Executive Summary and Policy Directions 1

The focus of this report is technologies for fish passage around hydropower generation facilities and protection against entrainment and turbine mortality. Emphasis is given to Federal Energy Regulatory Commission (FERC)-licensed hydropower projects where fish protection is a subject of controversy and congressional interest due to the Federal Power Act (FPA) and the Electric Consumers Protection Act (ECPA). Thus institutional issues related to FERC-relicensing are also discussed. (Major points of controversy are highlighted in box 1-1.) Federal hydropower projects, especially in the Columbia River Basin, and irrigation water diversions in the Pacific Northwest and California are included to the extent that they provide information on fish passage technologies (see table 1-1). Many of the technologies discussed are applicable to other types of dams and water diversions. In fact, there are many more obstructions to fish passage that are not covered by FERC-licensing requirements, than are (approximately 76,000 dams versus 1,825 FERC-licensed facilities) (70).

Fish passage is considered necessary where a dam separates a target species from needed habitat. Fish are generally unable to pass upstream of a hydropower dam unless some fish passage facility is present. Downstream passage facilities may not always be necessary if the fish can safely pass through turbines, spillways, or sluiceways, though there is significant debate about the adequacy of these latter two passage methods. [1]

Decisions about the need for fish protection measures at dams are often based on the perceived or measured impacts on one or more species at the site (242). Fish populations may be adversely affected by hydropower facilities and many other activities and facilities (e.g., multiple use, flood control, and water supply dams; land use practices like grazing and forestry; and facilities like coal-fired power plants that cause acid rain). Migrations and other important fish movements can be blocked or delayed. The quantity, quality, and accessibility of up- and downstream fish habitat, which can play an important role in population sustainability, can be affected. Fish that pass through power generating turbines can be injured or killed. Increased predation on migratory fishes has also been indirectly linked to hydropower dams (e.g., due to migration delays, fish being concentrated in one place, or increased habitat for predatory species). Habitat

[1] Spillways are used to pass water over a dam. Sluiceways are used to pass debris, ice, logs, etc.

BOX 1-1: Fish Passage At FERC-Licensed Hydropower Facilities: Controversial Issues

This study was initiated because of significant controversy about technical issues related to fish passage and the relicensing of a large number of hydropower facilities, beginning in 1993 and continuing through 2010. Major controversial issues that are discussed in this study are listed below:

Discussed in Chapters 1–4:

- Do riverine fish need passage? (chapter 2)
- Do riverine fish need protection from entrainment? (chapter 2)
- Is experimentation with alternative behavioral technologies warranted? (chapters 1 and 4)

Discussed in Chapter 5:

- Is FERC's balancing of developmental and nondevelopmental values adequate?
- How should the baseline goal for mitigation be defined?
- How timely is the licensing process?
- How well are license reopeners implemented?
- Should dams be decommissioned and/or removed?

SOURCE: Office of Technology Assessment, 1995.

TABLE 1-1. Columbia River Basin: Downstream Fish Passage Methods And Research

Downstream passage technique	Status	Stakeholder views		Effectiveness
		Resource agencies	Hydro industry	
TRANSPORTATION				
Barging	Conventional	Mixed	Accepted	Good
Trucking	Conventional	Mixed	Accepted	Good
SCREENS (low-velocity)				
STS	Conventional	Mixed	Contentious	Good
Vertical traveling	Conventional	Accepted	Accepted	Good
Rotating drum	Conventional	Accepted	Accepted	Good
SCREENS (high-velocity)				
Eicher screen	Experimental	Mixed	Mixed	Very Good
MIS	Experimental	Mixed	Mixed	Very Good
ALTERNATIVE BEHAVIORAL DEVICES				
Acoustics (sound)	Experimental	Hopeful	Hopeful	Unknown
Surface collector	Experimental	Hopeful	Hopeful	Unknown
OTHER METHODS				
Turbine passage	Conventional	Contentious	Accepted	Fair
Spilling	Experimental	Contentious	Accepted	Good

NOTE: Many of the downstream passage technologies and devices discussed in this report are being experimented with in the Columbia River Basin. For further discussion of these, see chapter 4. For further discussion of the Columbia River Basin, see appendix A.

SOURCE: Office of Technology Assessment, 1995.

alterations and increased predation pressure caused by hydropower dams are significant issues, but fall beyond the central scope of this report.

This study was initiated because of significant controversy about technical issues related to fish passage and the relicensing of a large number of hydropower facilities, beginning in 1993 and continuing through 2010. Major points of controversy are discussed below.

CONTROVERSIES

The need for fish passage facilities is widely accepted for anadromous fish (i.e., fish that migrate from the ocean to spawn in freshwater) (see box 1-2). Considerable controversy exists between resource agencies and hydropower operators about the passage and protection requirements for riverine fish (i.e., the so-called resident species that spend their entire lives in freshwater) (see chapter 2).

BOX 1-2: Chapter 2 Findings—Fish Passage and Entrainment Protection

- The need for entrainment protection and passage for riverine fish is very controversial. There is a growing body of evidence that some riverine fish make significant movements that could be impeded by some hydropower facilities. The need for passage for riverine fish is most likely species- and site-specific and should be tied to habitat needs for target fish populations. This will be difficult to determine without establishing goals for target species.
- The acceptability of turbine passage for anadromous fish is site-specific and controversial. There is major concern when anadromous fish must pass through multiple dams, creating the potential for significant cumulative impacts. Passage of adult repeat spawners is also a major concern for most Atlantic Coast species.
- The effects of turbine passage on fish depend on the size of the fish; their sensitivity to mechanical contact with equipment and pressure changes; and whether fish happen to be in an area near cavitation or where shearing forces are strong. Smaller fish are more likely to survive turbine passage than larger fish. Survival is generally higher where the turbines are operating with higher efficiency.
- Riverine fish are entrained to some extent at virtually every site tested. Entrainment rates are variable among sites and at a single site. Entrainment rates for different species and sizes of fish change daily and seasonally. Entrainment rates of different turbines at a site can be significant.
- Turbine mortality studies must be interpreted with caution. Studies show a wide range of results, probably related to diversity of turbine designs and operating conditions, river conditions, and fish species and sizes. Turbine mortality study design is likely to affect results. Different methods may yield different results.
- Methods for turbine mortality study include: mark-recapture studies with netting or balloon tags, and observations of net-caught naturally entrained fish, and telemetry. Methods for entrainment studies include: netting, hydroacoustic technology (used especially in the West), and telemetry tagging. These methods have advantages and disadvantages depending on target species and site conditions. Hydroacoustic technology and telemetry tagging can provide fish behavior information (e.g., tracking swimming location) useful for designing passage systems and evaluating performance.
- Early agreement on study design would help minimize controversies between resource agencies and hydropower operators. Lack of reporting of all relevant information makes it difficult to interpret results. Standardized guidelines to determine the need, conduct, and reporting of studies could help overcome this limitation.
- Mitigation by financial compensation is very controversial. The degree of precision necessary for evaluation studies and how fish should be valued are items of debate.

SOURCE: Office of Technology Assessment, 1995.

This controversy over whether riverine fish need safe passage relates to whether or not movement to habitats blocked by a dam have adverse impacts on the population. Although the paradigm is beginning to change, the predominant thinking has been that riverine fishes have restricted movements. This may be true at some sites, but the generalization may in part be an artifact of the movement studies that have been done. Recent research has identified major differences in fish movements among different species of riverine fish and there are some studies that document different movements of the same species in different watersheds. The need for mitigation to provide passage for riverine fishes is most likely site- and species-specific and should be tied to the specific habitat needs for target fish populations in a given river reach.

The controversy over whether riverine fish need protection from entrainment is largely unrelated to issues about passage requirements (see chapter 2). The controversy centers on the lack of information on the impact of entrainment on the overall fish population. Population impact studies would be exceedingly complex, time consuming and costly, and are rarely, if ever, done (146). The hydropower industry and resource agencies take very different positions about the need for entrainment protection, given the lack of good site-specific information. Industry generally says that entrainment protection is not necessary for riverine fish. Resource agencies consider entrainment a chronic loss of fish that requires mitigation, or at least compensation. As a result of this controversy, entrainment and turbine mortality studies are frequently done. These studies also have limitations.

