EVALUATION OF MITIGATION EFFECTIVENESS

AT HYDROPOWER PROJECTS: FISH PASSAGE, DRAFT REPORT

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EXECUTIVE SUMMARY

Hydroelectric dams can be barriers to upstream-migrating fish and a source of mortality from turbine passage to downstream migrants. To mitigate these impacts, many projects are required to install upstream and downstream fish passage facilities, as stipulated in the articles associated with the licenses that are issued by the Federal Energy Regulatory Commission. The present study was conducted to evaluate the effectiveness of this mitigation in achieving the goal of fishery resource protection. The evaluation was based on information from fish passage effectiveness monitoring plans and annual reports which are filed with FERC by licensees and stored in the eLibrary database. Fish passage is one of several mitigation areas (others include shoreline management, water quality, and recreation) that are being reviewed as part of the FERC strategic plan for meeting the intent of the Government Performance and Results Act of 1993.

The initial database consisted of 213 projects that had at least one license article related to fish passage and were licensed or relicensed during a 15-year period from 1987 to 2001. In this database were 123 projects that had only an article reserving authority under Section 18 of the Federal Power Act to prescribe facilities for fish passage at some time in the future. Because they did not have a specific requirement for fish passage, these 123 projects were excluded from further analysis. The remaining 90 projects, which consisted of 108 developments, constituted the database that was used to assess the effectiveness of fish passage mitigation.

More than 50% of the 108 developments were located in the Northeast and 75% had a generating capacity of <10 MW. Most of the developments (70%) were required to submit effectiveness monitoring plans, which were reviewed to identify quantitative measures of performance (i.e., the percentage of fish passed). In addition to these site-specific measures, the

fish management and restoration plans for several large river basins in the Northeast listed goals for the recovery of various anadromous fish stocks. However, criteria to assess the success of the fish passage mitigation were generally not available.

Adequate data on the number of fish using upstream passage facilities were available for eight developments, but only three had sufficient data to provide a quantitative estimate of effectiveness. These three developments had a fish lift or lock, and effectiveness ranged from 45 to 67% across three species (Atlantic salmon, American shad, and river herring, primarily alewives). These estimates, which were similar to those obtained in other studies, met the passage criterion of 40 to 60% that was proposed for American shad at each successive upstream barrier on the mainstem Connecticut River. No analysis of effectiveness was possible for other upstream fish passage designs due to insufficient data. Having sufficient attraction flows at the entrance of the upstream fish passage facility was an important factor affecting passage at several projects.

The proportion of fish that utilized downstream fish passage facilities was estimated at 11 developments. At seven of these, radiotagging or mark-recapture techniques were used to measure the effectiveness of downstream passage for Atlantic salmon smolts. The percentage of fish that utilized downstream passage facilities, including spill, was highly variable, ranging from 6 to 100% for anadromous species and 3 to 87% for resident species. The high variability seemed to be related to the variation in flow; passage effectiveness was lowest at higher flows, when spill occurred. Surface collection systems and those that employed angled trash racks with a downstream bypass facility were the most effective, although spill at one facility achieved 100% passage. Ensuring suitable bypass flows and adequate attraction flows (relative to generating flow) are critical variables affecting downstream fish passage effectiveness.

Monitoring of fish passage facilities to assess effectiveness is important not only for determining site-specific performance but also for evaluating potential applications to other sites. The technology available for upstream fish passage is more mature and advanced than that available for downstream passage, especially of resident species. Levels of effectiveness exceeding 50% for the passage of downstream migrants will be difficult to achieve on a consistent basis without also considering spill to pass fish below the dam. With no support from a major research program, advancement of the science of downstream fish passage must rely on site-specific applications and good effectiveness monitoring plans. Such plans should consider defining the duration of the monitoring period in all license articles requiring fish passage. Finally, it is the responsibility of all parties involved in a licensing action to ensure that the best technical information is used to evaluate various alternatives for fish passage, especially downstream fish passage.

1.0 Introduction

Mitigative measures are commonly implemented to reduce the adverse effects of construction and operation of energy production facilities on the environment. Licenses issued by the Federal Energy Regulatory Commission (FERC), which regulates nonfederal hydropower facilities, usually contain articles that condition project design or operation to protect, mitigate, and/or enhance environmental resources and to achieve nonpower benefits. The Government Performance and Results Act (GPRA) of 1993 defines how federal agencies manage their performance and requires the development of strategic plans that describe the goals and measures of progress and performance in achieving those goals. In response to GPRA, FERC implemented an initiative to evaluate the effectiveness of the environmental mitigation requirements incorporated in hydropower project licenses.

One of the most common environmental impacts caused by hydropower projects is the barrier to upstream and downstream fish passage created by dams. This report presents the results of an evaluation of the effectiveness of fish passage mitigation measures implemented at nonfederal hydropower projects that were recently licensed or relicensed by FERC. Shoreline management (FERC 2001a) and mitigation of water quality impacts (FERC 2003) were addressed previously, and the mitigation associated with recreation is currently being evaluated. This report is not intended to be a comprehensive review of the alternatives for mitigating the impacts of hydropower dams as barriers to fish passage. Such reviews are provided by Sale et al. (1991) and more recently by Weigmann et al. (2003).

1.1 Background

In the 1980's, environmental protection conditions in FERC licenses were implemented based on relatively limited information that was typically collected early in the licensing process. The effects of these measures were rarely evaluated, so little was known about whether the measures provided the level of protection intended at license issuance (Cada and Sale 1993). By the early 1990's, but especially after 1993, most FERC licenses included requirements to develop plans for assessing the effectiveness of mitigation measures, such as fish passage. These plans and the subsequent study results have been included in reports submitted to FERC by the licensees. Those reports and other compliance filings required under the various license articles and FERC orders were reviewed in this study.

1.1.1 Review of Previous Hydropower Mitigation Studies

Hydropower mitigation that provided for the maintenance of instream flows, dissolved oxygen (DO), and upstream and downstream fish passage was examined in a U.S. Department of Energy (DOE) study by Sale et al. (1991). The study used public information from FERC records and additional information obtained from a written survey of developers and state/federal resource and regulatory agencies, focusing on nonfederal hydropower projects that were licensed or exempted between January 1980 and July 1990.

From a target population of 707 projects that were identified in the FERC Hydropower Licensing Compliance Tracking System as having mitigation requirements for instream flow, dissolved oxygen, and/or fish passage, specific information was obtained from the project developers of 280 projects. Of these projects, 30 (11%) and 66 (24%) had operating upstream and downstream fish passage facilities, respectively. Nationwide, of the 1825 operating nonfederal hydropower projects in the United States (FERC 1992), 10 and 13%, respectively, have installed upstream and downstream fish passage facilities (Pringle et al. 2000). Sale et al. (1991) reported that more than 70% of the upstream facilities were fish ladders. The angled bar rack, which was used at 38% of the projects with downstream passage facilities, was the most frequently required downstream passage device, especially in the Northeast.

Relatively few of the projects with passage facilities were required to monitor the effectiveness of the facilities in moving adults upstream over the dam and in bypassing juveniles (and adults of some species) downstream around the dam. Indeed, 57% of the projects with operating upstream fish passage facilities and 79% of those with operating downstream passage facilities did not conduct any biological monitoring to assess the effectiveness of the facilities. Most projects had no performance monitoring requirements for fish passage (e.g., 82% of projects with downstream fish passage facilities). Although 60% of the projects with upstream passage facilities had performance monitoring requirements, the most common performance criterion was "no obvious barriers to upstream movement." It was the only criterion used to assess effectiveness in 17 of the 30 projects that responded to the survey question related to performance objectives.

The 1991 study concluded that the proportion of projects with environmental mitigation requirements had increased significantly during the 1980s, but little information was available on the effectiveness of that mitigation. This earlier study had to rely primarily on surveys of licensees to obtain information on the implementation of mitigation, because the availability of data to directly assess mitigation success was limited. The present study used the data from fish passage effectiveness studies that were stipulated in various articles associated with more recent FERC licenses to determine the success of fish passage measures implemented to mitigate the adverse impacts of dams as barriers to fish movement and as sources of mortality from turbine passage.

Several other trends on fish passage mitigation were noted in the DOE study by Sale et al. (1991). Downstream fish passage facilities not only were more common than upstream passage facilities, but also were installed more frequently to protect resident than anadromous fishes. Of the projects with a downstream passage requirement, 55% were designed to protect adult resident species. Thirty-eight percent of the projects with an upstream fish passage requirement were targeting migratory resident species, and 12% targeted only resident species. Moreover, there was a trend of increasing downstream fish passage requirements in the target population over the 10-year period (1980 to 1990) included in the study. No increase in upstream passage requirements was observed over the same period. Finally, all fish passage requirements were more common in the West than in the East.

1.1.2 Overview of Licensing Process

When a license is issued for a project, the articles may contain provisions for the licensee to submit plans for the installation, operation, and maintenance of upstream and/or downstream fish passage facilities. In many cases, fish passage design drawings and effectiveness plans are required in the same or a separate article. Often, the requirement for fish passage facilities is not specified; instead, the authority to require such facilities at some time in the future is reserved for the U.S. Department of the Interior and NOAA Fisheries under Section 18 of the Federal Power Act. However, if the license article stipulates that a fish passage facility be designed and installed, and its effectiveness be determined, then the licensee consults with the resource agencies and develops the appropriate plans, which are reviewed by the agencies prior to their submittal to the FERC for review and approval.

Once the plan is approved and the facility is installed, effectiveness monitoring begins. The type and frequency of monitoring is project-specific. Reports of the results with any recommendations developed in consultation with the resource agencies usually will be filed by the licensee with the resource agencies and the FERC. These reports assess the effectiveness of fish passage, identify problems encountered during the monitoring period, and propose measures to address any problems. The goal of the present study is to review these reports in order to evaluate the effectiveness of fish passage.

1.2 Purpose of Study

The purpose of this study is to assess the effectiveness of fish passage facilities that are required by FERC licenses. From this evaluation, the FERC will be able to determine whether the license requirements are achieving the desired result of resource protection. Studies such as this and the other studies of shoreline management, water quality, and recreation mitigation will help guide FERC decisions regarding the need for environmental mitigation. The findings of this study are intended to improve internal practices of the FERC, thus making regulatory procedures more cost effective and efficient. For example, the lessons learned from evaluating and improving mitigation effectiveness will enable FERC staff to design better license articles. This approach, which provides all stakeholders with additional flexibility to cooperatively decide the best and most cost-effective method of meeting license objectives, will help ensure that mitigation measures implemented at nonfederal hydropower projects are both necessary and effective.

