower Snake River projects to improve performance.

UPSTREAM STORAGE

This option studies potential sites for additional storage of water for use in flow augmentation. Additional upstream storage would expand the capacity to moderate flows and temperature in the Snake River for facilitating fish migration. The Bureau of Reclamation is continuing its inventory of sites begun as a result of commitments made at the Salmon Summit. The Bureau will provide by the end of 1993 a preliminary evaluation of potential sites. The Corps is participating in that effort and has included in the SCS Interim Status Report one potential site on the Weiser River in western central Idaho—the Galloway site.

The Galloway site is located at river mile 13 of the Weiser River, which enters the Snake River just above the town of Weiser. Because of previous studies the Corps has extensive information on the site. The river basin has two attractive characteristics for use in flow augmentation. First, the average runoff exceeds basin needs and use. Second, the basin's elevation is lower than the rest of the upper Snake River basin, providing earlier spring runoff by a month or two, and giving an opportunity to trap flows for later use. It is estimated that 900,000 acre-feet of water could be stored at Galloway.

As with all proposed dams, there would be some impact on local life, including roads, an irrigation canal, a railroad spur, and, of course, fish and wildlife. No study has yet been done on effects on cultural resources.

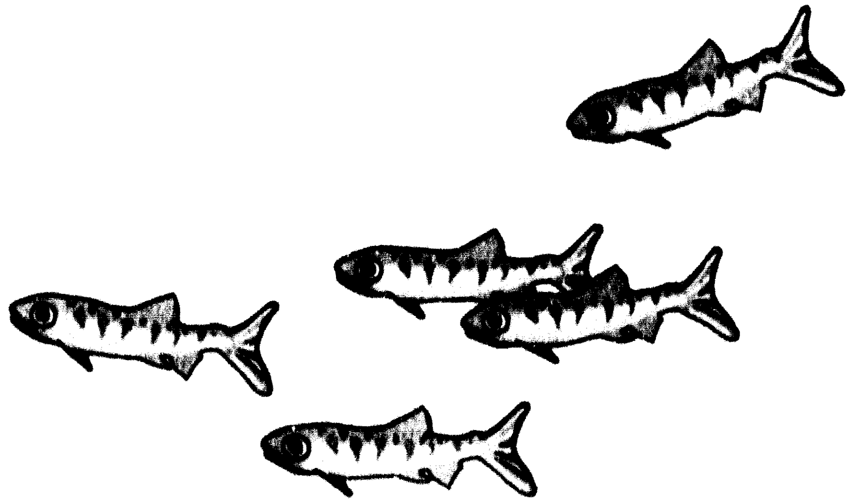
Total project costs to construct are estimated at $215 million.

THE NEXT STEP

Of course, cost and schedule information alone are not sufficient for making decisions on how to make improvements for fish. A critical piece of information is an analysis of potential effects of each of the alternatives on fish passage and survival.

The Corps' complete preliminary evaluation of these alternatives, the Phase I report, will contain this needed analysis, as well as other environmental and economic effects, and the impacts to power generation.

The Corps will continue to consult and coordinate with other federal and state agencies and regional interests in preparing the report, and will keep the public informed of progress. The Phase I report will be presented to the region in late 1993.



SUMMARY OF COSTS AND SCHEDULES

Lower Snake Drawdown	Cost ($billions)	Constr (yrs)
Variable Pool Options	1.3 to 1.7	14
Constant Pool Options	1.3 to 3.8	14 to 17
Natural River Option	4.9	17
John Day Reservoir Drawdown	.077	*
Upstream Storage		
Galloway Dam	.215	11
Other Sites	*	*
Collection and Conveyance		
Conduit and Silcott Collector	5.7 to 6.0	15 to 20
Conduit and Clearwater/Snake Collector	5.4 to 6.1	15 to 20

* Information under development

Copies of the Interim Status Summary Report and a full set of Technical Appendices, one for each alternative analyzed, are available at the main public library in several cities and municipalities in the region. If not at your library, please call Adele Merchant for further information at (503) 326-3417, or write to her attention at U.S. Army Corps of Engineers CENPD-PM-CP, P.O. Box 2870, Portland, OR 97208-2870.

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Salmon Passage Notes

Hatchery vs. Wild Salmon

Lewis and Clark opened the eyes of the nation to vast economic opportunities in the Northwest. In their journals they recorded seeing awesome numbers of salmon, and noted the ways in which they were being utilized and even worshipped by the Native Americans. Soon the fish did not belong to the natives alone. Fishing had become big business for new settlers.

Commercial and sport fisheries were established and a new industry — salmon

[illegible] Fish Hatchery [illegible] on the Clackamas River [illegible] three satellite fish traps and [illegible] 2.5 million [illegible] chinook annually [illegible] National Fish Hatchery.

canning — entered the picture in 1866. By the mid-1880s regional leaders were becoming concerned about the threat over-fishing posed to continued runs.

In 1894 an Oregon Fish and Game publication stated: "It is only a matter of a few years under present conditions when the chinook of the Columbia will be as scarce as the beaver that once was so plentiful in our streams. They are quickly disappearing and threatened with annihilation."

In 1887 Congress directed the Corps of Engineers to investigate the condition of the salmon fisheries of the Columbia. In its 1888 report to Congress, the Corps noted "an enormous reduction in the numbers of spawning fish, brought about through this fishing industry." A thriving gillnet industry, fish wheels and other harvesting techniques were severely depleting the fish runs. At their peak, fish wheels alone harvested more than one million pounds of salmon per year. Also cited as a factor in fish run reductions was "... stream pollution."

The report concluded "... enough is known to show that hatcheries and a weekly closed season should be established without delay."

By the time construction began on Bonneville Dam in 1933, the extent of depletion of the runs was not yet known. When Bonneville was completed in 1938, its built-in fish ladders went into operation and more accurate counting of returning adult salmon became possible. The region was shocked to learn just how greatly the runs, once estimated between 11 to 16 million strong, had been decimated. Fewer than one-half million salmon passed over Bonneville in that first year of operation.

More than 100 years after the first alarms were raised, the threats to the Northwest salmon runs continue. Today the blame is shared by dams, habitat destruction, navigation, irrigation, the fishing industry — commercial, sport and tribal — and the general encroachments of civilization. Even hatcheries, created to increase fish populations, are considered by some to be harming the remaining wild fish runs.

The first Oregon hatchery was built on the Clackamas River in 1877 by a commercial canning group to increase the numbers of fish available for harvest. State and federal interests took over fish propagation in 1890. Their goal was still to produce more fish to support commercial fisheries. By 1900, 18 Washington hatcheries augmented existing fisheries. In more recent times, facilities were built to mitigate for losses caused by construction or other environmental changes resulting from development.

Today there are some 64 hatcheries and 29 satellite facilities raising salmon and steelhead for release in the Columbia system. Production is approaching 200 million fish annually and supports the bulk of the total annual adult production of 2.5 to 3 million salmon and steelhead. According to U.S. Fish and Wildlife Service estimates (198[illegible]), hatchery fish comprise over 95 percent of the coho, 70 percent of the spring chinook, about 80 percent of the summer chinook, over 80 percent of the fall chinook, and about 70 percent of the steelhead produced in the basin.

State and federal hatcheries are authorized primarily under provisions of the Mitchell Act (Public Law 75-502), enacted on May 11, 1938, and amended in 1946, and the Lower Snake River Fish and Wildlife Compensation Plan. The Mitchell Act originally funded lower Columbia River hatcheries to offset, or in response to, changes related to construction of Bonneville and Grand Coulee dams and other human activities adversely affecting fish. The Lower Snake River Fish and Wildlife Compensation Plan was authorized by the Water Resources Development Act of 1976 to mitigate impacts to fish and wildlife attributed to construction of the four lower Snake River locks and dams. Among other things, the Plan called for the Corps of Engineers to construct 10 chinook salmon and steelhead

Hatchery continued...

hatcheries in Idaho, Oregon and Washington. Costs of these hatcheries are being repaid to the U. S. Treasury, with interest, from revenues collected from sales of electricity generated at federal hydro-projects.

Production from Plan hatcheries is designed to return 58,700 spring/summer chinook, 55,100 steelhead and 18,300 fall chinook to the impacted area. The Clearwater Fish Hatchery in Idaho, the final and largest hatchery constructed under the Plan has been completed and was dedicated August 22.

Another major hatchery constructed by the Corps to provide mitigation for a specific project is Dworshak National Fish Hatchery in Idaho. Construction of Dworshak Dam and Reservoir blocked the migration path of North Fork Clearwater River steelhead.

Though the Corps constructed a number of hatcheries in the Northwest it does not operate or manage any of them. State and most federal hatcheries are managed and operated by the Oregon Department of Fish and Wildlife, Idaho Department of Fish and Game, and the Washington departments of Fisheries and Wildlife. States receive operating funds for the federal hatcheries through the National Marine Fisheries and U. S. Fish and Wildlife services. USFWS also operates 13 hatcheries in the basin.

Today the benefits of hatchery production are being questioned. Opponents say "inferior" hatchery fish are further reducing wild runs, by competing for food, spreading disease and creating harvest opportunities in which wild fish are taken along with the hatchery fish (mixed harvest).

There is also a question whether hatchery fish are as genetically equipped for survival as wild stocks that have gone through a natural selection process. Unlike wild fish who have had time to become stream smart, hatchery fish are new to the natural environment when released, and must immediately learn to fear predators and deal with other threats and dangers of the wild. Often they have only one chance to learn to fear and escape a predator.

Another concern is that wild (natural) fish are taken for hatchery brood stock, reducing natural production and--depending on management practices--affecting the genetic integrity of both groups.

A higher percentage of wild fish do survive to maturity from the migratory juvenile (smolt) stage to adult. Survival from egg to smolt, however, is higher for hatchery fish because of the care taken of the eggs. Generally, hatcheries produce more returning adults per spawning female than do wild populations because more eggs survive to the juvenile stage.

On the plus side, more commercial and sports catches are possible because hatchery fish are in the equation. Wild fish alone would not support the industry. Recreational opportunities mean enjoyment for residents and tourist dollars for the region.

Some charge that harvests of mixed fisheries (wild and hatchery) are depleting wild fish. Harvest levels based on total fish, they contend, make quotas too high. Because the percentage of returning hatchery fish is higher than the percentage of wild fish, critics argue that a greater number of wild fish are taken than is reasonable to assure their survival.

For example, to sustain a hypothetical run of 4,000 hatchery fish and 1,000 wild fish, a return of 500 spawning adults in each category would be needed. If a 75 percent harvest were authorized, there would still be 1,000 hatchery adults after the harvest, but only 250 wild adults--half the number needed to sustain the wild population.

Today, hatchery and harvest management criteria are changing to address many of those issues. Endangered Species Act listings and the wild-versus-hatchery conflict have the region analyzing where the hatchery program has been, where it is going, and whether or not it is meeting identified goals.

"Often they have only one chance to learn to fear and escape a predator."

Phase three of the Northwest Power Planning Council's Columbia River Basin Fish and Wildlife Program amendment process is seeking to address a number of issues, including fish production, both in the wild and in hatcheries, and improvement of spawning and rearing habitat.

The use of native stocks in hatchery programs has increased and greater emphasis is placed on retaining, as much as possible, the genetic characteristics of the stock from which the broodstock was obtained. Avoided are practices that would result in selective breeding or inbreeding. The goal is to mimic the genetic diversity of existing natural runs.

There are three basic hatchery operational concepts. In the first, fish are reared in the hatchery and then released into a the stream that feeds the hatchery. Fish handled in this way will return to the hatchery to spawn.

Another practice is called supplementation where the intent is to increase depressed naturally-producing stocks. Hatchery fish are "outplanted" at specific locations or river reaches where enhancement is needed. Rather than returning to the hatchery, adults return to the selected habitat areas to spawn naturally.

The third concept involves hatchery satellites or acclimation ponds at selected locations where a fishery is desired or where stream conditions are more favorable when the fish return as adults. Fish from hatcheries are moved to a satellite or acclimation pond and released. As adults, these fish will return to the satellite or pond to spawn. Eggs from these fish are taken to the hatchery to produce the next generation.

The reasons for building hatcheries and the way they are managed have evolved as the human population has grown and resource needs have changed. The debate over the performance of hatcheries and their future role is far from over. The next few years are likely to be the most important period in the history of salmon resource development in the Columbia River Basin. Though hatcheries are not the total solution, they may be part of the solution.

Fisheries experts expect efforts to integrate natural and artificial production into a comprehensive fish production program will continue and even intensify. Fishery managers will also need to take a broader view and consider the unique management problems posed by domestic and international fisheries outside the Basin. A more focused and intensive research effort and application of results is needed to improve the control of fish diseases, reduce mainstem mortality and increase hatchery and wild production. There is also a need for increased sharing of expertise and coordination between all hatchery managers—Washington, Oregon, Idaho and federal—so all will be working under similar guidelines and toward common and regional goals.

Special Interests File Suits

Industry and environmental groups have filed lawsuits claiming that, in implementing the 1992 plan for operating the Columbia River system, the National Marine Fisheries Service, Bonneville Power Administration, Corps of Engineers, Bureau of Reclamation, and other involved federal agencies did not satisfy the comprehensive assessment and consultation requirements of the Endangered Species Act.

Environmental and fishery groups, represented by the Seattle-based Sierra Club Legal Defense Fund, allege that the government did not alter 1992 hydropower operations of the Columbia system sufficiently to assure survival of threatened and endangered salmon.

In addition, they say NMFS and the federal operating agencies used a "biologically and legally unsound concept of 'jeopardy'" and limited their consultation to a single year of river operations rather than considering long-term effects on the listed species.

Industry and user groups also filed claims saying that the 1992 plan relies too heavily on augmenting stream flows to improve salmon survival and that the NMFS is failing to adequately protect Snake River salmon by not limiting harvest and other activities that adversely affect their survival.

The Pacific Northwest Generating Cooperative, a group of 29 rural electric cooperatives with 750,000 customers in eight Western states, seeks, among other things, an injunction requiring consultation on activities likely to affect the listed salmon species to include the effects of harvest regulations, habitat management and hatchery practices.

Another group, Direct Service Industries, consisting of aluminum, titanium and chemical manufacturers in Oregon, Washington and Montana, filed a similar suit seeking consultation on harvest, land management and hatchery operations.

The group also filed to intervene in the Sierra Club Legal Defense Fund suit. They contend that the decision to provide increased summer flows and additional spill, intended to flush young fish downstream, is not supported by the best scientific evidence available.

The Sierra Club Legal Defense Fund has also filed a notice of intent to sue the U.S. Forest Service claiming that it has failed to protect the habitat of the threatened chinook salmon on the Umatilla and Wallowa-Whitman national forests in Eastern Oregon and Washington.

And just before press time, still another Portland-based group, the Public Power Council, which represents consumer-owned utilities in the Northwest, filed a lawsuit claiming the government has not done enough to protect threatened and endangered salmon and challenging the consultation process as it relates to salmon harvest, habitat and hatcheries.

We in the Corps would much rather the litigants, instead of suing, would have continued to work with the involved agencies and the region in fashioning a balanced and regionally acceptable solution to the salmon problem.

Now that the litigation has begun, there likely will be more suits and countersuits which can only hinder, not help, the salmon recovery process.

As of September 10, 1992, over 17.5 million juvenile salmon have been collected at Lower Granite, Little Goose and McNary dams and transported to below Bonneville Dam where they are returned to the river to complete their migration to the ocean on their own.

Though numbers of migrating fish get smaller toward the end of the migration season, the fishery agencies are calling for continued transport through the end of October at Lower Granite and Little Goose and through the end of December at McNary as some of the stragglers may be either threatened chinook or endangered sockeye salmon.

New collection and bypass facilities were completed and submerged traveling screens were installed at Lower Monumental Lock and Dam in time for this year's outmigration season. Bypassed juvenile salmon take a ride in this open flume which carries them from the dam to the holding facility where they may be loaded into barges or tanker trucks for transport or returned to the river. As the loading facility is under construction and will not be available for use until next season, fish are currently being bypassed to the river.

Study Update

In July, the Corps held a series of public meetings across the region to inform the public of some of our actions and studies for improving salmon migration conditions. Topics discussed in the presentation/workshop forums included: preliminary results of the March drawdown test of Lower Granite and Little Goose reservoirs; the Corps' intent to prepare a supplement to the 1992 Options Analysis Environmental Impact Statement (EIS); and, the alternatives to be evaluated under the System Configuration Study (SCS).

The meetings were well attended. We heard a number of concerns from the public about costs of measures to modify dams and system operation, equitable distribution of the sacrifice that may be necessary to improve salmon survival, and the importance of determining the biological effectiveness of the various alternatives before pursuing costly changes. The Corps was able to share some preliminary conceptual designs for SCS alternatives and to present slides of the drawdown test.

The SCS phase one reconnaissance level study efforts are underway at the Walla Walla, Portland, and Seattle Districts. An interim report will be available in December for review by the Northwest Power Planning Council and the public.

The draft report of findings of the March test drawdown of Lower Granite reservoir is expected to be completed in early fall and available for public review. Our April ... reported it would be out in June. That date proved to be unrealistic given the enormous quantities of physical and environmental data that were collected and the number of various agencies and contractors that were (and are) involved in the test and data analysis.

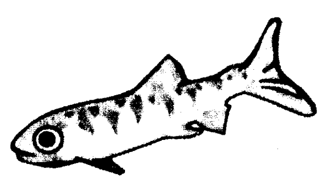
Delays have occurred as a result of complications in data analysis. Dramatic changes in Snake River flows due to spill tests that were conducted during the drawdown complicated analysis of water quality and water velocity and other data. Additional efforts in analyzing this data will result in a more accurate understanding of the effects of drawdown on dissolved gas supersaturation, water velocity, resident fish and other test objectives.

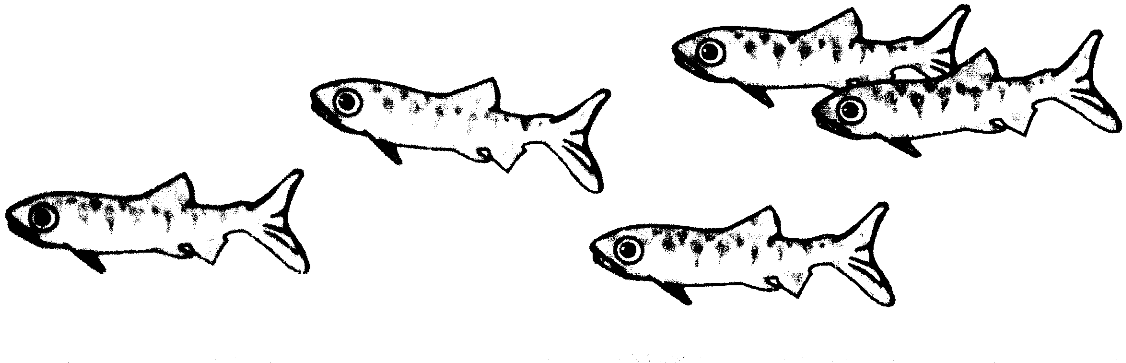
The Corps is producing a Supplemental EIS to address the operation of the Federal Columbia River Power System for 1993 and future years. In January the Corps released the final 1992 Columbia River Salmon Flow Measures Options Analysis EIS. This document analyzed effects of various alternative operation changes and water management options for 1992 operations, for dams and reservoirs on the lower Columbia and Snake rivers, to improve salmon migration conditions. The Corps is preparing the Supplemental EIS with Bonneville Power Administration, Bureau of Reclamation and the National Marine Fisheries Service (NMFS) as cooperating agencies.

It will address water management activities for 1993 and future years until results of several ongoing studies including SCS, System Operation Review and the salmon recovery plan to be issued by NMFS may be incorporated into a longterm water management plan. A draft of the Supplemental EIS will be available for public review in late October. A series of public meetings will follow.

We will keep you posted as further information becomes available on public meeting times and locations. To be placed on a mailing list for a specific report, call 509-522-6944 and leave your name and address, and the report you are interested in.

The Columbia River System Operation Review (SOR) team has announced a series of public meetings in September to obtain public input on ten strategies being considered for full-scale analysis under that study. The SOR is a joint effort by the Corps, Bonneville Power Administration, and the Bureau of Reclamation to review multipurpose management of the Columbia River System and provide a strategy for system operation. For more information call the SOR Interagency Team at 1-800-622-4519 (230-3478 in Portland), or write to P.O. Box 2988, Portland, OR 97208-2988.





The Corps of Engineers is holding its annual meeting to present research results of the Fish Passage Development and Evaluation Program (FPDEP).

The meeting will be held October 26 from 8:30 a.m. to 4 p.m. at the Portland District building, Robert Duncan Plaza, 333 SW 1st, 3rd floor Conference Center. The public is invited to attend.

The FPDEP has developed and coordinated biological and engineering research to improve anadromous fish passage activities at Corps dams since 1952. Research has resulted in refinements to adult fish passage facilities, development of the juvenile fish transportation program, and development of existing or planned juvenile fish bypass facilities at all eight of the Corps' lower Columbia and Snake river projects.

Current research includes studies of the condition of transported chinook, effectiveness of longer fish screens in diverting juveniles away from turbines, adult fish migration and project passage on the lower Snake River, juvenile fish passage survival, improved fish guidance efficiency (FGE) of bypass systems and improved fish transportation methods.

FPDEP study leaders will report on the status and results to date of research on the following topics. A question and answer period will follow each presentation.

Tests of prototype extended-length juvenile fish screens at McNary dam.

Underwater video observations of fish response to the McNary extended-length screens, standard-length screens and vertical barrier screens.

Evaluations of technologies for non-lethal measurement of fish guidance efficiency (FGE).

Evaluation of the new juvenile bypass system at Lower Monumental dam.

Evaluate Bacterial Kidney Disease levels in transported chinook salmon.

Evaluation of transport: Tongue Point release site study.

Improved fish collection, handling, and transportation techniques: scale analyses.

Evaluation of collection, holding, and transport facilities.

Evaluate factors affecting chinook salmon FGE.

Bonneville first powerhouse survival and project survival assessment.

Bonneville first powerhouse FGE determination.

Adult fish migration on the lower Snake River (radio-tracking).

Adult fish passage evaluations at Little Goose and Lower Granite dams (electronic tunnels and radio-tracking studies).

FOR MORE INFORMATION contact: Rudd Turner, 503-326-3829, or John Ferguson, 503-326-6482.

Salmon Passage Notes is published by the North Pacific Division of the U.S. Army Corps of Engineers.

If you would like to be added to our mailing list, or if you have questions or comments, please write to:

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Welcome to SALMON PASSAGE NOTES DIGEST

This publication is dedicated to letting you know what the U.S. Army Corps of Engineers is doing to aid the migration of salmon and steelhead past the dams operated by the Corps on the Columbia and Snake rivers.

So far we have published three issues of ***Salmon Passage Notes*** [illegible]

The bypass systems that guide fish around the dams.

A long-term study of structural modifications that may be made to the dams to aid fish passage.

A report on Drawdown '92.

We hope you find ***Salmon Passage Notes*** informative and useful. Please pass it on to others who are concerned about rebuilding our salmon and steelhead populations.

[illegible]

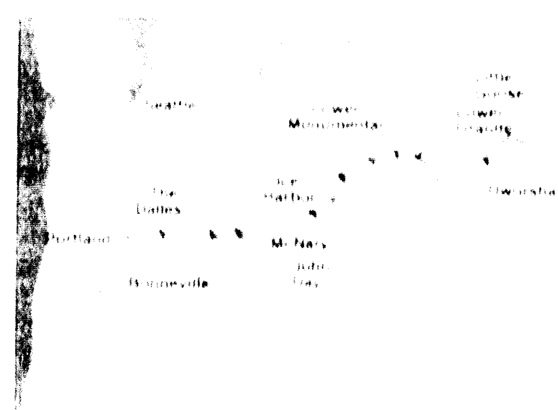
Fish Bypass Projects On The Snake and Columbia Rivers

A migrating five-inch chinook salmon starting down the rapids of the Snake River faces a long and perilous journey. Among the trials awaiting it on the way to the ocean are the hazards of passing the turbines at eight dams on the Snake and lower Columbia. As part of the regional program to protect and restore salmon runs, the Corps of Engineers is working to make that passage safer.

[illegible]

through the screens and rejoins the current passing underneath them on the way to the turbines. A portion of the flow is diverted by the screens to guide fish upward into a slot in the top of the intake passage. Once in this vertical channel, perforated barriers direct the fish into a bypass sluiceway while allowing more of the water to flow back to the turbine intakes.

[illegible]

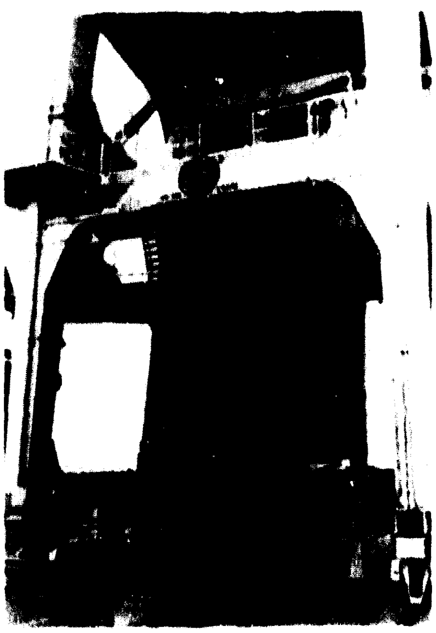


[illegible]

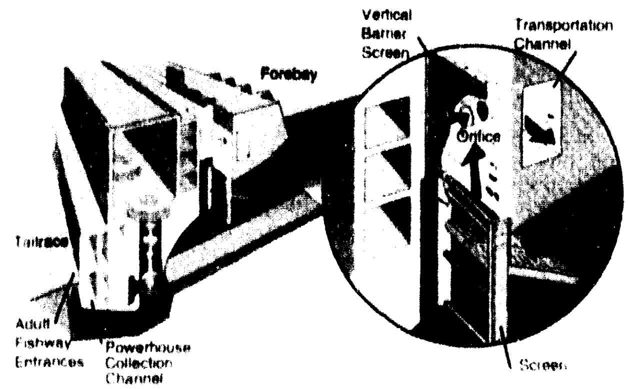
Because of their complexity, turbine bypass systems are a challenge to design and construct. Each is initially tailored to a particular dam and extensive follow-up research is conducted to improve efficiency. Frequent coordination meetings with tribes and agencies are a key part of the design and construction cycle.

One of the operating problems is keeping the screens from being clogged by debris carried in the water. The current "travelling screen" design uses an endless belt of heavy nylon mesh mounted like a vertical treadmill. When the belt moves, the mesh that was on the upstream side of the belt moves to the downstream side, and debris that has accumulated on it is carried off by the current. Another design under test uses stationary vertical bars that are cleaned by a brush periodically sweeping across them to dislodge debris.

Whatever the design, the diversion screens are huge, and expensive to build and maintain. Each one is 20 feet wide and 20 to 40 feet long. The frameworks that support them are built of massive steel girders to withstand the pressure of fast-moving water and the impact of floating debris. The 20-foot screens weigh some 30 tons — about as much as 20 full-size automobiles. The extended screens being tested weigh up to 65 tons each. At The Dalles dam alone, 66 of these massive devices are needed to guide the migrating fish out of the flow being drawn into the turbines.



The screens that guide migrating fish out of intake passages and into bypass facilities weigh many tons. Each turbine requires three of these massive structures.



Fish diversion screens are set in the upper part of turbine intake passages, where most migrating fish swim.

The bypass channels that carry diverted fish around the dams are also complex. Designs vary from dam to dam, but a typical installation is a flume eight feet wide and eight feet deep, carrying about 200 cubic feet of water per second.

In addition to the diversion screens and bypass channels, other extensive work goes into a bypass system. Using hydraulic models, Corps researchers have found that fish diversion is improved by modifying the massive intake gates that shut off the water to the turbines during maintenance. That work has been scheduled. Testing and installing extended-length screens also requires new gantry cranes that can handle the additional length and weight of the extended designs.

The Corps of Engineers is now working to install a complete system of bypasses at all eight dams on the Snake and lower Columbia. The Corps' fiscal year 1991 salmon programs include $17.5 million for the construction of fish bypass facilities at Lower Granite, Little Goose, Lower Monumental and Ice Harbor dams on the Snake, and McNary and The Dalles on the lower Columbia. There is also $1 million in the budget to complete the impact mitigation analysis to see what further bypass measures are needed. The Corps fiscal year 1992 appropriations include nearly $32 million for these programs. All of this work is part of an overall juvenile fish protection program that is budgeted at over $300 million.

A typical bypass installation or major modification takes three to five years to design and build once continuing funding is in the budget. The project at The Dalles is particularly large, and will run for seven or eight years. The table on the next page shows a schedule of key project components and completion dates.

Once fish are guided into a bypass channel, they can either be released back into the river below or held briefly in holding facilities until they can be transported by barges or trucks to below Bonneville Dam where their passage to the ocean is clear. The collection facilities provided by the bypasses are an essential part of this program. By late August of 1991, more than 15 million juvenile fish had been collected in the bypass systems at Lower Granite, Little Goose, and McNary dams.

The turbine bypass projects on the Snake and lower Columbia are major construction projects that will continue for several years. They represent a continuing commitment to rebuilding Columbia basin salmon and steelhead runs while still recognizing other benefits from multipurpose hydro-projects. ■

Mass Transit For Juvenile Salmon

How do you get 15 to 20 million young salmon downstream through slow-moving water, past eight dams, hungry predators, and the perils of nitrogen-saturated water? The Corps of Engineers uses a transportation program — mass transit for fish. They load young salmon into barges for a two-day trip down the Snake and Columbia rivers.

To some, the whole concept is difficult and often misunderstood. Putting fish in a barge to move them down river just doesn't make sense! But the National Marine Fisheries Service (NMFS), charged with the protection of marine resources and responsible for recovery of the listed salmon species, believes that transportation is a powerful tool for sustaining salmon runs on the Snake River. With over a decade of research behind it, the Corps transportation program is likely to be a part of any future policies and programs resulting from endangered species listings.

Transportation does more for migrating salmon than just getting them safely past the hydropower turbines. There are other serious hazards to the juvenile fish that transportation protects against.

Turbulent water downstream of dam spillways traps nitrogen gas from the air. Fish swimming through these waters can get something called "gas bubble disease," a distant cousin of the diver's "bends." Transport barges are equipped to remove excess nitrogen from the river water.

River currents slowed by the dams take two or three times longer to move young fish downstream than the historical free-flowing river. This delay may interfere with the biological clocks that regulate fish migration and adaptation to salt water. Fish barges make the trip in just a few days.

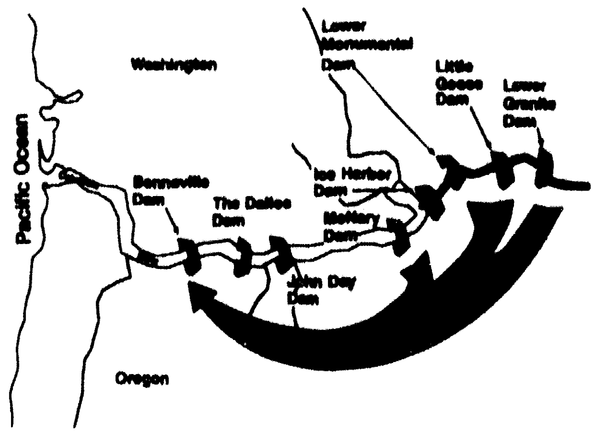
The slow-moving reservoir waters are also home to many more unfriendly fish and birds than inhabited the undammed river. More predators have more time to dine on more migrating fish, especially those concentrated at spillways and bypass outlets. The barged fish avoid being on the menu.

Moving fish past these dangers, according to the Corps and NMFS, increases survival rates for the passage between Lower Granite and Bonneville from 50% under best in-river migration conditions to over 98% with transport.

Transportation by itself is not enough to preserve salmon runs. If it were, there would be no shortage of fish by now. The Corps has been using it since 1977. But transportation is beneficial when used in conjunction with safe and efficient bypass systems, augmented river flow, and habitat maintenance and restoration.

Not All Species Are Equal

All salmon runs on the Snake are down, compared to historical figures. But the problems have hit some species harder than others. While the sockeye and chinook counts are declining, there has been a resurgence in Snake River steelhead populations. In 1975, some 17,000 returning steelhead were counted at Lower Granite Dam. By the mid-1980's those numbers had reached 136,000.



The Columbia and Snake transport program, in operation since 1977, moves migrating salmon from upriver collection points to below Bonneville Dam.

Many biologists believe that transportation has been largely responsible for this rebound and should be continued, especially in low-water years, to help maintain it.

Several studies have shown that wild fish respond better to transportation than the hatchery-bred stocks that have come to dominate the downstream migration numbers. As river operations and fishery management are tuned to foster re-growth of wild stocks, transportation is available to support that growth.

Transportation Starts With Good Facilities

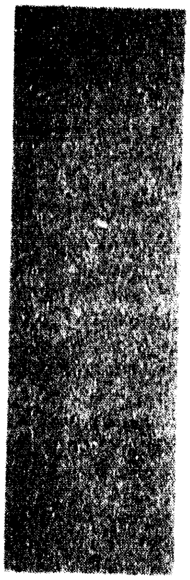
The transportation program works in conjunction with fish bypass facilities at mainstem dams. These facilities enable the juvenile fish to be routed around the

Bypass System Construction At Corps-operated Dams

	Bypass Channel	20-foot Screens	Modified Gates	Gantry Crane	Extended Screens
Lower Granite	Complete	Complete	1992	1994	1996
Little Goose	Complete	Complete	1991	1994	1996
Lower Monumental	1992	1992	1992	1994	
	(Holding/transport loading facilities scheduled 1993)				
Ice Harbor	1994	1993	1994	1994	
McNary	Complete	Complete	1992	1993	1995
	(Holding/transport loading facilities scheduled 1994)				
John Day	Complete	Complete			
	(No new construction scheduled at this time)				
The Dalles	1998			1998	1998
Bonneville	Complete	Complete			
	(Further improvements scheduled completion 1996)				

The Corps of Engineers is working with region and Congress to complete juvenile fish bypass systems on all dams it operates on the Snake and lower Columbia rivers.

System Configuration Studies



The Corps of Engineers has undertaken a major initiative to explore long- term structural modifications to Federal hydropower projects to improve survival of Snake and Columbia river salmon runs.

This is the System Configuration Study--or if you'd like to learn a new acronym--SCS. This is a two-phase study which will examine long-term modifications that can be made to dams on the lower Snake and Columbia rivers as well as possible addition of new "fish flow" storage dams and other structural measures that have the potential of improving the survival of Columbia and Snake river salmon stocks.

■ What is it?

The SCS is an element of the Columbia River Salmon Mitigation Analysis initiated by the Corps to address the need for mitigation of adverse impacts of the eight mainstem dams on anadromous fish runs.

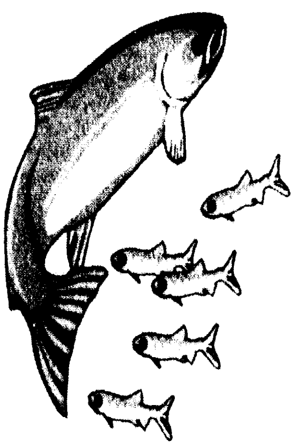
SCS is separate but related to the Columbia River System Operation Review (SOR) in which potential changes to the **operation** of the Federal projects are being studied jointly by the Corps of Engineers, the Bonneville Power Administration and the Bureau of Reclamation. Many of the potential operational changes would require **configuration** or **structural** changes to the system including modification of existing projects and new construction. These changes will be addressed in the SCS.

■ [illegible]

Alternatives to be analyzed include those recommended in the Northwest Power Planning Council's Fish and Wildlife Program (Phase Two) issued in December 1991. Other alternatives to be analyzed include some identified during the Salmon Summit and regional input that followed.

The study will analyze the following five categories of alternative long-term actions.

(1) **Existing system improvements.** The SCS will define and evaluate potential improvements to existing facilities which would improve passage and survival of both adult and juvenile fish. Potential improvements for juvenile facilities include how fish are released at bypass facilities, extending the length of diversion screens at the turbine intakes, replacing flume systems that take the fish from the bypass systems to the collection facilities, and modifications to loading and transport facilities and equipment.

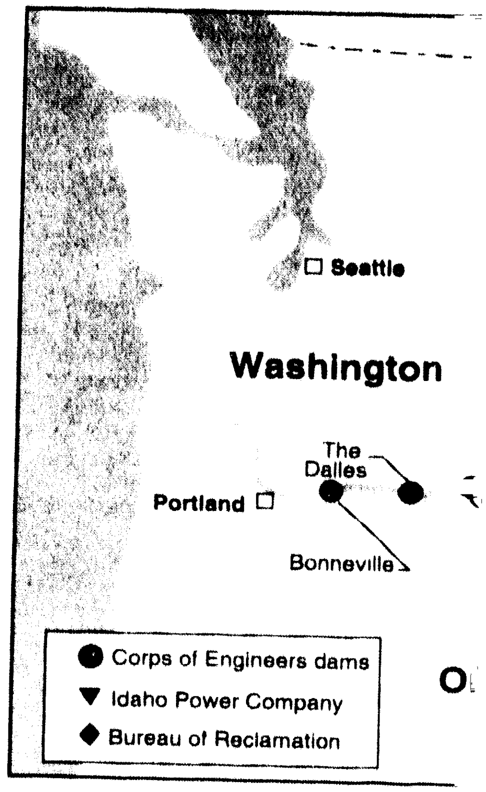


Potential adult facility improvements include water temperature reduction in fish ladders, installation of additional ladders and additional attraction water.