The National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (FWS), referred to throughout this report as federal resource agencies, have the authority to prescribe mandatory fish passage mitigation under section 18 of the Federal Power Act, as amended (FPA). These agencies, along with their state counterparts, may also make additional recommendations to protect, mitigate, and enhance fish and wildlife affected by hydropower development under section 10(j) of the FPA. The decision to include section 10(j) recommendations in a hydropower license order rests with the Federal Energy Regulatory Commission. FERC is required to balance developmental and nondevelopmental values of hydropower development in the licensing process. This requires an evaluation of the need for (i.e., benefits) and costs of recommended mitigation compared to the benefits of the hydropower project; such evaluations have many limitations.

Apart from the controversies about the need for fish passage and protection, there are issues about the technologies (boxes 1-3 and 1-4). For upstream technologies, the issues relate to proper design, operation and maintenance, understanding fish behavior, and the need to develop technologies for additional species (see chapter 3). These upstream technology issues are not particularly controversial.

For downstream technologies, the primary controversy is the value of investing time and money in alternative behavioral technologies, especially for conditions where conventional methods with high levels of effectiveness are possible. This issue is highly controversial and complex (see chapter 4). It is not readily explained without an understanding of the technologies for fish passage and the different positions of key stakeholders, including:

- resource agencies with responsibilities for protection of fish species, many of which are in serious decline;
- hydropower operators with the mission of providing a renewable form of electricity without the emissions and adverse environmental effects associated with alternative generation methods; many operators are seriously concerned about their viability in anticipated deregulated markets; and
- developers of new technologies who are convinced they have viable approaches to fish passage and protection that will cost much less than conventional methods.

Resource agencies take the position that conventional downstream passage technologies should be installed because the alternative meth-

BOX 1-3: Chapter 3 Findings—Upstream Technologies

- There is no single solution for designing upstream fish passageways. Effective fish passage design for a specific site requires good communication between engineers and biologists and thorough understanding of site characteristics.
- Technologies for upstream passage are considered well-developed and understood for particular species.
- Upstream passage failure tends to result from less-than-optimal design criteria based on physical, hydrologic, and behavioral information or from a lack of adequate attention to operation and maintenance of facilities.

SOURCE: Office of Technology Assessment, 1995.

BOX 1-4: Chapter 4 Findings—Downstream Technologies

- There is no single solution for designing downstream fish passage. Effective fish passage design for a specific site requires good communication between engineers and biologists and thorough understanding of site characteristics.
- Physical barrier screens are often the only resource agency-approved technology to protect fish from turbine intake channels, yet the screens are perceived to be very expensive.
- The ultimate goal of 100 percent passage effectiveness is most likely to be achieved with the use of physical barrier technologies; however, site, technological, and biological constraints to passing fish around or through hydropower projects may limit performance.
- Structural guidance devices have been shown to have a high level of performance at a few studied sites in the Northeast. The mechanism by which they work is not well understood.
- Alternative behavioral guidance devices have potential to elicit avoidance responses from some species of fish. However, it has not yet been demonstrated that these responses can be directed reliably; behavioral guidance techniques are site- and species-specific; and it appears unlikely that behavioral methods will perform as well as conventional barriers over a range of hydraulic conditions and for a variety of species.

SOURCE: Office of Technology Assessment, 1995.

ods are unproven, will likely remain highly site specific, and may never provide the levels of protection of well-designed and operated conventional measures under the wide range of conditions present at a site. On the other hand, hydropower operators and promoters of new technologies want the opportunity to find lower cost solutions to fish protection.

Hydropower licensing is a highly controversial issue among the many stakeholders involved in the process (see box 1-5). State and federal resource agencies, the hydropower industry, special interest groups (e.g., environmental), Native American tribes, individual owner/operators, and the public at large are all involved. Balancing all of these competing interests in licensing is a complex process, generating much dispute among the participants. Key areas of controversy include: adequacy of FERC's balancing of developmental and nondevelopmental values; defining the baseline goal for mitigation; timeliness of the licensing process; license reopeners; and dam decommissioning and/or removal (see chapter 5).

OTA does not resolve these controversies in this report. OTA does, however, discuss the issues underlying these controversies and the context in which they have developed. This chapter continues with policy directions, a summary of technologies, and overall conclusions related to technologies and hydropower licensing.

BOX 1-5: Chapter 5 Findings—Federal Role

- The Federal Energy Regulatory Commission (FERC) has exclusive authority to license nonfederal hydroelectric facilities on navigable waterways and federal lands, which includes conditioning of licenses to require operators' adoption of fish protection measures.
- Section 18 of the Federal Power Act gives the federal resource agencies authority to prescribe mandatory fish passage conditions to be included in FERC license orders. Section 10(j) recommendations relate to additional mitigation for rehabilitating damages resulting from hydropower development or to address broader fish and wildlife needs (e.g., minimum flow requirements). Yet, these recommendations are subject to FERC approval.
- FERC's hydroelectric licensing process has been criticized as lengthy and can be costly for applicants and participating government agencies. In some cases, the cost of implementing fish protection mitigations from the utility perspective may render a project uneconomical.
- FERC uses benefit-cost analyses in its final hydroelectric licensing decisions; yet economic methods for valuing habitat or natural resources are not well established and many economists feel that they fit poorly in traditional benefit-cost analysis.
- There is no comprehensive system for monitoring and enforcing resource agency fish passage prescriptions. FERC's monitoring and enforcement authority has been used infrequently, and only recently, to fulfill its mandate 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 hydroelectric projects.
- Parties must perceive a need to negotiate in the FERC hydropower licensing process, beyond the regulatory requirements of applicants and agencies, in order to achieve success. FERC must be seen as a neutral party to motivate participants to find mutually acceptable agreements in accommodating the need for power production and resource protection. If FERC is perceived to favor certain interests, the need to negotiate is diminished or eliminated.
- There are no clearly defined overall goals for North American fishery management, and Congress has not clearly articulated goals for management of fishery resources and/or priorities for resource allocation.
- Fish protection and hydropower licensing issues return repeatedly to the congressional agenda. The 1920 Federal Power Act (FPA) was designed to eliminate controversy between private hydropower developers and conservation groups opposed to unregulated use of the nation's waterways. Greater consideration of fisheries and other "nondevelopmental" values was called for in the Electric Consumers Protection Act of 1986 (ECPA) and oversight on these issues continued with the passage of the Energy Policy Act of 1992. In the 104th Congress, efforts continue to address power production (e.g., sale of PMA's; BPA debt restructuring) and developing sustainable fisheries (e.g., Magnuson Act Amendments; Striped Bass Conservation Act).

SOURCE: Office of Technology Assessment, 1995.

POLICY DIRECTIONS

Three key areas exist for policy improvements: establishing sustainable fisheries, improving performance of fish passage technologies, and advancing fish passage and protection technologies.

First, to establish and maintain sustainable fisheries, goals for protection and restoration of fish resources need to be clarified and strengthened through policy shifts and additional research. Congress could give FERC responsibility to sustain fish populations through legislative language similar to that used in the Central Valley Improvement Act (title 34 of the Reclamation Projects Authorization and Adjustment Act, PL 102-575), which elevates the importance of fish and wildlife protection in Central Valley Project management. Congress could direct FERC to expand river-wide planning and cumulative analysis in the hydropower relicensing process by synchronizing license terms on river basins. Additional research would be needed on the effects of obstructions and habitat alterations on fish populations.

Second, mechanisms to ensure the good design, construction, and operation and maintenance of all fish passage technologies are needed. Improved coordination is needed among fishway design engineers, and fisheries biologists, and hydropower operators, especially during the design and construction phases. Also, institutional mechanisms must be improved for adequate oversight, commitment, and enforcement of fishway operations and maintenance activities. An increased emphasis on monitoring and evaluation of fish passage performance could provide useful feedback information on the performance of technologies that could be used to make improvements.