1.2.1 Measures of Effectiveness

The effectiveness of fish passage facilities is often determined by counts of the number of fish using them. Such an evaluation of effectiveness is usually insufficient, because the number of fish that did not use the fishway is not known. A better expression of effectiveness is the proportion (percentage) of the population that use a fish passage facility. License articles can require the development of monitoring plans that specify how the effectiveness of the fish passage facility will be measured. The various measures of effectiveness are described in these sections.

1.2.1.1 Project-Specific Measures

The most frequent metric used to document the benefits of a fish passage facility is the number of fish utilizing it. For example, annual counts of 500,000 to 1,000,000 fish for the two lifts at Holyoke Dam (FERC No. 2004) are the basis for the statement that these lifts "are one of the most successful fish passage facilities on the Atlantic Coast" (Kynard 1998). Counts of adults migrating upstream to spawn and juveniles migrating downstream to the ocean provide a quantitative measure of fishway use but are not necessarily adequate measures of fishway effectiveness. These measures are not based on knowledge of the size of a source population from which the number of bypassed fish was drawn. Without such a frame of reference, the true success of the facility can not be assessed. Fishway counts are a necessary but not sufficient measure of effectiveness.

In most cases, measures of fish passage effectiveness should be based on the proportion of the target population(s) below (above) the dam that is passed upstream (downstream). So, for example, a fish ladder that passes 1,000 fish may appear to be effective, unless it is learned that another 9,000 fish reached the dam but could not find the entrance to the ladder. Although the number of adult fish that move upstream past the dam can be determined from direct counts or estimated from video records of the fishway, the number of adults constituting the source population below the dam (i.e., the number of fish available for passage) is rarely known or estimated. However, if there are two sequential, mainstem dams and both have fish passage facilities, fishway counts at the lower dam can provide a reasonable estimate of the source population available for passage at the upper dam. Again, fish passage effectiveness at the upper dam would be expressed as the percentage of the upstream-migrating population counted at the lower fishway that was subsequently counted at the fishway on the upper dam. Such an approach was approved by FERC to assess the effectiveness of the upstream fishway at the Caribou project (FERC No. 2367) on the Aroostook River, Maine when the goal of 10% of the restored salmon run, as estimated by the Maine State Salmon Authority, is passed at the next dam downstream (Tinker Dam).

Although they are not a measure of effectiveness *per se*, performance measures can be used to document the benefits of fish passage. For example, some river basin plans for the restoration of anadromous species in New England coastal rivers include species-specific targets for the number of upstream migrants passed at the lower dam(s). If the passage facility is ineffective, these goals might never be reached. On the other hand, an increase in passage that results in attainment of the goal may not be associated with more effective passage but with an increase in stock abundance that is due to other factors, such as higher ocean survival, lower harvest rates, etc. While these targets are important milestones to the assessment of the status and recovery of anadromous populations, they do not provide a measure of effectiveness that can be a basis for the application of the same passage technology to other projects and species.

That the dam is not a barrier to fish movement is another performance objective that is difficult to quantify (Sale et al. 1991) and therefore, not an adequate measure of fish passage effectiveness. Upstream-migrating fish may be delayed for hours or days searching for passage at a dam before finding the fishway entrance. This delay could reduce the fitness of spawning adults or the upstream extent of their migration. Methods have been employed to minimize delays in upstream migration, such as tailrace barriers, and these are included in the present study. Even if the effectiveness of a tailrace barrier is known, that information is not sufficient to address the question of fishway effectiveness; upstream migrants may successfully avoid the tailrace yet still be delayed in their upstream migration by fishway design and operation (e.g., inadequate attraction flows).

The effectiveness of downstream fish passage facilities is easier to quantify than upstream fish passage facilities because it can be measured using an experimental approach. For example, marked, tagged, or radiotagged juvenile salmon (e.g., smolts) can be released above the dam and collected at the downstream bypass facility. The proportion of tagged fish that used the facility can be calculated, and if radiotagging is used, the proportion of released fish that utilized other passage routes can also be directly estimated. Juvenile salmon are reared in hatcheries for release in river basins with anadromous fish restoration programs, so they are readily available in large numbers. Availability is the primary constraint with using tagged adult salmon in a similar manner to measure the effectiveness of upstream fish passage facilities.

1.2.1.2 River-Basin Goals for Fish Restoration

Successful fish passage at hydropower dams is necessary to achieve the goals for restoration of anadromous fish stocks, and some restoration plans include specific fish passage goals for hydropower projects in the basin. For example, the Greenville project (FERC No. 2441) on the Shetucket River, a tributary of the Thames River in Connecticut, has both upstream and downstream fish passage facilities, which were installed in 1996. The Thames River basin is included in the anadromous fish restoration program of the Connecticut Department of Environmental Protection (CDEP); the goal of the program is to develop and maintain a recreational fishery for American shad and Atlantic salmon in the basin. The restoration plan requires that the upstream fish lift at the Greenville Dam be capable of passing 110,000 adult American shad and 165,000 adult alewives each season; basin-wide production is estimated by CDEP to be 110,000 adult shad and 217,000 river herring (Kleinschmidt Associates 1999). In this case, the passage and the restoration goals can be important design criteria for the Greenville fish lift, but they are not considered to be adequate measures of the effectiveness of the lift. Although important to fish restoration efforts in the Thames River basin, achievement of these goals does not imply that the lift is effective in passing upstream migrants, only that it is effective in meeting the goals of the restoration program. That is, the lift may satisfy the agency goal of passing 110,000 adult shad, yet this number may be only a small fraction of the available population. Of course, to regulatory and resource agencies, the latter measure may be sufficient and only fishway counts are needed. In the present study, however, we have defined effectiveness based on site-specific studies that considered the size of the fish population available for passage in evaluating the effectiveness of fish passage facilities.

Projects in river basins that have not developed restoration plans often have no specific fish passage requirements. For example, upstream fish passage will not be required at the Marcal project (FERC No. 11482) until a comprehensive fisheries management plan is prepared for the Little Androscoggin River basin in Maine, and the Maine Atlantic Salmon Commission has no plans to restore Atlantic salmon in this river in the near future. Even when an upstream fishway is present, measuring its effectiveness can be linked to the status of restoration efforts in the basin. Because the salmon restoration plan for the Aroostook River was discontinued by the Atlantic Sea Run Salmon Commission in 1991, assessment of the effectiveness of the pool-weir fishway at the Caribou project has been delayed until the goal of 300 salmon is reached at the next lower dam (FERC 1998).

Finally, it is important to recognize the significance of modeling tools for assessing fish passage improvements at multiple projects in a river basin. Considering fish passage effectiveness from this level of analysis provides the most meaningful approach because cumulative benefits of fish passage and all other restoration measures in the basin can be assessed. An excellent example of this approach is described in Kareiva et al. (2000). The authors described the use of an age-structured matrix model that was applied to long-term fish population data to test the effectiveness of various past management actions, including the transportation downstream of juvenile salmon, in the Columbia River basin. None of the projects included in this present study used a modeling approach to evaluate fish passage effectiveness.

1.2.2 Description of Database

The review of the effectiveness of fish passage mitigation measures utilized information contained in the public record for hydropower projects that were licensed or relicensed since 1987. Fish passage effectiveness plans and reports filed with the FERC by licensees, as well as the orders issued by the FERC based on these documents, constitute the key elements of the eLibrary database used in this study. Formerly known as the Federal Energy Regulatory Records

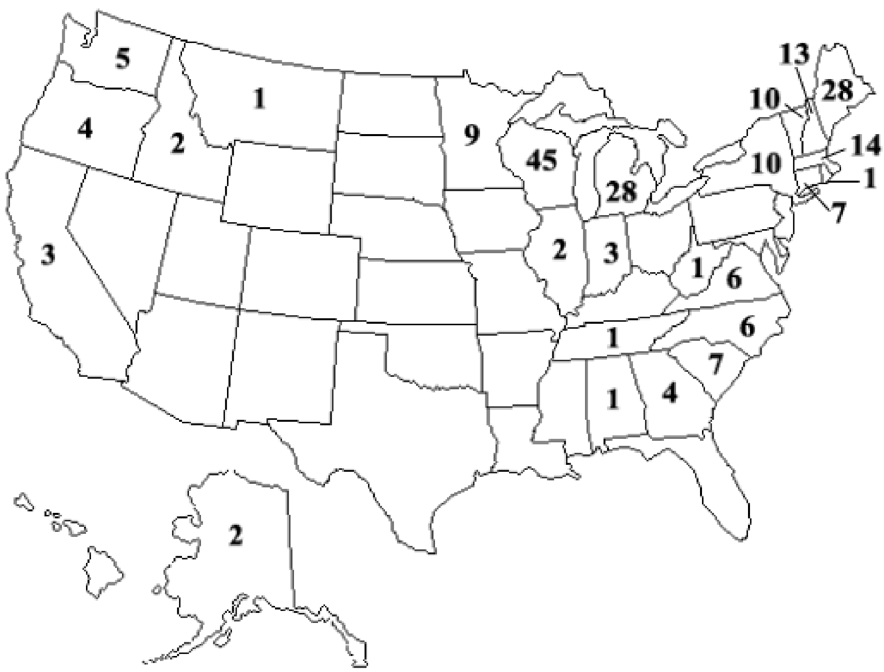
Information System (FERRIS), the eLibrary database contains (1) an index to all documents issued or received by the FERC since November 1981, (2) microfilm of documents submitted to and issued by the FERC for 1981-1995, (3) images of paper documents for 1995-present, and (4) documents submitted electronically through the FERC's web-enabled filing mechanism since November 2000. The eLibrary can be accessed from the FERC website (see www.ferc.gov).

The results of the analyses presented in Section 2.0 are based primarily on data presented in effectiveness monitoring reports submitted by the licensee and included in eLibrary before March 2003. For some projects, reports were submitted to the FERC for several years following approval and implementation of monitoring, and these were included in the review.

2.0 Data Analysis

The initial database used in this study consisted of a group of 231 hydropower developments (=dams) that (1) were licensed or relicensed during the period 1987-2001 and (2) had a license article addressing fish passage. This group of developments represented 213 projects (=licenses), which were clustered in the Northeast and North Central regions of the United States (Figure 2-1). Of these projects, 199 (93%) had a license article reserving the FERC's authority under Section 18 of the Federal Power (FPA) to require construction, operation, and maintenance of fishways as may be prescribed by the U.S. Department of the

Figure 2-1. Geographical distribution of 213 projects (=licenses) with at least one license article that addressed fish passage.