At fish hatcheries, the addition of tanker truck loading facilities and additional raceways or other containment facilities to reduce fish densities will be evaluated.

Improvements already scheduled for implementation, such as ongoing work to install or improve efficiency of fish screens and bypass systems at the dams will not be affected by the SCS.

(2) **Additional upstream storage.** The SCS will examine the possibility of providing additional upstream storage for flow and temperature modifications during fish migration periods. The SCS will develop information on site locations, storage, possible flows, type of structures, preliminary design and costs and estimated



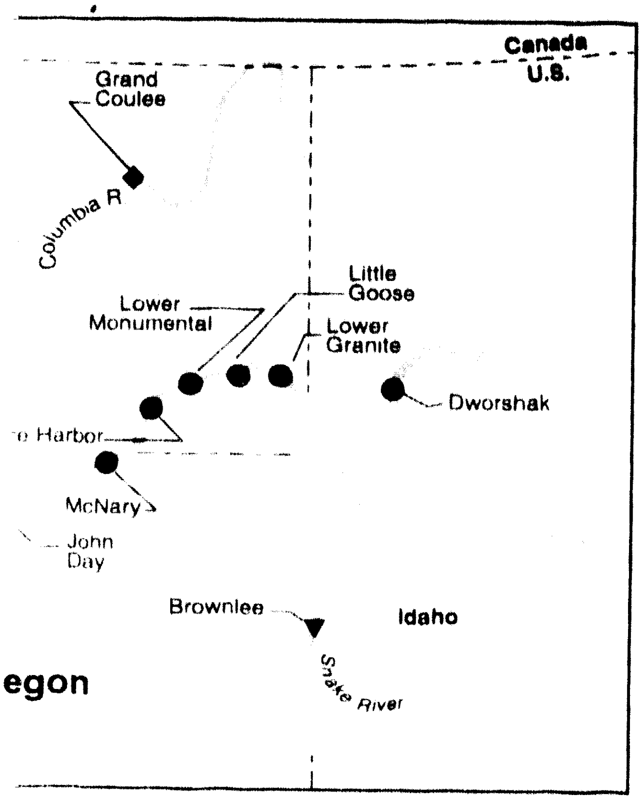
schedules for implementation. In addition, benefits to juvenile fish passage will be provided.

The Bureau of Reclamation is facilitating an interagency effort to inventory and screen potential storage sites for further study. One such site for which there is strong interest by the state of Idaho is the Galloway site on the Weiser River.

(3) **Lower Snake Projects and John Day Reservoir Drawdown.** Annual lowering of pool levels at the four lower Snake projects is under consideration (please see related story in this issue). An array of modifications to powerhouses, spillways and other project features which would allow the projects to operate under a range of drawdown conditions while maintaining safe and effective juvenile and adult fish passage will be evaluated by the SCS.

The impacts on existing project uses under these conditions will be assessed and measures to mitigate impacts will be evaluated. These primary uses include navigation, irrigation, hydropower generation, recreation, and municipal and industrial water supply. Modifications that may be required to protect structures, levees, railroads, highways and drainage systems during drawdown will also be examined.

Annual operation of the John Day project at minimum operating pool (elevation 257 feet) during the juvenile migration period will also be evaluated. The study will identify measures



necessary to mitigate impacts to irrigation and other water supply systems, navigation, fish and wildlife, cultural resources, recreation, Indian in-lieu fishing sites, and fish passage facilities. Alternative measures to mitigate impacts on water users, such as irrigation canals along both banks of the river and modification and relocation of existing pumping stations, will be examined.

(4) **Upstream Collector.** This alternative consists of a new collection facility (or facilities) near the upstream end of Lower Granite reservoir for collection of juvenile fish and diverting them to a barge or stream channel/pipeline for movement to below Ice Harbor dam or continue on to below Bonneville Dam. Collection concepts identified so far include one or more facilities upstream of Lower Granite near Lewiston, Idaho and Clarkston, Washington, or utilizing the existing dam as the collection point for juveniles and the diversion point for water.

(5) **Transport.** Transport options from a new upstream collector or Lower Granite Dam include an open canal along the river shoreline, a floating or underwater pressurized pipeline, and barge transport from the collection facility. The use of net pens instead of barges to move fish downstream will also be evaluated.

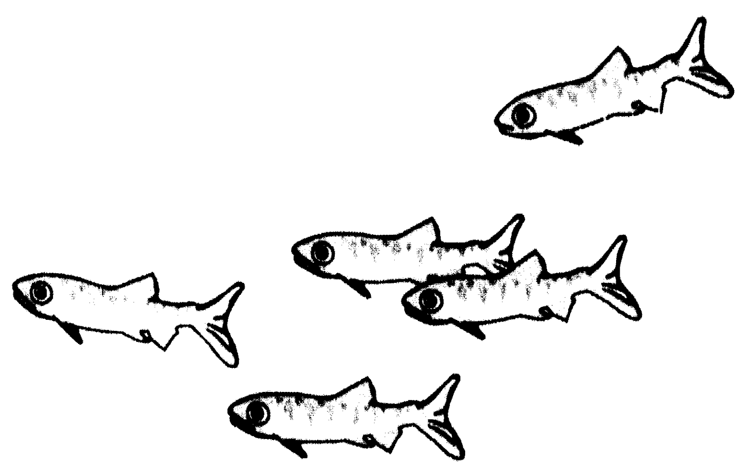
The concept of constructing a migratory canal into which fish could be diverted for travel past the dams surfaced at the Salmon Summit. The SCS will identify preliminary canal routes and designs as well as provide preliminary cost estimates.

Schedule

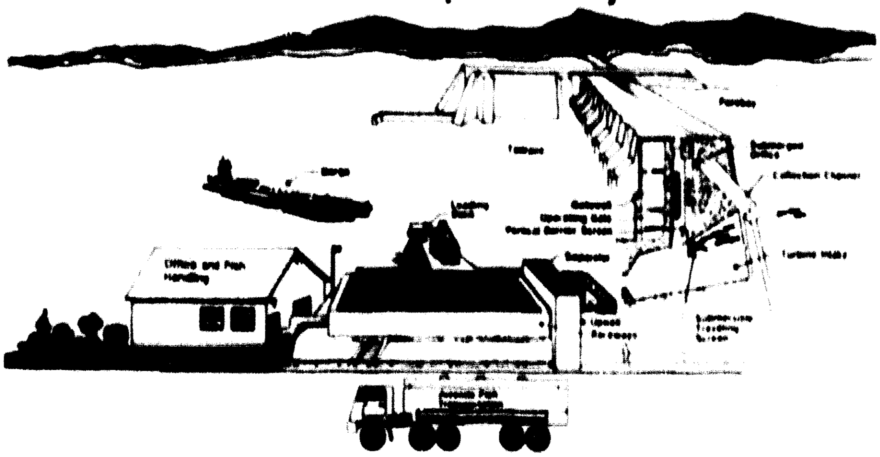
An interim report on the SCS is scheduled to be submitted to the Council by November 1992. The Council has requested a report containing a detailed analysis of viable alternatives identified in interim report by November 1993.

Elements of the study have been assigned to the Corps district offices at Portland, Seattle and Walla Walla. Involvement of the public in the formulation, analysis, and review of the elements of the SCS will be sought through various means--including public information meetings and direct mailings.

SCS drawdown alternatives will be monitored and overseen by the Columbia-Snake Drawdown Committee which is chaired by the Northwest Power Planning Council, and consists of representatives from the Bonneville Power Administration, the Bureau of Reclamation, the Corps of Engineers, the states of Idaho, Montana, Oregon and Washington, and the Indian tribes.



Juvenile Salmonid Collection and Transportation System



Fish bypass facilities at hydropower dams collect migrating juveniles for transportation by barge and truck.

powerhouses in a bypass channel and either released back into the river below the dam or held briefly in collection facilities for later transport. These facilities at Lower Granite, Little Goose and McNary dams are the sources of juvenile fish for the transport program.

> ***"Work to improve the system and collection procedures has produced results"***

A new collection facility is now under construction at Lower Monumental Dam. A new bypass facility was completed at Little Goose in 1989. Lower Monumental's will be done in 1992 and fish can be transported from that project in 1993. New bypass systems will operate at McNary Dam by 1994 and at Ice Harbor by 1996.

The Corps is also testing new designs for the diversion screens that guide the fish into the collection channels. Future programs include looking at alternate release sites and studying adult fish returns beyond Lower Granite to spawning grounds and hatcheries upriver of the transport points.

Transportation on the Snake River normally starts about the end of March and continues until the end of July. In 1991 the Corps continued to collect and transport juvenile fish from Lower Granite until the end of October. From August through October, 6,699 fish were transported from Lower Granite. That many fish passed the separators in 15 minutes during the record 1991 collection day at Lower Granite, when 670,000 were collected. In all, some 15.5 million salmon and steelhead were transported this year.

Barges And Tanker Trucks

The Snake River transportation fleet consists of six barges with capacities ranging up to 150,000 gallons. To protect the wild stock fish, the normal maximum loading in these barges is one-half pound per gallon of water, or four to eight fish per gallon, depending on fish size. This is a third of the density at which fish are normally transported at hatcheries.

Barges leave Lower Granite daily during the peak of the run, and take about two days to reach Bonneville Dam, including stops at Little Goose and McNary to take on more fish. The barges constantly circulate fresh river water, making a complete water change every 10 minutes. Pumping systems are equipped to maintain proper oxygen saturation in the holding tanks. The barges are also equipped to shut off the river intake completely in case a pollution spill is encountered.

When the fish numbers are less than 20,000 fish per day, the Corps uses 3,500 gallon tankers to truck them around the dams. A 200 gallon pickup-mounted unit is available for small loads. It costs about $15,000 per round trip for a barge, about $300 for the large tank trucks.

An alternative form of in-river transportation that has been proposed is called a net pen. One suggested design is a sort of fish corral made of netting. Suspended from pontoons, the net pen would be pulled by a towboat. Current designs are conceptual and would not offer any protection from gas-saturated river water, pollution, or stress. It will be some time before a prototype can be constructed and tested.

There Is Still Debate

There is still active debate about the level of benefits of transportation, especially on spring/summer chinook. The question of delayed mortality from the collection procedures has been a lingering issue over the years, and the Corps is working to reduce the hazards of in-river migration and the stress of transportation.

Work to improve the system and collection procedures has produced results. In the late 70s, 48-hour delayed mortality in collected fish was averaging about 12 percent at Lower Granite, with peaks up to 30 percent. Now it runs between 1/2 and 1 percent.

Transport Still A Useful Tool

The results-oriented question that is raised about transportation is this: If all these fish are getting to the ocean, why aren't they coming back? What factors affect the survival of salmon after they are released downstream of Bonneville Dam?

The answer to that question is not fully known. Effects of chronic diseases, especially in hatchery fish, appear to be partially responsible. Other adverse conditions in the estuary or ocean may also affect survival. The Corps along with the U.S. Fish and Wildlife Service, NMFS and several universities are currently conducting research to find answers.

Most research biologists believe that transportation stress is not the main culprit. They feel that even the runs that are in bad shape now would be worse without the transportation programs. As handling stress is further reduced, transportation is likely to be continued as an effective means of avoiding the negative impacts of predator-infested reservoirs and gas saturation below dam spillways.

Rebuilding the wild salmon stocks will take time, as there are many difficult decisions yet to be made. While that process is going on, transportation is helping to protect the salmon during their perilous journey. ■

Transport For '92 Underway

With completion of the Snake River Drawdown Test April 1st, fish bypass and transportation systems at Lower Granite and Little Goose dams were activated and collection of juvenile salmon arriving at the dams commenced.

This flow year is expected to be similar to, or even a little drier than 1991. As a result, the National Marine Fisheries Service, along with other regional fishery agencies, are again calling for truck and barge transport of as many migrating juveniles as can be collected.

Should river flows exceed 100,000 cubic feet per second (cfs) at Little Goose or 220,000 cfs at McNary, the smaller juvenile migrants such as chinook salmon would be bypassed to the river. Larger smolts such as steelhead would still be collected and transported. Currently inflow at Little Goose is averaging 30,000 cfs and 100,000 at McNary.

To effect increased survival, the transport season may againbe extended through the end of October at Lower Granite and Little Goose and through the end of December at McNary. Normally the transport season is terminated on the Snake River by the end of July and at McNary on the Columbia River by the end of August because of the small numbers of fish.

Even though the numbers are expected to be small, consideringthat some may be threatened chinook or listed sockeye salmon, helping only a few to avoid the perils of the journey to the sea justifies the added effort. Three new pickup-mounted tanks will be used for transporting small numbers of fish as needed.

Research efforts this year include releasing a few controlledbarge loads of juveniles off Tongue Point — about four miles upstream of Astoria and 18 miles from the mouth of the Columbia River. The usual release destination is off the Skamania Light House — seven to eight miles downstream of Bonneville Dam and about 130 miles from the ocean. The research is aimed at determining if it may be advantageous to release fish nearer the ocean. ■

Salmon Listings Advance Corps Planning Process

The National Marine Fisheries Service listing of the Snake River sockeye salmon as endangered in December 1991 and of chinook salmon as threatened in April of this year accelerated the Corps of Engineers system operations planning process and other initiatives to seek better ways of protecting salmon migrating through Columbia and Snake river dams.

In anticipation of the listings, the Corps has been working with cooperating agencies to explore both short and long term strategy and management options to benefit depleted runs of salmon in the Columbia Basin system - including the listed species.

This year, operations options being implemented include managing the system to provide increased flows during the migration period and continuing, at the request of the fishery agencies, both bypass and juvenile salmon transport programs.

The listing actions by NMFS bring into play provisions of the Endangered Species Act which formalize the ongoing coordination process of the Corps with the agency. All river operations and other activities that have a potential for impacting the listed salmon species are coordinated with NMFS to insure requirements of the Act are met. ■

DRAWDOWN '92

Although dams on the Columbia and Snake rivers have provided many benefits to the region--power, navigation, irrigation, recreation--they have had negative effects, particularly on salmon that must pass the dams to and from the ocean. To enable salmon to get past the dams, adult fish passage facilities were constructed in each of the eight mainstem lower Snake and Columbia river dams, and improved juvenile fish bypass facilities will be complete in all of them by 1998 (six of the eight will be operational in 1992). However, the reservoirs created by the dams pose additional problems. Water velocities through the reservoirs are much slower than natural river flows in pre-dam times.

Early in this century, an estimated 8 to 16 million salmon and steelhead returned to the Columbia and Snake rivers to spawn. Today's runs are estimated at approximately 20 percent of the original runs--the majority of which are hatchery fish. These declines are a result of many aspects of development in the region including the dams, but also irrigation, commercial and recreational fishing, logging, grazing, agriculture, water pollution and other effects of modern man on the environment. In December 1991, Snake River stocks of sockeye salmon were listed as endangered and spring/summer and fall chinook are proposed for protection under the Endangered Species Act.

Salmon Summit

In 1990 a regional team, comprised of State and Federal fish agencies, river system operating agencies, environmental groups and river users, was formed to develop a recovery plan for salmon stocks. The team met for several months--the so-called "Salmon Summit"--but were unable to reach consensus on a comprehensive plan. However, many ideas for additional measures to improve conditions through modification of the hydrosystem were suggested. Evaluation, and, in some cases, implementation of these concepts has been an ongoing process.

Flows at 100,000 cubic feet per second surge through the spillway at Lower Granite Dam to test physical and structural effects of spilling during drawdown conditions. Also, dissolved gas levels were monitored before, during and after spill tests.

The concept of drafting lower Snake River reservoirs to elevations at which water flows freely over the spillways--some 30-40 feet below normal operating ranges--was proposed at the Salmon Summit to assist juvenile salmonids in their downstream migration.

Responding to regional resolve, the Corps of Engineers, in cooperation with Bonneville Power Administration and the Bureau of Reclamation, developed potential alternatives for a test of the drawdown concept. These alternatives were addressed in the 1992 Columbia River Salmon Flow Measures Options Analysis/Environmental Impact Statement.

On February 14, 1992, a decision to conduct a drawdown test of Lower Granite and Little Goose reservoirs was made by Maj. Gen Ernest J. Harrell, at the Corps' North Pacific Division office in Portland. The purpose of the test was to gather data on reservoir drawdown to near spillway crest for potential use in developing long-term reservoir drawdown operations criteria.

The test was conducted from March 1 through March 31--a period when few migrating fish were present in the test area. Lower Granite was drafted to 696 feet elevation--37 feet below its minimum operating elevation of 733 feet. Little Goose reached its lowest level at elevation 620.5 feet--12.5 feet below its minimum operating level of 633 feet.

During the test a number of state and federal agencies worked with the Corps to collect information on physical, environmental and structural effects.

At this writing, the Corps and involved agency teams are still analyzing the data collected in the 31-day test. A full report of findings is due in June of this year. For the next issue of Salmon Passage Notes, we should have some preliminary findings.

We do know that during spill conditions, dissolved gas levels increase significantly above normal. These conditions can be harmful or even lethal to fish. We also found that as the reservoir was drawn down, the power output and efficiency of the turbines and generators decreased. But the good news is that operating the turbines at low levels does not appear to cause damage or undue wear.

Though no major structural or environmental problems were encountered, the month-long test that dropped reservoir levels some 37 feet halted commercial barge traffic used to export wheat and other commodities, damaged floating docks, marooned a swimming beach and several recreation areas, dried out a golf course, cracked a county road and killed unknown quantities of fresh water mussels, clams, and resident fish.

A great deal of data and understanding of physical effects of drawdown were gained by the test. One finding that became clearly evident is simply just how complex, costly and controversial the concept.

Salmon Passage Notes is published by the North Pacific Division of the U.S. Army Corps of Engineers.
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United States Committee On Large Dams

USCOLD

Engineering Solutions to Environmental Challenges

Thirteenth Annual USCOLD Lecture Series
Chattanooga, Tennessee, May 1993

Organized by USCOLD Committee on
Environmental Effects
Hosted by the Tennessee Valley Authority

Foreword

Engineering Solutions to Environmental Challenges is the theme of the Thirteenth USCOLD Annual Lecture.

The Lecture was organized by the USCOLD Committee on Environmental Effects to advance the knowledge and understanding of USCOLD Members and other water resources professionals regarding the technical, sociological and environmental aspects of dam project planning, design, construction and operation; and to promote the concepts and practices which contribute to the incorporation of environmental and sociological factors in water resources projects in balance with engineering and economic factors.

The Lecture papers address these two important issues, providing outstanding examples of how current engineering technology is being used to respond to a wide range of environmental challenges associated with water resources projects in general, and with special regard to dams.

A total of 21 Lecture papers are included in these Proceedings, as well as eight poster session papers. Authors represent consulting firms, universities, government agencies and utility companies.

The committee on Environmental Effects recognizes, with thanks and appreciation, the Tennessee Valley Authority for hosting the Thirteenth USCOLD Annual Meeting and Lecture.

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FISH PASSAGE AND HYDROPOWER DEVELOPMENT AT THE DALLES DAM

Lee DeHeer

Introduction

This paper describes a hydropower project that has been retrofit into the Attraction Water Supply System (AWSS) at The Dalles Dam North Shore Fishway on the Columbia River. The project not only uses water that is reserved for fisheries to generate power, it also preserves and enhances the conditions for downstream migration of the fish. Figure 1 shows the key features of the project.

The powerhouse is located below ground adjacent to the fish ladder and is connected to the dam by an intake channel and a steel penstock. It contains a single, vertical-shaft Francis turbine rated at 5,000 kilowatts at a head of 72 feet and a discharge of 800 cfs. Flow from the draft tube is discharged directly into the water supply channel beneath the ladder to provide fish attraction flows into the fish ladder.

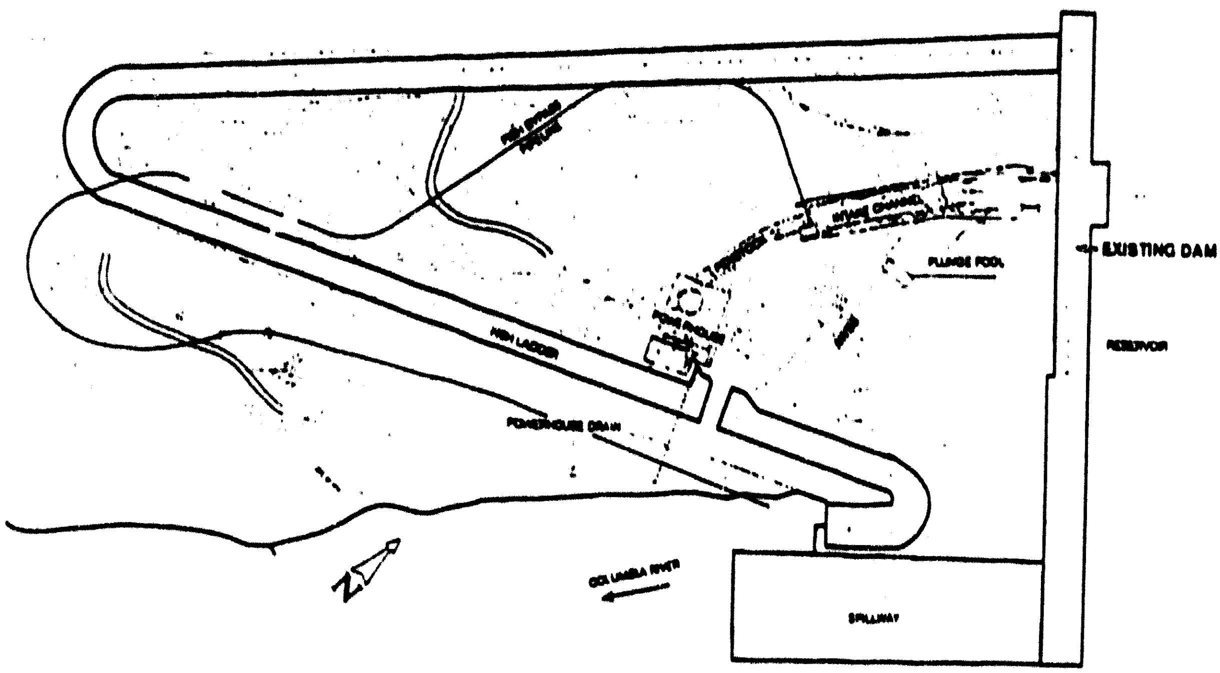

Figure 1. Project Plan View

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The Dalles Dam is located on the Columbia River, which is one of the most important sport and commercial fisheries in the United States because of the river's population of chinook, coho, and sockeye salmon, as well as steelhead trout.

The hydropower project has served as a mechanism to protect migrating fish as well as being a source of energy. Before the dam was retrofit, a large percentage of migrating fish perished in the passage over the falls and never finished their migration downstream to spawn. The bypass system guides the fish safely past the falls so they can continue their journey.

Adult fish migrating up the Columbia River are counted as they pass through the fish ladders at the dams on the river. The fish counting is done from April through October. In 1992, over 3.3 million fish were counted passing through the two fish ladders at The Dalles Dam. Approximately 2.7 million of the fish were shad, approximately 500,000 were salmon and steelhead, and the remainder were squawfish, sturgeon, walleye, and bass.

The Dalles Dam is a 90-foot-high by 8,735-foot-long concrete dam that includes a 24-bay gated spillway, 22 turbine generator units with a total generating capacity of 1,807,000 kilowatts, two fishways, and a navigation lock. The dam was built between 1952 and 1959. It is the second dam on the Columbia River, approximately 190 miles upstream of the mouth of the river and 45 miles upstream of Bonneville Dam. The Dalles Dam forebay (Lake Celilo) elevation varies between 155 and 159 feet mean sea level (msl), and the tailwater elevation varies between 73 and 87 feet msl.

The project's two fishways both have a fish ladder to transport the migrating fish upstream, and an AWSS to attract the fish into the ladders. The two fishways operate continuously between March and November, with a flow of approximately 70 cfs in the northshore ladder and 140 cfs in the east ladder. The flow in the east AWSS is approximately 4,000 cfs, and in the northshore AWSS varies between 800 and 1,600 cfs. The AWSS of the east fishway includes two 13,500-kilowatt turbine generator units in the original design. The northshore fishway, however, did not include generating facilities because the flow over the AWSS was considered to be too small to develop at the time the project was built.

The fish ladders and AWSS were designed by the United States Army Corps of Engineers. They are constructed on a slope of 1 vertical to 16 horizontal, with baffles every 25 feet. The flow from the AWSS is directed into a closed conduit under the downstream end of the ladders and enters them through a diffuser system under the floor of the ladders. This system increases the flow at the downstream end of the ladders to attract fish into them. The increased flow provided by the

AWSS at the downstream end of the ladder reduces the flow requirements in the remainder of the ladder for the passage of the fish.

Project History

The development of the hydropower potential at the fishway was first conceived in 1980. At that time there was a concern about an energy shortage in the United States, and small hydro was identified as a good resource for development of clean, domestic, renewable energy. The Corps of Engineers studied the project but did not receive funding approval from Congress. The concern over the energy shortage was soon replaced by a period of surplus energy in the Pacific Northwest region of the United States. Nevertheless, The Dalles fishway project was still an economically attractive project because of the nearly continuous flow of water and the relatively minor amount of civil construction involved. The output from the project was recognized as valuable to the region for reducing the use of fossil-fueled units, thereby conserving nonrenewable energy resources and lessening atmospheric pollution.

In 1985, the Northern Wasco People's Utility District of The Dalles, Oregon, filed for a license. In 1987 the Federal Energy Regulatory Commission granted them a license to design and construct the project.

The project is located in the State of Washington on federal land administered by the United States Army Corps of Engineers. It uses the flow released into the AWSS, which varies between 800 cfs and 1,600 cfs, depending on the flow conditions in the river. Prior to construction of the hydro project, the flow into the AWSS was controlled by a radial gate at the dam. This flow discharged into a plunge pool, then into a 20-foot-wide channel, and over a 70-foot-high water fall before entering the water supply channel under the fish ladder.

A new channel was constructed in the AWSS for the hydro project, to direct the flow into a penstock and through the powerhouse turbine rather than over the falls before being discharged into the water supply channel under the fish ladder. This new channel included a stainless steel screen system to direct the downstream migrating salmon and steelhead fingerlings into a bypass pipeline, which discharged into the river downstream of the powerhouse.

The protection of the downstream migrating fingerling salmon and steelhead was a primary issue in connection with the project. Provisions were required that would prevent these fish from entering the turbine. The upstream migration of the fish was not an issue because the water supply channel into which the powerhouse draft tube discharges was originally designed to prevent upstream migrants from entering.

The details to be resolved in connection with the downstream passage of the fingerlings included the arrangement, size, and orientation of a screen in the entrance channel to prevent fish from entering the penstock and turbine passage; the allowable flow velocities in the entrance channel; and the design of the fish bypass pipe.

The state and federal agencies involved in the review of The Dalles project included the State of Washington Departments of Ecology, Wildlife, and Fisheries; the United States Fish and Wildlife Service; and the National Marine Fisheries Service. Three Native American tribal fish commissions were also granted permission to intervene in the proceedings connected with licensing the project. The Federal Energy Regulatory Commission (FERC) is charged with the responsibility of evaluating the environmental protection measures that must be incorporated into the license of a hydroelectric project. This is done through the licensing process in which environmental agencies and other organizations review the proposed design of the project and comment on it. Depending on the size and nature of a project, the licensing process for hydroelectric projects can take several years, primarily to resolve environmental issues. In the case of The Dalles project, the process took only 2 years, because of the cooperation among the parties involved in developing the project and because acceptable solutions to the fishery issues were developed.

Project Design

Intake Channel and Fish Screen

The intake channel is a 130-foot-long by 26-foot-high reinforced concrete structure whose main purpose is to provide a place for the fish diversion screens (Figure 2). The screen allows water to flow into the turbine while directing outmigrating fish into the bypass pipe and into the river downstream of the powerhouse. If there had been no need to screen the fish, this structure could have been a closed conduit. Normally, 800 cfs will pass through the screen and into the penstock and the turbine passage while the fish are diverted into the bypass pipe by a flow of about 10 cfs.

The screen is located at an angle of about 19 degrees to the flow to provide a sweeping action along its face to prevent impingement of the fish on the screen. The design results in a ratio of the sweeping velocity along the screen to the flow through velocity of approximately 3:1. The flow velocity of flow through the screen is limited to 0.5 foot per second, based on the gross area of the screen. These limitations provide for safe passage of the fish past the screen and into the bypass pipe.

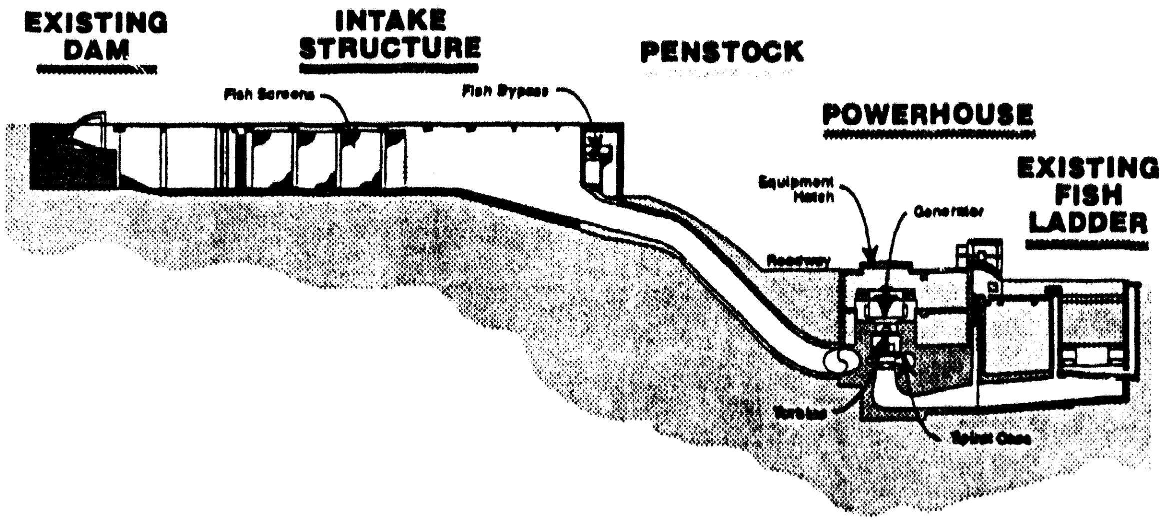

Figure 2. Project Cross Section

The issue of the flow velocity through the screens was the subject of several discussions with the agencies. A velocity of 1 foot per second was considered satisfactory to prevent impingement of juvenile fish against the screen, provided that the juvenile fish were at least 60 mm in length. However, approximately 30 percent of the fish in a 1987 sampling were less than 60 mm long; therefore, the agencies required the more conservative flow-through velocity of 0.5 foot per second. This was a significant difference, since the screen area is inversely proportional to the flow-through velocity.

The distribution of flow along the screen was also an important consideration. There was a concern that the flow through some parts of the screen would be higher than through other parts because the screen was oriented at an angle to the flow. If this were to occur, there might be locations along the screen where the head loss through the screen would be too high and fish might be drawn toward the screen or impinged on it. This problem was addressed in the design by including a set of adjustable baffles that can be installed in slots just downstream of the screens.

Stainless steel wedge wire screen material was used for the fish diversion screen. The screens are fabricated from 3-mm bars oriented vertically and spaced 3 mm apart horizontally. A total screen area of 1,600 square feet is required to provide the flow-through velocity of 0.5 foot per second at the design flow of 800 cfs. It is made up of seven bays, each about 16 feet wide and 16 feet high. Each screen is 6 feet high by 16 feet wide to provide ease of installation and removal with a gantry crane. In each bay, four screens are stacked on top of each other to provide the necessary area plus freeboard.

The design includes a cleaning system, which is automatically actuated when the differential water surface across the screen exceeds 6 inches. There is a trashrack at the intake on the upstream side of the dam, to prevent large trash from entering the channel; thus, only relatively small trash (in addition to grass and twigs) is expected to accumulate on the screen.

The screen is designed with a structural support system that will withstand a 2-foot-differential head across the screen without failing. This is to provide an adequate safety factor against failure of the screen in the event of a cleaning system malfunction.

Screen failure would not only result in the loss of the fish passing through the system at the time of the failure but, since the screens would be drawn into the turbine, would also result in substantial damage to the turbine. The project is therefore instrumented to actuate an alarm when the differential head across the screen reaches 1.5 feet. The turbine will be shut down at this point, and the intake screens inspected for debris or damage.

Several types of cleaning systems were considered for removing accumulated debris and grass from the surface of the screen. These included a high-pressure water backwash system located on the backside of the screen, such as was installed on a similar fish screening system in the Northwest a few years ago. Several types of brush cleaning systems were also considered.

Extensive research by the California Department of Water Resources, the California Department of Fish and Game, the U.S. Bureau of Reclamation, and the U.S. Fish and Wildlife Service has concluded that slowly moving fixed brushes work satisfactorily. Therefore, after the merits and costs of the various systems were compared, a linear brush system was developed, which appeared to be best suited to the project. This system consists of a vertical brush that covers the full height of the screen and travels from the upstream end of the screen to the downstream end at a speed of between 0.25 and 1.0 foot/sec. It directs the debris into the fish bypass pipe, from which it is discharged into the river downstream of the powerhouse.

It is anticipated that, for more extensive cleaning than the brush system can provide, the screens will have to be removed periodically and manually washed. An overhead gantry crane is included in the design to lift and transport the screens for cleaning or other maintenance. High-pressure hydrants are also located on the intake channel near the screens to facilitate the manual cleaning. Provisions have been made for installing a secondary set of screens when the primary screens are removed for manual cleaning.

Fish Bypass Pipe

The fish bypass pipe design also received considerable attention from the agencies and the designers (Figure 2). Prior to the construction of the project, the downstream migrating fingerlings passed under the radial gate in the dam into a plunge pool and over a 70-foot-high falls before entering the water supply channel and the fish ladder. However, the criteria for bypassing the fish around the powerhouse were much more stringent than the existing vertical drop condition. The velocity of flow in the pipe, the pipe material, the routing of the pipe, and the discharge point received special attention in the design of the bypass system. The pipe also had to be at least partially open so that the flow conditions in the pipe could be observed.

The fish bypass pipe is a 24-inch-diameter, high-density polyethylene (HDPE) pipe approximately 1,600 feet long, constructed on a slope of 0.04. The depth of flow in the pipe is approximately 6 inches, and the flow velocity is approximately 25 feet/sec for the design flow of 10 cfs. The HDPE pipe was chosen because of its smooth surface and because the sections can be fuse-welded together to make a smooth joint. This is important because a rough surface on the pipe or projections at joints could injure the fish as they travel down the pipe at a velocity of 25 feet/sec.

The discharge point of the fish bypass pipe had to be a location where predatory fish and birds would not be able to devour the bypassed fish that are disoriented immediately after being discharged. This meant that the fish had to be discharged into relatively fast-moving water rather than in calm water. Several discharge points were identified that were desirable from a construction and cost standpoint but would have been into slow-moving waters. One of the preferred discharge points was in the fish ladder itself, but there was concern that predator fish in the ladder would destroy the fingerlings. The location finally chosen was at the downstream end of the fish ladder where the ladder enters the river. Here the flow from the fish ladder passes over a weir and the velocity is relatively high. The fish drop 10 feet from the pipe and enter the river at a velocity of about 30 feet per second.

Project Construction

Project construction was substantially affected by the need to keep the fishway in operation for 10 months out of the year. The project was advertised for bids in the late summer of 1989, and construction began in early fall of that year.

The two parts of the project that had to be constructed during the shutdown were the connection of the draft tube to the fish ladder and part of the intake channel. All of the excavation for the powerhouse, intake channel, and penstock was in basalt rock, and therefore required blasting. This blasting was done under controlled conditions, not only to protect the dam but also to prevent interference with the passage of fish through the ladder. Blasting within 25 feet of the ladder while the ladder was in operation was done at night, since fish passage through the ladder was minimal at that time. A cover was built over the ladder in the construction area to prevent shadows on the flow through the ladder, which might be a distraction to the fish.

All of the excavation for the powerhouse and intake channel was done prior to and during the shutdown of the ladder during the fall and winter of 1989-1990. Two gates were installed in the intake channel and a new plunge pool was constructed adjacent to the intake channel to discharge water into the AWSS. This allowed the flow required in the AWSS to be diverted around the powerhouse while the penstock and powerhouse were constructed. The two gates are also used to maintain flow in the AWSS when the turbine is shut down.

The powerhouse draft tube and the fish ladder are separated by a concrete wall, which was constructed when the fish ladder was shut down. Two stoplogs were installed in the draft tube openings, which are removed and stored in the slot above the stoplogs when the powerhouse is in operation. The stoplogs are available during project operation to isolate the powerhouse from the fish ladder.

All of the construction required prior to rewatering the fish ladder was completed on time, and the fish ladder and AWSS were returned to service in March 1990. The remaining work on the powerhouse, penstock, and the intake channel was completed by May 1991. The project was in operation in June 1991. A photograph of the completed project is shown in Figure 3.

Fish Passage Evaluation

The FERC license required that the fish passage facilities be evaluated after the project was put into operation. The first evaluation period for the project was from July 10 until August 16, 1991. This evaluation period did not begin early enough to cover the complete summer salmonid smolt migration. A second evaluation was performed between April and October 1992. Fish passage sampling and evaluation were done by Richard C. Johnson, a fishery biologist hired by the Northern Wasco County People's Utility District.