Third, new initiatives are needed to advance fish passage technologies, especially for safe downstream passage. This area, the focus of this report, was addressed in an OTA-sponsored workshop, and is discussed in detail below.

Advancing Fish Passage Technologies

For the successful development of new fish passage technologies, there is a critical need for good science and independent evaluation of technologies. This is essential for experiments that are currently underway, future site-specific studies, and for any efforts to create more systematic and comprehensive research programs in the long term. A sound scientific approach to developing, executing, and evaluating a field study is critical to the successful advancement of fish passage technologies. The elements of a good test include the establishment of clear objectives, agreement amongst all parties on the study design including quantifiable standards of acceptability that are measurable in the studies, and a protocol that lends itself to repeatability. Studies should be designed by an interdisciplinary team including not only those knowledgeable about fisheries, hydrology, hydraulics, and hydropower operations, but also biologists knowledgeable about fish behavior and sensory response. In addition, there must be a proper accounting of environmental variability and documentation of underlying assumptions. Studies should span multiple seasons in order to collect adequate data and include appropriate statistical evaluation. Regular communication among stakeholders should occur throughout the study process. Evaluative reports on the work should be peer reviewed by credible professionals with no vested interest in the results, and then published. Agreement on performance criteria and standards prior to study will facilitate acceptance of data and recommendations (210). An effort to systematically evaluate the potential for acoustic technologies is underway in the Columbia River Basin. This may serve as a useful model for systematic research. However, a mechanism to transfer results and expand investigations to fish guidance problems in other parts of the country is needed (see box 1-6).

If Congress decides that a coordinated effort to advance fish passage technology is desired, a technology certification organization could be established that would provide unbiased data.

BOX 1-6: Columbia River Acoustic Program—A Model For Systematic Research

The U.S. Army Corps of Engineers and Department of Energy initiated a program to develop acoustic technologies to improve fish passage in the Columbia River Basin at the end of 1994 (165). This multi-year program provides a systematic guide for evaluating existing technologies; conducting needed research that prevents immediate application of acoustic methods; developing prototype systems; and evaluating their feasibility and potential effectiveness. It also demonstrates field performance of sound-based fish behavior modification systems under normal operating conditions for extended time periods. Specific research areas include: sound characterization, fish hearing characterization, target behavior stimulus identification, fish behavioral models, target behavior stimulus delivery, behavioral response monitoring and evaluation, assessing predictive tools for sound fields, and evaluating other potential behavioral stimuli. The program is directed at solving problems of downstream fish passage on the Columbia River, including need for increased bypass screen guidance efficiency, enhanced surface collection, increased spill effectiveness, and reduced predation losses. The Columbia River Acoustic Program involves technical reviewers as well as resource agencies, Indian tribes, Bonneville Power Administration, and the Corps of Engineers.

It is not clear how transferable results from these investigations will be for other smaller hydropower sites and water diversions in other parts of the country. Basic research to develop evaluation tools for fish behavior in sound fields, and information on fish hearing capabilities will be useful at other sites. If the background studies resolve uncertainties associated with the use of sound to guide targeted fish, then a similar effort to meet needs of targeted species in other parts of the country should be pursued.

It must be recognized, however, that other fish species in other locations will likely need different behavioral stimuli and delivery systems. Thus not all of the results that emerge from the Columbia River program will be applicable to other settings. However, a mechanism (e.g., a workshop) could be designed to review progress and evaluate transferability of results to other fish guidance problems. A parallel and broader research, development, demonstration, testing, and evaluation program, possibly centered at the Conte Anadromous Fish Laboratory of the National Biological Survey, could be developed to meet the needs for fish guidance at FERC relicensing sites. Additional centers of research may be needed to address other fish populations, such as riverine fish in the Midwest and declining populations in the Central Valley of California.

SOURCE: Office Of Technology Assessment, 1995.

This group would have no proprietary interest in the technology under investigation. It would carry out applied laboratory and field tests of newly developed technologies (as well as conventional technologies) and verify claims of performance and cost. The certifying organization would set the standards for methodology of investigation, would test the system, and would define the conditions under which certain levels of performance could be expected. It could arrange for pilot test locations on federal properties or private sites, and have a mechanism to compensate vendors as appropriate. The organization would not actually approve a technology, but would provide a controlled evaluation of its effectiveness under specific conditions. It would provide data on performance that would be the equivalent of peer reviewed material, thus removing the possibility of the misuse or misinterpretation of data. The work of such a certification organization would be considerably enhanced with the availability of clear standards and expectations for protection of species of fish in different regions.

The certification organization could produce a catalog similar to a physician's desk reference. Information would be provided on conditions where the technology is likely to be useful, counter-indications, possible problems, and performance at other sites. It would evaluate applications of the technology. All technologies to be included in the catalog would need to undergo the same levels of testing.

The certification organization should be adequately and independently funded and free of political pressure. One option might be to have a surcharge placed on all electricity generated through hydropower plants; this would be placed into an escrow account to pay for the operations of the organization and the dissemination of data. Alternatively, a portion of FERC license fees might be diverted to support such an organization. Other sources of funding that could be considered would be a tax on utilities, or the diversion of some public funds or taxes since hydropower sites are often not the only contributors to fishery problems in a watershed. However, one can be certain that any efforts to increase fees on electricity or raise taxes would be strongly resisted.

Congress could give certification responsibility to the National Biological Survey. This may only be feasible if NBS remains as an independent research group and is not reconsolidated with the FWS. (The FWS has a key role in recommending and prescribing fish protection in the FERC-relicensing process, and thus is not considered to be entirely objective in this arena.) This option would take advantage of the unique NBS Conte Anadromous Fish Laboratory. Other research facilities may be needed in other parts of the country.

Alternatively, Congress could create an independent, non-profit fish passage certification organization, modeled as a research and educational foundation. Possible models might be the Electric Power Research Institute (EPRI) or the Rocky Mountain Institute. EPRI knows the power generating industry, issues of concern and the stance of most of the parties involved. Although EPRI is now linked to industry, the new organization would be independent and impartial in its approach. The Rocky Mountain Institute has a broader mandate, crossing boundaries and addressing a number of disciplines. Both organizations provide an indication of the form that such an organization could take.

SUMMARY OF FISH PASSAGE TECHNOLOGIES

This section summarizes fish passage research programs and technologies for upstream and downstream passage. Brief mention is given to new concepts in hydropower generation.

Fish Passage Research Programs

Federal agencies play a pivotal role in water resources management and research and development of fish protection technologies. The National Biological Survey (NBS), Bureau of Reclamation (BuRec), U.S. Army Corps of Engineers (COE), Department of Energy (DOE), and the Bonneville Power Administration (BPA) are key agencies involved in current fish passage and protection research, and development and evaluation of technologies. Research on fish passage technologies under investigation by these federal agencies is summarized in table 1-2.

The need for more research and development in the area of fish passage is great. Federal money for fish passage research is extremely limited and funneled to a few research facilities. Although these centers conduct hydraulic modeling and behavioral analysis and develop their research agenda to generate broadly applicable results, the task is much broader than what they can accomplish alone. Partnerships between the agencies and the private sector show some promise in this respect. For example, Alden Research Laboratory and Northeast Utilities are testing a new weir design at the NBS Conte Anadromous Fish Research Center for application at projects on the Connecticut River and elsewhere.