Interior (Fish and Wildlife Service or FWS) or the U.S. Department of Commerce (National Oceanic and Atmospheric Administration or NOAA Fisheries). Although fish passage may not be required by FWS or NOAA Fisheries at the time of project licensing, it is the FERC's practice to include a license article that reserves FWS or NOAA Fisheries authority to prescribe facilities for fish passage at some time in the future. In many cases, however, the agencies recommend that reservation of authority be included in the license. The FERC recognizes that future fish passage needs and management objectives can not always be predicted at the time of the license issuance.

A license article reserving authority under Section 18 of the FPA was the only fish passage requirement at 123 projects. After excluding these projects because they only reserved authority and did not specify the requirements for fish passage, the actual database included in the study consisted of 108 developments associated with 90 licensed projects. The greater number of developments (i.e., dams) than projects (i.e., licenses) is accounted for by nine projects that had two or more developments under the same license. In addition to Section 18, other sources of fish passage requirements include (1) Settlement Agreements between the licensee and state and federal resource agencies and NGO's, (2) 401 Water Quality Certification issued by the designated state agency, and (3) FERC license articles.

2.1 Summary of Projects with Fish Passage Requirements

2.1.1 Background

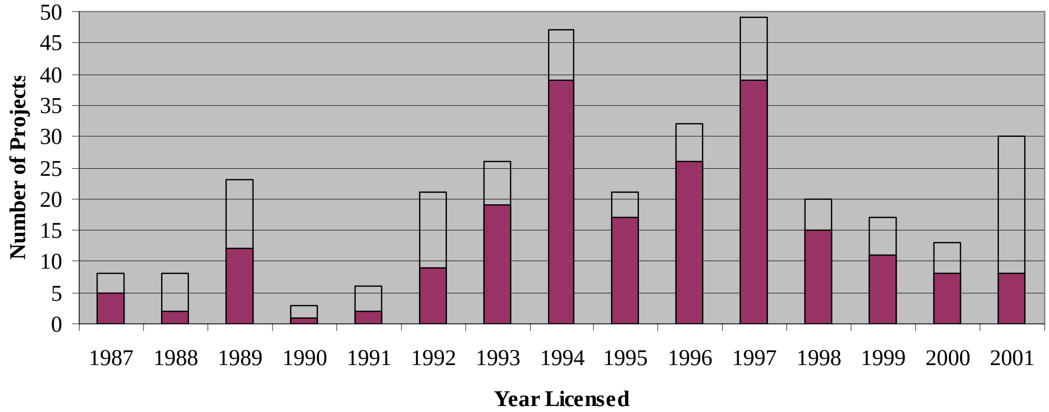
Fish passage requirements represent measures to mitigate adverse impacts of hydropower dams, which have been well documented (e.g., see reviews by Hildebrand 1980, Turback et al. 1981, and Jungwirth et al. 1998). These dams are barriers to the upstream movement of migratory fishes, and passage through the turbines or spillways is a source of mortality to downstream migrants. The life cycle of anadromous fishes, which spend most of their adult life in the ocean but return to freshwater to spawn, is impacted in both the adult and juvenile stages; adults often must pass one or more dams in the upstream journey to their natal streams, and the progeny that migrate downstream after one or more years must pass those same dams. Several Pacific salmonid species have such a life cycle, including chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*). Unlike Pacific salmon which die after spawning, steelhead (*O. mykiss*), Atlantic salmon (*Salmo salar*), and several anadromous nonsalmonids, including American shad (*Alosa sapidissima*), alewife (*A. pseudoharengus*), and blueback herring (*A. aestivalis*), are repeat spawners, so the adults also encounter dams during their post-spawning, downstream migration to the ocean. Because of its declining abundance, the American eel (*Anguilla rostrata*), a catadromous species that rears in freshwaters of Atlantic coastal river basins but spawns in the ocean, has received increased attention from resource agencies and hydropower developers (see review by EPRI 2001). Much less is known about the impact of dams on the more localized movements of resident fishes.

2.1.2 Project Characteristics

The hydropower developments used in this study were characterized by the year the project was licensed, the generating capacity of the development, and its geographical location. These characteristics are summarized and discussed below.

The initial database of 213 projects with a license article related to fish passage represented 66% of the total of 324 projects that were licensed or relicensed during the period 1987-2001. Of these 213 projects, 77% were licensed after 1993, and 64% were licensed during the five-year period from 1994-1998 (Figure 2-2). These trends are similar to those observed in the earlier study of water quality mitigation effectiveness (FERC 2003), although the actual

Figure 2-2. Total number of licenses issued and the licensing years of the 213 hydropower projects (shaded area) that were reviewed in this study.



percentages in that study were higher. Their similarity is not surprising, because many of the projects included in the water quality study were also included in the present study.

Several trends were evident in the percentage of licenses with fish passage requirements over the 15-year period from 1987 to 2001. The percentage of licenses issued in any given year that had one or more fish passage requirements ranged from 25% in 1988 to 83% in 1994 (Figure 2-2). Of the 48 licenses issued during the first five years, 22 (46%) had fish passage requirements. The volume of licenses granted per year increased almost threefold over the next ten years, averaging 28 licenses per year, and the percentage with one or more fish passage requirements increased to 69%. However, during the period from 1994-1998, 80% of the licenses issued contained at least one article that addressed fish passage. When the projects with license articles reserving authority under Section 18 of the FPA were excluded, only 90 of the 324 projects (28%) had specific requirements for fish passage and thus were available for review in this study. The 90 projects consisted of 108 developments, which constituted the actual database that was used in the analyses that follow.

The generating capacities of these 108 developments were categorized and compared with the capacities of projects included in the earlier DOE mitigation study (Sale et al. 1991) (Table 2-1). The proportion of developments within each of the five capacity categories was generally similar in the two studies. With one exception, at least 75% of the developments with

Table 2-1. Number of hydropower developments with fish passage requirements for each of five capacity categories included in an earlier DOE mitigation study (Sale et al. 1991) and the present FERC study. The DOE study included projects that were licensed or exempted between January 1, 1980 and July 1, 1990.
(Percentages of the total number of developments with upstream or downstream fish passage requirements are given in parentheses.)

	CAPACITY CATEGORY (MW)					
	<1	**1 to <10**	**10 to <50**	**50 to <100**	**≥100**	**Total**
Upstream Fish Passage						
DOE Study[a]	5 (17)	14 (48)	7 (24)	0 (0)	3 (11)	29
Present FERC Study	16 (22)	38 (54)	13 (18)	2 (3)	2 (3)	71
Downstream Fish Passage						
DOE Study[a]	24 (31)	38 (48)	16 (20)	0 (0)	1 (1)	79
Present FERC Study	16 (17)	58 (63)	16 (17)	1 (1)	2 (2)	93[b]

[a]SOURCE: Sale et al. (1991), Appendix C.
[b]Excluded four projects with dams but no generating capacity.

upstream and downstream fish passage requirements were associated with projects that had generating capacities of <10 MW. An equivalent proportion (74%) of the developments included in the water quality mitigation study were also <10 MW (FERC 2003). In the present study, almost 25% of the smallest developments (<1 MW) had an upstream fish passage requirement, an interesting finding considering the relatively high costs often associated with construction and operation of these facilities (e.g., Francfort et al. 1994). Very few large projects (>50 MW) were included in either study.

The 108 developments were reviewed to determine if there was any association between geographical location and (1) the type of fish passage requirements (e.g., upstream passage, downstream passage, and effectiveness monitoring) and (2) the number of Settlement Agreements, an important source of these requirements (Table 2-2). More than half of the

Table 2-2. Regional summary of 108 hydropower developments with fish passage requirements in addition to Section 18 authority.
(SA = number of projects with Settlement Agreements)

Region	No. of Projects	SA	FISH PASSAGE REQUIREMENTS			
			Upstream Only	Downstream Only	Upstream and Downstream	Effectiveness Monitoring
Northeast (CT, MA, ME, NH, NY, VT)	59	25	6	27	26	45[a]
North Central[b] (MI, WI)	30	25	--	6	24	17
Northwest[c] (AK, CA, ID, OR, WA)	16	4	5[d]	4	7	12
Southeast (GA,VA, WV)	3	1	1	--	2	2

[a]Includes monitoring the survival of fish in the downstream fish passage facility at two projects.
[b]Includes downstream fish protection requirements at 4 of the 6 'Downstream Only' projects and 15 of the 24 'Upstream/Downstream' projects.
[c]Includes downstream fish protection requirements at 2 of the 4 'Downstream Only' projects and 1 of the 7 'Upstream/Downstream' projects.
[d]Includes the closure of a fishway at one project.

developments (55%) were required to install both upstream and downstream fish passage facilities. This requirement for both facilities characterized 80% of the developments in the North Central United States. Only upstream passage was a requirement at just 11% of the developments and almost exclusively at those in the Northeast and Northwest where anadromous fish populations are the focus of major restoration efforts. Downstream fish passage was a more common requirement than upstream passage, a trend that was also noted by Sale et al. (1991) in a study of hydropower projects that were licensed between 1980 and 1990. Indeed, all 30 developments in the North Central region and 90% of those in the Northeast had a downstream fish passage requirement.

Most of the developments also had a requirement to monitor the effectiveness of fish passage (Table 2-2). Although 76 developments (70%) had this requirement, the regions with the highest proportion of developments requiring effectiveness monitoring were the Northeast (76%) and the Northwest (75%), where passage of anadromous fishes around dams is a significant issue. The emphasis on determining the effectiveness of fish passage facilities has only occurred within the past 10-15 years, because most of the hydropower projects that were reviewed by Sale et al. (1991) did not have such a requirement (see Section 1.1.1).

This increasing importance of effectiveness monitoring coincided with a recent increase in the use of Settlement Agreements as a component of the FERC licensing process. Only 4 of the 17 Settlement Agreements that were associated with the hydropower developments reviewed in this study were negotiated before 1994. Settlement Agreements are a common source of fish passage requirements (Table 2-2), and 55 of the 108 developments (51%), represented by 47 individual licenses, are included in these 17 Agreements. That is, more than 50% of the 90 licenses for projects reviewed in the present study are based on Settlement Agreements. Using this approach in the licensing process was especially favored in Michigan and Wisconsin, where 83% of the 30 developments were included in just three Agreements. They are an increasingly popular tool for resolving issues in hydropower relicensing proceedings in a timely and consenus-based manner (FERC 2000). The use of Settlement Agreements, which the FERC encourages, provides a mechanism for ensuring that the effectiveness of fish passage mitigation is appropriately evaluated.

2.2 Regional Assessment of Fish Passage Facilities

The fish passage facilities at the 108 developments included in this study were reviewed to identify common characteristics and to assess regional differences. This review included developments with planned facilities as well as those with operational facilities.