Figure 3. Completed Project

Each of the eight screen bays can be fitted with adjustable baffles to change the flow patterns through the screens to achieve a uniform velocity of 0.5 foot per second through the screens at all locations along the face of the screens. The baffles consist of a set of aluminum channels that are arranged horizontally, with adjustable space between the channels. The intention is to install these baffles at locations where excessive head loss is observed, in order to reduce the flow in these areas. The baffles were installed behind the fish screens in the four downstream bays of the entrance channel prior to beginning project operation because it was expected that the velocities in these bays would be higher than in the upstream bays owing to the configuration of the channel. The baffles were initially set at 50 percent open, which roughly matches the open area of the fish screens. The initial evaluation of the condition of the fish bypassing the fish screens was made with this baffle setting.

The fish pass over an adjustable weir and into a plunge pool at the downstream end of the fish screen before entering the fish bypass pipe. A flume and basket arrangement is located there to collect and inspect the fish after they have passed the screen. The species, size, and condition of the fish are determined and correlated with operational characteristics of the intake channel. All fish are retained in a 135-gallon holding tank for periodic examination.

The condition of the salmonids captured during the first period was excellent. Ninety percent of all of the fish examined were in good or very good condition. The mortality rate attributable to passage through the intake channel and past the screen was estimated to be less than 1.5 percent. Examination of all captured salmonids revealed about 6 percent descaling, and few fish appeared to have been descaled recently. It was concluded from this examination, as well as from observation of the flow along the screens, that there was little, if any, impingement of fish on the screens.

Substantially larger numbers of nonsalmonid fish were captured than salmonids. The condition of the nonsalmonids was also very good. Even juvenile shad, which are sensitive and difficult to handle in a lively state, were in very good condition, which indicated that the intake channel and fish screen are not detrimental to the passage of fish.

After project startup had been successfully completed, it was observed that the velocity distribution along the fish screens was higher at the downstream end of the structure than at the upstream end, as was expected. Subsequently, in the fall of 1991, flow measurements were made to determine the actual flow velocities so that the baffle openings could be adjusted accordingly. The fish screens were cleaned with one normal cleaning cycle of the brush mechanism before measurements were made. Arrangements were made with the Corps of Engineers to hold The Dalles forebay constant during the tests.

The measurements confirmed the observations. The velocity through the two downstream bays was approximately 1 foot per second, while the velocities through the other bays varied between 0.2 and 0.7 foot per second. As a result of these measurements, the baffles were adjusted in December 1991 when the fish bypass system was shut down for annual maintenance. The baffle openings were reduced from 8 inches to between 2 and 6 inches.

A second set of flow measurements was made in January 1992 with the screens and the adjustable baffles at the new settings. These measurements showed that the new settings improved the velocity distribution, but the velocities in the downstream bays were still too high. In addition, the new baffle arrangement increased the velocity in one of the other bays, which led to the conclusion that another baffle was required in that bay. The additional baffle was installed, and the other baffles were set at between 2 and 4 inches. A final set of measurements taken in May of 1992 indicated that the velocity distribution was within acceptable limits.

Conclusion

The Dalles Dam Fishway Hydroelectric Project demonstrates that the development of a hydropower project can be compatible with the protection of our fishery resource. By both protecting the migration of fish to their downstream destination and meeting the added power generation needs in the same project, it has been demonstrated that a win-win situation for the energy and fisheries interests is possible. These project objectives were clear from the start and followed through to the design. Cooperation among the involved parties resulted in an innovative design that met with the approval of all parties involved.

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EVALUATION OF A LOUVER ARRAY/BYPASS SYSTEM IN BYPASSING ATLANTIC SALMON SMOLTS FROM THE HOLYOKE CANAL TO THE CONNECTICUT RIVER

Jeffrey M. Boltz[1], David A. Robinson[2], Robert J. Stira[2], and Paul Ruggles[3]

INTRODUCTION

Background: A joint state and federal effort has been underway for more than 20 years to restore anadromous fishes, specifically Atlantic salmon and American shad to the Connecticut River (NUSCO 1987). Holyoke Water Power Company (HWP) began operating a fish lift for upstream passage of these species at the Holyoke Project in 1955, 11 years prior to the commencement of the restoration program. Most of the effort prior to 1990 had been to provide upstream fish passage for these species at existing dams on the Connecticut River. Since 1990, the focus has been changed to downstream fish passage at these facilities. Downstream fish passage facilities are currently being evaluated at numerous existing dams on the Connecticut River in an attempt to facilitate the restoration effort.

On February 26, 1988, the Federal Energy Regulatory Commission (FERC) added Articles 42 through 44 to the Holyoke Project License (Project No. 2004) regarding downstream passage of anadromous fishes. Northeast Utilities Service Company (NUSCO), filed a compliance plan in response to the Articles on May 23, 1988. Additionally, NUSCO, in 1990, signed a Memorandum of Agreement with the U.S. Fish and Wildlife Service and the Connecticut River Atlantic Salmon Commission committing to construction of downstream fish passage facilities for anadromous fishes at its Connecticut River hydroelectric facilities.

NUSCO commissioned an evaluation of potential downstream fish passage facilities in 1989 in which partial depth louvers were identified as a promising technology for bypassing emigrating Atlantic salmon smolts from the Holyoke Canal back to the Connecticut River (Ruggles 1990). In his report, Ruggles (1990) indicated that louvers had been successfully employed at the Ruth's Falls Facility in Canada (Ducharme 1972). Partial depth louvers were an intriguing idea from both the reduced capital cost and operations standpoint. Because the louvers would intercept

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approximately only one-half of the water column, large debris items would not accumulate on the louvers. From this concept, a prototype louver area bypass system was designed and constructed.

The purpose of this study was to evaluate the effectiveness of the completed louver array/bypass system in bypassing hatchery-reared Atlantic salmon smolts. Specifically, did the louver array/bypass system divert at least 80 percent of the smolts, and if so could the slat spacing be increased from 3 to 12 in.

Emigration of Atlantic salmon smolts begins during the spring when water temperature increases to approximately 50°F, and is generally associated with elevated river flows (McCleave 1978; Ruggles 1980). In the vicinity of the project site, these conditions typically exist in the months of April and May.

Study Site: The study was conducted at the Holyoke Project, which is located on the Connecticut River, river mile 86, in the City of Holyoke Massachusetts. Emigrating Atlantic salmon smolts that approach the project must follow one of four possible paths to pass downstream: (1) over the crest of the dam when river flows are high enough that spilling is occurring; (2) over the bascule gate, which is opened during critical emigration periods for fish passage; (3) through the Hadley Falls Station; or (4) through the Holyoke Canal system. The flow into the First Level Canal is controlled by a gatehouse, located approximately 200 ft upstream and to the west of Holyoke Dam (Figure 1). Flow through the gatehouse is regulated by 10 of 12 bottom opening gates. Two gates, one at each end, are kept closed. Maximum flow through the First Level Canal is approximately 7,000 cfs.

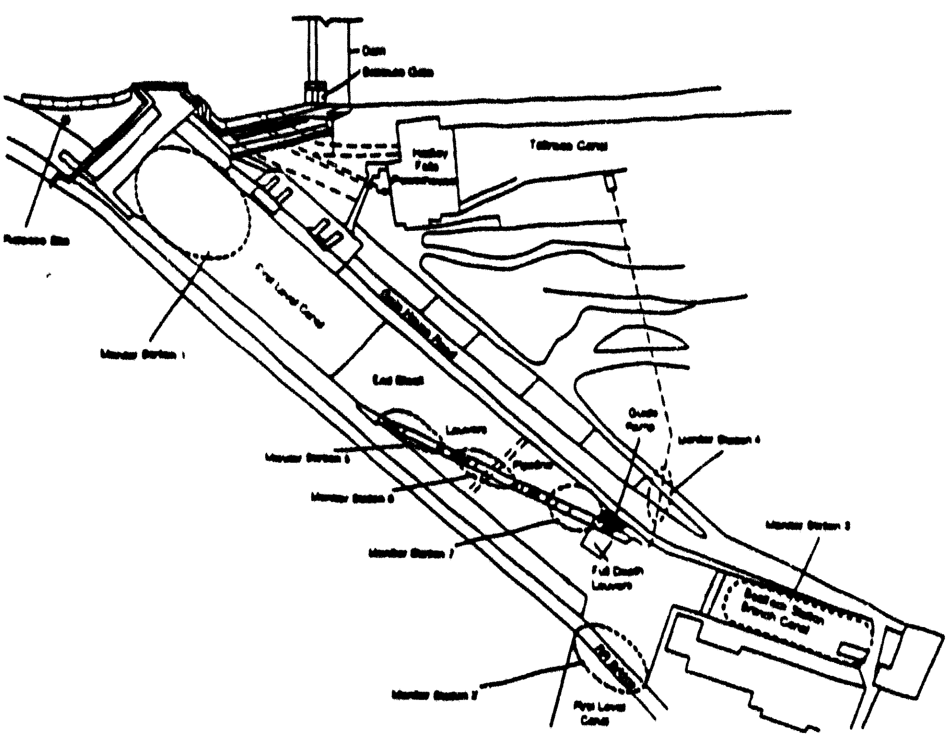

Figure 1. Plan view of Holyoke Canal and Louver Bypass System.

The louver array/bypass facility (Figure 1) was designed to pass emigrating fish from the Holyoke Canal to the tailrace of Hadley Falls Station, a maximum vertical drop of 52 ft. The louver array consists of a 40-ft section of full-depth louvers with clear opening between louver slats of nominally 3 in. and floating louvers (8 ft deep with clear opening between louver slats of nominally 3 in.) over the remaining length of 402 ft. The entire louver array is positioned at an angle of approximately 15 degrees to the flow. The bypass facility consists of three components, an intake structure, a pipeline, and a bypass collection facility. The design flow of the bypass facility is approximately 150 cfs at the normal canal elevation of 100 (Holyoke datum).

The intake structure is located on the left bank of the canal, approximately 950 ft downstream of the canal gatehouse. The bypass entrance is approximately 8 ft deep and 5 ft wide, having a nominal entrance velocity of 3.8 ft/sec, approximately 1.5 times the velocity in the canal at a flow of 7,000 cfs. The throat of the bypass intake is 18 ft long and has provisions for the insertion of Venturi-like restrictors that enable the bypass intake velocity to be increased. The transition to the pipeline is at the downstream end of the bypass intake.

The pipeline is 36 in. in diameter and is 550 ft long. At the intake structure, the pipe makes a combination 30 degree vertical and 120 degree horizontal bend.

The bypass collection facility is located on the right bank of the Hadley Falls Station tailrace, approximately 380 ft downstream of the powerhouse. The structure has provisions for separating the fish from the bypass flow and diverting them to a 5,000-gallon collecting pool. The separation is accomplished using a guide vane that can be lowered into the flow at the downstream end of the pipeline. The fish and water are guided to a wedge-wire screen with a porosity of 50 percent, through which most of the water is shed. A small portion of the flow with the fish is passed over a weir at the downstream end of the screen onto a sorting trough or into the collecting pool. When there is no need to sample the fish, the diversion vane is lifted and the flow and fish are discharged directly into the tailrace.

METHODS AND MATERIALS

Experimental Design: The efficiency of the louver array/bypass system was quantified by releasing known numbers of marked smolts (caudal punched or radio-tagged) upstream of the canal gatehouse and counting the number of these smolts recaptured to the number of smolts released. Additionally, a series of seven antennas was located at strategic locations along the First Level Canal to detect the radio-tagged smolts. The smolts were released upstream of the gatehouse between May 15, 1992 and May 23, 1992. One-year-old Atlantic salmon smolts from the U.S. Fish and Wildlife Service White River National Salmon Hatchery were used for these tests.

Each release nominally consisted of 500 fish, 10 being radio-tagged and 490 caudal punched fish. For radio tagging, smolts were immersed in an anesthesia bath of 50 mg/L tricane methanesulfonate. After the smolts were anesthetized, a transmitter was inserted through the mouth into each smolt's stomach. The radio-tagged smolts were held for approximately

24 hours to acclimate to the transmitters before testing. For release, the smolts were acclimated to the river water temperature at a rate of 3 to 5°F per hour and then placed in the release pen secured to the trashboom just upstream of the gatehouse.

Radio Telemetry Equipment: Radio transmitters, manufactured and supplied by Advanced Telemetry Systems, Inc., propagating signals on 12 unique frequencies, spaced at 10 Khz intervals between 40.010 and 40.150 Mhz, were used to radio tag smolts. Smith-Root RF-40 radio receivers and FDL-15p field data loggers were used to detect the radio-tagged smolts.

Seven monitoring stations were established in the Holyoke Canal to detect the movements of radio-tagged smolts (Figure 1). One each was established at the entrance of the Holyoke Canal immediately downstream of the gatehouse, at the junction of the First Level Canal and Boatlock Station Branch Canal, immediately in front of Boatlock Station, and one in the bypass pipe. The remaining stations monitored three locations along the length of the louver array. Data from the monitor station receivers were retrieved at the conclusion of each study period. Data were then consolidated with manual observations into a PC database. The manual observations were more complete and were the primary source of data for the analyses of the radiotelemetry portion of the study.

Net Sampling: Fyke nets were used to determine the vertical distribution of smolts approaching the louvers and to estimate the number of smolts passing under the partial depth louvers. The vertical distribution of smolts was determined using a vertical array of four fyke nets (Figure 2). Each of the four nets was identical, having a mouth 5.4 ft wide and 3.5 ft deep and a length of 15 ft with a 6-ft-long detachable codend. The nets were constructed of 1.5-in. stretch mesh outerliner and a 0.5-in. stretch mesh innerliner covering the entire length of the net. The nets were fished from a pre-fabricated tower located approximately 100 ft downstream of the upstream end of the louvers and 50 ft from the right bank of the canal. Net 1, the top net, fished from the surface to a depth of 3.5 ft; net 2 fished depths from 3.5 to 7 ft; net 3 fished depths from 8.5 to 12 ft; and net 4, the bottom-most net, fished depths from 12 to 15.5 ft (Figure 2).

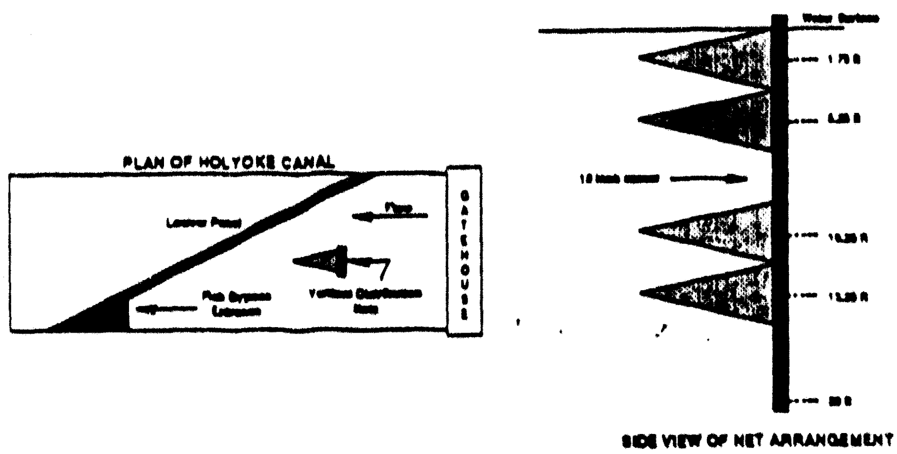

Figure 2. Schematic diagram of fyke nets for sampling the vertical distribution of Atlantic salmon smolts in Holyoke Canal during 1992.

To determine if the marked smolts were passing underneath the floating louvers, a series of three nets were fished under the louvers (Figure 3). Each of the three nets were identical and consisted of a 40-ft-long net body with 10-ft-wide by 12-ft-deep mouth and a 16-ft-long detachable codend. These nets fished the water column from a depth of 8 ft (just under the bottom of the louvers) to 20 ft (essentially the bottom of the canal). The body of the net was constructed of 1.5-in. stretch mesh outerliner and the codend was lined with a 0.5-in. stretch mesh liner. A 40-ft-long by 12-ft-deep lead, constructed of 3/4-in. stretch mesh was attached to the net mouth. The three nets were deployed at the upstream, middle, and downstream portion of the floating louvers (Figure 3).

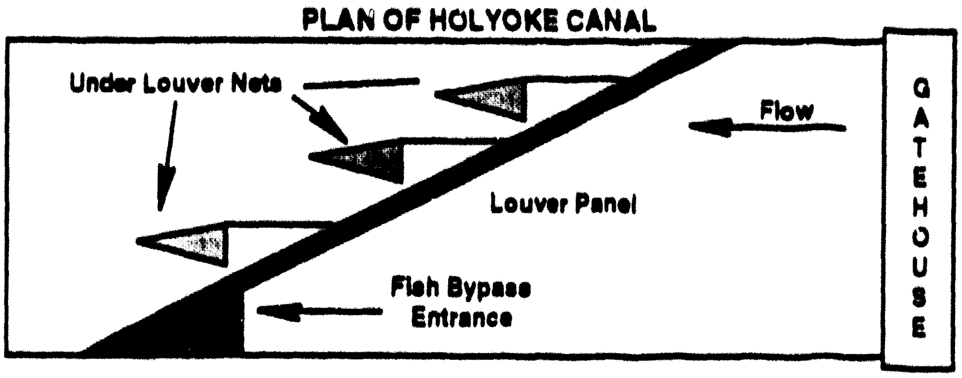

Figure 3. Schematic diagram of fyke nets for sampling Atlantic salmon smolts passing under the louvers in Holyoke Canal during 1992.

Bypass Facility: Fish that were successfully guided and bypassed were collected in the bypass collection facility described above (Figure 4).

RESULTS

Louver array guidance efficiency: Six releases of smolts were used in the analyses; the first three were conducted with louver slats spaced 3 in. on center, and the last three releases were made with louver slats spaced 12 in. on center (Table 1). All six of the releases were made at canal flows of between 3,700 and 4,200 cfs.

Three-inch louver spacings: For the three releases with the louver slats spaced at 3 in., the total guidance efficiency (radio-tagged plus caudal punched smolts) was 89, 90, and 95 percent, respectively (Table 1). The overall guidance efficiency, the three releases pooled, was 91.3 percent.

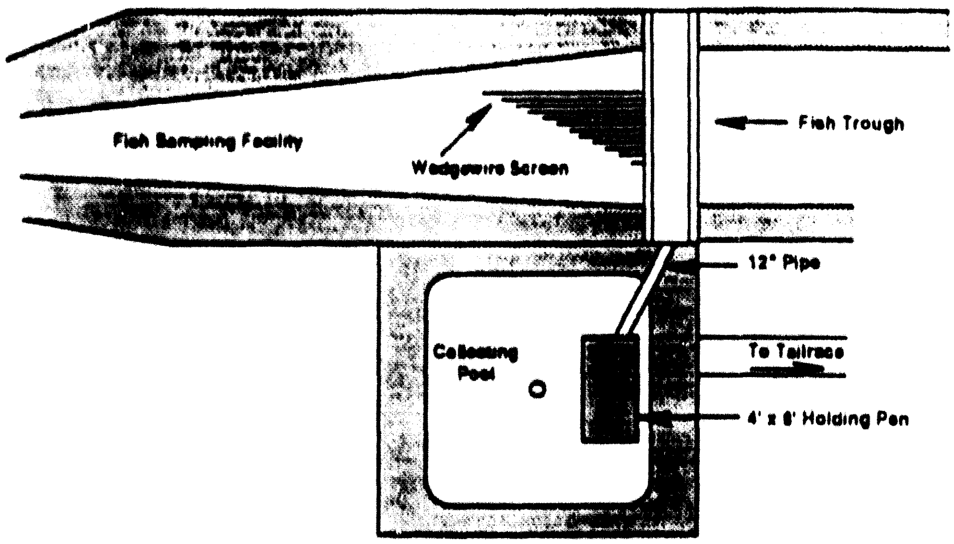

Figure 4. Bypass Collection Facility.

TABLE 1 RESULTS OF THE SPRING 19[illegible] HOLYOKE CANAL ATLANTIC SALMON SMOLT TESTS

Date	Number Released[a]	Water Temp (°C)	Louver Spacing	Recaptures: Bypass	UL1[b]	LL2	UL3	T1[c]	T2	T3	T4	Remained In Pen	Percent Bypassed
14 May	449	14.0	3 in.	419	0	0	0	5	0	0	0	25	89
15 May	500	17.0	3 in.	386	0	0	0	7	0	0	0	64	90
16 May	500	16.0	3 in.	470	0	0	0	1	0	0	0	2	95
20 May	498	16.0	1 ft	427	2	0	2	0	0	0	0	4	86
22 May	509	18.5	1 ft	304	2	1	0	1	0	0	0	25	63
23 May	500	19.5	1 ft	428	0	0	0	1	0	0	0	25	90

(a) Number released includes radio-tagged fish.
(b) UL1 = downstream under louver net
(c) T1 = surface lower net.

All of these estimates of guidance efficiency are underestimated because not all of the smolts that left the release pen migrated through the canal during the sampling period. This was evidenced by the recapture of low numbers (less than 10) of those fish the next day of sampling. These fish were not added to the recaptures for the previous release, thus the estimate was conservative. Of the smolts recaptured, 90 percent passed through the canal in less than 3 hours (Figure 5).

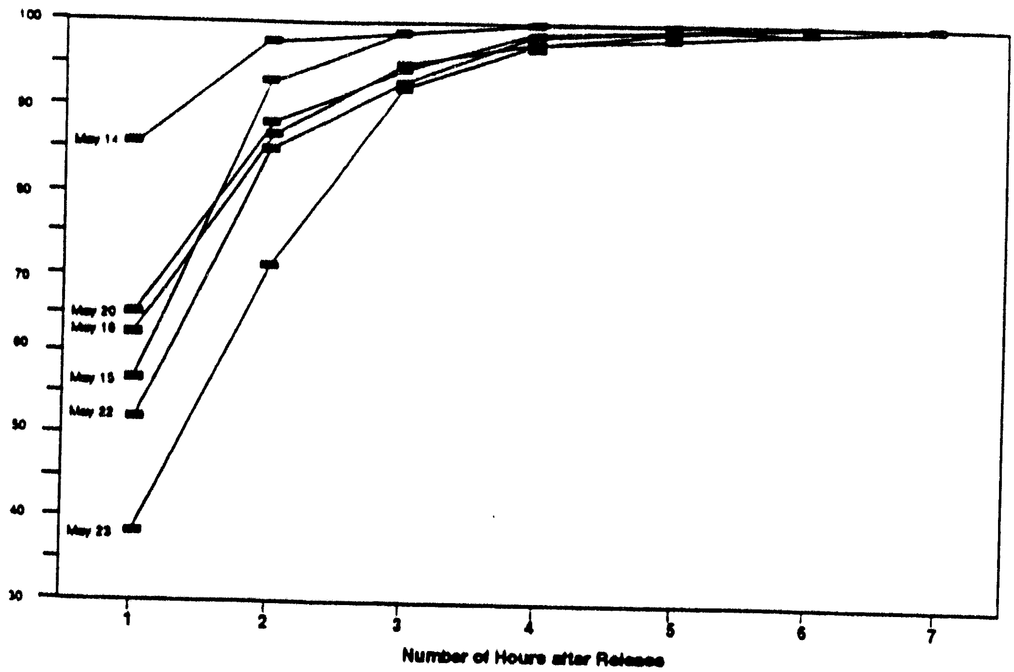

Figure 5. Cumulative percentage of Atlantic salmon smolts recaptured over time in Holyoke Canal bypass sampler, Spring 1992.

The guidance efficiencies for radio-tagged fish and caudal punched fish were similar (Table 2). There was no statistical difference in guidance efficiency between the two groups (P >0.05). Of the 30 radio-tagged fish released at 3-in. louver spacings, 90 percent (27) were detected in the canal or collected in the bypass. The guidance efficiencies of the radio-tagged Atlantic salmon smolts varied from 62 to 100 percent, with a mean of 84 percent (Table 3). These estimates include the smolts that were classified as unknown, to make them directly comparable to the estimates derived for the caudal punched fish. It is likely that the smolts that were classified as unknown did not enter the canal; therefore, these estimates of guidance efficiency are also conservative.

TABLE 2 COMPARISON OF GUIDANCE EFFICIENCIES OF RADIO-TAGGED AND CAUDAL PUNCHED ATLANTIC SALMON SMOLTS

Date	RADIO-TAGGED			CAUDAL PUNCHED		
	Released	Recovered	% Recovered	Released	Recovered	% Recovered
14 May 92	8	5	63	461	415	90
15 May 92	10	10	100	419	376	90
16 May 92	10	9	90	487	461	95
20 May 92	10	9	90	484	418	86
22 May 92	9	4	44	475	300	63
23 May 92	9	7	78	465	421	91

TABLE 3 RESULTS OF RADIO-TAGGED ATLANTIC SALMON SMOLT RELEASES AT HOLYOKE CANAL DURING SPRING 1992

Date	Number of Fish	Number of Non-Transmitting Tags	Remained in Pen	Bypassed	Boatlock Station	First Level Canal[c]	Unknown	Percent Bypassed
14 May	10	0	2	5	1	0	2	62
15 May	10	0	0	10	0	0	0	100
16 May	10	0	0	9	0	0	1	90
20 May	10	2[a]	0	9[a]	1	0	0	90
22 May	9	1	0	4	0	0	4	44
23 May	9	4[b]	0	7[b]	0	0	2	77

(a) Two non-transmitting tags removed from fish at bypass sampler.
(b) Three non-transmitting tags removed from fish at bypass sampler.
(c) Downstream of Boatlock Station Branch.

The three underlouver nets did not catch any smolts during these releases. However, a total of 13 smolts were captured in the vertical array of the fyke nets (Table 1). All of these smolts were captured un the uppermost net. No wild smolts were collected in any of the nets during the entire study period.

Twelve-inch louver spacings: For the three releases with the louvers spaced at 12 in., the total guidance efficiency of Atlantic salmon smolts (radio-tagged plus caudal punched smolts) was 86, 63, and 90 percent, respectively (Table 1). The overall guidance efficiency, the three releases pooled, was 79.7 percent. As explained above, all of these guidance efficiencies are underestimated.

Guidance efficiencies for radio-tagged and caudal punched smolts were similar (Table 2). There was no statistical difference in the guidance efficiencies between the two groups ($P > 0.05$). Of the 28 radio-tagged smolts released, 79 percent (22) were detected in the canal or collected in the bypass. The guidance efficiencies of the radio-tagged smolts varied from 44 to 90 percent, with a mean of 70.3 percent (Table 3). These efficiencies include those smolts categorized as unknown. It is likely that the radio-tagged fish that were classified as unknown did not enter the canal, and therefore these guidance efficiencies are also conservative.

The three underlouver nets captured a total of seven marked smolts during these three releases, with four, one, and two being captured in the upstream, middle, and downstream nets, respectively (Table 1). One smolt was captured in the uppermost vertical sampling fyke net.

Comparison of Guidance Efficiencies

The mean guidance efficiency when louver slats were spaced at 3 in. was 91.7 percent and was 79.7 percent when the louver slats were spaced at 12 in. A paired sample t-test using an arcsine transformation indicated that these guidance efficiencies were not statistically different (P >0.05). However, this statistical difference could be an artifact of small sample sizes.

Velocity Measurements

Velocity measurements were made six times during the study period and there was a general increase in velocity from the upstream end to the downstream end of the louver array (Figure 6). There was a lot of variability among the velocities at the same locations on various days, although the canal flow fluctuated only slightly. There is no noticeable difference in the velocity patterns between the 3-in.-spaced louvers and the 12-in.-spaced louvers. In both cases there was a slight decrease in velocity about three-fourths the distance down the louvers. The decrease was slightly more evident when the louver slat spacing was at 3 in.

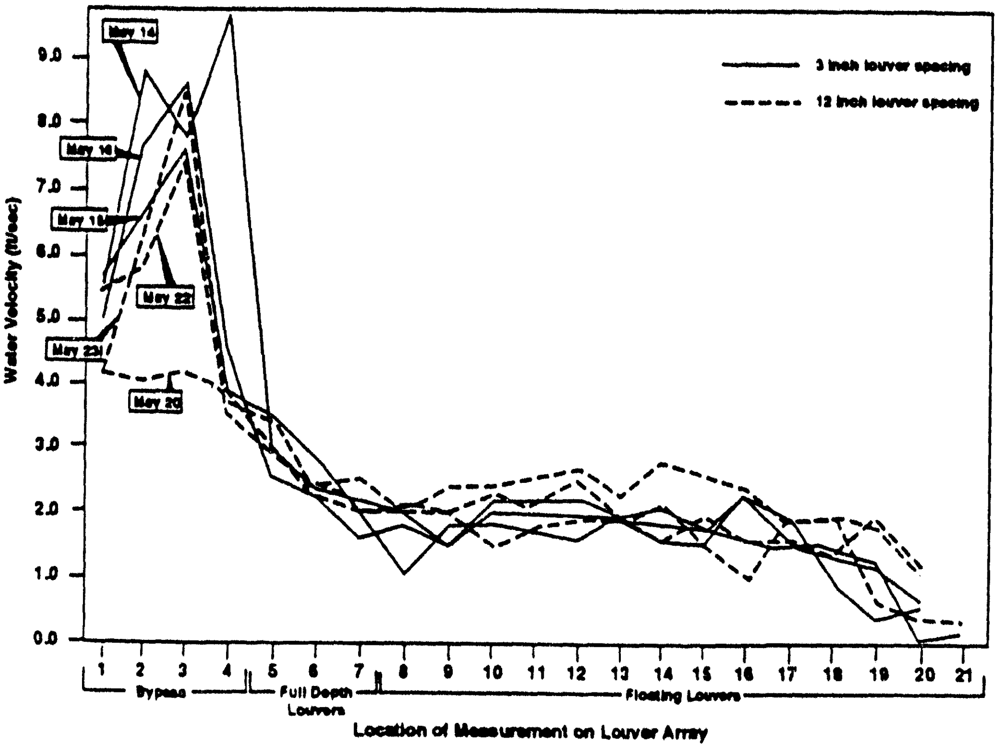

Figure 6. Velocity measurements along the length of the louvers in Holyoke Canal during Atlantic salmon smolt releases, Spring 1992.

DISCUSSION

The results of this study confirm that louvers are an effective means of diverting Atlantic salmon smolts from the Holyoke Canal to the Hadley Falls tailrace. The guidance efficiency of the louvers was not statistically different between tests that were conducted with louver slats spaced 3 in. or louver slats spaced 12 in. However, the means of the trials were different, with the 3-in. louver spacings having a higher mean guidance efficiency. An objective of this study was to determine the maximum slat spacing that would guide at least 80 percent of the smolts. The mean guidance efficiency with the 12-in. slat spacings was 79.7 percent. Studies with just the louver framework in place support the hypothesis that a guidance efficiency of 80 percent could be obtained with larger slat spacings (Ruggles et al. 1993). Tests by Ducharme (1972) also indicated that 12-in. louver slat spacings did not affect the ability of louvers to guide Atlantic salmon smolts. In order to rigorously test what is the maximum slat spacing that can be used to guide 80 percent of the smolts, more releases at test configurations with greater than 12-in. slat spacings need to be conducted. Due to the lack of test fish and inappropriate water temperatures, it was not possible to conduct additional studies at larger slat spacings during 1992.

Guidance efficiency for radio-tagged smolts was the same as for caudal-punched smolts. This fact is noteworthy from the standpoint of radiotelemetry studies. In most radiotelemetry studies, it is not possible to determine if radio-tagging affects the behavior of the fish, because there is nothing to compare them to. The results from this study indicate that the behavior of hatchery-reared Atlantic salmon smolts is not affected by the radio-tagging procedures used for these and other radiotelemetry studies by NUSCO.

The preliminary estimate of mortality of Atlantic salmon smolts (2 to 5 percent) associated with the bypass facility is lower than that estimated for juvenile clupeids (approximately 5 percent) (Harza and RMC 1992). These data indicate that mortality associated with passing through a pipe ad over a wedgewire screen inflicts very little damage and mortality, whether the test fish are salmon smolts or juvenile clupeids. The non-test smolts that were captured in the bypass were also in good condition with little descaling or other external injuries.

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Two Promising Technologies for Fish Protection at Hydroelectric Projects

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Abstract.-For projects with confined intakes or penstocks, the high velocity screen is a new, cost effective technology that offers promise in providing protection for juvenile fish. At projects where intakes, canals or penstocks are not confined or accessible, surface attraction at spillways, ice or trash sluiceways, or modified structures on the surface of the forebay near the face of the dam may provide the most promising alternative to attract and safely pass juvenile fish.

Introduction

In recent years, the development of technologies for the protection of juvenile fish at hydroelectric projects has become an increasingly important issue. This is due, in part, to the declining status of numerous populations of fish throughout North America. In 1992, for example, several stocks of salmon in the Pacific Northwest were listed as threatened or endangered under the Endangered Species Act. Because of this condition, methods to protect these populations require addressing numerous factors which can influence survival throughout all phases of their life history. Although we do not have control over many factors that influence survival of salmon and steelhead in the wild, we have some control over conditions in the freshwater environment. To preserve and rebuild weak stocks of fish, we can enhance and protect stream habitat, leave more water in the river, reduce harvest and provide more effective passage at water diversions. In particular, effective downstream passage for juvenile fish at hydroelectric projects can improve the overall survival of fish moving to salt water and subsequently increase the numbers of adults returning to spawn.

In the past few years, several new technologies have undergone evaluation as potential methods for protection of juvenile fish at hydroelectric projects. These have included behavioral systems, such as sounds and lights, physical systems such as high velocity screens, and hybrid systems using a combination of fish behavior and physical structures such as vertical sluiceways. Although the behavioral systems have demonstrated some success under particular conditions, they cannot offer comprehensive effectiveness at sites which do not meet specific criteria. Because our knowledge about these criteria is limited, and the number of variables associated with the concepts can be large, we are required to extensively evaluate behavioral systems at each site before we can demonstrate success. In contrast to behavioral systems, physical systems can be adapted to new sites with fewer constraints. Physical systems generally offer the highest likelihood of success. Hybrid systems, which involve fish behavior in combination with physical structures or facilities, also require evaluation, but can provide sufficient protection at some sites. In this paper, I will review the development of a physical system, the high velocity screen, and a hybrid system, surface attraction through vertical slots near the powerhouse.

High Velocity Screens

The high velocity screening concept was originally developed by researchers working in streams and reservoirs to collect juvenile salmon and steelhead migrating downstream. These researchers developed a method to collect fish with an inclined screen

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floating at the surface of a stream or in the forebay of a dam (Figure 1). In rivers, the screen is supported by floating pontoons and placed in an area where high surface velocities wash fish into the mouth of the screen, over the screening surface, and into a trap at the downstream end. In reservoirs, pumps on the downstream side of the screen create flow to attract juvenile fish (Figure 2). Inclined screens operating in reservoirs (called gulpers) trap fish or funnel them into a bypass pipe for transportation downstream. Similar systems (called skimmers) have been situated in reservoirs attached to the face of the dam (Figure 3).

In rivers, the floating scoop trap remains a successful tool for fisheries biologists studying juvenile fish migrations (Seiler et al. 1981; Wunderlich 1983; Seiler and Neuhauser 1985; Wunderlich and Dilley 1988; Dilley and Wunderlich 1992;). Its use in reservoir systems has been less successful. Several reservoir applications have been inefficient in attracting sufficient numbers of fish or unable to operate on a long term basis (Allen and Rothfus 1976; Stober 1986). The fish that are attracted to the opening, however, are effectively trapped.

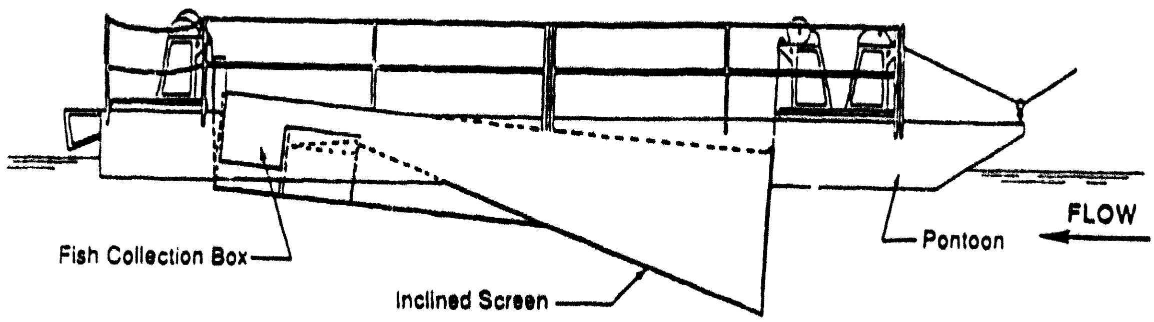

Figure 1. Inclined plane trap for river sampling of juvenile migrants (Seiler 1981)

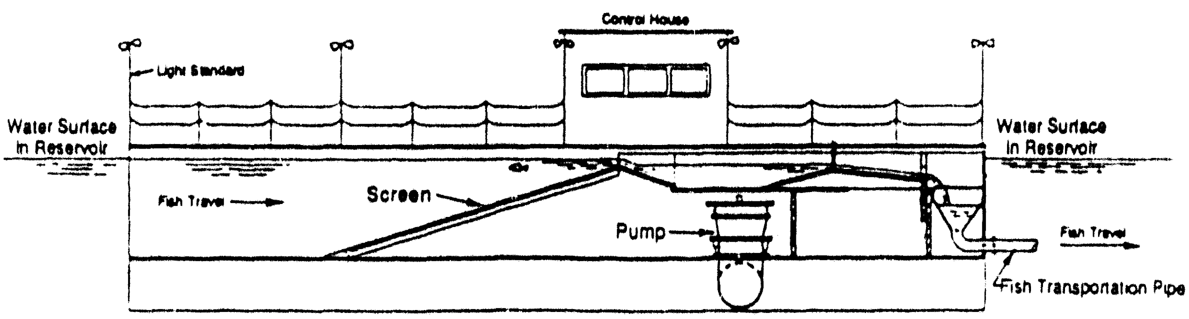

Figure 2. Floating inclined plane trap (gulper) in Baker Lake Reservoir (Warner 1961).