Many unanswered research questions remain, and the scope and variety are extensive. Despite this, the hydropower industry is becoming increasingly unwilling to provide high levels of financial support for research and development, and many feel that the burden for developing new and improved methods for fish protection should be borne by the resource agencies who

TABLE 1-2: Federal Agency Research on Fish Passage Technologies			
	Upstream	**Downstream**	**Alternative**
Federal Agency	**Conventional and physical barrier technologies**	**Conventional and physical barrier technologies (and other methods)**	**Behavioral guidance devices (and other methods)**
Bonneville Power Administration		Flat plate and rotary drum screens	Surface collector Acoustics
U.S. Bureau of Reclamation		Hydraulic modeling	Archimedes screw pump Hydrostal-volute pump
U.S. Army Corps of Engineers		Advanced turbine design	Surface collector Acoustics
U.S. Department of Energy		Advanced turbine design	
National Biological Survey/ U.S. Fish and Wildlife Service	Denil Steeppass Denil Notching	NU-Alden weir Cabot sampler	

KEY: NU=Northeast Utilities.

SOURCE: Office of Technology Assessment, 1995.

prescribe their implementation. However, the Electric Power Research Institute (EPRI), and the Empire State Electric Energy Research Corporation (ESEERCO), organizations financed by industry contributions, have funded a large part of fish passage research in the field. EPRI has produced numerous publications highlighting experimentation with new and evolving technologies and summarizing performance of more conventional methods. Hydropower operators indicated to OTA that funds for research, including for support of research groups like EPRI, are declining.

Upstream Passage Technologies and Alternative Methods

Upstream passage technologies are in use at 9.5 percent of the 1,825 FERC-licensed hydropower plants (242). The need for upstream passage is well established for anadromous species, whereas the need for upstream passage for riverine species remains controversial.

Upstream passage technologies are considered well-developed and understood for certain anadromous species including salmon, American shad, alewives, and blueback herring. Upstream passages have not been specifically designed for riverine fish, although some of these fish will use them. Special designs for catadromous fish (i.e., fish that migrate from freshwater to spawn in the ocean) are used in Europe, but have not been used in the United States.

The upstream passage or transport of fish can be provided for through several means: fish ladders, lifts (i.e., elevators or locks), pumps, and transportation operations. Ladders and lifts, or fishways, are widely accepted technologies. Pumps are a more controversial method. Transportation operations are often used as an interim measure until fishways are completed, especially when there is a series of dams that must be passed. Transportation is also used as the long-term solution at some high-head projects. Site- and species-specific criteria, project scale, and economics help to determine which method is most appropriate. Fish passage success is highly dependent on creating a "fish friendly" environment.

Fish Ladders and Lifts

Some fish ladders perform well because they accommodate fish behavior and the target species' ability to respond to particular hydraulic conditions. An understanding of fish swimming performance and behavior is essential to fish passage success. It is difficult to pinpoint the range of responses that fish might exhibit under natural conditions, but significant knowledge exists which must be applied to fishway design. Species require different types of flows and conditions to encourage and support movement, or in some cases to prevent movement of unwanted species. There is some controversy over the use of certain ladder types for some species.

Fish ladders (e.g., pool and weir, Denil, Alaska steeppass, vertical slot, hybrid) can be designed to accommodate fishes that are bottom swimmers, surface swimmers, or orifice swimmers, fishes that prefer plunging or streaming flow, and weak or strong swimmers (102). But not all kinds of fish will use ladders. Fish lifts, including elevators and locks, are favored for species that will not use ladders. Fish elevators can move fish to a high vertical level. Locks, like boat locks, where the water level is controlled to move fish to a slightly higher elevation, can move a large number of fish.

Poor fishway performance, on the other hand, can generally be attributed to inadequate operations and maintenance including ill-maintained flow regime; and poor design including inappropriate siting, inadequate capacity, inadequate coordination between design of fishway and hydropower generation, inadequate attraction flow, or excessive fishway length (e.g., fish become fatigued or delay in resting areas). Water quality may also affect passage performance. Lack of goals for fish passage often contributes to design failures.

Attraction flow can make the difference between fish passage success and failure. This is true for fish ladders and lifts. A lack of good attraction flow, or the inability to maintain the appropriate flow, can result in delays in migration as fish become confused, milling around looking for the entrance. The proper location and position of the fishway entrance will help enhance effectiveness by decreasing the time fish can spend looking for a means past the obstruction.

Conventional fish ladder designs have been experimented with and used often enough to pass certain species that the design criteria are almost generic. However, because river systems are varied and dynamic, each site presents the possibility of new challenges. The full involvement of agency personnel with the experience and expertise necessary for designing effective fish passage systems may not be possible, due to lack of sufficient staff and/or their time constraints. In addition, the individuals responsible for fish passage may not be as experienced or may not have the information necessary for proper design. As a result, a fishway may be inappropriate. Therefore, a successful passage project will likely depend on the cooperative efforts of the project owner, the resource agencies, consultants, and research scientists. In the Northeast, the FWS reviews and comments on all fish passage facility final designs under FERC project licenses.

Fish Pumps

The use of pumps for fish passage at dams is controversial and largely experimental. There are several different types of fish pumps in existence, a few of which are new methods under development, while others are technologies being transferred from other applications. This technology is relied upon in aquaculture for moving live fish, and in fishing operations for off-loading dead fish from boats. It has recently been tested at government-owned fish hatcheries. These pumps can be used to force both juveniles and adults into bypass pipes for passage either downstream or upstream of projects.

The FWS in the Northeast and some state resource agencies do not support the use of pumps due to the nature of the passage method. Fish movement is completely facilitated and fish are subjected to an artificial environment. Pumping of fish can lead to injury and de-scaling as a result of crowding in the bypass pipe (196). Pumping fish may also cause them to be disoriented once released back into the river environment. These conditions support the conventional wisdom of the agencies to use passage methods, like ladders, which allow fish to move of their own volition (196). The agencies also have concerns about capacity, and reliability of parts, and overall system operation. However, the resource agencies have approved the use of a fish pump as an interim measure for the upstream transport of adult alewives at the Edwards Dam on the Kennebec River in Maine. In the Northwest, the Bureau of Reclamation is currently testing two types of pumps for downstream passage of juveniles at the Red Bluff Diversion Dam on the Sacramento River.

Transportation

The use of trucks to move adult migrants upstream is somewhat controversial. (Downstream transportation is discussed below.) Some practitioners have concerns regarding the effect that handling and transport has on fish behavior, health, and distribution. On the other hand, transportation using trap and truck operations has been successful in some cases for moving adults upstream of long reservoirs where they might become lost or disoriented on their way to spawning grounds.

The trap and truck technique for transporting upstream migrants has been used as an interim measure until upstream fish ladders or lifts are constructed. In some high-head situations, transportation is the long-term passage method. Where dams occur in series and fishway installation occurs as a staged process, trucking may be used as an interim measure. For example, on the Susquehanna River in Pennsylvania, fish elevators are in operation at the downstream-most dam to assist a trap and truck operation which supports the restoration of American shad, blueback herring, and alewives. The fish are transported upstream of the four projects on the river and released in the highest headpond near to spawning grounds. The 10-year-old program supported by state and federal resource agencies is considered to be successful.

Trap and truck techniques can work well for some species, provided there is a good method for collecting and handling fish. However, resource agencies have concerns about potential adverse effects of handling on some species, the potential for trapping non-target fish, and the intensive labor requirements to implement trap and truck operations. In addition, objections can be raised by some fishing interests if fish are removed from key stretches of a river. For example, the proposed trucking of Atlantic salmon around the proposed Basin Mills hydropower project on the Penobscot River in Maine would remove fish from the usual and customary fishing locations of the Penobscot Indian Nation—one of their negotiated treaty rights.

Downstream Passage Technologies

Downstream passage technologies are in use at 13 percent of the 1,825 FERC-licensed hydropower plants (242). The primary passage method at other sites is through turbines. The need for downstream passage is well established for anadromous species, whereas the need for downstream passage for riverine species remains controversial.

Accepted Downstream Passage Technologies

There are regional differences in the recommendations of resource agencies for downstream passage. Variations relate to differences in target fish, including differences in swimming ability of down-migrating juveniles, susceptibility to injury, and the history of concern for endangered and threatened species. Structural methods, including screens that physically exclude fish from turbine entrainment and angled bar racks and louvers that may alter flow patterns and rely on fish behavior for exclusion, are the most widely accepted technologies for downstream passage. Downstream technologies that are accepted by resource agencies in different regions of the country, and those that are considered experimental, are summarized in table 1-3.