2.2.1 Upstream Fish Passage

Generally, there are three types of facilities for moving fish upstream: (1) fishways, which is a term defined in this report to be synonymous with fish ladders; (2) fish lifts (or elevators); and (3) fish locks (Bell 1980). The most common fishways include the pool and weir, Ice Harbor, vertical slot, and Denil, all of which have fish swimming up a series of successively elevated pools. Both fish lifts and fish locks crowd fish into an enclosure for transport over the dam. With fish lifts, this enclosure is a water-filled mechanical hopper; for locks, it is a chamber that fills with water, raising the fish above the dam. An important advantage of lifts and locks over fishways is that they can pass most fish species, including those that are small and those with weak swimming capabilities. They are employed for species that can not utilize fishways or where the height of the dam is great (Weigmann et al. 2003). Fishways, on the other hand, are species-selective, and passage via a fishway may be slower (Bell 1980).

In addition to these methods of upstream passage, trap-and-truck can offer an interim option while other, more permanent alternatives are considered for passage. Usually, a fish lift is used to collect fish at the dam, and a truck is used to haul them above the reservoir or above several dams farther upstream.

The types of upstream fish passage facilities at the developments included in the present study are summarized, by region, in Table 2-3. Most of the upstream passage facilities are located in the Northeast, and each type was about evenly represented. The targeted species at the Northeast projects are almost exclusively anadromous clupeids, Atlantic salmon, and the catadromous American eel. Only at the Felts Mill project (FERC No. 4715) on the Black River in New York was upstream fish passage (trap-and-truck) considered for resident species, but the license for that project was terminated by the FERC in May 2002. It is not surprising that anadromous fishes also constituted the majority of the targeted species at projects in the Northwest.

A comparison among regions showed that lifts/locks and the Denil fishway are primarily used in the Northeast. Also, as a proportion of the total facilities in the region (installed and uninstalled), the pool-weir fishway was more common in the Northwest, as were tailrace barriers. Although they are not actually an upstream passage device, tailrace barriers are used to minimize delay of upstream migrants that are searching for the entrance to the fishway. The low number of facilities in the Southeast suggests that upstream fish passage in this region is not yet a significant licensing issue. However, FERC expects to receive 137 relicense applications during the ten-year period from 2002 to 2012, and 26 of these projects, consisting of more than 50 developments, are located in North and South Carolina, Georgia, and Alabama (Hill and Murphy 2003). In Alabama and Georgia, dams operated by the U.S. Army Corps of Engineers are located downstream of many nonfederal dams, so the passage needs and fish management goals of the entire river basin should be identified when the need for fish passage at these latter

Table 2-3. Regional summary of upstream fish passage facilities for 108 hydropower developments (i.e., dams) that have fish passage requirements in addition to Section 18 authority.
(R = resident species; A = anadromous species; and C = catadromous species (i.e., American eel); TBD = to be determined)

Region	**No. of Facilities**	**TYPE OF FACILITY**							**TARGETED SPECIES**		
		Lift	**Pool-Weir**	**Denil**	**Trap -n- Truck**	**Eel Ladder**	**TBD**	**Fish Protection: Tailrace Barrier**	**R**	**A**	**C**
Northeast											
Installed	24	7[a]	6[b]	3	5	2		1	--	15	2
Uninstalled	19	--	--	4	3[c]	5[d]	6	1	2[c]	12	3
North Central											
Installed	1	--	--	1	--	--	--	--	--	1	--
Uninstalled	23	--	--	--	--	--	23	--	12	11	--
Northwest											
Installed	8	--	4[e]	1	1	--	--	2	4	3	--
Uninstalled	6	--	2	--	--	--	--	4	--	6	--
Southeast											
Installed	1	--	--	1	--	--	--	--	--	1	--
Uninstalled	2	1[f]	--	--	--	--	1	--	--	1	1
Total											
Installed	34										
Uninstalled	50										

[a]Includes two locks at the Springs-Bradbury development (No. 2528) on the Saco River, ME.
[b]Includes a vertical slot fishway at the Veazie project (No. 2403) on the Penobscot River, ME.
[c]Includes two developments (Upper and Lower Felts Mill, No. 4715) on the Black River, NY for which the license was terminated.
[d]Includes three ladders at the Holyoke project (No. 2004) on the Connecticut River, MA.
[e]Includes a fishway at the Kern River No. 3 development, CA (No. 2290) that was closed.
[f]Includes a refurbished navigation lock at the Stevens Creek project (No. 2535) on the Savannah River, GA.

dams is considered. That is, the barriers downstream may already limit fish movements, thus requiring a basin-wide rather than site-specific approach (Bell 1980).

Fifty of the 84 (60%) upstream fish passage facilities required by FERC licenses have not yet been installed. Almost half of these facilities are located in Michigan and Wisconsin at developments that are included in Settlement Agreements (e.g., 25 of the 30 developments are included in only three Settlement Agreements). Unlike other regions of the country where the method of upstream fish passage has been determined for most of the uninstalled facilities, the North Central region has not yet decided what type of facility should be installed. Fish passage seems to be an emerging issue in the North Central region where more than 50% of the uninstalled upstream passage facilities are targeting resident species. The method of passage has been selected for more than 60% of the uninstalled facilities in the Northeast, a region where fish passage is needed to support anadromous fish restoration programs. They remain uninstalled because requisite passage and/or restoration goals at the lower dams in the basins have not been met.

2.2.2 Downstream Fish Passage

A variety of fish passage facilities have been installed to divert downstream migrants away from turbine intakes and into a bypass system that transports them below the dam (Odeh and Orvis 1998, Weigmann et al. 2003). Physical barriers are designed to prevent entrainment or the passage of fish through the turbines where they are subjected to pressure and shear stresses as well as direct contact with the turbine itself. These barriers include several types of fixed and traveling screens in addition to barrier nets. Guidance devices are another group of downstream fish passage technologies that divert rather than exclude fish from the turbine intake area. This group includes structural guidance devices, such as angled bar racks, louvers, and surface collectors; and (2) behavioral guidance devices, such as the use of sound and lights (Weigmann 2003). Spill is another option for downstream passage and is commonly used in the Columbia River basin. Odeh and Orvis (1998) also included guide walls and curtain walls in their review of downstream fish passage mechanisms, but none of the projects in this study utilized them. Only one project employed a trap-and-truck approach to transport fish below the dam. At the Cabinet Gorge development, which is included in the Clark Fork project (FERC No. 2058) in Montana, this method is used to transport juvenile bull trout (*Salvelinus confluentus*) downstream of the Cabinet Gorge dam. This species is listed as threatened under the Endangered Species Act, and both the upstream and downstream transport of adults and juveniles, respectively, by trap-and-truck is designed to protect the genetic diversity of the populations and conserve the species (Epifano et al. 2003). In addition to trucks, barges have been used by the U.S. Army Corps of Engineers to haul downstream-migrating salmon smolts below Bonneville Dam, the lowermost dam on the Columbia River.

The downstream fish passage facilities at the developments included in this study are summarized in Table 2-4. These data illustrate that fish passage mitigation measures are diverse, representing several different technologies. In both the Northeast and Northwest, ice or trash sluiceways are utilized for downstream fish passage. Screens that minimize entrainment in the turbines were used or are planned for use at several projects in the Northwest. Downstream fish passage is planned for hydropower projects in the North Central region, but the type of facility has not been determined for nearly all of the developments.

Downstream fish passage facilities in the Northeast alone account for 71% of the total installed facilities that were reviewed in this study. When the facilities in the Northwest are

Table 2-4. Regional summary of downstream fish passage facilities for 108 hydropower developments (i.e., dams) that have fish passage requirements in addition to Section 18 authority.
(R = resident species; A = anadromous species; and C = catadromous species (i.e., American eel); TBD = to be determined)

Region	**No. of Facilities**[a]		**TYPE OF FACILITY**										**TARGETED SPECIES**		
			Sluice	**Spill**	**Surface Collection**	**Angled Bar Rack**	**TBD**	**Other**		**Fish Protection**					
										Screen(s)	**Barrier Net**		**R**	**A**	**C**
Northeast															
Installed	34		17	5	5	5[b]	--	2		--	--		10	21[c]	2
Uninstalled	26		8	3	1	7	7	--		--	--		11	9	2
North Central															
Installed	3		--	1	--	--	--	--		--	2		2	1	--
Uninstalled	27		--	--	--	--	27	--		--	--		27	--	--
Northwest															
Installed	7		3	1	--	--	--	1		2	--		3	2	--
Uninstalled	11		4	--	--	--	1	--		6	--		3	5	--
Southeast															
Installed	1		1	--	--	--	--	--		--	--		--	1	--
Uninstalled	1		--	--	--	--	1	--		--	--		--	--	1
Total															
Installed	45														
Uninstalled	65														

[a]The number of facilities can exceed the number of developments, which may have more than one facility. For example, the Veazie project (No. 2403) on the Penobscot River, ME has both angled bar racks and a sluice and the White River and Tule River projects (Nos. 2494 and 1333 in WA and CA, respectively) have screens and a sluice.
[b]Includes louvers at the Holyoke project (No. 2004) on the Connecticut River, MA.
[c]Includes landlocked Atlantic salmon at the Chace Mill (No. 2756) and Essex No. 19 (No. 2513) projects on the Winooski River, VT and the North Twin project (No. 2458) on the Penobscot River, ME.

included, the proportion exceeds 90%. Such a trend reflects the importance of anadromous fish restoration and protection as a management goal in the major coastal river basins of the Northeast and Northwest. Consequently, much of what we know about methods for safe downstream passage at dams is based on studies conducted on anadromous species in these two regions of the country.

Although the majority of the installed facilities in the Northeast region are used for passage of anadromous species (and catadromous eels), a substantial number are used for resident species (e.g., 29% and 42% of the installed and uninstalled facilities, respectively). The number of downstream passage facilities in the Northwest was considerably lower, but the trend was similar; 33% of the facilities targeted resident species. As was found with upstream passage at hydropower projects in the North Central region (Table 2-3), the facilities planned for this region of the country will be designed primarily for the passage of resident species.

2.3 Evaluation of Fish Passage Effectiveness

Many of the 108 hydropower developments had no data available for assessing the effectiveness of the fish passage facilities (Table 2-5). Passage facilities have not yet been installed at 52% of these developments, and no effectiveness monitoring was required at another 19%. Even if the development had a monitoring requirement, data were not always available. For example, anadromous fish stocks may have been too low to meet the goals that would require the initiation of monitoring (e.g., Table 2-5, footnote ‘d’). In a few cases, an effectiveness monitoring plan was in preparation or monitoring was in progress and no report was available yet.