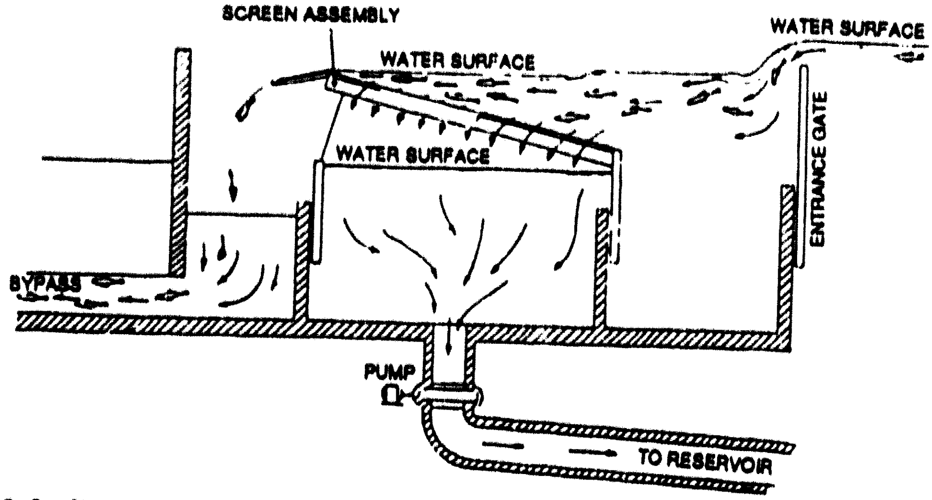

Figure 3. Inclined plane trap (skimmer) attached to Pelton Dam (Eicher 1958).

The success of the inclined plane screen as an effective trap provided the background upon which the concept was adapted for a new application: turbine intake screening. This transition came in 1979, when George Eicher was commissioned by Portland General Electric Company to design a screen to divert fish around one of thirteen turbines at the Willamette Falls Hydroelectric Project. It was determined that 92 percent of the fish upstream of the project migrated through this turbine (Eicher 1991).

A screen design for the project based on conventional criteria would have involved slow enough water velocities flowing through the screen such that juvenile fish could easily escape by swimming against the flow. Induced currents would then lead the fish to a bypass pipe at the downstream end of the facility for transportation around the project. Because of the low water velocities required, conventional screen surface areas would have been large and resulted in expensive structural and mechanical components for screen support and cleaning.

Because of the lack of space for a conventional screen, Mr. Eicher departed from a conventional approach and designed an inclined screen configuration that would fit inside the turbine penstock. Mr. Eicher's application for the screen was to retrofit two rectangular shaped, wedge wire screens into the penstock with one panel fixed to the walls and one panel attached to an axle to pivot the screen section backwards to the flow for cleaning (Figure 4).

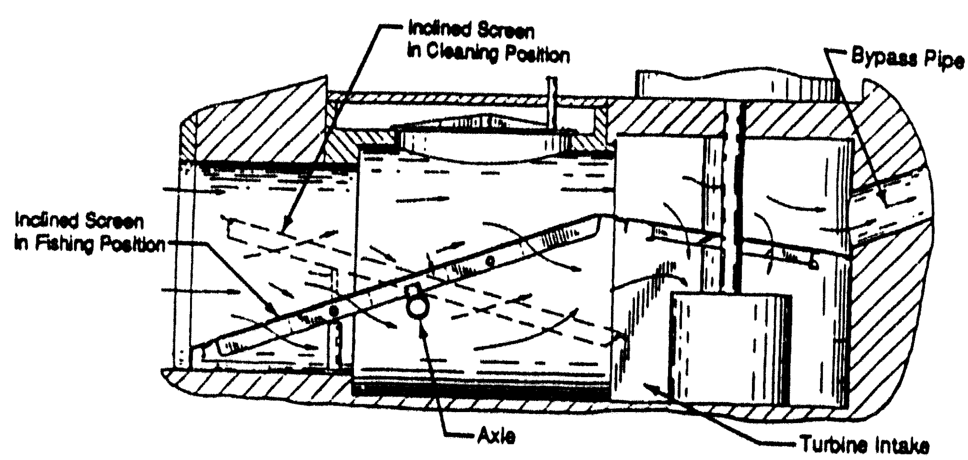

Figure 4. Eicher screen design for Willamette Falls Hydroelectric Project (Eicher 1985).

Although there was interest in the success of the screen installation at Willamette Falls, facilities for evaluation of the screen were not sufficient to accurately determine passage efficiency.

Following design and installation of the screen at Willamette Falls, Mr. Eicher constructed and tested a rectangular, sectional model of a pressurized penstock screen at the University of Washington in 1982 and 1983. The objectives of the model study were to evaluate different screen angles, determine thresholds for approach velocities (using rainbow trout as test fish in the model), and identify other factors affecting screen performance. Mr. Eicher knew the importance of understanding the relationship between fish behavior and screen operation. Similar to current programs to evaluate fish passage systems (Fletcher 1985; Anderson 1988), Mr. Eicher developed a program to characterize and quantify this understanding through experiments that determined the path of fish as they moved through the structure. These experiments were carried out using a plexiglas wall on one side of the model to observe fish behavior. After fish were released, it was observed that they oriented into the flow and swam upwards, away from the screen surface to avoid contact. Because of the high velocities present, fish were quickly forced downstream to the end of the screen and into the bypass.

Based on the model screen configuration, Mr. Eicher refined the design for applications in round penstocks (Figure 5). Similar to the model, the screen would be oriented at a shallow angle to the flow, using geometry and fish behavior to sweep fish to the bypass pipe at the downstream end of the screen. Because this screen application could occur under pressurized and relatively high velocity conditions compared to conventional screens, the screen surface could be small and compact. This small size would provide significant cost savings in screen installation. Based on this design, and several screen features, Mr. Eicher filed for a patent in 1982.

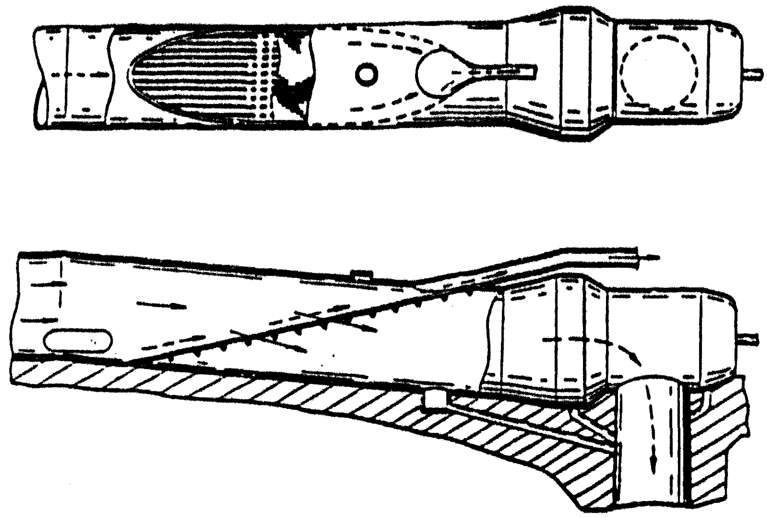

Figure 5. Refined design of Eicher screen for round penstocks (Eicher 1985).

After the initial model tests, the Electric Power Research Institute (EPRI) funded further model studies from 1984 through 1986. Screen tests were carried out with a refined model and improved water supply. During the EPRI funded study, juvenile coho and chinook salmon were released under various velocity conditions using different screen angles. Evaluations were also made of various screen materials, headloss characteristics, and debris conditions. At the conclusion of the model tests, Mr. Eicher and the Electric Power Research Institute believed that the technology was a promising approach for fish protection. With this in mind, 1986 began the search for a site where a prototype could be installed with a wider range of evaluation capabilities than the installation at Willamette Falls.

In 1988, discussions began between EPRI and James River Paper Company. James River was undergoing relicensing for their Elwha River Hydroelectric Project and the requirement for fish screen installation was imminent. Based on conceptual designs, Eicher screens could provide a $3.5 million cost savings over conventional screening technology. Therefore, James River was interested in evaluating an Eicher screen. If an Eicher screen demonstrated equal or better protection than a conventional screening facility, resource agencies could approve James River's use of Eicher screens.

In 1988, an agreement was signed between the James River Paper Company and EPRI. According to the agreement, James River would fund design and installation of the screen, while EPRI would fund all efforts to evaluate the screen.

Design of the Elwha screen began in 1988. However, because specific design criteria were not available, development of screen parameters involved consensus among the resource agencies, James River, James River's consultant (Harza Northwest), George Eicher, EPRI and EPRI's consultant (Stone & Webster). The process of design and evaluation was guided by a study plan which was jointly developed. The overall goal for the system was to provide 95 percent passage survival for all downstream migrating fingerlings and yearlings.

There was some disagreement whether velocity components should have absolute limits. General consensus was finally reached to develop uniform penstock velocity conditions (not to exceed 10 feet per second) and limit the velocity component through the screen as much as practical. These criteria were based upon professional judgment regarding the behavior of fish moving past the screen, and the swimming capability of juvenile salmonids. Additional objectives were to provide effective debris management and minimize headloss, operational constraints and lost power generation due to fish bypass flows.

To assist in screen design, Harza Northwest commissioned ENSR of Redmond, Washington to conduct a 1:4.7 scale hydraulic model study. The objectives of the study were to help develop the desired velocity patterns near the screen and minimize headloss. Additionally, the hydraulic effect of a 17° bend in the penstock upstream of the location where the screen would be installed was unclear.

The penstock was modeled using 24-inch clear acrylic tubing. Maintaining the same screen headloss coefficients in the model and the full-scale penstock screen required using penstock screen material in the model and operating at penstock velocities, thereby producing full-scale Reynolds Numbers in the model. Since the scale of the screen material was 1:1 and the support beams were scaled 1:4.7, the model did not have strict geometric similarity. The screen bars and openings of the model were large relative to the size of the support beams and to the model penstock diameter. Nevertheless, it was believed that the overall flow patterns in the model would be similar to the full-scale screen because of the high Reynolds Number (in the range of 0.7×10^6 to 1.4×10^6).

Initial hydraulic tests were conducted using 63% porosity screen material. These tests indicated that the velocities through the screen were highest on the downstream end of the screen near the bypass. To create a more uniform velocity distribution through the screen, a series of tests were performed using various combinations of baffles. A final model test was performed with actual wedgewire porosity to confirm the test results with baffles. Based on the model tests, the final variable porosity configuration selected for the Elwha penstock screen was 63% for the upstream 2/3 of the screen, and 32% and 8% for the remainder (Figure 6). This variable porosity was found to yield a relatively uniform penstock velocity along the length of the screen, while maintaining reasonable limits to the velocity component through the screen.

Final screen design was completed by Harza Northwest in the fall of 1989 and the screen was installed in a new penstock section at the project in the winter of 1989. Design for evaluation facilities was completed by Stone & Webster in the winter of 1989 and construction was completed in early 1990. In May of 1990, under contract to EPRI, Stone & Webster and Harza Northwest staff completed the first evaluation studies of the screen with juvenile coho salmon smolts. Tests were conducted at penstock velocities from 4 to 7.8 fps (corresponding to 50 to 100 percent turbine flow).

Results from the studies in 1990 indicated that the screen was over 99 percent effective in diverting coho salmon smolts without mortality. Results from evaluations in 1991 were similar, with over 99 percent of the steelhead smolts and 98 percent of the chinook fingerlings diverted without mortality. Some partial descaling occurred at the highest penstock velocity conditions. Observations during the evaluation indicated that of those fish that came in contact with the screen, the majority of these contacts occurred just upstream of the transition between the 63% and 32% porosity screen sections.

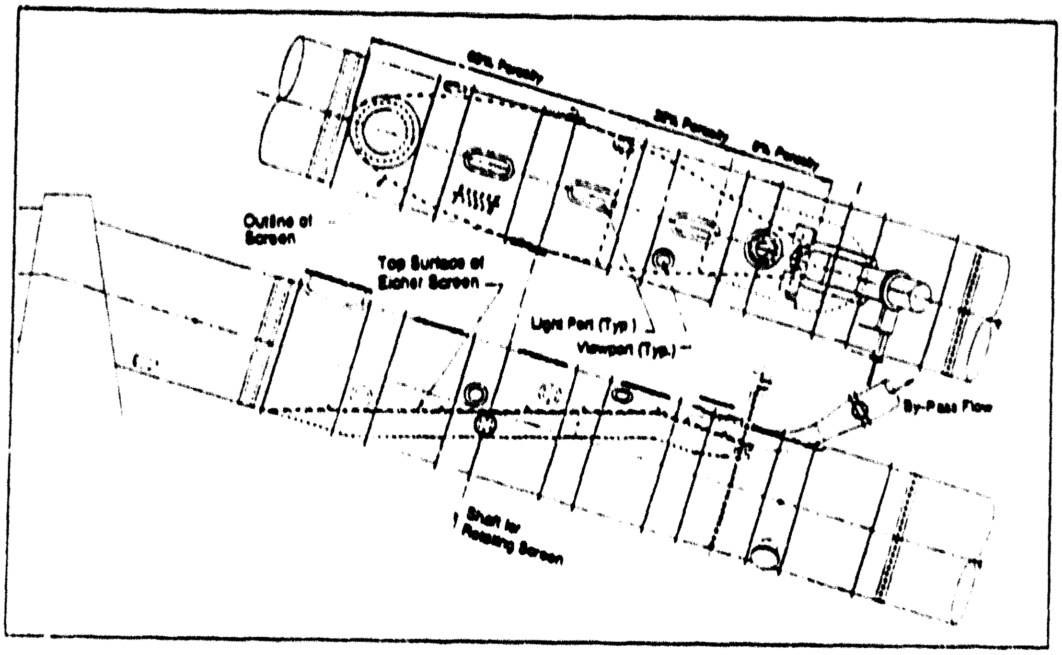

Figure 6. Eicher screen design for Elwha Dam Hydroelectric Project (Adam et al. 1991).

Following screen evaluation at Elwha, EPRI conducted an additional model study of the Elwha penstock screen at the Alden Hydraulic Laboratory in Massachusetts. Although the Elwha design was very successful, EPRI was interested in determining if a more gradual change in screen porosity could provide more uniform velocities through the screen. Of interest was the section where most fish contacts were observed during prototype evaluation at Elwha. Based on the additional model studies conducted, significant improvement in the uniformity of velocity through the screen could not be accomplished by a more gradual transition in screen porosity (T. Cook, Stone & Webster Engineering, pers. comm. 1992).

Based on the successful passage results at Elwha, BC Hydro became interested in an Eicher screen for their Puntledge River Hydroelectric Project on Vancouver Island, Canada. One of BC Hydro's first tasks was to conduct a workshop to develop screen criteria. The resulting criteria were based principally on the knowledge developed from the design and evaluation of the screen at Elwha. Following development of design criteria, BC Hydro funded a model study of the Puntledge Project's intake, screen and two penstocks. Various items were evaluated in the Puntledge model study, including velocity distribution across the screen (1:11 scale model) and head loss characteristics.

One interesting outcome of the Puntledge model study was the velocity distribution through the screen. With a single screen porosity in the penstock, velocities through the screen in the Puntledge model were much more uniform than the Elwha model (and prototype). This could be attributed to the longer section of straight pipe upstream of the screen at Puntledge compared to Elwha. Just upstream of the screen at Elwha is a 17° bend in the penstock. It is theorized that this difference in straight penstock length upstream of the screen caused the differences in velocity distribution through the screen. Due to this difference, model results indicated that porosity changes were not necessary for the Puntledge screen design and BC Hydro is developing the project with uniform, 50 percent porosity screen.

EPRI recently initiated efforts to modify the design of the Eicher screen concept and develop a modular approach to high velocity screening. In 1992, EPRI funded the design and construction of a 1:6.6 scale model of a modular inclined screen (MIS) at Alden Research Laboratory and conducted preliminary hydraulic and biological testing. EPRI's approach is to develop a design which will be applicable at sites where penstocks are unavailable. Additionally, EPRI is interested in studying the ability of various screen angles to divert different species of fish.

Preliminary results from EPRI's MIS evaluation indicate that 2 to 3-inch bluegill and 4 to 8-inch Atlantic salmon were successfully diverted at approach velocities of 2 to 4 feet per second (Taft et al. 1992). EPRI will be conducting additional MIS evaluations in 1993, as well as constructing a 1:3.3 scale model of the MIS in a test flume. Tests will be performed using rainbow trout, blueback herring, walleye, channel catfish, and Pacific salmon. EPRI is planning to evaluate passage at screen angles ranging from 10 to 20 degrees and approach velocities ranging from 2 to 10 feet per second.

An interesting aspect of the MIS program is the development of an intake design that eliminates the necessity to baffle the screen or use different porosity sections. Based on the experience gained through model testing of the Elwha and Puntledge penstock screens, it may be possible to develop an intake configuration that can control the velocity distribution across and through the screen surface. Questions still remain regarding the need to provide uniform velocity distribution compared to increasing velocity. It may be possible to provide effective passage with non-uniform velocity distribution if a constant ratio of the sweeping velocity component can be maintained. Answers to these questions, and comparisons between various designs are needed to further understand and develop the technology.

The MIS development program involves a concept to standardize a design to minimize the need for site-specific adaptations. Conceivably, the use of the MIS technology at a site could simply require a certain number of modules depending on the total project flow, however, site specific adaptations are likely.

With respect to the angle of the screen in an Eicher or MIS application, model studies conducted by Mr. Eicher and EPRI in the mid 1980's provide some important insight. Given the same velocity conditions, fewer fish came in contact with the screen when the screen was at lower angles to the flow. This indicates that weaker swimming fish, or smaller fish will require a shallower screen angle for any given velocity condition than stronger swimming or larger fish. Shallower angles may also be required where water temperatures are lower and the capability of fish to swim is reduced. It will be interesting to follow EPRI's future research with the MIS and learn if different species of fish react differently when passing through the system.

Surface Attraction

Surface attraction is a concept that has been incorporated into numerous devices developed over the years to guide and pass fish downstream around dams. These devices have developed for two reasons, logistics and behavior. We have better access to surface waters (especially for retrofitting) and juvenile salmon and steelhead orient themselves in the upper water column in rivers and reservoirs as they migrate downstream (Rees 1957, Long 1968, Ransom and Malone 1989; Bell 1991).

Reviewing the literature indicates that facilities designed to attract and bypass fish at the surface have had mixed results. Some of the most successful uses of this concept have been developed in the past few years and involve vertical slots adjacent to or above power intakes. This concept involves the use of a behavioral stimuli (surface velocities) to attract fish to a location where they can be collected or transported. This alternative can be successful if the penstocks or power intakes are inaccessible and conventional screens are not feasible.

Some of the first applications for utilizing surface orientation in fish were developed at hydroelectric projects on the Columbia and Snake rivers, and several high head dams in the Pacific Northwest. The design of these facilities developed from research that indicated juvenile salmonids concentrate towards the upper or surface most area as they pass through confined spaces at hydroelectric projects, such as turbine intakes (Long 1968; Swan et al. 1990). It has also been found that juvenile fish in the smolted condition are more positively buoyant than as a fingerling or parr (Giorgi et al. 1988).

Based upon juvenile salmon and steelhead concentrations nearest the surface in turbine intakes, submerged traveling screens or fixed bar screens were designed to intercept the upper one-third of the turbine intake flow. Unfortunately, fish guidance efficiencies with submerged intake screens has varied, depending on the specific physical and hydraulic conditions at each site. Submerged screening systems at projects on the mainstem Columbia and Snake river have ranged between 20 to 80 percent guidance efficiency (GAO 1990). Unanticipated flow patterns and fish behavioral responses have resulted in less than optimum screen efficiencies.

Surface attraction and bypass facilities have been used at numerous sites in the Pacific Northwest. The Corps of Engineers operate several facilities that utilize surface or multi-level outlets for fish attraction and passage. This includes hydroelectric projects such as Green Peter Dam and Cougar Dam, and water supply projects such as Wynoochee Dam and Fall Creek Dam. Successful juvenile fish passage at these sites varies. At those facilities where fish guidance efficiency is low, it is generally due to flows that are not large enough to attract sufficient numbers of fish or bypass facilities that cause high injury rates or mortalities.

At Green Peter Dam, one of the more successful sites, a floating system in the forebay is operated which provides approximately 250 cfs of attraction flow for juvenile migrants. After the fish are attracted to a vertical intake (called the horn), fish are screened at an inclined plane trap, similar to a gulper. Water which was pumped through the screen for attraction is recycled back into the reservoir and fish are transported downstream of the dam in a flow of less than 10 cfs. Based on an evaluation of this site, passage efficiency has been estimated at 75 to 84% for chinook, 67% for summer steelhead, and 33 to 57% for winter steelhead (Wagner and Ingram 1973).

Surface spill through ice and trash sluiceways has been another technique used to attract and subsequently bypass juvenile fish at hydroelectric projects. During tests at the Dalles Dam in 1985, sluiceways were able to attract and pass over 23% of the juvenile fish using only 1.6% of the total average river flow (Steig and Johnson 1986). At Ice Harbor Dam in 1983, sluiceways were able to pass 30% of the juvenile outmigrants in 2.3% of the river flow (Johnson et al. 1984). Other sluiceway tests show similar results, however, some logistical difficulties in existing facilities have been observed. Existing sluiceway capacities for water flow is limited. Additionally, sluiceways are more effective during daylight hours. During darkness, fish migration occurs deeper in the river and sluiceways have been observed to be less effective. Despite these difficulties, sluiceway passage is an active component of downstream passage at several projects on the Columbia River.

Spillways have been effective at some projects to pass fish, but this technique is usually expensive and inefficient. If spillways are near the powerhouse, or situated in surface waters above the turbine intakes, they can provide a successful attraction and passage system. However, if the majority of the river flow passes through the powerhouse in a different area from the spillway, spill can be inefficient and expensive in attracting and passing sufficient numbers of fish. Sluiceways appear to have an advantage over spillways because of their proximity to powerhouse flow.

Fisheries biologists and engineers have learned that utilizing existing or modified sluice or spillway facilities adjacent to, or near the powerhouse can provide a successful arrangement for fish attraction and bypass. Powerhouses use a relatively high percentage of the total flow, sometimes creating high velocities sufficient enough to attract fish. If surface flow can be provided nearby, surface velocities can provide a stimuli for downstream migrants. After juveniles are attracted to a central area or intake, they can be screened or bypassed with the water as spill.

The successful development of surface slots or ports on the face of a dam has recently been accomplished at Wells Dam on the Columbia River. Based upon the surface orientation of fish and the success of sluiceway attraction, a surface baffle system was designed, installed and evaluated in the 1980's (Figure 7). Recently, after evaluation and testing of several baffle configurations, fish guidance efficiencies of 95 to 99% have been achieved (Kudera 1992). The bypass system takes advantage of the hydrocombine design of the dam, where spillways are located directly over the turbine intakes. Baffles installed in the spill intakes increase surface forebay velocities and provide attraction for juvenile migrants (Erho et al. 1988).

The concept of retrofitting a surface attraction system near the powerhouse to attract and successfully bypass juvenile fish at Columbia River and Snake River dams has been considered (G. Aurdahl, Sverdrup Corporation, pers. comm.; R. Pearce, NMFS, pers. comm.). Although this concept may be expensive to construct, it may provide higher fish guidance efficiencies and survival than existing submerged screens, or the use of spillways and sluiceways. A facility of this type could involve a moveable barge (similar to a gulper) to provide flexibility on the location of where the majority of downstream migrants concentrate. It could also involve permanent surface slots on the upstream face of the dam.

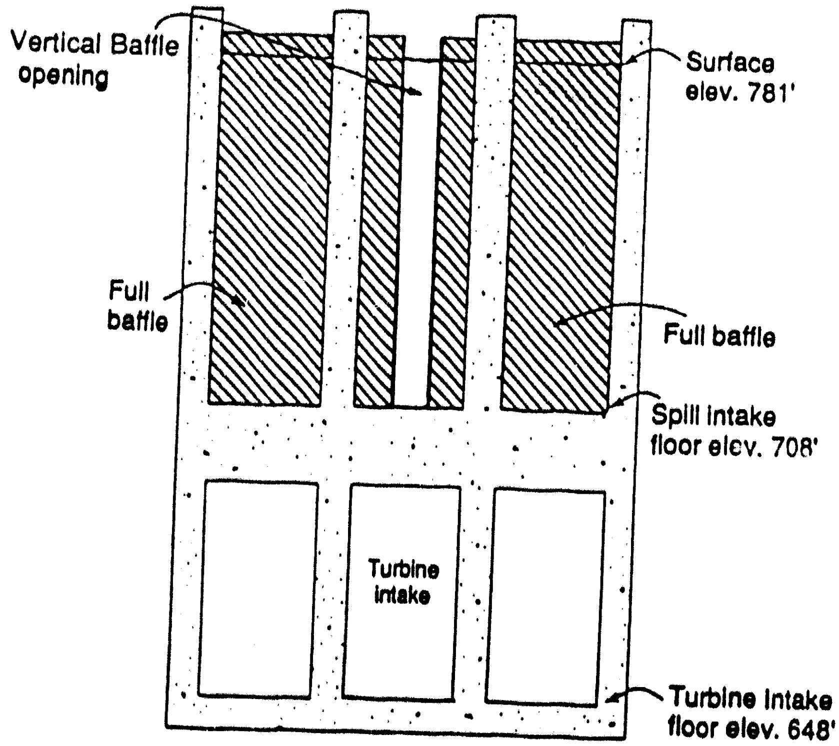

Figure 7. Wells Dam Hydroelectric Project spillway baffle system (Erho 1988).

Currently Harza Northwest is working with northwest resource agency biologists and engineers to develop fish passage facilities for the Cowlitz Falls Hydroelectric Project. Because of the hydrocombine design of the dam, and the success with surface attraction and bypass at Wells Dam, a system comprising of vertical spillway slots on the face of the dam is under consideration. Because juveniles require trucking around the dam, and two other dams downstream of the Cowlitz Falls Project, an attraction and screening system in two central spillways above the turbine intakes is assumed to be the optimum configuration for fish passage. A hydraulic model is currently in operation and various baffling configurations are being evaluated with dye tests and velocity measurements.

Conclusions

High velocity screening systems appear to hold promise in protecting fish at hydroelectric projects where penstocks, canals or intakes can be retrofitted with a rectangular or elliptical screen at a shallow angle to the flow. Designs are available for projects with penstocks, and a new rectangular, modular design is under development. Use of this technology may provide a cost effective alternative to conventional screens, or a solution to fish protection when conventional screens are not cost effective or logistically possible.

Surface facilities on the face of the dam near the powerhouse can provide a successful alternative for fish passage if penstocks or power intakes are inaccessible, or sufficient space for conventional screens is not available. In this situation, vertical slots or ports adjacent to or above the powerhouse can provide an efficient alternative to high velocity screens, intake screens or conventional screens. With this configuration, dewatering facilities can be installed downstream of the slot or fish can be passed downstream with spill.

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DEBRIS REMOVAL FROM A LOW-VELOCITY, INCLINED FISH SCREEN

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Abstract
The Potter Valley Intake Inclining Horizontal Fish Screen Facility is a state-of-the-art fish screen which has been designed for installation at the Potter Valley Hydroelectric Project in North Central California. An air backwash system for the 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.

1. 0 Introduction

The Potter Valley Hydroelectric Project, located near Potter Valley in Mendocino County, California, is owned and operated by Pacific Gas and Electric Company (PG&E). This 9.2-megawatt project was completed in 1928 and provides both irrigation water and power to Potter Valley. Since there are spawning grounds for Steelhead Trout and Coho and Chinook Salmon upstream from the project, providing for handling downstream migrants was necessary because virtually all of the river flow passes through the intake during a significant part of the migratory seasons. In order to comply with regulatory requirements for screening fish at the intake, a state-of-the-art Inclining Horizontal Fish Screen Facility has been developed. Cleaning these large screens was of particular concern because the site is unattended, and a reliable, automatic cleaning system was required to handle significant quantities of floating debris. The experimental testing of a full-scale section of the screen to develop a satisfactory air-backwash system for the Potter Valley Inclined Horizontal Fish Screen Facility is presented herein.

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2.0 System Description

Cape Horn Dam, located on the Eel River in North-Central California, forms Van Arsdale Reservoir. The reservoir is small and the project operates as a run-of-the river project with flows regulated by an upstream dam and reservoir. The Potter Valley Hydroelectric Project diverts up to 310 cfs through the intake in Van Arsdale Reservoir passes the flow through a tunnel and penstock and delivers the flow to the Potter Valley Powerhouse. Releases from the power house are used for irrigation in Potter Valley; excess flow is returned to the Russian River at Lake Mendocino.

As part of the relicensing requirements, PG&E modified the original intake in 1972 and installed a horizontal "Bates" traveling screen. The "Bates" screen concept is similar to trying to operate a conventional travelling screen on its side, but with several more pulleys to allow for travel across the tunnel intake and return to the fish screening area. Heavy debris loading during flood periods and accumulation of bed-load material at the intake resulted in continuous malfunctions and extensive maintenance. Because of the poor performance in screening fish and excessive operating cost, the "Bates" screen was taken out of service in 1976.

In order to comply with the regulatory requirements for an operating fish screen at the site, PG&E initiated a major program for design of a new fish screen facility. Figure 1 depicts an isometric view of the Inclined Horizontal Fish Screen Facility for the Potter Valley Intake which was developed by PG&E in close cooperation with the California Department of Fish and Game (CDF&G), the U.S. Fish and Wildlife Services (USFWS), and the National Marine Fishery Services (NMFS). The basic criteria governing the design of the screen itself were:

1. **Velocity**. CDF&G criteria require that the maximum discharge through the screen shall not exceed 0.33 cfs per square foot of screen opening. This is equivalent to an average approach flow velocity normal to the screen of 0.33 ft/sec.

2. **Screen**. The screen shall be wedgewire screen with 3 mm (1/8-inch) openings between wires, and the wedgewires shall be oriented perpendicular to the flow. CDF&G criteria state that the "screens shall have a minimum open area of 1.5 square feet per cubic foot/second." When combined with the approach flow velocity criterion, this implies that the screen porosity should be 50%. A range of 40 to 60% was deemed acceptable.

The approach flow velocity criterion requires that the minimum screen area be 310 cfs/0.33 ft/sec = 940 ft^2. The actual screen area is approximately 1200 ft^2 to provide some factor of safety in the design. The need for such a large screen area, the restricted space available, the necessity to handle significant debris, and the requirements for minimum operating costs led to development of the design shown in Figure 1. This new intake structure will be located directly over the existing tunnel to Potter Valley Powerhouse.

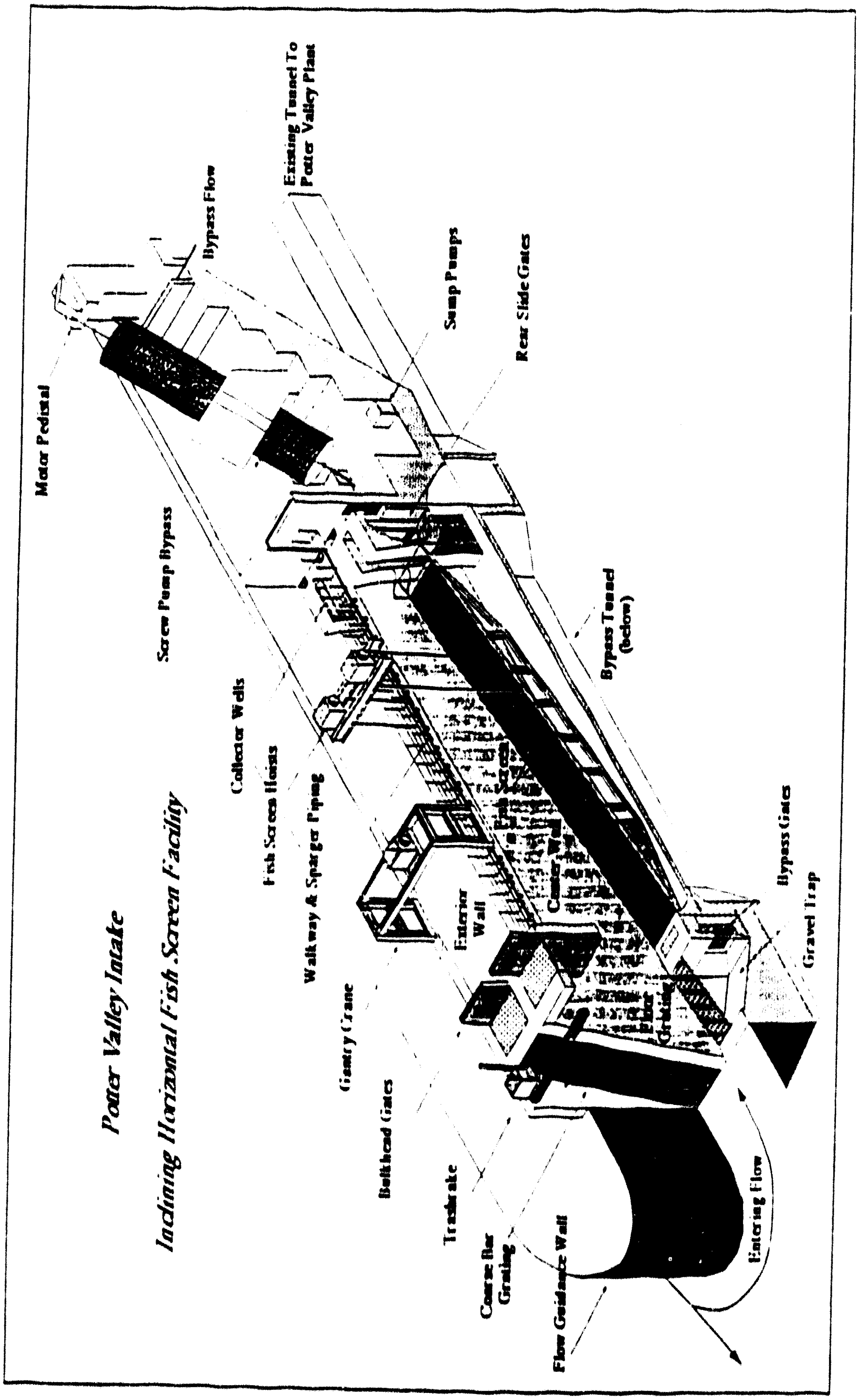
As shown on Figure 1, the structure consists of two bays aligned at approximately 135° to the direction of flow in Van Arsdale Reservoir. A hydraulic model study was used to develop a guidewall to provide a uniform approach flow to the screens for the full range of operating conditions. The fish screens are designed to operate when the flow in the Eel River is less than 7500 cfs. In the fish screening mode, flow passes over a gravel trap, through a set of bar screens and into the fish screening bays as illustrated in Figure 1. A maximum flow of 310 cfs, or 155 cfs per bay, will be screened. Approximately 8 cfs per bay will be used to bypass fish and debris. When flows in the Eel River exceed 7500 cfs, the flow will be bypassed through the gravel trap and directly into the power tunnel.

The fish screens will be mounted on an 80-foot long steel frame which will be adjustable between approximately 7° and 11° to maintain a constant depth of flow at the outlet into the fish pump chamber. Adjusting the angle of the screen allows for a 4-foot variation in the water level in Van Arsdale Reservoir.

The fish screens will be constructed of Hendrick B9 wedgewire screens with the bars oriented perpendicular to the flow as required by CDF&G and USFWS. The screens will be mounted 9 inches above a series of perforated plates whose porosity is varied from 50% at the downstream end to 4% at the upstream end to maintain a uniform flow through the screens. The variation in porosity of the perforated plates was determined using a hydraulic model of the intake structure and fish screen facility (Locher et. al., 1993).

3.0 Debris Removal

Debris loads at the existing intake in Van Arsdale Reservoir vary significantly in composition and quantity throughout the year. In late spring and summer, the principal debris problem is caused by filamentaceous algae, moss, and aquatic grasses which grow profusely during this period. The existing trashracks at the present intake are especially difficult to clear of the filamentaceous algae. Debris in the fall consists of leaves, long pine needles, twigs, branches, some remnants of filamentaceous algae and aquatic grasses. Deposition of debris could lead to non-uniform distribution of flow through the screen, or hot spots where the through-screen velocity could exceed the CDF&G velocity criteria. Operation and maintenance costs for cleaning the large screen area of approximately 1200 ft^2 were also of particular concern. Since the intake is at a relatively remote location, it was concluded that a


Potter Valley Intake
Inclining Horizontal Fish Screen Facility
Motor Pedistal
Bypass Flow
Existing Tunnel To Potter Valley Plant
Sump Pumps
Rear Slide Gates
Screw Pump Bypass
Bypass Tunnel (below)
Collector Wells
Fish Screen Hoists
Walkway & Sparger Piping
Bypass Gates
Gravel Trap
Exterior Wall
Gantry Crane
Bulkhead Gates
Trashrake
Coarse Bar Grating
Entering Flow
Flow Guidance Wall

reliable, automatic method of cleaning the screen was necessary, particularly in view of the fact that spring or summer flood flows could bring significant quantities of debris to the structure day or night.

Several mechanical means of cleaning the screen were considered, including various arrangements of scrapers, brushes, and modified rakes. None of these alternatives met criteria for simplicity in construction, ease of operation, and overall reliability. It was concluded that an air backwash system would be the most satisfactory method of cleaning the screens.