Resource agencies generally prefer physical barrier screening techniques with associated bypasses for downstream passage (e.g., drum, traveling, and fixed screens). This type of technology is well understood. Physical barrier and bypass systems can prevent entrainment in turbines and water intake structures. Design criteria incorporate hydraulic characteristics and take into account the swimming ability and size of fish present to avoid impingement problems. A commonly cited advantage of these systems is

TABLE 1-3: Downstream Fish Passage Technologies: Status and Use

Downstream passage technology	Accepted in the Northwest and California	Accepted in the Northeast and Midwest	In use	Considered experimental
PHYSICAL BARRIER DEVICES				
Drum screen	✓		✓	
Travelling screen (submersible; vertical)	✓		✓	
Fixed screen (simple; inclined)	✓		✓	
Eicher screen			✓	✓
Modular inclined screen				✓
Barrier net		✓	✓	✓
STRUCTURAL GUIDANCE DEVICES				
Angled bar/trash rack		✓	✓	
Louver array		✓	✓	
Surface collector			✓	✓
COMPLEMENTS TO TECHNOLOGIES				
Bypass chute or conduit	✓	✓	✓	
Sluiceway		✓	✓	
ALTERNATIVE BEHAVIORAL GUIDANCE DEVICES				
Acoustic array			✓	✓
Strobe and mercury lights			✓	✓
Electric field			✓	✓
OTHER METHODS				
Trapping and trucking	✓	✓	✓	✓
Pumping			✓	✓
Spilling	✓		✓	✓
Barging	✓		✓	✓
Turbine passage	✓	✓	✓	

SOURCE: Office of Technology Assessment, 1995.

that they are effective for any species of the size and swimming ability for which the system is designed. This type of downstream passage technology is usually recommended in the Pacific Northwest and California. Acceptance is based on experience at many sites and non-peer reviewed (i.e., gray literature) evaluations of performance. Design criteria are mandated for some species by some state and federal agencies. Criteria vary among the agencies but generally address approach velocities and flow-through velocities, size of mesh, and materials, for different sizes and species of fish. Designs generally must be tailored to the individual site and target fish.

In the Northeast, resource agencies more frequently recommend the use of angled bar racks with relatively close spacing and an associated bypass for down-migrating anadromous juveniles. This approach is also supported by favorable evaluations in one peer reviewed study (167) and a small number of gray literature studies, although the mechanism that leads to successful performance is not understood (198). A similar approach is louvers, a behavioral system that alters the flow characteristics of the water that fish are able to respond to. Louvers are viewed favorably by some, but have been criticized by the NMFS NW region as having unacceptably high entrainment rates for small fish, even with favorable hydraulic systems (see appendix B) (236,236a). In the Northwest, many poorly performing louvers have been replaced by physical barrier screens and bypass systems.

Screens built prior to the mid-1980s sometimes experienced poor performance in guiding juvenile fish. Since then, new screen designs in the Pacific Northwest and California have achieved nearly 100 percent guidance efficiency (59,245). However, these screens can be expensive. A significant portion of costs are due to structural measures required for proper anchoring and installation and there are frequently operation and maintenance deficiencies. Incompatible operation of hydropower facilities or water diversions may also reduce the effectiveness of the technology. These accepted technologies are usually designed to withstand normal variations in flow; however, flow conditions can be highly variable. In some cases, changes in the river itself can cause problems; the position of the river can actually change over time, resulting in screen failure.[2] This is more likely to be a problem at water diversions where there are no dams controlling water flow.

Adequate operation and maintenance is required to optimize the performance of these accepted technologies. Preventive maintenance can minimize failure. Manual methods of cleaning are generally favored to reduce capital costs, but few resources are devoted to ensuring that manual cleaning occurs. Frequent cleaning may be needed where there is a lot of debris. Some of the more sophisticated and expensive designs provide automated cleaning, but these are rarely installed due to the high capital costs.

Controversial Downstream Passage Techniques

There are some downstream techniques in use, especially for juvenile salmon in the Columbia River Basin, that are controversial. These techniques include: transportation (trap and truck, and barging) and spilling. Controversy centers around whether the techniques are actually beneficial to the fish populations. Both the trap and truck method and barging depend on the successful collection of fish. Methods are being explored to improve collection for transportation, including surface collectors and behavioral guidance, which are described below.

Transportation

Transporting juvenile out-migrants around dams in trucks or barges helps to prevent the loss of fish in long reservoirs, avoids the potential impacts of nitrogen supersaturation[3] that may be associated with spilling water, and decreases the possibility of turbine entrainment and predation problems at intervening dams and reservoirs. In the Columbia River Basin the use of transportation to move juvenile salmon is controversial. Benefits of transportation during low flow periods are generally recognized because transportation may reduce the time it takes fish to move through the system. The controversy mainly centers around transportation during the mid-range of flows. Delay in migration may have a negative impact on the physiological development of smolts which is critical to survival. Transportation may expose juveniles to disease, cause stress from overcrowding, and increase the chance of predation upon release.

Whether transportation contributes to more adult returns to spawning grounds does not appear to be conclusive. There is some agreement that barges are preferable to trucks. However, agencies indicate that barging should be regarded as experimental (251). Yet transportation is only as good as the collection technology; juveniles not collected pass through the turbines. Efforts are ongoing to improve the collection phase of this passage technology (see chapter 4).

[2] The Glenn-Colusa Irrigation District in Hamilton City, CA, is an example. A drum screen was built for the site, then the river changed course and gradient, and the technology was no longer appropriate.

[3] As spill water plunges below the dam, the hydrostatic pressure causes air—mostly nitrogen gas—to be entrained in the flows. The pressure at the bottom of the stilling basins forces the gases into solution, creating a supersaturated condition. When a fish is exposed to this supersaturated water, gas bubbles can form in its bloodstream and result in a variety of traumatic effects and even death.

Spilling

Spilling water to pass juvenile fish is a technique used to move down-migrants past hydropower projects in the Columbia River Basin. The COE considers the use of spills to pass fish to be one of the lowest mortality options for getting fish past dams, yet recognizes that spill has its own associated risks (231). There has been some dispute over the effects of spilling on the health of fish. However, recently the NMFS NW office and the Intertribal Fish Commission, which represents tribes in the Columbia River Basin, recommended that spilling should be implemented on a broader scale to support juvenile downstream migration.

Experimental Downstream Passage Technologies

There is a strong desire to have downstream passage technologies that are less expensive to design, install, operate, and maintain; easy to retrofit into existing facilities; and water-conserving with respect to the primary purpose of the facility. This desire has led to the investigation of methods to improve performance of currently used methods (e.g., surface collector) and alternatives to accepted passage methods. These alternatives include both physical barrier approaches and behavioral guidance techniques. (Fish pumps are also being investigated for downstream passage of juveniles, but are discussed previously under upstream passage technologies.) Efforts are underway to develop new turbine designs that reduce problems of turbine entrainment and mortality. New concepts in hydropower production that would eliminate some of the dangers for fish passing through generation systems also are being explored (box 1-7).

Improving current passage technologies

The COE has been working for decades in the Columbia River Basin to identify modifications that can be made at specific sites on the Columbia River to improve fish passage performance. One example of this effort is a new emphasis on surface collector technology that will capitalize on the surface orientation behavior of the juvenile fish. The concept was derived from observations of high levels of safe juvenile passage at Wells Dam, which uses a hydrocombine configuration where spill intakes are located directly above turbine intakes. If successful, the method may be useful for attracting juveniles to bypasses, or allowing more efficient collection of fish for transportation (40).