Fish passage monitoring data were available at 24 developments, 71% of which were located in the Northeast. At some of these developments, data were limited (i.e., the data were qualitative, anecdotal, or in other ways, too limited for meaningful analysis). After reviewing the data from reports submitted by licensees to FERC in compliance with the license article(s), the monitoring results from effectiveness studies at eight upstream passage facilities and 12 downstream facilities were analyzed in the sections that follow.

Table 2-5. Status of implementation of fish passage requirements at 231 hydropower developments categorized by region.

Status	NUMBER OF DEVELOPMENTS				
	Northeast	North Central	Northwest	Southeast	Total
Section 18 only	36	62	2	23	123
Construction not started/in progress	4	--	7	--	11
Passage facilities not installed	15	27	1	2	45
Passage facilities installed					
— No effectiveness monitoring required	14[a]	1	1[b]	--	16
— Data not available[c]	9[d]	--	3	--	12
— Data available	17	2	4	1	24
TOTAL	95	92	18	26	231

[a]Includes four projects on the Passumpsic River in Vermont, each with an article requiring downstream fish passage effectiveness monitoring but none is required to conduct formal, quantitative studies.
[b]Kern River No. 3 project (FERC No. 2290) in California where the fishway was closed.
[c]Data not available because (1) effectiveness monitoring plan not submitted, (2) monitoring is in progress, or (3) report of results is in preparation.
[d]Includes two developments (Caribou and Millinocket Lake) that will not conduct upstream fish passage effectiveness studies until specific goals are reached for Atlantic salmon returns to the lower dam on the Aroostook River in Maine (FERC No. 2367) and two projects (Bonny Eagle and West Buxton) that will not conduct downstream fish passage studies until sufficient numbers of river herring and Atlantic salmon are present in the Saco River in Maine (FERC No. 2529 and 2531, respectively).

2.3.1 Upstream Fish Passage

Adequate data on the number of fish using the upstream passage facility were available for eight developments (seven projects), but only three of these had data that could be used to measure the effectiveness of the fish passage facility (Table 2-6). Two of these developments,

Table 2-6. Results of monitoring upstream fish passage at eight hydropower developments. Fish passage effectiveness is the percentages of fish passed at the downstream dam that were passed at the dam noted in the table.
(ND = No data available; NA = Not applicable; NT = Not tested: TNT = Trap-and-truck)

Development (FERC No.)	Location			Facility			Number of Fish Passed				Fish passage Effectiveness (%)			River Basin Restoration Goals (Number of Fish)		
	River	State	Dam Location[a]	Type	Status[b]	Year of Initial Operation	Year	Atlantic Salmon	American Shad	River Herring[c]	Atlantic Salmon	American Shad	River Herring	Atlantic Salmon	American Shad	Alewife
Ellsworth (2727)	Union	ME	1	TNT	I	1974	2000 2001 2002 Maximum[d]	8 2 11 72	ND ND ND ND	362,610 446,850 666,967 666,967	ND	ND	ND	250-750	NA	2,000,000
Cataract[e] (2528)	Saco	ME	1	Lift/Denil	P	1993	2000 2001 2002 Maximum[d]	50 69 47 88	ND ND ND 4,629	5,429 44,839 20,198 44,839	ND	ND	ND	ND	ND	ND
Springs Bradbury[e] (2528)	Saco	ME	2	Locks/TNT	I	1997	2000 2001 2002 Maximum[d]	ND ND ND ND	ND ND 557 ND	3,626 27,271 ND ND	ND ND	ND ND	61 67	ND	ND	ND
Skelton (2527)	Saco	ME	3	Lift/TNT	P	2001[f]	2001 2002 Maximum[d]	31 26 31	ND 0 0	ND 11,582 11,582	45 55	ND 0	ND 57	ND	ND	ND
Greenville (2441)	Shetucket	CT	1	Lift	P	1996[g]	1996 1997 1998	2 10 16	926 2,860 5,577	142 950 471	NT	55[h]	NT	NA	110,000	217,000
West Springfield (2608)	Westfield	MA	1	Denil	P	1996	1996 1997	21 39	1,413 1,009	ND ND	ND	ND	ND	500	15,000	NA
Fort Halifax (2552)	Sebasticook	ME	1	Pump/TNT	I	2000	2000 2001 2002 Maximum[d]	0 0 0 0	1 1 0 1	128,741 145,067 153,103 153,103	ND	ND	ND	NA	725,000[i]	6,000,000[j]
Harvell (8657)	Appomattox	VA	1	Denil	P	1997	2001	NA	2	1,141[j]				NA	ND	ND

[a]First or lowermost dam on river = 1.
[b]I = interim; P = permanent.
[c]Includes alewife (primarily) and blueback herring.
[d]Maximum number of fish passed during 15-year period (1988-2002) or since year of initial operation.
[e]Development includes two upstream fish passage facilities.
[f]Fishway was not operational until August 2001.
[g]Monitoring initiated on May 16 and conducted through June 27 in 1996 (31 d) and from March-June in 1997 (74 d) and 1998 (83 d).
[h]Effectiveness was based on a mark-recapture study with 120 adult shad.
[i]Annual production goal for Kennebec River above Augusta.
[j]98.7% blueback herring; 27 hickory shad, another anadromous clupeid, not included.

Springs-Bradbury (FERC No. 2528) and Skelton (FERC No. 2527), are located on the Saco River in Maine; they are the next dams upstream of the Cataract development (FERC No. 2528), which is the first dam encountered by upstream migrating anadromous fishes. In this case, effectiveness can be evaluated unambiguously, because the population available for passage at the upper dams is the number of fish passed at the Cataract dam, which is known.

The third development (Greenville, FERC No. 2441) is located on the Shetucket River in Connecticut and utilized an alternative approach (mark-recapture study) to measure the effectiveness of the upstream passage facility. While the approach in this case may be different, this measure of effectiveness is sufficient, because the numbers of fish available for passage at the facility were estimated.

2.3.1.1 Summary of Results

The effectiveness of the three upstream fish passage facilities ranged from 45 to 67% (Table 2-6). Passage efficiencies were highest for river herring at the Springs-Bradbury development. The estimates of effectiveness at the Skelton project are somewhat lower, in part, because the counts there were compared to the first or lowermost dam on the river and not with the next dam downstream (i.e., Springs-Bradbury). The greater distance between dams 1 and 3 than between dams 2 and 3, the preferred comparison, may have increased the probability for delays during passage at the Springs-Bradbury facilities. Estimates of fish passage effectiveness from the mark-recapture study with American shad at the Greenville project were remarkably similar to those that were based on direct counts of other species using the Skelton upstream fish passage facility.

Effectiveness was not quantified at the other five developments, all of which were the lowermost dams on the river. Mark-recapture studies may represent the only quantitative method that can be used to estimate the effectiveness of upstream fish passage at dams such as these (i.e., the first dam in the basin). Nevertheless, these projects are included in this analysis because most (the exception is the Harvell project, FERC No. 8657, in Virginia) are located in a river basin that has specific numeric goals for anadromous fish restoration (not percent passage), and the counts made at the upstream passage facility provide a measure of attainment of those goals. When the actual counts at those five developments are compared to the restoration goals for these lowermost dams, only the Ellsworth project has passed enough fish to exceed 10% of the goal for the Union River (e.g., 14 and 33% of the goals for Atlantic salmon and alewives, respectively).

The recovery of anadromous fish stocks, especially Atlantic salmon, has been slow in many coastal river basins of the Northeast (Table 2-7). Even stocks of river herring, primarily alewives, are well below relatively recent historical levels in the Connecticut and Merrimack rivers, while populations in the Union River in Maine are recovering well. The slow recovery elsewhere can explain why 44% of the required upstream passage facilities have not yet needed to be installed (Table 2-3). For those developments with installed facilities, low anadromous fish abundance also may account for the absence of monitoring data at some projects (Table 2-5).

2.3.1.2 Assessment of Effectiveness

Although most of the facilities listed in Table 2-6 were successful in passing upstream-migrating anadromous fishes, their effectiveness (expressed as the numbers of fish passed as a

Table 2-7. Numbers of river herring (RH) and Atlantic salmon (AS) passed at dams on East Cost rivers (1983-2001).
(N/A = data not available)

Year	Connecticut River Holyoke Dam (MA)		Merrimack River Lawrence Dam (MA)		Saco River Cataract Dam (ME)		Androscoggin River Brunswick Dam (ME)		Penobscot River Veazie Dam[a] (ME)	Union River Ellsworth Dam (ME)	
	RH	AS	RH	AS	RH	AS	RH	AS	AS	RH	AS
1983	454,242	25	4,700	114	N/A	1	601	20	799	9,260	144
1984	480,000	86	1,800	115	N/A	2	2,650	94	1,451	77,900	39
1985	630,000	285	23,000	213	N/A	80	23,895	25	3,020	850,420	81
1986	520,000	280	16,000	103	N/A	37	35,471	80	4,125	1,038,920	82
1987	380,000	208	77,000	139	N/A	40	63,523	27	2,341	473,840	58
1988	340,000	72	381,000	85	N/A	38	74,341	14	2,688	526,911	45
1989	290,000	80	388,000	84	N/A	19	100,895	19	2,752	559,676	26
1990	390,000	188	254,000	248	N/A	73	95,574	185	2,953	368,400	21
1991	410,000	152	379,000	332	N/A	4	77,511	21	1,578	192,720	8
1992	310,000	370	102,000	199	N/A	N/A	45,050	15	2,233	390,210	0
1993	103,000	169	14,000	61	831[b]	53[b]	5,202	44	1,650	111,139	0
1994	31,766	283	89,000	21	2,224	21	19,190	25	1,042	117,158	0
1995	112,136	151	33,425	34	9,820	34	31,329	16	1,342	183,634	0
1996	56,300	260	51	78	9,163	54	10,198	38	2,045	301,253	68
1997	63,945	199	403	71	2,130	28	5,540	1	1,355	279,145	8
1998	11,170	298	1,832	123	15,581	28	25,177	5	1,210	441,923	14
1999	2,760	154	7,898	185	31,070	88	8,909	5	969	277,425	72
2000	10,593	77	23,585	82	25,136	50	9,551	4	532	389,810	8
2001	10,628	40	1,550	83	58,890	69	18,198	5	787	445,850[c]	2[c]

[a]No effective mechanism to count clupeids.
[b]New Saco River fishways began operating in 1993. The West Channel trap began operating in 1992.
[c]666,967 river herring and 11 Atlantic salmon were passed in 2002.