The principal advantages of the air-backwash system were:

1. There was a minimum of moving parts. The basic system is a passive set of pipes with solenoid-operated valves. All of the valves would be above the water surface and easily accessible.

2. There was no mechanical system that could harm the fish during the cleaning cycle.

3. A programmable controller would allow for complete flexibility in operating and changing the system to meet varying debris loads.

4. All operating equipment such as compressors, valves, and control equipment would be above the water surface and easily accessible for maintenance.

Although there was a precedent for using an air-backwash system at Twin Falls, located on the South Fork of the Snoqualmie River in the State of Washington (Ott and Jarrett, 1992), there were several major differences between the two sites:

1. The Twin Falls screen operates at a fixed angle of 4° from the horizontal, whereas the Potter Valley screen angle varies between 7° and 11°.

2. The through-flow velocity at Twin Falls is 0.5 ft/sec compared to the 0.33 ft/sec at Potter Valley.

3. The sweeping component, or flow parallel to the screen is 4 ft/sec at Twin Falls compared to 1.0 ft/sec at Potter Valley.

4. The screen wedgewires are oriented parallel to the flow at Twin Falls, but are perpendicular at the Potter Valley facility.

5. The characteristics of the debris differ with the debris at Twin Falls consisting primarily of leaves and organic material in the fall.

In view of the uncertainties associated with design of an air backwash system, it was concluded that a series of tests should be conducted on a full-scale section of the prototype screen. The principal objectives of the tests were:

1. To establish the spacing of the sparger pipes.

2. To determine size and configuration of the holes in the sparger piping.

3. To investigate the effects of the duration of the air burst and the operating pressure on cleaning the screen.

4. To study the effect of screen angle on the performance of the backwash system.

5. To evaluate the relative performance of various configurations using debris from the Eel River for test material, thus providing some confidence in the expected performance under actual debris conditions.

4.0 Test Facility

4.1 Flume The test facility was constructed at the existing intake in Van Arsdale Reservoir by Steiner Environmental Consulting of Potter Valley. The intake location was selected because of the readily available supply of water, but especially because of the ease with which debris from the Eel River could be obtained.

The test facility consisted of a flume 2.56 feet wide, 48 feet long and walls 6 feet high. A viewing section 16 feet long was constructed with lexan panels in the wall of the flume. Water was pumped from the Potter Valley intake structure, passed through the flume and discharged back to Potter Valley Reservoir. A once through system was chosen because of the extensive tests with large quantities of debris.

4.2 Screen

The test screen was a section of Hendrick B9 wedgewire screen with 1/8-inch openings between the wedgewires, and the wedgewires oriented perpendicular to the flow. The screen was 21 feet long, 2.5 feet wide, and could be raised and lowered to change the angle of the screen with the horizontal. The screen was mounted on the top of a truss 9 inches deep. Plywood panels were mounted on the lower chords of the truss. Two-inch diameter holes with different center-to-center spacing were drilled in the plywood to provide the required variations in porosity.

Four sections, each 4 feet long, were used to test the air-backwash systems. Interior baffles were initially installed every four feet to divide the screen into the four compartments. Division of the prototype screen into compartments is necessary because of the varying porosity of the perforated plates under the screen required to maintain uniform flow through the screen. Without the subdivision into compartments, short-circuiting would occur. A sketch of the test screen is shown on Figure 2.

4.3 Air Supply

Tests of the screens for the Twin Falls Project indicated that a volume of air equal to the volume between the screen and the perforated plate was required for an effective backwash system. On this basis, four air tanks with a volume of 20 ft^3 each were fabricated. Each tank supplied one 4-foot test compartment. The valves and piping were arranged so that more than one tank could be connected to one test section if required. The tanks were pressurized with a portable air compressor prior to testing. Test pressures up to 110 psig were used.

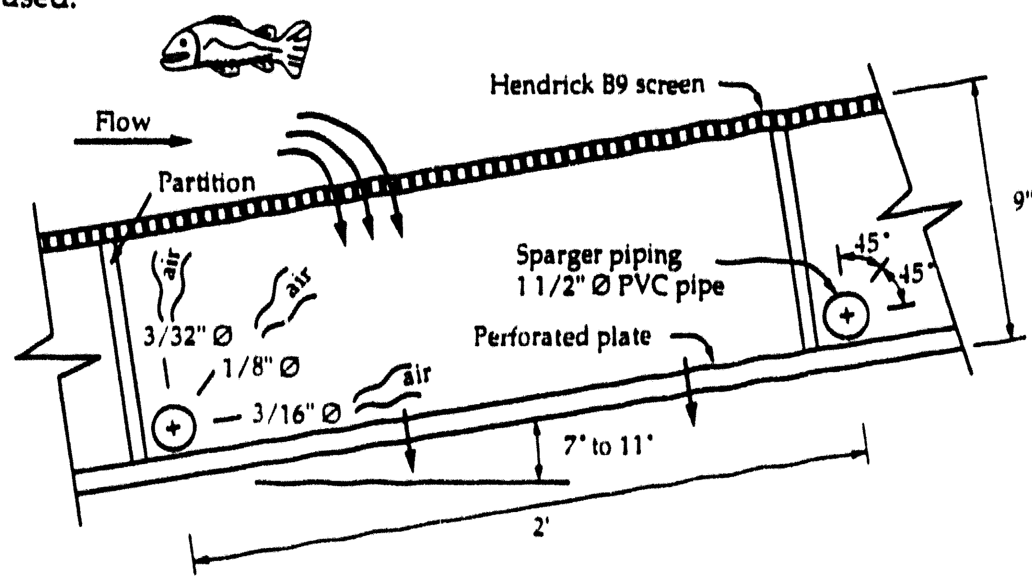


Figure 2. Final Configuration of Sparger Piping

5.0 Development of System

5.1 Preliminary Tests

Schedule 80 PVC piping 1-1/2 inches in diameter was used for the sparger piping. PVC will be used in the full-scale facility because it is easy to handle, maintain, and replace; it is also less likely to corrode and is less subject to biofouling. The initial size and spacing of the sparger holes was 3/16-inch diameter on 2-inch centers, based on the configuration of the Twin Falls system (Ott and Jarrett, 1992), with the sparger pipes spaced on 2-foot centers. The principal objectives of the tests were to study the effects of the duration of the air blast, the influence of porosity of the perforated plates, the size, number, and orientation of the sparger holes, the effect of the screen angle, and the type of debris on the performance of the backwash system.

Virtually all of the testing was qualitative. The flow rate and approach-flow velocity distribution were determined with a Marsh-McBirney electromagnetic current meter to establish prototype velocities in the test facility. A video camera was used to record each test. Upon completion of a test series, the video was viewed frame by frame on site with a monitor. Comparisons with previous tests were made and modifications made to the test apparatus. It would have been virtually impossible to make rapid judgements on the relative merits of the various configurations without the slow-motion, frame by frame analysis using the video.

Tests were conducted both with and without debris. Tests without debris were run to determine whether the air blast would satisfactorily cover the panel and to quickly eliminate unsatisfactory arrangements.

The initial tests were run with an arrangement similar to the Twin Falls air backwash system. The results were not satisfactory primarily because of the orientation of the wedgewire screens. With the wedgewires oriented perpendicular to the flow, the wedgewires acted like a series of turning vanes. Thus, when the jet from the air sparger hit the screen, it was immediately turned through almost 90° and exited normal to the screen. With the wedgewires parallel to the flow at Twin Falls, there was apparently considerable carry-over of the backwash effects from one sparger pipe to another due to the fact that the jet was not turned normal to the screen. Debris tests at Potter Valley showed that there were dead areas between the sparger pipes where debris was not removed from the screen. Consequently, a different configuration had to be developed.

5.2 Developmental Tests

A series of different configurations with different orientation and size of sparger holes and sparger pipe spacing were run. The following general observations were obtained as a result of these tests.

1. Jetting action is essential to removal of debris. Several configurations based on the idea that filling the space between the screen and perforated plate and letting buoyancy lift the debris off the screens was unsuccessful. The jets must act over the entire screen area.

2. A 3/16-inch size hole provided the best performance for one row of holes. Three rows of holes of different sizes were required to cover the screen with a jetting action.

3. The removal of the debris is accomplished primarily in the first few seconds. A one second burst is too short, two seconds is not entirely satisfactory, and three seconds appeared optimum. A longer burst often

resulted in recirculation through the screen which brought debris back to the screen, and running the system to steady-state definitely gave poor results. The initial entrainment of water and air, followed by a violent bursting action through the screen was most effective.

4. An initial air pressure greater than 100 psig gave significantly better debris removal than pressures less than 100 psig.

5. The effect of changing the angle of the screen had a significant effect on the trajectory of the air-water jet. Consequently, what was the optimum alignment of the sparger holes at 7° often left a dead area at 11°.

6. A 4-foot long compartment appeared marginally satisfactory, but compartments 2 feet in length with one sparger pipe per compartment were a significant improvement. A divider wall was necessary for each sparger pipe to prevent interference between one section and the next, so that using 4-foot long compartments and reducing the number of sparger pipes and interior baffles was unsuccessful.

7. The porosity of the perforated plate did not have a significant effect on the performance of the system because it is only the initial transient burst which entrains the volume of water between the screen and perforated plate that is effective in removing debris.

5.3 Final Configuration and Tests

The final layout consists of 1-1/2 inch diameter PVC pipe spaced on 2-foot centers as shown on Figure 2. There are three rows of sparger holes, the first row aligned with the perforated plate, the second at 45°, and the third at 90°. The hole sizes are 3/16 inch in the first row, 1/8 inch at 45°, and 3/32 inch in the row at 90°. Each sparger pipe is located within a 2-foot long compartment. The additional baffles are actually desirable from a hydraulic point of view because they further reduce any problems of short-circuiting the perforated plate.

Several types of debris were tested. Initial testing used filamentaceous algae because operators at the site had experienced difficulty removing this growth from the bar racks at the site. Although every effort was made to embed the filamentaceous algae material into the screen, the air burst readily lifted the material from the screen. Since the tests were conducted in late October of 1992, the algae were not in full bloom, and there was no time to permit growth to occur on the screen. Hence, a test was run with a coat of latex paint on the wedgewires which was allowed to dry just tacky to the touch. The scrubbing action of the air-water jets successfully removed 90% of the latex. We believe that periodic air blasts during the summer months will thus control any algal growth on the screen.

Final tests were run with debris consisting of a mix of long pine needles, filamentaceous algae, aquatic grasses and leaves that were obtained from the trash racks at the intakes and from the reservoir. The pine needles seemed to interlock the mass and provide the most tenacious mix of debris we could obtain. A layer of this material 1-1/2 to 2 inches thick was deposited on the screen which resulted in a pressure difference across the screen of 2 to 4 inches of water.

Since the air lines were vented prior to each test, the lines filled with water. This resulted in an initial jet of water prior to the air burst. While filamentaceous algae and leaves could be lifted from the screen by the water jet, the mat of pine needles, etc., would not move until the air burst occurred. The air burst satisfactorily cleaned the screen. There were some dead areas at the end of the sparger piping due to interference with the supporting truss. These dead areas were eliminated by making all three of the holes at the very end of the sparger 3/16-inch diameter. Successive operation of the chambers from downstream to upstream with a pause of 10 seconds or more between successive panels moved debris downstream over the screen. In the prototype, this debris will thus move out of the screen bay.

One unexpected result of the air-backwash operation was that air bubbles became entrapped between the transverse wedgewires. The through-screen velocity provided just the right force to balance the buoyancy of the bubbles. Some tests indicated that the entrapped air did increase the screen head loss. In order to avoid potential non-uniformity of the velocity through the screen, it was necessary to remove this air. Stopping the flow through the screen to release the bubbles was most effective, but impractical from an operational point of view. The problem was solved by noting that the initial jet of water due to venting the air lines prior to each test effectively removed the air bubble. Therefore, the prototype system will be designed with vent valves on the downcomers for the air sparger system. This will permit filling of the air lines after each air backwash cycle. A pulse of air will then result in a short-duration water jet which will remove the entrapped air from the screen.

Juvenile Steelhead Trout from a fish hatchery were also used in a series of tests to study the effect of the air backwash system on the ability of the fish to reorient themselves after the air-backwash cycle was complete. Although the action of the backwash system was similar to a front-loading washing machine when viewed form the side, the fish readily reoriented themselves within a matter of seconds after the backwash cycle had been completed. Successive air blasts failed to disorient the fish, so it was concluded that the backwash system was not detrimental to the fish (except for the ones that we had to rescue after they were blown out of the test facility during the air blast).

Tests with gravel showed that gravel sizes up to 1-1/2 to 2 inches could be moved up the screen by successive air blasts. Since the sweeping velocity is only about 1.5 ft/sec, we could not move as large a size as with the 4 ft/sec sweeping velocity at Twin Falls.

Very small sizes became wedged in the screen and had to be removed with pliers and tweezers. The gravel trap at the intake to the Potter Valley Inclining Horizontal Fish Screening Facility shown on Figure 1 will effectively prevent gravel from entering the screen bays from the reservoir. Thus, transport of gravel onto the screen should not be a problem.

6.0 Conclusions

1. An air backwash system will satisfactorily remove debris from the Inclined Fish Screen Facility proposed for the Potter Valley Intake.

2. The orientation of the wedgewires had a significant effect on the design of the sparger system. Three rows of holes oriented as shown on Figure 2 were required to provide the jetting action necessary to clean the screen.

3. Most of the debris removal takes place in the first few seconds. A three-second burst of air was found to be the most effective.

4. An initial pressure of 100 psig or greater provided the most satisfactory cleaning action.

5. Successive operation of the screen panels from upstream to downstream effectively removal the debris from the screen and screen chamber.

Acknowledgements: Detailed design of the test flume was carried out by Mr. David Menasian of Steiner Environmental Consultants, who also assisted with the test program. Mr. Gene Geary, Fisheries Biologist, Pacific Gas and Electric and Dr. Scott Tu, Civil Engineer, Pacific Gas and Electric also assisted with the testing and evaluation of results.

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USE OF A DAM TO REVITALIZE AQUATIC ENVIRONMENT IN AN INTERMITTENT RIVER

By C. Liang Lee[1], Patrick J. Ryan[2], and Zoran Lakicevic[3]

Abstract

A new roller-compacted concrete dam is proposed on the Carmel River in the Coast Ranges of central California. The river in its existing condition runs intermittently, with the water flowing through the entire river length only in winter and spring months. The proposed reservoir is designed to increase water supply for the area, and to keep a year-round measurable flow in the river during all normal or wetter years. The effectiveness of various design alternatives and reservoir operating conditions in enhancing the aquatic habitats and providing acceptable water temperature for steelhead trout was evaluated using a computer program which can be used to compute water temperatures in a network of rivers and reservoirs.

1.0 Introduction

A new dam is proposed to be built on the Carmel River in the Coast Ranges of central California. Several dam sites were evaluated, including a dam at the new San Clemente site which would store up to 29,000 acre-feet of water. The new reservoir will provide a much-needed increase in municipal water supply. As part of the project studies, a temperature simulation was conducted to predict the effect of the dam on river temperatures and to assess the need for multi-level release capability. The analysis considered various design options such as reservoir sizes and locations, elevations from which releases can be made, and enhancement of riparian vegetation. The computer program developed for the analysis, the simulation, and the results are described in this paper. Although the New San Clemente Dam is no longer the preferred project alternative, the water temperature simulation for that project is presented here.

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2.0 Existing River and Reservoir System

The reach of the Carmel River under study is approximately 25 miles long. The river originates in Coast Ranges in central California, and discharges into the Pacific Ocean near the town of Carmel just south of the Monterey Peninsula. There are two small existing reservoirs on the river. San Clemente Reservoir is located about 19 miles upstream from the coast. The dam is a concrete arch structure 85 feet high. Built in 1921, the reservoir drains a watershed of 125 square miles. The storage volume in the reservoir is approximately 320 acre-feet, with 190 acre-feet being dead storage. Los Padres Reservoir is located about 6 miles upstream from San Clemente Dam. Los Padres Dam is an earthfill embankment built in 1948. With a height of approximately 150 ft, the dam stores 2200 acre-feet of water drained from a watershed of 45 square miles. A location map showing the river and drainage area is presented in Figure 1.

Both existing reservoirs were designed to provide water supply. Very little flood storage was provided. The main supply for water service distribution is provided through a pipeline from San Clemente Dam. Water in Los Padres Reservoir is released as needed for water level maintenance at San Clemente Reservoir. During the dry summer months in a normal year, fish release from San Clemente is reduced to a minimum of 3 to 5 cfs. This small river flow plus heavy groundwater pumping usually causes the water tables in the lower river reaches to drop so much that a dry river bed occurs in a reach approximately 9 miles long near the coast.

3.0 Proposed Reservoir and Related Steelhead Issues

The intermittent flow condition reportedly kills a large number of juvenile steelhead in the river [Li, 1983]. To maintain a continuously flowing river to sustain the steelhead run, and to satisfy the increasing water demand, a new dam was proposed in the river system. The proposed new dam will be a roller-compacted concrete structure, built with fish trapping and transport facilities for both upstream and downstream migrating steelhead.

The steelhead, Salmo Gairdneri, is the sea-going rainbow trout. In this river adults migrate upstream in winter, beginning in December and ending sometime between March and May [Wagner, 1983]. The main spawning habitat is upstream from the existing Los Padres Dam. Juveniles migrate downstream in the spring [Love, 1991]. Steelhead will survive in water temperatures of 32 to 80 °F [Moyle, 1976]. Optimum temperatures for growth and for completion of most stages of their life history seem to be 52 to 70 °F.

Several designs for different dam heights and locations were proposed. They were evaluated based on the criteria of satisfying the projected water demand, meeting the fish-release objective, minimizing adverse environmental effects, and cost. The goal for fish release was to provide a range of flows downstream of the dam to meet the needs for each portion of the steelhead life cycle.

4.0 River and Reservoir Temperature Simulation

A computer simulation was conducted to predict river temperatures which would occur under various proposed reservoir sizes and operations.

4.1 Computer Model

The computer program used for the analysis was based on two public-domain programs, the U. S. Fish and Wildlife's SNTEMP model [Theurer and Voos, 1982] for computing river water temperatures, and the Massachusetts Institute of Technology's MITEMP model [Octavio et al., 1980] for computing reservoir water temperatures. The program links SNTEMP and MITEMP together to result in a package which computes transient water temperatures for a network of rivers and reservoirs. The program was modified to allow the outlet elevation to vary automatically as the reservoir water level changes, in order to simulate continuous release from near the surface.

The program was developed to be run on a UNIX platform, taking advantage of the convenient system commands which greatly facilitate the model linkage.

4.2 Computer Simulation

The numerical model of the river system was composed of 5 separate reaches, 2 simulating the two reservoirs and 3 simulating the river sections. There are two distinct weather patterns which occur over the study area. The lower reach of the river is in a coastal climate. Coastal fog travels inland as far as 10 miles from the sea; modulated by the ocean, diurnal air-temperature fluctuation is relatively mild in this region. The upper reach of the river is affected more significantly by the inland climate, with sharper air temperature fluctuation and lower relative humidity.

The computer model was calibrated against field-measured data. Surface water temperatures were continuously monitored in both Los Padres and San Clemente reservoirs. Bottom temperatures were also measured in Los Padres at the low level outlet. The period of February to November, 1982, was selected for calibration, because during this wet year there were continuous flows and temperature measurements in the river to allow for comparison.

The calibration result for Los Padres Reservoir is shown in figure 2. The match between the measured and computed temperatures is satisfactory. The result shows that the existing reservoir began to stratify in May. Stratification lasted through the summer, and turnover occurred in early fall. During the summer, the surface and bottom temperatures could differ by 10 - 15 °F. The calibration result for San Clemente Reservoir is shown in Figure 3. The temperature fluctuation pattern is similar to that of Los Padres Reservoir, except that surface-water temperature was approximately 2 °F warmer during the summer.

The calibration results for the river simulation are shown in Figures 4a and 4b, for two stations in the river. The computed and measured water temperatures compare reasonably well, although the magnitude of measured diurnal temperature fluctuation appears to be less than that computed. These results verified the capability of the computer model in performing the temperature analysis.

A number of alternatives were simulated including different dam locations and sizes, different outlet designs, and different riparian vegetation enhancement schemes. Only results pertaining to one new dam alternative, a 23,000 acre-feet New San Clemente Dam, are presented here to illustrate the effect of a new dam on river-water temperature. The historical data used for the simulation were from February 1980 through October 1987. A set of synthetic daily climatic data, for a one year period, was developed to simulate the extreme dry and hot condition.

4.2.1 Effect of Low Level Release

The proposed new dam will have a multi-port outlet structure. Simulation runs were made to examine the effect of releasing the reservoir water from different levels. Using the 1982 meteorological and hydrologic conditions for example, the release temperatures were computed and are presented in Figure 5. As shown in Figure 5, adjusting the elevation of the reservoir release allows the river water temperature immediately downstream from the dam to be controlled. Temperature differences between low (El. 530 ft) and high (El. 610 ft) levels of release were approximately 10 °F during the summer months. Releasing reservoir water from outlets above El. 610 ft would result in summer river temperatures higher than those suitable for the steelhead.

After being released from the reservoir, the water tends to reach an equilibrium condition as it flows downstream. The water temperature distributions for various stations along the river are shown in Figure 6. In this case, the river temperature increases in the downstream direction, reaching equilibrium temperature near the Shulte Bridge station, 12 miles downstream from the dam.

Because of this tendency to reach an equilibrium condition, the effect of releasing from different elevations diminishes in the downstream direction. As shown in Figure 7, the difference in stream temperatures between low and high levels of release was approximately 4 °F at Robles del Rio (River Mile 14.4); dropped to approximately 1 to 2 °F at Narrows (River Mile 9.6) as shown in Figure 8; and was almost negligible when the water reached the Lagoon (River Mile 0.0) as shown in Figure 9. This result shows that other means of temperature improvement will be required, in addition to multi-level outlets, in order to achieve optimum temperatures along the entire river.

4.2.2 Effect of Riparian Vegetation Enhancement

The native vegetation along the river is mostly deciduous trees. Based on field observations between 1982 and 1989, a riparian density of 85% on both banks of the river was considered to be a reasonable goal for the riparian-vegetation-enhancement effort. The existing riparian density was estimated to vary from 35 to 85%. The enhancement effort would involve establishing a drip-irrigation system along the river to sustain greater growths of vegetation. The post-enhancement trees were estimated to be approximately 50 ft high, growing on the banks with no direct canopy over the water surface.

The predicted effect of vegetation enhancement is shown in Figures 7, 8 and 9, for Robles del Rio,Narrows and Lagoon, respectively. A temperature drop of approximately 10 °F from the no-project condition is achieved at Robles del Rio, (Figure 7); 5 °F at Narrows (Figure 8); and 2 to 3 °F at the Lagoon. The effect is less pronounced at the Lagoon because the downstream reaches is presently well vegetated. This result shows that vegetation enhancement can complement the multi-level release operation to maintain desirable temperatures in the river.

The vegetation enhancement would not only reduce the average daily water temperatures, as shown in Figures 7 to 9, but would also diminish the magnitude of diurnal fluctuations. The reduction in the magnitude of diurnal temperature swing appears to be proportional to the increase in vegetation density. During the hot period of the day, fish reportedly seek out the cooler areas near the bottom, such as behind a rock. The increased vegetation shading will also provide additional sanctuaries of this type for the fish.

5.0 Conclusions

A computer program was developed to predict water temperatures in a network of river reaches and reservoirs. The program was used to predict the ability of new dam operations to enhance the aquatic environment of the river system. The results can be summarized as follows:

(1) A fish release of 50 cfs will be required to eliminate dry reaches in the river. Low groundwater level in the river valley, created by pumping, will reduce the river flow to approximately 5 cfs in the lower reaches near the coast.

(2) Optimum temperatures for steelhead can be provided in the upper

reaches of the river (8 - 10 miles from the dam) by adjusting the elevations from which releases are made. Outlets located between El. 530 and 610 ft will be required depending on the climatic condition.

(3) The effect of low-temperature releases diminishes in the downstream direction, because of the tendency for water to reach an equilibrium condition.

(4) Suitable temperatures to permit steelhead migration through the lower reaches of the river may be achieved through a combination of multi-level releases and riparian vegetation enhancement.

(5) Vegetation enhancement will reduce the average daily temperature, and also diminish the magnitude of the diurnal fluctuation. Both of these temperature effects enhance the aquatic environment for the fish.

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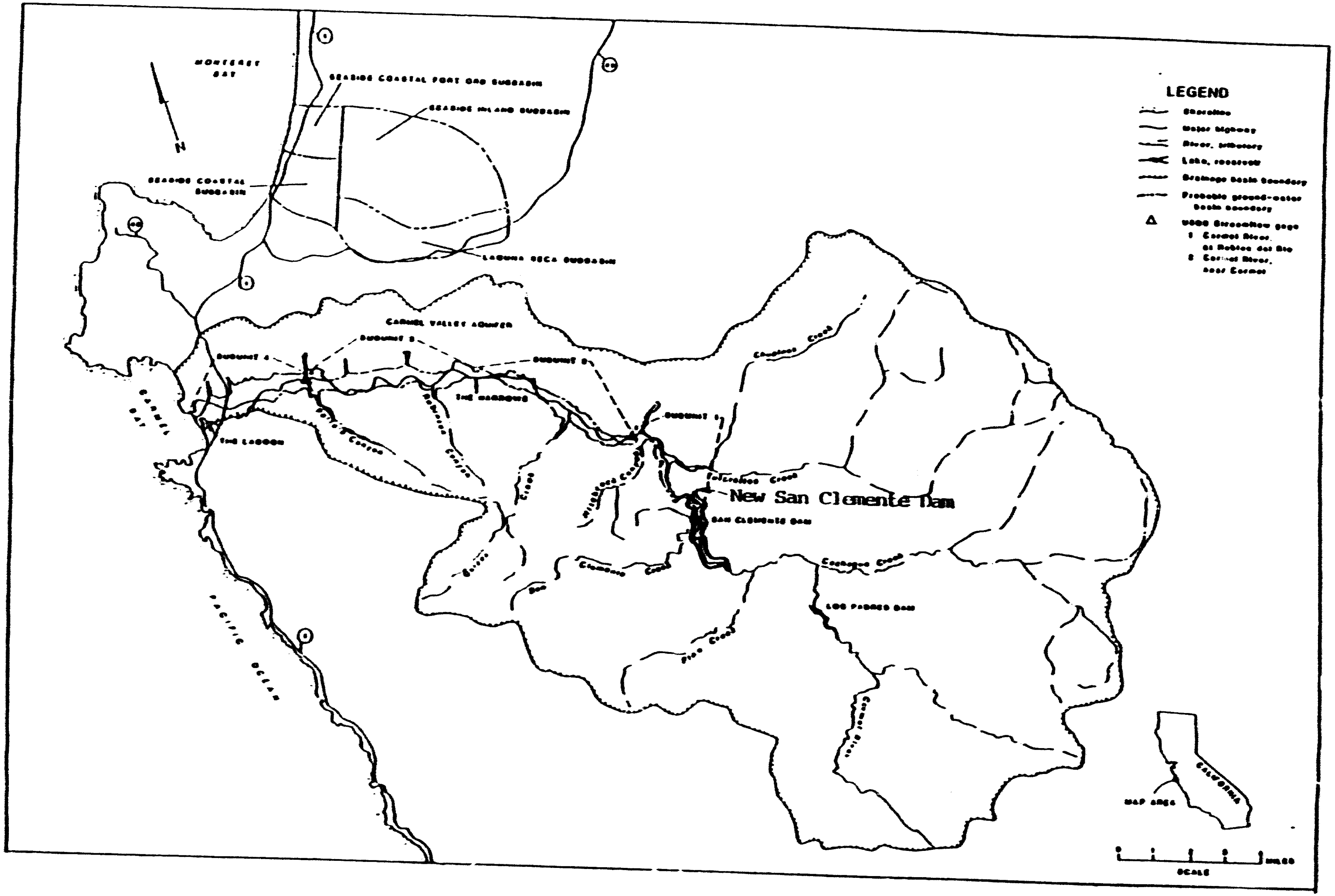


Figure 1. Location Map

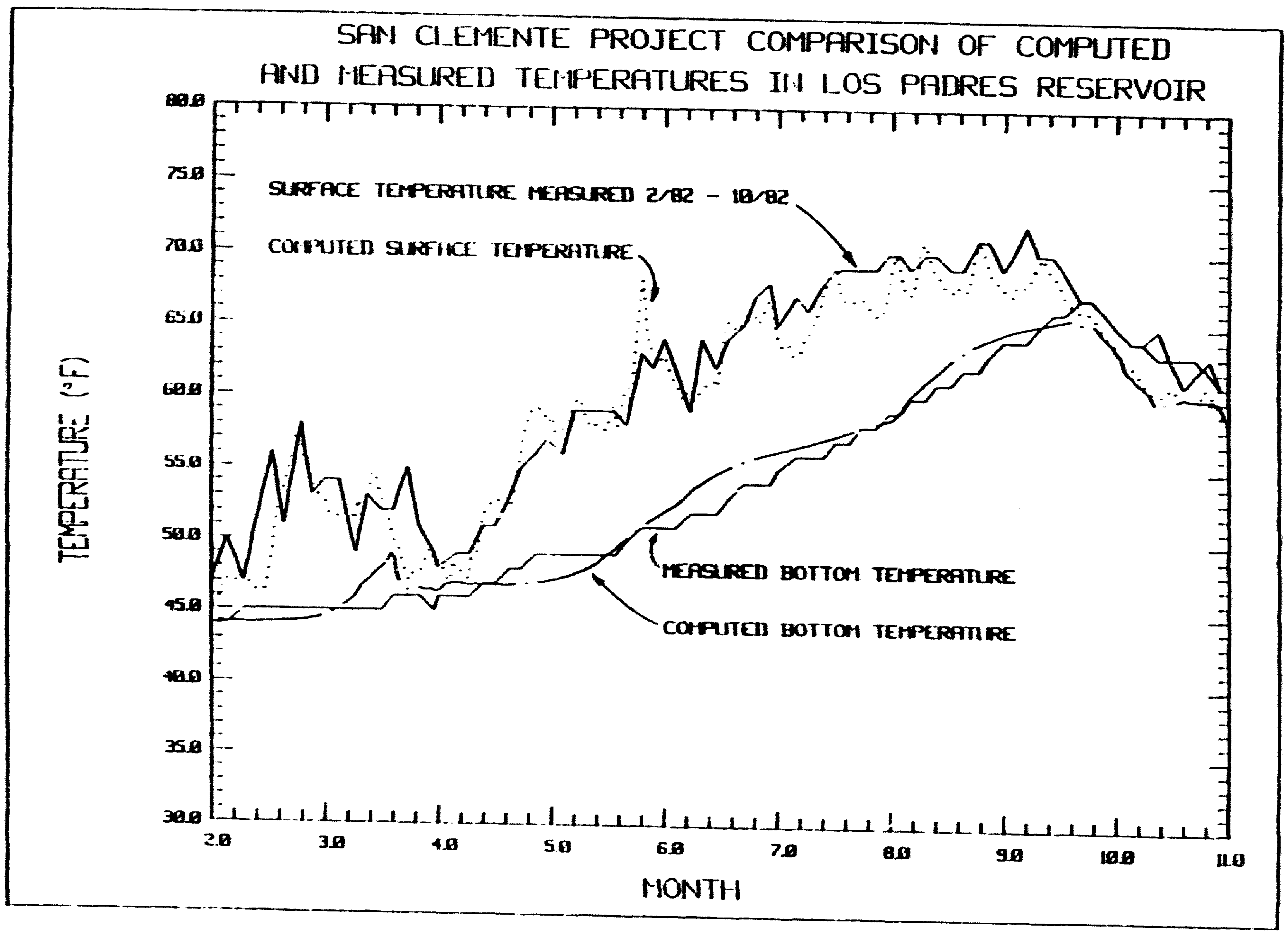

SAN CLEMENTE PROJECT COMPARISON OF COMPUTED
AND MEASURED TEMPERATURES IN LOS PADRES RESERVOIR
SURFACE TEMPERATURE MEASURED 2/82 - 10/82
COMPUTED SURFACE TEMPERATURE
MEASURED BOTTOM TEMPERATURE
COMPUTED BOTTOM TEMPERATURE
TEMPERATURE (°F)
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
MONTH

Figure 2

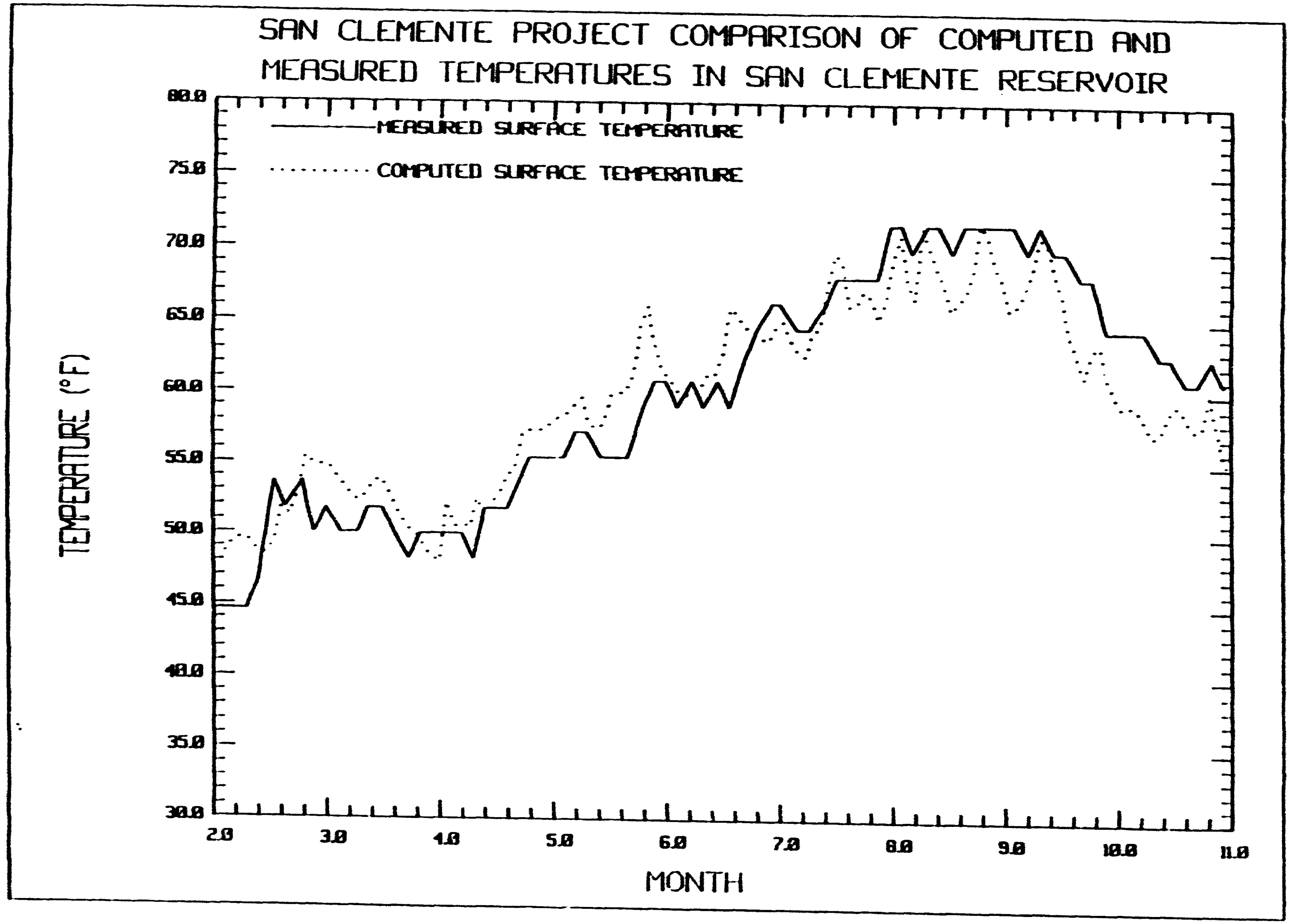

SAN CLEMENTE PROJECT COMPARISON OF COMPUTED AND
MEASURED TEMPERATURES IN SAN CLEMENTE RESERVOIR
MEASURED SURFACE TEMPERATURE
COMPUTED SURFACE TEMPERATURE
TEMPERATURE (°F)
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
MONTH