Experimental high-velocity screens

The development and application of the Eicher screen and the Modular Inclined Screen (MIS) have followed similar paths. Both have undergone a deliberate process of development which has included extensive laboratory testing with a variety of species, as well as prototype development and field evaluation. These efforts have been championed largely by EPRI, in some instances working jointly with Alden Research Laboratory (ARL) and Stone and Webster Environmental Services. Successful laboratory experimentation led researchers to identify appropriate sites for field testing of prototypes. These applications have shown both screening technologies to be successful in guiding certain types and sizes of fish under a range of high-velocity conditions. However, these screens only collect fish when water is flowing over them. Operational changes may be necessary to ensure adequate flow to the screens, especially during seasons when reservoirs are filling and little power is produced.

Research and evaluation of the Eicher screen has led to approval from agency personnel for specific sites. Eicher screens are in use at the Elwha Hydroelectric Project on the Elwha River in Port Angeles, Washington, and at the Puntledge Hydropower Project in British Columbia. Resource agency approval for use at other sites will depend on documentation that the design performs well for target fish at velocities present at the site.

A prototype (reduced-scale) MIS has been constructed and will be field-tested in the spillway sluice gate at Niagara Mohawk Power Corporation's 6-MW Green Island hydropower plant on the Hudson River in New York during Sep-

BOX 1-7: New Approaches to Hydropower Generation

Turbine passage in current settings potentially exposes fish to blades and physical contact, which can either de-scale or kill them, and pressure changes, which may cause physical injury and/or death. Turbine entrainment has become a major issue in FERC relicensing. Turbine entrainment levels and mortality vary widely from site to site. Results of studies of turbine passage vary and there is some dispute over the necessity and interpretive value of these studies. Entrainment studies are most common when relicensing applicants question the level of adverse impact and the need for protection measures, especially for riverine species. Nevertheless, the cumulative impact of entrainment on juveniles passing through turbines, especially where dams exist in a series, can have a significant impact on the population.

The Department of Energy's (DOE) Hydropower Program and the hydropower industry have co-funded the Advanced Hydropower Turbine System Program. It is an effort to look at innovative solutions to problems associated with the operation of turbines at hydropower projects. DOE has the lead role in program development, proposal review, and implementation. The program is meant to stimulate and challenge the hydropower industry to develop new environmentally friendly concepts in power generation by applying cutting edge technology and innovative solutions to support safe fish passage. The Army Corps of Engineers-Portland District is also working to develop relatively minor modifications of existing turbines in the Columbia River Basin to increase survival of downstream migrants.

Technologies that can produce large quantities of electricity without adverse effects to river ecosystems may be feasible. However, a significant commitment to research and development, demonstration, testing, and evaluation will be required. The current hydropower generation technologies were developed with the objective of producing power. Although the need for fish passage was recognized when many of our nation's existing dams were built, effective passage was not incorporated into designs. New designs that simultaneously optimize for energy production, fish protection, and ecosystem integrity are conceivable. OTA received information on more than one concept of this nature during the course of this study. However, evaluation of these ideas was beyond the scope of this study.

SOURCE: Office of Technology Assessment, 1995.

tember of 1995. This test is important in the development and acceptance of the technology. However, resource agencies will be unlikely to approve full-scale applications of the MIS without additional testing (12).

Barrier nets

Barrier nets are used to prevent fish entrainment and impingement at water intakes. The ability of the net to exclude fish depends on local hydraulic conditions, fish size, and the size and type of mesh used (59). Low approach velocities, light debris loading, and minimal wave action are critical to success. Barrier nets are not considered to be appropriate at sites where the concern is for entrainment of very small fish, where passage of fish is considered necessary, and/or where there are problems with keeping the net clear of debris. At sites where icing is a problem, nets may be difficult to use in winter and thus may only provide seasonal entrainment protection.

Alternative behavioral guidance methods

Experimentation with various stimuli (e.g., lights, sound, electricity) to elicit a response in fish has been going on for decades. With a few notable exceptions for specific species at specific sites, there is no behavioral guidance technology that has been used to meet resource agency objectives and guide fish downstream at hydropower sites or at water diversions. Behavioral methods can repeatedly elicit startle responses in various species of fish, but the problem of getting fish to move consistently in the desired direction has proven to be more difficult. Given the limited swimming ability of many down-migrating juveniles, behavioral mechanisms may not be able to direct fish to bypasses that are small compared to an intake or river flow. It is rarely economical to devote a significant percentage of flow to a hydropower fish bypass.

Successful guidance has been reported for clupeids (e.g., blueback herring and shad) using ultrasound and strobe and mercury lights. Experimentation with sound has also shown some promise with salmonids. General claims of high performance and low cost cannot be verified with the limited experience available. However, there are indications that lower costs than conventional methods and good performance may be possible for some systems at some sites.

Sound is a potentially useful stimuli to guide fish. Advantages of sound are that it is directional, rapidly transmitted through water, not affected by water turbidity, and unaffected by light changes (i.e., diurnal changes). Sound is used by fish to get a general sense of their environment (207). There is some evidence that fishes may respond to sounds that are produced in association with structures such as barrier screens and turbines (6,164), although little is known about the actual behavioral response to these sounds.

Various species have narrow ranges of sound which they can detect, and some species respond differently at different times of the day. This may be an advantage or disadvantage, depending on which species are targeted for guidance. It may be possible to develop systems that species respond to differently, allowing management objectives for different species to be met. One disadvantage of sound stimuli is that they can be masked by dam noises and other ambient sounds.

Experimental sound guidance technologies include several methods that use various frequency ranges. For the purposes of this discussion, methods are loosely divided into three frequency ranges: ultrasonic (above 30 kHz), low-mid frequency (50-900 Hz), and infrasonic (<50 Hz).[4] The response of fish to ultrasonics was discovered in experiments with a high-frequency fish counter. Most of the work has been done with clupeids (especially *Alosa* spp., including blueback herring, alewives, and American shad). Signals from 110-130 kHz have been used for clupeids. The COE is completing testing of a system at the Richard B. Russell pumped storage site in South Carolina. A commercial system, FishStartle™, by Sonalysts, Inc., has been tested at hydropower facilities on the Connecticut and Susquehanna Rivers and at other kinds of generating stations.[5] Other species have been evaluated in laboratory cage tests with variable, species-specific results.

Low-mid frequency sound experiments have included historic tests of pneumatic poppers and hammers conducted by Ontario Hydro. Results with these technologies were variable, and problems with the reliability of the equipment led to the utility abandoning the effort.

Another low-mid frequency concept of playing back modified fish sounds was developed and tested by American Electric Power (141). This system has been further refined and is currently being marketed by Energy Engineering Services Company (EESCO) and has been undergoing testing since 1993 at a number of water diversion sites on the Sacramento River. Much of the work on this system has been focused on defining the appropriate array of transducers, dealing with equipment anchoring and reliability problems, and establishing appropriate testing protocols and statistical methods. Investigations have been hampered by difficulties installing equipment due to extreme flows and high water levels. There have also been delays in the studies due to the presence of endangered species. The experience at several sites has been very contentious and the evaluations have failed to reach the efficiency goals of the resource agencies. The process has been proceeding best at Georgiana Slough, a natural diversion site

[4] OTA did not identify any mid-high frequency (900 Hz–30 kHz) systems.

[5] Full-scale sound system tests of the Sonalyst, Inc., Fish Startle System at a nuclear power plant on Lake Ontario have been peer reviewed and are highly regarded. However, the hydraulic conditions at this site are very different from those at hydropower facilities.

which carries about 15 percent of the flow, where there are no practical physical barrier alternatives. An interagency group is involved in the tests, and results during the spring of 1995 were considered encouraging (50 percent overall guidance at a statistically significant 95 percent level) by at least one agency (100).

The EESCO technology is also undergoing tests on the Columbia River system in 1995 as part of the new Columbia River Acoustic Program, sponsored by DOE and COE to evaluate existing sound-based fish guidance and deterrence systems for the Columbia River system (see box 1-5). The EESCO system uses military grade speakers, originally designed for use by the U.S. Navy, that weigh 50 pounds and can be installed on buoys (170). The speakers produce a sound field with very little particle motion (39). Field test results are not consistent with what is known about sound detection capabilities of salmonids, thus some reviewers are very critical of this system (179). However, the mechanisms that fish use to respond to other more accepted technologies are not well understood either.