SOURCE: PPL Maine, LLC. 2002. Union River Fisheries Coordinating Committee Annual Report, 2000-2001. PPL Maine, LLC, Milford, Maine. 23 pp.

percent of those available, for example) was adequately measured at only a relatively few developments. Moreover, all species were not passed upstream with equal effectiveness.

Design and Species Considerations

Three of the eight upstream fish passage facilities in Table 2-6 were Denil fishways, the most common fishway in the Northeast because it can pass most migratory species and all alosids (Schaefer 2003). A plan to monitor the effectiveness of the fishway at the West Springfield project (FERC No. 2608) was submitted and approved, and monitoring was conducted for two years. After the FWS and the Massachusetts Division of Fisheries and Wildlife (MDFW) concurred that the facility was functioning effectively, the MDFW assumed responsibility for day-to-day operations, as outlined in a Memorandum of Agreement with the licensee. Another Denil fishway is located at one of the two dams at the Cataract development (FERC No. 2528). Because the passage data from the two dams were not presented separately, no analysis of the Denil fishway effectiveness was possible.

The Denil fishway at the Harvell project in Virginia was evaluated in a 2001 study that showed the percentage of the target species, anadromous clupeids, using the fishway corresponded to the percentage observed from concurrent electrofishing surveys conducted 200 m below the dam. FERC approved the combination of the two datasets as the basis for estimating passage efficiency. A Compliance Order issued by FERC on March 4, 2003 required submittal of a report on the monitoring results within 60 days of the date of the Order, but the issue of fish passage at the Harvell dam has not been resolved. A vertical-slot fishway installed at the Buchanan project (FERC No. 2551) on the St. Joseph River in 1990 was reported by

Francfort et al. (1994) to pass 92% of the chinook salmon and 69% of the steelhead that migrated upstream from Lake Michigan.

A quantitative measure of fish passage effectiveness was obtained at three of the four developments with fish lifts or locks (Table 2-6). Estimates ranged from 45 to 67% across developments and species. These values are within the range of passage efficiencies given in the management plan for American shad in the Connecticut River basin (Connecticut River Atlantic Salmon Commission 1992). That plan stipulates an annual passage of 40 to 60% of the spawning run at each successive upstream barrier on the mainstem Connecticut River. Based on this comparison, the lifts/locks at these three developments (Table 2-6) can be judged successful, while recognizing that the Connecticut River criterion applies only to American shad, and the estimated effectiveness values in Table 2-6 are based on the passage of Atlantic salmon and river herring, in addition to American shad. The FWS and CDEP concur that the fish lift at the Greenville project is effective in passing the target species (shad and river herring) above the dam.

Problems with the passage of American shad were noted at the Fort Halifax project (FERC No. 2552) and the Springs-Bradbury development (FERC No. 2528), which actually consists of two dams, each with a fish lock. The low numbers of American shad passed upstream in the pump at the Fort Halifax project on the Sebasticook River, a tributary of the Kennebec River in Maine, may be due to low numbers of shad below the project, as the Licensee postulates, rather than to other factors related to facility operation. Whether the cause of the low passage of shad is due to a passage or pump-related problem is not known. Studies to improve fish passage at the Springs-Bradbury dams have been conducted since 1997, when the locks were installed. Many actions were tried, including altering flow through the deep gates and the position of the crowder gate, collecting extensive velocity measurements, installing underwater cameras, installing lighting, and other actions, which are continuing. In the interim, shad will be collected at the downstream Cataract fish passage facilities and transported above the Springs and Bradbury dams.

The movement of radiotagged American shad was studied near the two fish lifts at Holyoke Dam (FERC No. 2004) on the Connecticut River in Massachusetts (Barry and Kynard 1986). Passage efficiencies were 42 and 50% in 1980 and 1981, respectively, and the two lifts combined passed 350,000 or more shad upstream each year from 1976 to 1983. Another study of American shad passage was conducted at a navigation lock on the Cape Fear River, North Carolina (Moser et al. 2000). Passage efficiency for 86 radiotagged shad ranged from 18 to 61% during the three-year study, and the lowest efficiency coincided with a year of high river discharge. High flow was also observed to decrease fish passage effectiveness at the Springs-Bradbury development.

The abundance of catadromous Anguillid eels has been declining throughout North America and worldwide (EPRI 2001), raising concerns about the passage of American eels at hydropower developments on coastal rivers and streams. Upstream eel passage facilities were installed at two developments included in this study: the Millville Hydro Station (FERC No. 2343) on the Shenandoah River in West Virginia in 2002, and the Fort Halifax project in 1999. The estimated number of eels passed at the Fort Halifax upstream passage facility ranged from 551,262 in 1999 to only 56,292 in 2002. An upstream passage facility is planned for installation in 2003 at the Weston project (FERC No. 2325) on the lower Kennebec River, and three upstream eel passage facilities will be installed in 2002-2003 at the Holyoke project. Also, studies are being conducted to evaluate potential sites for an upstream eel passage facility at another project, Medway (FERC No. 2666), on the West Branch Penobscot River in Maine. No information is available on the effectiveness of these eel passage facilities.

Trap-and-truck has been employed at several other developments, usually as an interim measure until restoration goals are reached. At that time, permanent fish passage facilities would be installed. The Fort Halifax project employs trap-and-truck but uses a Transvac fish pump to capture river herring. The pump has achieved interim passage goals for alewives, and the collection and transport of 153,103 river herring in 2002 was the largest number of fish collected since anadromous fish restoration efforts in the Kennebec River basin were initiated in 1986. However, the pump has not been successful in passing American shad, Atlantic salmon, or blueback herring.

Adequacy of Effectiveness Monitoring

The best measures of the effectiveness of upstream fish passage incorporate the number of fish available for passage, as well as the number that actually pass the dam, in the calculation of effectiveness. Mark-recapture or radiotagging studies are good examples of the types of effectiveness monitoring approaches that can be used at the lowermost dam on the river. Such studies were conducted at the Greenville dam on the Shetucket River, a tributary of the Thames River in Connecticut (Table 2-6) and at Holyoke Dam by Barry and Kynard (1986). Both studies focused on the upstream passage of American shad. For other dams that are farther upstream, a quantitative estimate of upstream passage effectiveness can be obtained from fish passage counts at the dam of interest and the next lower dam. In this case, effectiveness is expressed as a proportion of the number of fish available for passage (i.e., those that were passed above the lower dam).

In this study, facilities were determined to be satisfactory and fish passage was judged successful by regulatory agencies based on substantially less information, such as direct observations of fish passage, conformance with design criteria, and a comparison of relative abundance of target species in fishway counts with relative abundance in the population below the dam. These are qualitative measures that may be applicable in some cases, but additional emphasis should be given to the use of more rigorous, quantitative evaluations of facility performance. Fewer than half the developments in Table 2-6, all of which were required to develop effectiveness monitoring plans, utilized such an approach.

2.3.2 Downstream Fish Passage

The proportion of fish that utilized downstream fish passage facilities was estimated at 11 developments, and actual counts of downstream migrants were made at one (Table 2-8). The larger number of developments that evaluated the effectiveness of downstream compared with upstream fish passage facilities reflects both the greater number of developments with downstream fish passage requirements (Table 2-2), and a more straightforward, experimental approach that can be used to measure downstream passage effectiveness (Section 1.2.1.1).

2.3.2.1 Summary of Results

At seven of the 12 developments (58%), radiotagging was used to measure the effectiveness of downstream passage for Atlantic salmon smolts. All of these developments are located in New England. A different technique was utilized at each of the other five developments; these included radiotagging, acoustic tagging, marking (floy tags), video monitoring, and complete census by draining the facility.

The range in effectiveness of the 12 downstream fish passage facilities listed in Table 2-8 was very broad. The percentage of radiotagged or marked fish that utilized downstream bypasses (compared to other passage routes) ranged from 6 to 100% for anadromous species and from 3 to 87% for resident species. This same degree of variability was evident when only the studies that utilized radiotagged Atlantic salmon smolts were considered. High variability in effectiveness also occurred among years for the same facility and species (e.g., Atlantic salmon smolts). For example, effectiveness ranged from 17 to 63% over a four-year period at the Cavendish project (FERC No. 2489) on the Black River in Vermont and, similarly, from 17 to 59% at the Mattaceunk project (FERC No. 2520) on the Penobscot River in Maine.

The high variability in downstream passage effectiveness between years that was observed at most of the projects may be associated with flow differences. Tests of effectiveness were generally scheduled to avoid periods of spill during high river flows. Recapture rates of marked Atlantic salmon smolts at the Cavendish project on the Black River in Vermont were observed to be highest later in the migration season when river flows had subsided. Because of the configuration of the project, relatively low flows in the Black River can result in passage of some of the water over the spillway. The low effectiveness of the Essex 19 downstream fish bypass facility on the Winooski River in Vermont (FERC No. 2513) was attributed to unusually high river flows and having to conduct tests during spills. Likewise, the effectiveness tests conducted at the Deerfield project (FERC No. 2323) were scheduled to avoid spills over the dam. Moreover, these tests showed that the probability of downstream passage via the bypass facility increased with reduced intake flows (i.e., a higher bypass: intake flow ratio). Similarly, at the Gardner Falls project (FERC No. 2334), which is located on the Deerfield River between the Deerfield No. 2 and Deerfield No. 3 developments, bypass effectiveness was higher at lower

Table 2-8. Results of monitoring the effectiveness of downstream fish passage at 12 hydropower developments.