Figure 3

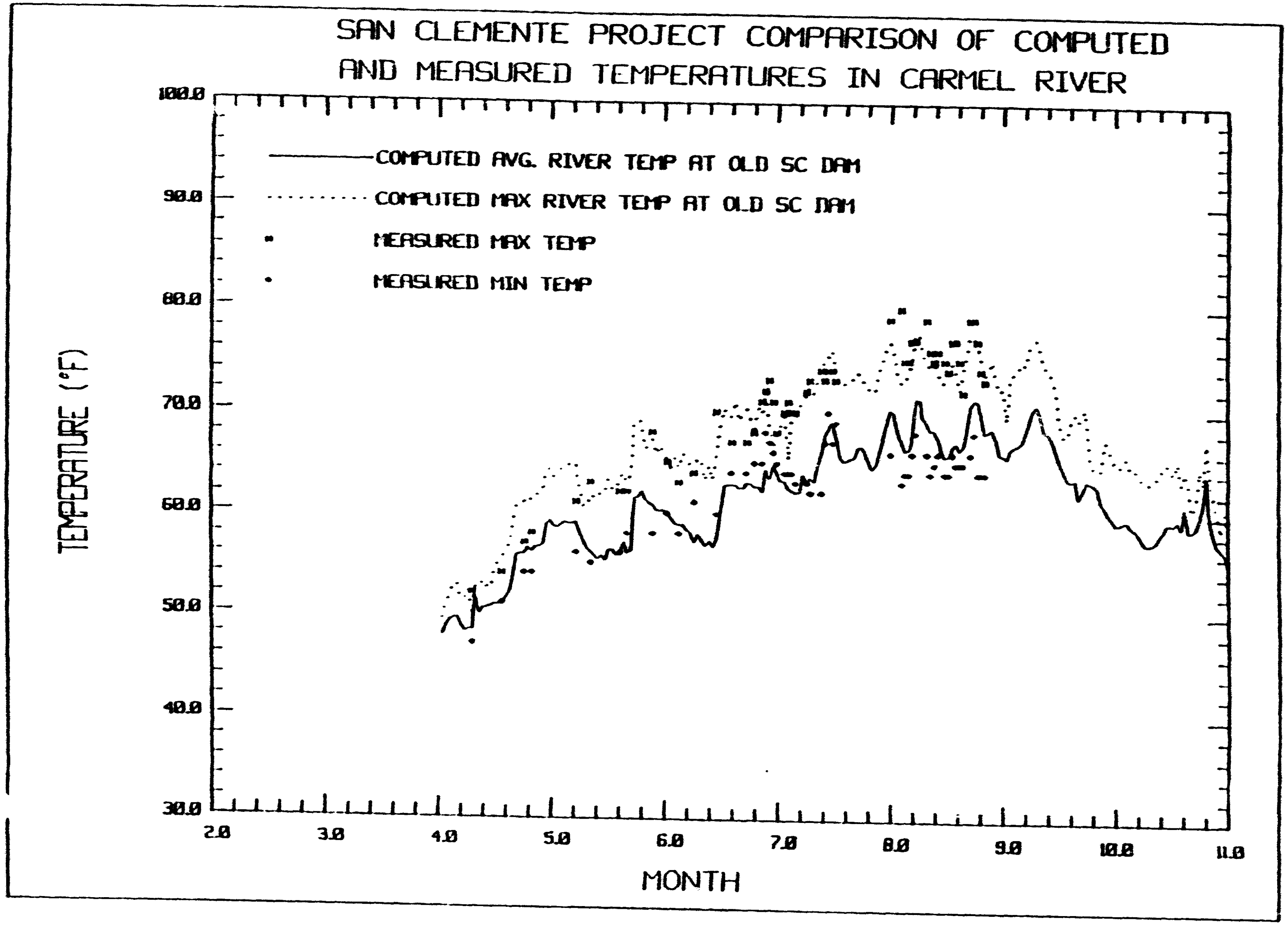

SAN CLEMENTE PROJECT COMPARISON OF COMPUTED
AND MEASURED TEMPERATURES IN CARMEL RIVER
COMPUTED AVG. RIVER TEMP AT OLD SC DAM
COMPUTED MAX RIVER TEMP AT OLD SC DAM
MEASURED MAX TEMP
MEASURED MIN TEMP
TEMPERATURE (°F)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
MONTH

Figure 4a

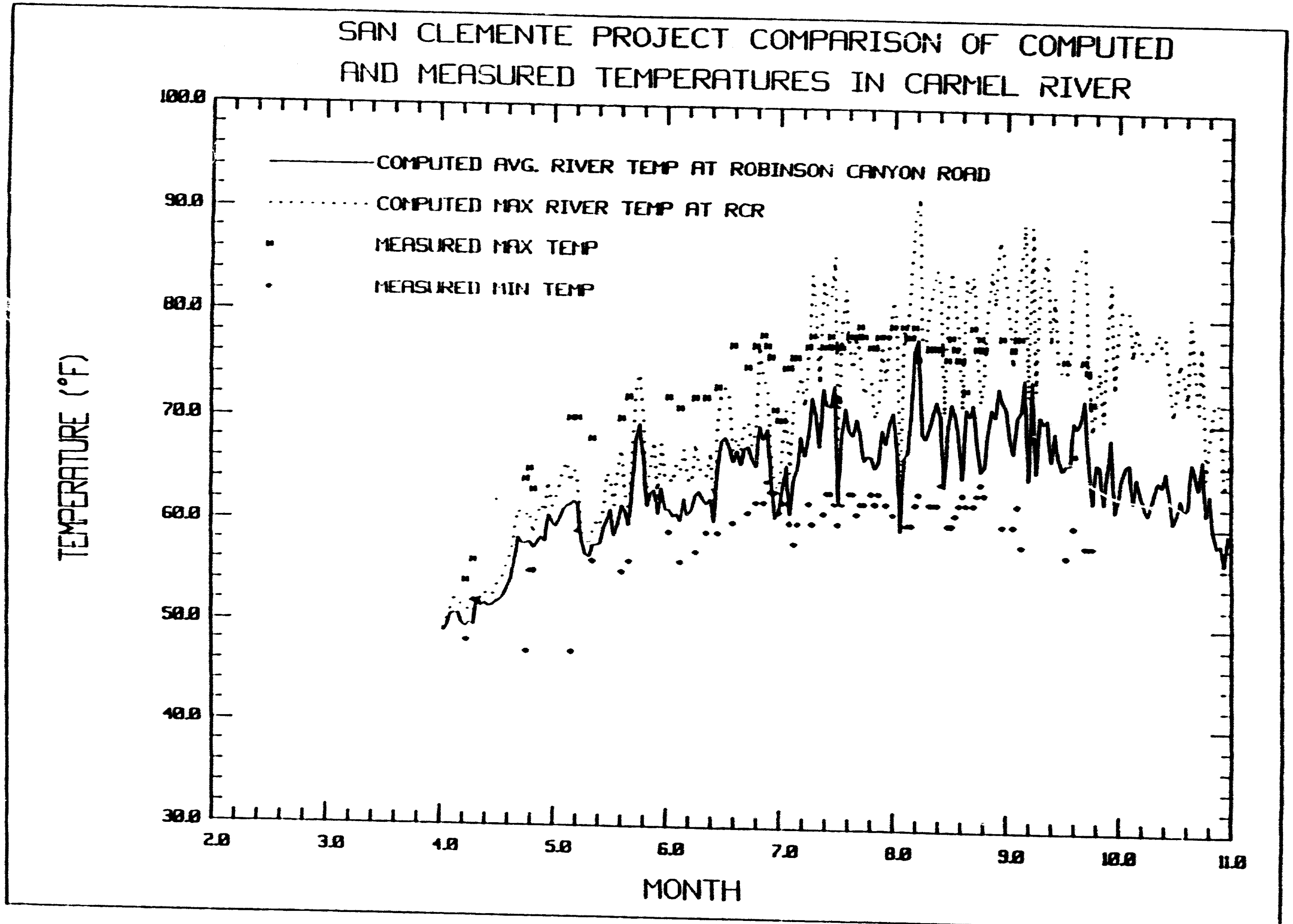

SAN CLEMENTE PROJECT COMPARISON OF COMPUTED
AND MEASURED TEMPERATURES IN CARMEL RIVER
COMPUTED AVG. RIVER TEMP AT ROBINSON CANYON ROAD
COMPUTED MAX RIVER TEMP AT RCR
MEASURED MAX TEMP
MEASURED MIN TEMP
TEMPERATURE (°F)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
MONTH

Figure 4b

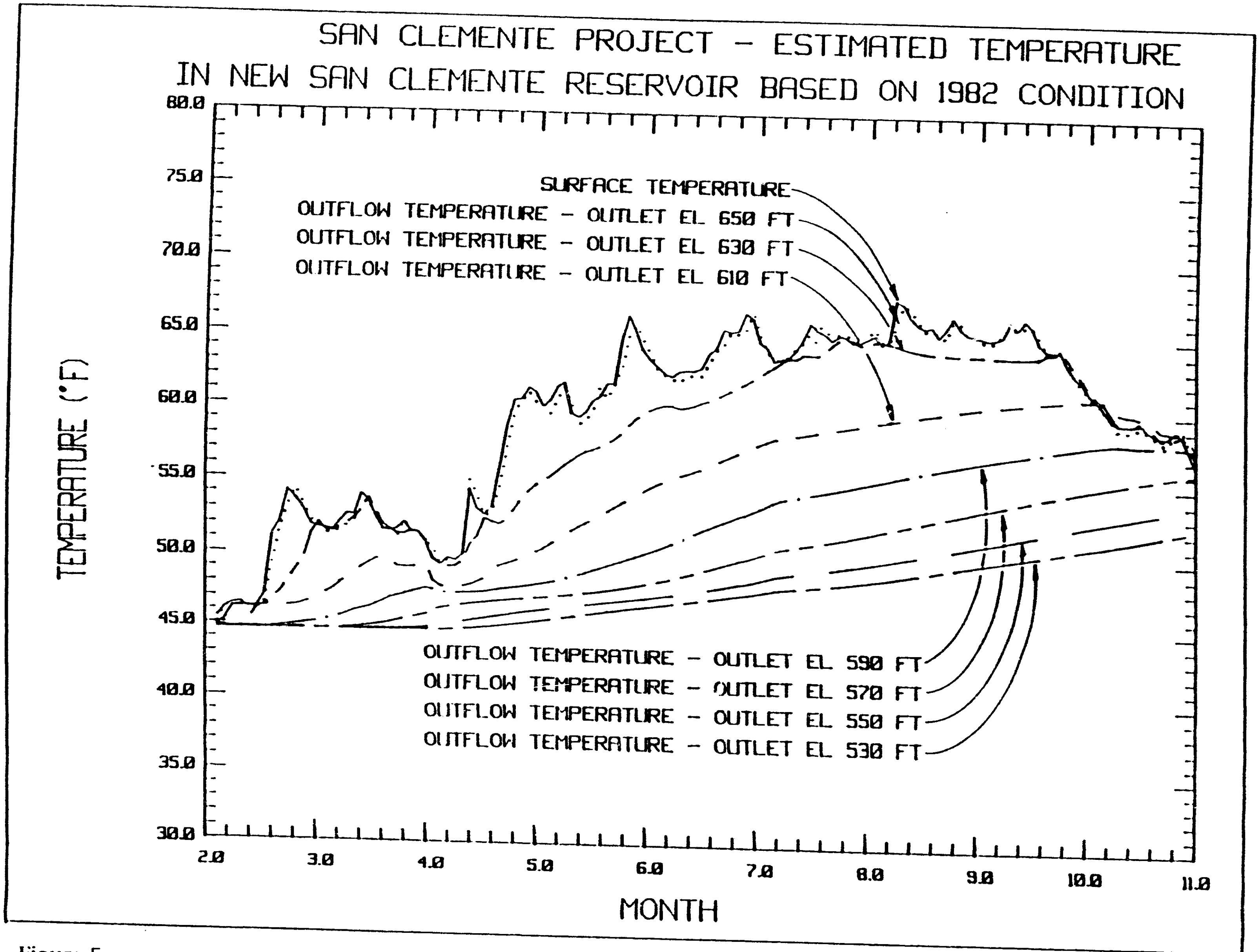
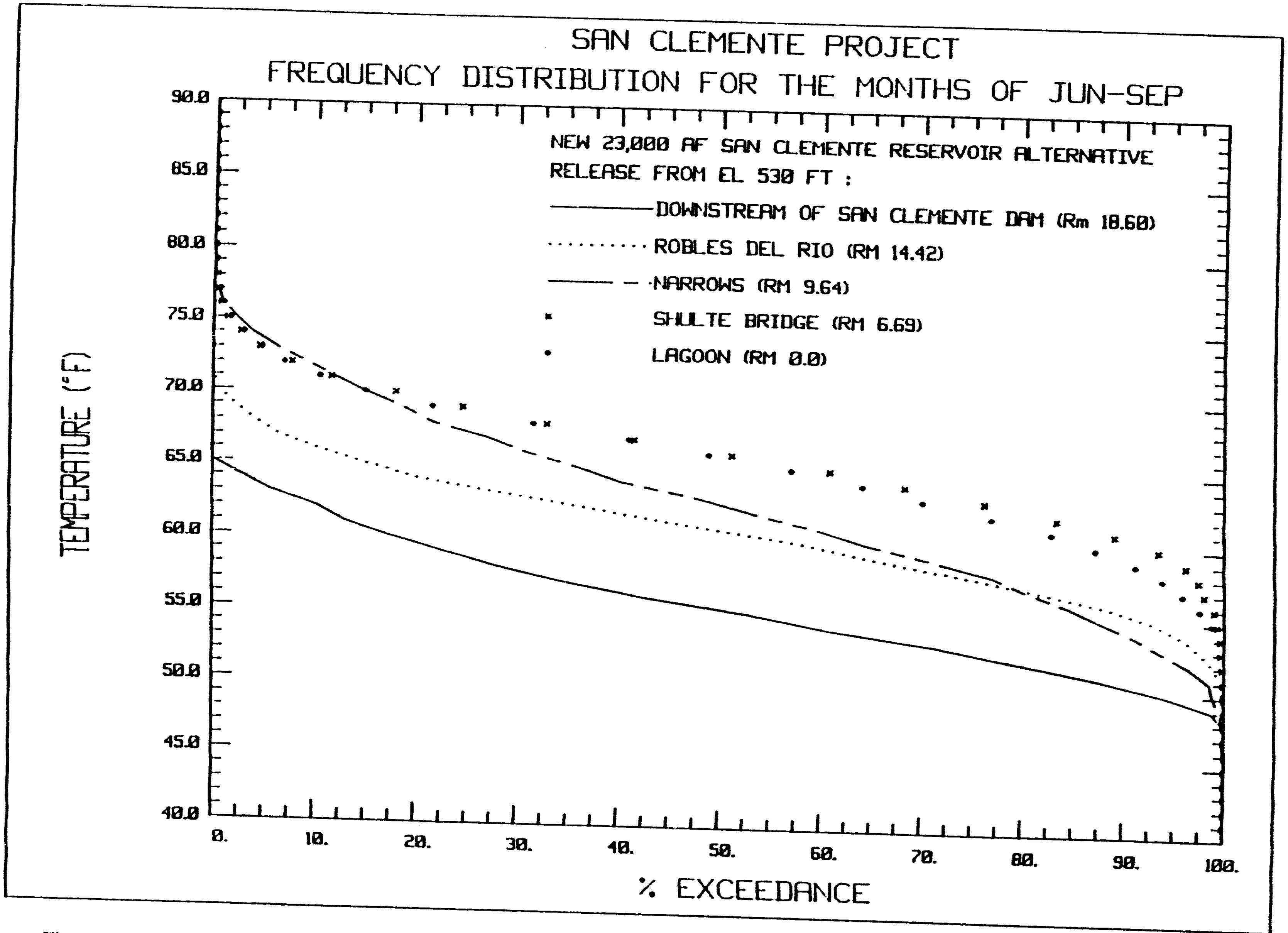
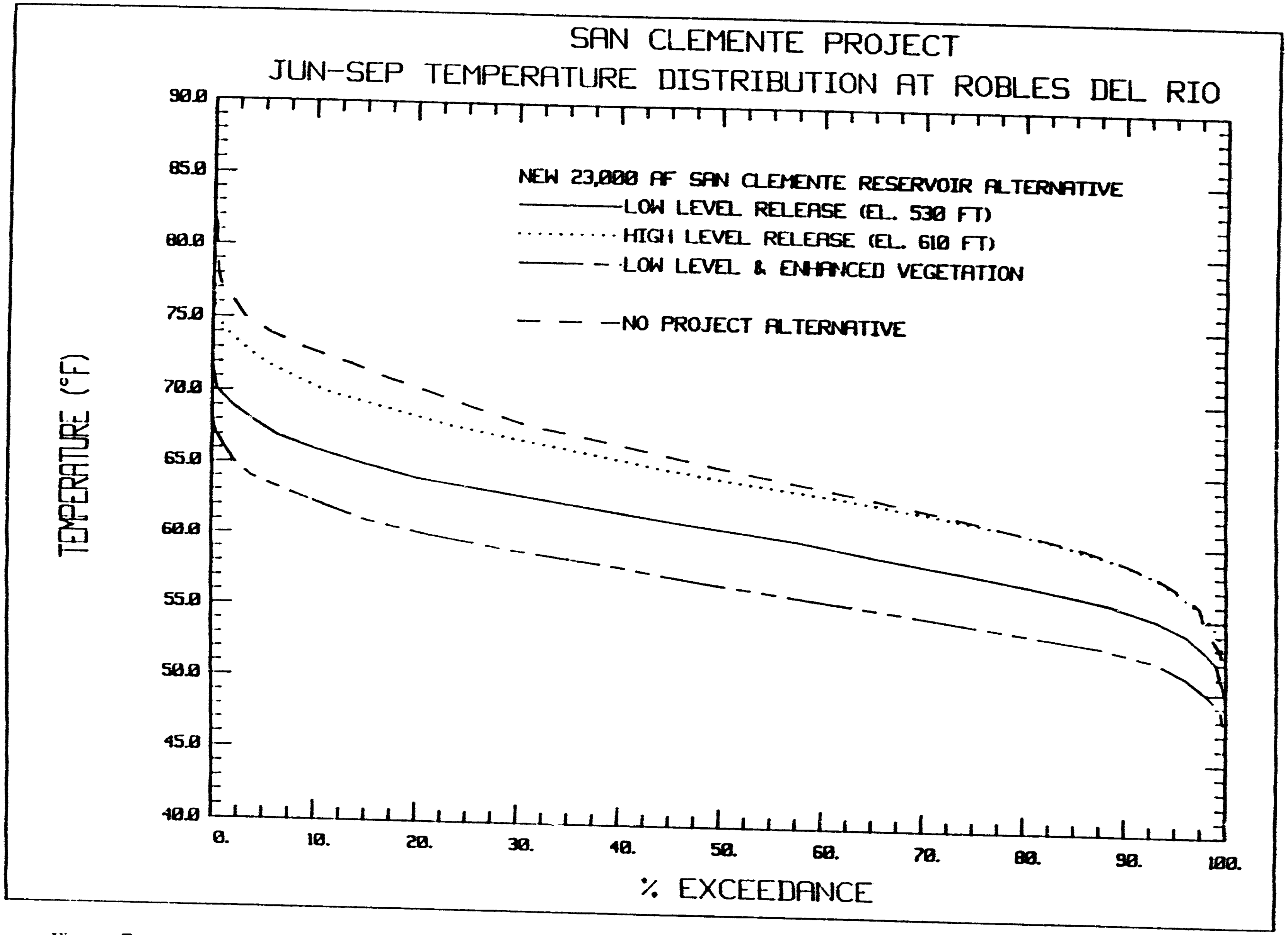

SAN CLEMENTE PROJECT - ESTIMATED TEMPERATURE
IN NEW SAN CLEMENTE RESERVOIR BASED ON 1982 CONDITION
SURFACE TEMPERATURE
OUTFLOW TEMPERATURE - OUTLET EL 650 FT
OUTFLOW TEMPERATURE - OUTLET EL 630 FT
OUTFLOW TEMPERATURE - OUTLET EL 610 FT
OUTFLOW TEMPERATURE - OUTLET EL 590 FT
OUTFLOW TEMPERATURE - OUTLET EL 570 FT
OUTFLOW TEMPERATURE - OUTLET EL 550 FT
OUTFLOW TEMPERATURE - OUTLET EL 530 FT
TEMPERATURE (°F)
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
MONTH

Figure 5



SAN CLEMENTE PROJECT
FREQUENCY DISTRIBUTION FOR THE MONTHS OF JUN-SEP
NEW 23,000 AF SAN CLEMENTE RESERVOIR ALTERNATIVE
RELEASE FROM EL 530 FT :
DOWNSTREAM OF SAN CLEMENTE DAM (Rm 18.60)
ROBLES DEL RIO (RM 14.42)
NARROWS (RM 9.64)
SHULTE BRIDGE (RM 6.69)
LAGOON (RM 0.0)
TEMPERATURE (°F)
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.
% EXCEEDANCE

Figure 6



SAN CLEMENTE PROJECT
JUN-SEP TEMPERATURE DISTRIBUTION AT ROBLES DEL RIO
NEW 23,000 AF SAN CLEMENTE RESERVOIR ALTERNATIVE
LOW LEVEL RELEASE (EL. 530 FT)
HIGH LEVEL RELEASE (EL. 610 FT)
LOW LEVEL & ENHANCED VEGETATION
NO PROJECT ALTERNATIVE
TEMPERATURE (°F)
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.
% EXCEEDANCE

Figure 7

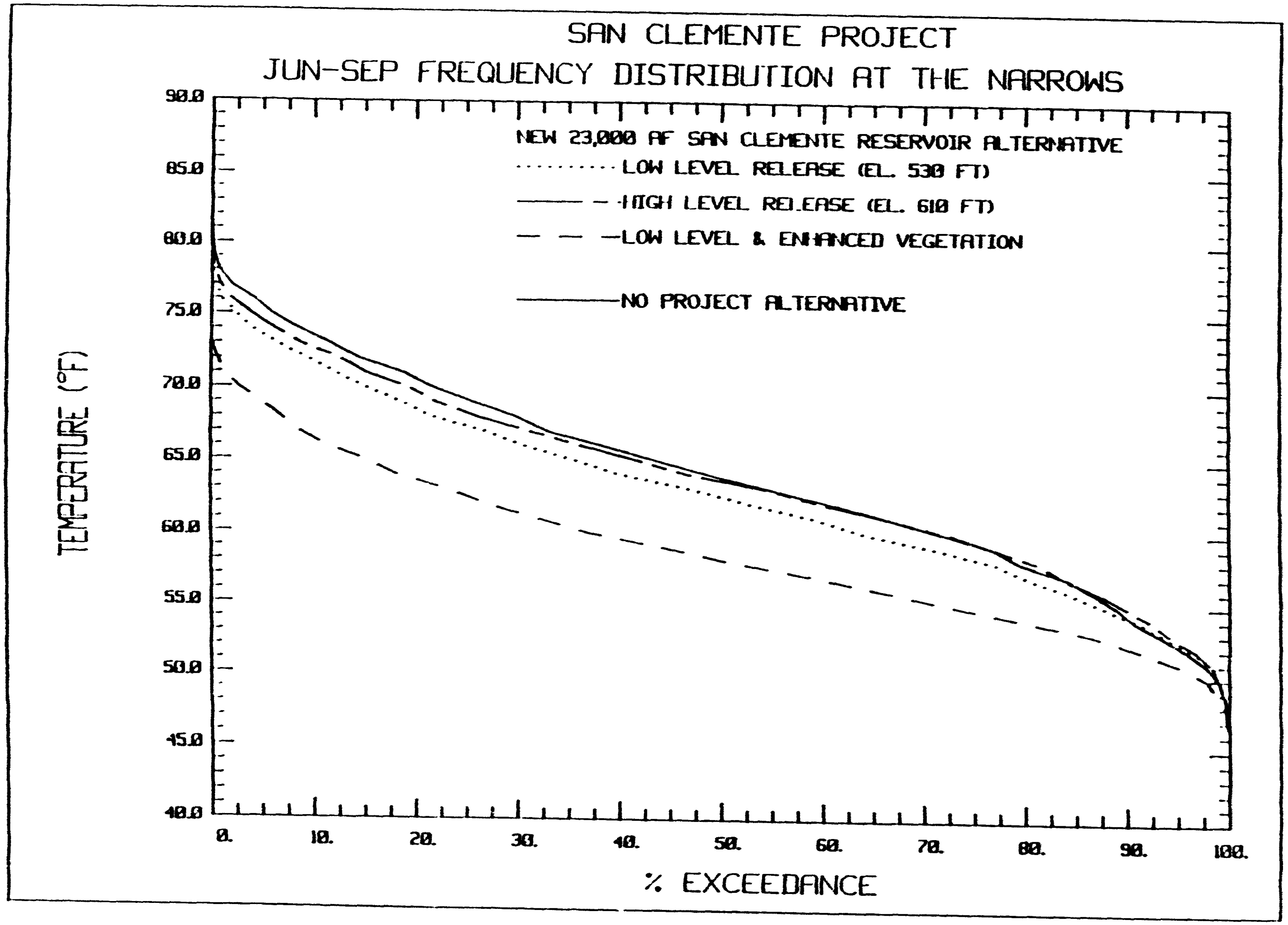

SAN CLEMENTE PROJECT
JUN-SEP FREQUENCY DISTRIBUTION AT THE NARROWS
NEW 23,000 AF SAN CLEMENTE RESERVOIR ALTERNATIVE
LOW LEVEL RELEASE (EL. 530 FT)
HIGH LEVEL RELEASE (EL. 610 FT)
LOW LEVEL & ENHANCED VEGETATION
NO PROJECT ALTERNATIVE
TEMPERATURE (°F)
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.
% EXCEEDANCE

Figure 8

FISH GUIDANCE AND EXCLUSION STUDIES

UNITED STATES DEPARTMENT OF THE INTERIOR

★

BUREAU OF RECLAMATION

HYDRAULIC DESIGN OF ANGLED DRUM
FISH SCREENS

Perry L. Johnson
U. S. Bureau of Reclamation
Mail Code D-1531
PO Box 25007
Denver, Colorado 80225

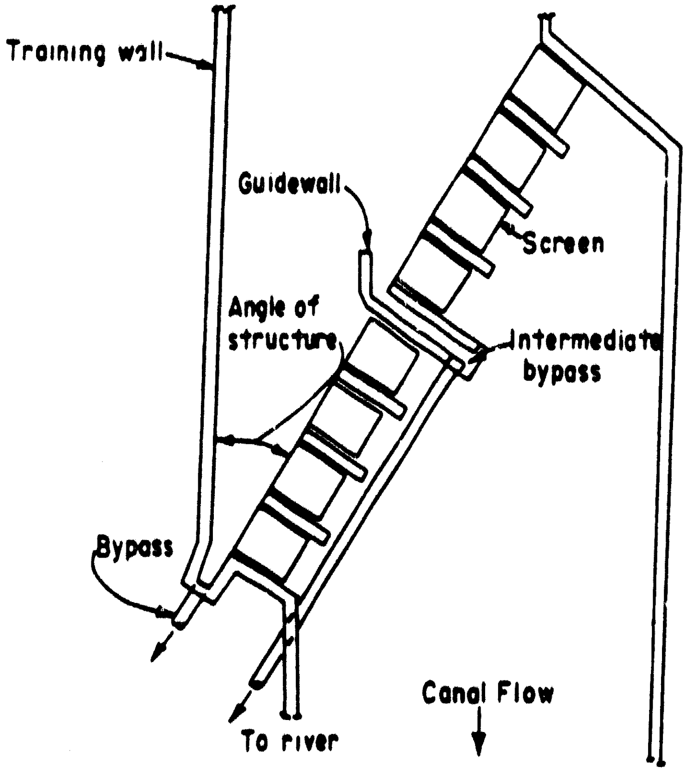
ABSTRACT

Angled drum screens, a recent development in fish control structures, are best suited for open channel applications such as on flow diversion canals. The concept combines angled screen placement to the flow, which minimizes fish impingement and maximizes fish guidance, with drum screens, which are proven cost effective traveling screens. For optimum guidance the approach flow to the screens should be eddy and slack water free, the flow field through the screens should be uniform and should comply with velocity criteria, and the flow into the bypass intakes should be uniform or gradually accelerating. Parameters influencing hydraulic performance include initial flow distribution, intake and exit channel geometry, intake and exit channel losses, head losses across the screens and screen structure, and geometric details of transitions, screen structure, and bypass intake. This paper presents hydraulic design guidelines that were developed through use of three site specific physical model studies and through use of a generalized hydraulic model study.

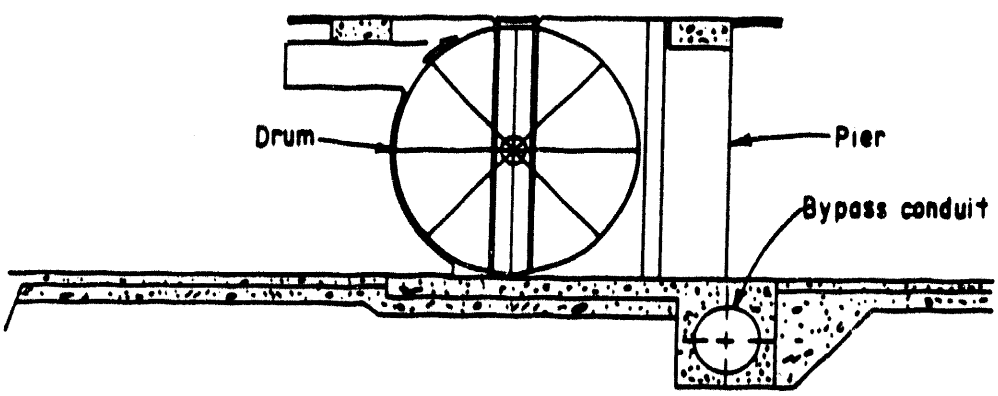
INTRODUCTION

A problem of current active interest in both the hydropower and irrigation disciplines is fish exclusion. Passage of fish through turbines and diversion of fish into irrigation systems can result in substantial or total mortalities. Consequently, regulatory and fisheries agencies are insisting on the inclusion of effective fish passage and control facilities in new projects and the addition of effective facilities to projects that require relicensing.

The appropriate fish exclusion device or technique to be used is strongly dependent on site specific factors such as structure type and configuration, fish species and development stage, operating seasons, debris types and load, and water quality. One type of structure that has been recently designed and constructed at several sites is the angled drum screen (fig. 1). This structure is best used at open channel flow sites. A typical installation would be on a power or irrigation canal downstream of the canal headworks. Flow with entrained fish is diverted into the canal. Through use of the angled drum screen the fish are removed from the diverted flow and returned to the initial water body. Hopefully sufficient head is available to allow return of the fish by gravity flow. The concept offers the combination of two proven elements. The first is placement of the screens at a slight angle (less than 25°) to the flow which creates hydraulic conditions that expedite guidance of fish to bypasses and that minimizes fish impingement. The second element is use of drum screens, which are widely used and proven mechanical screens that have relatively low



PLAN



SECTION

Figure 1. - Typical angled drum screen.

associated capital and operating costs as compared to traveling screens, that have a history of low maintenance, and that have good debris handling and cleaning characteristics.

Regulatory and fisheries agencies may require use of physical hydraulic models to confirm hydraulic flow characteristics, particularly for major new designs. Physical models can be used to confirm and adjust large scale flow patterns and to refine localized structural and flow details. Costs of physical model studies are often more than offset by savings realized due to improved designs. For smaller structures, however, the time and cost associated with a physical model study may not be justifiable. Presented in this paper are hydraulic design guidelines. Items discussed include the influence of the angle at which the screen is set to the flow, the influence of intermediate pier size and spacing, the influence of loses through the drum screens and thus the influence of screen fabric, the influence of structure related losses, the influence of approach and exit channel cross-sectional area, the influence of approach flow distribution, and considerations in the design of structural details and channel transitions. The information presented results from three site specific physical model studies and from brief generalized studies that were done in conjunction with the site specific studies. It is intended that this paper supply sufficient information to allow design of a reasonably well performing structure. If an optimized design is needed, use of a physical model study would be required.

DESCRIPTION OF STRUCTURE

An angled drum screen structure consists of drum screens set end to end between piers (fig. 1). The front face of the piers is shaped to conform to the drums which minimizes blockage of fish movement as the fish are guided along the screens. The individual drums consist of rigid cylindrical frames covered by woven screen. The allowable size of openings in the screen depends on the size of fish and the screen fabric criteria of the regulatory agencies [typically 3 to 6 mesh with 0.10- to 0.25-in (2.5- to 6.4-mm) openings]. Rubber seals that seat against the piers are attached to both ends of the drums. A bottom seal is fixed to the structure beneath the drum and seats against the drum surface. The drums rotate about their axis with a maximum outer circumference rotational speed of 10 ft/min (3.0 m/min). Typically the drums are chain driven from electric motors located on top of the piers. The drums rotate such that the front (upstream) face rises and the back face descends. The drums are typically operated 0.7 to 0.8 submerged. Debris that impinges on the screen is carried over the top by the rotation and washed off the back by the through flow. If the submergence drops much below 0.7, debris tends to not cling to and carry over the drum but instead accumulates along the front face. Sprays and brushes have been used to improve cleaning. Drums have been constructed ranging from a few feet to 20 feet (6.1 m) in diameter and from the typical 10 to 12 feet (3.0 to 3.7 m) up to 25 to 30 feet (7.6 to 9.1 m) in length.

Positioned at the terminal end of the structure and at intermediate positions within the structure (depending on the structure length and the flow velocity field) are bypass intakes (fig. 2). W. S. Rainey (7) presents a thorough discussion of the design of bypass systems. Bypass intakes function as velocity traps, intercepting and capturing the fish as they move along the screens and directing them toward a pipe system which returns them to the waterway from which they came. The spacing between bypass intakes is dictated by the fish species and development state (swimming strength), the magnitude of the velocity components, and the time required for a fish to be guided down a length of screens and into a bypass intake. Typical spacing between bypass intakes is 100 to 125 feet (30.5 to 38.1 m). The bypass intake includes a guidewall, a vertical slot intake, an overflow weir gate, and a downwell (fig. 2). The guidewall intercepts the fish and directs them to the vertical slot intake. The vertical slot intake runs the full depth of the water column so that approaching fish do not have to change their vertical position to enter. The required width of the slot varies but is often 1 to 2 feet (0.3 to 0.6 m). Required intake velocities also vary depending on regulatory agency, but are always required to be equal to or greater than the velocities in the approach channel. Typically, required intake velocities are 2 to 3 ft/s (0.6 to 0.9 m/s). It should be noted that required slot width, slot height, and intake velocity, yield a required bypass discharge. The overflow weir often includes a telescopic weir gate that allows desired intake velocities to be maintained with varying canal water surface elevations. It also allows for control of hydraulic drop at the downwell and thus allows for control of turbulence levels to which fish are exposed.

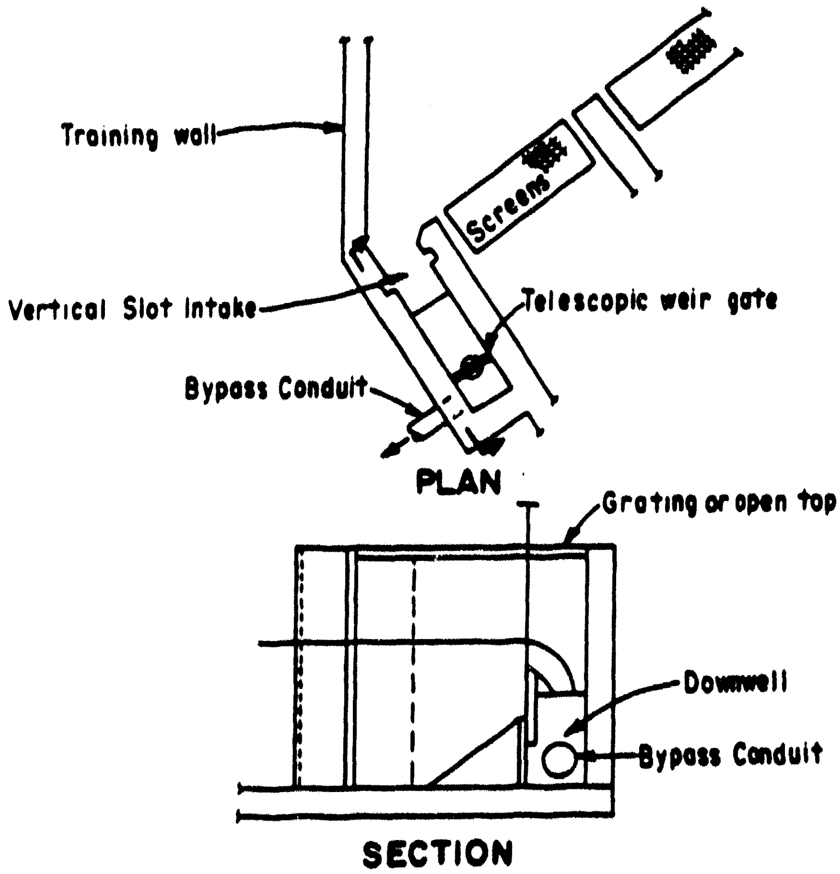


Figure 2. - Typical bypass intake.

The appropriate velocity and structure criteria on which an angled drum screen design is based tends to be dependent on the regulatory and fisheries agencies who are responsible for design review. Consequently, it is recommended that time be spent with the regulatory agencies, be they state or federal, to determine their specific criteria and objectives.

Angled drum screen structures, as described, are a relatively recent development. Only one such structure (Tehama-Colusa dual purpose canal screen, California) has experienced numerous years of operation. Several other structures sized to screen discharges ranging from 100 to 3,200 ft/s (2.8 to 90.6 m^3/s) are in various phases of design, construction, or early operation. Limited field evaluations have been conducted at the Sunnyside (6) and Wapato screens, Washington. At both sites the structures have proven effective in guidance and bypass of the target fish (fingerling steelhead and salmon).

HYDRAULIC OBJECTIVES

The approach channel to the screens should be designed to minimize slack water areas and back eddies. Predatory fish can hold in these areas with low energy expenditure and feed on the target fish. Elimination of slack water areas also allows for more direct movement of the fish to the screens and then on to the bypasses. Elimination of slack water and eddies basically requires that transitions be sufficiently long to prevent flow separation or significant reduction in boundary velocities. Likewise, any appurtenances to the structure, such as the bypass intake guidewalls, should be correctly aligned and shaped to minimize flow separation.