Infrasound has shown some success in highly controlled field experiments in Norway with Atlantic salmon. A consistent behavioral response was demonstrated in laboratory experiments. The developers of this approach are now working with the Columbia River Acoustic Program on Pacific salmonids. This approach requires large displacement transducers of special design that generate a sound field with large particle motion. The current system only works with fish within a few meters of the sound source. This finding is consistent with what is known about the sound detection capabilities of salmonids (39). Other private initiatives are underway to develop infrasound systems (50, 219).

Lights are also a potentially useful stimulus to guide fish. Light is directional, is transmitted rapidly through water, and is not masked by noise. However, light may be hampered by turbidity. Although it is most effective as a stimulus when there are sharp contrasts between the light and background (usually at night), this may not be an issue if the target species move downstream primarily at night (as is the case with juvenile American shad).

Mercury or other forms of incandescent illumination and strobe lights have undergone laboratory testing for a number of species. Field testing also has been conducted for a few selected species. The effect of the lights varies by species and the type of lights. Some species are attracted to the lights, others are repelled. And the response may change with age of the fish, physiology, motivation, etc. EPRI has supported research in this area and has developed guidelines for implementing light systems at water intakes (60). These guidelines recognize the need for careful site-specific evaluation of field conditions.

Strobe lights have been receiving considerable attention in recent fish guidance studies in the mid-Atlantic region and New England. A multiyear testing effort has been underway to guide juvenile American shad to a bypass at the York Haven Hydropower Plant on the Susquehanna River (61,152). These tests have often been hampered by water conditions, years when there were few fish, and other environmental variables. Nevertheless, there are positive indications that the lights can increase use of the bypass, although effectiveness varies with environmental conditions. At this site, preliminary tests combining strobe lights and ultrasonic methods have had encouraging results. Tests of strobe lights are also being conducted at other hydropower sites in New England. These tests are primarily being done as enhancements to conventional trash rack measures. Yet, the installation of some of the conventional measures and dam operation has not been in accordance with resource agency expectations at some of these sites.

Electrical barriers have been successfully used to prevent upstream passage of fish. Systems are operating in Salt River Project irrigation canals in Arizona to prevent the mixing of species of fish from the Colorado River and other Rocky Mountain streams.

Development of downstream protection is more challenging. Key requirements are favorable flow conditions and adequate security to ensure safety of people and other animals. There have been field trials that were abandoned due to problems in these two areas. Other problems have been encountered with corrosion of electrodes. A number of questions about the impact of electrical pulses on fish have been raised by resource agency biologists reviewing experiences with electric barriers (111). Field tests of the Smith-Root Graduated Field Fish Barrier (GFFB) are underway at a water diversion on the Sacramento River. In this test, major efforts have been devoted to ensuring appropriate flow conditions with the installation of structural devices (209). Tests by the manufacturer have indicated that flow (i.e., velocity) requirements will vary with different species. Yet, results of the 1995 tests were inconclusive and indicated that flow and velocity conditions were still difficult to control (100).

Alternative behavioral guidance issues

Several generalizations can be made from experiments to date with alternative behavioral guidance measures. Response to various behavioral stimuli is very species specific and is variable even for a single species, depending on conditions at the site. Site conditions are influenced by environmental variables (e.g., weather, time of day, flow conditions) as well as the way the facility is operated. It is also likely that the response of a single species will vary depending on its life stage and motivation. Favorable hydrology is a key element to the success of any of these systems. Fish must be capable of moving in the desired direction for a stimuli to be effective. Many juvenile fish have very limited swimming abilities.

For the most part, knowledge of fish behavior is very limited. Nothing is known of how fish of many species respond to various stimuli, flow conditions, and structures. In the more well-studied species, major informational gaps remain in our knowledge of behavioral responses and mechanisms.

Field investigations of behavioral methods have for the most part been weak. Analysis and statistical methods have been too limited to assess the effectiveness of the techniques. Much of the work is not peer reviewed, and the gray literature often does not contain sufficient information to allow critical analysis and possible replication of the experiment. In some cases, claims of high levels of guidance and reliability of equipment have not been supported in further field tests.

There is general consensus among resource agencies and scientists that development of new behavioral approaches requires a combination of lab and field experimentation. Because there are many variables at work when dealing with living organisms, especially in uncontrolled environments, there have been many cases when lab results of response to stimuli have not been repeatable in field tests. Thus, laboratory investigations of fish behavior are not sufficient. Nor are field tests alone. Data from field studies need to be evaluated in the lab to fully understand the nature of the results.

Studies to determine the basic sensory abilities of fishes are best done in the laboratory, while studies of overall fish behavior in response to environmental variables might be started at field sites. But there needs to be close interaction between lab and field work if the mechanisms by which behavioral methods work are to be fully understood. Understanding mechanisms of response is necessary to design widely applicable systems to control fish behavior.

Many of the technology vendor companies are frustrated in their efforts to conduct field investigations. Generally, they must obtain agreement from the hydropower operator and resource agencies to conduct a test. Hydropower operators are motivated by a desire for lower cost fish protection, yet they have little interest in participating in a test, let alone helping to finance it, if they cannot be assured that positive results will be viewed favorably by the resource agencies. Hydropower operators are concerned that they may be forced into paying for conventional measures after having invested in testing new approaches, or even penalized with fines if the experimental methods result in significant loss of fish.

A technology company may be successful in getting an initial field test sited at little or no cost to the hydropower operator. If positive results are obtained, the next hurdle is locating another appropriate test site and possible sale. Yet, major questions exist regarding the transferability of performance information from one site to another.

Performance of any passage technique is generally considered to be site specific. Information that is most transferable from one field site to another concerns what went right and what went wrong. One would also generally expect that the operation of the device would be similar from site to site. It is the species response that may be expected to vary, due to different site and environmental conditions.

In general, the resource agencies' responses to requests to test new technologies have been negative. Yet they are under considerable pressure to allow field testing. Resource agencies are skeptical about performance claims, and are concerned that testing of unproved technologies is time consuming, expensive, and may detract from hydropower operators' willingness to spend funds to install the technologies agencies prefer. Resource agencies are concerned that technologies installed for experiments tend to become the permanent solution at the test site, despite substandard performance relative to conventional measures. Resource agencies are concerned that experiments with alternative technologies may be used as a delay tactic to avoid expenditures for conventional technologies. Resource agencies are more willing to entertain innovative approaches, either as an enhancement to conventional measures or at locations where conventional measures are not practical. The NMFS regional offices in the Northwest and Southwest have developed policy statements that allow testing of experimental systems, provided a tiered process of research and evaluation is followed, along with the simultaneous design for a physical barrier/bypass system for the site (237,238,239). By setting standards and criteria for effectiveness, NMFS establishes goals for technology vendors and state agencies to follow. The FWS has no similar policy.

The current system of site-by-site investigation, short-term funding of experiments, lack of rigorous scientific methods, and lack of wide dissemination of favorable and unfavorable results is unlikely to result in robust technologies acceptable to agencies within a time frame relevant for relicensing activities in the next 10 years. Even with a major coordinated research and development effort to advance alternative behavioral technologies, it is unclear whether significant progress will be made in developing behavioral systems to guide fish past hydropower generation facilities and water diversions. And yet, if behavioral methods prove successful, they could mean large cost savings for the industry.

Is it worth pursuing a significant research program on behavioral methods, for settings where conventional approaches are available? On the one hand, there are few demonstrated successes with behavioral systems and so little is known about the behavior of fish that further investment may not be warranted. The process of applying a system developed for one site to another will require significant expenditures and time for testing and fine tuning. Also, too many species are involved at most sites to assume that a single control system will be effective. On the other hand, the successes with sound and lights suggest that behavioral systems have real potential for at least some species. Alternative behavioral systems, if perfected, may be very cost effective; and they may be particularly useful when several are combined, or they are used to enhance the performance of physical barriers.