Development (FERC No.)	LOCATION			FACILITY			RESULTS				Facility Modifications
	River	State	Dam Location[a]	Type[b]	Status[c]	Year of Initial Operation	Species[d]	Method[e]	Effectiveness (%)		
Deerfield No. 2 (2323)	Deerfield	MA	1	Sluice	P	1999	ATS	RT	1999 2000	20 21	Flow inducer system installed after 1999
Gardners Falls (2334)	Deerfield	MA	2	Sluice (with louvers)	I[f]	1999	ATS	RT	1999 2000	72 28	Louver depth increased after 2000
Deerfield No. 3 (2323)	Deerfield	MA	3	Surface collection	P	1999	ATS	RT	1999 2000	78 48	1"- bar rack installed and log boom near fishway entrance relocated after 1999
Deerfield No. 4 (2323)	Deerfield	MA	4	Surface collection	P	1999	ATS	RT	1999 2000	59 29	
Greenville (2441)	Shetucket	CT	1	Sluice (with ABR)	P	1996	JC	V	1997	1,030[g]	Intermittent lighting installed
Cavendish (2489)	Black	VT	6	Surface collection	I	1996	ATS	MR	1998[h] 1999 2000 2001	46 (3)[i] 56 (4) 17 (4) 63 (5)	System to increase current turbulence with less flow tested in 1999.
Essex 19 (2513)	Winooski	VT	3	Sluice	P	1996	ATS[j]	RT	1996 1997	27 6	
Ayers Island (2456)	Pemigewasset	NH	2	Spill	I	1992	ATS	RT	1992 1993 1999	54 61 100	Plunge pool and fish sampler constructed in 1996; plunge pool modified and new fish passage flashboard installed in 1998 to smooth flows entering fish spillway

Development (FERC No.)	LOCATION			FACILITY			RESULTS				Facility Modifications
	River	State	Dam Location[a]	Type[b]	Status[c]	Year of Initial Operation	Species[d]	Method[e]	Effectiveness (%)		
Mattaceunk (2520)	Penobscot	ME	5	Surface collection	P	1992	ATS	RT	1993 1994 1995 1997 1998 1999	59 45 52 41 22 17	Strobe and vapor lights installed in 1995 to enhance passage; trashracks rounded in 1998 to reduce turbulence
Rock Island (0943)	Columbia	WA	7	Spill	I	1996	JCS	AC	2001	43	
Hudson Falls (5276)	Hudson	NY	2	Surface collection (with ABR)	P	1995	RES	RT	1998 1999 (1) 1999 (2)	21 (6)[k] 44 (28)[k] 3 (2)[k]	
Prospect No. 3 (2337)	S. Fork Rogue	OR	1	Slice (with included screen)	P	1996	RBT	CC	1999	87	Tested four perforated-plate baffle configurations to identify a design that provided an approach velocity of <0.8 fps

[a]First or lowermost dam on river = 1.
[b]ABR = angled bar rack.
[c]I = interim; P = permanent.
[d]ATS = Atlantic salmon smolts; JC = juvenile clupeids; JCS = juvenile chinook salmon; RES = resident species (several); RBT = rainbow trout.
[e]RT = radio-tagging; V = video monitoring; MR = mark-recapture study; AC = acoustic tagging (internal); CC = complete census by draining.
[f]Approval to construct permanent downstream fish passage facilities issued on 7-25-01.
[g]Number of fish observed using downstream fish passage facility based on monitoring conducted from 6-8-97 to 7-1-97 and 9-8-97 to 10-31-97 (no fish were observed prior to 10-16-97).
[h]Results of earlier studies not included due to extended periods of spill (1996) and the use of landlocked Atlantic salmon parr as surrogates for sea-run smolts (1997).
[i]Mean value; number of tests in parentheses.
[j]Landlocked Atlantic salmon smolts, which is the population inhabiting Lake Champlain and the Winooski River, a tributary.
[k]Values represent the percentage of fish that utilized the fishway of those fish that moved downstream to the forebay; number in parentheses represents the percentage of fish that utilized the fishway of the total fish released.

generating flows. Finally, reduced or no generation at one of the units of the Mattaceunk project (FERC No. 2520) on the Penobscot River in Maine may be a major factor contributing to higher bypass efficiencies.

2.3.2.2 Assessment of Effectiveness

Substantially more data are available on the effectiveness of downstream fish passage facilities than on upstream passage facilities (Section 2.3.1.1). There were 28 studies of downstream fish passage effectiveness (Table 2-8) compared to only three quantitative studies of upstream passage effectiveness (Table 2-6). The former effectiveness tests, however, exhibited considerably more variability than the upstream effectiveness studies, even though the same method and species were used in 19 of the 28 downstream passage tests.

<u>Design and Species Considerations</u>

Of the 28 tests to assess effectiveness, 14 were conducted on Atlantic salmon smolts at downstream fish passage facilities consisting of some method of surface collection and conveyance below the dam. At the Cavendish project (FERC No. 2489), an uncovered ogee chute served as a sluiceway to transport fish from the entrance at the side of the dam to the plunge pool below. At the Mattaceunk project (FERC No. 2520), fish were transported from surface inlets in two of the four turbine forebays (strobe lights were used to repel fish in the other two forebays) to a collection chamber and a 42-inch, stainless steel underground fish passage pipe. A surface entrance to a downstream bypass channel characterized the facilities at the Deerfield No. 3 development and presumably Deerfield No. 4 as well. Despite the general similarities among these four developments in the type of downstream passage facility and the use of the same species (Atlantic salmon smolts) and experimental approach to measure effectiveness, the results were highly variable (Table 2-8). Although the maximum effectiveness in passing Atlantic salmon smolts downstream for each of the four passage facilities ranged from 59 to 78%, effectiveness exceeded 50% in only six of the 14 tests. Studies conducted on existing surface bypass systems on the Columbia River suggest that they can be very effective in passing Pacific salmon smolts around mainstem dams (Ferguson et al. 1998).

Sluices can be very similar in design to downstream passage facilities that utilize some method of surface collection. If fish tend to be oriented toward and concentrated in the upper portions of the water column, they may use surfaces or overflow areas that lead to existing ice and trash sluiceways to bypass the turbine intakes (Rainey 1985, as cited in Sale et al. 1991). Moreover, it is not uncommon to find sluiceways that incorporate a behavior guidance device, such as angled trash racks or louvers, in their design. They function to guide fish to a downstream bypass entrance. Although the data on sluice effectiveness in Table 2-8 are very limited, the project that utilized such a device (louvers at Gardner Falls) achieved a substantially higher level of effectiveness (72%) than those two that did not (maximum = 27%). No conclusions can be drawn regarding the effectiveness of angled trash racks, because they were not evaluated using an appropriate method or species.

Trash racks placed at an angle to the intake flow with one-inch spacing between bars are commonly required in the Northeast (Sale et al. 1991). Effectiveness studies of this technology were conducted at the Wadhams project on the Boquet River in New York (Nettles and Gloss 1987). More than 90% of the radiotagged Atlantic salmon smolts utilized the bypass (58%) or the spillway (33%), and none were entrained through the turbine perstocks when the angled trash rack was deployed. In another study of the Lower Saranac Hydroelectric Project located on the

Saranac River in New York, the same experimental technique (radiotagged Atlantic salmon smolts) was used with similar results (Simmons 2000). Bypass effectiveness exceeded 95% for the salmon smolts and none passed through the turbine. Steelhead trout were also tested; almost 70% used the bypass (62%) or the spillway (6%) but 9% passed through the turbine. The same system of angled trash racks and bypass was recommended for installation at three other projects in New York (FERC 1996).

Based again on limited data, the most effective downstream passage technology was spill. Following several years of continuous design modifications, the Ayers Island project (FERC No. 2456) achieved 100% effectiveness in passing radiotagged Atlantic salmon smolts downstream (Table 2-8). The project is located on the Pemigewasset River, a tributary of the Merrimack River, in New Hampshire and uses surface spill through a newly installed flashboard that was modified to pass downstream-migrating smolts. The length of the spillway section of the dam is 267 feet (length of dam is 699 feet) with a maximum height of 72 feet. A bypass survival study involving 33 radiotagged smolts released into the bypass flow indicated that 29 fish (91%) had moved to a monitoring station 1.6 miles downstream; the other four fish remained in the plunge pool (two fish), the reach between the dam and monitoring station (one fish), or passed undetected (one fish). Spill is also the preferred method of passage at many of the dams on the Columbia River, including Rock Island (FERC No. 943). However, a new permanent downstream bypass facility was recently installed at the 1300-MW Rocky Reach hydropower project, which was not included in the database used in this study, at a cost of $112 million (Anonymous 2003). Because it reduces the need for spill, the facility is expected to save $400 million by generating electricity with water that would otherwise have been spilled.

Studies of the effectiveness of downstream fish passage have focused almost exclusively on salmonids, because they are the targets of major restoration programs in the Northeast and the Northwest. Downstream passage of other species, such as American shad, has not been addressed with equivalent experimental rigor. Effectiveness testing with juvenile clupeids, using the same experimental protocols as those used for salmon smolts, may not be feasible due to their sensitivity to stress. On the other hand, the preferred technique of counting juvenile clupeids utilizing downstream passage facilities by video monitoring does not provide a quantitative measure of effectiveness. Also, the behavioral response of fish to a guidance device is species-specific, so extrapolating the results from one species to another (e.g., Atlantic salmon smolts to juvenile shad) may not be appropriate, especially between different families of fishes, such as salmonids and clupeids. Clearly, additional research on nonsalmonids is warranted in order to ensure that the most effective downstream fish passage facility is selected for the targeted species.

Likewise, little is known about the effectiveness of methods for diverting resident species away from turbine intakes and into a downstream bypass facility. The only study to use quantitative techniques to estimate the effectiveness of the downstream passage of resident species was conducted at the Hudson Falls project (FERC No. 5276) on the upper Hudson River in New York. Studies were conducted with a total of 154 radiotagged fish, including four centrarchids and three percids, that were monitored for 30 days during each of three periods of testing (fall 1998, early spring 1999, and late spring 1999). Most of the fish (77%) did not pass downstream of the project, but of the 35 fish that did move downstream, 51% used the fish passage facility and 31% used the spillway. These results were controversial in terms of their adequacy for assessment of fish passage effectiveness. The resource agencies requested an additional radiotagging study with several modifications in study design. The licensee recommended deletion of the downstream fish passage requirement from the license. FERC decided that the requirement was necessary but no additional monitoring was required. Because no other studies have been conducted on downstream fish passage of resident species, future controversies similar to this one can be expected. The unresolved issue is the appropriate methodology to use in evaluating downstream passage effectiveness for those species that are not migratory (i.e., most movements, at least for the centrarchids, are highly localized). With so many developments requiring downstream passage of resident species in the future, especially in the North Central United States (Table 2-4), a consistent approach to effectiveness monitoring is needed.

Concern for the declining abundance of the catadromous American eel has resulted in the assessment of eel passage at hydropower dams. Utilization of downstream fish passage facilities by eels has been studied at the Medway project (FERC No. 2666) on the West Branch Penobscot River in Maine. A video camera was used to monitor eel passage through the weir and flume located adjacent to the spillway. Difficulties were encountered with lighting and obscurance of the lens by insects and algal growth, so additional future monitoring is planned after resolving these problems. Studies to determine the best location for an upstream eel passage facility at this project are also continuing.

Adequacy of Effectiveness Monitoring

Most of the studies of downstream fish passage reviewed in this study used an appropriate measure to determine effectiveness. The percentage of fish utilizing a downstream bypass facility from a sample of marked or radiotagged fish released above the dam is the best procedure. In this case, the problem is not with the measure of effectiveness that was used, as was the case in evaluating upstream fish passage effectiveness (Section 2.3.1.2), but with its limited application to nonsalmonid species. Most of the effectiveness monitoring of downstream fish passage has focused on salmonids, especially Atlantic salmon smolts, with highly variable results. Achieving levels of effectiveness above 50% is often difficult. High passage efficiency is dependent upon flow conditions, including the volume of flow for spills, power generation, and fish bypass well as the apportioning of flow among these three uses.