Beyond this the objective is to maintain approach velocities that are of equal or somewhat smaller magnitude than the velocities in the vertical slot of the bypass intake and to create a uniform flow field over the length of the structure that will minimize impingement of fish against the screens and maximize guidance of fish to the bypass intakes. To minimize impingement it is required that the component of the approach velocity normal to the screen be small, often 0.5 ft/s (0.15 m/s) or less at the maximum discharge. To maximize guidance it is typically required that the component of the approach velocity parallel to the screens have a magnitude that is equal to at least twice the magnitude of the normal component. To achieve these objectives requires that both the magnitude and the angle of attack of the approach velocity be within set limits. For the parallel component to have at least twice the magnitude of the normal component the angle of attack of the approach flow to the screens must be 26.5° or less. The magnitude of the normal component is equal to the sine of the angle of attack times the magnitude of the approach velocity. For the magnitude of the normal component to be 0.5 ft/s (0.15 m/s) the angle of attack must be 26.5° if the magnitude of the approach flow is 1.0 ft/s (0.30 m/s), 14.5° if the magnitude of the approach flow is 2.0 ft/s (0.61 m/s), and 9.6° if the magnitude of the approach flow is 3.0 ft/s (0.91 m/s).

It has been observed that the screen structure and in particular the piers intercept the flow, turning a portion of the flow through the structure and deflecting a portion of the flow downstream at a reduced angle. Consequently over the bulk of the structure the angle of attack will be something less than the angle at which the structure sits across the channel. For example at one site the structure was placed at an angle of 17.5° to the channel but the resulting angle of flow attack was approximately 12° over the bulk of the structure. At another site the structure was set at an angle of 15° to the channel. Resulting angles of attack were, however, approximately 10°. At a third site the structure was set at an angle of 21.33° and resulting angle of attack was approximately 16°. Thus, it appears that for typical structures, deflection of the approach flow results in approximately a 5° to 6° reduction in the angle of attack. An exception occurs at the first few drums where the structure has not deflected the flow and consequently where the angle of flow attack is equal to the angle at which the structure is set. Consequently, the normal components at the first few drums may exceed criteria while the normal velocity components over the bulk of the structure are in compliance. Three options are available to reduce normal component magnitudes at the first screens. The structure may be realigned at a flatter angle, the cross section of the approach channel may be enlarged and thus the magnitude of the approach velocities reduced, or the flow approaching the first drum could be deflected to both reduce the angle of attack or reduce local velocity magnitudes.

Another hydraulic concern is sedimentation. Often construction of an angled drum screen requires enlargement of the channel cross section. This results in reduced velocities and reduced sediment carrying capacity. Consequently sedimentation in the screen approach and exit channels is likely. In addition because the structure is designed in compliance with the normal component criteria, average velocities through the screens and immediately behind the screens will be equal to or less than the maximum allowable normal component. This is a low velocity zone which is very prone to deposition. Sediment deposition can potentially modify flow patterns through the screens and result in abrasion of screens and seals. Removal of deposition also represents a constant maintenance demand. To minimize deposition, entrance and exit channel velocities should be held as high as possible. To reduce deposition immediately behind the drum screens, stoplogs could be used to reduce the flow area and create a sluicing action. Use of uniform stoplogging over the length of the structure has little impact on approach flow distribution.

PARAMETER DISCUSSION

The following is a discussion of the parameters that influence the hydraulic performance of an angled drum screen structure.

Angle of Structure

In the generalized phase of this study a design was considered with the angle of the structure set at 22° and 0° (fig. 1). The cross section areas of the approach and exit channels were held constant as were the other geometric details of the structure. The angle was observed to have negligible influence on the resulting approach velocity distributions. As previously noted the one advantage of the 0° alignment is that the angle of flow attack on the first few drum screens is flat and consequently the normal and parallel velocity components will be in compliance. Beyond this, selection of the angle of structure set is largely dependent on site specific geometric details and use of an angle that minimizes structure complexity and cost.

Pier Length and Spacing

Beyond screen support, the piers function as vanes or louvers intercepting and turning a portion of the flow through the structure while deflecting a portion of the flow down the approach channel. The piers are sources of flow separation, flow concentration, momentum change, and head loss. These effects are maximized due to the sharp angle of pier placement to the flow.

To evaluate the influence of pier length and spacing two structures were studied. One had piers with a length equal to two drum screen diameters positioned with a clear space between piers equal to 0.67 drum diameters. The other structure had piers with a length equal to one drum diameter positioned with a clear space between piers equal to 1.4 drum diameters. This represents probable extremes in pier size and spacing for large diameter drum screen structures. Both structures studied were 30 drum diameters long and were set at an angle of 22°. Approach and exit channel cross sections and all other geometric details were the same for both cases. The two cases were studied at maximum discharge with average velocities in the approach channel of from 2 to 3 ft/s (0.6 to 0.9 m/s). The longer more closely spaced piers caused a progressive increase in approach velocity as the flow passed down the structure length. Approach velocities at the start of the structure were not influenced (and thus were the same for both cases) but velocities 80 percent of the way down the structure were approximately 10 percent greater with the longer and closer spaced piers. At least a portion of this increase may be due to loss of screen area resulting from use of additional piers. From these data it was concluded that for the possible angles of structure set (0° to 26.5°), pier length and spacing has only secondary influence on resulting approach velocity distributions.

Discharge

The discharge equation:

$$Q = AV$$

where Q = volume discharge
A = cross-sectional area
V = mean velocity

can be used to size the approach channel. Flow down the approach channel is one directional and relatively parallel to the channel banks (or normal to the channel cross sections) which allows for direct application of the discharge equation. In addition, velocities down the length of the approach channel can be selected to reflect the desired velocity distribution and corresponding discharges and channel cross sections computed.

Findings indicate that this is a valid approach. The findings, however, show that the configuration of the exit channel also influences the flow distribution in the approach channel. Direct sizing of the exit channel through use of the discharge equation is less straight forward. The flow exits the screen structure parallel to the piers or perpendicular to the exit channel. The flow crosses the channel while turning to the down channel alignment. The result is a concentrated down channel flow in the outer one-third to one-half of the exit channel. Lancaster and Rhone (5) found that, depending on exit channel cross section and orientation, a substantial backwater buildup may be required to turn the flow in the exit channel. They show that this can result in increased head loss across the structure and modification of approach flow distribution. In attempting to apply the discharge equation to sizing of the exit channel one must recognize the flow pattern and oversize the exit channel to compensate. It is recommended that the exit channel be at least half again wider than what is indicated by direct application of the discharge equation. The model studies indicate that the exit channel may be further oversized with little resulting influence on the approach channel velocity distribution. As an option to oversizing Lancaster and Rhone (5) show that flow straighteners, or walls placed parallel to the exit channel immediately behind the screen structure, may be used to turn the flow with reduced head loss and allow use of an exit channel sized directly by the discharge equation.

Screen Fabric

It was observed that energy, or the energy gradient field around and through the screen structure, likely has a significant influence on velocity distribution in the approach channel. A source of energy loss through the structure results due to flow through the screen fabric of the drums. As previously noted, 3- to 6-mesh (openings per inch) screen with 30 to 50 percent open area is often used. Usually there is flow through both the front and back surfaces of the drum. In some designs only the front half of the drum seats against the piers in which case a portion of the exiting flow passes out of the open sides of the drums.

In either case the screen fabric yields constriction of the flow path with localized acceleration and head loss. Studies done by Armour and Cannon (1) and confirmed by the TVA (Tennessee Valley Authority) (3) can be used to evaluate head losses associated with flow through screens. Armour and Cannon (1) indicate that:

$$K = \frac{1}{3\epsilon^2}\left(\frac{103.4\,(da)^2}{R}\right) + 6.24\,\frac{d}{l}$$

where
- K = pressure drop coefficient = $\Delta h/(V^2/2g)$
- ϵ = screen void fraction
- d = wire diameter
- a = area/volume ratio = $12/\pi\, m^2 l_1$
- m = mesh (openings per inch)
- l_1 = length of a crimped wire segment = $(d^2 + m^{-2})^{1/2}$
- l = width of hole in screen
- R = screen wire Reynolds number = Vd/υ
- V = upstream flow velocity
- υ = kinematic viscosity

These studies were conducted for a single flat plane screen - not a screen with a drum configuration. Limited studies reported by Bell (2) imply that losses associated with perpendicular flow through both faces of a drum screen would equal 1.7 times losses associated with perpendicular flow through a single flat plane screen. These studies also indicate that for a drum screen with fabric that has 63.3 percent open area (the screen mesh was not given) the head loss (H_l) with flow through both faces of the screen is:

$$H_l = 2.9\,\frac{V^2}{2g}$$

The TVA report (3), notes that for situations where the angle of attack of the flow on the screen is other than 90° the head loss can be estimated using the normal component of the velocity for "V" in the equations above. This being the case, and because of the flat angle of attack, losses due solely to flow passage through the drums will amount to 10 to 50 percent of the approach flow velocity head. This does not include losses associated with the structure.

To evaluate the influence of the screen fabric on the approach velocity distribution a simplified hydraulic model was studied sequentially with 2-mesh, 18-mesh, 30-mesh, and 60-mesh flat screens installed in the drum screen bays. With consideration of scale Reynolds number effects these screens should yield losses that range from 10 percent to 400 percent of losses associated with a 2 ft/s (0.6 m/s) approach velocity on a 4-mesh, 33.6 percent open area drum screen. It was found that there was very little difference in approach channel velocity distributions for the four cases. Consequently it was concluded that screen fabric and its associated losses are not significant factors to be considered in structure design.

Energy Gradient

Beyond losses due to screen fabric the flow experiences energy losses due to boundary friction and due to flow through the piers of the structure. Friction losses can be evaluated through the use of a relationship such as the Chézy equation:

$$V = C\sqrt{rS}$$

where V = mean velocity in the cross section
C = Chézy coefficient
r = hydraulic radius = A/P
A = cross-sectional flow area
P = wetted perimeter
S = energy slope

The Chézy coefficient can be evaluated either through the use of a modified Moody diagram that considers Reynolds number and relative boundary roughness (4) or through a relationship such as:

$$C = \frac{1.49\ r^{1/6}}{n}$$

which relates the Chézy coefficient to Mannings "n" for English units. For the approach channel with a selected approach velocity and with an estimated boundary roughness, energy slope and total friction head losses can be evaluated. Note that the channel cross section is reducing over the length of the structure which requires an integrated application of the Chézy equation. When such calculations were made for a 570-ft-long (174-m) structure which includes 32 18.75-ft-diameter (5.715-m-diameter) drums with a uniform approach velocity of 2 ft/s (0.6 m/s) the resulting calculated loss over the length of the approach channel was 0.041 ft (0.0125 m) of water or approximately two-thirds of a velocity head. It was also noted that half of this loss occurred over the last four to five drums where the approach channel cross section was small.

As previously noted flow patterns in the exit channel are more complex and thus not as well suited for analysis. However, since the exit channel is typically oversized and since the narrowest portions of the exit channel (behind the first few drums) tends to experience reduced velocities, it is felt that friction losses in the exit channel will be small and may typically be half or less of the losses experienced in the approach channel.

A final source of energy loss would be due to the structure itself. The work of Lancaster and Rhone (5) supplies insight into these losses. This work studied angled louver fish screens which create in effect a reduced scale representation of the flow patterns through the pier structure of the angled drum screen. Lancaster and Rhone found that losses through the structure are a function of angle of structure placement, angle of pier placement to the flow, magnitude of approach velocity, and size and configuration of the exit channel. A modified presentation of the Lancaster and Rhone head loss data is presented in figure 3. In figure 3 note that for angles of structure placement less than 30° (without flow straighteners) the angle has no affect on associated head loss. This finding is somewhat confirmed by the previously mentioned observation that angle of structure placement, be it 0° or 22°, has no noticeable influence on approach channel velocity distribution. The angle of pier placement for drum screen structures is tied directly to the angle of structure placement. To maintain a smooth screen face for fish guidance the piers must be placed perpendicular to the structure alignment. With this being the case the angle of pier placement is equal to 90° minus the angle of flow attack (fig. 3). For example, with a 12° angle of attack the associated structure head loss would be 4.8 approach velocity heads. Note that these data were obtained in a constant cross section flume. Thus the loss reducing influence of an oversized exit channel is not considered. Note, also presented on figure 3 is a curve that defines losses that occur when flow straighteners are used. These values likely correspond to losses associated with an oversized exit channel. From figure 3 with a 12° angle of attack and flow straighteners the structure loss would be three velocity heads. At 0° the loss would be 3.8 velocity heads, and at 26.5° the loss would be 2.25 velocity heads.

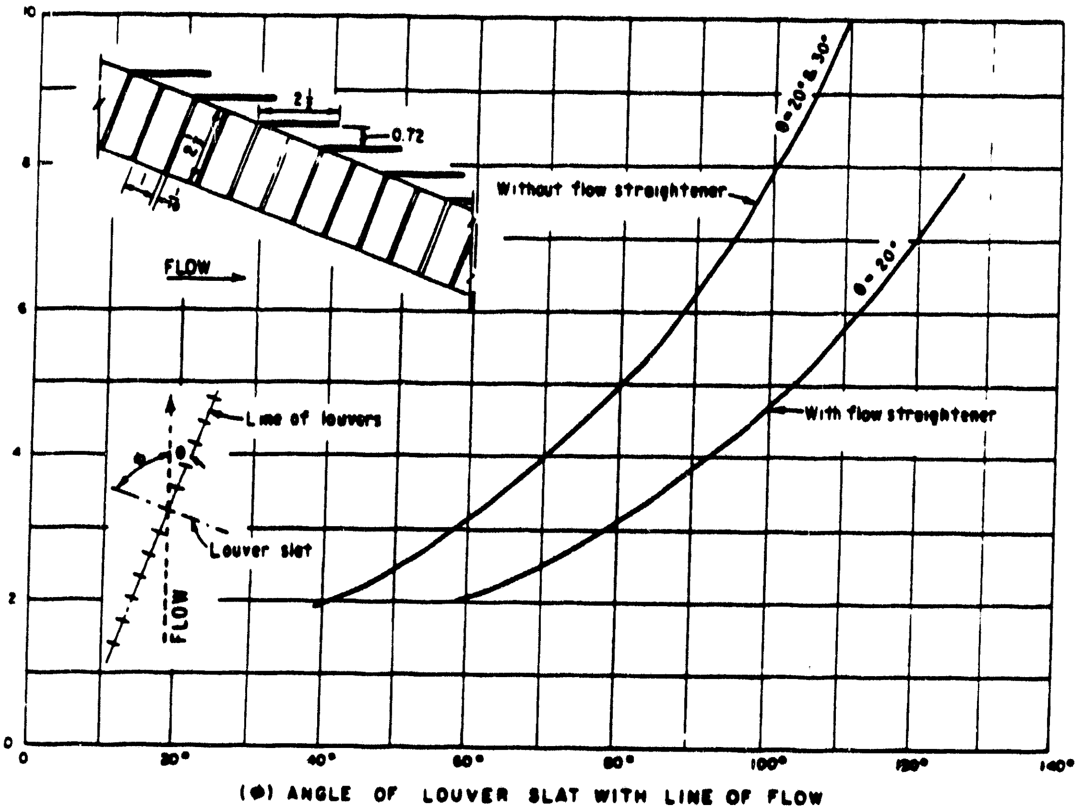


Figure 3. - Head loss characteristics of louver structure.

In summary, with adequately sized approach and exit channels, the loss across the structure (structure plus screen loss) is a dominate factor. If the approach channel is sized based on the discharge equation and the exit channel oversized (or if flow straighteners are included), the energy characteristics of the design can be considered as a line loss between two uniform elevation reservoirs. This implies that if the loss characteristics along the screen structure are uniform then the approach flow distribution will also be uniform. The exception to this would be at localized transitions or disturbances such as at the first few drums and immediately around the bypass intakes.

Transitions

Transitions and structural disturbances are sources of back eddies, slack water zones, and velocity concentrations. To minimize these adverse conditions it is recommended that transitions, in particular expansions in the approach channel, be as long as possible. For example at one site where the approach channel bottom width expanded from 50 to 100 ft (15 to 30 m) with a 10-ft (3.0 m) flow depth and with average approach velocities transitioning from from 3.5 to 1.8 ft/s (1.1 to 0.55 m/s), a 300-ft-long ([illegible]0-m-long) expansion yielded an adequate velocity distribution while an 80-ft-long (24-m-long) expansion did not.

Care should also be taken at the bypass intakes to achieve both a uniform or slightly accelerating approach flow to the bypass and an eddy-free flow on the back side of the guidewall (fig. 4). The first requirement to achieve these objectives is to properly align the guidewall with the approach flow. Basically the guidewall should be set parallel to the flow or at the angle of flow attack. For example at one site the screen structure was set at an angle of 17.5° with the canal centerline, the angle of approach flow attack over the midportion of the structure was 12°, and consequently the bypass guidewall was set at an angle of 12° with the structure. If the guidewall is set at too large of an angle with the structure a separation or eddy zone will result on the back side of the wall and a flow deceleration will occur between the wall and the screens approaching the bypass intake. The eddy on the back of the wall not only supplies predator habitat but also, if large enough, will disturb flow patterns across the drum immediately downstream from the bypass. The discharge between the guidewall and the screens is the sum of the local discharge through the screens and the bypass flow. This discharge is fairly independent of guidewall position, consequently if the wall is set too far from the structure the resulting velocities are reduced.

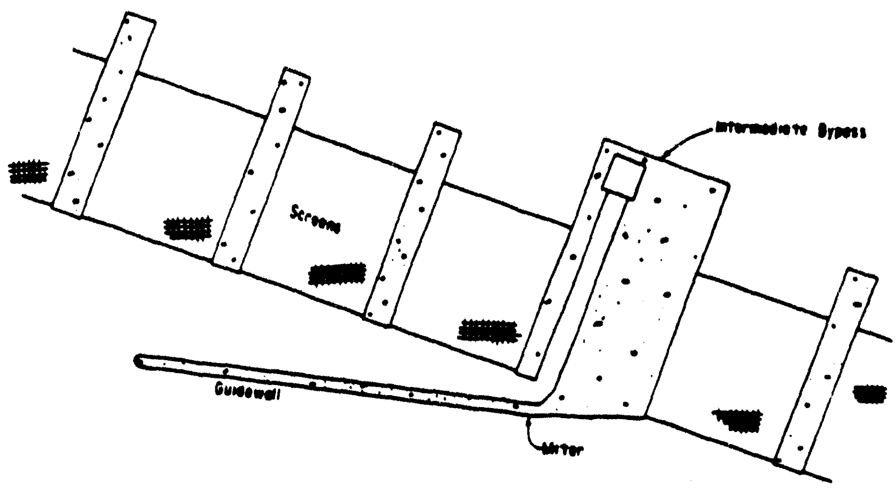


Figure 4. - Intermediate bypass design.

Care should be taken in the design of the transition from the intermediate bypass to the drum screen immediately following. The guidewall must be placed a sufficient distance away from the screen structure to meet minimum bypass intake width criteria. This distance plus the guidewall width results in the outer face of the guidewall being well out away from the screen structure. A transition is therefore required to bring the flow cleanly back to the screens. If too abrupt of a transition is used eddies that extend over much of the immediately following drum can result. The transition shown in figure 4 has proven to be a simple but effective design. An extended blank structure is placed between the bypass intake and the following drum. An appropriate length for this blank reach would be 10 to 12 feet (3.0 to 3.7 m) for a 2-ft/s (0.6 m/s) approach channel velocity. This blank reach allows sufficient length for the transition. The transition itself is typically a vertical face extension of the outer face of the guidewall. A small angle (5° to 10°) miter between the guidewall and the transition is included to reduce the transition length. The vertical face of the transition extends from the guidewall to the drum. The intersection of the vertical face and the cylindrical drum yields offsets from the flow at the bottom and surface. However, it has been concluded that the resulting eddies are not substantial and are a small price to pay for the simplified transition construction.

Approach flow distribution

All of the information presented to this point assumes a uniform flow distribution in the canal as it approaches the screen structure. Approach flow concentrations or nonuniform distribution can greatly modify flow patterns at the screen structure. It can result in high velocity zones (hot spots) on the screens which can yield the impingement of fish. At one site an angled drum screen structure had to be positioned on a canal bend. Due to the flow concentrating effects of the bend in conjunction with an ineffective expansion design, a large back eddy resulted which created reverse flow through the first three drums of the 18-drum structure. Flow concentrations can result from many causes with the most common being ineffective transitions, poor alignment of flow control or flow influencing structures immediately upstream of the screen structure, and bends in the approach canal. Efforts have been made to correct poor approach flow distribution through use of flow resistance (stoplogging) selectively placed behind the drums. The author has found this to be an ineffective technique and suggests that efforts concentrate on improving the flow distribution well upstream of the structure. As a first option it is suggested that a straight, well aligned channel that is at least 80 hydraulic radii long be supplied upstream of the screen structure. For typical canal applications with velocities less than 3 ft/s (0.9 m/s) this should be a sufficient length to equalize the velocity distribution. When canal velocities are greater than 3 ft/s (0.9 m/s) additional length of well aligned approach channel may be required. If sufficient length cannot be supplied then care should be taken to design the approach and any structures it might contain to minimize flow concentrations. Headworks structures, inverted siphon exits, tunnel exits, or any other structure that strongly influences flow distribution and direction should be carefully designed and aligned. Transitions should be of sufficient length to prevent separation or slack water zones. If good flow distribution and direction cannot be supplied, guide vanes, variably distributed upstream stoplogging, or other structures which force redistribution of the flow can be used to establish good initial approach flow conditions. It is difficult to be specific about such options because of the site specific nature of the problem. It is recommended that where such problems exist the use of a physical hydraulic model study be strongly considered.

SUMMARY AND CONCLUSIONS

Angled drum screen structures offer a state-of-the-art technique for excluding fish from canal flows. Currently numerous angled drum screen structures with hydraulic capacities ranging from 100 to 3,200 ft^3/s (2.8 to 90.6 m^3/s) are in design or construction. As of this writing three major structures have gone into operation and have proven effective in supplying mortality free fish guidance and bypass. Angled drum screen structures combine two proven elements: angled screen placement which creates flow patterns that guide the fish to the bypasses while minimizing fish impingement, and drum screens which are relatively simple mechanical screens offering good cleaning and debris handling characteristics while being relatively inexpensive and maintenance free as compared to other traveling screen options.

The flow patterns approaching and through the screens are critical if optimum performance of the structures is to be obtained. The approach flow should be free of back eddies and slack water to eliminate zones where predator fish can hold and to optimize fish guidance and bypass. This requires that transitions and structure details be well aligned and hydraulically clean. Beyond this, the approach flow to the screens should be uniform with magnitude and angle of approach such that the components of the velocity normal to the screens will be small, 0.5 ft/s (0.15 m/s) or less, and the components of the velocities parallel to the screens will be at least twice the magnitude of the normal components. The approach velocity should also be such that uniform or slightly accelerating flow to the bypass intake results. Specific velocity criteria is dependent on the regulatory agencies reviewing the design. Physical hydraulic model studies should be used to optimize and confirm the flow characteristics of a design. However, the information presented in this paper can be used to develop either initial designs or to develop designs of smaller structures that do not warrant a model study.

Through the use of three physical model studies of specific structures and limited general study the design significance of various parameters was evaluated. It was concluded that the angle at which the screen structure is set (be it parallel to the canal or at angles up to 26.5°), the length of and spacing between the drum screen supporting piers, and the screen fabric with its particular mesh and percentage of open area have at most limited influence on approach velocity patterns and distribution. Consequently these parameters can be evaluated based on site and economic considerations and regulatory agency preference. The critical factor to be considered in the hydraulic design of the structure, beyond supplying eddy free approach flow, is to supply adequately sized approach and exit channels. The approach channel should be sized based on the discharge equation. Thus, desired approach velocity distributions can be selected and corresponding channel cross sections computed.

Beyond this the energy gradient approaching, through, and exiting the structure has major influence on the approach flow distribution. If properly sized, losses in the approach and exit channels are small. The dominate loss (2.25 to 4 approach flow velocity heads) occurs due to the screen structure. Consequently, the energy gradient can be described as a line loss between two fairly constant elevation water bodies. Therefore, if losses along the length of the screen structure are constant, the resulting flow distribution will also be constant. With respect to sizing the exit channel, the flow exits the screen structure normal to the structure. Frequently this flow is also normal to the alignment of the exit channel. The flow crosses the exit channel gradually turning to a down channel direction. Studies have shown that with smaller exit channel cross sections substantial backwater is required to turn this flow. This backwater can modify the energy gradient across the screen structure and yield nonuniform approach flow distribution. To eliminate this problem the exit channel may be oversized (at least half again larger than indicated by direct application of the discharge equation), the exit channel may be realigned, or flow straightener vanes can be used to turn the flow to a downstream direction.

Finally the initial flow distribution can significantly influence approach flow patterns. It is recommended that every effort be made to supply relatively uniform initial distribution. If because of upstream structure alignment or bends in the upstream channel this cannot be done, it is recommended that a physical model study be used to develop satisfactory hydraulic conditions.

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HYDRAULIC MODEL STUDY OF A FISH SCREEN STRUCTURE FOR THE McCLUSKY CANAL

Engineering and Research Center
Bureau of Reclamation

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December 1975

Hydraulics Branch
Division of General Research
Engineering and Research Center
Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

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ACKNOWLEDGMENT

The studies were conducted by the author and reviewed by D. L. King, Head, Applied Hydraulics Section (now Chief, Hydraulics Branch), under the general supervision of W. E. Wagner, Chief, Hydraulic Branch (now retired), J. G. Starbuck, Hydraulic Structures Branch, and J. J. Sartoris, Applied Sciences Branch, along with the author, formed the planning team that conceived the initial structure.

PURPOSE

These studies were made to refine the design of a fish control structure for the McClusky Canal, Garrison Diversion Unit, North Dakota. The structure was a new concept and, therefore, no design guidelines existed.

RESULTS

1. The structure as developed functioned satisfactorily in the model. The screen should remove all fish, fish eggs, and fish larvae from the flow. Likewise, the model data indicates that the screen surface should be self cleaning.

2. The flatter the downward slope of the screen, the shorter the flow length of the screen required to pass a given discharge. Thus, a horizontal screen would result in a smaller structure than would be required for a downward sloping screen.

3. The steeper the downward slope of the screen, the more efficient the screen self-cleans. The tendency for debris to cling to the screen depends on the angle at which the flow impinges on the screen. If the flow direction is nearly tangent to the screen's surface, then the debris is swept clear of the surface and no clogging occurs. But if the flow impinges sharply, then the debris will accumulate in the impingement area. This accumulation resulted from the impact head of the flow, forcing and holding the debris against the screen surface. The debris did not actually tangle with the screen fiber; therefore, it could easily be dislodged and washed clear.

4. Screen mesh and wire size affect the length of screen required to pass a given discharge. Finer mesh screens tend to require more screen length as do screens made from larger diameter wire.

5. If the region under the screen is inadequately vented, reduced pressures will develop. Reduced pressures under the screen tend to suck water through the screen, which reduces the required screen length and increases clogging. The reduced pressures also place additional loading on the screen structure.

6. The quantity of debris that will be encountered in the prototype is unknown. Therefore, it is conceivable that the screens might be overwhelmed by debris, and clogging could become a problem. The screen arrangement allows the installation of several possible devices which would improve self cleaning. For the present, none of these devices is to be incorporated in the prototype structure. If a clogging problem is found to exist when the prototype structure goes into operation, then the devices could be installed without major modifications.

7. The optimum screen configuration developed from this study has a screen length in the direction of flow of 6.5 feet (2.0 m) and a slope of 5^{0} downward from horizontal. This structure was developed to pass a maximum unit discharge of 6 ft^3/s (0.2 m^3/s).

APPLICATION

The results of these studies may be used as generalized design guidelines. The study yields the configuration of typical screen sections. Thus, the analysis is independent of the size and shape of the overall structure. The particular structure for which this study was undertaken has a V-shaped overflow wier with a crest length of approximately 325 feet (99.0 m). The structure will pass a maximum discharge of 1,950 ft^3/s (55.2 m^3/s). Structures with smaller maximum discharges would be built proportionately smaller. However, the typical screen sections would remain the same and only the weir crest length would be reduced. In addition, the analysis is applicable to structures with many different weir shapes. The only limitations are that both the typical section and the approach flow conditions to the section be similar to those in the model. Any transverse component of velocity (parallel to the weir) in the approach flow should be small compared to the flow velocity down the screen surface.

INTRODUCTION

The Garrison Diversion Unit of the Missouri River Basin Project consists of an extensive, multibasin, irrigation system (fig. 1). About 250,000 acres (100,000 hectares) in east-central North Dakota will be served by the system. The water will be withdrawn from the Missouri River and delivered to the farmland through a series of pumping plants, reservoirs, and canals. The land to be served lies in the Souris, Sheyenne, James, and Wild Rice River drainages. The James River is a tributary of the Missouri. The Sheyenne and Wild Rice Rivers are tributaries of the Red River of the North. The Souris River and the Red River of the North both flow into Canada. In addition, several isolated closed-basin areas (that generally contain shallow lakes and marshlands which have great importance as habitat and breeding areas for water fowl) will receive water.

The Missouri River contains species of fish that are considered undesirable. It appears, however, that the

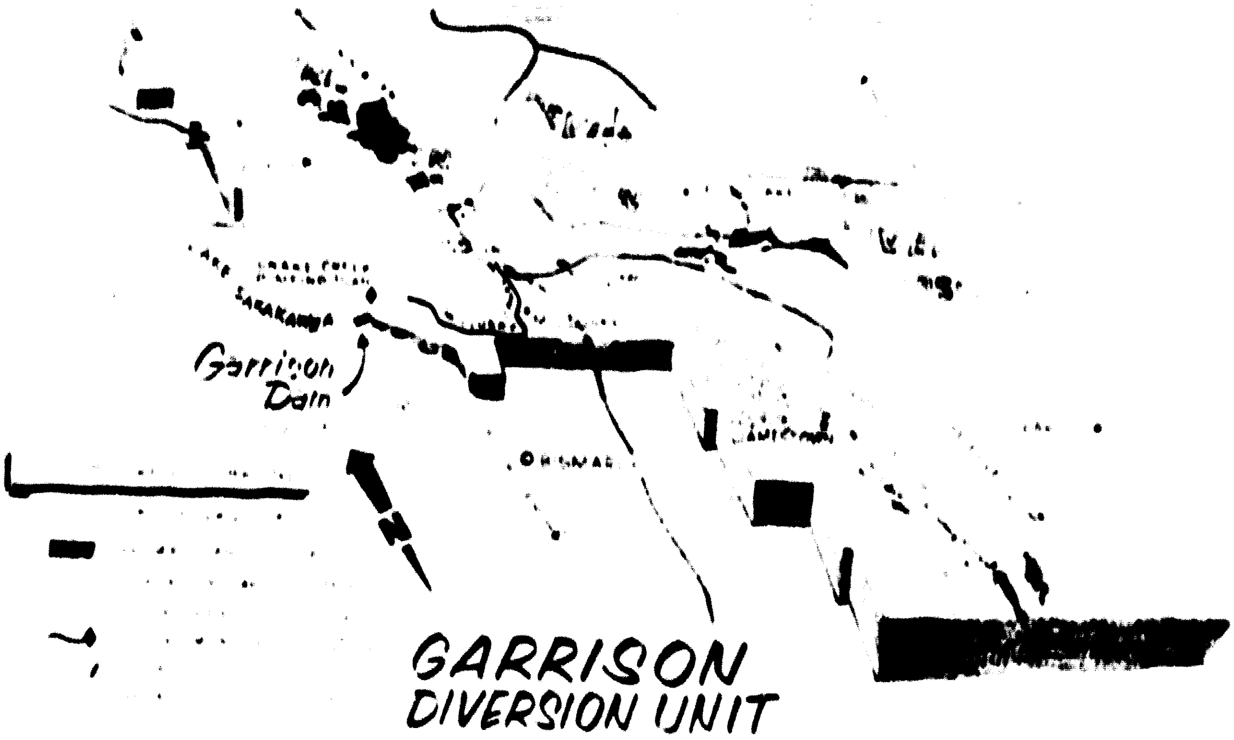

Figure 1 Map of Garrison Diversion Unit Photo P769-D-48127

Souris and Red River of the North may not contain all of these species. It is also known that some of the tributaries of these rivers and many of the closed basins contain none of the undesirable species. Of importance is that the presence of these undesirable fish can eliminate the effectiveness of waters as breeding areas for waterfowl as well as having a negative impact on the water as a sports fishery.

A study team was organized at the E&R (Engineering and Research) Center of the Bureau of Reclamation to evaluate and develop methods for eliminating the possibility of transporting these fish. The team reviewed the literature and evaluated modern methods of fish, fish egg, and fish larvae control. In addition, the team contributed its own ideas for more effective control. A contract was awarded to the University of North Dakota to survey the fish populations in those bodies of water that may be affected. The survey would determine which waters presently contain the undesirable fish and define the extent of the problem in each. However, the survey would not be completed before canal construction was to be initiated in the locations that were most suitable for fish control structures. Therefore, designs proceeded on the assumption that no fish, fish eggs, or fish larvae migration could be tolerated.

The E&R Center team began by attempting to comprehend the biological aspects and constraints of the problem, which would give the team insight into the problem and, consequently, give significant direction to the study. A brief review indicated that the species of fish which might be of concern include carp, goldeye, burbot, green sunfish, shortnose gar, quillback, buffalo fish, saucer, and freshwater drum. The findings indicated that the minimum egg diameter was larger than 1 mm, that the larvae will be approximately the same size as their eggs, that eggs or larvae will be present in the system throughout most of the summer and early fall (the peak operation periods for the canals), and that most of the eggs will not float but that some do. The implications of these findings are that:

1. Any filtration system used must filter every drop of water that passes the structure.

2. If filters are used, all material larger than 1 mm in diameter must be removed.

3. The control structure must be large enough to handle the maximum discharge of the system.

4. Whatever control system is used must be able to either remove or kill all fish, eggs, and larvae in the flow under all operating conditions.

A second aspect of the problem considered early in the analysis was the physical layout of the project. It was realized that this layout (number, size, and location of turnouts, canal branching to various drainages, etc.) would dictate the number and size of fish control stations required. The water will be withdrawn from the Missouri River at Lake Sakakawea and lifted by the Snake Creek Pumping Plant to Lake Audubon (fig. 1). The water then flows through most of the remainder of the system by gravity. From Lake Audubon, the water flows approximately 80 miles down the McClusky Canal to Lonetree Reservoir. Only a few small deliveries are planned from the McClusky Canal. In the initial phase, the water will flow from Lonetree Reservoir (which will store and regulate the flow) north into the Souris River drainage, and east and southeast into the Sheyenne, James, and Wild Rice River drainages. Both distribution canals leaving Lonetree Reservoir—the Velva Canal going north and the New Rockford Canal going east and southeast—have maximum discharges approximately equal to that of the McClusky Canal. Therefore, it seemed advantageous to locate the fish control structure on the McClusky Canal. Placement of the controls on the Velva and New Rockford Canals would require facilities that could process a combined flow of nearly twice that of the McClusky Canal. This alternative would probably cost nearly twice that of the single structure. In addition, placement of the fish controls on the Velva and New Rockford Canals would allow the undesirable fish to pass into Lonetree Reservoir. This would not only adversely affect the fishery and recreational uses of the reservoir, but also might allow fish to pass through the outlet works or spillways of Wintering and Lonetree Dams and into the protected drainages.

The team considered several possible means for achieving the desired controls. Operational techniques were considered initially. It was thought that the canal might be dewatered when eggs or larvae were present, thus eliminating the eggs and larvae as a concern. But this cannot be done because eggs and larvae will be present in the flow throughout most of the peak operational season.

Poisons were also considered briefly. Poisons could control the fish, but the canal system passes through several lakes used for both recreational and wildlife purposes. Portions of the delivery system will serve as habitat and breeding areas for waterfowl. These uses not only have environmental significance, but are also economically important to the region and poisons could have detrimental effects on these functions. It was concluded therefore, that a physical method of fish control was most desirable. In this vein, several control methods were given limited consideration during the initial portion of the review. Violent hydraulic action such as turbulence in a hydraulic jump or cavitation is not 100 percent lethal to mature fish for the heads considered. No data were found on the effects of violent hydraulic action on eggs and larvae. The indications were that violent hydraulic action does not offer a solution. When electrocution was considered, it was found that voltages that would effectively control all sizes of fish, eggs, and larvae would pose danger to people. Sound wave control was also briefly considered, but was also found impracticable.

The attention of the team therefore shifted to various screening methods and devices. The team's initial reaction was that screen systems cannot be expected to be 100 percent effective. There would be small openings at seams and seals, especially for moving screens. Eggs might cling to moving screen surfaces and be transported past the structure. Fixed screens initially did not appear to hold any promise because of the large amounts of trash (aquatic plants and algae) expected in the system. Fixed screens are generally susceptible to clogging which would pose a very serious handicap to the operation of the screen structure. More detailed consideration revealed two types of screen structures that appeared to meet the needs. The first was a sand filter similar to but much larger than those used for domestic water treatment. This type of structure would have filtration capabilities far beyond those required for this particular problem and a sand filter could be expected to be 100 percent effective. Cursory designs revealed that a sand filter capable of handling the full canal discharge [1,950 ft^3/s (55.2 m^3/s)] would have a surface area of from 5 to 10 acres (20,000 to 40,000 m^2). The cost of such a structure would be prohibitive. The second promising structure considered was a sloping screen filter [redacted]. With a sloping screen filter, the flow passes over a weir and through a fixed slightly downward-sloping screen. The screen mesh is sufficiently fine to meet the filtration requirements. Seals around the fixed screen could be made sufficiently tight so that no flow would pass through. Previous experience with field installations indicated that this type of structure is nearly self cleaning. The screen weave is so fine (24 to 80 mesh) that the screen has a slick, fabric-like texture. Openings in the screen are generally small enough that debris will not cling to the individual wires. Therefore, the debris passing onto the screen is washed down the screen surface to the point where the last of the flow drops through the screen. As the debris accumulates, the leading edge of the debris stays at the flow limit; thus the debris is pushed down the screen.