CONCLUSIONS

The incomplete state of knowledge regarding fish population dynamics, the impacts of hydropower development on fish, the need for mitigation in various contexts, and the protection/passage effectiveness of available mitigation technologies exacerbates the sometimes adversarial relationships among stakeholders. This situation is unlikely to be alleviated unless a solid, science-based process for mutual understanding and rational decisionmaking can be developed (see box 1-8).

BOX 1-8: Development of Fish Passage Technologies: Research Needs

There are no "sure things" in the world of fish passage technology. The technologies themselves, which are based on hydraulic engineering and biological science, can be designed to accommodate a wide range of environmental conditions and behavioral concerns, but in the real riverine world *anything* can happen.

Upstream and downstream fish passage problems differ considerably and both present a range of obstacles and challenges for researchers and practitioners. Despite these differences, common considerations in design and application exist, including: hydraulics in the fishway, accommodating the biology and behavior of the target fish, and considering the potential range of hydrologic conditions in the waterway that the passage technology must accommodate. Engineers and biologists in the Northeast and Northwest are collaborating in a number of research programs designed to improve understanding of the swimming ability and behavior of target fish. Understanding how fish respond to different stimuli, and why, is critical to improving passage methods.

Using a scientific approach to explore as many scenarios as possible, and collecting data in a careful manner, can improve researchers' abilities to design improved technologies. In addition, producing information that all parties can acknowledge as credible is key to the successful advancement of fish passage technologies. A sound scientific approach to developing, executing, and evaluating a field study is critical to the successful advancement of fish passage technologies. The elements of a good test include the establishment of clear objectives, agreement among all parties to the study design, and a protocol that lends itself to repeatability. In addition, there must be a proper accounting of environmental variability, documentation of all assumptions, and sufficient replications to support findings. Regular communication among stakeholders and peer-reviewed research results are key requirements.

Employing a process of this type could increase the potential for information transfer between sites. That information might include data regarding the response of the device to hydraulic parameters (e.g., flow/acoustical response), fish response to stimuli under hydraulic parameters, and basic biological information within species. Agreement on performance criteria and standards prior to study will avoid lack of acceptance of data and recommendations in the long term.

SOURCE: Office of Technology Assessment, 1995.

A combination of academic, government, and industry expertise is needed in a concerted effort to focus science and technology resources on the question of the effects of hydropower development on fish population sustainability; and on the assessment of available and developing fish passage and protection technologies at hydropower facilities.

Technologies

Technologies for upstream passage are more advanced than for downstream passage, but both need more work and evaluation. Upstream passage failure tends to result from less-than-optimal design criteria based on physical, hydrologic, and behavioral information, or lack of adequate attention to operation and maintenance of facilities. Downstream fish passage technology is complicated by the limited swimming ability of many down-migrating juvenile species and by unfavorable hydrologic conditions. There is no single solution for designing up- and downstream passageways; however, both types must be designed and applied in such a manner that in theory, model, and reality they should suit the range of conditions at the site—structurally, hydraulically, and biologically. Effective fish passage design for a specific site requires good communication between engineers and biologists and thorough understanding of site characteristics.

Downstream passageways for fish and protective measures to reduce turbine mortality are probably the areas most in need of research. Many evaluations of conventional and alternative technologies have not been conducted with scientific rigor. This results in unsubstantiated claims and arguments. Moreover, some experimental results contradict others. Ambiguous or equivocal results of many fish passage studies have caused concern as to whether certain technologies are effective or generally useful. The variability of results may reflect site variability; uncontrolled environmental conditions in field studies; or incomplete knowledge of fish behavior. Thus, some performance claims may be based on incomplete assessments. Advocates on both sides of the fish/power issue can select from a diverse body of scientifically unproved information to substantiate their points of view. Care must be taken in interpreting much published information on fish protection, arguments drawn from it, and conclusions reached. When good scientific research and demonstration is carried out, results can be dramatic.

Hydropower Licensing[6]

Controversy abounds in the FERC hydropower licensing process. In part, this may be a result of the lack of clearly identified *goals* to be achieved through mitigation. Although *objectives* exist in the legislative language of the FPA, as amended, these lend themselves more to a philosophy than to hard goals that describe numbers, timeframes, and methods for achieving and measuring the stated goal. Clearly defined goals for protection and restoration of fish resources might refer to numbers or percentages of fish expected to successfully pass a barrier and/or projected population sizes. Since resource management goals are rarely articulated, mitigation and enhancement measures are judged on a case-by-case basis, with no means for assessment or comparison.

The lack of clear goals is, in part, reflected in the disjunction between section 18 prescriptions and section 10(j) recommendations of the FPA. Section 18 fish passage prescriptions are mandatory; however, section 10(j) recommendations may be altered based on consistency with other applicable law or the goals for the river (e.g., whitewater rafting/recreation, power production needs). Yet, the recommendations made under section 10(j) may be critical to maintaining habitat for fish populations or promoting timely migrations for certain species. FERC, as the final authority for balancing developmental and nondevelopmental values, is not specifically charged with sustaining fish populations. Without clear identification of the goal for mitigation, monitoring and evaluation become less meaningful and fail to become critical to the process.

Monitoring and evaluation conditions for hydropower licenses are infrequently enforced, resulting in little information on how effective available mitigation technologies are in improving fish passage and survival at hydropower plants. Operation and maintenance failures have been implicated in poor efficiency of fishways. Forty percent of nonfederal hydropower projects with upstream fish passage mitigation have no performance monitoring requirements. Those that do generally only quantify passage rates, without regard to how many fish arrive at and fail to pass hydropower facilities. Moreover, most monitoring has dealt with anadromous salmonids or clupeids; much less is known about the effectiveness of mitigation measures for "less-valued" or riverine fish. Research is needed to determine whether river blockage is even negatively affecting riverine species.

Relicensing decisions often are not based on river-wide planning and cumulative analysis. FERC is required to review existing river management plans to assure that the project will not interfere with the stated goals (pursuant to section 10(a) of the FPA). Yet, comprehensive river basin planning is fragmented. Synchronizing

[6] These conclusions are largely based on discussions with the OTA Advisory Panel for this project. Due to the elimination of OTA, this project was terminated early, without an opportunity to analyze fully many of the issues addressed in this section.

license terms on river basins could improve the relicensing process and promote cumulative impact analyses. Terms could be adjusted to meet the ecological needs of the basin and to provide timeliness and predictability for licensees. Under such a plan, multiple sites could be relicensed simultaneously, although operators may be unlikely to respond positively to undergoing the relicensing process "early." On the other hand, consolidation could yield benefits, allowing licensees to develop integrated management plans to maximize the energy and capacity values of their projects; making it easier for all involved parties to view the projects and their impacts in their totality; and facilitating understanding of cause and effect relationships.

There is a need for further research on cumulative fish passage impacts of multiple projects, and for consideration of fish needs at the watershed level. In several northeastern states, cooperative agreements between resource agencies and hydropower companies have generated successful approaches to basin-wide planning for fish protection. Carefully planned sequential construction and operation of fish passages could provide significant opportunities for restoring historic fish runs. In the western states, watersheds on national forests provide about one-half of the remaining spawning and rearing habitat for anadromous fish in the United States. Ecosystem or watershed management in these areas could have immediate and long-term impacts on fish populations.

The following chapters provide detailed information about current understanding about the need for fish passage and protection associated with hydropower facilities (chapter 2); the status of fish passage technologies, both conventional and emerging (chapters 3 and 4); and the federal role in fish passage at hydropower facilities (chapter 5). Appendices provide historical information on fish passage research in the Columbia River Basin (appendix A); experimental guidance devices and resource agency policy statements (appendix B); and additional suggested readings related to fish passage technology issues (appendix C).