Spill was the most effective method of bypassing downstream migrants around dams, but data on the effectiveness of spill, and the mortality associated with this route of passage, are limited. At many hydropower developments, the costs associated with spill for the purpose of downstream fish passage will be too high and this approach will not be feasible. However, at some projects, it may be practical to make better use of this route of passage.

3.0 Summary and Conclusions

A database of 213 hydropower projects licensed between 1987 and 2001 was reviewed to assess the effectiveness of the mitigation that was implemented to pass fish upstream and downstream around dams. The review focused on 90 projects comprising 108 developments that had specific requirements for upstream and downstream fish passage. The other 123 projects in the database could not be evaluated for effectiveness because they had only a license article reserving authority under Section 18 of the Federal Power Act and no other fish passage requirements.

3.1 Mitigation Effectiveness

Having well defined performance criteria would provide an unambiguous measure of the effectiveness of fish passage facilities. Such criteria were available in an earlier FERC study of the effectiveness of water quality mitigation at hydropower projects (FERC 2003). In that study, compliance with water quality criteria was used because states have established clearly defined criteria to protect aquatic ecosystems. Although no similar performance standards exist for fish passage, effectiveness can be assessed using the percentage of fish that are passed upstream or downstream. Nevertheless, the question remains regarding what passage percentage is acceptable.

3.1.1 Upstream Fish Passage

Of the 108 developments that had one or more license articles related to fish passage, 71 developments (66%) required an upstream passage facility. More than 70% of the installed facilities are located in the Northeast where they are used to support efforts to restore anadromous fish stocks in coastal river basins. Upstream passage of resident species was required at four of the eight installed facilities in the Northwest and will be required at 12 of the 23 uninstalled upstream fish passage facilities planned at hydropower developments in the North Central United States. The technology for passing anadromous fishes upstream around dams is well developed, but its success can be difficult to measure at individual dams. Successful upstream passage of resident fishes and catadromous eels, on the hand, will require additional research to identify the best approaches and those critical design and site-related factors that influence effectiveness.

Eight hydropower developments had quantitative data available on upstream fish passage, but only three developments in the Northeast had data that could be used to directly assess the effectiveness of the upstream passage facilities. Using the counts of fish at two dams, the number of fish passed, when expressed as a percentage of the fish available for passage, provided an objective measure of effectiveness. At the three developments, passage effectiveness for three anadromous species ranged from 45 to 67%, which met the performance guideline of 40 to 60% for annual passage of American shad at each successive upstream barrier on the Connecticut River (Connecticut River Atlantic Salmon Commission 1992). Only one study used radiotagging to assess effectiveness, and that value (55%) was similar to those obtained from the comparison of direct counts between dams.

3.1.2 Downstream Fish Passage

Downstream fish passage was required at 96 of the 108 developments (89%) that had more than a license article reserving authority under Section 18 of the Federal Power Act. Most of these downstream passage facilities (59%), however, were not yet installed. Of the 45 facilities that have been installed, most (76%) are located in the Northeast, a trend similar to that observed with upstream fish passage. Nationwide, 51% of all the downstream passage facilities, both those in operation and those that are planned, must consider resident fish passage.

Because an experimental approach (i.e., mark-recapture or radiotagging studies) could be used to assess effectiveness and because downstream fish passage was a more common requirement in FERC licenses, more quantitative estimates of effectiveness were available for downstream than upstream passage. The results from 28 tests at 11 hydropower developments were highly variable even though the experimental approach and species tested (Atlantic salmon smolts) were similar in most of the tests. The percentage of radiotagged or marked fish that utilized downstream passage facilities ranged from 6 to 100% and from 3 to 87% for anadromous and resident species, respectively. This variability decreased somewhat when the test method, species, and type of facility were similar. For example, 14 of the 28 tests were conducted on Atlantic salmon smolts at four facilities that employed surface collection with conveyance below the dam. At these developments, maximum effectiveness ranged from 59 to 78% but exceeded 50% in only 6 of the 14 tests.

A major cause of the variability observed in the effectiveness of downstream fish passage was testing during periods of high flow, resulting in spill. Avoidance of such periods during testing can be difficult; the time for the outmigration of smolts often overlaps with historical peaks in the hydrograph. Also important as a factor influencing bypass effectiveness is the volume of flow used to pass downstream migrants relative to that used for power generation.

Compared with the mature technology of upstream fish passage, downstream passage technology remains experimental. Except for spill, the variety of the physical and behavioral approaches to downstream passage has met with about the same degree of success. That is, levels of effectiveness exceeding 50% passage are difficult to achieve, or if achieved, are difficult to sustain. The technology for downstream passage of anadromous fishes is not mature, and additional research is needed to identify suitable alternatives that have applicability across sites. Even though the data from the present study are limited, further research seems warranted to investigate the use of spill as an additional, secondary route of passage. There may be relatively minor, cost-effective modifications that can be made to enhance passage via spill whenever it occurs. Also needed are suitable measures to divert and bypass resident species away from turbine intakes. Sixty-three percent of the currently uninstalled downstream fish passage facilities will require effective passage of resident fishes.

3.2 Adequacy of Effectiveness Studies

Although data on effectiveness were available for only 10% of the 213 projects (=231 developments) included in the database, enough studies of fish passage effectiveness were conducted to evaluate the methods and criteria that were used to determine effectiveness. A summary of this evaluation is presented below.

Importance of Effectiveness Monitoring

The process of mitigating adverse environmental impacts should include an assessment of the effectiveness of the mitigation that is implemented. A license article requiring effectiveness monitoring was included in the license for 76 of the 108 developments (70%). This percentage represents a significant increase over the percentage of projects that were required to monitor fish passage effectiveness in a survey conducted almost 15 years ago (Sale et al. 1991).

In that survey, only 43 and 21% of the operating projects had monitored the performance of upstream and downstream fish passage, respectively.

The estimate of 70% of the licenses having an effectiveness monitoring requirement may be conservative. Even though a project may not have a license article that requires effectiveness monitoring, such monitoring may be required in the future when the fish passage facility plan is actually submitted. For example, effectiveness monitoring is not specifically addressed in the Settlement Agreement for 11 projects on the AuSable, Manistee, and Muskegon rivers in Michigan, but no plans for upstream or downstream fish passage have been submitted yet. These plans do not preclude a requirement for monitoring.

Monitoring of fish passage facilities is needed to not only determine the site-specific effectiveness of the facility but also evaluate its potential use at other sites. Without such monitoring, knowledge gained at one site can not be applied to other sites (Sale et al. 1991). Larinier (2001) recommended that fish passage facilities must be systematically evaluated, noting that the most significant progress in fish passage technology occurred in countries that conducted such systematic assessments of facility effectiveness. Cada and Sale (1993) noted that field studies to assess the effectiveness of fish passage facilities were limited. With no national research program available to develop and evaluate existing and alternative designs for fish passage, the knowledge needed to advance the technology must come from site-specific studies of mitigation effectiveness.

Although studies of fish passage effectiveness occur more frequently now than 15 years ago, there remains a critical need for more information on effectiveness, especially for downstream fish passage facilities. As noted by Sale et al. (1991) but still valid today, the designs of these facilities are relatively recent and varied. Moreover, the operating experience with downstream passage facilities is less than that with their upstream counterparts. That many are actually demonstration projects is yet another reason why studies of their effectiveness must be considered part of the planning for such facilities. No fish passage mitigation should be implemented without extensive consideration of the need for studies to assess the effectiveness of that mitigation.

Selection of Suitable Methods and Criteria

Many of the methods used by licensees to evaluate the effectiveness of fish passage requirements are appropriate measures of facility performance. For upstream fish passage, these methods include counts of the number of fish passed at the dam of interest as a function of the number available for passage, which can be obtained from fish counts at the next dam downstream. If no data are available for the lower dam or one does not exist, then a radiotagging study to estimate the proportion of fish that are passed upstream can be an appropriate method of assessing effectiveness.

Radiotagging is also an appropriate procedure for assessing the effectiveness of downstream passage. When necessary, mark-recapture studies can be used to determine effectiveness, too. Counts or direct observation of the number of fish that utilize an upstream or downstream passage facility may be necessary but are usually not sufficient without some estimate of the size of population available for passage. In addition, assuring that the facility was constructed properly and that all passage-related parameters, such as attraction flows and bypass flows, is a necessary but not sufficient requirement for effective passage.

Having obtained an estimate of passage effectiveness, it is important to be able to compare it with some criterion of acceptability. What does a passage efficiency of 50% for an anadromous species mean to the restoration of the stock in that river basin? Establishing criteria for passage efficiency or effectiveness seems necessary if anadromous fish restoration efforts are to be successful. Such criteria are expected to be specific for a given species and river basin. With the exception of the 40 to 60% passage criterion developed by the Connecticut River Atlantic Salmon Commission, such criteria have not been proposed.

3.3 Recommendations to Improve Effectiveness

The process established by the FERC to address the problem of dams as barriers to fish passage emphasizes the importance of early interactions between the licensee, resource agencies, and other stakeholders to assess the need for mitigation. Including a good, technically sound plan to assess the effectiveness of the proposed mitigation will provide the necessary quantitative data that can be used not only for a site-specific evaluation but also for the application of the same technology to other sites. Successful mitigation is dependent upon the development of such effectiveness monitoring plans.

In addition to the recommendations included in Section 3.2, the following recommendations should be considered:

1. Consider having all license articles requiring upstream or downstream fish passage also include an effectiveness monitoring plan as part of that requirement.
2. Consider defining the duration of monitoring in the effectiveness monitoring plans. When radiotagging is used to assess the effectiveness of upstream and downstream fish passage, testing should be conducted during the outmigration season for 2-4 years, depending on flow

conditions, and then discontinued if passage is judged to be effective. In addition, the number of fish using the upstream facility should be routinely monitored and reported to FERC annually. Effectiveness should also be measured and included in these reports, if counts are available at the lower dam.

3. Obtain additional information on the most effective downstream fish passage mitigation measures. Field applications of new technologies, including quantitative approaches to measure the success of the applications, are especially important. No existing research program is available to develop and test innovative downstream passage technologies, so new knowledge must be gained from experience and the widespread exchange of information. It is important that the best technical information be used to evaluate various alternatives for fish passage.

These recommendations and those identified in the previous section would contribute to the goal of implementing the most effective measures for fish passage mitigation.

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