Previous installations of this type screen have been used for relatively small discharges [less than 100 ft^3/s (2.8 m^3/s)] with the objective of either filtering weed seed from irrigation water or collecting biological samples from small streams. Structures using the same principal but with coarser screens have also been used for collecting or concentrating fish.

The final canal structure (fig. 2) is a new concept because of its size and because of the fine mesh and structural configuration. It is felt that a structure of this type can be designed to function satisfactorily and meet the filtration requirements at a reasonable cost. With these factors in mind, the sloping fixed screen structure was selected and studies were initiated to develop and refine the design.

THE MODEL

To aid in developing the design, a sectional hydraulic model of the screen was constructed (fig. 3). The model was a full-scale representation of a 20-inch (51-cm) wide section of the proposed prototype structure (fig. 2 and 3). Included in the model were the overflow weir [the crest of which was 6 feet (1.8 m) above the test flume floor], the screen with a backup screen 1 foot (0.305 m) below it, and a trough at the end of the screen into which the trash and overflow water would dump. The screens were mounted on frames which fit into a support box. The screens could thus be changed easily, and the effects of screen mesh and wire size quickly evaluated. The screens placed in the model were approximately 10 feet (3.1 m) long, which is longer than any screens envisioned for the prototype structure. It was realized that the required screen length would vary with screen mesh, screen slope, and unit discharge. The model screen was made extra long so that a wide range of flow conditions could be tested. For the different test conditions observed, the location on the model screen where the last of the flow dropped through was used to establish the screen length required. The model was constructed with the screen structure hinged to the weir wall, making it possible to easily vary the screen slope. A skimmer weir upstream from the overflow weir was also included in the model during a portion of the testing. The flow was filtered through an 80-mesh screen after it passed through the model to evaluate the filtration efficiency of the screen structure. All discharges through the model were established through the use of venturi meters.

THE INVESTIGATION

The three main objectives of the model study were to:

1. Evaluate the ability of the screen to self-clean.

2. Confirm that the screen will satisfactorily meet the filtration requirements.

3. Minimize the screen and structure size required to filter the total canal flow.

Six basic factors considered to achieve these objectives were:

1. Unit discharge.

2. Drop from weir crest to screen.

3. Slope of screen.

4. Length of screen.

5. Screen mesh and wire size.

6. Effects of various types of debris.

Many of these factors are interrelated, which required observing several hundred specific operating conditions to obtain a complete understanding.

As an example, as the unit discharge (the discharge per foot width of screen) increases, the length of screen required to pass that discharge also increases. Likewise, as the downward slope of the screen increases, the required length of the screen increases. Conversely, as the unit discharge increases, so does the amount of debris per unit width of screen. And as the downward slope of the screen increases, the screen more effectively self-cleans. Also, it could be reasoned that the finer the screen mesh, the greater the resistance to the flow, and a longer screen would be required. But a finer mesh might give the screen a slicker finish and, therefore, improve self-cleaning capabilities. A drop from the overflow weir crest to the screen surface might also be incorporated into the design. This would give the flow an additional velocity as it impacts on the screen, which would increase the flow rate through the screen in the impact zone and thus reduce the required screen length. Conversely, the higher velocity would result in a larger impact head on the screen, which

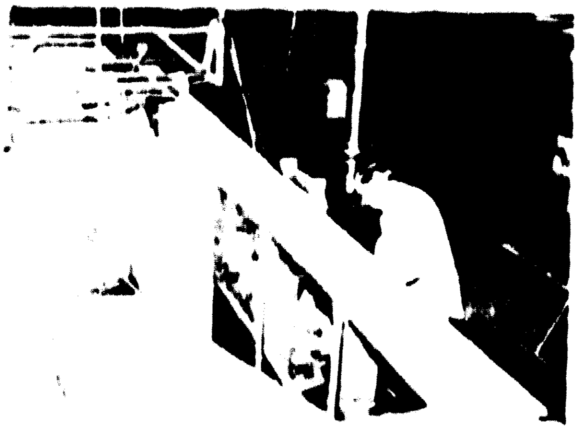

Photo P769-D-76122

Photo P769-D-76120

Figure 3. Hydraulic model operating.

might cause structural problems or which might tend to press and hold debris against the screen surface. As can be seen, the overall problem is one of give and take. The model study was made to determine the optimum balance among these factors to best satisfy all three objectives. The structure had to be designed to meet filtration and self-cleaning requirements, yet be of minimum structural and screen size, and thus be built at minimum cost.

To achieve these objectives, the model was studied under a broad range of operating conditions. The model operating under typical conditions is shown in figure 3. Forty-mesh screens made from 0.010-inch (0.25-mm) and 0.006-inch (0.15-mm) diameter wire and 80-mesh screens made from 0.007-inch (0.18-mm) diameter wire were used. For each screen, an initial study was made with no debris in the flow. The screens were observed operating at unit discharges of 3, 4, 5, and 6 ft^3/s (0.08, 0.11, 0.14, and 0.17 m^3/s). For each unit discharge the screen was set at slopes of 5° and 10° upward, horizontal, and 5°, 10°, and 15° downward. For each slope setting the length of the screen required to pass the flow was noted. This information yielded the various structure sizes and slopes required to filter the canal discharge. Data obtained are shown in figures 4 and 5 for the 40-mesh screen with 0.010-inch (0.25-mm) wire and the 80-mesh screen, respectively. It can be seen that, as previously hypothesized, for a specific unit discharge the length of screen required increases as the downward slope of the screen becomes steeper. Likewise, for a particular slope, it can be observed that the length of screen required increases as the unit discharge increases. Both observations can be readily explained. First, for a given discharge, as the downward slope of the screen increases, the acceleration of the flow along the screen surface caused by gravity also increases. Additional velocity causes the flow to carry farther down the screen and increases the length of screen required. When the screen is horizontal or sloping upward, the flow moving along the screen surface decelerates. In addition, for upward sloping screens a component of the flow velocity is normal to the screen surface. Both the normal velocity component (which indicates flow impact on the screen surface) and the flow deceleration would reduce the required screen length. It can also be noted that if the screen slope is held constant and the discharge is allowed to increase, a longer screen surface is required to pass a larger flow. One other point might be noted when observing these two initial sets of data: The performance of the two types of screen is quite different. In most cases the 40-mesh screen requires less length than the 80-mesh screen to pass a given discharge. Also, the length of screen required at a given screen slope appears more variable with respect to unit discharge for the 40-mesh screen.

At this point, consideration was given to having the flow drop from the crest of the weir to the screen surface. This arrangement was considered desirable for two reasons. First, this drop would increase the velocity of the flow as it impinged on the screen surface. The drop would also result in a more direct impact on the screen. The combination of a more direct impact and a higher impact velocity would result in a significant increase in impact head. It was thought that this head, when combined with the weight of the water, would increase the flow rate through the screen.

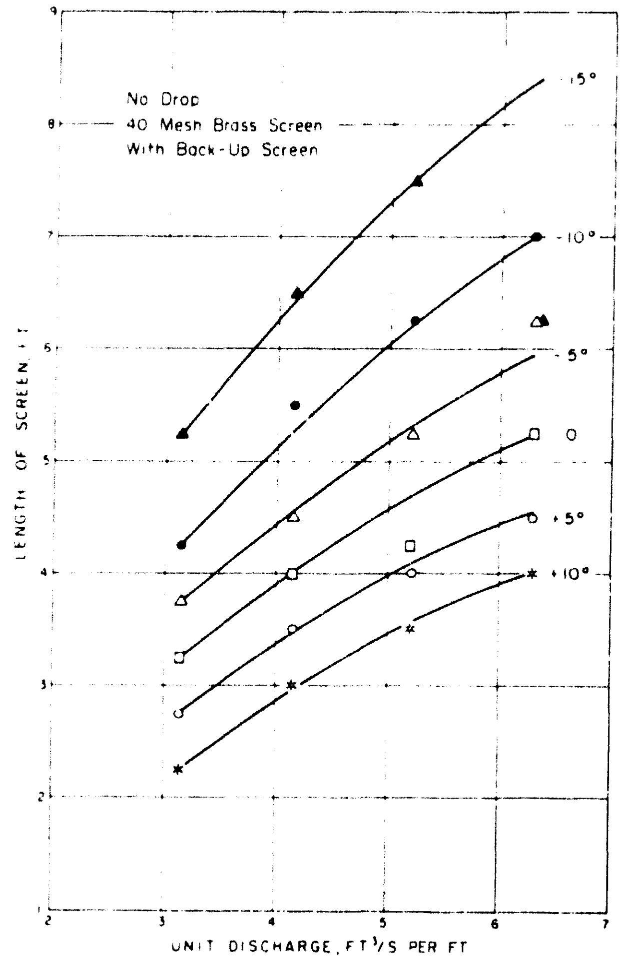

Figure 4. Design curves.

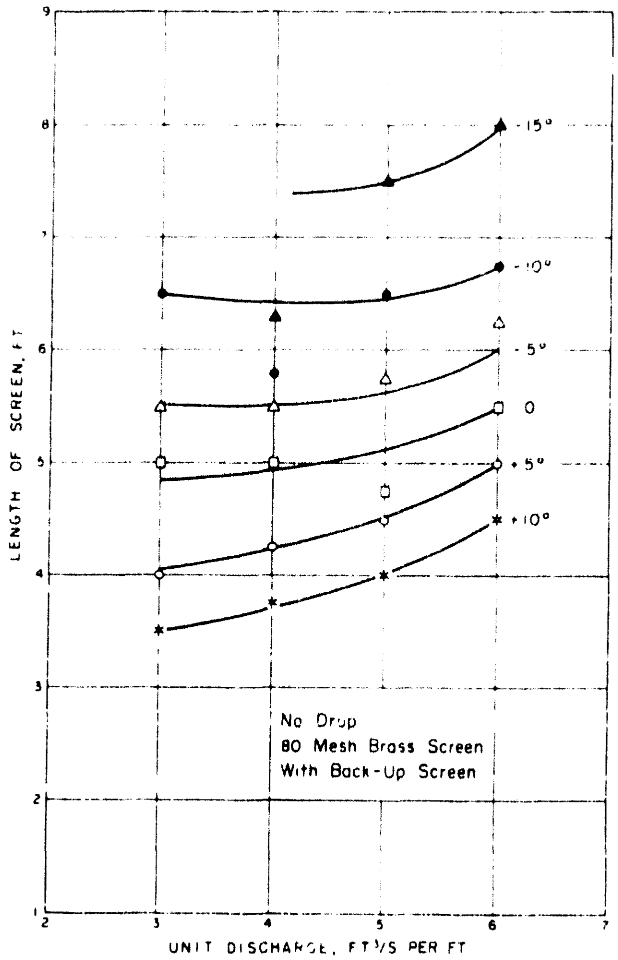

Figure 5. Design curves.

The greater flow rate would reduce the screen length required. The drop was also considered desirable because it would impart a trajectory on the flow so the flow would not come into contact with the upper edge of the screen (where the screen ties into the weir wall). This would allow greater simplification of the seal design at the upper edge. The drop would also result in additional forces on the screen structure, which could either require a stronger and more expensive structure, or shorten the life of the screen and, therefore, increase operation and maintenance costs. After consultation with the designers, it was concluded that a drop of from 3 to 6 inches (7.6 to 15.2 cm) would be most satisfactory. A drop of this size would create the flow features desired and yet would not place excessive forces on the screen structure. A drop of 6 inches (15.2 cm) was incorporated in the model (fig. 6). A test similar to those previously described was made, the results of which [for the 40-mesh brass screen with 0.010-inch (0.25-mm) diameter wire] are shown in figure 7 In comparing these results to those in figure 4, it can be observed that the 6-inch (15.2-cm) drop in all cases caused the required screen length to be longer. Observations of the model operating indicated that the flow would strike the screen and a portion of the flow would then be deflected down the screen surface. This had been observed for all previous operating conditions of the model, but with the 6-inch (15.2 cm) drop, the deflected flow had a higher velocity and, therefore, traveled farther down the screen before it dropped through. It may be that the higher impact pressure resulting from the drop caused a larger portion of the flow to pass through the impact zone of the screen, but the deflected flow definitely carried farther down the screen surface. It was concluded that the drop did not improve performance of the structure. However, because of the upper seal design, a drop from the weir crest to the screen was still considered desirable. Therefore, a 3-inch (7.6-cm) drop, the minimum considered feasible, was placed in the model. Again hydraulic tests were run, the results of which are shown in figure 8. By comparing figure 8 [the 40-mesh

Figure 6. Drop from weir crest to screen. Photo P769-D-76123

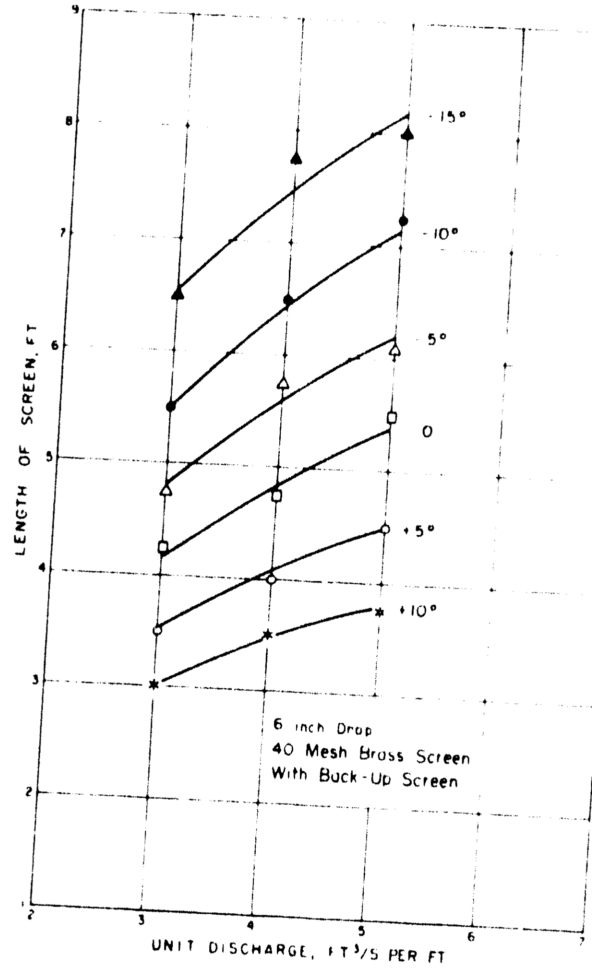

Figure 7. Design curves.

brass screen with 0.010-inch (0.25-mm) wire] with figure 4, it can be observed that the 3-inch (7.6-cm) drop required the screen length to be longer, although the additional length was small. The 3-inch (7.6-cm) drop was, therefore, considered satisfactory.

To evaluate the effect of the wire size, 40-mesh screens with 0.006-inch (0.15-mm) diameter wire were placed in the model with a 3-inch (7.6-cm) drop from the weir crest to the screen surface. The resulting design curves are shown in figure 9. By comparing figure 9 with figure 8, it can be seen that the smaller wire size reduced the required screen length by at least 20 percent for all cases and in some cases the reduction was as high as 30 percent. The change in wire size resulted in approximately a 60 percent increase in the opening area of the screen.

Two other hydraulic factors were considered during the model studies. First, because of the way that the model was constructed, there was concern that the region between the two screens was not adequately vented. The turbulent flow passing between the two screens would entrain large quantities of air. If the region was not properly vented, a negative pressure could develop which would put an additional structural load on the screens as well as increase the flow rate through the screens and, therefore, reduce the observed required screen lengths and increase clogging. In the model the two screens (top screen and backup screen) were mounted in a box with solid walls. The box wall facing the weir wall was set at a 45° angle with respect to the screen surfaces to allow changing the slope of the screen (fig. 3). This wall restricted the airflow to the underside of the jet; thus, any venting of the flow between the two screens was by air passing through the screens themselves. However, large portions of these screen surfaces were often sealed by water passing over them. The model arrangement probably allowed less venting than would exist in the prototype. To evaluate the significance of the venting and to determine the upper limit on the required screen length (the screen length required when venting is complete), tests were run with the lower screen removed and with holes drilled in the wall of the screen box that faces the weir wall. This provided a vented condition equal to or better than that of the prototype. Observations

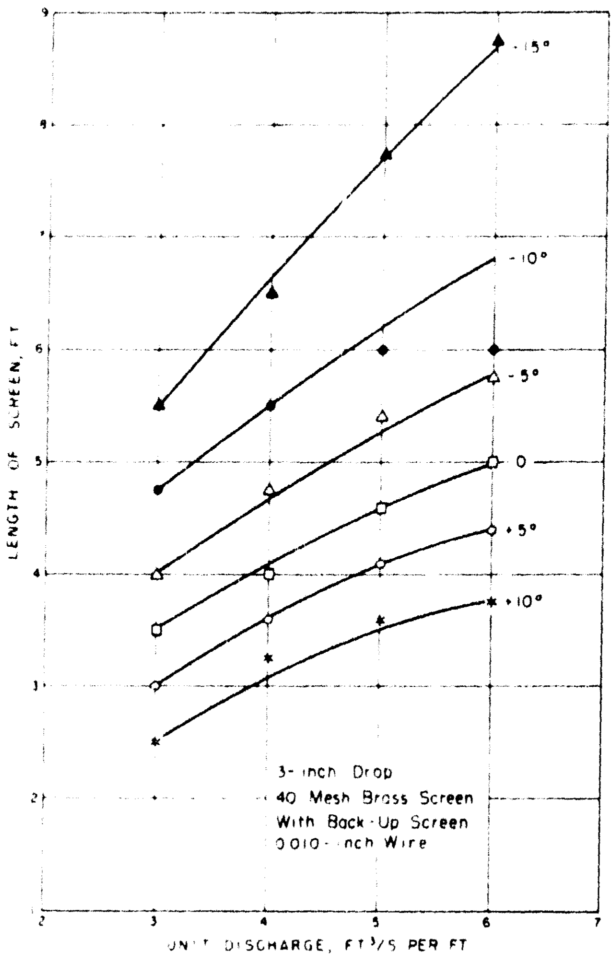

Figure 8. Design curves.

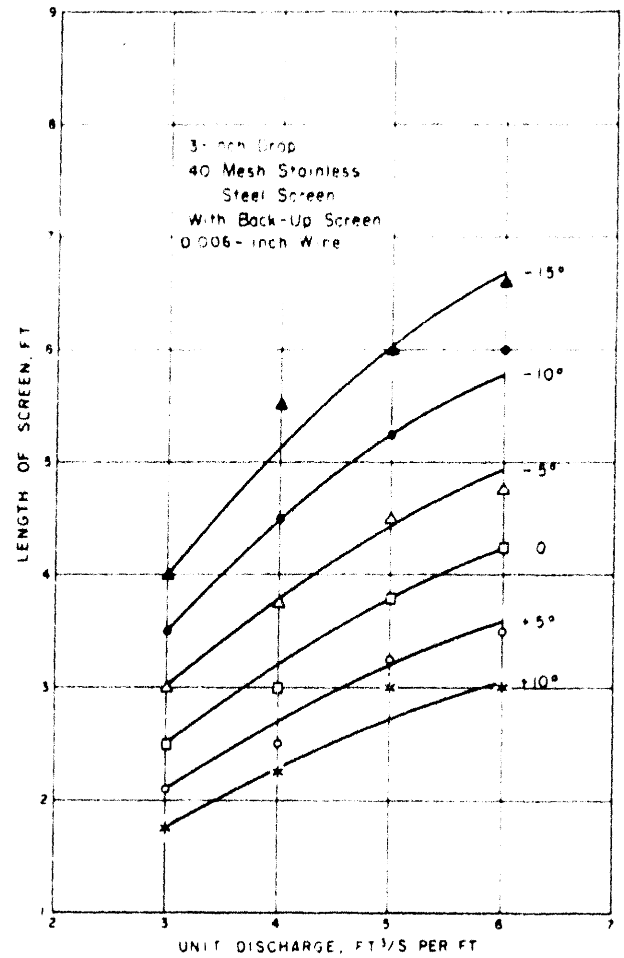

Figure 9. Design curves.

indicated that these conditions resulted in full venting of the flow. Hydraulic tests were run, the results of which are shown in figure 10. By comparing these results with those in figure 8 (same top screen and flow conditions but without the additional venting), it can be seen that the well-vented condition requires significantly more screen length. The actual prototype screen length required is probably somewhere between the length shown in figure 8 and the length shown in figure 10. The screen length in figure 10 may be slightly longer than is actually required, but it is best to allow enough screen surface to pass the maximum flow. Attempts to evaluate the negative pressure between the screens in the unvented model were inconclusive, but did indicate that the negative pressure was small.

One other observation should be noted. Under many of the test conditions observed, the flow on or through the screen made a whistling noise. The noise varied in pitch and intensity with changes in the screen slope and unit discharge and occurred in both the vented and unvented models. The cause of the whistle was never completely determined even though a considerable amount of time was spent in trying to resolve it. Because of the high frequency of the whistle, it seemed unlikely that physical vibration of the screen was the cause. The sound was more like air being drawn into a negative pressure region to aerate a flow, but, as previously stated, even the highly vented model whistled. The whistle may have resulted from aeration of the flow passing through the individual orifices or openings in the screen. The prototype structure may also whistle, but the whistling, although distracting, does not represent a force that could damage the structure or hinder its operation.

A final hydraulic factor studied was the effect that a skimmer weir, placed upstream from the overflow weir, would have on the screen's performance. The skimmer weir studied extended 2.25 feet (0.69 m) below the crest of the overflow weir and was located 4 feet (1.2

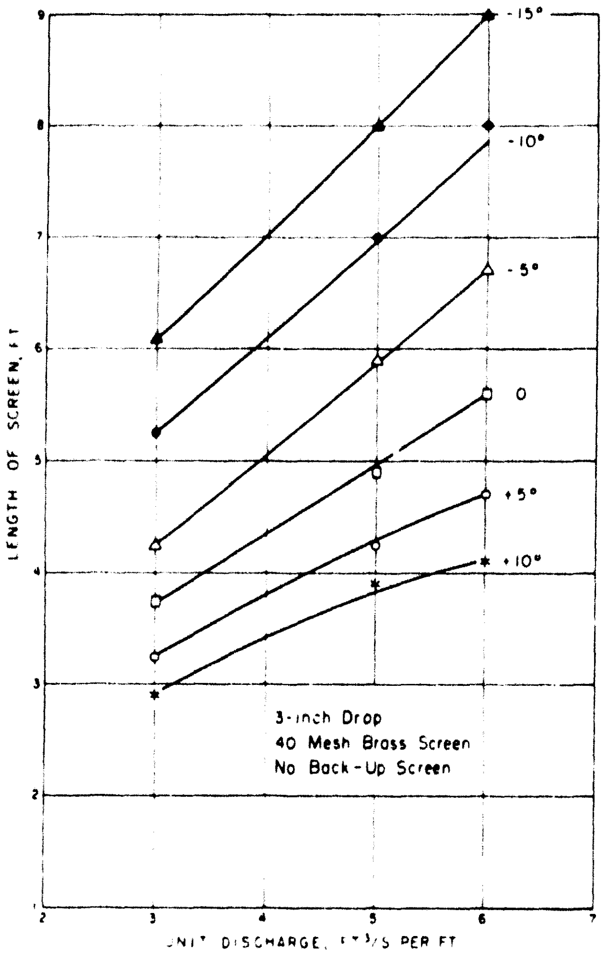

Figure 10. Design curves.

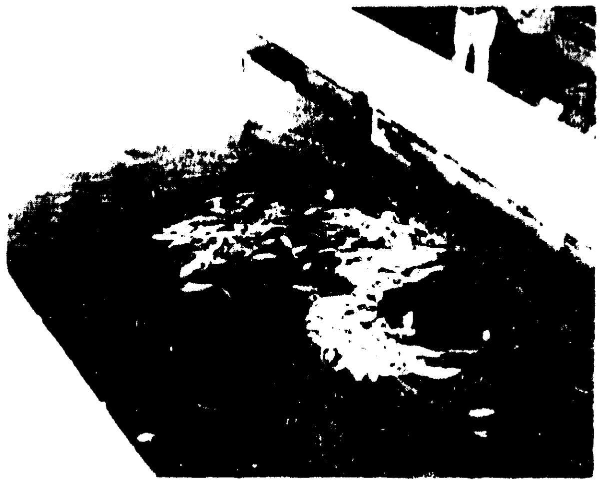

Figure 11. Skimmer weir in operation. Photo P769-D-76121

m) upstream from the weir wall. It was thought that the skimmer weir would intercept large quantities of floating debris and guide it to a point where it could be removed mechanically which would reduce the need for self-cleaning. With the skimmer weir in place, tests were again run to relate the screen slope, screen length, and unit discharge. The skimmer weir had no effect on the hydraulic characteristics of the structure and was only partially effective in retaining debris. It effectively intercepted high floating material such as wood and woody aquatic plants (fig. 11). However, materials having densities near that of water (algae, water-logged materials, etc.) were drawn under the skimmer weir. A weir that extended to a deeper level below the overflow weir crest might be more effective in retaining this type of debris, but it is unlikely that any such structure would be 100 percent effective. Therefore, the skimmer weir was not included in the final design.

Following each hydraulic test, studies were made to determine how effectively the different structures (operating under various conditions) would self-clean. In these studies, soaked dry leaves, soaked paper, and soaked sawdust, along with wood, algae, and other aquatic plants, were allowed to flow onto the screen. These materials represented the many types of debris that might possibly clog the screen. The high-floating materials (wood and woody plants) posed no problem because they were always washed clear by the flow. Materials with densities near that of water were most likely to clog. In general, the findings indicated that the screen most effectively self-cleaned when the direction of the flow was nearly parallel to the screen surface. The worst clogging occurred in areas where the jet impinged on the screen surface. The reason for this is quite clear. No debris was ever observed entangled in the screen's fabric. All the clogging that was noted consisted of debris held to the screen surface by the weight and force of the water. In the areas where the flow impinges on the screen surface, both the weight of the water and the impact head resulting from the impingment hold the debris to the screen (fig. 12). In the areas where the flow is passing nearly parallel to the screen, the flow can get under any debris that might come in contact with the screen and push it clear. The result was that the screens tended to clog in the immediate area where the jet first impinged. The remainder of the screen surface remained quite clear (fig. 12).

Upward sloping screens clog more than downward sloping screens. In a few instances, 5° and 10° upward sloping screens were completely clogged. The conclusion was that this occurred because the flow on the upward sloping screen passed more directly through the screen. It did not flow as fast or as far down the screen surface as did the flow on the

Photo P769-D-76124

Photo P769-D-76125

Photo P769-D-76126

Figure 12. Final screen with algae.

downward sloping screen and, thus, the flow was more inclined to hold debris on the screen surface and not wash it clear. The flows on the downward sloping screens generally had higher velocities and were more nearly parallel to the screen surface. Thus, the upward sloping screens required much shorter flow lengths, but they also clogged much faster than the downward sloping screens.

The next step in the study was the selection of a final screen configuration and unit discharge. The designers chose the structure size and configuration shown in figure 2 as being the most desirable. This screen structure is capable of passing a unit discharge of 6 ft^3/s (0.17 m^3/s). A unit discharge of 6 ft^3/s results in a required weir crest length of 325 feet (99.1 m). The screen length (in the direction of flow) of 6.5 feet (1.98 m) was considered small enough to allow simplified support. In the model study, the 5^0 downward slope created good self-cleaning flow conditions on the screen surface. In all aspects, the structure was considered operationally satisfactory. Likewise, the overall size and cost of the prototype structure were considered minimal.

To verify this final design, another series of hydraulic tests was run with the backup screen removed. During these tests, full venting of the flow occurred. The resulting observed screen lengths should be conservative. A 40-mesh, stainless steel screen with 0.006-inch (0.15-m) diameter wire was used. This corresponds closely to the wire size and mesh of the screen being considered for the prototype. The screen being considered for the prototype would, however, be constructed of a material having a high copper content. Copper, being an algaecide, should prevent algae growth on the screen. Screen made of high copper alloy was not immediately available, so the stainless steel was used in the model. The results of the test are shown in figure 13. The screen operating at a 5^0 downward slope and at a unit discharge of 6 ft^3/s (0.17 m^3/s) required a screen length of 5.2 feet (1.6 m).

With the completion of the hydraulic tests, a large amount of algae was allowed to wash onto the screen. Figure 12 shows the resulting clogging. As can be seen, some algae clogged the screen at its upper end where the flow first impinges, but most of the algae was washed to the point where the last of the flow dropped

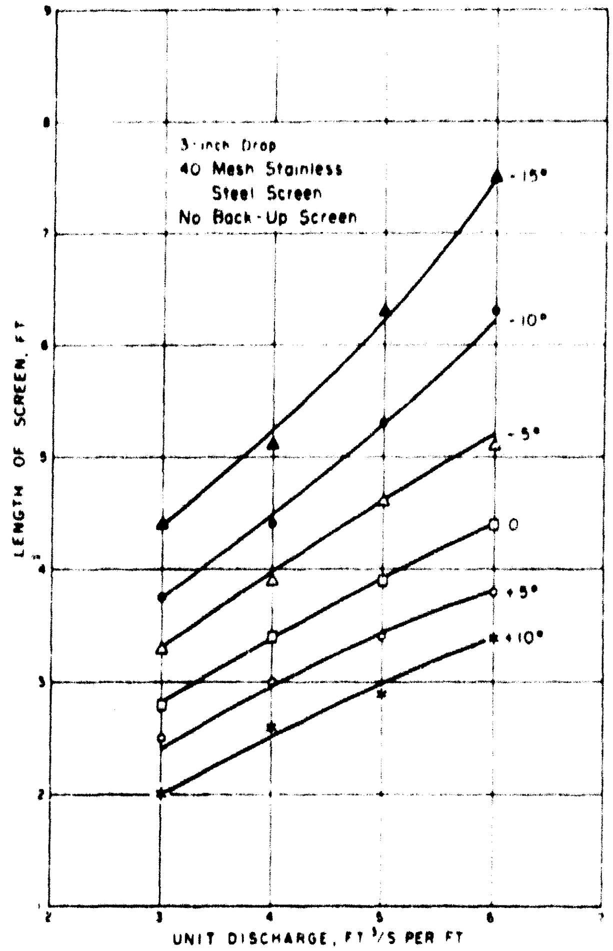

Figure 13. Design curves.

through. The self-cleaning properties of this final screen were, therefore, considered satisfactory. It was hoped that real fish eggs of the size expected could be used to test the screen. There was no doubt that the screen would satisfactorily filter out the eggs (the smallest eggs expected are larger than 1 mm in diameter, while the openings in the screen are approximately 0.48 mm square), but the test would show in general how the screen would handle them. However, no eggs could be obtained when the tests were scheduled. Thus, testing of the final screen configuration was considered complete and the screen as shown in figure 12 was determined to be satisfactory.

7-1750 (12-74)
Bureau of Reclamation

CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-72) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, it gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg, that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
LENGTH		
Mil	25.4 (exactly)	Micron (μ)
Inches (in)	25.4 (exactly)	Millimeters (mm)
Inches	2.54 (exactly)*	Centimeters (cm)
Feet (ft)	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters (m)
Feet	0.0003048 (exactly)*	Kilometers (km)
Yards (yd)	0.9144 (exactly)	Meters (m)
Miles (statute) (mi)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers (km)
AREA		
Square inches (in^2)	6.4516 (exactly)	Square centimeters (cm^2)
Square feet (ft^2)	*929.03	Square centimeters
Square feet	0.092903	Square meters (m^2)
Square yards (yd^2)	0.836127	Square meters
Acres	*0.40469	Hectares (ha)
Acres	*4,046.9	Square meters (m^2)
Acres	*0.0040469	Square kilometers (km^2)
Square miles (mi^2)	2.58999	Square kilometers
VOLUME		
Cubic inches (in^3)	16.3871	Cubic centimeters (cm^3)
Cubic feet (ft^3)	0.0283168	Cubic meters (m^3)
Cubic yards (yd^3)	0.764555	Cubic meters (m^3)
CAPACITY		
Fluid ounces (U.S.) (oz)	29.5737	Cubic centimeters (cm^3)
Fluid ounces (U.S.)	29.5729	Milliliters (ml)
Liquid pints (U.S.) (pt)	0.473179	Cubic decimeters (dm^3)
Liquid pints (U.S.)	0.473166	Liters (l)
Quarts (U.S.) (qt)	*946.358	Cubic centimeters (cm^3)
Quarts (U.S.)	*0.946331	Liters (l)
Gallons (U.S.) (gal)	*3,785.43	Cubic centimeters (cm^3)
Gallons (U.S.)	3.78543	Cubic decimeters (dm^3)
Gallons (U.S.)	3.78533	Liters (l)
Gallons (U.S.)	*0.00378543	Cubic meters (m^3)
Gallons (U.K.)	4.54609	Cubic decimeters (dm^3)
Gallons (U.K.)	4.54596	Liters (l)
Cubic feet (ft^3)	28.3160	Liters
Cubic yards (yd^3)	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters (m^3)
Acre-feet	*1,233,500	Liters

Table I

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb avdp)	64.79891 (exactly)	Milligrams (mg)
Troy ounces (480 grains)	31.1035	Grams (g)
Ounces (avdp) (oz)	28.3495	Grams
Pounds (avdp) (lb)	0.45359237 (exactly)	Kilograms (kg)
Short tons (2,000 lb)	907.185	Kilograms
Short tons (2,000 lb)	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms (kg)
FORCE/AREA		
Pounds per square inch (psi)*	0.070307	Kilograms per square centimeter (kg/cm²)
Pounds per square inch	6894.76	Pascals (Pa) or Newtons per square meter (N/m²)
Pounds per square foot (lb/ft²)	4.88243	Kilograms per square meter (kg/m²)
Pounds per square foot	47.8803	Pascals (Pa) or Newtons per square meter (N/m²)
MASS/VOLUME (DENSITY)		
Ounces per cubic inch (oz/in³)	1.72999	Grams per cubic centimeter (g/cm³)
Pounds per cubic foot (lb/ft³)	16.0185	Kilograms per cubic meter (kg/m³)
Pounds per cubic foot	0.0160185	Grams per cubic centimeter (g/cm³)
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.) (oz/gal)	7.4893	Grams per liter (g/l)
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.) (lb/gal)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch pounds (in-lb)	0.011521	Meter kilograms (m-kg)
Inch pounds	1.12985×10^6	Centimeter dynes (cm-dyn)
Foot pounds (ft-lb)	0.138255	Meter kilograms (m-kg)
Foot pounds	1.35582×10^7	Centimeter dynes
Foot pounds per inch (ft-lb/in)	5.4431	Centimeter kilograms per centimeter (cm-kg/cm)
Ounce inches (oz-in)	72.008	Gram centimeters (g-cm)
VELOCITY		
Feet per second (ft/s)	30.48 (exactly)	Centimeters per second (cm/s)
Feet per second	0.3048 (exactly)*	Meters per second (m/s)
Feet per year (ft/yr)	0.965873×10^{-6}	Centimeters per second
Miles per hour (mi/h)	1.609344 (exactly)	Kilometers per hour (km/h)
Miles per hour	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second² (ft/s²)	*0.3048	Meters per second² (m/s²)
FLOW		
Cubic feet per second (second-feet) (ft³/s)	*0.028317	Cubic meters per second (m³/s)
Cubic feet per minute (ft³/min)	0.4719	Liters per second (l/s)
Gallons (U.S.) per minute (gal/min)	0.06309	Liters per second
FORCE*		
Pounds (lb)	*0.453592	Kilograms (kg)
Pounds	*4.4482	Newtons (N)
Pounds	$*4.4482 \times 10^5$	Dynes (dyn)

Table I—Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram calories (kg-cal)
British thermal units (Btu)	1,055.06	Joules (J)
Btu per pound	2.326 (exactly)	Joules per gram (J/g)
Foot pounds (ft-lb)	*1.35582	Joules
POWER		
Horsepower (hp)	745.700	Watts (W)
Btu per hour (Btu/hr)	0.293071	Watts
Foot pounds per second (ft-lb/s)	1.35582	Watts
HEAT TRANSFER		
Btu in/hr ft² degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in/hr ft² degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft² degree F	*1.4880	Kg cal m/hr m² degree C
Btu/hr ft² degree F (C, thermal conductance)	0.568	Milliwatts/cm² degree C
Btu/hr ft² degree F (C, thermal conductance)	4.882	Kg cal/hr m² degree C
Degree F hr ft²/Btu (R, thermal resistance)	1.761	Degree C cm²/milliwatt
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	*1.000	Cal/gram degree C
Ft²/hr (thermal diffusivity)	0.2581	cm²/s
Ft²/hr (thermal diffusivity)	*0.09290	m²/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft² (water vapor transmission)	16.7	Grams/24 hr m²
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	*304.8	Liters per square meter per day
Pound seconds per square foot (viscosity)	*4.8824	Kilogram second per square meter
Square feet per second (viscosity)	*0.092903	Square meters per second
Fahrenheit degrees (change)*	5/9 (then subtract 17.78)	Celsius or Kelvin degrees (change)
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	*35.3147	Millicuries per cubic meter
Milliamps per square foot	*10.7639	Milliamps per square meter
Gallons per square yard	*4.527219	Liters per square meter
Pounds per inch	*0.17858	Kilograms per centimeter

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